Urban Expansion, Land Use Land Cover Change and Human Impacts: A Case Study of Rawalpindi

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Abdul Sattar Khan

Abstract

Urbanization in Pakistan has increased rapidly from 25% in 1972 to 42% in 2012. Peripheral zones are being pushed by urbanization much beyond their previous extents. Moreover, dispersed developments along the highways/motorways and unplanned expansion of existing urban centres is instigating a substantial loss of vegetation and open spaces. This research is an effort to analyse the relationship between urban expansion and land use/cover change using a combination of remote sensing, census and field data. Rawalpindi has been chosen as a study area because of its rapidly changing population density and land cover over the last few decades, and availability of satellite and census data.

Landsat MSS and TM images of 1972, 1979, 1998 and 2010 which are compatible with the 1972, 1981, 1998 and 2012 Census of Pakistan dates were classified using the Maximum Likelihood classifier. The results of the assessment of classification accuracy yielded an overall accuracy of 75.16%, 72.5%, for Landsat MSS 1972, 1979 images and 84.5% and 87.1% for Landsat TM 1998 and 2010 images.

Results reveal that the built up area of the study area has been increased from 7,017 hectares to 36,220 hectares during the 1972 -2012 period. This expansion has been accompanied by the loss of agricultural and forest land. There has been a decrease of approximately 10,000 hectares in cropped area and 2,000 hectares in forest land of the study area during the 1998-2012 inter-censal period. Corroboration of official census data, remote sensing results and field based qualitative data supports the view that high population growth rate, industrialization, better educational and transportation facilities and proximity of the study area to the capital (Islamabad) are the major factors of urban expansion and resulting land cover changes

The present research is expected to have significant implications for other rapidly urbanizing areas of Pakistan in particular, and the Global South in general, in delivering baseline information about long term land use/cover changes.

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A Case Study of Rawalpindi

A thesis submitted for the degree of Doctor of Philosophy

Department of Geography

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Declaration

The material contained in this thesis has not been previously submitted by the candidate for the degree in this or any other university.

Statement of Copyright

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1 INTRODUCTION

The “author’s background” is in the Punjab province of Pakistan which has gone through extensive land use changes in the last few decades due to accelerated population growth, developmental and educational advancements; industrialization and urbanization. The thesis is about the urbanization and its impacts on land use and land cover change of Rawalpindi- strategically an important district of the Punjab province. It is a pertinent topic for analysis and assessment, as environmental impacts of urbanization and rapidly changing land use/cover have been growing in complexity and relevance, generating a strong imbalance between the urban areas and their hinterland. Without knowing the complexities of and context of change it is hard to achieve effective planning, land management and environmental monitoring (van Oort, 2007; Yuan et al., 2005).

Anthropogenic processes on the Earth surface operates at varying spatial and temporal scales and remote sensing techniques have advantages to measure spatial variability (Aplin, 2006). Thus one of the advantages of satellite imagery is its ability to capture a synoptic view of the Earth’s surface and to acquire repeated measurements (Donoghue, 2002). Change detection is a key task in remote sensing studies and wider availability of large archives of historical Landsat images at no cost makes long term change detection possible, particularly in developing countries like Pakistan where financial constraints are of major concern for such a longitudinal study. The primary focus of the research is to examine the applicability of remote sensing technologies, Geographical Information Systems, Census and field data for the identification of urban expansion and land use/ cover change as part of resource management and development planning in a rapidly changing district of Pakistan.

Although city areas are relatively speaking small in size, comprising just 2% of the earth’s land area, they accommodate nearly 3.8 billion people (UN, 2010a). Several decades of population expansion and accelerated urban growth have had profound environmental and socio-economic impacts felt in both developing and developed countries alike (Yang & Lo, 2002). Hence with the rapid urbanization, the expansion of urban land and urban land use/cover change studies lie at the heart of modern theories of urban spatial structure, as it deals with the spatial aspects of all human activities on the land and the way in which the Earth’s surface is adapted or could be adapted (Antrop, 2004). Although both natural and human factors are responsible for land use/cover change, human modification of land use/cover has recently appeared as unprecedented around the world in general and in developing countries in particular, profoundly affecting the Earth’s ecological system (Lambin et al. 2001).

With the continuing improvement in spatio-temporal resolution of satellite sensors, remote sensing data has been proved to be the best data sources for detecting urban expansion (Kennedy et al. 2009). The integration of Geographic Information Systems (GIS), Global Positioning Systems (GPS) and Remote Sensing (RS) has created new and resurgent roles for Geography, and has placed Geography at the centre of multidisciplinary research. Since land cover change is the result of multiple land use processes, the analysis of land use/cover change processes involves a wide range of observations (Aspinal & Hill, 2007). Research into patterns and processes of urbanization and its impact on land use/ land cover change crosses multiple disciplines and employs a range of methods such as remote sensing, Census data analysis, qualitative methods for social data collection and GPS- based field observations. This thesis will focus on all of the above methods to analyse the urban land cover change in a case study of the Punjab province of Pakistan.

This chapter is divided into two parts. Part I describes the background and motivation of the study, human-environmental relationship, aims and objectives of the research, selection of the study area and research questions. Part II is exclusively a review of the literature on the themes and methods applied in the research. It explains the ways of integrating remote sensing, census, field, and ancillary data for detecting land cover change in response to urbanization. Finally a discussion on Public Participation GIS concludes the chapter.

1.1 Background and Motivation

The current level of urbanization in Pakistan, approximately 41.4 % in 2012, though not high by global standards, is high in South Asia. In fact Pakistan like other developing countries of Asia is engaged in urbanization that has been particularly rapid over the last four decades. It is largely driven by the concentration of better economic, health and education opportunities and almost all other amenities in urban areas. The loss of agricultural and forested land to urbanization is most severe in the developing countries. One estimate suggests that nearly half a million hectares of built-up land is being added every year since 2000 in low and middle income nations (WRI, 1989; cited in Fazal, 2000). The condition is worst in the Global South. A common element among them is population growth that has led to urban overcrowding or a severe strain on resources. China is engaged in the most rapid process of urbanization in its long history. It is estimated that some 300 million Chinese have migrated to cities in the last 20 years. That is also Pakistan's situation in a nutshell. Pakistan is just one of many countries in which high population growth has fuelled urbanization, unemployment and depletion of resources. Almost 25 million people moved to cities during the last 10 years and annually approximately 1000 hectares of non-urban land is converted to urban land (Haq, 2009).

Hence in Pakistan urban expansion has badly affected the settlement pattern and land uses around the suburbs increasing the urban area and population concurrently. Deforestation is a key impact of urban development**.** Among the consequences of urban expansion and population explosion there exist many environmental challenges; some of them have affected air quality and greenhouse gas emissions, energy consumption, water resources shortage, vegetation redistribution, and put stress on agriculture (Malik & Husain, 2006). Notwithstanding its large urban population, most of Pakistan's population still live in rural areas. Agriculture is the main source of employment and income, which accounts approximately 40% of the national labour force and 21% of the nation's GDP. Understanding land use/cover change is particularly important in countries like Pakistan, where agricultural products suffer many constraints, including lack of precipitation, small size of land holdings and increasing urban population growth. The dynamics of the settlement system in Pakistan shows an increasing trend of people moving from small settlements to more urban centres in search of better education and job opportunities. Hence with the concentration of resources and industry and commerce in urban centres, urbanization in Pakistan is increasing at a rapid pace. The urban population, which currently is 75 million, is expected to be doubled by 2030 (Government of Punjab, 2010).

More than 50% of the world's population lives in cities and the urban centres of the global south are experiencing new patterns of cultural and demographic super diversity. Migration to urban areas is incorporating an understanding of emergent urbanism, and land cover change affecting the migrant and established communities both. This project is interested in how physical and social aspects of this emerging urbanism are negotiated, modified and reproduced. The thesis analyses impacts of population growth on urban expansion and resultant land cover change as seen from satellite images. The results will help district authorities to better plan for and manage their changing populations and communicate with their populations about these issues.

To manage the land resources and tackle the urban expansion locally and provide input to global understanding of environment requires accurate understanding of the land cover/land use dynamics. Unfortunately the data required for this purpose is not currently available for all parts of the country especially the southern part. This study will not only help to understand the land cover/use change mechanism in the study area but its results can be applied to the other parts of the country and in other developing countries of the global south as well. This research is expected to equip policy makers/ district administration with the ability to weigh alternative development strategies to answer many questions such as: 1) How can the present population growth patterns be reconciled with resource management? (2) How can urban expansion can be monitored? (3) What are feedback loops between land cover/use and urban expansion? and (4) What are the implications of land use/cover change over the past forty years (1972-2012).

Land cover/ use information is important for many planning and management activities, as it constitutes key environmental information for many resource management and policy purposes, as well as a range of human impacts. Moreover this work is significant to the range of themes, issues which area central to the study of global environment. For example large scale deforestation and industrialization due to high population growth rate and resultant urban expansion increases the greenhouse gases mainly CO_2. Through these environmental impacts at regional and global level, land use and land cover change mainly driven human and bio-physical factors have the potential to affect the sustainability of the agricultural and forest supply systems at a global level. Hence accurate land cover information has been identified by researchers as "priority data" for better management and absence of accurate land cover/ use information affects the working of a wider range of scientists, policy makers, urban planners and resource managers. This research emphasises the location, distribution, magnitude and currency of land cover and use information. Such type of databases, which need to be characterized by accurate and easy updating information, are currently not available in many parts of the world especially in the countries of global south including Pakistan. Hence there is great need and demand of such a study which uses remote sensing/ social data based land cover/ use information to analyse the effect of urban expansion on land use change of any area.

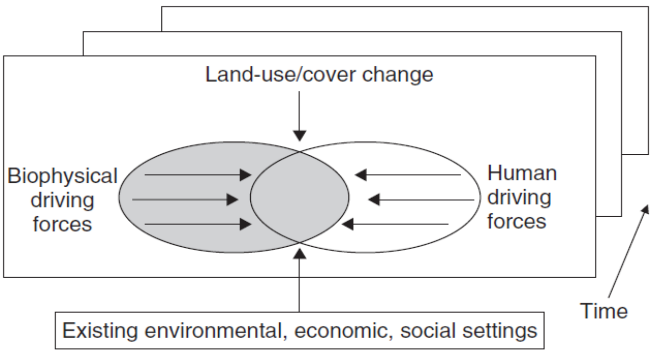
The broad viewpoint of the project is to combine social science data and methods with satellite imagery and mapping. This study follows an emerging area to extract information from remotely sensed imagery for social science analysis (Rindfuss & Stern 1998). Thus this study will encourage the social scientists to work with remote sensing and GIS and help them to interpret social data like population censuses in a novel way. Moreover it is a prime focus of this research that without any detailed study of the district which evaluates the relationship between urban expansion and land cover change in historical perspectives, the planners, and governmental officials cannot assess the magnitude of socio-environmental problems. Therefore, for district administration, natural resource managers and planners who are interested in the impacts of urbanization, this research can provide a model to help manage the potential changes in land cover and natural resources. Moreover results of this study also can aid the development and implementation of urban growth-management plans in other areas of Pakistan and Global South.

1.2 Human Environment Relations in Land Use Land Cover Change

Definitions and descriptions of the terms *land use* and *land cover* vary with the purpose of the applications and the objectives of their use. In general, land cover is the type of physical surface present on a given point on the Earth e.g. (forest, water, build up area etc.). Land use on the other hand denotes the type of human activity taking place at that point e.g. agriculture or residential (Bibby, 2009; Braimoh and Onishi, 2007; Lambin et al., 2003).

Land use and land cover both are linked by the proximate sources of change, the human actions and goals that alter the physical environment (Meyer and Turner, 1994). The clearing of forests, use of fertilizers, ploughing, irrigation, crop species, crop rotations, fallow farms are examples of proximate sources. These proximate sources influence the land use change under three main types: (1) *urban expansion*, the conversion of other types of land to use linked with the growth of population and their economies; (2) *deforestation*, the conversion of forests to cropland and other uses; and (3) *loss of agricultural land*, loss of cropland owing to urbanization and other factors. Thus these proximate sources produce alterations to the environment, ranging from minor modifications to the complete conversion of new cover type (Weng, 2012). Although land use is the product of interactions between physical and human environments, mostly land use is changed by human use and less by natural processes. Fig.1.1 illustrates the interaction between the biophysical environment and human actions in land use land cover change. Meyer and Turner (1992) and Stern et al. (1993) confessed that among the possible human forces that cause the land use change, population, level of affluence, technology, political and economic institutions and cultural attitudes and values are the most important. The processes of modernization and industrialization lead to land use changes as urbanization quickens its path with the help of rapid economic growth. However the unbalanced development between economy and urbanization threatens the ecosystem, and becomes a major concern for administrators and researchers.

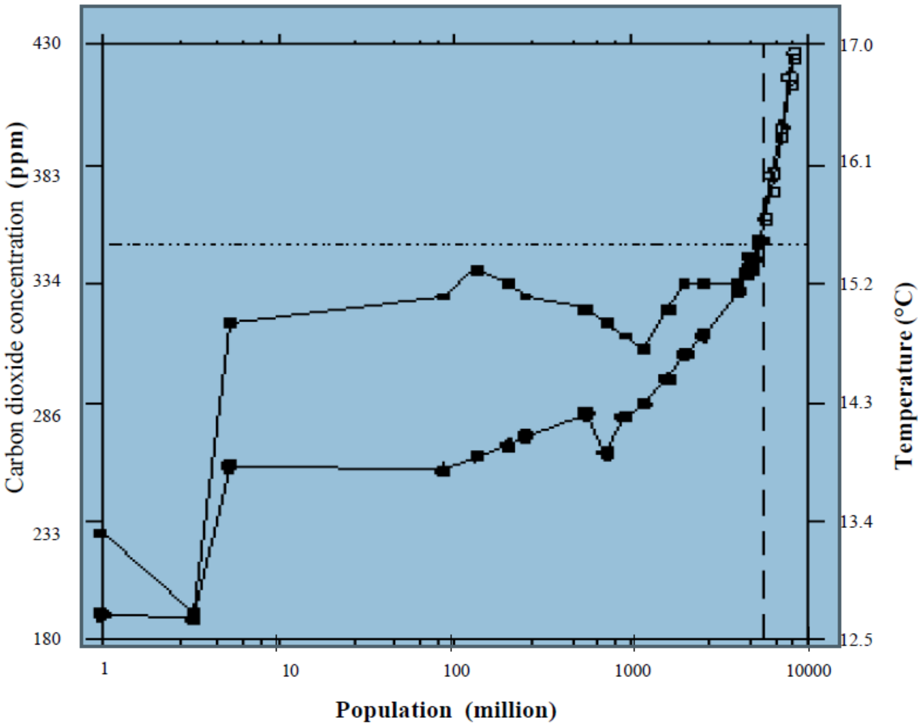
Figure 1.1: A Conceptual model of human-environment relationship



Land and people both are very important resources, which are mutually interrelated and interdependent for their sustainable development. Land use pattern is greatly influenced by the deliberate interventions of people, and it is very important in the context of increasing population pressure, particularly where there is a concentration of population at one place (Lambin, 1997). Scientists and the public alike now fully understand that contemporary change in many realms of the biosphere is largely the product of human activities. Human impacts on the environment operate at unprecedented magnitude, rates, and spatial scale. For example, at a global level, half of the ice-free surface of the Earth has already been substantially altered for a variety of human uses.

The annual human diversion of water is about a quarter of the total yearly stable run off on all of the world's lands, and the amount either diverted or polluted is more than a third. In addition the methane content of the troposphere has doubled and the level of carbon dioxide increased by 45%, since preindustrial times (UNEP- WCMC, 2001). Forests and green areas sequester higher amounts of carbon. But large scale deforestation and loss of agricultural lands due to population pressure leads to changes in the amount of carbon stored in vegetation biomass, thus increasing the concentration of carbon dioxide in the atmosphere (Chen et al., 2007; Coppin et al., 2004; Fischel 1982). Figure 1.2 illustrates the effect of population on CO_2 concentration and mean Global temperature. Due to the high population growth, Industrialization and deforestation is increased which increases the greenhouse gasses mainly CO_2. Atmospheric concentrations of greenhouse gases have increased approximately 25% since 1870 to date and may increase further (Khali & Rasmussen, 1992).

Figure 1.2: Effect of population (log-population) on CO_2 emissions and mean global temperature



Source: IPCC, 2001

High amount of these gasses in the atmosphere are increasing the greenhouse effect there by warming the Earth. , Two fundamental, linked, sets of questions underlie in land use/cover change research: the first concerns the nature, location, and rates of anthropogenic modification of land cover; while the second seeks to understand the reasons behind land use-practices leading to such modifications (Ichinose et al., 1999). The first set of questions are generally examined at relatively broad scales, often using satellite imagery to determine spatial and temporal patterns of change, while the explanation of land use practices requires local-scale research, and often involves one-to-one and group interviews with community and land managers and direct observation of land management practices. As answers to these two sets of questions take shape, it becomes possible to model the trajectories of change that have been observed, and to project future land -cover outcomes (Amiri et al., 2009; Rogan et al., 2004). The primary focus of the present research is to examine the process of urbanization in the district of Rawalpindi, and its impact on the biophysical environment and the humans themselves during the last four decades, i.e. 1972 to 2012. The district with its further subdivisions into tehsils is considered in Pakistan as the focal point of local government, land use planning, and development policies. The broad view point of this research is to combine the human geography and technology together, that is in the terminology of Rindfuss and Stern (1998) integrating *people* with *pixels*: *census* and *satellite* data. Hence human-environment relationship of Rawalpindi and its effect on land use /cover change has been identified, mapped and analysed by establishing GIS and image analysis systems, by using qualitative, census, GPS data.

1.3 Aim of the Research

The urban population of the Punjab as seen from census data shows a remarkable proportion of total population and a very high growth rate. Census data however do not show the impact of high levels of urban living in rapidly expanding cities. This study seeks to combine decadal satellite imagery with population statistics and qualitative methods to better understand the relationship between land cover change and rapid urban expansion caused by the high population growth rate in the Punjab. Thus the aim of the study is to investigate the ability of satellite remote sensing to produce the land cover data base which can be used along with the census and field based qualitative data by the decision makers for better and efficient urban planning, particularly tackling the problems of illegal urban expansion in the study area.

I do not intend to argue for an interdisciplinary method as a philosophical imperative but the melding of the wonderful technical possibilities of RS/GIS with demographic and qualitative methods from human geography serves my particular practical purpose in this thesis and in my view adds value to the studies of change that might have been achieved separately.

1.4 Research Objectives

1. To undertake a spatial analysis of Pakistan Population Census data for 40 years, i.e. 1972 to 2012, to contextualize and interpret the process of urbanization.

2. To acquire and analyse medium spatial resolution satellite data from the Landsat platform at intervals coincident with the population census data to map urban expansion and peri-urban land cover change.

3. Urban expansion cannot be fully understood without considering the interrelationships of rural, peri-urban and urban land uses (Couch et al 2008; Herold et al 2003). This study will establish the quantitative relationships between population and land use using remote sensing land cover data as a proxy for land use and population density.

4. Qualitative data will be used to gain insights into the people, attitudes, behaviours, value systems, concerns, motivations, aspirations and life styles. Qualitative data involves the scrutiny of social phenomena and looks beyond ordinary every day of seeing social life and tries to understand it in novel ways. Qualitative research involves complex issues of interpretation. Pile (1991) describes qualitative methods as being a vehicle for the researcher to be "less authorial, authoritative and authoritarian". The study aims to develop a better understanding about the collection and utilization of qualitative data.

1.5 Research Questions

To accomplish the objectives discussed above, it is important to focus on the key issues of the research. Table 1.1 shows research questions tabulated against the methods that will be used to answer them.

Table 1.1: Research Questions

Method	**Research Question**
Census	• How can census data be related to land use data over the decades? What will be the validation and scaling procedure? (Objective 1)
Remote sensing	• What kinds of images are suitable for the study of urban expansion? How can they be made compatible with the decennial census data? (Objective 2)

Mix Methods	• What land cover changes occurred in Rawalpindi between 1972 and 2010? How did such changes affect natural resources? (Objective 2) • How can the census data and field data based on GPS survey, interviews, focus group discussions and participant observation be integrated with the RS data? Is it possible to generate better resolution maps in a GIS? (Objective 3) • Can the merging of satellite, census, and field data produce robust and valuable findings? (Objective 3)
Field work	• Is it possible, by field observation, to characterise the built up area, agriculture, and forests statistics associated (a) with particular image features and (b) with census data? (Objective 4) • Is there added value in asking local people about (a) changes between successive images, and (b) the story behind the processes of urbanization? (Objective 4)

1.6 Need for Land Use and Land Cover Mapping in Pakistan

The changing patterns of land use/cover reflect changing economic and social conditions, therefore monitoring of such changes is important for coordinated actions at all levels i.e. national, provincial and district levels. The spatial dimensions of land cover of an area should not only be known to the policy makers of that area but also to the local scientists to amply equip them to take decisions. For example frequent mapping of various prevailing land covers in an area such as built up area, forest, farmlands and grasslands by remote sensing will rapidly generate information for the government about the encroachment of one land cover on another. Thus for efficient resource management there is a need for precise maps at large scale having high positional and thematic accuracy. Pakistan is very rich in natural resources, and for proper management of its natural resources there is currently a need for high quality spatial resolution digital maps. For this purpose remote sensing data can be used for the production of land cover maps on a frequent temporal basis having well defined classification schemes and land cover categories (Aplin et al., 1999, Dai and Khorram, 1998). In this way a resource inventory can be created, maintained and used not only for safeguarding resources but also for their proper usage.

Satellite remote sensing plays a crucial role in change detection studies by providing a viable source of information from which updated information about different land covers can be extracted efficiently and cheaply for change detection. Mas (1999) has noted that satellite data has become a major application in change detection because of its repetitive coverage at short intervals. In change detection studies, a researcher seeks to know (a) processes of land use change, (b) patterns of land cover change, and (c) human responses to these changes. This knowledge is then integrated into regional land cover models for the development of data bases (IGBP/IHDP, 1999). The big advantage of satellite data is that it provides permanent and authentic records which can be reused for further verification and reassessment, and can discourage corruption in various departments.

Although some researchers (Malik & Hussain, 2006; Farooq, 2012; Shirazi, 2012) have used remote sensing techniques in their individual studies on Pakistan, at the national and regional level, no such attempt has been seen in the national departments such as Forest, Agriculture and Housing and Physical Planning, for updating their records. Although at the Survey of Pakistan and SUPPARCO[1] remote sensing based mapping has recently been introduced, its development is still in its infancy due to lack of expertise, finance, and lack of willingness of senior members to engage with new technology. To change this situation, in future the efficacy of technology needs to be demonstrated in front of politicians, departmental administrators and most importantly the top bureaucracy, to convince all to include it in their policies on priority basis. It is hoped that the results of this study will provide some aid to the development and implementation of urban growth-management plans at the country level in general and at district level in particular.

1.7 Selection of Study Area

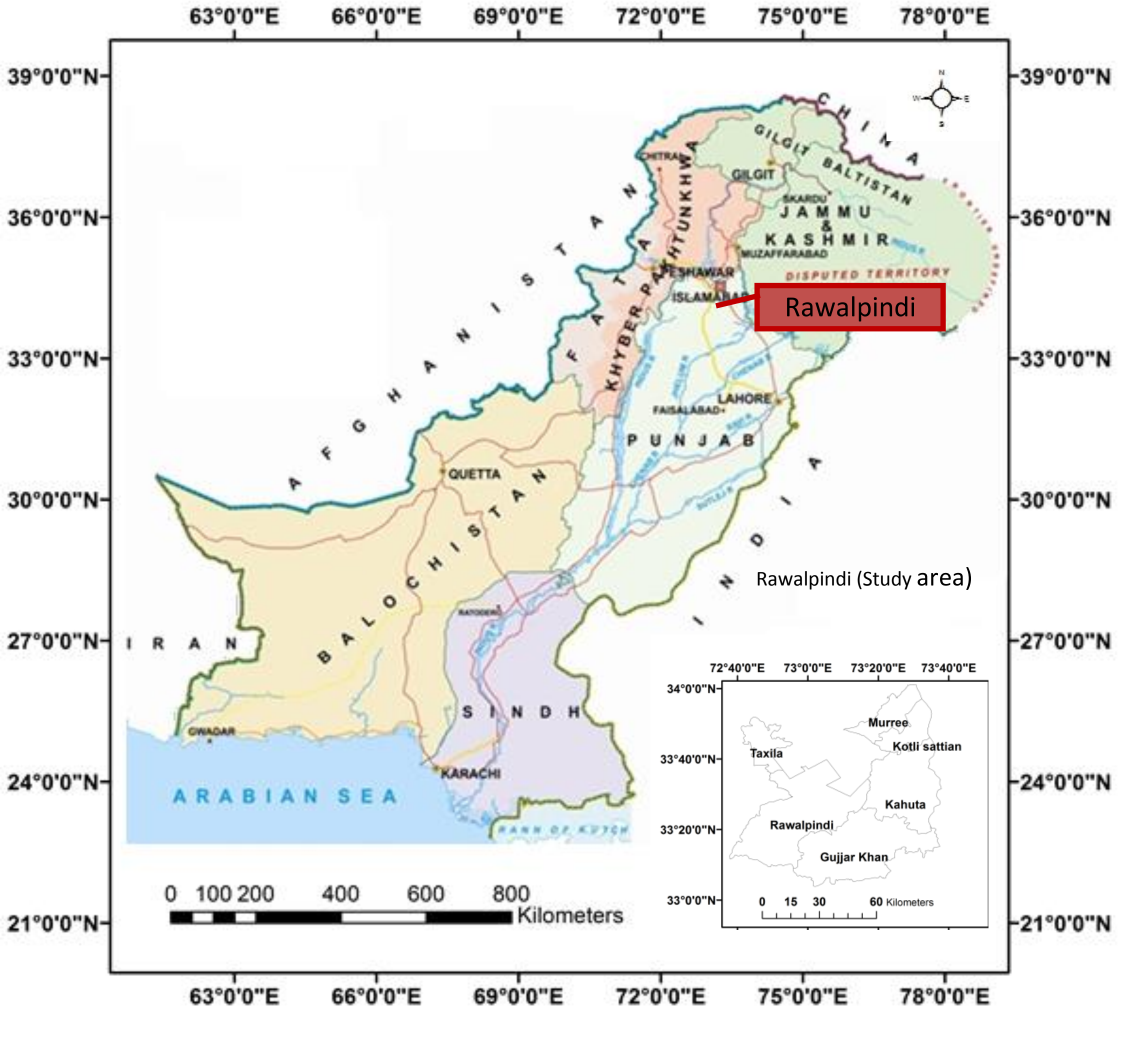
Rawalpindi District is situated in Potohar plateau of Pakistan in the north of the Punjab province (Fig.1.3). It lies between 33° 04 ’ to 34° 01’ north latitudes and 72° 38’ to 73° 37’ east longitudes. It has a population of 4.5 million, of whom 60% are urban. The total area of the district is 5,286 km² with a density of 845 persons /km². The average household size is 6.6 members. It is among the few districts which have over 24% of forest cover. The agriculture of the district depends almost entirely on the rainfall. Due to small land holding size, and rugged topography, agriculture is considered a less profitable profession in the district.

The district is further subdivided into seven tehsils: Gujjar Khan, Kotli Sattian, Kallar Seddan, Kahuta, Murree, Rawalpindi and Taxila. Murree is the chief hill station of Punjab which attracts a considerable proportion of the country’s population for visits during the days of snow fall in winter and pleasant weather in summer. Kahuta is strategically very important. Taxila is ancient city having significant archaeological importance. Rawalpindi is the headquarters of the Military and Air forces of Pakistan and also remained as the acting capital of Pakistan for more than 11 years during the phase of shifting of the capital from Karachi to Islamabad in 1960. Rawalpindi city acts as the service centre for nearby towns. Because of the emergence of industries, higher growth of

[1] Pakistan Space and Upper Atmosphere Research Commission

urban population, migration of people from different parts of the country in search of jobs, its urban area is encroaching on to nearby fertile agricultural land. The forest cover of the study area has been decreasing continuously due to huge human intervention and builders wishing to raise big plazas and residential colonies in the vicinity of the existing urban land. The development of industry, job opportunities at nearby federal capital and comparatively cheaper prices of residential land as compared to the capital; attract people not only from the hinterland but also from further away.

Figure 1.3: Location of the study area Rawalpindi in Pakistan



Source: Survey of Pakistan

Rawalpindi has been selected as a study area because of its rapidly changing population density; it is undergoing rapid biophysical and socio-economic transformations, rapidly, land cover has dramatically changed, satellite and census data is available, and its location is of strategic importance. Moreover due to its high literacy rate, the people were aware of the study therefore their cooperation during the collection of qualitative data was excellent. The proximity of the Rawalpindi city to the capital of Pakistan was another advantage as most of the departments have their headquarters in Rawalpindi city; therefore it was easy for the researcher to interview the policy makers/district administrators and also to collect maps/data, relevant to the study, from various departments.

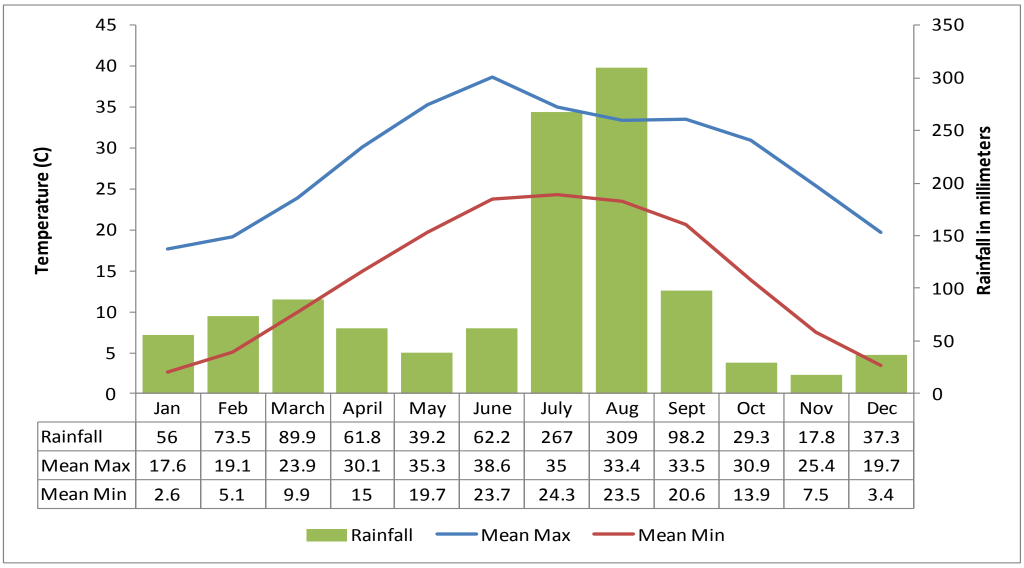
1.7.1 Physical Features

The physical features of the study area exhibit a rich variety, continental in dimension, containing mountains, plateaus, and hillocks, ravines, torrents, streams, plains and varied type of topography. Generally the district divides into three parts. The first, which is mountainous, consists of Murree and the northern portion of Kahuta and Kalar Syedan tehsils. The highest area of the district is in Murree tehsil where the Murree hills rise to about 2400 metres. These hills extend southward along the eastern border, forming the Kahuta hills and towards the west forming the Margala range. The second part is the hilly area of Rawalpindi, Kahuta and Gujjar Khan tehsils. The third part is the Potohar plain comprising the tehsil of Taxila. The main mountains in the district are in the Murree, Kahuta and Kotli Sattian, consisting of five spurs more or less parallel to each other. Murree spur is the highest one. The greater part of the district is a rough, rolling plain extending from the foot of the outer Himalayas towards the Salt Range. The landforms of Rawalpindi district can be subdivided into *depositional* and *erosional* landforms. Each type exhibits a distinct variety of slopes, soil types and active geological processes which determine its suitability for various uses. The geologists further divide the depositional landforms into streambeds, low islands, bars, stream flood plains, stream and fan terraces, alluvial fans and loess plains, and erosional landforms in loess bad lands and gullies, bedrock bad lands and gullies, gentle hill slopes with angular and rounded clasts, rocky ridges and pinnacles, and steep rocky hill slopes (Ali & De Boer, 2007).

1.7.2 Climate

Rawalpindi district features a sub-tropical continental sub humid type of climate with very hot and long summers and short but wet winters, there is a variation of climate between various parts of the locality. For instance Murree and Kotli Sattian tehsils have severe winters and short summers; in contrast Gujjar Khan, Kallar Syedan, Rawalpindi and Taxila tehsils have long hot summers and short winters. Two distinct types of climate are found in the study area, i.e. (a) Humid climate in Murree and Kotli Sattian tehsils (b) Sub Humid climate in the rest of the tehsils. There is usually snowfall during the months of December, January and February in the hills and the night temperature generally remains below freezing point in these months. The summer climate is very pleasant in the hills, particularly at the chief hill station Murree, where maximum temperature rarely goes above 30^{o} C. On average, the coldest month in the district of Rawalpindi is January when the mean minimum temperature is 2.6^{o} C and mean maximum temperature is 17^{o} C (Fig.1.4).

Figure 1.4: Month wise temperature and precipitation (2010)

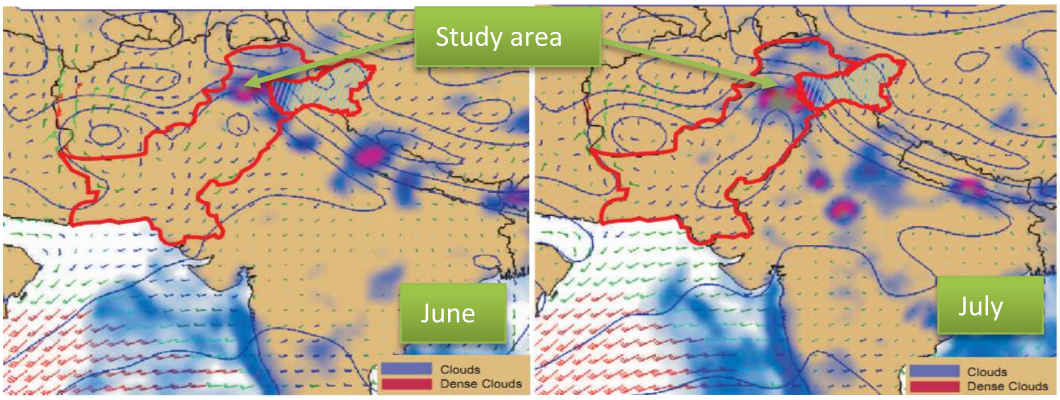


	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Rainfall	56	73.5	89.9	61.8	39.2	62.2	267	309	98.2	29.3	17.8	37.3
Mean Max	17.6	19.1	23.9	30.1	35.3	38.6	35	33.4	33.5	30.9	25.4	19.7
Mean Min	2.6	5.1	9.9	15	19.7	23.7	24.3	23.5	20.6	13.9	7.5	3.4

Source: Pakistan Meteorological Department, Islamabad

The Rawalpindi district is situated at a rather high altitude. For the three months of summer, i.e. July to September, its climatic conditions are dominated by easterly monsoon depressions (Fig. 1.5), while rest of the year, particularly the months of February, March and April, is marked by their retreat and the influence of western disturbances. In fact these two influences not only determine the climate of the region but also of the whole Indian sub-continent. They provide the Rawalpindi district with a rainfall which is more or less sufficient (except the extreme drought conditions) for its agriculture. The summer rainy season usually starts in the second week of July and ends with the beginning of September; it receives more than two thirds of its total annual rainfall. The eastern part of the district receives more rain than the west.

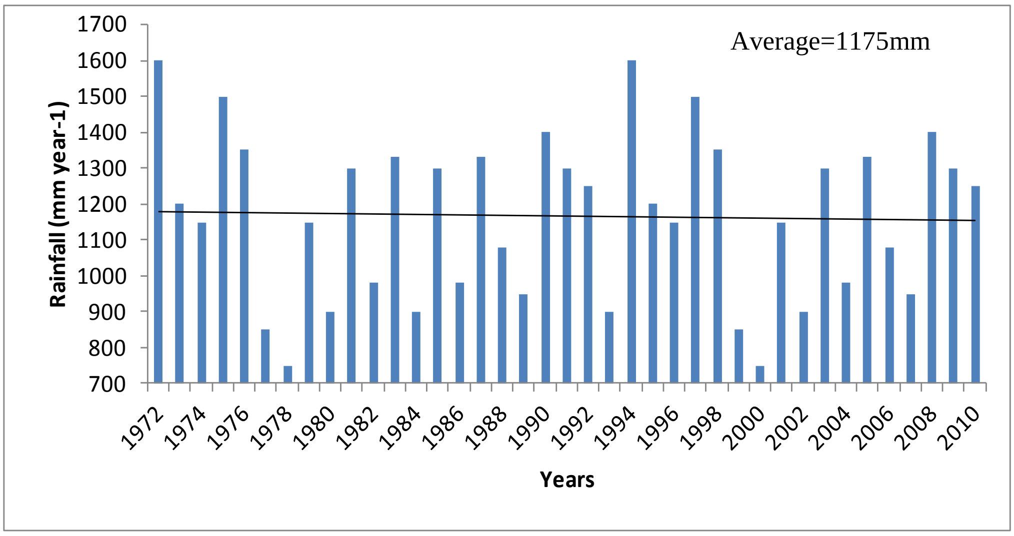
Figure 1.5: Monsoon cloud system of Pakistan during June and July, 2010



Source: SUPARCO Islamabad

The highest rainfall during the monsoon season that has been received by Murree is 853 mm. Annual rainfall shows great fluctuations. For example in the period 1972 to 2012 drought prevailed in the region from 1976 to 1978 and 1999 to 2002. Longitudinal data of rainfall shows great fluctuations in rainfall during the last forty years. Figure 1.6 shows that during the period of forty years only eighteen years were above the average rainfall which was 1175mm. The years 2000 and 1978 were the driest and 1972 and 1994 were the wettest.

Figure 1.6**:** Annual rainfall distribution of Rawalpindi (1972- 2012)



Source: Pakistan Meteorological Department, Islamabad

1.7.3 Hydrology

1.7.3.1 Rivers

Soan and Korang are the main streams which drain the area. The Soan rises from the Murree hills and after flowing through the district it finally joins the Indus. It is believed that in the Gondwana age, the Indus, the Ganges and the Brahmaputra rivers had a common course at the place where at present the bed of the Soan is. The Korang River also rises from the Murree hills near Ghora Gali, and it joins the Soan near Sihala village of Rawalpindi tehsil. Both the Soan and the Korang rivers are dammed at the Simbili lakes and the Rawal lakes respectively and from there they supply drinking water to the urban area. Extensive forest reserves in the headwaters of these rivers benefit the quality and quantity of this water supply (Khan, 2011). The Jhelum River flows in the outskirts of the district. The Haro River also rises from the Murree hills near the Donga Galli of Abbottabad District, and after cutting across a small portion of the Rawalpindi tehsil it then enters Attock District to join the Indus.

1.7.3.2 Nullahs[2]

Kanshi nullah rises from the Kahuta hills, drains Gujjar Khan tehsil of the district and joins the Jhelum river near Baghans. The Sarin which rises from Kahuta hills is its main tributary. Ling nullah rises near Lehtrar hills close to the Kahuta tehsil and then joins the Soan. Tamrah nullah rises from Margallah hills, passing through Taxila tehsil; it ultimately joins the Haro River. Nullah Lai is a rainwater-fed stream, the tributaries of which shoots from the foothills of Margallah and join into a single stream which flows through the densely populated area of Rawalpindi. Out of its 240 km^2 basin, nearly 40% is residential. At one time this stream was the main source of water for the urban area of the Rawalpindi but the accelerated urbanization and population growth has converted this natural stream into a sewerage nullah, where 65% of the waste water of the Rawalpindi city is disposed of (the Director WASA[3] Rawalpindi, disclosed this during an interview). In the monsoon season heavy rains cause flash floods in this nullah and every year many people die and a majority of the residents living at the bank of the nullah have to migrate from their houses. In this way this stream has become a major nuisance for the district administration.

[2] In Urdu (national language of Pakistan) Nullah means tributary river or stream

[3] Water and Sanitation Agency.

1.7.3.3 Agriculture and Horticulture

In Murree, Kahuta, and Kotli Sattian tehsils of the study area, agriculture depends entirely on rainfall and in some places at a micro scale, on the water of the mountain streams. The hilly tehsils of the study area have an undulating type of topography with terraced land available for agriculture having sloppy and dissected patches under natural vegetation. That is why people of these areas have very small land holdings. Generally two crops are grown in a year in two distinct rainy seasons, Kharif in summer followed by Rabi, in the winter rainy season. This system is locally called Do-Sala[4]. Wheat is the main crop, intercropped, in patches, with Barley, Gram, Pulses/ lentils (Mong, Mash and Masoor), grown in the Rabi season. Bajra (Millets), Maize, Groundnuts, Jawar (Sorghum), and Barley are the Kharif crops. Besides, Potato cultivation has also made considerable progress, especially in the hilly areas. In the hilly areas where water is available from springs and mountain streams, vegetables are also a source of income for the local residents. Due to unfavourable conditions for agriculture and very small size of land holdings even in the plain areas, people don't take much interest in crop husbandry. Moreover the use of latest agriculture implements and fertilizers is not very common. The Walnut (Akhrot) is very common in the study area. The pleasant climate is also favourable for Guava, Apricot, Peach, Pears and Apples. In 2010-11 the cultivable area was 230,000 hectares out of which only 105,000 hectares were cultivated (Government of the Punjab, 2010).

1.8 Forestry

Although the forest area of Pakistan is less than 4% of the total land area, but the study area is rich in forests. Almost over 20 % of the study area is covered with forests including linear plantations (Governemnt of Punjab, 2010). Evergreen Coniferous and Sub Tropical Deciduous Forests are mainly found in the study area. Silver Fir, Deodar and Chir pines are tall trees which are of immense importance for the economy of the area and they are found in Bhurban, Masot, and Patriata regions of Murree tehsils and also in some areas of Kotli Sattian. The Sub Tropical Deciduous forests are found mainly in Rawalpindi, Gujjar Khan, Kallar Syeddan and Taxila tehsils. During the last two decades (1990-2010), Pakistan lost one quarter of its total forest cover. This deforestation rate of nearly 3% per annum was the second highest in the world (Malik & Husain, 2006). The situation is no different in the study area. In Murree and Kotli Sattian tehsils of Rawalpindi, deforestation and changing land use pattern has resulted in the loss of precious forests. Besides illegal and uncontrolled cutting of trees for energy, timber and farm area purposes by the local community, the provincial government has also been involved in deforestation, for the purpose of erecting government buildings and establishing residential colonies both for general

[4] Do (two) and Sala (year), which means two in one year.

public and government officials. For instance in 2005, the Government of Punjab started a huge residential project "New Murree City" in the environs of the old city, which could have destroyed the scenic beauty of the Murree hills and nearly 20,000 hectares of forest cover of the study area, but it was stopped by a suo moto notice of the Supreme Court of Pakistan, considering the project as a big threat to the environment (Supreme Court of Pakistan, 2006). According to Malik et al. (2000), Environmental problems associated with urbanization have caused major deforestation in the study area. In their study on the Loi Bher reserved forest situated along the Rawalpindi/ Islamabad highway, they noticed that the forest area of Loi Bher which was 450 hectares in 1972 and had shrunk to 130 hectares in 2005 (Malik & Hussian, 2006); and this loss of forested area was due to builders establishing residential colonies. They further commented that the increased construction of urban buildings, roads, parking lots, all are water proofing the surface of the city, and so channelling precipitation quickly into the drains there, thus reducing the moisture level, and increasing the temperature of the Rawalpindi/ Islamabad.

1.9 Review of Literature

Scientists have made great efforts in detecting land cover changes with the help of geospatial techniques including remote sensing. Satellite remote sensing provides an objective and consistent view of urban areas in terms of required coverage and revisit capability (Lillesand et al. 2004). Multispectral, multiscanner and high resolution imagery has further validated the potential capability of satellite remote sensing for collecting more precise and detailed geospatial information (Stefanov et al., 2001). But remote sensing methods provide information at a scale and extent that is often difficult for people to perceive; field based qualitative methods illuminate the complex meanings, motivations, and mechanisms of human land use activities. Hence both methods, when used together, can examine the multiple causal linkages between human activities and land cover processes over a range of scales, crucial for policy makers (Stevens et al., 2007).

The first part of this section gives a brief review of the satellite based techniques used for detection of urban land cover change. Since the start of the research attention has been drawn to the thoughts and guidelines of those authors who have conducted urban land use studies using the mixed methods i.e. qualitative and quantitative methods. Therefore the second half of this section discusses the application and integration of mixed methods.

1.10 Satellite Remote Sensing for Urban Analysis: An Overview

In the past, land cover change in an area was examined through traditional methods of field surveying and by using aerial photographs. No doubt these has proven successful in the past, but at the rate and magnitude of land cover changes that are occurring today, there is need to collect information at larger spatial and temporal scales (Wilkie and Finn, 1996). Since remote sensing measures electromagnetic radiation from features of the earth' surface (Aplin, 2003) therefore it can provide the data necessary for consistent monitoring. Today it is not only an important component of urban land use planning but also it is a valuable tool that aids the decision makers in the creation of their policies for better environmental conservation (Treitz and Rogan, 2004). Generally there are two main areas of remote sensing based land cover research; (1) environmental understanding and; (2) Environmental management (Aplin, 2006). Compared to other applications, the remote sensing of urban areas is rather a new topic for geographers (Maktav & Erbek, 2005), but the interest of researchers in using remotely sensed data for urban applications has shown a quantum increase (Bhatta, 2010). Nowadays satellite remote sensing is widely applied as a tool in detecting urban land cover change. Satellite remote sensing collects multispectral, multi resolution and multi temporal data and turns them into information valuable for understanding and monitoring urban land processes and for building urban land cover data bases (Griffiths et al., 2010; Van, 2006; Kressler & Steinnocher, 1999; Liu et al., 2010). Because of their widespread availability, frequency of update and cost, the focus of urban remote sensing has shifted from traditional aerial photographs to use of digital multi-spectral satellite images (Lu & Weng, 2006).

Since the launch of the Landsat MSS first generation in 1972, technical improvements are in progress leading to the second generation of earth observation satellites such as Landsat TM, Landsat ETM+, SPOT, Indian Remote Sensing Linear Imaging Self Scanner (LISS) sensors and third generation satellites with very high geometric resolution such as IKONOS-2, QuickBird-2, Orbview-2, GeoEye-1, WorldView 1, Worldview-2, Cartosat, Pleiades-1 and Pleiades-2. Considering the improvements in remote sensing technology, particularly the ability of the sensors to measure spectral properties of the objects, Aplin (2006); Batty and Howes (2001); Herold et al. (2003) and Donoghue et al. (2007) believe that these sources can provide a unique perspective on growth and land use change processes, and in establishing an urban information system (Longley & Mesev, 2000; Taubenböck et al., 2009).

Landsat's long lasting history of image acquisition is unique in acquiring imagery of a scale that is very useful for urban studies (Dewan et al., 2010; Guindon et al., 2014; Haack et al., 1987; Small, 2002). Due to more than 40 years of its operation, Landsat data is of very high value for long term change detection studies. Another big advantage of Landsat data is its availability at no cost for downloading through the internet. Medium resolution sensors like Landsat TM with 30 metre pixel size are suitable for study of land use/cover change and to derive the detailed classification of almost all parts of the world including Pakistan. Landsat 8 launched in February 2013, with additional bands and improved signal-to-noise (SNR) radiometric performance is expected to improve further the characterization of land cover state and condition in future research. Retrospective and consistent synoptic coverage of Landsat satellites and ease of availability from archival resources provides an excellent opportunity to the researchers of the developing countries to study historical land cover change and relate the spatio-temporal patterns with environmental and human factors**.**

One of the primary uses of remote sensing is mapping of land cover, change detection and environmental monitoring (Aplin, 2004; Foody, 2002; Gallo et al., 2005; Roberts et al., 2003; Rogan et al., 2002) and satellite imagery is an “appropriate” source of obtaining land use and land cover data where it can be acquired at more frequent intervals and is less expensive than using traditional methods such as ground surveys and/or aerial photographs (Martin and Howarth, 1989).

Phinn et al. (2002) summarizes five current application themes of remote sensing in urban environments. They are; (1) delimitation types of LULC types; (2) assessment of utility of texture measures to aid in separating urban LULC types; (3) mapping areas of pervious and impervious surfaces (Bauer et al ., 2008; Yang et al.,2003); (4) mapping LULC changes in urban areas (Aplin, 2003; Du et al., 2007; Weng, 2001) and (5) application of empirical models to estimate, biophysical, demographic and socio-economic variables (Jensen & Cowen, 1999; Lathrop et al., 2007; Lo et al., 1997; Van, 2008).

There are substantial studies in the last decade in which the researchers have demonstrated the applicability of remote sensing in a wide range of urban applications, particularly in urban change analysis (Bahr, 2001; Gatrell and Jensen, 2008; Hardin & Jensen, 2007; Hathout, 2002; Herold et al., 2003; Maktav & Erbek, 2005; and Zeilhofer and Topanotti, 2008), land use/ cover change evaluation (Jat et al., 2008; Griffiths et al., 2010; Xiao et al ., 2006) modelling of urban growth (Jensen and Cowen, 2011; Jensen and Im, 2007; Liu & Phinn, 2003; Liu and Lathrop, 2002; Lopez et al., 2001; Yin et al., 2011; Yuan & Bauer, 2007; and urban heat-island effect (Kato and Yamaaguchi, 2005; Weng et al., 2004).

Cheng & Masser (2003) found that remotely sensed imagery is an ideal primary data source for urban growth modelling, and timely and inexpensive satellite images make dynamic monitoring of urban growth more operational. Lu et al. (2008) explored an integrated approach based on combined use of multiple remotely sensed data to map settlements in southern china. They mapped human settlements for selected sites from Landsat ETM+ images, and combined DMSP-OLS and Terra MODIS NDVI data to develop a settlement index image. Jones et al. (2009) noted that data for quantifying indicators of LULC changes are derived from two main sources, i.e. remote sensing images give the information about characteristics of landscape and ancillary demographic and infra-structure data provide information about how the land is populated and used. Dewan and Yamaguchi (2009) analysed the Land use/land cover changes and urban expansion in greater Dhaka using Landsat MSS, TM and ETM+ data. Their study reveals that urban land expansion has been largely driven by elevation, population growth and economic development, and rapid urban expansion through infilling of low-lying areas and clearing of vegetation resulted in a wide range of environmental impacts including habitat quality. Mundia and Aniya (2005) by using Landsat MSS TM and ETM+ images of 1976, 1998 and 2000 respectively, found that built up area of Nairobi had increased three fold. They noted that the road network has influenced the spatial patterns and structure of urban development.

van der Linden and Hostert (2009) by using the airborne imaging spectrometer Hyperspectral Mapper (HyMap) specifically addressed the delineation of built-up and non-built-up impervious surfaces, and studied patterns of misclassification that depend on urban 3-D geometry, illumination effects, and tree coverage. They found that hyperspectral analysis is most effective in regions near the nadir that is with small field of view sensors counteracting the ability to cover extended areas. Ridd (1995) suggested a new conceptual model of Vegetation-Impervious-Soils (V-I-S) to enrich urban ecological investigations through remote sensing. The model sums up heterogeneous urban areas into simple combinations of basic components of V-I-S and provides an objective and quantitative means of measuring and mapping change caused by urbanization.

1.11 Integration of Remote Sensing (RS) Geographic Information System (GIS) and Ancillary data

Remote sensing (RS) and GIS can be combined in three ways to enhance each other: (1) RS to be used as a tool for gathering data; (2) GIS data to be used as ancillary information to improve the products derived from RS; and (3) RS and GIS be used together for modelling and analysis (Wilkinson, 1996). GIS offers an excellent environment for storing, sorting, analysing and displaying digital data necessary for studying land cover change detection studies (Weng, 2002; Wu et al., 2006; Zhao et al 2001). Moreover it as a data base management system, offers forward data mapping for displaying spatio- temporal information and backward data retrieval functions for “querying “ maps, interactive data modelling, cartographic analysis, thus enhancing urban analysis (Hassan & Atkins, 2007; Stanilov, 2003; Weng 2002).

In fact GIS can be used to enhance the functions of image processing, classification and accuracy assessment. For instance the ancillary data can prove very useful in image classification when incorporated into the analysis in a structured and formalized manner (Campbell et al., 2005) with the help of GIS (Williams, 2001). Mesev (1998) and Williams (2001) are of the view that by storing the ancillary data as GIS layers it can be used to stratify the image into smaller areas, or to assist the selection of training samples, and can be used as reference data for accuracy assessment. They further added that this GIS data can also be increasingly used for geometric and radio corrections at the pre-processing stage of images. Thus in addition to enhancing the functions of image processing at various stages, GIS provides an environment for entering, analysing, and displaying data from various sources such as Census, GPS, ancillary, and field data, for remote sensing applications. For example census data collected within spatial units can be stored as GIS attributes. In the same manner the GPS and field data can be stored as GIS layers, as per specifications of spatial units of census tracts. Then the combination of Census, GPS, Field data, and remote sensing data through GIS can be envisioned in the aforementioned three ways described by Wilkinson (1996). Each of these ways can be related to urban analysis in the following manner.

First, remote sensing images are used in extracting and updating build-up areas and transportation networks (Harvey, 2002; Kim et al., 2004; Lacoste et al., 2002; Lee et al., 2003) providing land use and cover information (Lu and Weng, 2004; Weng and Hu, 2008; Weng, 2002) and detecting urban expansion (Cheng and Messer, 2003; Deng et al., 2009; Griffiths et al., 2010; Liu, et al., 2004). Second, census, GPS and qualitative data is used to improve image classification in urban areas (Heller, 2011; Lu and Weng, 2006; Mesev, 1998; Turner and Taylor, 2003, Walker and Peters, 2007). Finally both sets of data are integrated to estimate the desired variables, for instance population and residential density (Briggs et al., 2007; Harris and Longley, 2000; Harvey, 2002; Li and Weng, 2005; Lo, 2001; Lu et al., 2006) to assess socio economic conditions and quality of life in the urban areas (Hall et al., 2001; Li and Weng, 2007; Sutton et al., 2001). In short, the integration of RS, GIS and social data has been recognized as an effective tool for urban studies (Weng, 2002). Determining the urban growth and land use changes from remote sensing data and integration of the ancillary data into GIS for a wide spectrum of applications is now the prevailing approach for analysis of urban land use (Abed and Kaysi, 2003; Barredo et al., 2004; Batty, 2000; Donnay et al., 2003; Du et al., 2010).

Scientists and social scientists have made great efforts to develop techniques suitable for population estimation using remote sensing and GIS techniques. These techniques can be proved helpful for countries like Pakistan where the census is not being conducted at regular intervals. Since the quality of census data the developing countries is low, in many instances, RS methods may be proved superior to ground based methods (Jensen and Cowen, 1999).

Tobler (1969) was the first to measure the radii for a given city using remote sensing and found a strong positive correlation between the radii and population. Langford et al (1991) used Landsat TM imagery covering 49 wards of Leicestershire (United Kingdom) to estimate population. They first classified the TM image into five land use classes using principal component Analysis (PCA) and supervised classification. Then they counted the pixels of each category within each ward and so they computed the correlation between population and land cover pixel count. Population estimation methods using remote sensing estimates derived from land use classification (Dobson et al., 2000; Lo, 2003; Langford et al., 1991; Yuan et al., 1997, cited in Morton and Yuan, 2009) were mostly coupled with statistical modelling to infer the relationship between population and other variables for the purpose of estimating the total population in an area (Wu et al., 2005).

Recently a new indicator of population- *impervious surface fraction*- has been proposed and tested by Lu et al. (2006) and Wu and Murray (2007). Impervious surfaces refer to buildings, tarred and paved roads, parking lots and bridges etc., which are quintessential elements of the urban environment. Xian et al., (2008) used impervious surfaces to monitor and detect changes in urban land cover /land use at a sub-pixel level. They identified the anthropogenic impervious surfaces as impermeable features such as rooftops, roads, and parking lots, as key indicators for identifying the spatial extent and intensity of urbanization and urban sprawl. van der Linden and Hostert (2009), by using the airborne imaging spectrometer Hyperspectral Mapper (HyMap) , specifically addressed the delineation of built-up and non-built-up impervious surfaces, and studied patterns of misclassification that depend on urban 3-D geometry, illumination effects, and tree coverage. They found that hyperspectral analysis is most effective in regions near the nadir that is with small field of view sensors counteracting the ability to cover extended areas.

Lu et al. (2006) estimated the residential population of Indiana, based on impervious surfaces from a Landsat ETM+ image with an overall population estimation error of -0.97%. Most of the above studies used Landsat Thematic Mapper and Landsat Enhanced Thematic Mapper (ETM+) coupled with digital image analysis techniques for Land use/cover or impervious –surface extraction, except Lo (2001) and Sutton et al. (2001), who applied thresholds to night-time light from the Defence Meteorological Satellite Program Operational LineScan System (DMSPOLS) to extract the information about built up areas, on the basis of which they estimated the population.

The resolution of remotely sensed data is very important. Haack et al. (1997), Stefanov et al. (2001) Tian et al (2005) and Treitz et al. (1992) asserted that imagery must be of sufficient spatial resolution to identify individual structures even through tree cover and whether they are residential, commercial or industrial buildings assumptions. Another challenge faced to urban analysts is the availability of parallel spatial and temporal resolution of data-image, and their availability in the forms that are compatible (Rindfuss and Stern, 1998).

1.12 Public Participation Geographical Information System (PPGIS)

Public Participation GIS and Community-integrated GIS are context- and issue-driven approaches rather than technology-led and seek to emphasize community involvement in the production and use of GIS (Dunn, 2007). These involve members of the community, both at individual and grass root levels, for participation in the processes of data collection, mapping, analysis and /or decision making, affecting their lives.

Williams and Dunn (2003) assert that PPGIS is an inclusive means of gathering and analysing information on human-environment interactions, seeking the active involvement of local people in the creation of information that can subsequently inform spatial decision making. This Public

Participation GIS confers importance to all types of geographical information to reveal contradictions and similarities in spatial thinking and activity (Dunn et al., 1997; Harris et al., 1995; Hassan, 2005). Historically public participation originated from spatial planning and spatial decision making, and GIS is a tool to assist and enhance spatial decision making (Ghose and Elwoods, 2003). The PPGIS focus should be more on public participation and less on technology. In other words it is socio-technical mix that is social shaping and social construction of technology. But participation often involves the sort of interactive meetings and discussion of social issues at length which may be alien and intimidating to people unfamiliar to such environments (Involve, 2005).

In the context of PPGIS, as part of urban system analysis and revitalization efforts, the ideas developed in existing critical GIS research suggest the necessity of considering how PPGIS production might be shaped by relationships between local government actors and institutions and community-based organizations. In particular, it is important to consider precisely how these relationships shape the local opportunity structures of citizen participation, digital data access, technology access and use, and, ultimately, PPGIS production. Understanding the capacity and effectiveness of public participation GIS efforts in a place requires conceptualization of how the efforts are contingent upon aspects of local political context. The project is concerned with participatory application of GIS in analysing population distribution, problems related to urbanization, and mapping and analysing the local politics regarding land use/land cover. This research is unique in its context that by using PPGIS techniques issues of concern to local neighbourhood are aired through a community portal. Further using satellite remote sensing and socially differentiated local knowledge public perception of the people about land cover change in response to urbanization over the last four decades has been complied through participatory mapping. In other words, a Participatory Urban Appraisal (PUA) approach has been adopted in the context of the needs of communities that are involved with, and affected by development programmes. In short, PPGIS methods helped the author to understand the reasons of high population growth rate, concentration of the people into the urban areas, the deforestation by local people and government, diminishing trend of agriculture practices, commercial use of urban residential land, industrialization and resulting pollution problems and water related issues within the study area.

1.13 Incorporation of Ancillary data for improving image Classification

Generating an accurate classification from remotely sensed data is not as simple as it appears. Because of the confusion of spectral signatures some in land cover types, for example, built-up area and bare land, low density forest and farmland, the importance of field based ancillary data is fully recognized for improving urban land use /cover accuracy (Cihlar and Jansen, 2001; Ellis et al., 2009). The topographical characteristics of the study area, availability and seasonality of the images, classification algorithms, and analyst's experience are the other factors which contribute to the accuracy of classification (Foody, 2002; Lu & Weng, 2007). A range of land use practices in various contexts have been mapped by the researchers using remote sensing, field and census data, including census data (Mesev, 1998, Rashid, 2003), irrigation (Biggs et al., 2006) crop species and crop varieties (Akbari, 2006 ; Rao, 2008) crop rotations (Martinez-Casasnovas et al.,2005) and structure or contextual information (Stuckens et al., 2000). According to Hutchinson (1982) and Lu and Weng (2007), ancillary data can be incorporated into standard supervised image processing at three stages: before, during and after classification.

- In the pre-classification stage field data is used to assist the selection of class training samples and to divide the study scene into smaller subunits (stratification)
- During classification two methods can be used. The first approach is using it as additional channels and second approach is a classifier modification that involves altering a *priori* probabilities of classes in a maximum likelihood classifier according to estimated aerial composition or known relations between classes and ancillary data.
- In the post classification sorting approach, ancillary data is used to refine the misclassified pixels based on defined rules.

Fleming and Hoffer (1979) used topographic data for mapping forest cover of Colorado. They used topographically stratified random samples to derive both spectral and topographic statistics for a supervised classification. This method provided a more accurate classification rather than spectral data alone. Franklin (1987) extracted five geomorphometric variables from DEM, and incorporated them with as additional channels into Landsat data of mountainous areas of Canada. He achieved an accuracy of 46 to 75% for nine land cover classes.

Maselli et al. (1995) by incorporating elevation, slope, and soil with Landsat TM data in a classification procedure, increased the accuracy of classification, and achieved a considerable increase in Kappa value from 0.744 to 0.910. Richetti (2000) combined slope maps with Landsat MSS and demonstrated an increase in accuracy of the classification. Shaban and Dikshit (2001) improved the classification accuracy from 9% to 17% by incorporating textural features with SPOT images of urban areas of India, taking Lucknow as the case study.

It is important to mention here that above discussion are useful in the context of the current research, but no single study has been found which has used the census data, remote sensing data and qualitative data together. Additionally most of the authors have used the census data and remote sensing data for a single year. There are no examples which help to develop population/urban change studies based on decennial census reports and field based qualitative data. This study may be considered a unique opportunity make use of all of the available sources.

1.14 Conclusion

Rapid urbanization in Global South is causing the expansion of existing urban areas, and thus putting strain on infrastructure and development potentiality. Encroachment of the existing urban areas into the peri-urban areas has damaged the ecosystem. In many parts of the Global South such as Puerto Rico, Saharanpur (India) Dhaka (Bangla) Gujranwala, Sialkot, and Rawalpindi (Pakistan) abandoned agricultural lands have been lost to urbanization. If this pattern of encroachment of urban areas continues in the Global South, food production may be limited in future and many other related problems may arise.

Pakistan is a developing country with the fourth largest population in Asia. More than 42 % of its population is living in cities in areas with remarkable economic, demographic and cultural diversity. Rawalpindi is one of the highest urbanised districts of Pakistan, having more than half of its population living in urban areas. Rawalpindi has been selected for this study because of it being in the proximity of the capital. It is undergoing rapid biophysical and socio- economic transformations and relatively high population growth rate due to immigration of skilled labour and government employees from different parts of the country.

The increasing population and economic growth has resulted in rapid urban expansion of the study area during the last four decades. To manage the land resources and tackle the urban expansion locally and provide input to global understanding of environment requires accurate understanding of the land cover/land use dynamics. Unfortunately the data required for this purpose is not currently available for all parts of the country especially the southern part. This study will not only help to understand the land cover/use change mechanism in the study area but its results can be applied to the other parts of the country and in other developing countries.

Satellite remote sensing data has been proved to be the best data source for detecting urban expansion, by deriving land cover/use maps by means of classification of images. The raster data can be further combined with vector based census and qualitative data to investigate the urban expansion and resultant land use change. Moreover GIS allows for detection of changes between different period of times and extraction of information on changes in land cover. In most of the studies the researchers have only used the satellite data and some ground truthing with the help of GPS to detect the land cover change. This project is unique that it utilises all sources of data at length, particularly qualitative aspects of the human geography (which is usually found missing in most of the satellite data based urban land cover studies). The longitudinal census data of forty years further polishes the research. In short, this research focused on the aspects of understanding the dynamics of land cover using combination of qualitative and quantitative data. This research has investigated the ability of satellite, census, and qualitative data to produce a land cover data base which can be used by the following researchers for better understanding of the study area in terms of urban expansion and land cover change. Moreover the district administration of Rawalpindi can use this research for better urban planning and tackling problems of illegal urban expansion over government lands. This chapter has so far described the background, motivation, aims objectives and research questions, and the rationale for selecting Rawalpindi as the study area. The second half of the chapter throws light on the literature related to the present project.

1.15 Thesis Structure

The thesis is organized into nine chapters. The first chapter briefly describes the background and motivation, aims and objectives, research questions, the need for land cover mapping in Pakistan and the selection of the study area and its physical setting. Moreover a brief review of literature about the methods used in the research has also been included in this chapter. Chapter two describes in detail the various data sets used for this research. Chapter three delineates the methodology used in the study. The chapter describes in detail the data processing, data collection, data evaluation and change detection methodologies. The following chapter presents a detailed discussion on population patterns of Pakistan and the study area. The second portion of this chapter has envisaged the urbanization processes and patterns of Pakistan in general and the study area in particular. The fifth chapter demonstrates how multiple qualitative methods, namely interviews, focus group discussions, participant observation and transect walks, have been employed to understand and analyse the land use and land cover change of the study area. This chapter also offers a brief discussion on integration of GIS and qualitative methods. This chapter discusses the people’s perception about urban expansion of the study area during the last forty years and its effect on the deforestation and loss of agricultural land. An important element of this chapter is the “mental mapping” of the area with the help of the local community.

The sixth chapter is about classification and accuracy assessment techniques used to extract the accurate land cover information of the study area. Seventh chapter presents the land cover statistics derived from the remote sensing data. The land cover change of the study area for the last forty years is discussed with the help of transitional matrices. A further discussion on the classification outcomes and their correlation with various socio economic variables derived from the census qualitative data and governmental records has been delineated in the second last (eighth) chapter. Chapter nine discusses the main findings, evaluation of the research objectives, and strengths and weaknesses of the data used in this study. It further outlines the reflections on the study, and gives an insight into the directions for future study.

2 DATA SOURCES

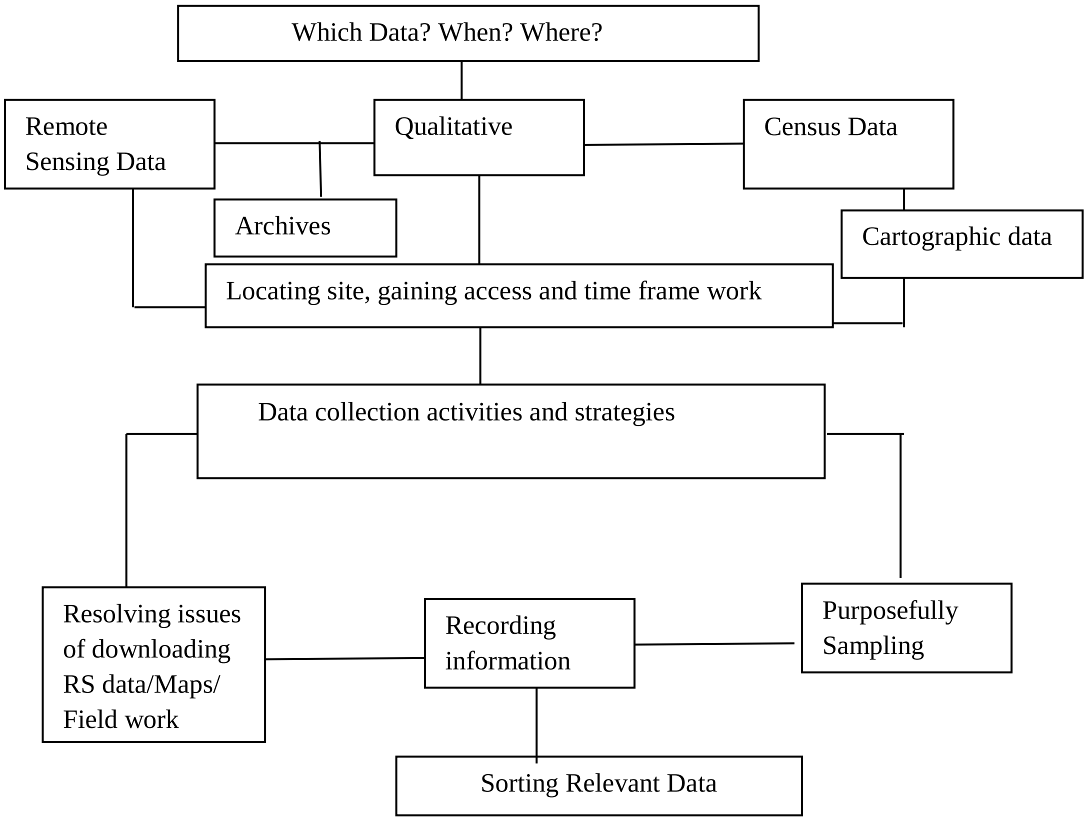
2.1 Introduction

Data is an imperative tool of the researcher. Applicable and reasonable data sources are vital to ensure the implementation of the study objectives. In fact data collection offers one more instance for assessing research design within each approach to inquiry (Creswell, 2009).This chapter throws light on various kinds of data, their sources and the issues related to their resolution. A number of different kinds of methods, strategies and techniques will be discussed in this chapter, which is about the acquisition of data to achieve the required research outputs in an efficient way with good quality control. Data sets play a pivotal role in this research and the choice and implementation of the methodology (Chapter 3) is largely driven by the availability of the input data and the ways it has been collected. The structure and content of the entire thesis is highly dependent upon the foundations laid in the following sections of this chapter. Both raster and vector data sets were used in this study. Land cover changes were assessed from Landsat Multispectral Scanner (MSS) and Landsat Thematic Mapper (TM) satellite imageries of 1972, 1979, 1992, 1998 and 2010. Other raster data sets utilised in this study were SPOT (20 m), Landsat Enhanced Thematic Mapper ETM+ and Google earth images, which were used for accuracy assessment. Vector data included GIS shape files and tabulated excel spread sheets. Census and qualitative data served as a base for much of the vector analysis.

2.2 Data Collection activities

Keeping in view the data quality dimensions and different nature of the data, before to begin, a circle of interrelated activities that best displayed the process of data collection were thoughtfully visualised. For instance, major questions for discussion were how to gain access to appropriate satellite data, what kind of qualitative data could be gathered and how population data, published and unpublished, could be accessed. There were also issues relating to the ways in which information was recorded, issues related to downloading, data resolution, and practical problems to be faced during the field work. Figure 2.1 briefly summarizes these data circle activities as visualized by the researcher.

Figure 2.1: Data collection activities



Source: Author

An important step in any land use land cover change analysis is the selection of the appropriate scale of the study area, and with this, the selection of appropriate data to conduct the study at an adequate resolution. Before starting a detailed discussion on data, Table 2.1presents the way in which following chapters will be based on the information portrayed in them.

2.3 Remote Sensing Data

Remote sensing is the measurement or acquisition of information of an object or phenomena by a recording device that is not in physical or intimate contact with that object or phenomena (Colwell, 1983; Lilisand et al., 2004; Jensen, 2009). Modern remote sensing has more to do with the technical ways of collecting airborne and space borne information (Donoghue, 2002).The first collection of Earth information with the help of balloon in 1860 is considered an important landmark in the history of remote sensing. Hence remote sensing is not a new technology. Aerial photographs, taken by using an automatic camera have been in widespread use for a century, but the launch of the first satellite paved the way for remote sensing applications in many fields, including urban land use/land cover change detection.

Table 2.1: Data sets and their relevance to the chapters of the thesis

Data	Description	Main Chapter(s)
Remote sensing data Landsat MSS,TM and ETM+	To describe the study area, and extract LULC information	Chapters 6,7 &8
Census data District Census Report Provincial Census report Agricultural Census Reports	Population based analysis of the area, and linking it with Remote sensing results.	Chapter 4, 6 & 8
Field data Qualitative data Focus Group Discussions Interviews Public Participatory GIS GPS data	**For verifying images** Incorporating community Knowledge into the GIS &RS Explanation of urbanization Preparation of base map Geo correction of images	Mainly Chapter 5 and partially all chapters
Cartographic data Planning maps District/tehsil/UC/Mauza maps Topographic maps Revenue maps(Latha[5])	For evaluation of the LULC phenomena and incorporating results into GIS	Chapters 6,7,8
Archival Data Survey reports, Ministerial reports, Research reports, Theses etc.	To be used as secondary data and information of the study area	Chapter 2 & 6

Passive and *active* are the two main types of remote sensing. The former detects natural radiation that is emitted or reflected by an object or surrounding areas, while the latter emits energy in order to scan objects and thereafter measures the radiation that is backscattered from the target (Aplin, 2005). Satellite remote sensing is being widely applied as a tool in detecting urban land use and land cover change. Because of widespread availability, frequency of update and cost, the focus of urban remote sensing has shifted from traditional aerial photographs to the use of digital multi-spectral satellite images (Lu & Weng, 2006). Satellite remote sensing collects multispectral, multi resolution and multi temporal data and turns them into information valuable for understanding and monitoring urban land processes and for building urban land cover data bases (Lambin, 1997; Kressler et al., 1999; Van, 2006; van der Linden and Hostert, 2009). The information provided through remote sensing analysis can also be converted and used within GIS for mapping and analysis. Since the advent of the first Landsat satellite, research on image interpretation and analysis has never stopped. Various imaging satellites ranging from Landsat to QuickBird create considerable challenges in terms of developing data processing techniques to exploit information in urban scenes (Jansen, 1986). In section 2.4 some details can be found regarding the characteristics

[5] In Urdu, Latha means a piece of white cloth. But here the term has been used for those detailed maps of the mauza/village which have been made on white cloth by the revenue officials.

of the satellites. This section has been added particularly for those human geographers who are interested to extract social information from the images taken from different sensors.

2.4 The Landsat System

The Landsat series of satellites have provided good quality multispectral data since 1972. There have been a total of 8 Landsat satellites launched. Landsat 1, 2, 3 and 4, launched in 1972, 1975, 1978 and 1982 respectively, are no longer in operation while Landsat 6 (1993) suffered an early demise. Landsat 5 Thematic Mapper (TM) was launched in 1984 to collect 30 metre pixel size high quality radiometric imagery in seven spectral bands and TM data. Landsat 7 launched in 1999 carries an Enhanced Thematic Mapper Plus (ETM^+) sensor which is essentially the same as Landsat -5 TM data except it has two distinct enhanced features: a new panchromatic band (Band 8) with 15 metre resolution, co-registered with the Multispectral bands; and a thermal infra-red band (Band 6) which has a resolution increased from 120 metres to 60 metres. Landsat 8 launched in February 2013 includes additional bands and combinations used to create RGB composites differ from Landsat 7 and Landsat 5. For example to create a colour infra-red (CIF) image in Landsat 7 and 5, bands 4, 3, 2 are used, whereas for Landsat 8, bands 5, 4, 3 are used to create CIF image. Currently only Landsat 5, 7 and 8 are operational, however the data from all sensors can be obtained from archival sources (WIST, GLOVIS), for almost for all parts of the world, free of cost. Table 2.2 compares the MSS, TM and ETM^+ sensor characteristics.

The Moderate Resolution Imaging Spectroradiometer (MODIS) was launched in 1999 to image the Earth in 36 spectral bands. The spatial resolutions of MODIS at nadir are 250 m for Bands 1 and 2 with 40 detectors each, 500 m for Bands 3 to 7 with 20 detectors each, and 1 km for Bands 8 to 36 with 10 detectors per band. Advanced Very High Resolution Radiometer (AVHRR) is also of particular value in monitoring seasonal variations in crops and other types of vegetation but only at the coarse resolution of around 1km.

The first SPOT imaging satellite was launched in early 1986. So far five SPOT launches have provided medium to high resolution optical image data of the earth’s surface over the visible (green & red) to near infra-red portion of the electromagnetic spectrum. SPOT 1, 2 and 3 have two HRV (High resolution visible) sensors with Multispectral (XS: bands 1-3) and panchromatic (Pan) modes on board. SPOT 3 failed in November 1996. SPOT 4 & 5 both carry two HR VIR (High Resolution Visible Infra-red) sensors. The HR VIR is similar to HRV except HR VIR has an additional short wave Infra-red (SWIR) band (X14) and narrower wavelength bandwidth of the panchromatic mode, also named as the mono-spectral model (Xian, 2009).

Table 2.2: Landsat Multispectral Scanner, Thematic Mapper and Enhanced Thematic Mapper Plus sensor system Characteristics

	Landsat (1-3) Multispectral Scanner (MSS)		Landsat 4 and 5 Thematic Mapper (TM)		Landsat 7 Enhanced Thematic Mapper Plus ETM^+	
	Band	**Spectral Resolution (µm)**	**Band**	**Spectral Resolution (µm)**	**Band**	**Spectral Resolution (µm)**
	4[6]	0.5-0.6	1	0.45-0.52	1	0.45-0.52
	5	0.6-0.7	2	0.52-0.60	2	0.52-0.60
	6	0.7-0.8	3	0.63-0.69	3	0.63-0.69
	7	0.8-0.11	4	0.76-0.90	4	0.76-0.90
	8[7]	10.4-12.6	5	1.55-1.75	5	1.55-1.75
			6	10.40-12.5	6	10.40-12.5
			7	2.08-2.35	7	2.08-2.35
					8 (panchromatic)	0.52-0.90
IFOV at Nadir	79x79 m for bands 4-7 240x240 m for band 8		30x30 m for bands 1-5 and 7 120x120 m for band 6		30x30 m for bands 1-5 and 7 60x60 m for band 6 15x15 m for band 8	
Data rate	15 Mb/s		85 Mb/s		250 images per day @31.450km^2	
Altitude	919 km		705 km		705 km	
Swath	185 km		185 km		185 km	
Inclination	99º		98.20º		98.20º	

Source: Morain (1998); Jensen (2005) and Lilisand et al. (2004)

High resolution commercial imaging satellites like IKONOS, Quickbird and ORBIMAGE were launched in 1999, 2001 and 2003 respectively. RapidEye and GeoEye-1 has been launched in 2008 and 2009 respectively. However the cost of data from these sensors is still very high. It is important to mention here that Landsat satellites provide an unparalleled record and are being used in LUCCdetection studies over the globe, not only due to their cost-free availability, but also because

[6] MSS bands 4, 5,6 and 7 were renumbered as bands 1,2,3 and 4

[7] MSS band 8 was present only on Landsat 3

Landsat's 30 metre resolution is ideal for human impact on the land. Moreover the consistency of their digital image data from sensor to sensor and year to year makes it possible to trace land cover changes from 1972 to the present.

2.5 Processing Landsat Data

The USGS Global Visualize Viewer managed by Earth Resources observation and Science (EROS) is the main browser for downloading/ ordering Landsat data. It now offers to all users the Landsat 1-5 and 7 archive data at no charge, using a standard data product recipe. Earth Explorer[8] and GlOVIS[9] are very effective for satellite image browsing, which provides access to satellite, aerial photographic, and mapping cartographic data products. It is important to mention here that when a suitable image is identified, it can either be downloaded at once or a request submitted to the USGS, where the concerned scene is processed by the National Land Archive Production System (NLAPS). This takes a few days for a response to the request. Actually during the time of request processing, the systematic radiometric and geometric corrections are generated, employing both ground control points and a digital elevation model (DEM), which is time consuming. That is why this L1 standard product may take three to six days to become available for downloading. For this research twelve Landsat scenes – four from MSS for the years 1972 & 1979 (two for each year) and Eight TM scenes for the years 1992, 1998, & 2010 (two for each year) were downloaded at different times during first and second years of the present research. It should be mentioned here that the years of these images were selected keeping in view Pakistan's census dates. Sample met data information of Landsat TM 1998 is given at Table 2.3

The spectral response of features varies from season to season due to variations in the growing cycles of vegetation, and amount of rainfall in different seasons. Images of the same seasons/months of different years (anniversary images) minimize the changes in refelectance of particular feature due to a season. As discussed earlier although efforts were made to select those images which were of the same dates of census organization, but seasonality of the images were also taken into consideration. Therefore in this study, near anniversary/ census organization dates compatible images were used. These were Landsat MSS scenes of Path 161 and Rows 36 and 37 acquired on September, 07, 1972 and 1979; Landsat TM scenes of Path 150 and Rows 36 and 37 acquired on October 12, 1992; October, 08, 1998 and September, 24, 2010.

[8] http://earthexplorer.usgs.gov
[9] http://glovis.usgs.gov

Table 2.3: Met data file of Landsat TM Scene (150/37) of October 10, 1998

Spacecraft Identifier	**LANDSAT_5**	**Landsat Scene Identifier**	**LT51500371998280AAA01**
Sensor Mode	N/A	Stop Time	1998:280:05:21:26.69438
Station Identifier	AAA	Data Type Level 1	TM L1T
Day Night	DAY	Sensor Anomalies	N
WRS Path	150	Acquisition Quality	9
WRS Row	037	Quality Band 1	9
WRS Type	2	Quality Band 2	9
Data Category	NOMINAL	Quality Band 3	9
Date Acquired	1998/10/07	Quality Band 4	9
Start Time	1998:280:05:20:59.61988	Quality Band 5	9
Quality Band 6	9	Cloud Cover Quadrant Lower Rig	10
Quality Band 7	9	Sun Elevation	45.26734125
Cloud Cover	0	Sun Azimuth	145.14130392
Cloud Cover Quadrant Upper Right	0	Scene Center Latitude	33.18155 (33°10'53.58"N)
Cloud Cover Quadrant Lower Left	10	Scene Center Longitude	72.89565 (72°53'44.34"E)
Corner Lower Left Latitude	32.52808 (32°31'41.09"N)	Corner Upper Left Latitude	34.11144 (34°06'41.18"N)
Corner Lower Left Longitude	71.70885 (71°42'31.86"E)	Corner Upper Left Longitude	72.12733 (72°07'38.39"E)
Corner Lower Right Latitude	32.24617 (32°14'46.21"N)	Corner Upper Right Latitude	33.82454 (33°49'28.34"N)
Corner Lower Right Longitude	73.64679 (73°38'48.44"E)	Corner Upper Right Longitude	74.09916 (74°05'56.98"E)
Browse Exists	Yes		

2.6 Data Resolution Consideration

Various parameters of data resolution such as spatial, spectral, radiometric and temporal resolutions are very important in change detection studies. They therefore need to be examined carefully. For instance spatial resolution of the satellite data in land cover classification is an important consideration, as it dictates the size of the feature that can be detected in the image. Spatial resolution is also described as the instantaneous field of view (IFOV) of the sensor and it is a measure of the area viewed by a single detector. IFOV measures the "ground resolution cell" i.e. a view of the one section of the ground that emitted energy back to the sensors. Therefore the IFOV of sensors is a good measure to make a comparison among different sensors (Jensen, 2005). Landsat imagery is considered to be of medium resolution, and many researchers recommend Landsat, particularly Landsat TM as most suitable for urban studies (Jat et al. 2008; Zhang et al 2006; Lo and Nobel, 1990).

IFOV is mathematically calculated as:

$$IFOV = HD/f \qquad \text{(Townshend et al., 1998)}$$

Whereas D= Detector size, H= Flying height above the earth and f= Focal length of a scanner

Spectral resolution of an image refers to the specific wavelength intervals in the electromagnetic spectrum. Narrow intervals in the electromagnetic spectrum refer to the spectral resolution fine, and wider intervals are referred to as coarse spectral resolution. For instance, band 3 of Landsat TM records energy between 0.63 to 0.69 µm, therefore due to narrow interval its spectral resolution is considered to be fine, as compared to Band 1 of SPOT panchromatic which records between 0.51 to 0.73 µm, and is considered to be a coarse spectral resolution band. It is important to note that many change detection algorithms do not function properly when bands of one sensor system do not match those of another system.

The radiometric resolution of an image refers to the number of possible file values in each band or in other words it characterises the total energy that each band captures in a particular sensor. For example Landsat TM records data in 8 bits, which means that the data file value or Digital Number (DN) of each pixel ranges from 0 to 255. This is much improved radiometric resolution as compared to Landsat MSS missions which recorded the data in 6 bits, containing DN values from 0 to 69. Particularly for comparison purposes, it is necessary to know the radiometric resolution of the data acquired. Temporal resolution, commonly known as the repeat cycle, refers to the amount of time taken by a sensor to return to a previously imaged location. For example Landsat 4-7 views the same area of the globe once every 16 days. On the other hand SPOT revisits the same area after every three days. Temporal resolution is an important factor to consider in change detection studies, as temporal differences between remotely sensed images are not only caused by the changes in the spectral properties of the Earth's surface features/objects, they can also result from atmospheric differences and changes in the position of the sun during the course of the day and during the year (Weng, 2012). Temporally satellite data was selected to provide a phenological picture of the land cover of the study area over the course of different stages of development as well as sufficient separation for changes to occur. Jensen and Cowen (1999) suggested that for such kinds of change detection studies, multiple satellite images for different times during the same phonological order are ideal. Also to detect the kind of urban developments, it is preferred that imagery should be separated by at least five years (Coppin et al., 2004). The intention in this study was to select satellite data that was in phonological order compatible to the organization of the national censuses.

2.7 Sources of primary Data

As discussed earlier, in this research modern geospatial technologies (Remote sensing and GIS) as well as traditional urban geographic methods have been applied. In other words, data in this study links geospatial technologies with public participatory methods. Since primary data refers to the type of data which has never been gathered by anyone before, and which serves a purpose, this section describes the methods used to obtain the perception and experiences of local communities for an in-depth understanding of the uneven urbanization with different speeds in different parts of the study area. The primary data generated in this research is mostly qualitative in nature, although several secondary and specialized methods of data collection supplement them.

2.7.1 Qualitative data

Qualitative data is usually gathered in multiple forms such as texts, images, audio and video, rather than as numbers from the field, and this study is not the exception. Having said that,the distinguishing uniqueness of this data is that it truly reflects the everyday life of community in question, as it has been collected close to the situation rather than from a distance (Denzin & Loncolon, 2000). Its richness lies in its strong potential to reveal vivid contexts. In fact qualitative data collection is a "lived experience" and is a very useful supplement in explaining the issues in their social context, which remotely sensed data cannot illuminate. Crang (2005) argues that the usefulness of qualitative data depends on how we analyse it and pull out the significant insights from it. Qualitative data used in this study refers to the quintessence of people, objects and situations, and is "a source of well-grounded descriptions and explanations of multiple processes in identifiable local contexts" (Miles & Huberman, 1994). The qualitative data in this research, refers to the range of "in the field" human to human interactions, that the researcher undertook, for the purpose of gathering information, which later on were analysed qualitatively (chapter 5) and in GIS settings (chapter 6). Mainly the second part of "field work" was spent in collecting qualitative data, which was extremely varied in nature, and for the most part involved the actions and reactions of the policy makers and the community. The focus was specifically on the methods used during field work, to collect qualitative data in this research; namely ***participant observation***, including transects and walks; ***interviews***, covering the range from semi-structured to conversational including individual to group, from policy makers to policy effectors; and *focus group discussions.* A brief literature review and analytical account of all methods employed in the field can be found in chapter 5. It is imperative to highlight here that the selection of the qualitative methods was driven by the nature of research questions, which seek to evaluate social structures and processes. The desire was to "get behind" the facts, as they exist and appear and to understand the underlying processes as well. There is a need to understand the prevailing socio-economic and political environment, the concerns of people and their individual perceptions of the effect of particular physical factors on social settings. All of these require data that can penetrate deeper into social structures. The ultimate goal of the qualitative data was to produce a coherent, focused analysis of some aspects of the social phenomena that have been observed and recorded, an analysis that is comprehensible to readers who are not directly acquainted with the social world and its issues (Esterberg,. 2002). The qualitative data were collected using all scales of measurement, i.e. nominal, ordinal, interval and ratio scales, depending upon the response and convenience of the respondents. Reliability, validity, objectivity and subjectivity are the main issues related to qualitative data, and they were borne in mind during the collection process. Therefore, while collecting qualitative data particularly thorough interviews and focus group discussion, the following key points were considered:

- Taking self as an instrument
- Thinking about selecting a site
- What kind of ethical dilemmas might arise during field work?
- Cultivating informants
- Preparing for the interviews
- Planning interviews
- Handling the pre and post interview situations
- Sampling procedures
- Formation of a focus group (harmony and interaction)
- The role of a moderator
- Transcribing and analysing FG material

2.7.2 GPS Data

Global Positioning System (GPS) data is considered to be the backbone of all map and image data because it gives strength to the accuracy of the data. Cunningham (1998) has noted that modern GPS technology has developed into a well-organized GIS data collection technology, which allows the researchers to compile their own data sets directly from the field as part of ground truthing, which is a necessary component for accuracy assessment of a classified imagery (Congalton, 1991). Given below is a brief description of the GPS technology to find the location of an object. The GPS operational constellation consists of twenty four satellites that orbit the Earth twice a day, emitting continuously navigation signals, indicating the location and time of the object.

GPS has three parts, i.e. satellites, receiver and software. The GPS receiver compares the time when a signal was transmitted by a satellite, with the time when it was received. And this time difference tells the GPS receiver, how far away the satellite is.

Distance= Velocity (v) x time (t)

Using the formula above the distance of the object can easily be calculated. For instance ,if a receiver took 0.04 seconds to receive a signal transmitted by a satellite, then the distance of the object will be 186,000[10] miles/sec x 0.04 sec= 7440 miles. A GPS receiver uses time measurements to calculate distance to several satellites with known locations at every moment of time. To achieve a "position fix" a minimum of three visible satellites are required. With the presence of more and more visible satellites, a better accuracy of the GPS receiver can be managed. An extensive GPS survey was performed throughout the study area (Rawalpindi), in order to obtain locational point data for different kinds of land covers and land uses. Moreover this GPS data has also been used:

- To verify the quality of the existing maps issued by various departments;
- For geo-correction of raw Landsat images;
- To identify and map the major land features on the images and maps;
- For creation of training sites (Section 2: Chapter 6); and
- For creating independent data for accuracy assessment (Section 3: Chapter 6).

2.8 Sources of Secondary Data

2.8.1 Population Data

The Global South, particularly in Asia, is experiencing the most profound demographic transition ever and Pakistan is at the centre of it. Pakistan's high population growth rate has fuelled urbanization. Almost 20 million people have moved to cities during last 10 years and annually

[10] Radio waves travels with the speed of light i.e. 186,000 miles per second

approximately 1000 hectares of non-urban land is converted to urban land (Awan & Iqbal, 2010). Sudhira et al (2004) contend that population and economic growth adjacent to natural and human resources are the main reasons for urbanization. Hence there is a need to know the different aspects of population such as patterns of growth, sex composition, fertility, mortality and migration patterns, etc. Census data allows an inductive exploration of land use and land cover change that may provide clues to the underlying dynamics involved (Rashid, 2003). The major source of population data in this research is the periodic population censuses from pre independence (1881-1947) to post independence (1947 to date). A number of variables have been used in these censuses, which helped the researcher to interlink the population data with remote sensing data, for finding the effect of urbanization on land cover and land use change. In fact the population census is the only source of detailed and comprehensive data in Pakistan providing the size, spatial distribution and basic characteristics for Mauza, Patawar Circle, Union Council, Tehsil, and District level. District Census Reports issued by the Census organization are the major source for obtaining census data. Hence the sources of population data include the census reports at district, provincial and national level for the censuses conducted from 1881 to 1998 (for detail, see chapter 4). In addition, the population data for the year 2012 has mainly been extracted from the *Development Statistics of Punjab, 2012* and estimates of the household enumeration of census 2011-12. The data about patterns of fertility and mortality at national and provincial level has been obtained from the reports of the National Health and Demographic Survey (NHDS) and National Fertility and Health Survey (NFHS). It is important to mention here that these surveys were conducted at the national level during 1972, 1976, 1985, 1990, 2004 and 2006, and these dates were the approximate mid periods of the censuses, so it also helped to compare the data at short intervals of five years.

The decennial *Agricultural Censuses Reports* (ACR) of Pakistan is another source of secondary data pertaining to population, agriculture, and forests and related to land utilization. The first Agricultural Census was held in 1960, and so far six censuses have been organized under the auspices of *Federal Bureau of Statistics,* Pakistan. The “mauza” is the basic unit of enumeration in both censuses, i.e. the Population and Agricultural Censuses, and this proved helpful for using the data, extracted from these censuses, as reference data. The sources of population data used in this research are listed in Table 2.4. Besides the sources listed in table 2.4, the secondary data (population data) has also been collected from the annual/ historical publications and reports of the various departments, mainly government departments, including, Revenue, Public Health Engineering, National Institute of Population Studies (NIPS), Pakistan Institute of Development Economics (PIDE), Punjab School Education Department, Rawalpindi Development Authority (RDA), Capital Development Authority (CDA), National Engineering Services of Pakistan (NESPAK), and Population Institute Asia Pacific Bangkok.

Table 2.4: Sources and years of population data

Sources	**Collection years**
Government of British India (*Population Census reports of Punjab)*	1881,1891, 1901, 1911, 1921, 1931, 1941
Government of Pakistan, Islamabad Population Census organization of Pakistan *(District Census reports, Provincial & National census reports)*	1951, 1961, 1972, 1981, 1998,2011-12[11]
Government of the Punjab, Lahore *Development Statistics of Punjab*	2009, 2010, 2012
Government of Pakistan, Islamabad *National Health and Demographic Survey Reports*	1972, 1985, 2006
Government of Pakistan, Islamabad *National Fertility and Health Survey Report*	1976,1990,2004
Government of Pakistan, Islamabad Federal Bureau of Statistics, Islamabad *Agricultural census reports/ Sample surveys reports*	1972, 1981, 1880, 2000, 2010

Source: Author

2.8.2 Sources of secondary maps

Maps are very important tool in the present research. All GIS data/ coverage, layouts and remote sensing images have been clipped, digitized and overlayed on the basis of the information contained in the maps. Any kind of historical information, location of mauzas, union councils, patwar circles and roads, was gathered with the help of maps. A GPS survey of the study area during the field work was also conducted with the help of map information. Although some maps contained errors in comparison with the real ground status, mainly due to the lack of survey skills of map makers, and ambiguities in cartographic and compilation work, these maps proved to be a good source during field work, particularly during GPS survey and later for geo-referencing. Different organizations develop maps in Pakistan depending upon the purpose and demand, but those maps which are prepared by the organizations working under the aegis of government, such as Survey of Pakistan etc., are considered to be reliable. Table 2.5 summarizes the various sources of relevant maps used in this research.

[11] Household enumeration only

Table 2.5: Summary Information of the maps

Map name	**Detail about map**	**Scale**	**Organization**
District Map	District administrative map of Rawalpindi	1: 150,000	Survey of Pakistan, Islamabad
Tehsil Map	Tehsil administrative map of Rawalpindi, Gujjar Khan, Kahuta, Kallar Syyadan, Murree, Kotli Satian,Taxila	1: 20,000 1: 50,000 1: 10,000	1:Survey of Pakistan, Islamabad 2:Population Census Organization of Pakistan, Islamabad 3:Tehsil Municipal Administration, Rawalpindi
Land use map	Land use guide plan of Rawalpindi	1:20,000	Survey of Pakistan, Islamabad
Latha	Map of a village/mauza on white cloth having marked name and size of land holdings of every person in the village	1:120	Revenue Department of Rawalpindi
Rawalpindi Guide Map	The important features /land marks of Rawalpindi tehsil are shown on the map	1: 20,000	Survey of Pakistan, Islamabad
Topographic map	Topographic maps (1981) Third edition bearing index numbers $43\frac{G}{1}$, $43\frac{G}{2}$, $43\frac{G}{3}$, $43\frac{G}{4}$, $43\frac{G}{5}$, $43\frac{G}{6}$, $43\frac{G}{7}$, and $43\frac{G}{8}$ (Restricted versions)	1: 50,000	Survey of Pakistan, Islamabad
Master plan	Rawalpindi Master plan (1996-2006)	1:42,000	Regional and Physical Planning office Rawalpindi (Govt. of Punjab, Lahore)
Land use Map	Rawalpindi city land use map (Master Plan 1970-1990)	1:20,000	Government of Punjab, Lahore
Rawalpindi Plan	Development and strategic plan of Rawalpindi (2010)	No scale	Rawalpindi Development Authority
UC Map	Union Councils Map of Rawalpindi (2006)	1;10,000	District Government Rawalpindi
Mauza map	Mauza wise maps of tehsils of Rawalpindi, Gujjar Khan, Taxila,Kahuta, Kallar Sayyadan, Kotli Sattian and Murree(2010)	1:10,000	Government of Pakistan
Road map	Rawalpindi Ring Road Map	Not shown	Rawalpindi Development Authority
Lai map	Nullah Lai drainage map showing catchment area of nullah Lai and its tributaries	Not shown	Ministry of Planning and Urban development, Govt. Of Punjab, Lahore

Soil Map	Soil and land types map of the Punjab (1978)	1:100,000	Survey of Pakistan, Islamabad
Geology map	Geological map of Pakistan (1991)showing different physiographic regions of Pakistan	1:200,000	Geological Survey of Pakistan, Islamabad
Land productivity map	Land Capability map of Punjab(1978) showing different carrying capacity classes according to productivity	1:100,000	Survey of Pakistan, Islamabad
Potohar map	Map of Potohar plateau(1994) showing administrative units	1: 200,000	Survey of Pakistan, Islamabad
Pakistan map	Map of Pakistan (1994 & 2000) showing administrative units (provinces to tehsils)	1:500,000	Survey of Pakistan, Islamabad
Capital Transport Plan	Integrated transport network plan of Rawalpindi /Islamabad(2000)	1:30,000	CDA/ RDA and Ministry of Planning and Urban development, Govt. of the Punjab, Lahore
Country map	Pakistan agricultural and land use map	Not shown	Perry- Castaneda Library map collection- University of Texas (web maps) www.lib.utexas.edu/maps/ams

Source: Author

Along with published sources, relevant data has also been extracted from unpublished sources for this research. For instance, the unpublished PhD theses of different universities on the topic of urbanization, population dynamics, socio-economic development of Pakistan, have been consulted. Moreover, non-commercial digital data sets of the Sui Northern Company and GIS department of the Population Census Organization of Pakistan have also been utilized. The Sui Northern conducted GPS surveys in 2005 of very important landmarks of Rawalpindi, including each and every location in local perspective. Similarly, the Population Census Organization of Pakistan, since 2010, is engaged in collecting data of feature layers such as: Educational institutes, Police stations and Post offices at Mauza level. With the permission of the both departments, the GPS survey data of both departments pertaining to Rawalpindi district has been used in this study.

2.9 Conclusion

The description of the study area emphasizes the importance of the chosen area for supporting the research objectives. In fact the description of the area, in combination with visual and digital interpretation of remote sensing data highlights a rationale for good research.

Land use is dependent upon many variables such as climate, topography, soils, land values and governmental policies. Integration of at least some of these parameters with field work, ancillary and remote sensing data gives a realistic picture of the study area. Thus the first part of the chapter basically provided information in respect of location, climate, topography, water resources, soil, geological hazards such as frequency of floods and earthquakes, agriculture, horticulture, forest resources, mineral resources and industrial set-up. The second part described the various sources of data used in the research. The primary and secondary sources of data ranging from qualitative data collected through interviews, focus group discussions, participant observation, population data collected from Population Censuses, Population surveys, various types of satellite data and their procedure of downloading, various kinds of maps and their sources, all have been discussed in detail under the caption of data sets.

In short, efforts have been made to describe all those aspects of the study area, and data sets, which may further help in the analysis of the relationship between urbanization and land use change patterns of the study area. The reasons of choosing Rawalpindi as study area are achieved so that further inferences can be made from this study area to other parts of the Global South having some resemblance.

3 METHODOLOGY

3.1 Introduction

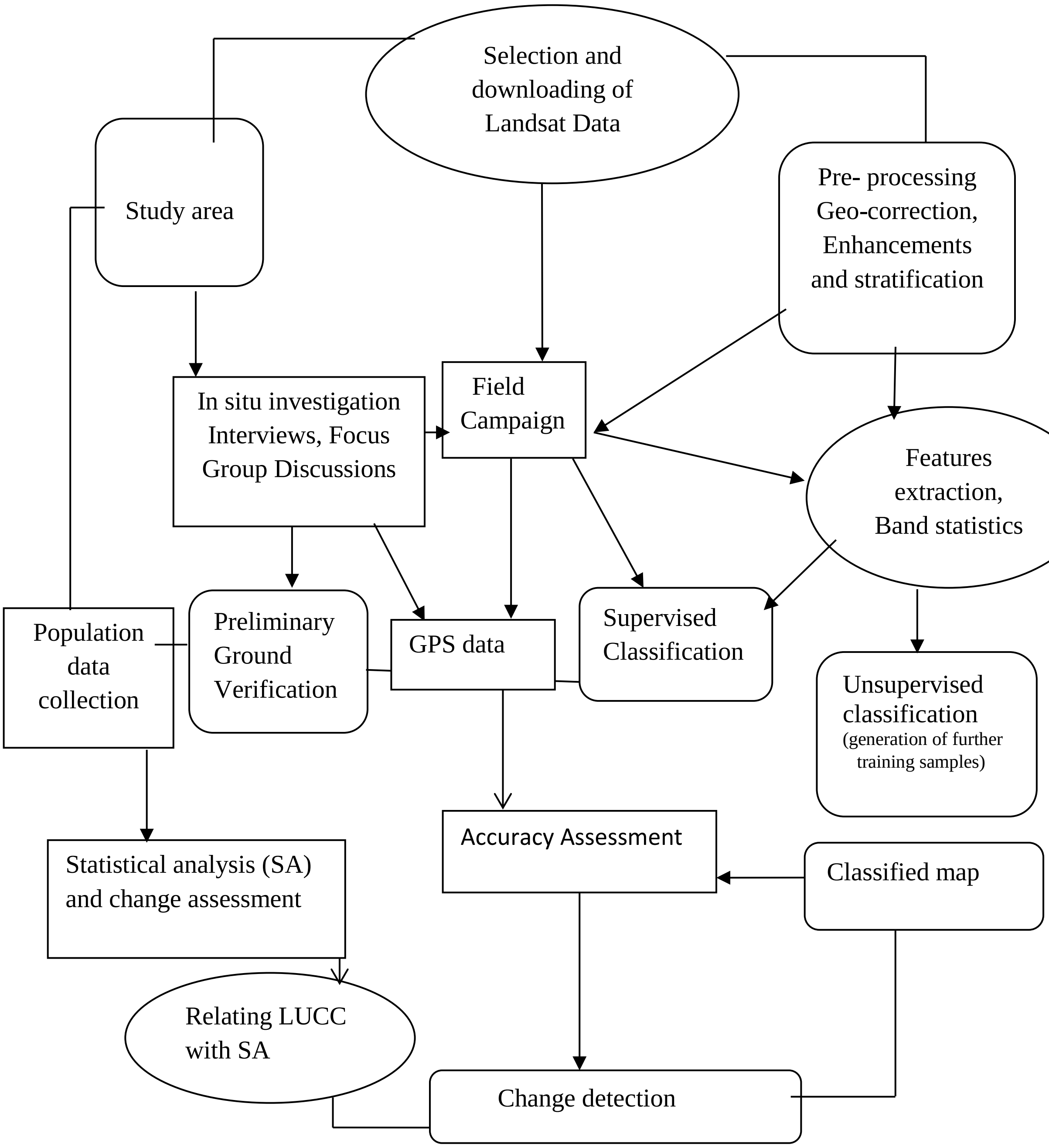
Methodology is a way to systematically resolve a research problem. Pragmatically the methodology adopted in this research reflects the elements of both qualitative and quantitative approaches. In order to address the wider issue of how urbanization is linked to the different land cover changes, this research aims to analyse a case study of Rawalpindi (Pakistan), using remote sensing, Geographical Information System, GPS, qualitative survey methods, and historical census data. Remote sensing is a cost effective and increasingly used technology to characterize urban land use/cover (Jensen and Cowen, 1999). During the last few decades some extensive research efforts have been made to detect and monitor urban land use/cover from remotely sensed data with varying accuracy (Aplin & Smith, 2011; Ridd, 1995; Yang and Lo, 2002; Deng et al., 2009).

As discussed above, for a complete understanding of the impact of urbanization on the land use of the study area, effective synthetic indictors of both physical and qualitative components need to be extracted and integrated together before analysis. Satellite data acquisition parameters and field data specifications require a number of decisions. Landsat data has a major influence on the selection of the processing methods. Consequently, the research methods used in this study have been developed on the basis of the availability of the satellite data, suitability of the study site, and the availability and quality of the ancillary and qualitative data (Chapters 2 and 5). Therefore a variety of approaches outlined in fig.3.1 have been adopted to achieve the aims and objectives which have been listed in the first chapter. Based on the data analysis, this thesis can be divided into four major parts: (1) urbanization characterization; (2) people's perception about urbanization and land use changes; (3) multispectral image classification from selected spatial methods; and (4) dynamics of land use/ cover.

3.2 Data Collection Methodology

A data collection methodology was established beforehand for Landsat image acquisitions and field data collection. A number of Landsat images of the study area were acquired which were thought useful to portrait the urbanization patterns during the last four censuses. An effective interpretation of images and supervised classification requires *a priori knowledge* of the scene (Cheng and Masser, 2003). This knowledge was derived from ground truth data including GPS and qualitative data. The gathering of qualitative, Population and GPS data was performed using a "well thought" field work strategy. The main aim of the field data collection was to collect suitable data for land cover assessment and validation. Although multi temporal satellite data was acquired, the 2010 satellite images and field data were approximately acquired simultaneously.

Figure 3.1: Methodology Chart



3.3 Data Processing Methodology

Data collected from Landsat MSS and TM sensors, field work, census and ancillary sources were processed according to a specific framework described in detail in chapter 6 and outlined in Fig. 6.1. This phase involved pre-classification, classification and post classification treatment of the above kinds of the data. The pre-classification phase involved geometric correction, resampling, enhancements and stratification of satellite images. The digitization, geo-referencing of the census tracts and maps such as topographic, land use and district boundary maps were also performed during this phase. The GPS data were also re-projected and prepared for further use as training and test data. Before using the conventional methods of classification, a methodology was also outlined to perform the visual interpretation and classification of remote sensing data by extracting various features sets, using band wise land cover statistics, principal component analysis and application of band ratios including Normalized Difference Vegetation Index (NDVI), Normalized Difference Built up Index (NDBI) and Normalized Difference Barren land Index (NDbal). Following the identification of land covers through appropriate measures, mainly the supervised classification approach was adopted for land cover mapping. Finally some post classification enhancements techniques were also applied to encounter the salt and pepper effect.

3.4 Data Evaluation Methodology

The data evaluation methodology mainly focussed on assessing the accuracy of the Landsat images with the help of the reference data. The scope of this work was to conduct an assessment of different land covers and urban and non-urban change estimates. Three major operational phases of thematic accuracy assessment: response design (field methods), sampling design, and data analysis were planned out to derive the results. The analysis of results from the different classifiers was subjected to a comparison procedure, to identify the suitability of different classifiers in detecting the land cover. Different procedures were adopted to calculate the user's, producer's overall accuracy, Kappa statistics.

3.5 Data Analysis Methodology

A framework for application of different statistical measures was devised and is used in the sixth chapter to analyse the urban landscape during the different census periods. A methodology was developed to convert the DN values into temperature and comparing it with the Land cover types. Further different statistical approaches were devised to analyse urban expansion during the last four decades and comparing it with the remote sensing and census derived information. Each phase of data inputs involved a specific framework and this will be explained and justified in each section.

3.6 Field Methodology

The field methodology was developed in the context of research objectives with an aim to determine the LUCC in response to urbanization and its impact on the health, education and economic conditions of the local residents. The *field campaign* not only provided first hand observation but also the acquisition of accurate locational data, focus group discussion data and interviewing of the community and experts as done by Dewan et al (2010) and Chen et al (2007). The study area was visited twice, i.e. in 2010 and 2011 for the following purposes:

1) **Intensive GPS Surveys:**
   A general GPS survey of the study area was done to identify a sufficient number of GCPs for geo-referencing, geometrical correction of images and to further their use as training and test data. Ground truthing was done with the help of a hand-held Garmin GPSMAP 60CSx instrument, on homogeneous stretches of land in all tehsils of the study area, and marked on the images, corresponding topographic maps, field books and on a base map. For checking purposes, some mauza maps shape files and GPS data collected during the field work were converted to KML format and viewed in Google Earth to match the location of the different land covers.
2) **Preliminary Ground Verification**
   Preliminary classified satellite images maps were verified during the field work, which helped to identify some unknown features on the satellite images. In the second slot of the field work in 2011, besides extensive collections of qualitative data, training pixels were selected on the Landsat TM 2010 image (the most recent) and located in the field.
3) **Qualitative Data Collection**
   To understand the causes of land cover change, population patterns, and human impacts, Interviewing, Focus Group discussions and Participant observation techniques were adopted and the planning policies and views and perceptions of the local community were documented.
4) **General Data Collection**
   Many relevant maps, censuses and research reports and important information related to the study area that is published by the local authorities and not available in the UK, were collected and photocopied. For instance the mauza maps (Latha) were available with the Patwari (revenue official), and not officially printed, therefore some of these maps were traced from the original maps during the field work. Moreover with the help of these maps and local people, standard land use map of the tehsils were prepared. Historical population and agricultural censuses reports were also collected during the field work.

5) **Participant Observation**

Participant observation is a key aspect of my research (chapter 5), to develop a linkage between ethnographic data and remote sensing. The field work during 2010 and 2011 helped the author a lot to collect the relevant data through sporadic observation and participation, perimeter walks and informal interviews.

6) **Observing Census Work**

During the time of field work in 2011, "household identification" work was carried out by the Population Census Organization (PCO) of Pakistan. The author utilized this opportunity and worked with the census team to visit some of the remote areas of the study area where he collected the raw census data of some mauzas to make some estimates about population.

7) **Topographic Maps Collection**

Topographic maps are restricted maps in Pakistan. It is not possible to bring hard copy of these maps out of Pakistan. Therefore, primary interpretation, vital digitization work, was carried out during the field work in the office of the Deputy Surveyor General, Survey of Pakistan, Islamabad.

8) **Public Participatory GIS**

During the Focus group discussions with different social status groups, a participatory mapping methodology was used to understand the change of the area over 40 years, using the local community perceptions about the urban development through the identification of the land features from the satellite images (chapter 5, section 5.5.3). The preliminary classified printed maps were shown to the Focus groups, and different land features were identified with their help. In the first phase, the focus groups also mapped their areas without having satellite images (mental mapping) and later, they did the same job with the help of images and explained the reasons behind the change as well. Some of them interpreted the images better than the readily available image processing techniques. This helped the researcher to identify the historical mapping of the land cover using remote sensing and community knowledge.

The overall field work activities, played a very crucial role in this research to assist, interpret and map the census, remote sensing and qualitative data.

3.7 Review of the Qualitative Methods

Remotely sensed data can be combined with qualitative data to provide information on urban expansion and land use change by supplementation with insights from residents and urban planners. One important task is ground thruthing of image data in relation to real features on the ground, which can be greatly enhanced with some input from the local community, who can usually provide information on recent and historical land cover in particular locations. Robbins (2003), Smucker et al. (2007) and Wood & Skole (1998) have all found that participatory ground truthing and mapping methods can be extremely beneficial for enhancing the accuracy and detail of classification. Farley et al. (2012) conducted in-depth structured interviews with ejidatarios [in Mexico] mainly focussing on those who had lived locally for at least 20 years and were able to speak to land use change over time in the location. Naidoo and Hill (2006) used extensive perimeter walks with indigenous hunters through a protected forest and collected the ground truthing data for the supervised classification of forests types.

There are many researchers who have carried out remote sensing analysis in association with field-based qualitative data such as household surveys. Examples include: Campbell et al. (2005); and Dennis et al. (2005). Moran and Brondizio (1998) linked detailed ethnographic data, land use histories to the spectral analysis to achieve a field-based understanding of changes in land cover and the regional analysis of land use/cover. For this purpose they classified the satellite images using "unsupervised classification" before going into the field to collect ground truth as well as household survey data. Then by combining the household surveys and field walks with remote sensing images, they carried out detailed vegetation and soil sampling. Finally they used the collected field data to perform a "supervised classification" and returned in subsequent years not only to enhance the quality of the field data but also to improve the remote sensing classification. With this data the authors were able to investigate the correlation between land use practices, household characteristics and bio physical land cover. These examples show how the participation of local people can contribute to deepening analysis based on satellite data. In the following section, the researcher has focused on interviews, focus group discussions and participant observation including transects and walks as a means of collecting qualitative data.

3.7.1 Participant Observation

Participant observation is a technique of field research, by which a researcher studies the life of the people by taking part in daily activities, rituals, interactions and events of a group of people as one of the means of learning the explicit and tacit aspects of their life routines and their culture. The point here is to *observe* and *experience* the study area as a participant, while retaining an *observer's eye* for understanding analysis, and explanation (Dewalt and Dewalt, 2002). Though this method has been used most extensively in the ethnographic and anthropological contexts, a good number of human geographers are now using this technique of knowing the context.Analysis of participant observation data can be instrumental in providing nuanced insights concerning the context and background of more formalized interviews and focus groups that take place in the field. For the purpose of "participant observation" the researcher temporarily rented houses at different places for different intervals of time and spent a lot of his time during the field work with the local people, learning their language and customs, sharing views and learning about the problems they face in everyday life. By way of spending several nights in each urban and peri-urban cluster, walking around, participating in local festivals, attending marriage ceremonies, and long informal and formal discussions with both the youth and old, the researcher gathered a treasure of information which would have been inaccessible through non-living images and census data.

3.7.1.1 Sporadic Observation and Participation

Sporadic Observation is a kind of observation where the researcher is not involved in "intended" observation but "rather he gets information spontaneously". As a matter of fact there were many occasions when I was doing nothing, just walking around, talking to my friend, enjoying the scenic beauty, watching the children playing, and listening to the loud local music (coming from inside the houses). But at the end of day, I realized these were the precious moments when I got more information than I could obtain through formal means. For example, while watching innocent bare foot children playing on footpaths and roads in the urban areas, I learned about the scarcity of playgrounds and poverty of the people. Indeed during this kind of silent "sporadic observation" I explored many themes of urbanization, land use, industrialization, population growth and loss of agricultural land, pollution, and pattern of drainage system, etc., which added both empirical and conceptual depth to the image-based land classification.

I hired a vehicle to take me round of those areas which I could not cover while walking, and during these journeys, my 60 year old driver-cum-guide not only showed me the entire area, but also explained the causes of deforestation, sites of newly established colonies, construction of new roads/parks/schools and misuse of the recreational facilities. He also told me about local politicians and their role in so many stories. (Sometimes I also noted his bias and his gift for "elaboration", but he nevertheless gave me far more useful information than I was expecting).

Overall, my experience of sporadic and participant observation during the field work proved to be very positive for exploring and utilizing the mixed / ethnographic data in understanding land use/ cover change at various scales and times, within the urban centres and between neighbouring centres.

3.7.2 Interviews

Kahn and Cannel (1957) provided the straightforward definition of an interview as "a conversation with a purpose". Maccoby and Maccoby (1954:499) had earlier offered a similar definition of interviews as a "…face-to-face verbal interchange in which one person, the interviewer, attempts to elicit information or expressions of opinion or belief from another person or persons." Jones (1985) distinguishes between a general interview (used by a magazine or newspaper editor) and a research interview arguing that the latter never loses track of its objectives. Jones (1985:138) goes further to define a research interview as "… a social interaction between two people in which the interviewer initiates and varyingly controls the exchange with the respondent for the purpose of obtaining … information relevant to an emerging or stated hypothesis." In fact interviewing is more than "having a chat" requiring hours of preparation, planning and background work as well as ample time for transcription and analysis of the information gathered (Gubrium and Holstein, 2002). Never the less knowledge extraction is simple game of question.

There are three broad types of interviews: structured, unstructured and semi-structured. Structured interviewing tends to follow a predetermined and standardized list of carefully worded questions. The structured interviews are in the form of standardized questionnaire-based interviews with a little to no room for clarification or elaboration by either the interviewer or interviewee. By contrast, semi-structured interviewing has some degree of predetermined order, but flexibility is built into the way issues are addressed by the informant (Dunn, 2000). The questions asked in semi-structured interviewing tend to be content focused and deal with the issues or areas judged by the researcher to be relevant to the research question. This form of interviewing according to Dunn (2000:61) "…is organized around ordered but flexible questioning". Semi-structured interviews were preferred for the present study (Baxter & Eyles, 1997). Their open format is ideal for generating data-rich descriptions, integrating multiple perspectives and learning how events are interpreted and identifying variables and hypotheses for future research (Weiss, 2008). While conducting a semi structured interview I used a list of "prompts" to be asked of the respondents (see appendix 5.1). These were drawn up beforehand and, while striving for conversational tone, I was seeking to elicit a deeper understanding of the respondent's feelings, experiences and motivations (Berg, 2004). I found that semi-structured interviews were particularly helpful for interactions with key informants (planning and implementation officers of the district). These, in the words of Elwood and Martin (2000), were a kind of negotiated dialogue between interviewer (researcher) and interviewees (bureaucracy) in which the personalities of both were acknowledged and explored.

3.7.3 Focus Group Discussions (FGD's)

Focus group discussions as a method of research have been defined by Cameron (2000:84) as "… small groups of people discussing a topic or issues defined by a researcher". Many researchers also use the term 'group interview' to recognize any interview situation in which a researcher and more than one other individual is present. Bedford and Burgess (2001:121) defined Focus Group Discussions (FGD) as "…a one-off meeting between four and eight individuals who are brought together to discuss a particular topic chosen by the researcher (s) who moderates or structures the discussion." In each of these definitions, the 'group' element and 'discussion' component are an explicit characteristic of the research strategy. Therefore a focus group is a useful way of obtaining a large amount of information from multiple people in a short time.The composition of a focus group needs to be thought about carefully. Traditionally FGDs were recommended to be composed of strangers but this often stultified the discussion and therefore modern researchers have recommend the use of pre-formed groups to encourage "fluid discussions" for the dynamics of groups and research both.

In geographic research, FGDs were initiated in the mid-1980s in the UK (Burgess, 1996) and have since gained prominence and popularity across the globe as a rich research tool. Cameron (2000) stressed that focus groups are an excellent research tool for geographers interested in the process of knowledge production, while Johnson (1996) felt that the technique was ideal for geographers committed to the idea that research can be used to effect social change and empower the researched. Important examples of studies that have employed FGDs include, Zeigler et al. (1996) investigated people's responses to emergency procedures during a major hurricane in the US, and Burgess (1996) is notable for using FGDs to study factors that inhibit visits to, and use of woodlands in the US. Unfortunately in remote sensing based studies of urban land use, less attention has been paid to FGDs by the researchers, particularly in Global South. The present research is among only a few where qualitative methods have comprised FGDs, semi-structured interviews and other methods along with census and remote sensing data.

3.7.4 Perimeter Walks

For the purpose of remote sensing based land use studies it is always useful to have a GPS-assisted walk, along with one or more local people, around the study area to establish rapport and gain an understanding of the area regarding its land cover and land use, marking the prominent features and places on the map. This kind of field observation is usually called perimeter/field or transects walks and these are commonly a feature of Participatory Rural Appraisal, Urban/Rural System Analysis tool kits. Moran and Brondizio (1998) accompanied land use surveys with detailed field walks of the land holdings of their sample households and found perimeter walks to be particularly useful for studying the geography of land use and land cover in rural and village areas. In fact, perimeter walks are now widely practised in the context of land use studies. It is particularly relevant in the context of remote sensing, as it helps to classify the land cover of the region in an efficient way (Cook, 2005). Naidoo and Hill (2006) used the data of transect walks of indigenous hunters to classify the protected forests using remote sensing images. The researcher utilized his time while spending days and nights in the study area and with the help of local participants walked a lot around the area, with his hand held GPS, for ground truthing and classifying the satellite images of the study area. During my walks, I asked questions, discussed important matters with the local people and this helped me to understand the barriers faced by the community in question, how they are being addressed by the key actors, and what needs to be done to improve livelihoods. My several transect walks within the whole district of Rawalpindi built a complete picture of the community and enabled me to capture a number of different perspectives. Transect summaries were later used as “reference data” (Chapter six) for assessing the accuracy of the classified satellite images. Having discussed above the different methods of qualitative data collection, the following sections, describe how the researcher adapted specific methods and utilized these methods in the context of the field work, to fit the needs of the research.

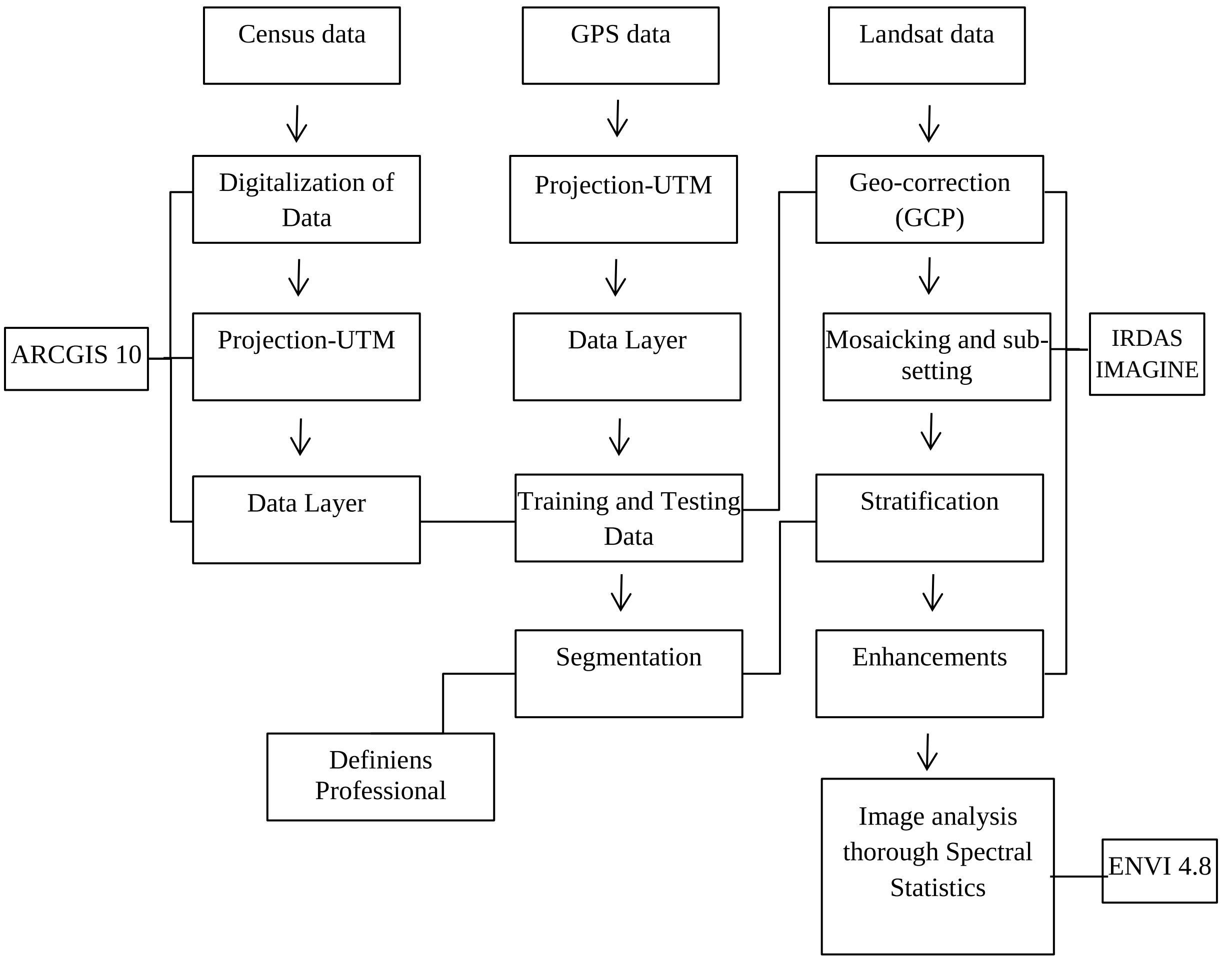
3.7.5 Qualitative Research Methods and GIS

This section offers a discussion of how GIS can be integrated with various forms of qualitative data, and presents a picture of using GIS during the field work, using a public participation planning approach, and the analysis of collected data after the field work. In this study, GIS overlays, area analysis and buffering, remote sensing ground truthing and GPS transect walks were initially employed to develop a GIS database of Rawalpindi district. This methodology is premised on populating a conventional GIS database with qualitative data as an information layer. To undertake a GIS-based analysis of residential development in various tehsils of Rawalpindi district requires the development of a baseline of spatial data for the area in the form of a base map. This includes a land use map, physical and social infrastructure information, residential housing data, and other land-related information. The work involved scanning topographic map sheets, district and tehsil maps, and tehsil maps showing the mauzas, then geo-referencing the raster data and vectorizing it to extract the required layers of information marked as part of the initial GIS. The analysis involved GIS overlays, the buffering of various kinds of data, and distance and area calculations. Geo-referencing the GIS data, reconciling ancillary municipal data with digital GIS data, and ground truthing using topographic maps and Landsat TM images were all part of the GIS activities. GPS transect walks were also undertaken to input spatial information that communities identified as important during the mental mapping workshops.

3.8 Data Preparation

The methodology of data preparation involved remote sensing, field and census data. Landsat data pre-processing was performed using ERDAS IMAGINE, ENVI and Definiens Professional (eCognition) software, while field and census data was processed and analysed within a GIS environment using ARCGIS and Microsoft Excel 2010 software. Fig. 3.2 illustrates the general flow chart of the satellite, field and census data pre-processing methodology.

Figure 3.2: Methodology workflow chart of pre-processing of data

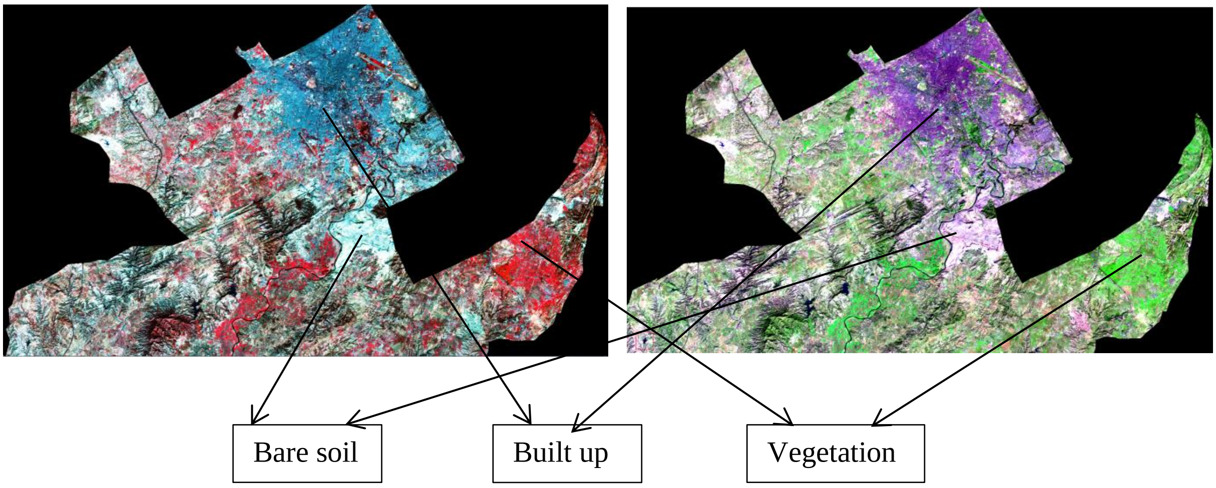


3.8.1 Pre Processing of Satellite Data

When multi-date images from different sensors are used, different atmospheric conditions may cause variations in the data, thus leading to errors in change detection. Despite the fact that some satellite data corrections are carried out at ground receiving stations, there is often still a need on the part of user for some further processing of the raw data to create a consistent and reliable image data base (Donoghue et al., 2004). Pre-processing commonly involves a series of sequential operations for change detection. These types of preparations of satellite images prior to the analysis of change detection are essential for the removal of data acquisition errors and image noise. The objective is to produce an image close to the true radiant energy and spatial characteristics of the study area at the time of the data collection (Lillesand et al. 2004). The pre-processing procedures for the Landsat data commonly comprised a series of sequential operations such as atmospheric corrections or normalization, image registration, resampling, geometric corrections, enhancements, sub-setting and masking. The goal conveniently was that all images should appear as they were acquired from the same sensor. A band combination of red, green and blue is used to display images in standard colour composites for land use mapping. Selection of appropriate bands has a huge impact on the features in an image.

Therefore the Landsat TM images were displayed in different band combinations (FCC- False colour compositions) to describe and interpret the ground features in an effective way. In fact the discrimination of different features types necessitated to experiment the images with different band combinations (chapter 6). For example in the 432 RGB band combinations the features looked different when compared with 321, 542, 753 and other combinations. Different combinations of these bands provided useful information about different land covers. Fig.3.3 illustrates the difference of appearance of different land covers when LANDSAT 5 image displayed in RGB band combinations of 432 and 753. Besides testing different band combinations, general contrast filters such as Histogram Equalization, Gaussian, Linear, Level slice, Minimum/Maximum, Square root were also tested using the built-in functions of ERDAS and ENVI.

Figure 3.3: Landsat TM image of Rawalpindi displayed in band combinations of (left) 432 RGB and (right) 753 RGB



3.8.1.1 Image Rectification and Resampling

Rectification is a procedure that distorts the grid of image pixels on to a known projection and datum. According to Elhers (1997), remote sensing image rectification or geocoding is the process of an actual pixel wise geometric transformation of an image to an absolute coordinate system. Aplin & Atkinson (2004) clearly demonstrated the need to achieve a high value of registration accuracy if there is to be reliable monitoring of change. Likewise, Gong et al (2011) argues that geometric rectification is crucial for producing spatially comparable maps along the time axis.The goal of the image rectification in the study was to have facilitation of the overlay of additional images and geographic data sets. “Image to Map” and “Image to Image” are the two common methods of rectification. The researcher has applied both in this study.

Two[12] Landsat TM images of 1998 of Rawalpindi were registered using the method of Image to Map. The two images were rectified to the Universal transverse Mercator 43N projection system, using the 1:50,000 and 1:250,000 topographic maps of the area as well as Global positioning system (GPS) data collected from the field. It is pertinent to mention here that prior to using these topographic maps; they were also geo-referenced. The procedure requires the use of prominent features that exist on both the image and the map. These features are commonly referred to as Ground control Points (GCPs). A total of as many as 250 GCPs were used in the rectification process distributing evenly across the both images. Root Mean Square (RMS) error of half a pixel (15 metres) was achieved.

Geometric correction of images was performed using the “image to image registration” method using a master slave approach (Jensen, 2005). With the aid of 1998 TM image as reference (master) all other images were rectified, treating them as slave images. Landsat TM 1998 was selected as master image because of the comparatively better radiometric quality of the image and ease of selecting Ground Control points. According to Justice et al. (1997) the Landsat images are assumed to have regular pixels and therefore can be geometrically corrected using the non-parametric method of selecting ground points and using polynomial transformations. At least six GCPs are required for second order polynomials (Hansen et al., 1996). Initially seventy five control points were digitized for 1972, eighty five for 1979, seventy five for 1992, sixty five for 2000 and seventy for 2010, but all points were progressively edited and less accurate(having RMS error more than one pixel) were deleted until required RMS error was attained. Hence RMS values associated to each registration were less than 1 pixel, having 0.83 for 1972, 0.84 for 1979, 0.5 for 1992, 0.41 for 2000 and 0.33 for 2010. Using the ERDAS IMAGINE 2010 software, both 1st and 2nd Polynomial transformation functions were chosen for registration purposes. The image registration process needs one more step after the application of the model, *the resampling*, which is also the part of the registration process. There are three main resampling methods such as *Nearest Neighbour, Bilinear Interpolation and Cubic Convolution Interpolation.* Nearest Neighbour resampling is usually preferred if a registered image is to be classified (Richard, and Jia, 1999). In this research, Nearest Neighbour resampling was chosen. According to Richard and Jia (1999), cited in Galiatsatos (2004), Cubic Convolution is the method used for Photo interpretation purposes. However, Galiatsatos (2004) argues that resampling is merely the choice of the photo interpreter. Anyway all

[12] The study area of Rawalpindi does not lie completely in one scene and some of its upper part (Murree: chapter 1) is in the other scene of northern areas. Therefore, before mosaicking and sub setting both images were rectified.

images were resampled to 30 metres by using the Nearest Neighbour method for comparison purposes.

3.8.1.2 Instrumental Corrections

Noise in a digital image is the result of sensor malfunctions and can manifest itself as either inaccurate grey level readings or data missing altogether. It is readily identifiable by the users applying satellite data to their study. Striping and line drop outs are the commonly encountered types of noise, and can easily be handled by using any satellite image processing software. In this study a line drop out replacement algorithm was applied to the some images using the ERDAS IMAGINE interpreter option.

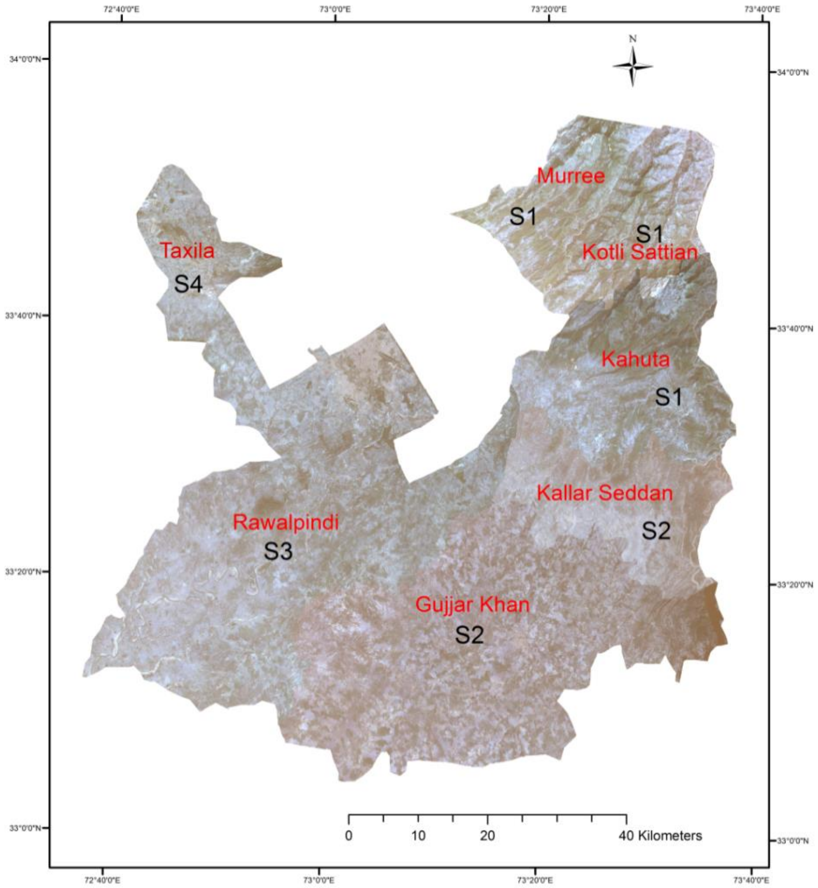
3.8.1.3 Mosaicking and Sub-setting

Image Mosaicking or stitching is the process of combining several images to form one large radiometrically balanced image such that the boundaries between the original images are not seen in the new image and desired coverage is also achieved. A Landsat image covers a 185x185 km (34225 Km^2)) synoptic view. The Rawalpindi district, occupies only 15% of a total Landsat scene, but none of the images of any sensor wholly covers the study area. Therefore scenes had to be blended together and clipped according to where the study area boundaries. The MSS Scenes of 1972 and 1979 years having path 161 and rows 036 and 037 were rectified; The 161036 and 161037 covered the 4 % and 96% of the study area. Likely TM scenes of 1992, 1998, and 2010 years having path 150 and rows 036 and 037 which covered the 3 % and 96.5% of the study area respectively, were rectified. After rectification of all images they were mosaicked using the *Mosiacpro* function of ERDAS IMAGINE. And finally the area of interest (AOI) was developed in the form of geo-referenced vector data and a subset was taken out on the basis of AOI.

3.8.1.4 Image Stratification

Administratively the study area of Rawalpindi is divided into seven tehsils/strata, but for the purpose of field work, and keeping the homogeneity / heterogeneity within the region, the study area of Rawalpindi district was divided into four main strata and this approach was applied to the satellite data as well. Stratification was achieved by subdividing the Landsat data into four strata as illustrated in Fig.3.4.

Figure 3.4: Stratification of Landsat data



Source: Landsat TM, 1998

Stratification was done because of diverse and complex structure and composition of land cover, particularly vegetation species differentiation among the different strata. Three tehsils of Murree, Kotli Sattian and Kahuta were merged to one stratum (1) Kallar Syedan and Gujjar Khan as stratum (2), Rawalpindi tehsil stratum (3) and Taxila Tehsil as stratum (4). Following the work of Harris and Ventura (1995), a further subset of Kahuta were delineated to remove the confusion between farmlands and fallow farms. Image stratification is an important pre classification process, especially used for those images which are difficult to classify by signature extension (Trotter, 1998). Therefore the aim to divide the image into different strata was:

- To reduce the confusion between different land cover classes to improve the overall accuracy. For instance altitude is seen as a critical variable in this study, on which the stratification of the whole scene is based, which allowed the separation of lowland from uplands.
- To rectify any problems of poor classification on a stratum basis

- To evaluate the classification, as certain agronomic practices such as harvesting of different crops at different periods in different regions may produce distinctive cropped signatures during the cropping season (Turner and Congalton, 1998).
- Convenience of dealing with smaller subsets of the full image scene.
-

Stratification of images earlier to classification is crucial for increasing the discrimination of LULC classes correctly. And the essence of stratification is to utilize a series of steps that divide the image scene into strata, reducing the heterogeneity within in an image, to improve its interpretation and comparison with training data (Thenkabail, 1999; Sannier et al., 1998). Therefore the division of image(s) into homogeneous discrete subsets was done on the basis of topographic and geomorphological information, extensive ground truth data and field survey of the study area and image interpretation techniques. Each subunit (stratum) was then classified separately, and finally all strata of the image were mosaicked into a single whole. The above approach has been adopted by many researchers such as Turner and Conglaton (1998) and Rodriaguez et al., (2000), in discriminating various types of land cover, before classification, and finally they achieved high classification accuracy.

3.9 Image Familiarization

.This approach is highly dependent upon human behaviour and expertise. The software enhances the interpreter's ability and perception through image enhancements. In this study, image familiarization has mainly been used for qualitative assessment of the landscape, and to take further help from this technique in the digital classification of the images for land cover analysis. It is pertinent to mention here that value of the satellite data increased with adequate preprocessing, and with the awareness of the data quality and characteristics. The following section presents a detail of the image familiarization techniques used in this research.

3.9.1 Image Enhancement

This is the process of making an image more interpretable for a particular application. Enhancement techniques make important features of raw remotely sensed data more interpretable. In fact image enhancement algorithms are applied to remotely sensed data to improve the appearance of an image for visual analysis or occasionally, for subsequent machine analysis (Jensen, 1996). Due to easy implementation and requiring less time, enhancement techniques are often used instead of classification techniques for feature extraction−studying and locating areas and objects on the ground and deriving useful information. *Point operations* modify the brightness values of each pixel in an image independent of the characteristics of neighbour pixels, whereas *local operations* modify each pixel in the context of brightness values of the pixels surrounding it.

Images can sometimes be reduced in size or magnified during the image interpretation process, as reduction techniques allow the analyst to view a regional perspective of the remotely sensed data and, by magnifying the image, the analyst views very site-specific characteristics. Broadly speaking these enhancements are of three types:

1. Radiometric Enhancement
2. Spatial Enhancement
3. Spectral Enhancement

3.9.1.1 Radiometric Enhancement Techniques

After the data is integrated under a common coordinate system and spatially enhanced, the next step is to improve its appearance for human visual analysis or subsequently for machine analysis. In fact *Radiometric Enhancement Techniques* are different from *Spatial Enhancement Techniques* as the former deals with the individual pixels in the image, while the latter takes into account the value of neighbouring pixels (Schowengerdt, 2006). Both of them highlight spatial information. However, generally, only the radiometric enhancement amplifies the spectral character of an image (Richard & Jia, 1999). But Jensen (1996) argues that there is no such thing as an ideal technique because the results are ultimately evaluated by humans, who make subjective judgements as to whether the given image enhancement is useful. Generally, the techniques to be used depend upon the data, the objective and expectations and background of the user. However the analysis of these enhancements is beyond the scope of this chapter. Anyway in this research, various useful enhancement algorithms are applied to improve the quality of the images by using ERDAS IMAGINE 2010 and ENVI 4.8 versions. It is important to note here that an enhanced algorithm was sometimes permanently applied to the image bands and saved directly, whereas sometimes enhanced values were saved as Look up Tables (LUT) files separately and these LUTs were applied at the time of visual interpretation over loaded image bands in RGB channels. The main radiometric enhancement techniques applied in this study are Contrast Stretching, Histogram Equalization, Histogram Matching, Brightness Inversion and Density Slicing.

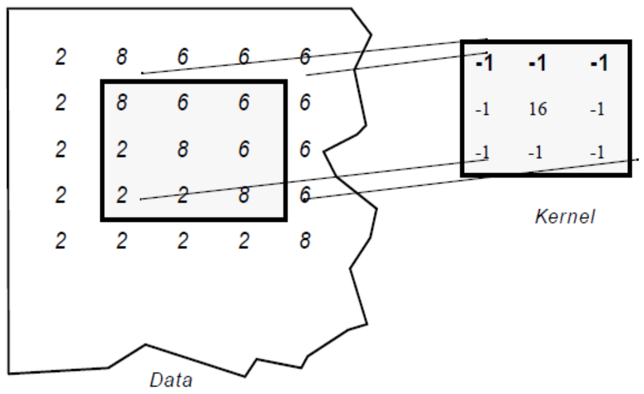
3.9.1.2 Spatial Enhancement Techniques

In spatial enhancement techniques the emphasis is on *spatial frequency*[13] which characterizes the spatial character of the brightness values. The main spatial enhancement techniques applied in this study using ERDAS IMAGINE and ENVI software, are convolution filtering, crisp filtering, edge detection, line detection, shape detection and adaptive filtering. As to how these filters are applied, the following example may clarify the concept of spatial enhancement techniques.

[13] According to Jensen (1996), it is the number of changes in the brightness value per unit distance for any particular part of an image.

Convolution Filtering is an important technique to change the spatial frequency of an image. During this process a table called a *kernel* is defined which is moved over the image row by row and column by column. A convolution kernel is a matrix of numbers, used to average the values of each pixel with the values of surrounding pixels in a particular way.Therefore in convolution filtering, convolution kernel is overlaid on the data file values of the image (in one band) so that the pixel to be convolved is in the centre of the window. Fig. 3.5 shows a 3 x 3 convolution kernel applied to the pixel in the third column and third row of the sample data (ERDAS 2010).

Figure 3.5: Applying a convolution kernel



Source: ERDAS (2010)

3.9.1.3 Spectral Enhancement Techniques

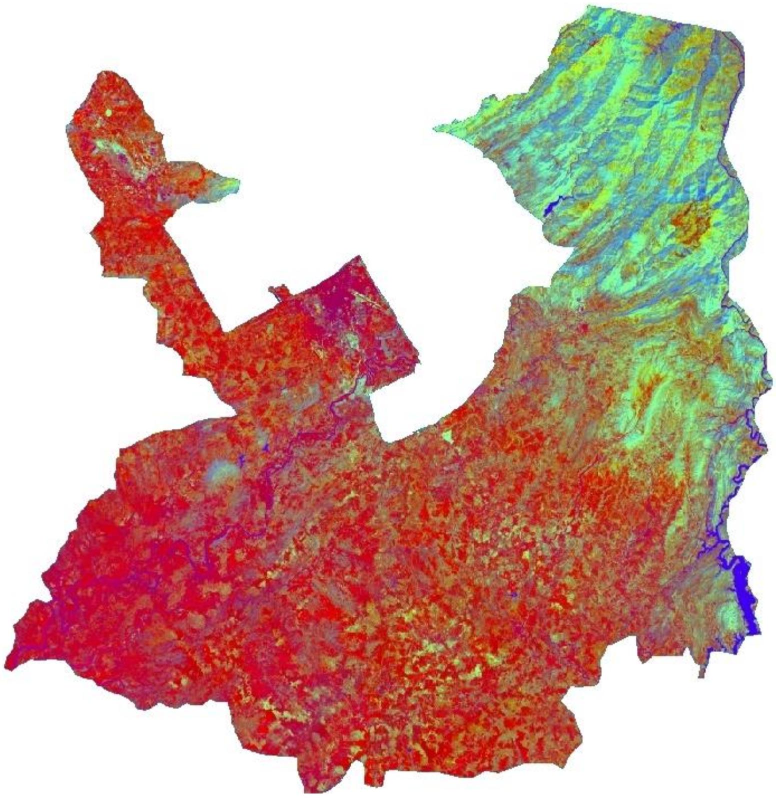
These techniques require more than one band of the data and are usually used to:

- compress the similar bands of the data
- extract new bands
- apply mathematical transforms and algorithms
- display a variety of information in the three colours RGB

Images generated by digital data from various wavelength bands often appear similar and convey essentially the same information. Principal component transformation is a technique designed to remove or reduce such redundancy in multispectral data. In fact spectral enhancements are the various techniques to reduce such redundancy in multispectral data. Principal component transformation, ratio images, and tasselled cap are the main spectral enhancement techniques that are usually applied by researchers. Other spectral enhancements are some indices, otherwise known as *Image Arithmetic*. Division, multiplication, addition, subtraction, are all simple transformations, as may be implemented to form new images. In this study the tasselled cap transformation, band differences and ratio techniques have been applied. Fig.3.6 is a Landsat TM 2010 tasselled image of the study area, showing a degree of brightness, greenness and wetness as calculated by the tasselled coefficients.

- Layer 1 (red)= the brightness component indicating areas of low vegetation and high reflectors
- Layer 2 (green) = the greenness component indicates vegetation
- Layer 3 (blue) = the wetness component indicates water and moisture

Figure 3.6: Landsat TM 2010, tasselled image of the study area



The Components of Brightness, Greenness and Wetness can be used in conjunction with one another to interpret a landscape. The researcher experimented Brightness, Greenness and Wetness, derived by a K-T transformation. Table 3.1 shows the values of Brightness, Greenness and Wetness for different land covers calculated from Tasselled Cap image of Landsat TM-5 (2010

Table 3.1: Landsat 2010 Thematic Mapper tasselled cap coefficients

Landover	Brightness	Greenness	Wetness
Agriculture	133	-13	-25
Bare Soil	173	-45	-38
Built up	167	-39	-45
Forest	129	-24	-28
Fallow land/Grassland	155	-32	-27
Water	112	-37	-24

3.9.2 Exploring Image Ratios

Land covers in urban areas tend to change more drastically even over a short period of time, because of incessant urbanization, especially in the peri urban area as a result of rapid economic development. These changes can ideally be monitored and detected using various classification techniques. But to extract the information instantly before classification, various *Band Arithmetic Methods* can also be applied in the form of *Band Ratios*. Thus a good method of manipulating the spectral information is by creating the *Ratio Images*. Almost all image software permits the user to perform band ratio functions, highlighting image elements caused by that particular index, particularly accentuating the temporal differences. Dividing one spectral band by another can be a simple but very effective image analysis. For instance a ratio of the Near Infra-red and red band is very effective for separating vegetation and non-vegetation. This is one of the commonly used indices, the *Normalized difference Vegetation Index* (NDVI). This index takes the advantage of detecting the vegetation cover in the scene. Its value ranges from -1 to 1 showing scarcity of vegetation to complete vegetation cover. NDVI is calculated as follows:

$$\text{NDVI} = \frac{NIR - Red}{NIR + Red}$$

Virt and King (2006) used NDVI for monitoring forest cover and found it a good index to detect the vegetation cover. Lyon et al (1998) applied NDVI for deforestation and loss of vegetation. While, Coppin and Bauer (1996) reviewed more than 80 change detection studies and concluded that this *vegetation Index* appeared to perform better than other change detection methods. It is important to note that all of them found NDVI change detection as most accurate for the analysis of multi date satellite imagery. In this study the NDVI index was applied to all satellite images of the Rawalpindi district as shown in Fig. 3.7 using the built in ERDAS functions. Hence, before classification of images, the researcher used NDVI as a proxy variable for the intensity of development, with the assumption that vegetation is inversely related to intensity of development. This enabled him to compare the images to detect the loss of agricultural land and deforestation due to development, in the area during the forty year period.

Zha et al. (2003) devised a method for the extraction of built up areas from Landsat TM images and named it the Normalized Difference Built up Index (NDBI).NDBI is based on the assumption that built up areas and bare lands experience a drastic increment in their reflectance from band 4 to band 5, while vegetation has a slightly larger or smaller DN value on band 5 than on band 5.

$$\text{NDBI} = \frac{band5 - band4}{band5 + band4}$$

In this research, NDBI was applied on Landsat TM 1998 and Landsat TM 2010. ENVI 4.8 Software was used to write the following NDBI calculation model in the band math option.

The Normalized Difference Barenness index (NDBal) is another transformation of original bands, and was derived as under:

$$\text{NDBal} = \frac{band5 - band6}{band5 + band6}$$

Chen et al (2006) suggested that by setting threshold values, the above three indexes can effectively differentiate different land use / cover types for example vegetation, built up areas, water, etc.

Figure 3.7: A view of processed colour composite images and NDVI images

Sensors & Dates **Colour Composite Images (432)** **NDVI Images**

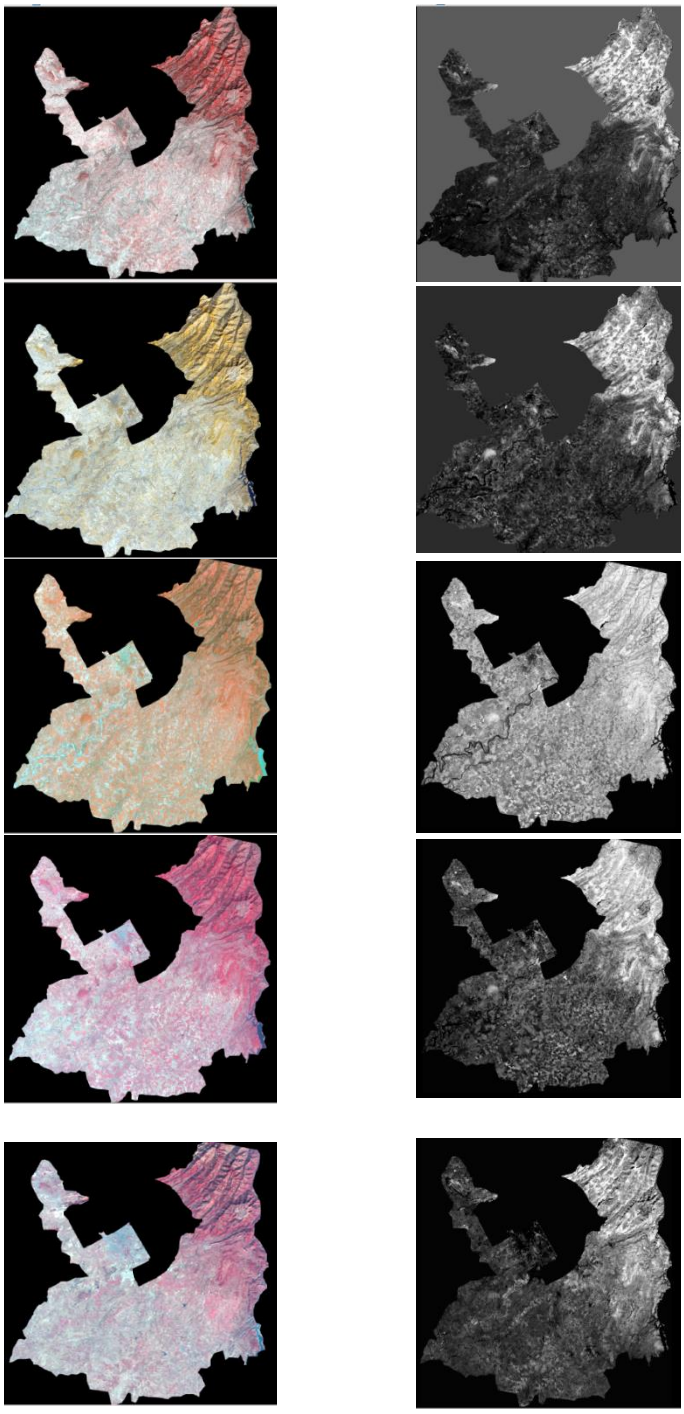
Landsat MSS (1972)

Landsat MSS (1979)

Landsat TM (1992)

Landsat TM (1998)

Landsat TM (2010)

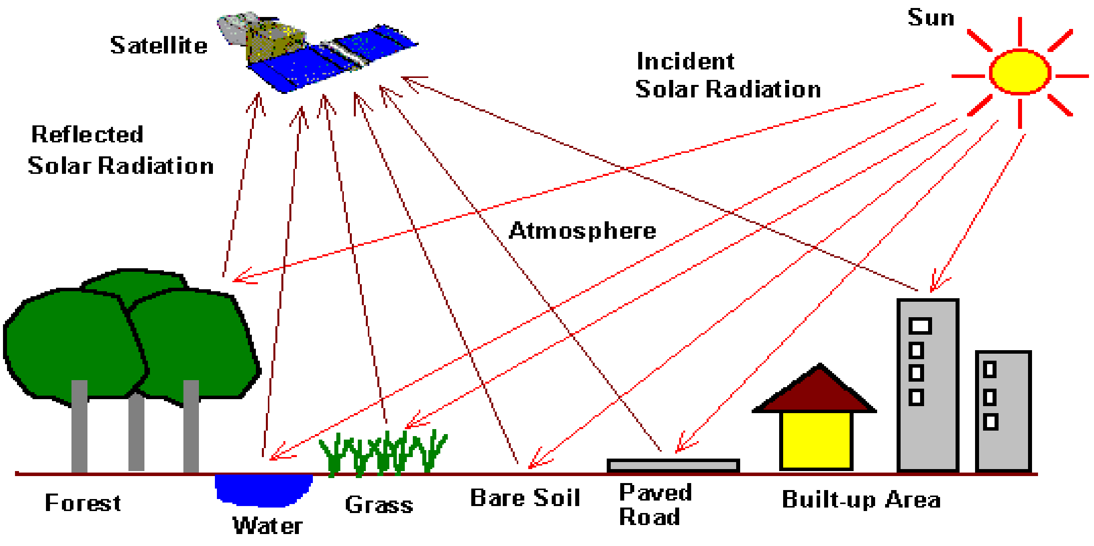


3.9.2.1 Image Analysis through Spectral Statistics of Land Cover

Image analysis is the process by which humans and /or machines examine satellite digital data for the purpose of identifying objects and judging their significance. Unlike photo interpretation techniques, image analysis requires little human interaction and is mainly dependent upon the machines computational capability, therefore it has high qualitative accuracy but low spatial assessment capability. Optical remote sensing makes use of visible, near infrared and short-wave infrared sensors to form images of the Earth's surface by detecting the solar radiation reflected from targets on the ground. Different materials reflect and absorb differently at different wavelengths. Thus, the targets can be differentiated by their spectral reflectance signatures in the remotely sensed images as illustrated in Fig.3.8.

Information extraction from a satellite image is an art. Satellite images can be analysed in different ways by different people by using several methods that involve visual and digital techniques. Visual analysis requires good band combinations that represent the best understanding for the phenomenon under investigation. No doubt different band combinations show different information more clearly depending upon the reflectance value of specific objects.

Figure 3.8: Solar reflectance of signatures



Source: CRISP, 2013

The visual interpretation and classification of remote sensing data was performed by extracting various features sets, using band wise land cover statistics, and application of band ratios and through principal component analysis. For this purpose samples were collected to discover the effective features and rules for a specific land use type. Spectral curves of different land cover were drawn and features means of training samples of different land cover types were extracted for the images of the different years (chapter 6). The basic idea to investigate the spectral features of different land cover types was to select effective feature sets as evidence of classification.

3.10 Development of a Base Map

A digital base map acts as the foundation for any geographical analysis as it not only contains the general information of the area; but all relative factors and information can also be integrated with it to enable a cumulative analysis. In fact, for the proper application of image processing techniques and integration of satellite information into GIS, the base map is the only thing that directs the data to clear spatial dimensions. Arsalan (2003) argues that to develop any GIS model it is essential either to have a base map beforehand or to make a suitable base map in vector format so that any kind of attribute data can be attached to the geographical entities such as Polygons (Regional features), Poly lines (Linear features) or Points (exact object locations). The mauza maps, topographic maps and other paper maps of the study area issued by various organizations were scanned and stratum wise digital maps were developed by converting the analogue data into digital codes by the process of *Digitization.* From the digital maps, a base map was produced having the prominent feature layers used in this study. The base map was brought to a common projection system i.e. Universal Transverse Mercator's Projection (UTM) Zone 43 North and also geo referenced using GPS ground control points. The base map consisted of the major infra-structure information of the built up area, administrative boundaries up to the mauza level, water bodies (rivers, nallahs, lakes, dam etc.), Major Roads and tracts (highways, motorways, and local city roads, railway lines, etc.), Parks, and Forests, etc. This base map was not only widely used during the field work, it was also a foundation for socio-economic and census data integration with remote sensing.

3.11 Land Cover Classification System

Remotely sensed data may be analysed to extract thematic information. Multi spectral classification is one of the most practising methods to extract the information, and this information is the best source of available, updated and synoptic land cover information. Land cover is the observed bio- physical cover of the Earth's surface. The land cover classification System is a standardized a priori classification system, designed to meet specific user requirements, and created for mapping. A classification system needs to cover mutually exclusive land cover classes comprising a standard name, numerical code and attributes.

Classification is an abstract representation of the situation in the field using well-established diagnostic criteria. Sokal (1974) defined classification as ordering or arrangements of objects into groups or sets on the basis of their relationship. A classification therefore should be scale and source independent. Thus classes at all levels of system should be applicable at any scale and also independent of sources of data used to collect these classes.

A priori and *a posteriori* are two types of classification systems. In an *a priori* system, the classes are notions of the types actually occurring and are based upon definition of classes before any data collection, whereas in *a posteriori* classification, the approach is based upon definition of classes after clustering homogeneity or heterogeneity of the field samples.

A priori classification was mainly carried out by dividing the images of 1972, 1979, 1981, 1992 and 2010 into six classes i.e. *Agriculture, Bare land, Built-up, Forest, Fallow-land and water.* The classification scheme used was an adaptation of Pakistan land use and land cover classification system, which was modelled on that of Anderson et al (1972). Choice of classes was guided by; (1) objectives of the research; (2) degree of accuracy in image classification; and (3) easiness of classifying classes. Moreover the classification system developed was in accordance to Global terrestrial Observing Systems (GTOS), Food and agriculture Organization (FAO) land cover classification systems, United States Geological Survey (USGS) and United States Department of Agriculture (USDA) Systems. The primary unit used for categorizing land cover is *category* and secondary unit is surface area of land covers taken in hectares.

While devising a classification system, following important things were kept in mind:

- The classes should meet the needs of a variety of users: other users can use just a subset of the classification and can develop from there according to their own specific needs.
- Should fit into a common reference system and facilitate comparisons between classifications derived from different classifications
- Describe the important land covers
- Description of classes should be clear and systematic

3.12 Land Cover Mapping Using Digital Classification

After the visual interpretation of the images by taking into account the spectral characteristics of various input features, as described above, the quantitative analysis, which the computer uses to label each pixel to a particular spectral class (Classification) was the main aim of the this research for the further interpretation of the remote sensing data. For detailed land use mapping, spectrally oriented classification is considered to give the better results than visual classification, as it allows a detailed interpretation of smaller and complex mapping units (Viovy, 2000). Two main broad classification procedures: *Supervised* and *Unsupervised* classifications are normally used by researchers.

3.12.1 Supervised and Unsupervised Classification

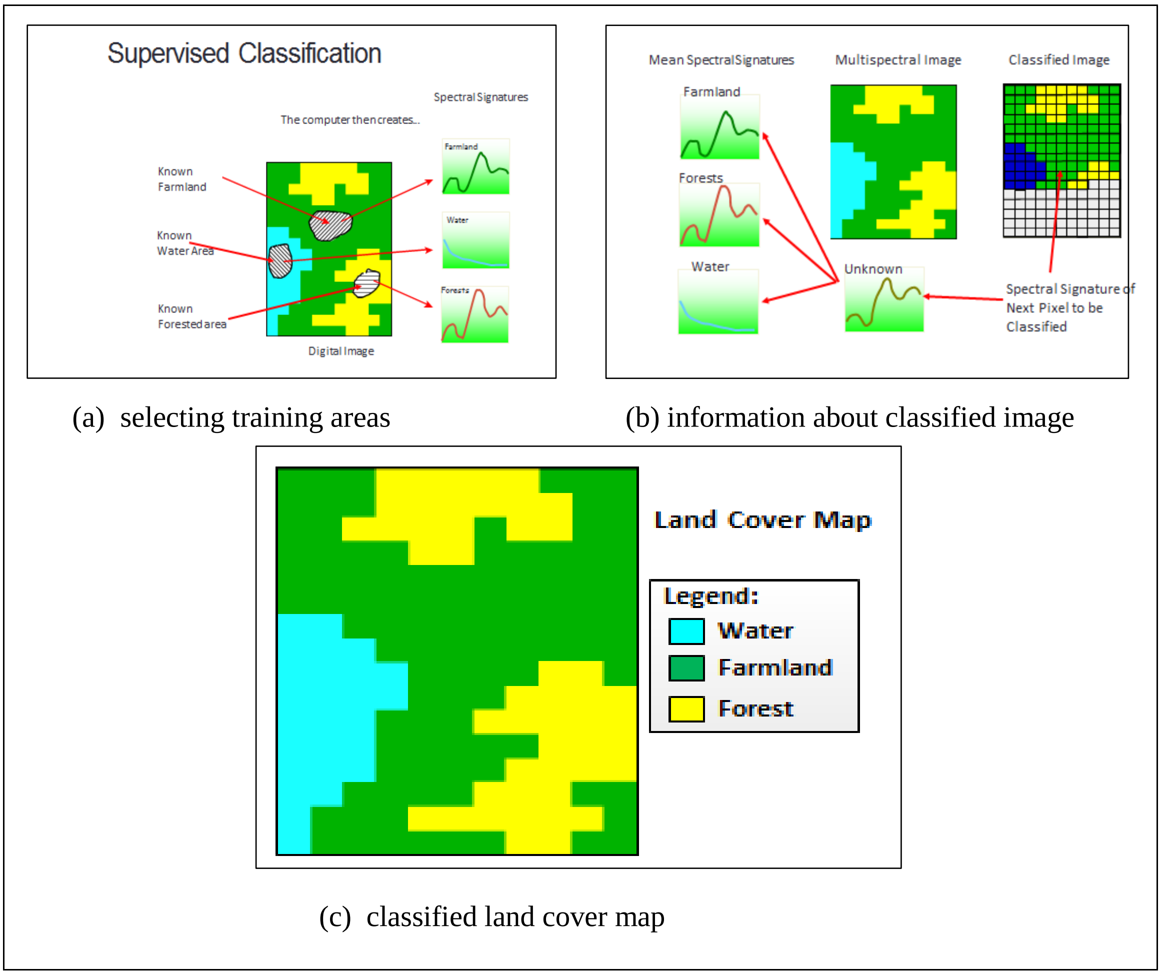
According to Grey et al. (2003) supervised classification (SC) is the most often used procedure for quantitative analysis of remotely sensed images. Through the supervised classification method an analyst with the help of sufficient known pixels for representing parameters of each class of interest, extracts qualitative information. This important step is called training. Once trained, the classifiers are used to attach labels to all the image pixels according to the trained parameters. Thus the analyst in supervised classification first identifies the training areas to determine their spectral characteristics. Thereafter the spectral signatures of the pixels of the chosen areas are then calculated and used to recognise pixels of similar signatures throughout the image.In unsupervised classification (USC) instead of training data, a clustering technique is used. The software by using an algorithm, and after examining a large number of unknown pixels, clusters all pixels on the basis of their spectral groupings present in the image. Unsupervised clustering is appropriate in situations, when it is difficult to choose homogeneous training areas of sufficient size and where the variations within and between classes are not adequately described by the available reference data (Shueb & Atkins, 1991).

While the SC, as described above requires a set of training sites which represent all land cover types within the scene, USC allows the computer to examine the unknown pixels and aggregate them with the help of class means and covariance matrices to produce spectral classes. These classes are meaningless to the analyst until transformed into information classes which definitely require the awareness of the spectral characteristics of different land covers. This means that the technique does not use statistics taken from known training areas, but rather the number of spectral classes defined by clustering methods, into which data are to be divided are computed. That is why this classification process is called unsupervised classification. Anyway when the classification was completed the researcher identified the land cover types represented by each spectral class using available reference data. Lillesand and Kiefer (2004) and Trotter (1998) suggest that supervised classification is based on following three major steps (Fig. 3.9)

- Selection or generation of training areas
- Evaluation of training signature statistics and spatial patterns
- Classification of the images

In the SC type the location of various land cover types such as built-up area, farmland, forested area or wetland, are known through field work, maps, aerial photographs, and personal experiences as well (Foody, 2010). The spectral characteristics of these training sites are used to train the computerized classifier to classify the whole image. Any pixel in the image is assigned to a training class which has the highest probability of being a member of that class. If all land cover types which exist in the image are not included in the training classes, those missed are assigned to unknown or unclassified class (Fig. 3.9).

Figure 3.9: Process of supervised classification



(a) selecting training areas (b) information about classified image

(c) classified land cover map

Source: Al-Ali, 2011

The factors which affect the SC performance include how a sufficient number of training samples are used and how well they were distributed in relation to the target class distribution (Al-Ali, 2011). In summary, the main difference between the SC and USC relates to whether the analyst trains the classifier or classifier determines its own grouping. There is also another option to combine both methods to produce more successful results (Liu et al., 2010). This is usually adopted because supervised training does not necessarily result in class signatures numerically separable in feature space, and USC does not necessarily result in classes that are meaningful to the analyst. Therefore a new *Hybrid approach* is also very common nowadays, which involves a combination of both unsupervised and supervised classification. Following algorithms are frequently used in SC.

1) The Parallelepiped Classifier (PC)
2) The Minimum Distance Classifier (MDC)
3) The Maximum Likelihood Classifier (MLC)

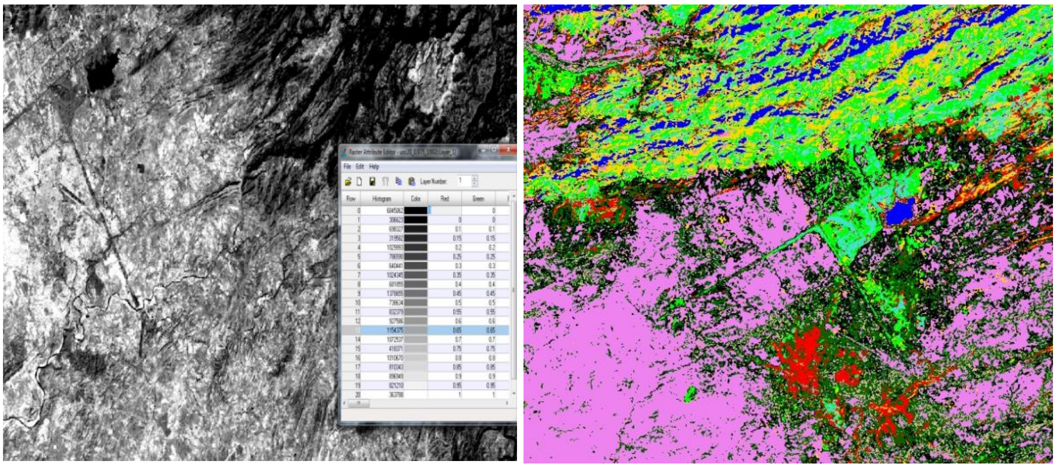
The choice of a particular classifier depends upon the data and aim of the classification. PC is sensitive to class variance but not to class variance; therefore it does not take into account the overlapping problem of classes. MDC classifies each pixel to the nearest mean DN in the training areas and is insensitive to variance of the spectral properties of each class; therefore for images having classes close to each other this classifier is appropriate. MLC is the most commonly used classifier which assumes that each spectral class can be described by a multivariate normal distribution (Jensen, 2005; Lillisand and Kiefer, 2004). It thus addresses the shortcomings of previous two classifiers as it calculates the mean variance of each class in each band and calculates variance and correlation for each class in the training sets. In fact MLC is the most robust and widely used method, which assigns a likelihood function to each pixel of the class with the highest probability (Weng, 2002).

The above classifiers can also be divided into two main groups such as parametric and non-parametric classification algorithms. Parametric algorithms use statistical parameters (mean, standard deviation) and make assumptions of the probability distribution functions of each class to establish decision boundaries between them. This means that while using the parametric technique, the classifiers must be trained with class signatures defined by a statistical summary (Duadze, 2004). MDC, MLC and Mahalanobis Distance algorithms are called parametric algorithms.

3.12.2 Land Cover Mapping of Study Area Using Unsupervised Classification

In unsupervised classification, as described above, the classifier examines the unknown pixels and aggregates the pixels of different values into a number of classes. Interactive Self Organization Data Analysis Technique (ISODATA) and K-Means are two common techniques used for USC. In this study ISODATA has been used. Using ISODATA, first Multi temporal Landsat MSS and TM images of the study area were segmented into unknown classes, and thereafter in the light of the knowledge of the study area, ground truth data and pixel values, identification of the separable spectral classes were done by the researcher. In the last all classes were labelled as per identification of their land cover types. Fig. 3.10 shows the result of ISODATA algorithm applied to Landsat MSS 1998 (a) the image has been divided by the classifier into 20 classes, (b) by visual inspection and with the help of training samples, the attributes has been edited in the signature editor and different land cover types have been identified by merging the classes of same pixel value. The image under process is strata 3 of the study area

Figure 3.10: Unsupervised classifications (ISODATA) and resultant map of land cover for Landsat TM 1998

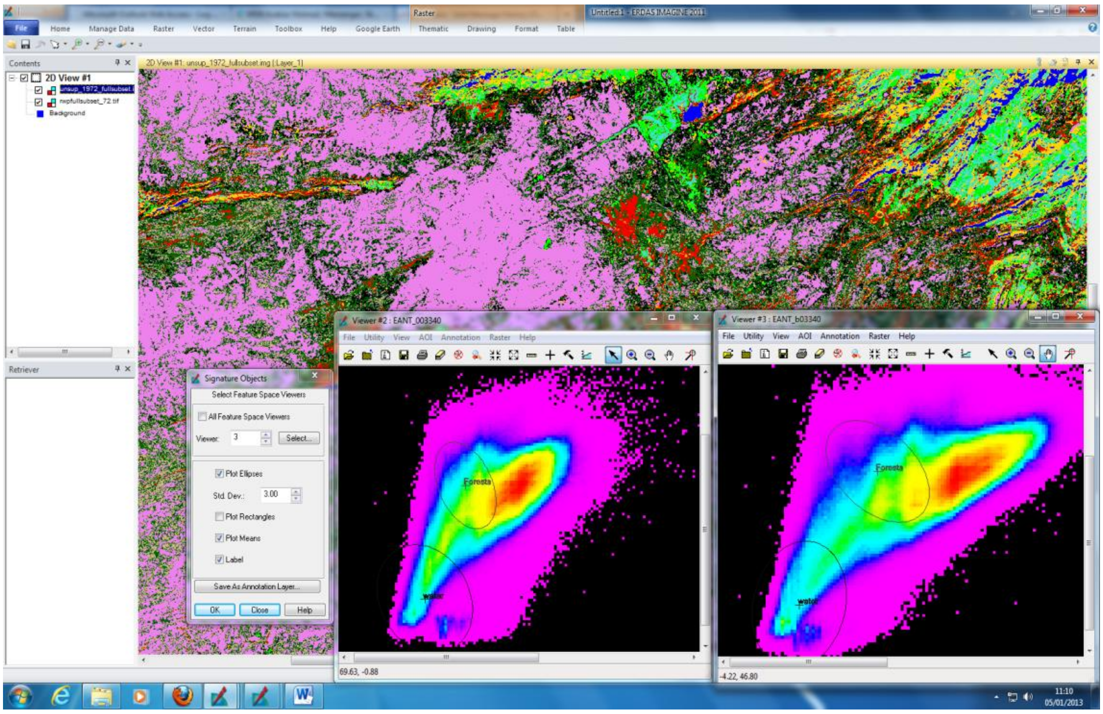


a) Result of ISODATA b) classified map on the basis of pixel values

Scale: Width of each image is 40 km across

ISODATA needs three input parameters: (1) number of classes; (2) the maximum number of iterations; and (3) the convergence threshold. Keeping in view the further merging down process of the classes, the number of classes (clusters) was set to 20. (After experimenting with 30, 25 and 15 classes, the number 20 was found to be appropriate). The most important thing in ISODATA is to specify the processing options. Therefore maximum number of iterations was set to 60 to reach to the goal of a convergence threshold, which is the maximum percentage of pixels whose class values are allowed to be unchanged between iterations, of 0.975. These values were set as the same for all strata of the images for the different time periods i.e. 1972, 1979, 1992, 1998, and 2010. After the execution of the algorithm, the 20 assigned classes were grouped into various land cover groups, on the basis of their spectral appearance and knowledge of the area. Visually the pixels in the above image can be divided into different land covers such as Agriculture, Built-up land, Forests, Bare land, Fallow farmland, Water.. Feature space image is a graphical representation of the pixels and it is obtained by plotting two bands vs. each other. For instance from Landsat TM 6 bands combinations, 15 feature space images can be obtained and can be used to evaluate the separability of the classes. The feature space images were used to evaluate the separability between different classes. The result of the ISODATA classifier although showed a good separability in some classes like water and forests, (Fig. 3.11), but some of the classes were overlapping and the results indicated confusion among some land cover types.

Figure 3.11: Feature space layers with different combination of bands



(a) Bands 2-5 (b) Bands 3 and 4

Source: ISODATA performed in ERDAS IMAGINE 2010.

Vinas and Baulies (1995) observed that USC is useful in areas of extreme heterogeneity. Therefore a test USC was carried out on the images of the study area. But as observed by Trotter (1998) and Thomson et al (1998) in their studies, the USC of differently vegetated surfaces with similar reflectances produces inconsistent results, and the same problem faced in this study rendered the use of USC ineffective. In fact following the work of Sunar, 1998, USC was performed with an aim to generate training samples, which were later used together with the field work samples for a subsequent supervised classification.

3.13 Data Evaluation

Evaluation of anything is generally considered a challenging work; particularly in the field of remote sensing the map generated from any remotely sensed data needs to be assessed as to whether it has been classified accurately or not. Moreover land cover is a critical variable that links the human and physical environments; therefore the accurate and up to date information is required for a plethora of applications such as land resource planning, environmental change and biodiversity conservation etc. (Foody et al., 2004).

3.13.1 Accuracy Assessment

Accuracy assessment is an important factor in analysing Landsat data and to judge how well a classifier has worked. For accuracy assessment, *reference data* (ground truthing) is required for the determination of the class types at specific locations and identification and measurement of map errors (Congalton & Green, 2008; Foody, 2010). The sources of reference data in this study included ground truthing with GPS, GIS layers, qualitative data including interviews and focus group discussions, and topographic maps. An assessment of classification accuracy has been performed through choosing a set of pixels on the classified image and comparing them to the actual image and ground reference data. The relationship between the above two sets of information was compared and summarized in a *Cell Array*. From the Cell Array, an *error matrix* and *accuracy report* was derived. Two error measurements were derived from the error matrix, i.e. *omission error or producer's accuracy* and the *commission error or user's accuracy.*

Producer's accuracy indicated the probability of a reference pixel being correctly classified. It was estimated by dividing the total correct number of pixels in a category by the total number of pixels of that category. The user's accuracy indicated the probability that a pixel classified on the image actually represented that category on the ground. It was estimated by dividing the total of correct pixels in a category by the total number of pixels that were classified in that category. Besides the above two measurements, overall accuracy was also found by dividing the total number of correct classes by the total number of classes. Kappa Coefficient, which statistically measures the relationship between the beyond chance agreement and expected disagreement, and is an indicator of the extent to which the correct values of an error matrix are due to "true "agreement versus "chance" agreement, was also calculated using the following formula.

$$K = \frac{\text{Observed Correct} * - Expected\ correct}{1 - Expected\ correct}$$

The methodology approach for accuracy assessment consisted of three main components: *response design, sample design and analysis design*. These phases have been discussed in detail in chapter 6.

3.14 Change Detection Analysis Methods

Land cover change of the study area over the period of forty years is a response to social, economic and political forces. Information about the nature of change in land use/cover is essential for proper planning management and regulations of the resources. Change detection is therefore key topic in remote sensing image analysis (Foody, 2002; Singh, 1989; Wong et al., 1997) and is a major application of Landsat data. Change detection enables the assessment of changes between images acquired in different times either visually or using digital techniques. Digital techniques have the advantage of ease of data capture into GIS (Prakash and Gupta, 1998).

Different change detection algorithms are used by researchers depending upon the type of applications, satellite sensors, regions, and targets of interest as well as amount of detail required (Seto et al., 2002). The most commonly used change detection algorithms include:

- Multi-date composite image comparisons
- Image Algebra (e.g. band differencing, band rationing, image regression)
- Post classification comparison
- Binary mask applied to date 2
- Cross correlation
- Visual on screen digitization
- Knowledge based vision systems
- Chi-square transformation
- Write function memory insertion
- Spectral vector change analysis

Each method has its own merits and no single method can be considered optimal. For instance, image differencing is commonly used for forest and agricultural studies (Fung & Chan 1994; Singh, 1989). Image rationing diminishes the effect of topology such as shadowing and illumination and vector analysis detects changes present in the input of multispectral data (Berberoglu and Akin, 2009). Regression methods reduce the adverse effects from divergence in atmospheric conditions (Coppin and Bauer 1996). The high temporal variability of the spectral properties of major land covers types; scene complexity due to topographical variations of the study area and the spectral separation difficulties of some land covers because of their similar reflectance, limit the use of some of the above change detection techniques in the study area. Therefore, to detect and quantify the land cover changes and compare it with the census data and governmental policies, the post-classification algorithm was applied to the study area. It has the following three advantages over the other methods

- Does not require atmospheric correction
- Provides “from-to” change information
- Next base map is already created.

Shalaby and Tateishi (2007) applied post classification change detection techniques to examine the urban development in the North-western coastal zones of Egypt. They utilized the *cross-classification* function of IDRISI to perform the spatial distribution of “*from-to”* change information of different land covers. By using the above function, Munoz-Villers and Lopez–Blanco (2008) studied deforestation and agricultural land transformations in mountainous areas of Mexico. Sherazi (2012) used post classification method for temporal analysis of land use and land cover changes in Lahore-Pakistan. Gosai (2009) found post classification an appropriate change detection method, while analysing the land use changes in Thimpu, Bhutan from 1990 to 2007.

3.14.1 Methodology Adapted for Land Cover Change Detection of Rawalpindi

In this study, change detection has been carried out through the post-classification procedure. Landsat MSS data of 1972, 1979 and Landsat TM of 1992, 1998, and 2010 are independently classified using the maximum likelihood classifier. It is important to mention here that initially 1972, 1979, 1998 and 2010 images were classified which approximately coincided with the census dates i.e. (1972, 1981, 1998, and 2012, but to bridge the big gap between last two censuses an image of 1992 were later added in the analysis. Since there are different temporal sequences of images and census, therefore given below is the explanation of the time periods of image and census data which hereafter will be used.

T1 = 1972 (census and image)

T2 = 1981 (census) and 1979 (image)

T2.5 = 1992 (image)

T3 = 1998 (census and image)

T4 = 2012 (census) and 2010 (image)

An accuracy assessment was done for each classification, as is necessary for the post classification method. Area statistics of each of the land use/cover classes was derived from the classification of the images for each date using ArcGIS10 software. This simple analysis is similar to the form in which many land use/cover data are supplied (Van Oort, 2007). The difference in the quantity of land cover (net loss or net gain) in a year compared to a proceeding year was calculated. Though this process determined the direction of changes in each land cover types between different years, this simple description did not identify the transition properties of change i.e. how much area of a particular land cover category remained in that category and how much converted to other categories in the preceding years. A transition Matrix (Pontius and Cheuk 2006; Braimoh, 2006) compares the two maps and is a representation of land cover classes in one year against the classes in other years. Transitional matrices were prepared for different time periods using the "combine" tool (spatial analyst tools) of ArcGIS 10 software package. Thus maps of change for 1972 to 1981, 1981 to 1991, 1981 to 1998, 1991 to 2001, 1998 to 2012, and 2001 to 2012 were prepared using the "combine" tool. A generalized form of transition matrix is illustrated in Table 3.2.

Table 3.2: Illustration of a transition matrix

		Year 2							
	Class	**Agriculture (a)**	**Bare_soil (b)**	**Built-up (B)**	**Forests (f)**	**Fallow land/ grassland (g)**	**Water (w)**	**Total Year 2**	**Loss**
Year 1	**a**	X_{aa}	X_{ab}	X_{aB}	X_{af}	X_{ag}	X_{aw}	X_{a+}	$X_{a+} - X_{aa}$
	b	X_{ba}	X_{bb}	X_{bB}	X_{bf}	X_{bg}	X_{bw}	X_{b+}	$X_{b+} - X_{bb}$
	B	X_{Ba}	X_{Bb}	X_{BB}	X_{Bf}	X_{Bg}	X_{Bw}	X_{B+}	$X_{B+} - X_{BB}$
	f	X_{fa}	X_{fb}	X_{fB}	X_{ff}	X_{fg}	X_{fw}	X_{f+}	$X_{f+} - X_{ff}$
	g	X_{ga}	X_{gb}	X_{gB}	X_{gf}	X_{gg}	X_{gw}	X_{g+}	$X_{g+} - X_{gg}$
	w	X_{wa}	X_{wb}	X_{wB}	X_{wf}	X_{wg}	X_{ww}	X_{w+}	$X_{w+} - X_{ww}$
	Total Year1	X_{+a}	X_{+b}	X_{+B}	X_{+f}	X_{+g}	X_{+w}		
	Gain	X_{+a}- X_{aa}	X_{+b}- X_{bb}	X_{+B}- X_{BB}	X_{+f} - X_{ff}	X_{+g}- X_{gg}	X_{+w} - X_{ww}		

Table 3.2 is a 6 x 6 transition matrix, the rows of which display the proportion of the six classes in year 1, whereas the columns display the proportion in year 2 having the quantities X_{ij} . The main diagonal (X_{jj}, grey shaded) indicates the proportion of land classes that have remained the same between two years and off diagonal elements are changed from year 1 to 2. The difference in the sums of one class in two years shows the gain (if positive) or loss (if negative). The difference between the gain and loss is the net change. For example X_{+a} - X_{a+} is the net change in the agricultural class. The concept of *swap* implies to the certain quantity of land cover lost at one location, but gained in another location, therefore it was computed by multiplying by 2 to the value of either gain or loss whichever was minimum (Braimoh, 2006).

Swap = 2 x min (gain, loss)

Absolute change was calculated, which showed the net difference between gain and loss. Persistence[14] of land covers; loss to persistence ratio (Lp), gain to persistence ratio (Gp) and net change to persistence (Np) were calculated using the following formulas.

$$Lp = \frac{Loss}{Persistence}$$

$$\mathrm{Gp} = \frac{Gain}{Persistence}$$

$$\mathrm{Np} = \mathrm{Gp} - Lp$$

To detect change, a commonly 2x2 change/no change error matrix is used. This kind of matrix is widely used to quantify the quality of the classification and characterizing the error (Foody, 2002; Van Oort, 2007). The full transition error matrix compares the two confusion matrices from two dates, for instance Year 1 and Year 2, and has the ability to produce the normal 2x2 change/no change matrix (Table 3.3) and the transition error matrix (Table 3.4).

Table 3.3: Change/No change error matrix

		Reference Data		
Map	**Class**	**No change**	**Change**	**Sum**
	No change	X_{11}	X_{12}	X_{1+}
	Change	X_{21}	X_{22}	X_{2+}
	Sum	X_{+1}	X_{+2}	1.00

Source: Adopted from van Oort (2007)

14 The proportion of land covers that were static between year 1 and year 2 (diagonal values)

The transition error matrix represents the possible types of change/no change and their corresponding errors in six categories (van Oort, 2007; Binging et al., 1998), as described in Table 3.4 (a) by using the terminologies such as "*true no change-correct class*" containing diagonal entries (dark grey-**A**) in light grey box (pixels not changed between two years, hence correctly classified- No- Error); "*true change-correct class"* is represented by the dark grey cells in yellow box **-F-** (pixels that are correctly classified but changed – No error); "*true no change-incorrect class"* are the pixels that are not changed, but have classification error (light grey cells- **B**);

Table 3.4: Illustration of (a) full transition matrix, (b) Change /no change error matrix and (c) Condensed transition matrix

(a)		**Reference Data**										
		No Change			**Change**							**User's Acu.**
		AgAg	**BupBup**	**FF**	**AgBup**	**AgF**	**BupA**	**BupF**	**FAg**	**FBup**	**Total**	
NO Change	**AgAg**	X_1	X_2	X_3	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6		
	BupBup	X_1	X_2	X_3	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6		
	FF	X_1	X_2	X_3	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6		
Change	**AgBup**	X_{11}	X_{22}	X_{33}	Y_{11}	Y_{22}	Y_{33}	Y_{44}	Y_{55}	Y_{66}		
	AgF	X_{11}	X_{22}	X_{33}	Y_{11}	Y_{22}	Y_{33}	Y_{44}	Y_{55}	Y_{66}		
	BupA	X_{11}	X_{22}	X_{33}	Y_{11}	Y_{22}	Y_{33}	Y_{44}	Y_{55}	Y_{66}		
	BupF	X_{11}	X_{22}	X_{33}	Y_{11}	Y_{22}	Y_{33}	Y_{44}	Y_{55}	Y_{66}		
	FAg	X_{11}	X_{22}	X_{33}	Y_{11}	Y_{22}	Y_{33}	Y_{44}	Y_{55}	Y_{66}		
	FBup	X_{11}	X_{22}	X_{33}	Y_{11}	Y_{22}	Y_{33}	Y_{44}	Y_{55}	Y_{66}		
	Total											
Producer' Accuracy												

A= Dark grey cells in light grey box; B= Dark grey cells in yellow box; C= light grey cells; D= yellow cells; E= Blue; F= Red box

Transition Detection accuracy = $\sum$ (A and B)/ ($\sum$ A,B,C,D,E,F)

b)		Reference Data	
		No Change	Change
Classified Data	No Change	∑ (A and C)	∑ (E)
	Change	∑ (F)	∑ (B and D)
Change detection Accuracy = ∑ (A and C)/ (∑ A,B,C,D,E,F)			

(c)		Reference Data			
		No Change		Change	
		Correct	Incorrect	Correct	Incorrect
Classified Data	No Change	∑ (A)	∑ (C)	∑ E)	
	Change	∑ (F)		∑ (B)	∑ (D)
Transition Detection accuracy = ∑ (A and B)/ (∑ A,B,C,D,E,F)					

Source: Adopted from van Oort (2007)

"True change-incorrect class" are the pixels (Yellow box **-D-** excluding light grey cells) which are incorrectly classified and both reference and the test data have changed, hence there is classification error. Counts in cells blue shades (**C**) are *false negative* and those in red shades (**E**) are *false positives*. The above matrices for all classifications were constructed with the help of the respective full transitional matrices. A sample full transitional matrix (Table 3.4 a) along with change/no change error matrix (Table 3.4 b) condensed transition error matrix (Table 3.4 c) for three classes i.e. Agriculture (A), Built-up (B) and Forest (F) has been illustrated above.

3.15 Statistical Analysis

This section mainly deals with the methodology involved for the statistical analysis of population data (chapter 4) GIS, remote sensing and census data integration and statistical analysis of the urban expansion (chapter 6).

3.15.1 Population Data Analysis

This work analyses the population distribution of Pakistan in general and the study area in particular since independence, i.e. 1947. It examines the process of urbanization and its consequences in the redistribution process of population and land use changes in time and space. Quantitative analysis in this connection has been carried out to find the interrelationship between population growth and urbanization change. The main sources of data for this section are census publications. In all twelve complete censuses have taken place since 1881. Five of them have been conducted after independence, in 1951, 1961, 1972, 1981, and 1998. The statistical analysis of the results of these censuses particularly of those which have been conducted during the last four decades have been carried out to present a broad overview, by using a number of population variables from district to mauza levels. The census data have been tabulated systematically for acquiring certain results. Besides, the results have also been drawn out by the application of various mathematical equations such as net population change, inter-censal variations, annual average growth rate, population density, physiographic density, population potential, urban density, level of urbanizations, rank size rule, sex ratio, correlation and regression, settlement index and nearest neighbour index, etc.The census data was processed using SPSS. Various cartographic and GIS techniques have also been applied to produce the maps for illustrating the temporal and spatial changes in population distribution and urbanization. The census data from 1951 to 2012 has also been enhanced with the help of GIS. The present study recognizes the need for sophisticated methods of analysis. The methodology is thus based on integration of quantitative-cartographic methods and Geographical information System analysis (Taylor, 1991). GIS has widely been used for data integration to generate maps using different indices.

3.16 Statistical Analysis of Urban Expansion

As discussed above, this PhD project mainly seeks to detect the land use/cover changes in response to the urbanization that has occurred in the study area over the last four decades i.e. 1972 to 2012, at the district level and Rawalpindi city level. Following statistical measures were applied to the Rawalpindi (S3) and Taxila (S4) tehsils of the study area to compare the landscape patterns in the last three census periods to explain the land use /cover changes.

3.16.1 Built-up Sprawl Analysis

The "Impervious surfaces" or urban built-up areas contain structural information about urbanization. Therefore built-up area analysis is a discussion point in this thesis. The built-up sprawl analysis was performed using following three parameters:

BUSI = Built-up sprawl index

LCR = Land consumption rate

LAC = land absorption coefficient

3.16.2 Built-up Sprawl Index (BUSI)

BUSI is a measure of the built-up environment in the study area. The value of BUSI was used to estimate the built-up pattern in different censuses periods. BUSI was simply calculated by dividing the built-up area calculated from the classified images, by the population increase during an inter-censal period.

BUSI = total built-up expansion/ population increase

Since most of the built-up area falls in the Rawalpindi and Taxila tehsils of the study area, therefore statistical measures for urbanization analysis were applied to these two tehsils only. Table 3.5 shows the value of BUSI for two tehsils during the last four decades.

Table 3.5: BUSI for Rawalpindi and Taxila Tehsils of the study area

Year	**Rawalpindi Tehsil**			**Taxila Tehsil**		
	Built-up area (h)	**population**	**BUSI**	**Built-up area (h)**	**population**	**BUSI**
1972-1981	4844	225000	0.0197	130	82000	0.00158
1981-1998	8922	851000	0.0104	544	209000	0.0026
1998-2012	10430	770000	0.0135	1165	212000	0.0054

3.16.3 Land Consumption Rate and Land Absorption Coefficient

Land consumption rate (LCR) estimated the pace and trend with which the land has been consumed by the development. LCR is a measure of compactness which indicated spatial expansion of the two tehsils of the study area.

LCA = built-up area of a particular year/ population of that year

Land absorption coefficient (LCA) measured the change in consumption of land by the new urbanizing areas by an increase in the population.

$$LAC= \frac{A2 - A1}{P2 - P1}$$

A1 and A2 are the areal extents for the early and later years and P1 and P2 are population figures for these years respectively. LCR and LAC for both tehsils were calculated for all censuses years and implied to the explanation of land cover changes in the study area. Table 3.6 explains the LCR calculated for Stratum 3 and Stratum 4 of the study area during the different census years.

Table 3.6: LCR for Rawalpindi (S3) and Taxila (S4) tehsils

Year	Rawalpindi			Taxila		
	Area (ha)	**Population**	**LCR**	**Area (ha)**	**Population**	**LCR**
1972	5600	852000	0.0066	212.000	141000.000	0.0015
1981	10044	1077000	0.0088	342.000	223000.000	0.0015
1998	18966	1928000	0.0096	806.000	432000.000	0.0018
2012	29395	2698000	0.0108	1961.000	644000.000	0.0030

3.17 GIS, Remote Sensing and Census Data Integration

GIS is a unique to input, store, retrieve, manipulate and analyse geographic data to produce interpretable information. The major steps involved in implementing GIS to the present study are:

a) Data input: Creation of a database
b) Analysis : Combining data layers and producing new layers for extracting meaningful information

Data bases created and used in this study are remote sensing images, all kinds of hard copy maps, statistical data, census data, qualitative data, GPS data, administrative boundaries, etc. The integration of the census data with remote sensing images was a big challenge in this research. Figure 3.12 gives the detail of how the process has been carried out to integrate the census data with the parallel remote sensing data. The following steps were carried out to perform this arduous task.

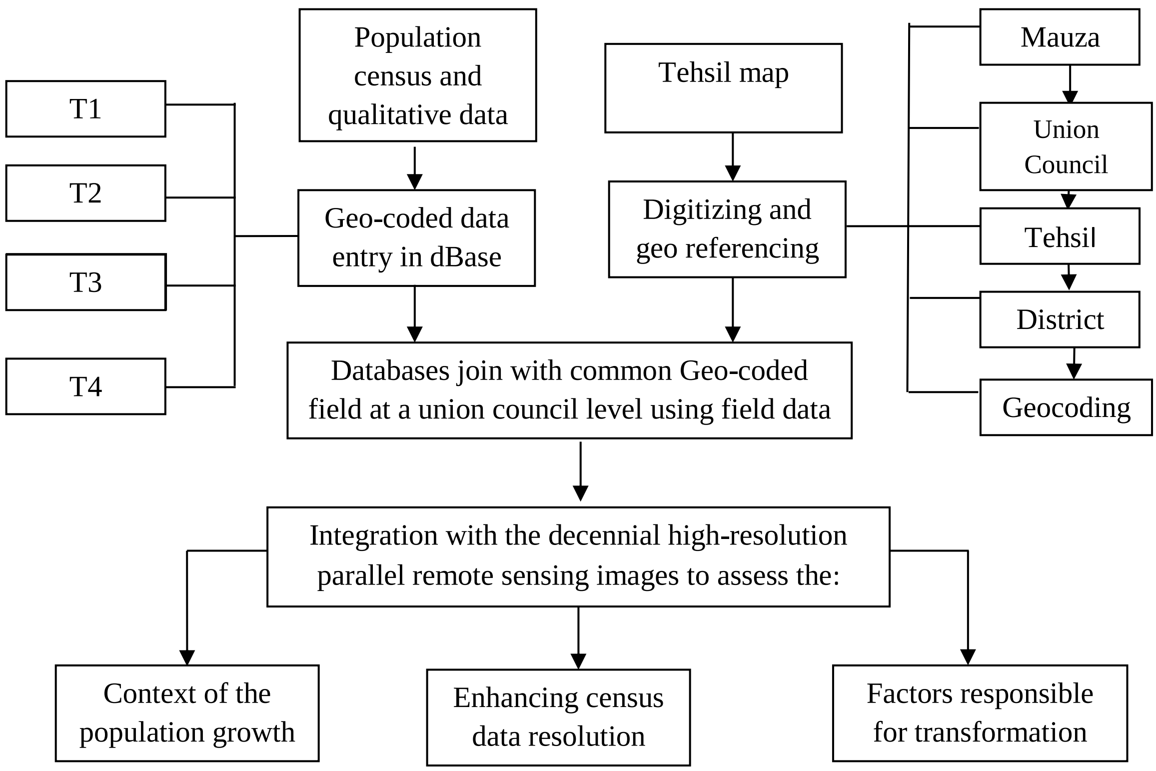
1. Pakistan does not have good digital census archives, so the researcher first collected hard copies of all district census reports (DCR) of the study area from different sources. The census data was then entered into DBF format. For this purpose the lengthy tables of population were typed in Microsoft Excel to bring them in digital form. Transferring all of the censuses data into digital form and bringing it into a GIS data base was very laborious and time consuming.
2. The tehsil level maps of Rawalpindi having information up to mauza level were obtained from some anonymous sources[15]. The quality of these maps was not good and there were even some mauzas that could not be found in the census enumeration. Anyhow, the next step was to

[15] Mauza level maps are not very common Pakistan. They are prepared by the Revenue officials and are kept under strict lock and key. These maps are very confidential and people and even researchers usually cannot access them. The author obtained the mauza maps of the all seven tehsils of district Rawalpindi from some anonymous sources for the purpose of use in this research only.

digitize these maps and to transform them to the coverage to the common Projection system compatible to that, earlier used in geo-referencing of satellite images, i.e. WGS 1984 43 N. The coverage contained a hierarchy of boundaries such as Patwar circle (PC) Union council (UC), Mauza, Tehsil, and District.

3. The function of joining of the attribute data and coverage dbf data sets was performed in ARCGIS 10 software. Now the spatial distribution of the census data could be seen from the tabulated form. Finally both mauza and censuses databases were integrated with the remote sensing images and different maps were produced.
4. The quality of the census data was assessed by employing different overlapping methods and image interpretation techniques.

Figure 3.12: Integration of RS & Census data



(Modified after Rasheed, 2003)

3.18 Conclusion

In the present study both geospatial and statistical techniques have been used. Thus the methodology adopted reflects the elements of satellite, census, qualitative and GPS data. In fact the present study is a blend of physical and human geography techniques. For instance on the one hand, it processes, analyses and evaluates the satellite data by using different algorithms and accuracy assessment techniques, on the other hand it devises techniques to collect and analyse the census, qualitative, and social data, by using qualitative methods and statistical techniques. The challenging segment of the methodology is to integrate the data which highlight the changes in the study area.

The methodology adopted in this study can be summarized under five major steps. The first step focused on the field work methodology to collect the qualitative, census and GPS data. The second and important section of the methodology dealt with the processing of the satellite data. This section described how remote sensing data was rectified, geo-corrected, enhanced, and classified by using different techniques and classification algorithms. The third step focussed on classification scheme, classification procedures and evaluation procedures of the remote sensing data. It described statistical measures for change detection techniques. It discussed the preparation and evaluation of *transitional matrices* for assessing land cover change during the different censuses. A mixed methods approach has been adopted in the final section. This section not only dealt with the statistical analysis of population data, and built up land cover data extracted from the remote sensing classified images, but also the integration of census, remote sensing and GIS data has also discussed in this step. The results of the all of these steps are discussed in the following chapters.

4 POPULATION DYNAMICS

PART- I

4.1 Introduction

Urban populations vary spatially and temporally, in size and in composition, within cities and among cities. In the developing countries of Asia, particularly in Pakistan, urban populations are usually dense around city centres and dispersed in the suburbs, growing rapidly on the urban fringe. Because of the complex relationships between urban populations and the entire human-environment system, variations in urban populations and their causes and effects are difficult to explain, predict, or influence. That's why neighbourhood variations are important in urban studies as both outcomes of and influences on the economic, social, and environmental conditions in cities and in the regions to which cities are connected. While studying the past population growth, many questions come to mind. For instance, how did population trends tend to vary within major urban areas of Pakistan since independence? How can we compare the spatial extent and patterns of different trends in different urban areas? What is the rate of spatio-temporal analysis of population change from macro (provincial) level to micro (mauza) level)? Past research on population distribution, particular.rly urban population density structure and dynamics provides some answers to these questions, both theoretically and empirically, but no prior work has directly addressed these questions over a broad spatial and temporal scale. This may in part be due to the technical difficulties of assembling data at such a micro level, covering multiple urban areas over multiple decades. This research is an attempt to address these questions.

Urbanization in the developing countries of Asia is proceeding exceptionally fast. Peripheral zones of the cities are being squeezed, causing rural to urban conversion of large areas. Pakistan like China and India is engaged in urbanization that has been particularly rapid over the last four decades largely driven by the concentration of better economic, health and education opportunities and all other amenities present in urban areas. Although the world's urban centres comprise just 2% of the land area, they accommodate more than 3.5 billion people (UN, 2012). Several decades of population expansion and accelerated urban growth have had profound environmental and socio-economic impacts felt in both developing and developed countries alike (Yang, 2002). In short urbanization has significant impacts on land use changes of many developing countries of Asia including Pakistan and particularly in the densely populated Punjab province of Pakistan, which alone constitutes more than half of the total population of the country. Analysis of urban development and population distribution provides an opportunity to visualize and understand the human use of the landscape, for projecting trends in urbanization, assessing "smart growth" and conservation efforts, and for evaluating ecosystem impacts of human activities (Martinuzzi & Gonzalzes, 2007). An important topic in urban studies is the population distribution because the size, pattern and spatial distribution of urban land use and land cover are closely related to population characteristics. Census data provides an inductive exploration of land use and land cover change that may provide clues to the underlying dynamics involved (Rasheed, 2003). In Pakistan, since census data is collected within spatial units it can be stored as GIS attributes; therefore a combination of census and remote sensing data along with GIS can be envisaged in an efficient manner.

Hence the broad viewpoint of this chapter is to analyse the census data statistically and further to combine it with satellite data for mapping the trends of population growth and urbanization process in GIS environment. In fact the writing of this chapter is the accomplishment of the second objective of my research, i.e. "To undertake a spatial analysis of Pakistan Population Census data for 40 years, i.e. 1972 to 2012, to contextualize and interpret the process of urbanization". The aim is to explore the complex relationship between urban growth and peri- urban environments including land use and resource distribution.

4.2 The Census in Pakistan

As discussed earlier, the main sources of data for this chapter are census publications; therefore a brief introduction of the census operation in Pakistan is summarized below.

The first population census in India was conducted in 1855 (Robertson, 1887), but it did not cover many areas of the present Pakistan[16]. Data for Pakistan and particularly the regions comprised in Punjab are available for 1881 onwards for the thirteen censuses conducted since then. The last census conducted in British rule was the one in 1941. Pakistan continued the British tradition of holding censuses, the first census in Pakistan was conducted in 1951 and the last in 1998. So far five censuses have been conducted in Pakistan according to the schedule given in Table 4.1. The first phase (household identification) of the sixth census was completed in 2011, but complete enumeration has been delayed for the last two years due to political reasons. This whole chapter is an attempt to synthesize and analyse the results of these periodic censuses to present a broad overview of number of population variables of Pakistan, province of Punjab and district Rawalpindi, including population growth, density, urbanization, and demographic transition. Cartographic and GIS techniques have been used to represent some of the demographic indicators of population and urbanization aspects of land use change.

[16] Before Pakistan emerged as a separate nation, the areas now constituting Pakistan were included in India ruled by the British.

Table 4.1: Census schedule of Pakistan after independence (1947)

Census Year	Enumeration Period	Census Date	Inter-censal	
			Interval (year)	Growth Rate (%)
1951	9 -18 February 1951	28 Feb. 1951	10	1.8
1961	12-31 January 1961	31 Jan. 1961	10	2.4
1972	16-30 September 1972	16 Sep. 1972	11.62	3.7
1981	1-15 March 1981	1 March 1981	8.46	3.1
1998	2-18 March 1998	2 March 1998	17	2.7
2011-12[17]	03 March -10 May 2011	Not held yet	14	2.4[18]

Source: Government of Pakistan, 1951a-1998a

4.3 Historical Growth of Population of Pakistan

To understand the processes and patterns of urban development, let us first have a look at the historical growth of population of Pakistan (Table 4.2) The regions which now constitute Pakistan have registered not only a rapid growth in human population during the past hundred years, especially in the post 1950 era, but have also experienced a perceptible change in its rural-urban distribution (Khan, 1987, cited in Ali, 2004). With a population of over 180 million in 2012, Pakistan has become the sixth most populous country in the world. It was at 10th most populous country of the world according to 1972 census, 9th according to 1981 census and 7th according to 1998 census. According to UN (2010) projections, it is expected to become the third most populous by the year 2050. Approximately 2.5 million persons are added in the population of Pakistan every year. The growth of population in Pakistan since the start of the 20th century to date shows a gradual and continuous increase. Pakistan still stands apart from its populous neighbours in South Asia, all of which with the exception of Nepal experienced a substantial decline in fertility during the last two decades and now shows markedly lower fertility. Having 16.5 million in 1901, the population of Pakistan reached 180 million in 2012 (Fig.4.1) and this increase is approximately eleven times. Detailed analysis of each inter-censal period shown in the Table 4.2 portrays that the population of present Pakistan increased gradually since 1881 to 2012, except the inter-censal period of 1911-21. During 1911-21 period the inter- censal increase was lowest ever that is 7.6% with an annual growth rate of 0.7 % (Table 4.2). The reasons for decline were large causalities in

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[17] Household identification only

[18] Estimated on the basis of last census

World War I, high deaths from epidemic diseases like malaria, cholera, and influenza, and the migration of people from NWFP[19] province to Afghanistan due to poor harvests (Khan, 1987). In the next decade the irrigation systems of Punjab and Sindh were upgraded on a large scale, causing the development of new canal colonies on a large scale. This resulted in large movements of people from the subcontinent to the areas of Punjab and Sindh causing 12% increase in population. An abnormally high growth rate of 2.2 % during the next inter-censal period of 1931-41, was the result of an anomaly in the census on the part of both Hindus and Muslims, as both nations exaggerated numbers to gain more seats in the legislature on a communal basis (Ali, 2004).

Table 4.2: Pakistan: Population growth and inter-censal variations of Population 1881-2012)

Census year	Total population (in thousands)	Inter-censal increase		Average annual growth rate (%)	Density persons/km^2
		Number(000)	Percentage		
1881	12,693	-	-	-	15.9
1891	14,300	1607	12.7	1.2	18.0
1901	16,576	2276	15.9	1.5	20.8
1911	18,805	2229	13.4	1.3	23.6
1921	20,243	1438	7.6	0.7	25.4
1931	22,640	2397	11.8	1.1	28.4
1941	28,244	5604	24.8	2.2	35.5
1951	33,740	5496	19.5	1.8	42.4
1961	42,880	9140	27.1	2.4	53.9
1972	65,309	22429	52.3	4.3	80.1
1981	84,254	18944	29.0	3.1	105.8
1998	132,352	49094	57.1	2.7	166.3
2012[20]	180,000	47648	36.0	2.4	226.1

Source: Census of India, 1901a-1941a; Government of Pakistan 1951a-1998a; Government of Punjab, 2012

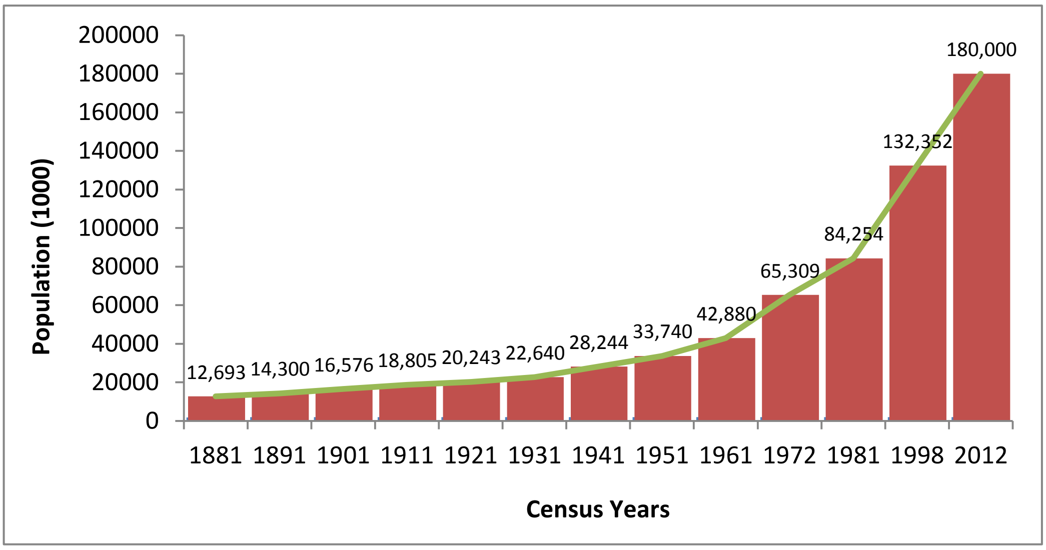
In 1947 the separation of India into two countries caused an influx of population moving across the border on both sides. Since the Muslim population moved on a large scale from India to Pakistan in 1947, therefore an increase of 20 % can be seen in the first census conducted in 1951 under the auspices of new government of Pakistan. The increase in fertility rate and decline in mortality rate due to better environmental conditions and global progress in medication recorded an increase of

[19] North West Frontier Province, In 2010, Khyber PukhtunKhah" a new name for it has passed from the National Assembly of Pakistan

[20] Estimated according to the Development Statistics of Punjab, 2012

27 % in the 1951-61 decade. The inter-censal annual growth rate also increased from 1.8 % to 2.4 % during 1951-61 period. Due to the better policies of the military government in 1961-72, a comparatively rapidly developing economy and relative stability of economic life, and predominantly high fertility rates, the population of Pakistan increased for the first time 52.3% in the history. Khan (1987) is of the view that neither the extremely high birth rates and or exceptionally low death rates which were required for this high growth rate in Pakistan were experienced during this decade, nor was there any massive immigration, therefore the unmatched record increase was probably due to errors in enumeration. Such doubts have also been expressed by some other authors (Afzal & Hussian, 1974; Bean, 1975; Krotki, 1975, cited in Khan, 1987).

Figure 4.1: Trend of population growth of Pakistan (1881-2012)



Source: Census of India, 1901a-1941a; Government of Pakistan 1951a-1998a; Government of Punjab, 2012

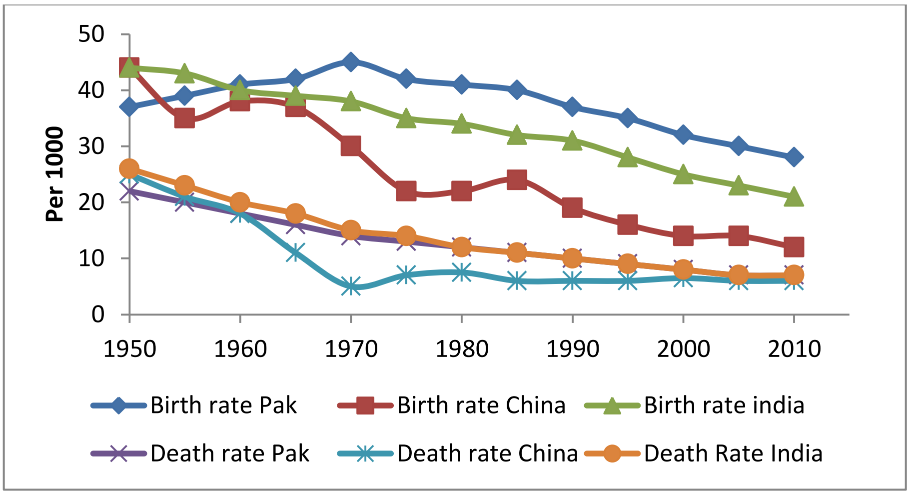
Nevertheless Pakistan was at the peak of its demographic transition in this period mainly due to the early marriages of young girls, even sometimes before the attainment of the legal age of 18. The census period of 1972-1981 recorded an increase of 29 % in population, having annual growth rate of more than 3%. Though this rate was a decrease compared to the 1961-72 censuses, it was a failure of the governmental policies of family planning. The famous slogan (Children: two are too good) of "Family Planning Commission of Pakistan" though was much higher than the population replacement Index, it was not popular among the illiterate masses of Pakistan. The census of 1998 held after a long break of 17 years due to long on-going dialogue among the provincial governments, amounted to GIGO[21]. Actually Pakistan's political leadership draws much of its

[21] Garbage in Garbage out

power from rural landholdings, power that could be greatly reduced if a census confirms a drastic decrease in rural population. This politicization underscored the perils of census-taking in Pakistan. The 1998 census tendered the figure of 132.4 million, showing a decrease in the annual growth rate from 3.1 to 2.7. Though over the globe, the census is a routine process conducted regularly, yet in Pakistan, countless factors - from catastrophic flooding and insufficient funding to the turbulent security situation and intense political opposition - conspired to delay the last census, which was supposed to be held in 2008.

The estimated results list the current figure at about 180 million, while the United Nations believes it to be over 185 million. Though no longer increasing at the rate of 3% as seen since the late Eighties, Pakistan's population is still growing at a pace of over 2 per cent (United Nations Population, Estimates 2011). United Nations Population's division's estimates suggest that if the country's fertility rate drops from the current average of four children per woman to two, then its population will rise to 335 million in 2050. Should fertility rates remain constant; the UN estimates indicate a massive increase of 300 and 450 million in years 2030 and 2050 respectively. The world population tripled over the past half-century and much of this increase was accounted for by developing countries, particularly the most populous countries of Asia such as China (1), India (2), Indonesia (4), Pakistan (6), and Bangladesh (7). Fig. 4.2 is a comparison of demographic transition of three populous neighbouring countries i.e. China, India and Pakistan. The graph suggests that the demographic transition process started with a decline of the Crude Death Rate (CDR) in the early 1950s.

Figure 4.2: Demographic transition in China, India and Pakistan



Source: UN, 2010b

This decline proceeded from Pakistan, followed by China and India. The decline was sharper for China after 1960, but at the end of 2010, the three countries were meeting near the same point. Although not shown, the Infant Mortality Rate also declined.

4.4 Population Distribution Patterns

Distribution of population as well as the spatial pattern of population-related phenomena forms very important aspects of research in Geography. Moreover the analysis and explanation of these patterns have not always been easy because of dearth of spatially disaggregated data, and variety of basic areal units. This section is an attempt to analyse the distribution patterns of Pakistan from the provincial level to the district level. The present uneven spatial distribution of population throughout the world represents just one stage of a continually changing pattern of adjustment by millions of individuals to the variety of physical and socio-economic factors that influence their lives. There are also very significant variations in distribution within particular continents and countries. Many factors affect the distributional patterns of population.

Afzal & Abbasi (1979) noted that:

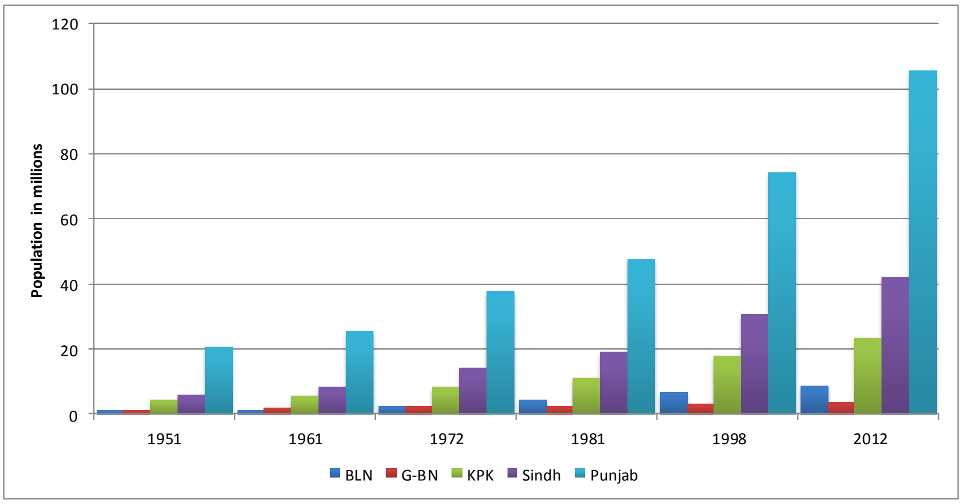
1: The highest densities are in the areas of favourable physical environment, ***irrigation*** being an important 'cultural' improvement of some areas that have seasonal or erratic rainfall but are otherwise physically attractive.
2: People are attracted to live in areas of low ***elevation***.
3: Population clusters along ***borders***, leaving the interior empty.

These generalizations are clearly exemplified in Asia and particularly in Pakistan. The other major concentrations of dense population in Pakistan are associated with industrialization, better education and health facilities, employment opportunities, which has encouraged high levels of urbanization especially during the last two decades. The Population of Pakistan is unevenly distributed among its five provinces-Baluchistan, Gilgit- Baltistan[22], Khyber Pukhtunkhwa, Pujab, and Sindh. Fig. 4.3 illustrates the patterns of population distribution in different provinces of Pakistan from 1951 to 2012. Table 4.3 illustrates the share of each province in the total area of Pakistan and share and growth patterns of the population of provinces between successive censuses since 1951. Table 4.3 further illustrates that Punjab is the densest province since 1951 followed by KPK and Sindh. Baluchistan is the sparsest province of Pakistan. Punjab although has the total area less than 25% of the total, but its population has been over half of the total national population since 1951. Sindh's share of above 23% in the total population makes it the second most populous

[22] From 1947 to 2010 the country was divided into four provinces. Northern areas were though considered a separate independent region, but not the status of province. In 2010, the Northern areas were given the status of a province, by the National Assembly of Pakistan.

province. Sindh's relatively high share is primarily due to Karachi, which has been main hub of the country throughout the country's history. Karachi is also counted among the mega cities of the world, currently accounting for a population of approximately 18 million. Extensive canal irrigation and concentration of textile and manufacturing industries in Punjab and Sindh has also contributed towards increasing population pressure on both provinces. Further, one main obstacle to reducing fertility in these provinces is the rigidity of the illiterate husbands, who in their desire for a son, and to prove their virility don't allow their wives to use contraceptives (Government of Pakistan, 1998a). Khyber Pukhtunkhwa is the smallest province by area but has 13% of the national share of its population. On the other hand Baluchistan is the largest province by area, but merely shares the burden of only 5 % of national population. Due to the rugged topography and severe cold in winter, Gilgit – Baltistan province has not attracted the national population on a large scale.

Figure 4.3: Population by province (1951-2012)



Source: Government of Pakistan, 1951a-1998a; Government of Punjab, 2012

Punjab is the second largest (in area) and most populous and comparatively more developed province of Pakistan. Its Population is more than the population of 230 individual countries of the world. Mostly the state's institutions are located primarily in Punjab. It's a hub of Pakistan's society and culture. Its demographic predominance colours Pakistan's society and polity.

Table 4.3: Variation of population among Provinces (1951-2012)

Province	Population (in millions) as per cent of total population of Pakistan						Inter-censal Variation (%)and [23]AAGR %				
	1951	1961	1972	1981	1998	2012[24]	1951-1961	1961-1972	1972-1981	1981-1998	1998-2012
Punjab **(25.80)**	20.64 **(60.80)**	25.58 **(59.40)**	37.84 **(57.9)**	47.63 **(56.53)**	74.43 **(56.23)**	105.60 **(58.67)**	23.93 **(2.17)**	47.93 **(3.62)**	25.87 **(2.69)**	56.26 **(2.66)**	41.88 **(2.53)**
Sindh **(17.70)**	6.05 **(17.90)**	8.37 **(19.50)**	14.16 **(21.68)**	19.03 **(22.59)**	30.44 **(23.00)**	42.12 **(23.40)**	38.34 **(3.29)**	69.17 **(4.90)**	34.39 **(3.34)**	59.96 **(2.80)**	38.37 **(2.34)**
[25]KPK **(9.36)**	4.56 **(13.6)**	5.73 **(13.30)**	8.39 **(12.84)**	11.06 **(13.12)**	17.74 **(13.40)**	23.40 **(13.00)**	25.66 **(2.31)**	46.42 **(3.53)**	31.82 **(3.12)**	60.39 **(2.82)**	31.91 **(2.00)**
[26]BLN **(43.61)**	1.17 **(3.50)**	1.35 **(3.20)**	2.43 **(3.72)**	4.33 **(5.14)**	6.57 **(4.96)**	8.55 **(4.75)**	15.38 **(1.44)**	80.00 **(5.45)**	78.19 **(6.63)**	51.73 **(2.48)**	30.14 **(1.90)**
[27]G-BN **(3.53)**	1.33 **(3.90)**	1.85 **(4.30)**	2.49 **(3.81)**	2.50 **(2.61)**	3.18 **(2.40)**	3.7 **(2.06)**	39.10 **(3.35)**	34.59 **(2.74)**	0.40 **(0.04)**	27.2 **(1.42)**	16.35 **(1.08)**

The figures in brackets in province column show the percentage of total area of Pakistan whereas in population columns show the percentage of total population of Pakistan. The figures in parenthesis (bold) in the inter-censal variations columns show the average annual growth rate.

Source: Government of Pakistan, 1951a-1998a; Government of Punjab, 2012

Northern and central Punjab is more developed and more populous as compared to the south, having approximately 75 % of the urban population. The Potohar region of Northern Punjab, where the study area of Rawalpindi is situated differs physically as well as socio-culturally from other parts of the province and country. Geographically known as the Potohar plateau, it's one of the ancient regions of the world where human settlements of early civilization have been found. Its excellent location advantage helped in the past, to emerge as an important region of economic and political interests in Pakistan in particular and South Asia's economy in general. The Taxila region excavations reveal that in 4th millennium BC, and even earlier Potohar had most modern and populous cities of Soan and Indus Civilization. The old Brahman literature of around 800 BC reveals that some of the villages of the Potohar region had grown into towns and capitals within an urban mode of life. Its scenic beauty impressed Alexander very much while invading Potohar (Ali, 2003).

[23] Average annual growth rate
[24] estimated
[25] Khyber Paktunkhah
[26] Baluchistan
[27] Gilgit Baltistan: The population figures of this province has been estimated by the author on the basis of the census records of the area.

4.5 Case Study of Rawalpindi

Rawalpindi is an important district[28] and urban centre of the Potohar plateau of Punjab province. The total area of Potohar region is 23160 km^2. It comprises five districts: Rawalpindi, Islamabad, Jhelum, Chakwal and Attock. Although area wise share of Rawalpindi is only 22.8 %, its population share has never been less than half of Potohar as a whole.

During 1881-2012, population of Potohar and Rawalpindi experienced an annual growth rate of over 2.3 % and 2.7 respectively. Table 4.4 explains that the total population of the Potohar increased seven fold during the period 1881-2012. The population of Rawalpindi increased faster than Potohar and its increase during the century was more than nine fold. The growth trend of both has been inconsistent throughout the thirteen censuses. In 1911 the population of Rawalpindi, and in 1921 the population of Potohar was less than their previous census totals. The outbreak of Spanish Influenza in these decades could be a possible factor in this decline (Ali, 2003).

Table 4.4 shows that the population of the Potohar region increased by nearly eight million during the period of 1951-2012. Rawalpindi contributed almost half. Throughout history Rawalpindi has been the most populous district of the Potohar region of Northern Punjab. The highest ever annual growth rate of Rawalpindi was during the 1961-72 census period (Fig. 4.4). This was the time when Rawalpindi was officiating as the Capital[29], and therefore attracted a large population in the shape of governmental employees and labourers both. In fact the post 1961 period witnessed unprecedented developmental activities in the region, such as the construction of the Mangala and Tarbela dams on the flank of Rawalpindi district, the shifting of the country's new capital to Islamabad in the proximity of Rawalpindi city, and the establishment of industrial complexes at Wah, Taxila, Sanwal and Kamra.

During this period the economy of Rawalpindi received a great boost, inducing a large scale in-migration, intra-regional rural urban migration and forced migration[30] which provided a foundation for a considerable rise in the socio-economic indicators (Khan, 1987). The population of Rawalpindi doubled in twenty years (1951-1972), and it increased 2.6 times from 1972 to 2012. Overall the population of Rawalpindi increased fivefold from 1951-2012. A high inter-censal variation of over 61% was recorded during 1961-72, followed by the 1981-1998 period which was 59%.

[28] The administrative structure of Pakistan in the descending order of hierarchy is: province, division, district and tehsil. The district in Pakistan has been the basic unit of administration and focal point of all social, economic, cultural and development activities.

[29] In 1959 the national capital was shifted in Islamabad, and in the absence of any infra-structure there, Rawalpindi was upgraded to the status of interim capital. Rawalpindi enjoyed this status of acting capital for more than 12 years.

[30] A large number of people were displaced due to construction of the two dams, and many were offered land holdings in the study area)

Table 4.4: Total Population, Inter-censal variation and Average annual growth rate comparison of Potohar and Rawalpindi (1881-2012)

Census Year	Population of Rawalpindi (000)		Inter-censal Variation (%)		Average annual Percent change	
	Rawalpindi	Potohar	Rawalpindi	Potohar	Rawalpindi	Potohar
1881	471	1410	-	-	-	-
1891	534	1496	13.4	6.1	1.3	0.2
1901	559	1525	4.7	1.9	0.5	0.3
1911	548	1579	-2.0	3.5	-0.2	0.3
1921	569	1559	3.8	-1.3	0.4	-0.1
1931	634	1759	11.4	12.8	1.1	1.2
1941	785	2090	23.8	18.8	2.2	1.7
1951	873	2276	11.2	8.9	1.1	0.9
1961	1085	2653	24.3	16.6	2.2	3.8
1972	1748	4016	61.1	51.4	4.4	1.6
1981	2121	4773	21.3	18.8	2.2	1.9
1998	3364	7465	58.6	56.4	2.8	2.7
2012[31]	4467	9565	32.8	28.1	2.2	2.1

Source: Census of India, 1881a-1941a, 1881b-1941b; Government of Pakistan, 1951a-1998a, 1951b-1998b; 1998b; Government of Punjab, 2012

Since 1961, the growth rate of Rawalpindi has never been less than 2.2 %, showing a particular trend of rapidly growing areas. The construction of motorways from Rawalpindi to Lahore (M2), Rawalpindi to Peshawar (M1) and Rawalpindi to Faisalabad (M3) in 1996, 2001 and 2006 respectively had also profound effect in increasing the population of the district.

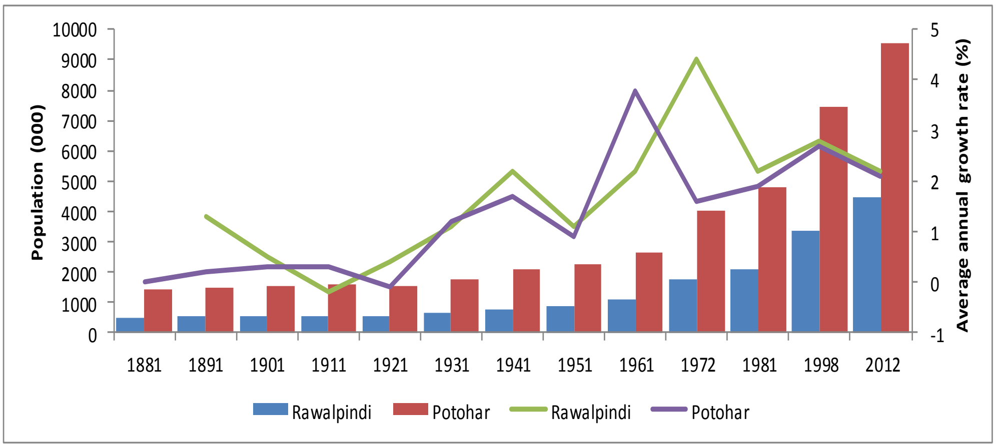
4.6 Population Growth in Tehsils of Rawalpindi

In the preceding parts of the chapter the focus was on the growth trends of Pakistan, Punjab, Potohar and Rawalpindi regions as a whole. In this section the growth trends at tehsil level are analysed. The time reference is 1951-2012, as older data for the individual tehsils is neither available, nor is it appropriate to look back into the distant past at tehsil level. In fact the post 1951 period's scenario is totally different from the preceding fifty years making the two periods quite incomparable. To focus the analysis the tehsils wise details of population from 1972 to 2012 are summarized in Table 4.5. The above table shows that although Rawalpindi tehsil is the most populous, but the inter-censal variation in the population of Taxila tehsil has been more than

[31] Estimates of Government of Punjab vide publication: Government of Punjab, 2012.

Rawalpindi. Its population was only fifty eight thousand in 1951, increasing above nine fold and approaching near to figure of five hundred thousand.

Figure 4.4: Population and average annual growth rate of Rawalpindi and Potohar Region (1881-2012)



Source: Population Census Organizations of India, and Pakistan

Murree is a recreational town hill station of Punjab, and therefore increasing in population. The population of Kahuta has been kept limited as per the policy of the government. The other tehsils of the study area grew at a normal rate. Tehsil of Kallar Syedan was established in 2007; hence past record is not available.

Table 4.5: Tehsil wise population analysis of Rawalpindi district

Census Year	**Name of Tehsils**													
	Gujjar Khan		**Kahuta**		**Kotli Sattian**		**Murree**		**Rawalpindi**		**Taxila**		**Kallar Syedan**	
	Pop	**ICV**	**Pop**	**ICV**	**Pop**	**ICV**	**Pop**	**ICV**	**Pop**	**ICV**	**Pop**	**ICV**	**Pop**	**ICV**
1951	210	-	116	-	36	-	73	-	382	-	58	-	-	-
1961	232	10.6	137	17.6	38	12.8	89	21.6	521	36.6	70	20.2	-	-
1972	348	50.0	204	49.2	65	72.7	136	53.0	852	63.5	141	102	-	-
1981	361	3.6	232	13.9	83	27.4	157	15.9	1066	25.1	223	59.0	-	-
1998	494	37.0	313	35.0	81	-2.1	176	12.3	1928	80.9	371	67.0	-	-
2012	595	20.4	385	23.0	90	10.4	194	10.0	2519	29.9	489	31.8	194	-

N.B: Population is in thousands and inter-censal variations (ICV) is in %

Source: Government of Punjab, 2012

4.7 Population Density

The concept of population density was first used in 1837 by Henry Drury for assessing overpopulation and under population. Despite criticism it is still useful for abstraction, assisting in the analysis of the diversity of man's distribution in the space (Clarke, 1979). Thus besides absolute figures, a useful indicator of population concentration is the density of population. This measure has been used in the present study to analyse the spatio-temporal changes within the provinces, and districts, for the comparison of the study area with the other districts at par. I have employed several variables of population density. I did this because no one measure fully captures the full "essence" of the density construct, but instead each measure reflects a different dimension. Each of the measures clearly has relative strengths and weaknesses; nevertheless they provide different foundations for comparison. Two measures, crude density of population and density by arable land or physiographic density (Clarke, 1979) have been used to generate a series of maps of districts of Punjab (Figs. 4.5 and 4.6) which represent variations in man/land and man /arable land ratios at census interval since 1972. These measures provide a good foundation for the comparisons of process of urbanization and land cover change, among the districts. The comparison of arable density of different districts makes it clear the pressure of population on the agricultural areas. Fig. 4.6 shows that arable density of those districts increased rapidly which are urbanizing at a fast rate. Density wise Rawalpindi occupies a prominent position in Punjab as well as in Pakistan. Table 4.6 gives a comparison of the study area with Potohar region, Punjab and Pakistan.

Table 4.6: Density Comparison of Rawalpindi with Potohar, Punjab and Pakistan

Census year	**Rawalpindi**	**Potohar**	**Punjab**	**Pakistan**
1901	106	66	50	21
1911	104	68	54	24
1921	108	67	57	25
1931	120	76	68	29
1941	149	90	84	36
1951	165	98	101	42
1961	206	115	125	54
1972	331	173	184	80
1981	401	206	231	106
1998	637	322	362	166
2012	845	400	514	226

Source: Census of India, 1881a-1941a, 1901b-1941b; Government of Pakistan, 1951a-1998a, 1951b-1998b; Government of Punjab, 2012

Table 4.6 shows that the population density of Pakistan rose steadily from 1901 to 1941. However, a boost came in the 1961-72 inter-censal period when it increased from 53.9 (1961) to 80.1 in 1972, having more than a 50% inter-censal increase. In the 1972-2012 inter-censal periods, the density of Pakistan increased approximately three times. Density of Rawalpindi increased from 106 in 1901 to 845 in 2012. This increase was more than the national, provincial and Potohar's average.

Table 4.7: Distribution of population and area of Rawalpindi by Punjab's density of population in1998 census

Population Density	**% of total population above each category of population density**	**% of total land above each category of population density**
100	100	100
200	100	100
300	100	100
400	88.28	73.50
500	73.60	45.94
600+	68.34	37.73

Source: Author

As shown in the Table 4.6, a value of 362 persons / km^2 is the average density of Population of the province of Punjab in 1998. Table 4.7 shows that a population density of 362 people per sq. km applied to the whole district of Rawalpindi yield 88.28 percent of the total population and 73.50 of the total land area within this density circle. Thus 68.34% of the district's population lives at 33.73% of the area, which is above the density circle of 600. Siddique (1989) used regression techniques to show which factors are significant in determining the pressure of population in the country. He developed a statistical relationship between resource structure and population density. The residual (r) values derived from regression analysis were used to determine the areas of low and high population pressure respectively. He found that large areas in the north western and western sections of Pakistan have negative residuals, therefore they exhibit low population pressure, whereas in the central sections of the Indus plain high positive residuals occur. His results predict that very high positive residual values in the districts of Karachi, Lahore Rawalpindi, Peshawar, and Faisalabad reflect economic development in these districts fuelling urbanization. The above tables and Physiographic density maps also witness that the central and northern Punjab is more economically developed and due to higher growth of population the agricultural areas are being squeezed and converted to urban land. This resultantly is putting more pressure on agriculture.

Figure 4.5: Density of population in various districts of Punjab in 1972, 1981, 1998 and 2012

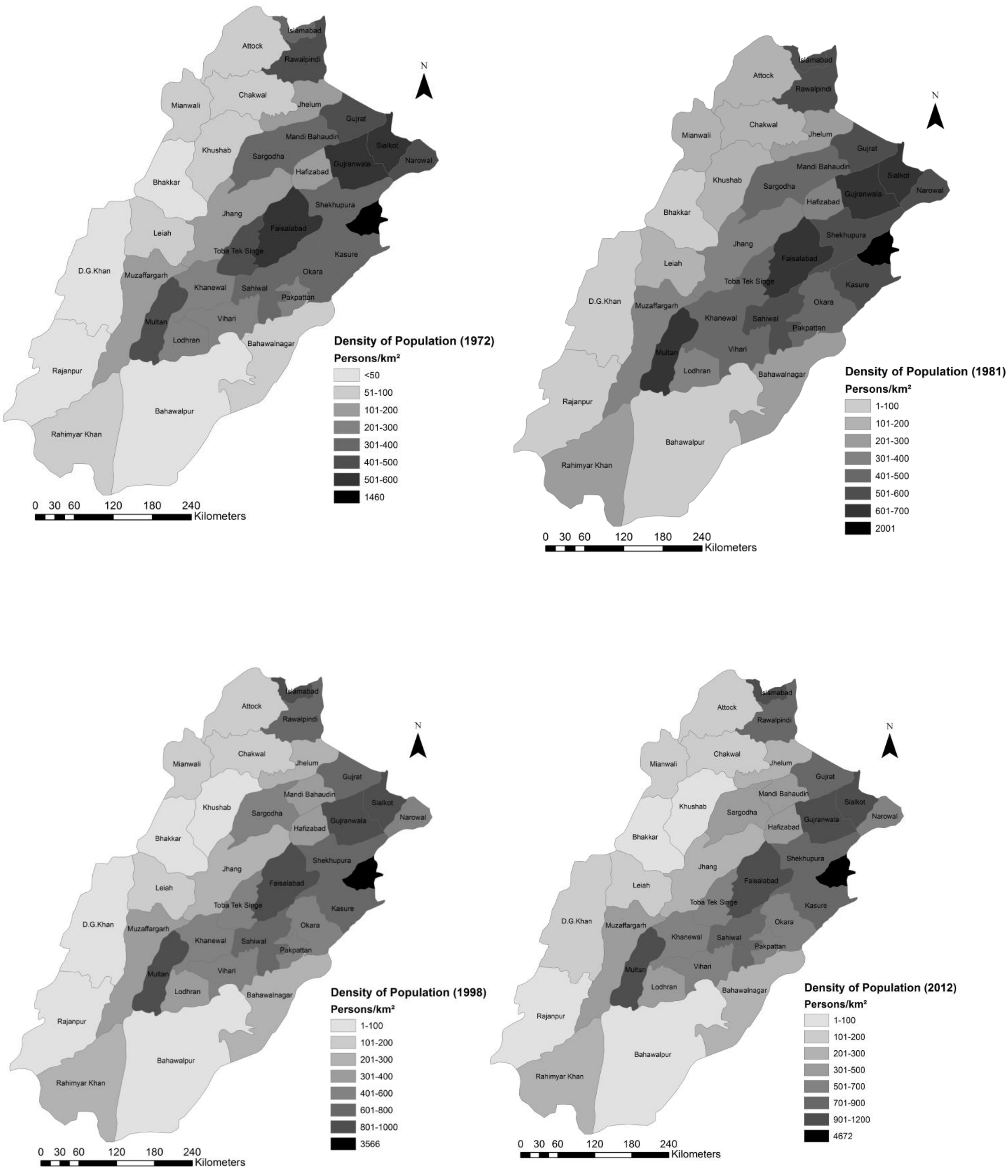
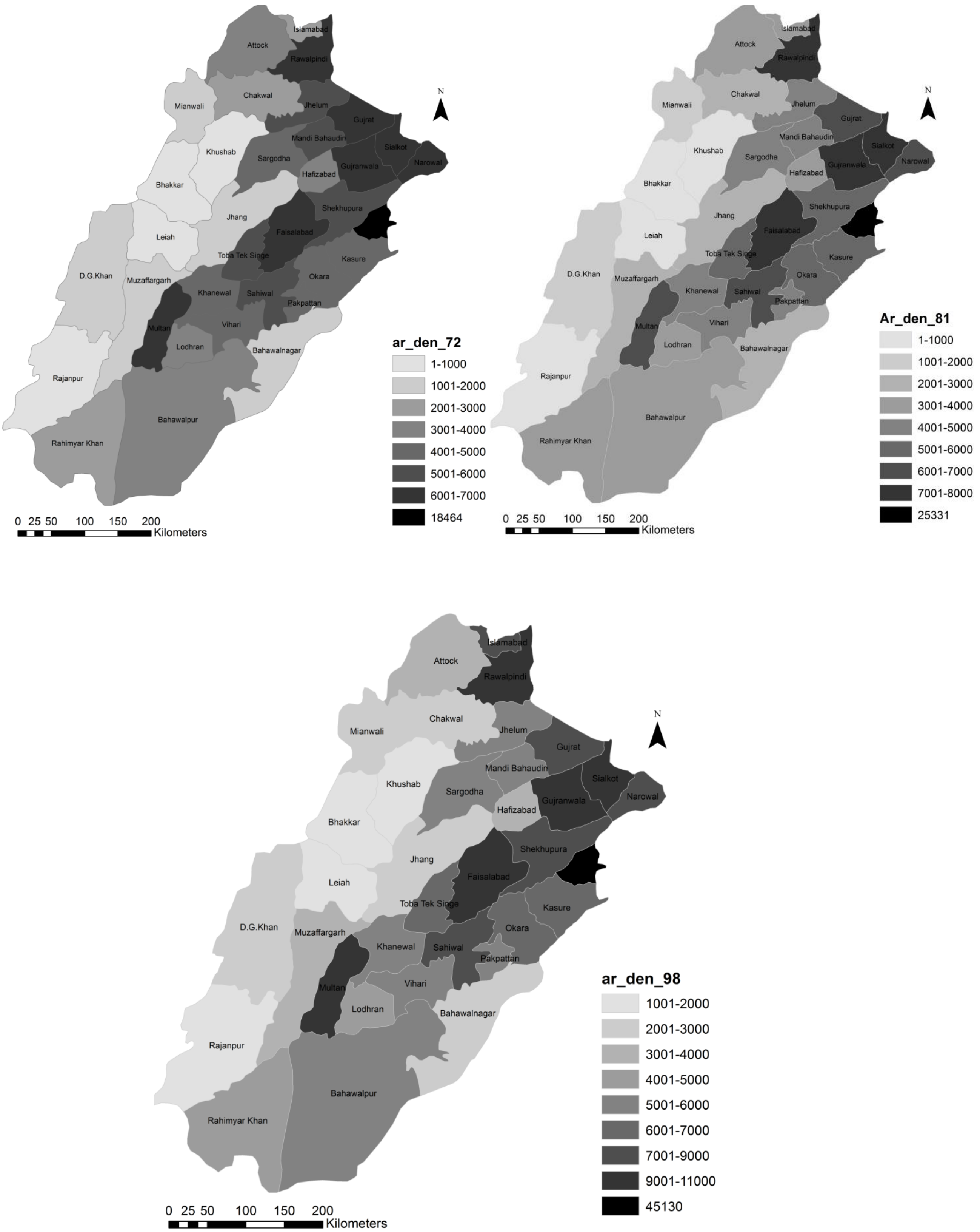


Figure 4.6: Arable density of Punjab in 1972, 1981, 1998 and 2012



The comparative data of density of population in the all tehsils of Rawalpindi for 1951 to 2012 periods is summarized in Table 4.8. It is obvious from the table that Rawalpindi and Taxila tehsils experienced the fastest growth in terms of density within the district.

Table 4.8: Tehsil-wise area, and population density of Rawalpindi (1951-2012)

Tehsil	Population Density Persons/km²					
	1951	**1961**	**1972**	**1981**	**1998**	**2012**
Gujjar Khan	144	159	239	248	339	408
Kahuta	106	125	186	212	286	169
Kotli Sattian	110	124	215	274	268	296
Murree	168	204	312	362	407	447
Rawalpindi	227	310	506	634	1146	1545
Taxila	185	223	449	714	1190	1567

Source: Government of Punjab (2012)

Taxila and Rawalpindi tehsils has shown extraordinary increase in the density since 1972 and density of population of Taxila tehsil in 2012 was more than any tehsil of the Punjab, except Lahore. The relationship between built-up area and density of population of Taxila and Rawalpindi was also inspected and there is a strong correlation in a linear form (chapter 8) which highlights the socio-economic development of the area and population pressure on both tehsils.

4.8 Age and Sex Composition

The age structure and sex composition of population of any area are important components of a demographic study for identification of gender specific socio-economic problems. In the context of urban planning, the study of these characteristics is useful to determine future demand patterns pertaining not only for housing needs, but also social infra-structure and gender specific amenities.
Data concerning population of Potohar and Rawlpindi reveal some striking features. Fig. 4.7 graphically presents the age and sex distribution of the population of Rawalpindi district in 1998 and 1981. The general broad base of the pyramids indicates the preponderance of young population, which has very important social and economic implications. These pyramids are of "progressive" type indicating a same kind of trend that is common in developing countries.

The sex composition of a population is represented by sex ratio. Usually the sex ratio is taken as the number of males per 1000 females. The normal sex ratio should represent 1:1 that is 1000 males over 1000 females, but there exists a clear difference between developed and developing countries. In the former case females are surplus, whereas in the latter category males are surplus. The sex ratio patterns of Potohar and Rawalpindi represent the specific patterns of developing countries. This means a preponderance of males over females. This disparity in sex composition has however been declining with the passage of time as can be seen in Table 4.9 and Fig.4.8.

Table 4.9: Gender variations in Rawalpindi District (1901-2012)

Census Year	Gender Ratio		Census Year	Gender ratio	
	Potohar	Rawalpindi		Potohar	Rawalpindi
1901	1091	1159	1961	1052	1081
1911	1132	1180	1972	1131	1161
1921	1104	1210	1981	1049	1144
1931	1127	1175	1998	1035	1051
1941	1124	1182	2012	1029	1032
1951	1119	1182			

Source: Census of India, 1901b-1941b; Government of Pakistan 1951b-1998b;
Government of Punjab, 2012

The Sex ratio of Rawalpindi which was 1081 males to 1000 females has considerably decreased to preponderance of 1031 males to 1000 females which clearly indicates the decreasing trend of migration of males only to the large districts such as Rawalpindi. The high male sex ratio in Rawalpindi districts since 1900, as compared to Potohar region, indicates a temporary settling of young males in the district for employment and education, leaving their families in the villages and towns. But now this trend is changing and married young couples prefer to live together.

Figure 4.7: Population Profile of Rawalpindi District in 1998 and 1981 censuses

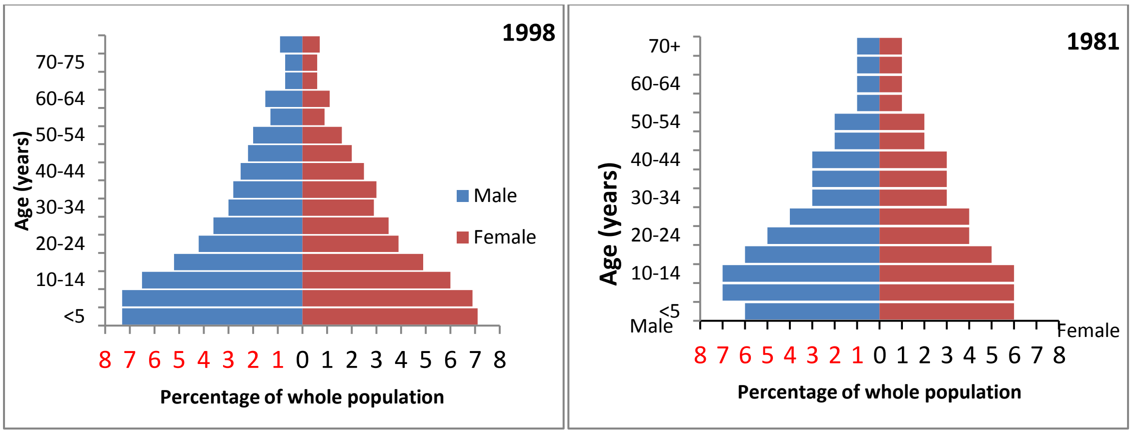
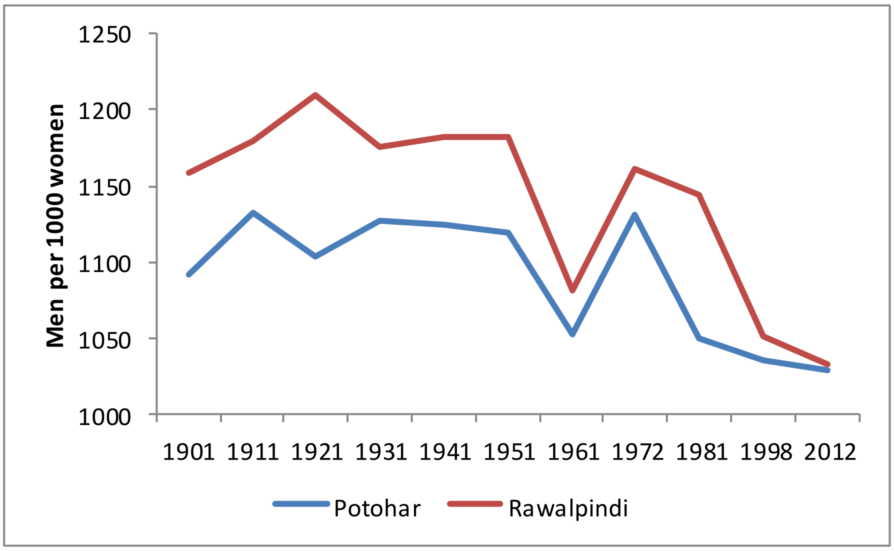


Figure 4.8: Comparison of Gender ratio between Potohar and Rawalpindi



Source: Census of India, 1901b-1941b; Government of Pakistan, 1951a-1998a, 1951b-1998b; Government of Punjab, 2012

Part – II: Patterns of Urbanization

4.9 Introduction

In 2012, a majority of the world's population lived in cities, an important milestone actually reached in 2008; by 2050, this proportion will approach 70 %. Urbanization is a manifestation of socio-economic development of a complex nature. First it lifts or is supposed to lift the population to higher levels in most aspects, particularly in terms of income, access to civil amenities and the quality of life of developing countries. Simultaneously it brings in its wake when it proceeds fast, and unplanned--a number of socio-economic problems. Urbanization from the geographer's point of view can be taken from three broad view points: (a) locational; (b) regional; and (c) spatio-structural. The locational approach offers a useful framework for generating behavioural and normative theories about city location, which in turn has significant implications for the spatial planning of emerging landscapes. The regional approach has two facets, i.e. analysis of the level of urbanization and various aspects of urbanization in the different regions, and examination of the rural urban fringe of the larger cities. The spatio-structural approach focuses on the intricate patterns of land use in residential, commercial and industrial areas. Thus it examines the spatial segregation of the city's population into zones, localities/sectors and sub sectors. The section below analyses the regional as well spatio-structural viewpoints in detail.

4.10 History of Urbanization in Pakistan

The Indian subcontinent shares with Mesopotamia and Nile valley, a long history of urbanization. The first phase of urbanization in the Indus valley is associated with the Harrapan civilization dating back to 2350 BC (Ramachandran, 1992). Many well-known cities of this time still exist today in the form of small mounds or ruins, such as Mohenjo Daro (Sindh- Pakistan), Harappa and Taxishilla[32] (Punjab- Pakistan), Hampi, Vijayanagara and Nalanda (India). Some other ancient and historical cities of Pakistan survive to this day as Taxila[33] , Multan and Thata. The history of urbanization in Pakistan (Burki, 1973; Khan, 1982), India (Ramachandran, 1993; Datta, 2006) and Bangladesh (Rouf and Jhan, 2011) reveals broadly three processes of urbanization at work in any given point in time and space. These processes are categorized as ; (a) social change through new social relationship among cities and between cities and villages; (b) Political order; and (c) alteration of economic base and attraction of migrants in search of livelihood and a new way of life. While thinking about urbanization of Pakistan, through a socio-cultural process, although a wide range of cultural influences have made their imprint- the Greeks, Iranians, Turks, Central Asians, Arabs and Europeans, three major socio cultural processes such as Aryanization, Persiananization and Westernization have had a major significance.

Political-administrative aspects of urbanization have also had a great history. Urban centres in Pakistan emerged, declined or even disappeared with the rise and fall of kingdoms. During British rule, many districts, tehsils and capitals grew fast under political influence. This process has not stopped after independence, and examples are the shifting of capital from Karachi to Islamabad, the interim officiating of Rawalpindi as capital, Abbottabad as, summer capitals of PaktunKhah, division of Karachi into five districts, and currently the upgrading of Chiniot, Nanakana Sahib up to the status of a district. The contribution of industries to employment, in fact is a major force attracting the rural people to the city. Thus the cities of Karachi, Lahore, Faislabad, Multan, Hyderabad, Gujranwala, Sialkot all emerged as big cities due to economic growth and attracted a large number of young people from the small cities and towns. Thus rural-urban migration in the beginning under push- pull factors played a mjor role in the growth of cities. Urban areas in need of manpower for their industrial and manfacturing units pulled in people from rural areas, who were un/under-employed due to farm mechanization. The rapid growth of big cities, has also caused them to expand into the adjoining rural areas in a haphazard and unplanned manner. These newly developed areas being outside the ambit of municipal taxes, having no urban facilities, but cheaper land rates, act as incentives for housing construction. This kind of suburbanization, after a few years put pressure on the cities to extend their municipal limits and include these areas. The current level of urbanization (42%) in Pakistan though not high by global standards is high in South Asia.

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[32] Near the present Taxila tehsil of Rawalpindi district

[33] An ancient but rapidly growing city and tehsil of Rawalpindi district

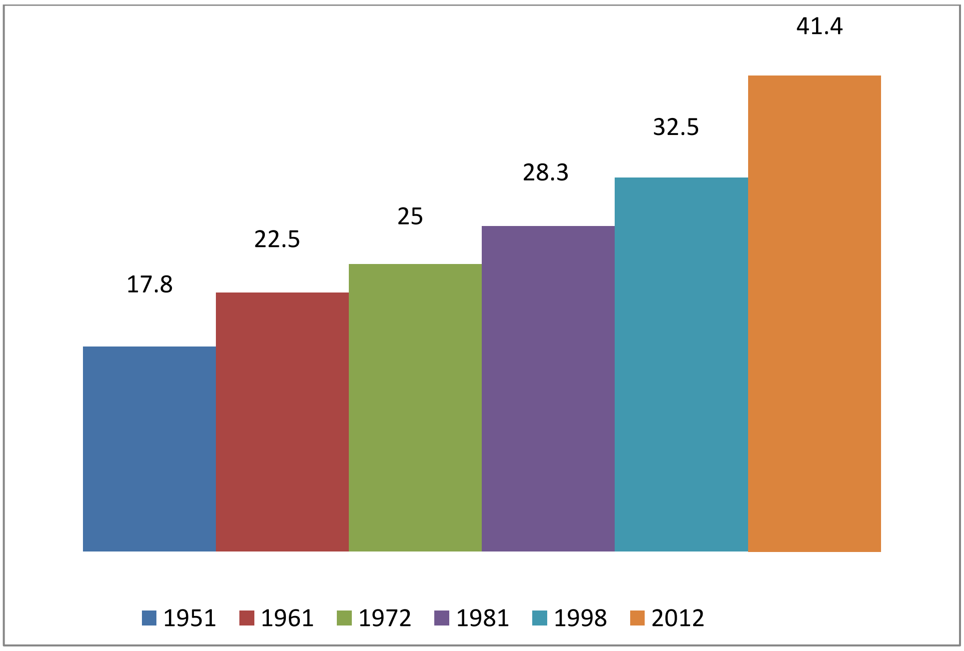
In fact the three most populous countries (China, Pakistan and India) of South Asia have been urbanizing very rapidly for the last three decades. The only difference now is that China has embraced and shaped the process, while India and Pakistan are still waking up to its urban realities and opportunities. Data showing the evolution of country's urban population growth of Pakistan since 1901 to date are presented in Table 4.10. The share of the total population living in urban areas in 1901 was 8.1 % which increased fivefold in the next hundred years. Figure 4.9 further shows that the share of urban population in the total population increased from 17.8 % in 1951 to 41.4% in 2012. In terms of absolute numbers the urban population of Pakistan increased from 6 million in 1951 to 75 million in 2012. Thus the increase in urban population after independence has been more than 12 fold in 66 years. Table 4.10 reveals that in the first quarter of the twentieth century the average annual growth rate of both urban and rural areas were almost the same, but thereafter the trends of concentration of population in urban areas increased. It is important to note that although the growth rate of urban areas has decreased to some extent from 1972 to 2012 (the study period), yet it is approximately four times high then the rural areas.

Table 4.10: Urban and Rural Population growth of Pakistan (1901-2012)

Year	**Population (000)**				**Inter-censal variations (%)**		**Average annual growth rate (%)**	
	Total	**Urban**	**% of UP**	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**
1901	16,576	1343	8.1	15,233	-	-	-	-
1911	18,805	1749	9.3	17,056	30.2	12.0	1.1	1.1
1921	20,243	1943	9.6	18,300	11.1	7.3	1.1	0.7
1931	22,640	2785	12.3	19,855	43.3	8.5	3.7	0.8
1941	28,244	4039	14.3	24,205	45.0	21.9	3.8	2.0
1951	33,740	6006	17.8	27,734	48.7	14.6	4.0	1.4
1961	42,880	9648	22.5	33,232	60.6	19.8	4.9	1.8
1972	65,309	16327	25.0	48,982	69.2	47.4	4.9	3.6
1981	84,254	23844	28.3	60,410	46.0	23.3	4.3	2.4
1998	132,352	43014	32.5	89,338	80.4	47.9	3.5	2.3
2012	180,000	74713	41.4	104,787	74.9	17.3	4.0	1.2

Source: Census of India, 1901a-1941a; Government of Pakistan, 1951a-1998a; Government of Punjab, 2012

Figure 4.9: Level of Urbanization in Pakistan (1951-2012)



Source: Government of Pakistan, 1951a-1998a; Government of Punjab, 2012

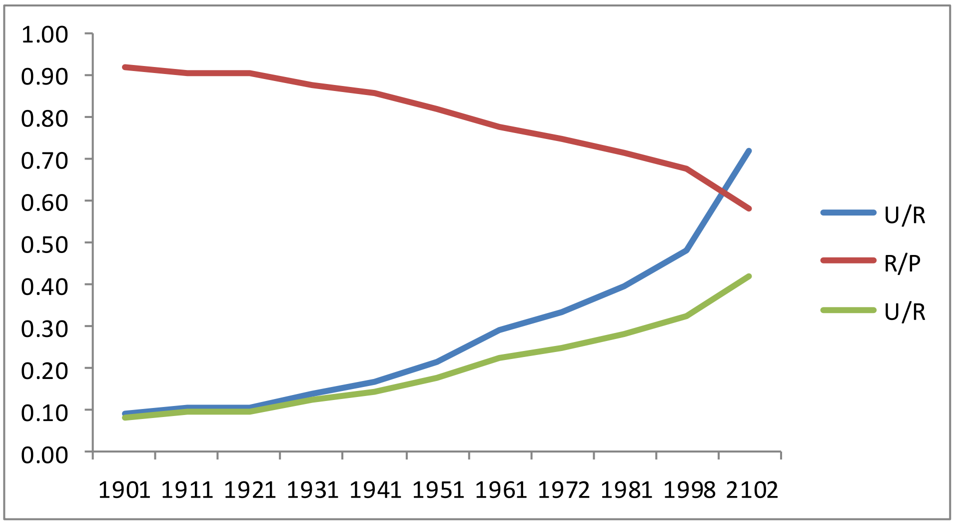
The tempo or pace of urbanization is commonly used to understand the process in a country over the years. A further look of the figures in Table 4.10 indicates that the tempo of urbanization over the years has never been uniform and has been fluctuating in different inter-censal periods. For instance, average annual urban growth rate declined from 4.9 per cent in 1972 to 4.0 per cent in 2012, but the rural growth rate also dropped substantially from 1972 to 2012. Because of fluctuations of the rural growth rate, the rural urban ratio dropped from 4.6 to 1 in 1951; 3.4 to 1 in 1961; 3 to 1 in 1972; 2.53 to 1 in 1981; 2.1 to 1 in 1998 and 1.4 to 1 in 2012, which consequently increased the level of urbanization over time as shown in fig. 4.9 above.

The level of urbanization is a relative measure, to find the number of people who live in urban areas. Urban ratio[34] (U/P), rural ratio[35](R/P) and urban rural ratio[36] (U/R) are used to measure the level or degree of urbanization in any area. Urban and rural indices range between 0 and 1. For instance if urban Index is 0, then it can be perceived that whole population is living in the rural areas, and 1 means that there is no rural population. Urban rural ratio is an index which measures the number of urbanities for each rural person in an area. Theoretically its upper limit will be infinite, when the rural population is zero. Fig. 4.10 describes the gradual trend of increase in per cent urban population from 8% in 1901 to 41% in 2012, and inversely a gradual decrease in rural

[34] (Urban population/Total Population)
[35] (Rural population/Total population)
[36] (Urban population/Rural population)

population from 92% in 1901 to 59% in 2011. The urban- rural ratio of 71 as measured in 2012 indicates that for every hundred rural areas there were 71 urbanities which clearly depicts that Pakistan is still in a process of urbanization.

Figure 4.10: Degree of urbanization in Pakistan (1900-2012)



Source: Census of India, 1901a-1941a; Government of Pakistan 1951a-1998a; Government of Punjab, 2012

The overall magnitude of the urban change can be gauged by the fact that from 1901 to 2012 the total urban population increased by 3.70% annually. The corresponding figures for 1972- 2012 are 4%. Such a massive growth in urban population, and overall, is unprecedented in the regions comprising Pakistan. According to the 2012 household census unofficial results, 75% of Islamabad District's population enjoys urban facilities. Being in proximity of Rawalpindi city, it has a great impact on the economy and urban patterns of Rawalpindi, Murree, and Taxila tehsils of Rawalpindi district. Rawalpindi and Islamabad are called the twin cities, with a large daily movement of people on both sides. Table 4.11 reveals another dimension of process of urbanization among various administrative divisions of Pakistan. Sindh is the most urbanized province having more than half of its population living in cities. In contrast Gilgit-Baltistan is the least urbanized.

The inter-censal annual urban growth rate (ICAUGR) of Baluchistan province has been fluctuating the most, followed by the Sindh province. During the period of 1998 to 2012, the Punjab province has been highest having the ICAUGR more than 4 %, followed by Kyber Pukhtunkhwa and Sindh provinces. The urban morphology of Pakistan is brought into sharp focus by the growth in the numbers of urban places in the country. There has been a considerable increase in the number of urban centres. In 1901 their number was 112 rising to 230, 315, 399, 424, and 515 in 1951, 1961, 1972, 1981 and 1998 census[37]. In 1998 the country had 56 urban centres having more than hundred thousand inhabitants, as compared to the corresponding figures of 9 in 1951 (Government of Pakistan, 1998a). In 1951 there were four cities whose populations were over one million, whereas this number increased to ten in 1998.

Table 4.11**:** Growth of Urban Population by Province 1951-2012

Province	**Census Year**	**Total Population (000)**	**Urban Population (000)**	**Urban Population (%)**	**Inter censual urban annual growth rate (%)**	**Urban/ rural ratio**
Balochistan	1951	1170	133	11.2	-	-
	1961	1354	228	16.5	5.5	4.6
	1972	2432	400	16.4	4.9	0.9
	1981	4332	677	15.6	6.4	1.0
	1998	6571	1516	23.3	4.9	3.4
	2012	8550	2137	25.1	2.5	2.7
Gilgit/Baltistan	1951	1330	94	7.1	-	-
	1961	1850	152	8.2	4.9	2.1
	1972	2490	252	10.1	4.7	1.8
	1981	2500	278	11.1	1.1	2.3
	1998	3180	433	13.6	2.6	1.6
	2012	3700	521	14.1	1.4	1.8
Khyber Pukhtunkhwa	1951	4563	502	10.9	-	-
	1961	5732	758	13.2	4.2	2.2
	1972	8392	1196	14.3	4.1	1.3
	1981	11061	1666	15.1	4.0	2.0
	1998	17745	2973	16.9	3.5	1.4
	2012	23400	4492	19.2	3.0	1.7
Punjab	1951	20648	3587	17.4	-	-
	1961	25463	5461	21.4	4.3	3.0
	1972	37611	9183	24.4	4.5	1.6
	1981	47292	13052	27.6	4.2	2.3
	1998	72585	22699	31.3	3.3	1.6
	2012	10560	40237	38.1	4.2	1.1
Sindh	1951	6054	1768	29.2	-	-
	1961	8374	3169	37.8	6.0	4.1
	1972	14158	5726	40.4	5.2	1.3
	1981	19029	8243	34.4	4.4	1.6
	1998	30440	14662	48.9	3.4	1.8
	2012	42120	481	51.2	2.8	1.9
Federal Capital Territory Islamabad	1951	94	-	-	-	-
	1961	119	-	-	-	-
	1972	234	77	32.9	-	-
	1981	340	204	60.0	11.4	1.9
	1998	799	525	65.6	5.7	4.3
	2012	980	720	73.5	2.9	3.4

Source: Government of Pakistan, 1951a-1998a; Government of Punjab, 2012

[37] No details available for last census of 2012.

Table 4.12: Share of urban population by size of the urban centres

Categories	Size of urban centres (persons)	Number of urban centres			Share in Urban population (%)		
		1972	1981	1998	1972	1981	1998
I	Million or more	2	3	10	27	39	51
II	500,000-999,999	4	5	3	15	15	5
III	200,000-499,999	4	4	13	7	5	10
IV	100,000-199,999	14	19	30	11	10	9
V	<100,000	377	393	459	50	31	25
All		399	424	515	100	100	100

Source: Government of Pakistan, 1972a-1998a

The above table shows that the share of million plus cities has increased in 1998, as compared to 1981 and 1972, due to the concentration of population into the major urban centres. The estimates of the provincial governments as detailed in the "Development Statistics 2011/12" of respective provinces show that the share of million cities in the total urban population has decreased to 45% in 2012 because of the faster growth rate of the medium sized cities such as Gujranwala, Quetta, Rawalpindi, Islamabad and Peshawar. Karachi alone contributes over 20 % in the national and more than 70 % in Sindh province's population. Lahore is the second highest city in population having a share of urban population 11.5% and 20% in National and Punjab Province urban population respectively. After Karachi the next five cities, i.e. Lahore, Faisalabad, Rawalpindi, Multan and Gujranwala, all belong to the province of Punjab and their share of urban population at National level is 11.5, 8, 6, 6, and 5.5 respectively. These five cities in total make approximately half of the provincial urban population. Table 4.13 shows the 4 city Primacy Index[38] of the largest and the second largest cities of the country from 1951 to 2012.[39]

The increasing ratio of index of primacy for Karachi (Table 4.13) from 1981 to 2012 indicates its rank as a primate city of the country, as next to it Lahore has almost half of its population. Lahore has been the primate city of Punjab province as during history, the total population of the next three cities have never been over or equal to it. But one notable thing is that in 1972, the Index of primacy was much higher for Lahore as compared to subsequent censuses. The reason is the increasing concentration of urban population in Faisalabad and Rawalpindi cities during 1981-1998.

[38] 4 City Primacy Index = the population of the largest city divided by the cumulative population of the next three largest cities.
[39] Based on estimates

Table 4.13: Index of primacy of Karachi and Lahore cities 1951-2012

Census year	Share in Urban population (%)		4 city primacy Index	
	Karachi	Lahore	Karachi	Lahore
1972	21.5	13.3	0.97	1.78
1981	21.8	12.4	1.07	1.14
1998	21.7	12.0	1.09	1.11
2012	20.3	10.9	1.10	1.07

Source: Government of Pakistan, 1972a-1998a; Government of Punjab, 2012

In the public mind, urban growth is usually attributed to natural increase and rural-urban migration. But it is in fact, due to three different sources i.e. net natural increase of the urban population, net rural urban migration and net reclassification through the annexation of towns into urban areas. Jones (1991), cited in Arif and Ibrahim, (1998) considers the international migration as the fourth component, having a considerable role in urbanization in some countries, such as Singapore, Hong Kong, Canada, and even in Pakistan[40]. Table 4.14 shows the contribution made by these three components to urbanization during the census years of 1972 to 1998. Although the dominance of natural increase has been seen during the all periods, the role of migration can't be neglected, particularly for 1961-1972.

Table 4.14: share of different components of urbanization (1961-1998)

Census Period	Natural increase (%)	Internal Migration (%)	Reclassification (%)
1961-72	68	24	8
1972-1981	78	19	3
1981-1998	70	20	10

Source: Government of Pakistan, 1961a-1998a

Due to the mechanization of farms, a considerable proportion of the uneducated population in the villages had nothing to do except to move into the cities, and to work there as labourers. This period of industrialization in Pakistan, therefore added a large number of unemployed agricultural youth to Karachi, Lahore, Faisalabad and Rawalpindi cities. Many were assimilated in the new

[40] An influx of illegal Afghan refugees has settled in the urban areas of Peshawar, Karachi, Rawalpindi, Islamabad, and Quetta.

industrial sector; however a considerable proportion remained unemployed. Some of them became involved in street crimes, and violence, due to the frustration of unemployment. Here I would like to quote John Reader on the beginning of cities:

> The first cities are said to have arisen from rural comminuites whose intensified farming practices produced surplus large enough to free craft workers and other specialists from working on the land. But it could have been other way around. Compelling evidence suggests that the rise of cities actually proceeded –and inspired- the intensification of agriculture. (Reader, 2004: 10)

Unlike Australia, Europe and USA, although the population of undivided India was less mobile, Punjab was the only province that gained a large influx of migrants throughout the pre-independence period, mainly due to the extension of canal irrigation and subsequent colonization. Besides the impact of irrigation, Lahore, being the capital of Punjab, and providing employment and educational facilities, and Rawalpindi being the gateway to northern areas, its pleasant climate and better educational facilities too, were two main factors which were major attractions for migrants (Kozel & Alderman, 1990).

The patterns of inter provincial migration after independence from the 1951 to 1961 census period reveals that the direction of the major stream of migrants during both decades were towards Sindh, from all provinces. This increased the urbanization rate of the province considerably above the others and subsequently Karachi and Hyderabad emerged as mega and big cities of the province respectively. Relatively fast industrial and urban development in Punjab after 1961 enabled it to make up initial losses. Though detailed discussion on migration is outside the domain of this thesis, an analysis of the situation from the latest censuses divulges that Karachi and Lahore due to their Primacy recorded a sustained flow, followed by Islamabad, Rawalpindi, Faisalabad and Gujranwala due to comparatively high level of economic and urban development. Khan (1987) argued that besides natural growth, immigrants also played an important role in increasing the size of these cities. She identified four categories of catchment of immigrants of these cities during the census period of 1951-81, Bongaarts et al. (2013) has witnessed the same pattern for Census 1998, as well. These categories are:

1. Karachi and Islamabad attract immigrants from all provinces
2. Lahore, Faisalabad, Peshawar, and Rawalpindi attract immigrants from three provinces
3. Gujranwala, Quetta and Multan attract immigrants from two provinces
4. Hyderabad and other medium size cities attract migrants usually from the province in which they are located.

If we see the district wise distribution of urban and rural population of Punjab only five out of thirty six districts have exceeded the national average of 41.3% and provincial average of 38.1 %, indicating that only a few large cities are responsible for the national and provincial average being as high as it is. These five districts contain the leading agglomerations of Punjab and Pakistan as well: Lahore (83.15%), Rawalpindi (56.1%), Gujranwala (51.1%), Faisalabad (42.9%) and Multan (42.5%). The trend is an indication towards the strengthening of the urban core of Northern and central Punjab.

Rouf and Jhan (2011) measured the urban functionality of the all urban centres of Bangladesh using an urban index. They used three variables, population size of an urban centre, literacy rate and area of the urban centres to determine the functionality level of urban centres. With some modifications, the researcher has devised an Urban Functionality Test (UFT) to classify the different urban centres of Punjab into different categories according to their role as urban. The criteria used to test how "urban" the different urban centres of Punjab are, as under

1. Population Size of the urban centre
2. Municipal Density Index
3. Proportion of Agriculture Population

The above UFT has been applied to all urban centres of Punjab up to sub-district level (tehsil) having population not less than 20,000. Following eligibility criteria were applied to the 135 urban centres having population above 20,000 and designated as urban in the 1998 census.

Thresholds considered for different categories are as follows.

1: Population size 50,000

2: Municipal Density Index (MDI), Person/ municipality area in km^2.

3: Agricultural population 50%

The abbreviations used are:

P = Population 50,000 or more

p = population less than 50,000 but not less than 20,000

M = MDI, 5,000 or above

m= MDI less than 5,000

A= Proportion of agricultural population less than 50%

a= Proportion of agricultural population more than 50%

The combination of these three aspects gives following eight possible combinations:

PMA, PMa, PmA, Pma, pMA, pMa, pmA and pma

Presence of all capital letters shows that the particular urban centre fulfils all three conditions, and presence of any small letter shows absence of that particular attribute. Table 4.15 summarizes that how 135 urban centres fall in different categories.

Table 4.15: Share of Urban Centres in Different categories

Category	Urban centres	Percent of total urban centres	Share of total urban Population
PMA	34	18	51
PMa	66	48	35
PmA	12	8	2
Pma	4	3	7
pMA	6	4	1
pMa	7	5	2
pmA	3	2	1
pma	3	2	1

Source: Government of Pakistan, 1998b

The above table shows that only 18. 5 of the total urban centres of Punjab having population of 50,000 and more were found to have less than 50% of their population engaged in agriculture, and more than 5000 persons residing within the municipal limits. It clearly showed that out of 135 centres only 34 were purely urban in nature. While almost half of the urban centres had their more than half of the population although living in the municipal limits of the centres, but were engaged in agricultural activities. 1 % of the urban centres although did not fulfil any of the above criteria, yet they were given the status of urban centres, which shows the political administrative aspects of urbanization discussed in the introductory section.

The results when applied to the study area of Rawalpindi, shows that only three urban centres of Rawalpindi district such as Rawalpindi, Wah and Taxila fall in the first category, while the remaining centres fall in the other categories. In fact more than 75% of the urban centres in category 1 comprised over 50% of urban population. The knowledge of concentration of urban population in urban areas is another measure which helps the urban planners to judge the fair utilization of the land and pressure on the urban services. Many geographers have used urban density to measure urban pressure. They have calculated the urban density ratio of urban population to total land. The author has modified this urban density by dividing the urban population by the urban area, and has named this index as the urban man-urban land ratio. The Urban Density Index of the province of the Punjab is higher than any province. The Urban density calculated for the whole province of Punjab is 1799. Taking this figure as threshold for the tehsils of Rawalpindi, Table 4.16 summarizes the urban pressure during the census year 1998.

Table 4.16: Distribution of Population and area of Rawalpindi by urban density of Punjab (1998)

Urban Density	% of total population above each category of urban density	% of total land above each category of urban density
1000	100	100
1800	91.8	89.3
2000-6000	95.07	73.77
6001-11500	72.85	49.77

Source: Government of Pakistan, 1998b

The above table shows that 98.8% of the population of the Rawalpindi district was living above the threshold of 1800 urban density index, covering 89.3 % of the total area and 73% of the population was living within the urban density Index of 11500 covering nearly half of the area. These measures show the concentration of urban population of the study area.

4.11 Urban Growth Trends of Rawalpindi

In 1901 census of population conducted under the auspices of the British Empire, approximately 10% of Potohar and 17% of Rawalpindi's population was recorded as urban. The corresponding figures for 2012 are 47% and 56% respectively. As discussed earlier, Rawalpindi, Islamabad, Wah (Taxila) and Jhelum are the four major urban centres of the Potohar region. Rawalpindi and Wah fall in the study area of district Rawalpindi. For historical comparisons we will look at the urban and rural distribution of population in the study area. The urban rural distribution of the population of Rawalpindi as recorded in the decennial censuses of 1901 and later years is given in Table 4.17. Taking the aggregative view of the Rawalpindi District as a whole, the urbanity level increased approximately fourfold during the 20^{th} century. Between 1901 and 2012, the study area's total population increased from 0.6 million to 4.5 million in absolute numbers. Thus incremental population was over 700 per cent. In the same period the proportion of the urban population to the total population increased 56%. The incremental urban population during the hundred years was 2.4 million. As evident from the Table 4.17, the study area's urban population increased steadily in every inter-census period, though the rate was not smooth. It even increased between the inter-census period of 1901-11, when there was a net decrease of 9000 people in the total population and 12000 people in the rural population, because of widespread epidemic diseases. Fig. 4.11 illustrates the urban and rural population differences during the last 110 years. For better perception of urban growth the period 1901-2012 is split into three sub periods 1901-1941, 1951-1972 and 1981 to

2012 (Table.4.18). Figure 4.12 compares the trends of growth of urban and rural population in different intervals of time.

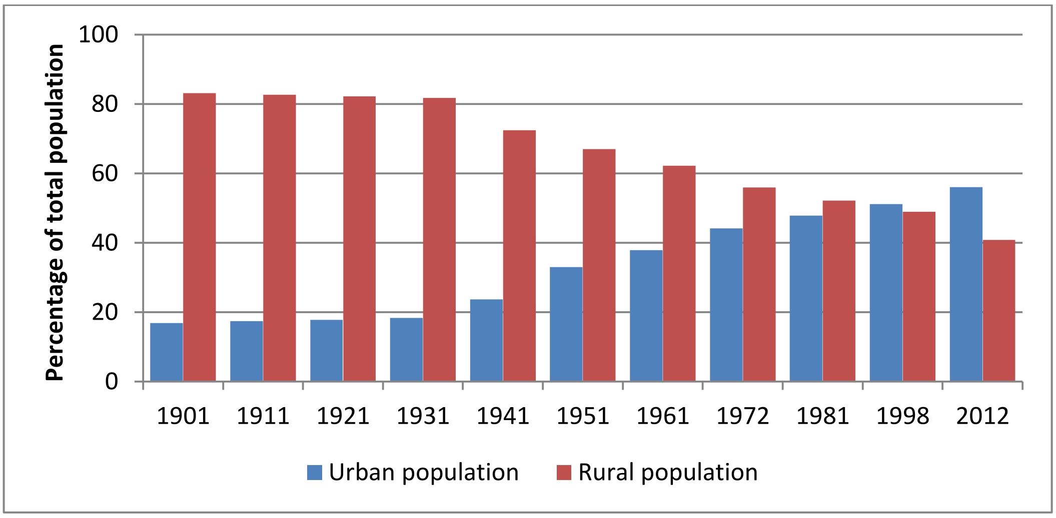
Table 4.17: Rawalpindi: Population Growth of Rawalpindi 1901-2012

Census Year	Population (in thousands)			Percentage of total Population		Decennial Variation			Average annual growth rate	
	Total	Urban	Rural	Urban	Rural	Total	Urban	Rural	Total	Urban
1901	559	94	465	16.8	83.2		-	-		-
1911	548	95	453	17.3	82.7	-2.0	1.1	-2.6	-0.2	0.1
1921	569	101	468	17.8	82.2	3.8	6.3	3.3	0.4	0.6
1931	634	119	515	18.8	81.2	11.4	17.8	10.0	1.1	1.7
1941	785	185	600	23.6	76.4	23.8	55.5	16.5	2.2	4.5
1951	873	299	574	34.2	65.8	11.2	61.6	-4.3	1.1	4.9
1961	1086	407	679	37.5	62.5	24.4	36.1	18.3	2.2	3.1
1972	1748	772	976	44.2	55.8	61.0	89.7	43.7	4.4	6.0
1981	2121	1015	1106	47.9	52.1	21.3	31.5	13.3	2.2	3.1
1998	3365	1719	1646	51.1	48.9	58.7	69.4	48.8	2.8	3.1
2012	4467	2501	1966	56.0	44.0	24.8	36.7	12.4	2.2	3.2

Source: Census of India, 1901-1941; Government of Pakistan 1951b-1998b;
Government of Punjab, 2012

Tables 4.17 and Fig. 4.12 depicts that the urban population growth rate during 1951-1972 was high as compared to other periods. Actually after the mid-fifties, an economic boom came in Pakistan which ostensibly accelerated the process of urbanization.

Figure 4.11: Proportion of Rural and Urban population in Rawalpindi (1901-2012)



Source: Census of India, 1901-1941; Government of Pakistan 1951b-1998b;
Government of Punjab, 2012

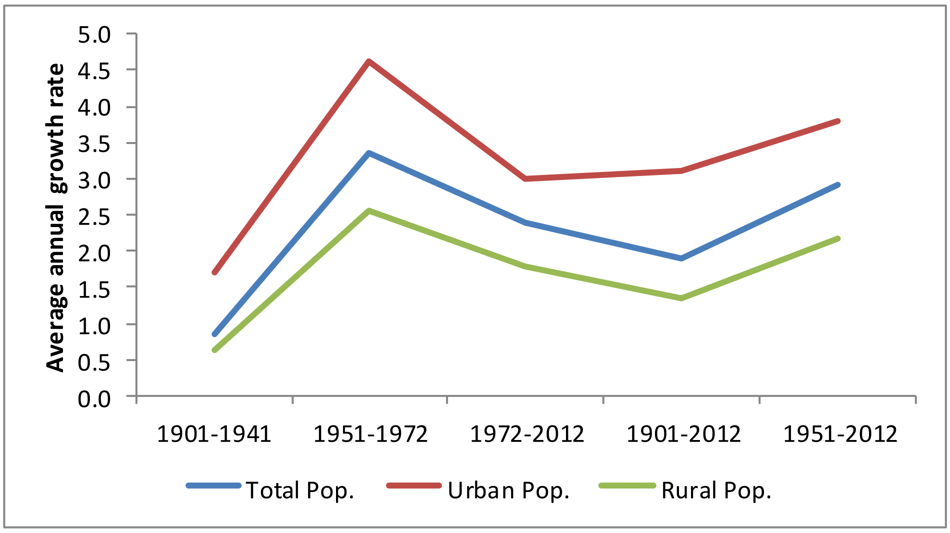
During the period of 1981 to 2012, the urban growth trends of the study area were steady, but were above 3%, which were more than the National, Provincial and Potohar's rates. During 1951-2012, the urban population of the study area increased almost eight fold, while from 1972 to 2012 it increased almost three fold. During 1981– 1998, an absolute increase of 700,000 people was recorded. While during 1998-2012, it is estimated that 782,000 people has further been added in the urban population of the study area. For a comparison purpose the urban and rural population profile of the study area in 1998 has been shown in Fig. 4.13 with the help of population pyramids.

Table 4.18: Rawalpindi Pre and Post-Independence trends of urban growth

Census period	Inter- censal variations (%)			Average Annual Per cent growth rate		
	Total Pop.	Urban Pop.	Rural Pop.	Total Pop.	Urban Pop.	Rural Pop.
1901-1941	40.4	96.8	29.03	0.9	1.7	0.6
1951-1972	100.2	158.2	70.1	3.4	4.6	2.6
1972-2012	155.6	224.0	101.4	2.6	3.2	1.3
1951-2012	411.7	736.5	242.5	2.8	3.7	2.1
1901-2012	699.1	2560.6	322.8	1.9	3.1	1.3

Source: Census of India, 1901b-1941b; Government of Pakistan 1951b-1998b; Government of Punjab, 2012

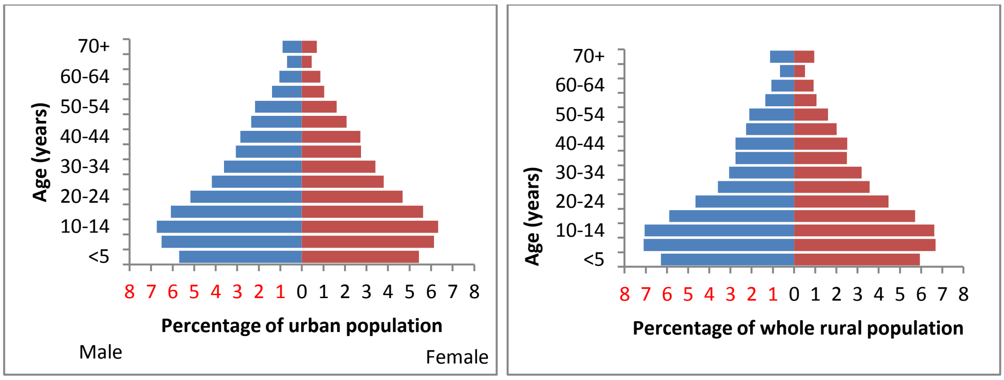
Figure 4.12: Comparison of total, urban and rural population growth rates of Rawalpindi



Source: Government of Pakistan 1998b

Figure 4.13: Profile of Urban and Rural Population of Rawalpindi District in 1998

Urban Rural



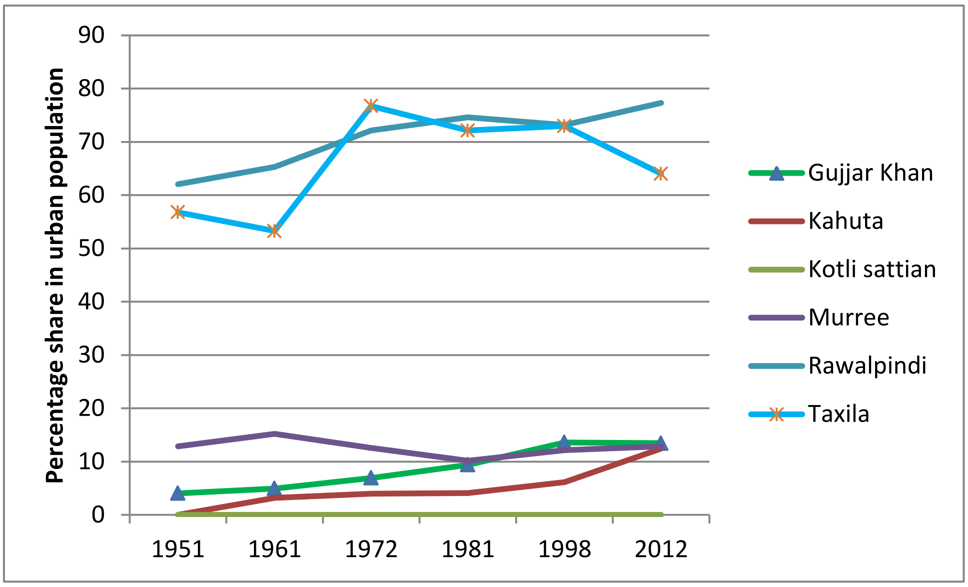
Source: Government of Pakistan 1998b

4.12 Urbanity in Tehsils

Three out of the seven tehsils, of which the Rawalpindi district comprise, were created after 1981 in different census periods; Taxila and Kotli Sattian in 1998, and Kallar Syeddan in 2004. The other four tehsils: Gujjar Khan, Kahuta, Murree and Rawalpindi were established since independence. The tehsil-wise growth is analysed over the 1951 to 2012 census period, because of the unavailability of the data before 1951. The share of urban population of each tehsil in the district's total population, since 1951 to 2012 is shown in Fig. 4.14. A marked difference can be seen among the different tehsils in the context of the concentration of urban population in different inter-censal periods. Rawalpindi tehsil as the headquarters of the district has enjoyed a higher degree of urbanization since 1951. Two persons out of three were living in urban areas of Rawalpindi since 1951. This ratio has increased in 2012 and in 2012 every three people out of the four were living in the urban area of Rawalpindi. Taxila is not far behind.

The rank size rule gives the balanced system of city size distribution, characterized by uniformity and smoothly increasing size of settlement in hierarchy. Ali (2003) applied the rank size rule to all of the urban settlements of Potohar for the years 1951-1998. He noted that the settlement system of Potohar is characterized by the over-dominance of Rawalpindi and Islamabad. The results he discussed are similar to this study

Figure 4.14: Degree of Urbanization in Tehsils of Rawalpindi



Source: Government of Pakistan 1951b-1998b; Government of Punjab, 2012

In the present study, the dominance of Rawalpindi tehsil over the all other tehsils of the district has also been observed, which shows a disproportionate rate of development with respect to other tehsils of the district. In fact the other tehsils of Rawalpindi are not developing fast, only due to their proximity to the big cities of Rawalpindi and Islamabad. Here the question arises, why Wah of tehsil Taxila is urbanizing so fast, while it is nearer to Rawalpindi than the other tehsils. The answer to this question is first the presence of heavy industry in Taxila tehsil, secondly comparatively low rates of urban land, and thirdly low rents of the houses attracting a lot of people to temporarily establish themselves living at Taxila and finally preparing to shift to Rawalpindi Islamabad in near future. For instance during the field survey the question of residing in Taxila instead of Rawalpindi, to those who had migrated in Taxila during the last ten years were asked, more than 80% were of the view that their final destination is Rawalpindi. They stayed committed that when they will be able to earn enough money, they will move to Rawalpindi /Islamabad.

There are number of reasons that Rawalpindi is developing into the biggest town of the Potohar as well as the Punjab. Some are:

- It is located on the Grand Trunk Road, and Motorways M1, M2 and M3
- Presence of almost all civil and military offices in the Rawalpindi tehsil contributing to the inflow of population from all provinces
- Its own proximity to the federal capital

Two city primacy index calculated for Rawalpindi and Taxila tehsils (Table 4.19) in comparison to other urban centres located in all other tehsils, reveals that it had shown high primacy in the early years with respect to the urban centres next to it, but in 1972 to 1998, the fast growth of Wah city of Taxila, its primacy decreased, but in 2012 it has again emerged as a city with a high primacy index.

Table 4.19: Indices of Primacy for Rawalpindi and Wah cities

Census year	Urban population (%)		2 city primacy Index	
	Rawalpindi city	Wah	Rawalpindi	Wah (Taxila
1951	62.1	56.7	5.01	2.2
1961	65.2	53.2	5.5	2.1
1972	72.17	76.7	4.1	2.2
1981	74.6	72.1	3.8	2.7
1998	73.1	73	3.9	2.5
2012	77	68	4.9	2.5

Source: Government of Pakistan 1951b-1998b; Government of Punjab, 2012

The following assumption can be derived from the above table of primacy index. Rawalpindi is since expanding very fast, therefore neither of the other urban centres of its other tehsils is able to match the pace of Rawalpindi, nor are new urban centres developing. Instead the peri urban areas are being engulfed by Rawalpindi. Let's unlock the environmental and social potential of the urban rural fringe by studying the changing population patterns of nearby villages/mauzas during the last censuses. It will help to measure the fragmentation or scattered development in the village.

Each district in Pakistan is divided into tehsils. These tehsils are further subdivided into Qanungo Halqas, then into Patwar Circles and Villages/Mauzas. The basic unit of administration in Pakistan is the "Mauza". The area of each mauza is properly demarcated, measured and recorded in documents in the revenue department.

Currently the District of Rawalpindi is divided into seven tehsils, 26 Qanungo Halqas, 271 Patwar Circles, and 1164 Mauzas. The Census organization of Pakistan records the population up to mauza level. This population statistics of mauzas has helped the researcher to use these mauzas as reference data in analysing the satellite images. Here in this section population analysis of Mauzas of Rawalpindi tehsil (Stratum 3-chapter 6) in 1998 and 1981 censuses has been made. In 1998, the rural population of Rawalpindi was 1.6 million as compared to 1.7 million urban populations, making a total of 3.3 million.

The evidence of population growth in the peri-urban and rural areas comes from the internal pattern of population change given by the percentage increase over the preceding census and increase/decrease in the densities at mauza level. According to 1998 census data, the average size of the population of mauzas in 1998 was 1100 persons, whereas the average size of the area of the mauzas was 3 km^2. The average density of population of the mauzas was 366 persons per km^2. Figures 4.15 & 4.16 shows the population size of mauzas of Rawalpindi tehsil in 1981 & 1998. It is pertinent to mention here that there were gaps in the reporting of population in some mauzas. For instance Rakh Banga, Rakh Pindi Ranjha,Rakh Doongi North, Rakh Doongi South,Rakh Idiala,Rakh Takhat Pari,Chak Azimullah Khan, Rakh Banda, there were no figures in the 1981 Census. Likely in 1998 census, the population figures for Narhal, Ferozi and Burji were missing. Considerable variability characterizes the spatial pattern of population growth. Of the 303 mauzas, 270 recorded increases of their population and 33 of them registered decreases. The percentage increase ranges from as little as 5% to as high as 1135.2 %.

Figure 4.15: Population of Mauzas of Rawalpindi district in 1981

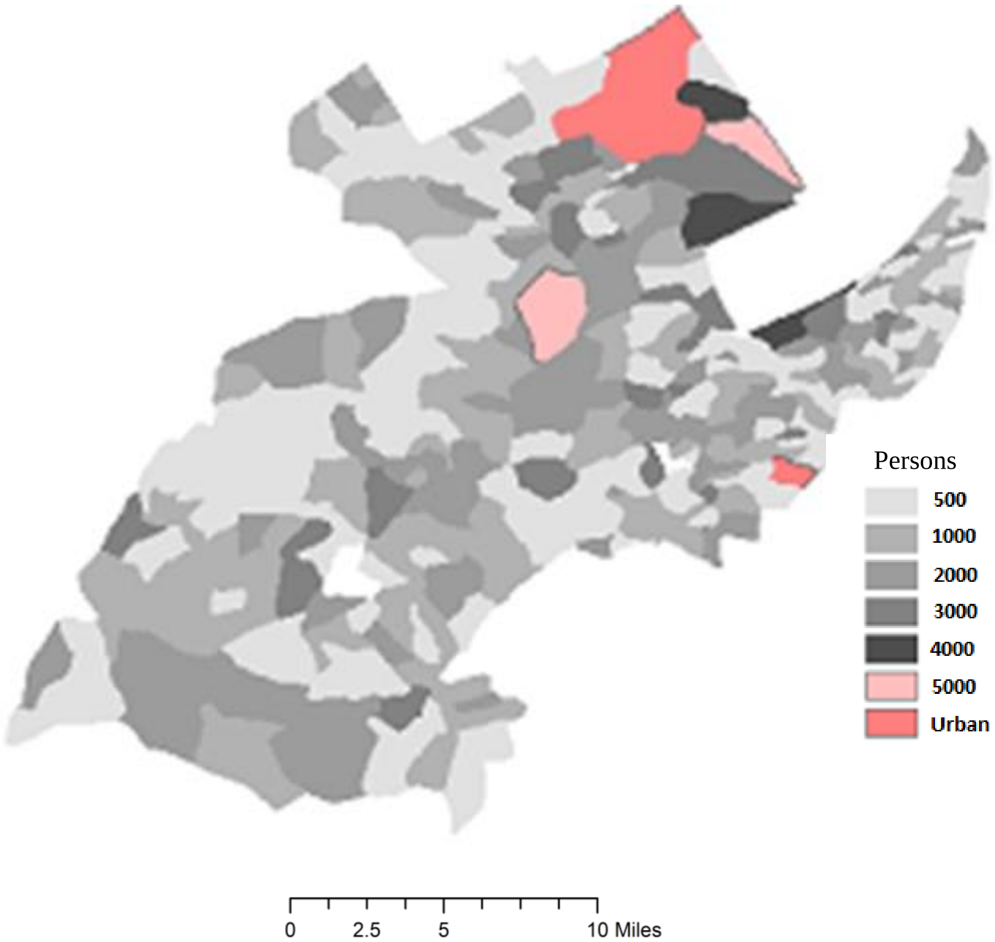
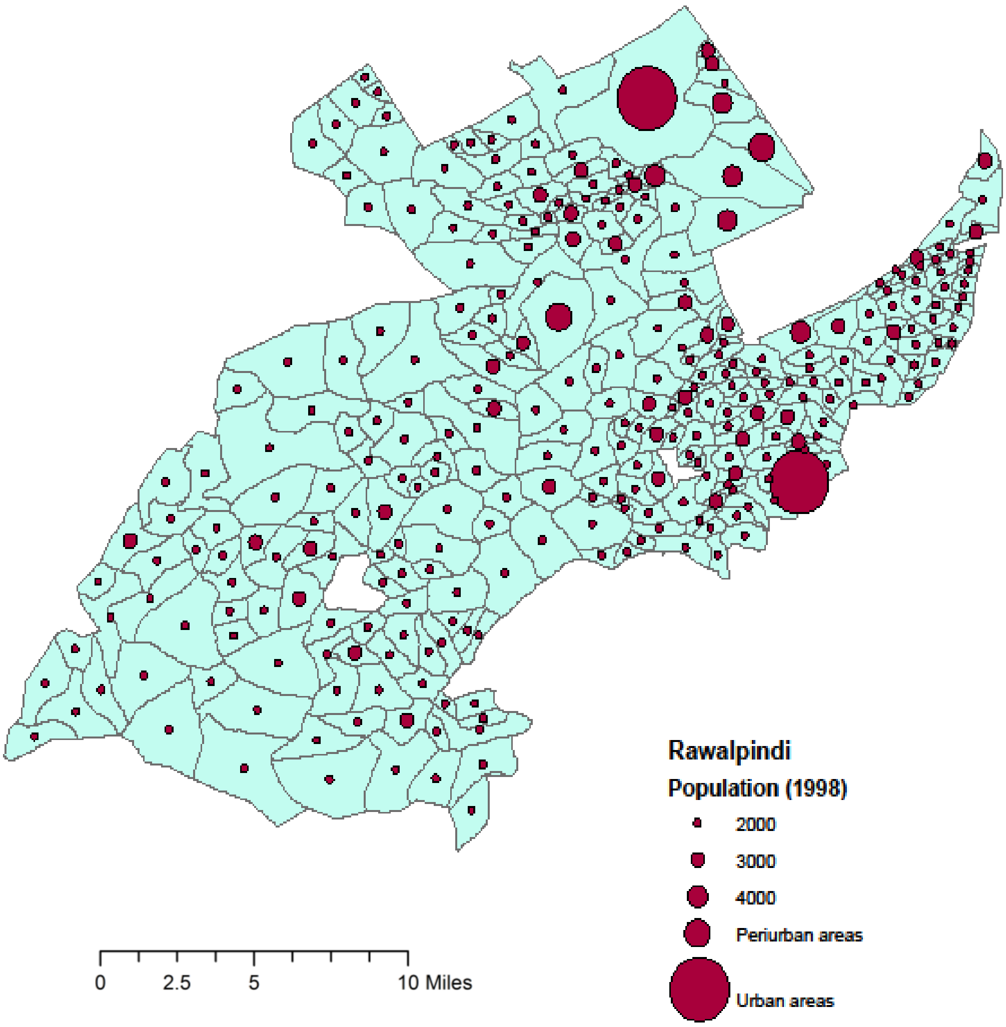
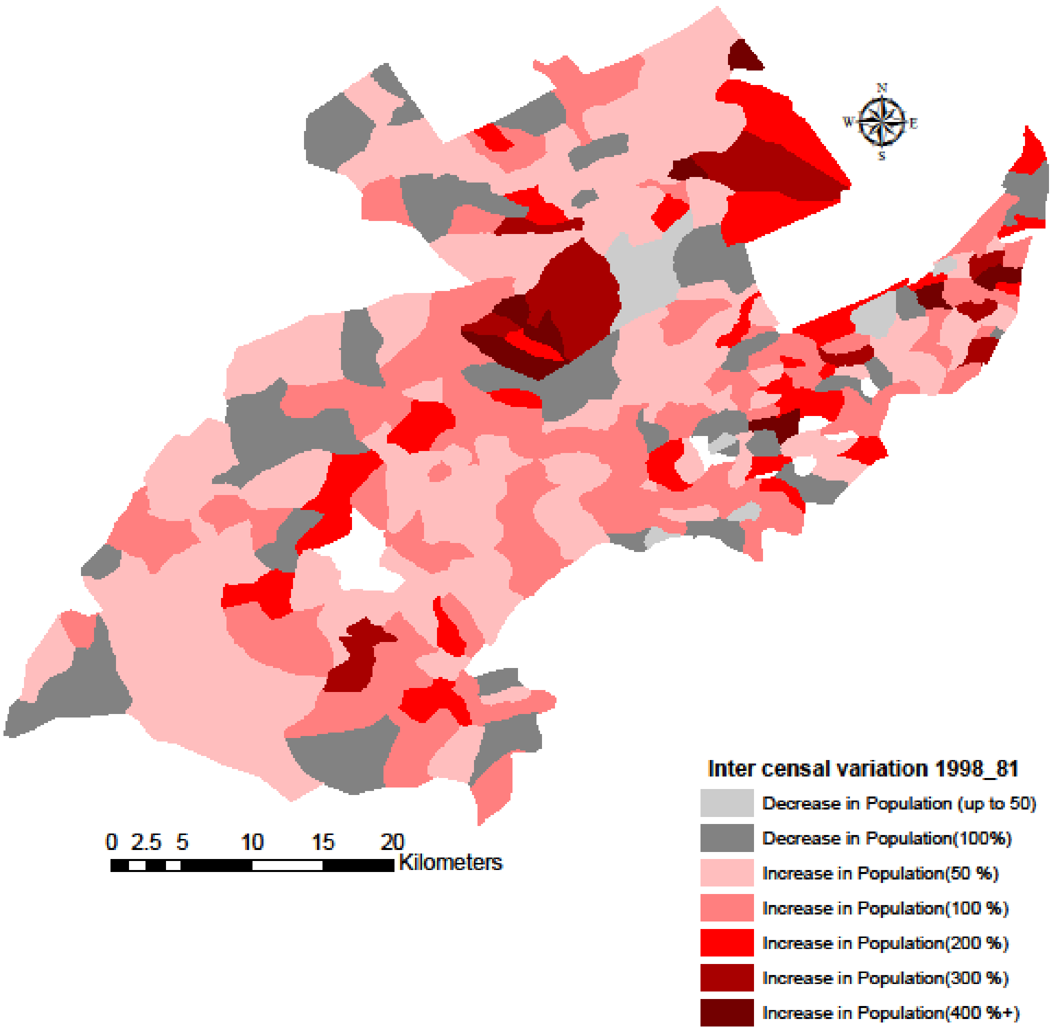


Figure 4.16: Population of Mauzas of Rawalpindi district in 1998



The coefficient of variation of percentage increases in 277 mauzas was 188 % and average per cent increase was 146.6. Figure 4.17 shows the inter-censal variations in the population of mauzas of Rawalpindi from 1981 to 1998. High percentage increases exceeding the average were recorded by those mauzas which had small populations in 1981, but were later affected by urban expansion and development. Most of these mauzas represented, as they still do, what may be regarded as the rural-urban fringe, and may be next to be treated as urban areas in the next census. Those mauzas which have either shown low percentage increases or decrease in their population during the inter-censal period 1981-98, are mostly those which are far from the urban areas and practising agriculture, but have limited prospects for higher agricultural development. Due to migration of families of young people who were already working in some other areas from those mauzas which were far from urban centres, the population of these mauzas decreased considerably. That’s why in 1998, the population of some mauzas decreased instead of increasing.

Figure 4.17: Inter-censal variation of population of mauzas of Rawalpindi (1981-1998)



The spatial pattern of population growth of these mauzas has been accessed by applying three variables: (a) density of population of mauzas in 1998, (b) Inter-censal variation of population during 1981-1998, and (c) distance from the nearest urban centre. On the basis of the following threshold of these variables demographic functionality and encroachment of urban areas into these mauzas has been analysed.

Variable 1: Density of population

X = over 200 persons/km^2

Y= between 101 to 200 persons/km^2

Z= less than 100 persons/km^2

Variable 2: Inter-censal variations (1981-1998)

x= over 200 %

y= between 101 to 200 %

z= less than 100 %

Variable 3: Distance from the nearest urban centre

x_1 = less than20 km

y_1 = 20 to 30 km

z_1 = above 30 km

Each Mauza has been differentiated in terms of the above categories to which it belongs and designated by notional symbols described above. Twenty seven types have been recognized. These are Xxx_1, Xxy_1, Xxz_1, Xyx_1, Xyy_1, Xyz_1, Xzx_1, Xzy_1, Xzz_1, Yx_1, Yxy_1, Yxz_1, Yyx_1, Yyy_1, Yyz_1, Yzx_1, Yzy_1, Yzz_1, Zxx_1, Zxy_1, Zxz_1, Zyx_1, Zyy_1, Zyz_1, Zzx_1, Zzy_1 and Zzz_1.

On the basis of the above twenty seven classes, all 303 mauzas of Rawalpindi tehsil were further divided into following four categories

I: Urbanized

II: Semi –urbanized falling in rural urban fringe

III: Agricultural regions

IV: Remote non-agricultural regions

The above results were used for collecting training and test samples from the study area and further utilized during the classification. The study of population analysis at mauza level helped in the following chapters to identify the regions with rapidly changing land use.

4.13 Conclusion

There is wide variation among the districts of Punjab as far as population is concerned. The average annual population increase of Punjab in 1901-1951 was 1.01 %, whereas between 1951 to 1972 and 1972 -2012 it was 1.6 and 2.3 % respectively. Potohar region‘s share of population in 1998 and 2012 was 5.6 and 5.3% respectively. It ranked fourth after the three provinces of Punjab, Sindh and Khyber PakhutunKhah, which had 52 %, 23 % and 14 % of population respectively. In contrast Baluchistan, the largest province by area has the least population i.e.5%. Rawalpindi shares 2.45 % of the national’s total population and nearly half of Potohar’s. The British penetration into the Potohar region in the middle of the nineteenth century gave a boost to the development of the region. The construction of roads, cantonments and rail stations had a substantial effect on the growth of the population.

Rawalpindi district showed the highest density of 845 persons/ km^2 in the region, however among its own tehsils there were large variations. Taxila is densely populated town since 1972, having more than the density of the headquarters District and tehsil of Rawalpindi. The density variations also reflect topography and development level. It is positively associated with the level of development and the availability of social services. Population pyramids give an overall picture of broad based age structure. The young age group, below 15 years of age constituted more than 37.5% of the total Rawalpindi's population , which is different to the national figures but close to that of Asia (38.2 %). The adult population in 1998 accounted for 46.8 %, followed by 6.5% of old age group (60+). This trend shows high fertility and a relative decline in mortality.

There have been seen marked disproportions of gender ratio between Potohar and Rawalpindi district and among the tehsils of Rawalpindi, which support the view that immigration to urban areas was male specific. However, this trend of preponderance of males over females has started declining in the last two decades.

During the last four decades urban population has shown a rapid increase. The urban population of Pakistan increased from 16.3 million in 1972 to 74.5 million in 2012 showing the five-fold increase. The urban population of Rawalpindi increased from 0.7 million in 1972 to 2.5 million in 2012 showing inter-censal variation above 350 %. The average growth rates of the four big cities of Potohar, including two from Rawalpindi district (Rawalpindi & Wah) remained as high as 8.7 %. During the last century Rawalpindi remained the second most urbanized district of the Punjab, and top most district in the Potohar region followed by Islamabad and Wah. Among the Tehsils Rawalpindi tehsil is the most urbanized followed by Taxila and Gujjar Khan. Kahuta tehsil was not urbanized since 1961 and Kotli Sattian tehsil is still not urbanized.

The degree of urbanization of Rawalpindi district is comparatively higher than the other thirty six districts of Punjab. It is only less than Lahore. Due to topography and strategic position two of its tehsils are either un-urbanized or less urbanized; otherwise it could have been the most urbanized district in Punjab, even leaving Lahore behind.

The distribution pattern of urban localities shows that Rawalpindi tehsil is the primate city, and Wah is still much behind it. This pattern also shows that due to the disproportionate rate of urbanization in the potohar region in general, and Rawalpindi district in particular, not so many urban centres have been developed during the last many decades. However the population of the peri urban areas is increasing rapidly. The population analysis of mauzas further helped to understand the growth of population at micro level.

5 UNDERSTANDING LAND USE CHANGE THROUGH QUALITATIVE METHODS

Standing in front of building of "Survey of Pakistan" Roshan Ali, a 55 year old ex-farmer of Dhoke Kala Khan, raised his finger sadly towards the "Ali Plaza"; which was recently built on his land. He then explained that just ten years ago, there were his green fields of wheat, maize, and sunflowers. But now ---- (taking a sigh after a long pause, he said), I'm searching the fresh air. He continued to say that till 2000, he was living happily there with his six sons, three daughters and a wife. They were practising agriculture day and night and earning their living. They were very happy, but one day, there came a contractor (city builder) who offered to buy their agricultural land at good price. His sons were trapped, and forced him (Roshan) to sell his land and to shift into the nearby city, to start a garment business. Within a year his family was scattered. Two sons shifted to Karachi, one to Lahore, and two to Faisalabad in search of jobs or business opportunities and at the time of the interview he was living in a small house with his wife, two daughters and a younger son. His money was quickly running out, and he was scared how he will survive in future, as he needs money to marry his daughters and sons. He started crying saying, "alas, why didn't he act on the advice of his father", who had said "Don't cut the fruit tree, but eat only its fruits". Later when I showed him the region around "Shamshabad" in the classified image of 1998, he cried saying "yes these were my fields". I told him that I'm also an eye witness, as in my childhood I played hide and seek there with my cousins.

5.1 Introduction

Land use land cover change is determined by a complex interaction between human and biophysical environments. Therefore in order to understand biophysical and social interactions and the multiplicity of land use/cover patterns, a methodological pluralism demanding multiple scales of investigation spanning both quantitative and qualitative aspects is necessary.

In fact the field investigations, especially qualitative data, provide insights into multiple meanings of land cover change, which remote sensing data alone can't provide. For example the remote sensing maps tell us that the decrease of the "canopy cover" at first glance could be considered an indicator of success, but participant observation and interviews with the local community led to a conclusion that decrease in canopy cover has been due to the builders' efforts who, after buying the forested land, cleared the trees for the future building of a residential colony. Now the story is told on the ground and the sky both, which explained the phenomenon that is driven both by ecological and social factors.

This chapter deals with the social science element of this research, which complements the remote sensing analysis. Here I have used qualitative methods such as interviews, focus group discussions, and participant observation in order to understand the land use/land cover change in the past. This chapter is about my fifth objective namely ”*Qualitative data will be used to gain insights into the people, attitudes, behaviours, value systems, concerns, motivations, aspirations and life styles”.*

The field work that I carried out in two slots (25 June 2010 to 17 October 2010 and 15 March 2011 to 15 May 2011) consisted of a series of interviews from local inhabitants and government officials. During the field work I travelled extensively, covering the whole area of the district, staying in urban, peri-urban and rural areas, and spending multiple nights with local people in order to become part of their culture. During “Participant Observation” I walked around and talked with people in both formal and informal ways. In sum, my interviews with the key informants, scheduled focus group discussions (without any discrimination of gender, age, and social status), and ground truthing through participant observation are the main focus of this chapter and form the core of the qualitative mixed methods I employed in understanding the urban expansion and land use patterns of the area.

Rawalpindi’s land use and land cover changes are complex phenomena that operate across multiple scales, and this chapter will demonstrate how multiple qualitative methods can be used for their investigation. The basic aim is to employ the qualitative methods to gather data on the mechanism and meaning urban expansion and land use, and the people’s responses and perceptions regarding urban governance and planning policy. Central to all of my research objectives are two important components. First is the concept of multi-temporal satellite images and second is the usefulness of bridging between human and natural systems through the use of multiple methods (Turner, 2003), the aim being a matter of “socialising the pixel and pixelizing the social” in land use-land cover change (Fox, 2002).

This chapter discusses how the researcher got responses from the people while living with them and then how he used this ethnographic data to understand the tempo of urbanization and land use /cover change during the last 40 years, and how census data provides supporting witness. After a brief introduction, the second section describes how the different qualitative methods were utilised in the field. It throws light on utilising the field maps and mauza information for qualitative data analysis. The next section describes the results derived from the qualitative methods to understand the urban expansion, loss of agricultural land and deforestation in the area. It describes the view of the local people and government both, in terms of the main issues of the study area and urban expansion and land cover change. The last section throws light on working with the remote sensing and qualitative methods together.

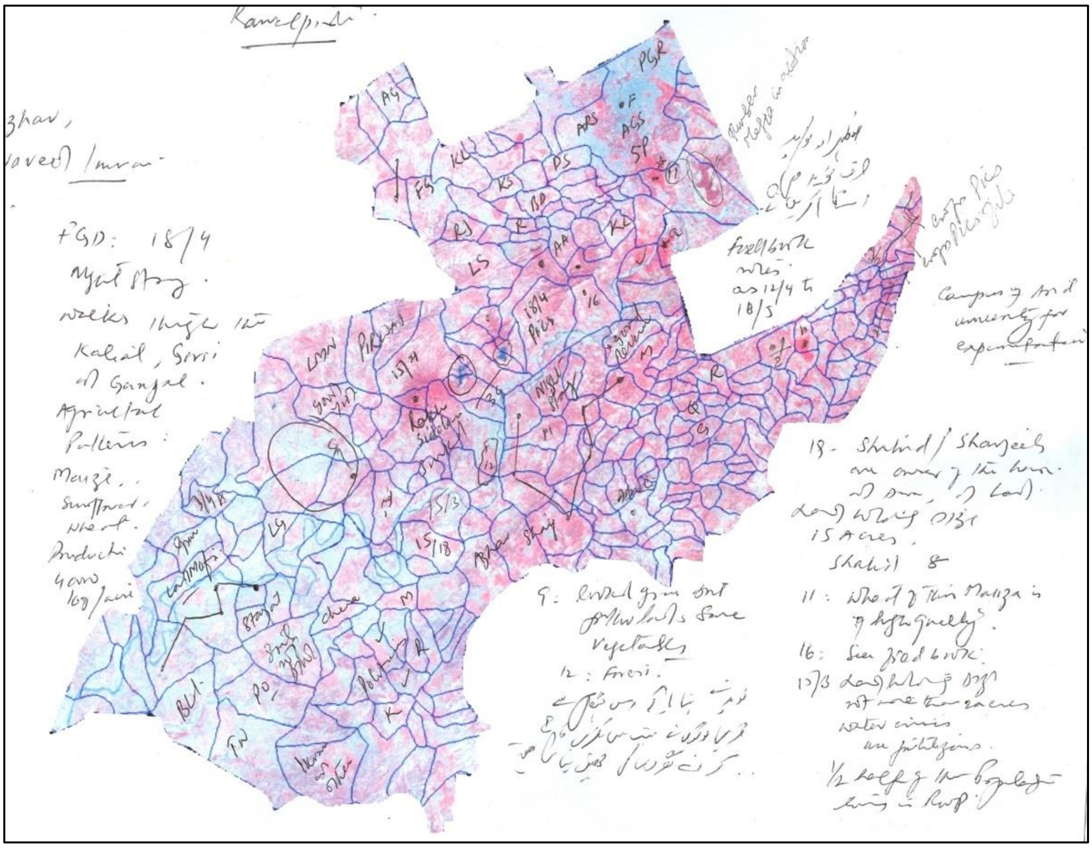
5.2 Utilizing Qualitative Data

This section concentrates on the details of the specific qualitative data I utilised to fit the needs of my research and the research context. Before starting the field work, as agreed with my supervisors, I planned to primarily gather the data through semi structured interviews with the key policy-making officers of the district and provincial government who were responsible for the implementation of the development plans and their amendment (where necessary) as per the demands of the masses. Besides conducting these interviews, I aimed to collect the information through group interviews, i.e. focus group discussions. I almost remained as per my plan, except that in addition to above I also conducted some semi-structured interviews with some prominent people, such as retired civil, military, government and semi government officers, and retired university/college/school teachers, who had either served in or lived in the area for a long time. I got very good responses from these people, as neither were they in a hurry during the interview, and nor did they want to hide anything or take a government point of view. My long stay in the field generated great curiosity in me and gave me an opportunity to collect the data day and night through interviews, sporadic observation, transect walks, participation observation and public participatory GIS methods.

Using feature identification and interpretation techniques, before going to field work, I developed an interpretation chart to aid the identification of each land feature clearly, which was further used as the basis for image interpretation with other sets of data. I also prepared a research field map of every stratum/tehsil to record events and carried it during the whole field survey. In fact the image identification chart and the research field map helped me a lot, while interviewing, and during focus group discussions, observation, and transect walks. Figure 5.1 is an example of a “Research Field Map” which was prepared by overlaying the mauza map on the Landsat TM 2010 of Rawalpindi tehsil.

I usually carried these maps with me whenever I went to the field, and used them for marking and writing notes. I usually marked the places that I noticed anything interesting or got a special impression. I also marked the places that I took pictures and recorded audio clips. Coming back from the field, my research field map shows all the locations that I collected various types of qualitative data, and it has been a very helpful tool especially when I added the information to the GIS. I also marked the places and times where and when I held different FG Discussions. The author concludes here the each method used during this process of qualitative data collection, generated something new to the research and therein lay the robustness of his strategy.

Figure 5.1: Field map of Stratum 3 (Rawalpindi tehsil)



Source: Author

5.2.1 Utilizing Mauza Maps for Qualitative Data analysis

Pakistan’s revenue system involves a hierarchy of districts which has also been adopted by the census organization for the identification of houses and the collection of population data. Each district is divided into tehsils which contain municipalities and villages. These municipalities are further divided into Patwar Circles. Each Patwar circle is further divided into Union councils and union councils into mauzas. Thus Mauzas are the smallest units, but they may contain many hectares of land having a large number of dwellings. Figure 5.1 is an ideal example of a mauza map of the Rawalpindi district. Some Mauzas are small and some are large, and the shape of the mauzas is not uniform, reflecting local topographic features and size of land holdings. Each mauza is drawn on a white cloth called a ”Latha” map showing the landholdings and subdivision of land holdings. The record of these land holdings are kept in a book called a “Khasra Gardawari[41]”. Every plot or land holding is marked with a number. Since plot level study is out of the domain of this thesis we will discuss the developing data sets at the mauza level only.

[41] Description of Khasras - Khasras is local name for each land holding.

For integration all the information from the primary, secondary sources up to mauza level, comprehensive data sets for each mauza were developed. All of these mauza boundaries have been entered into a GIS, along with the qualitative data gathered from the field, and the analysis of images and qualitative data has been carried out at the mauza level. In fact the most important thing was to develop data sets as GIS attributes at the mauza level, and match the qualitative, census data at mauza level with the geo-referenced images. For instance, Rawalpindi tehsil is divided into 309 mauzas, (Fig. 5.1), I collected field and census data for population, household size, land holding size, of each mauza for 1972, 1981, and 1998 censuses, and based on each attribute table, a number of maps were drawn. The information interpreted from image data was also added to the GIS data base of the mauzas. For example several types of information, such as the location of settlements, forested plots, land cover types, and water bodies, was extracted from the RS images up to mauza level. Table 5.1 illustrates the basic database structure and attributes in GIS of Mauzas of Rawalpindi district. In short all the information/data gathered during the field survey was added as attributes of GIS, and with the help of these databases, an in-depth understanding of the land cover change was monitored, evaluated and the local complexity of land and its interaction with population was assessed.

Table 5.1: Basic database structure and attributes in GIS for Rawalpindi Tehsil, in this instance for 1981 and 1998

Fields	**Value/Class/Name Example1 of 309 Mauzas**	**Value/Class/Name Example 2 of 309 Mauzas**
Mauza_name	Mohra Phephra	Dhulial
Qanoongo Halqa	Chaklala QH	Basali QH
Patwar Circel	Katarian	Dhulial PC
Area_km²	7.32	3.12
X_cord	314437.96	325427.80
Y_cord	3721462.07	3719992.50
Plots_Latha	2012	3121
Population_1981	14020	4000
Population_1998	32300	7020
Houses_1981	1300	500
Houses_1998	2700	900
Major_LU/LC_1981	Residential and agri	Agricultural
Major_LU/LC_1998	Residential	Mixed_agri_resi
Density_1981	1912	359
Density_1998	4723	629
Av_household_1981	6.2	7.5
Av_household_1998	5.3	8.2

Land_ value_1981_Rp/272Ft	Rs. 100,000	Rs. 40,000
Land_ value_1998_RP_272Ft	Rs. 400,000	Rs. 300,000
RDA_limits_1981	yes	No
RDA_limits_1998	yes	yes
MP_1981	7560	2459
FP_1981	6450	1541
MP_1998	16400	3816
FP_1998	15900	3204
Dist_city	8	34
Agri_pop	<40%	>50%
ICV_1981_1998	128.57 %	75%
AAGR_1981	4.9	3.3
AAGR_1998	5.1	3.5
Wheat_ yield_acre_1981	120Kg	210 Kg
Wheat_yield_acre_1998	NA	170Kg.

Source: Image interpretation, and Field survey

5.2.2 Individual Interviews

For this study, it was important to develop a conceptual connection between the current activities that influence residential development and historical events and processes. For this I utilized the richness of oral narratives to understand the roots of the socio-spatial differentiation from the point of view of the government planners and organisers responsible for the development and betterment of the people and area. During each interview with the key officers/ informants, the researcher began with an informal introduction and a brief explanation of the purpose of the activity and what was expected of the participant. Upon obtaining permission to conduct the interview, a statement of confidentiality was read to assure the participant of full rights as far as privacy was concerned. A semi-structured interview was conducted following a checklist of items or interview guide of sorts in which open-ended questions were listed (Appendix 5.1)

Issues under discussion with the key informants revolved around local histories of urban expansion and land use; perceptions of land use and land allocation; perceptions and history of residential development; historically persistent local issues including drinking water and sewerage problems; the evolution of the town; lived experiences, and many other related issues which are discussed in the results. Fourteen interviews were conducted with key officers of the district administration serving at Gujjar Khan, Kallar Syaddan, Kahuta, Kotli Sattian, Murree, Rawlpindi and Taxila tehsils in various capacities. The principal officers were the District Coordination Officer (DCO), the Assistant Commissioners (AC), officers from forest department, officers of the Rawalpindi Development Authority and Murree Development Authority, Housing and Physical Planning, NESPAK, the Census Organization of Pakistan, the Water and Sanitation Agency (WASA), and Pakistan Electric Power Company (PEPCO). Five interviews were also conducted with the top bureaucracy of Punjab province having the ranks of Secretary of the Ministry of Housing, Urban Development and Public Health Engineering, Secretary Agriculture, Secretary Population Welfare, Secretary Communications and Works, and the Commissioner of Rawalpindi Division. My aim in interviewing these top bureaucrats was to know their point of view about historical events and current residential problems of the area and to understand their role in providing the basic infrastructure in the study area.

In total 27 semi-structured interviews were conducted, as follows: 14 interviews with officers of the Rawalpindi district, 5 with top ranked officers of the province of Punjab, and 8 with retired people and leaders of the study area, as discussed above. Table 5.2 illustrates the type of interviews and held at various places. Chambers (1994) in his discussion of rapid Rural Appraisal (RRA) lauds the key informants and identifies them as crucial for constructing social reality and asserts that it researcher should enquire who are the local experts and seek them out, sometimes through participatory social mapping. Though the interview schedule was pre-decided and set as per the availability and approval of the officers through email or telephone contact before leaving Durham, yet upon arrival the researcher had to face many problems in interviewing the officers. Many times he had to sit for hours in waiting rooms; despite the fact he had valid appointments, the officers were frequently not available at that time.

Though the interviews with the officers mostly took place in their respective offices in a formal way discussed above, the informal interviews with the retired officers were conducted in a flexible way at varying locations ranging from big drawing rooms to restaurants and sometimes walking through the streets or sitting in parks under the shadow of some old trees. The interviews of the officers were scheduled while those of with the second category were mostly unscheduled. While the first category was selected according to the importance of their designation, the second category was chosen by snowball sampling, with the help of gate keepers, who were my hosts and helpers throughout the survey. It is worth mentioning that before arriving for my field work I was expecting one to one interviews with the officers (as requested by emails or telephone), but this happened on only a few occasions when I had a chance to interview the officers without any disturbance. Usually I had to conduct these interviews while a varying number of people were present, ranging from subordinates to visitors, who also played their own role throughout the interview. After the fieldwork, each interview was transcribed and coded according to an interview protocol. Themes were thus developed for further analysis.

Table 5.2 shows the sampling methodology used for this research. It is notable that in addition to the above interviews I also conducted two pilot interviews on the focus group model, one in the Rawalpindi tehsil and the other at Taxila tehsil, which helped me a lot to learn how to use flip charts, satellite images, and how to divide the time into different questions, control the discussion and take notes. It is worth mentioning here that the different regions which I selected for the qualitative methods portion of this thesis were chosen after a prior analysis of the area, based on remote sensing analysis, census information and reasons of logistics convenience. Specifically I used field-based knowledge in conjunction with the classified land use maps produced in the laboratory, to identify the area.

Table 5.2: Types of interview held at various places

Interview type	Officers from the Tehsils of District Rawalpindi							Govt. Officers	Total
	Gujjar Khan	Kallar Sayydan	Kahuta	Kotli Sattian	Murree	Rawal-Pindi	Taxila		
Total	3	2	1	3	2	7	4	5	27
Formal	2	1	1	2	1	4	2	5	18
Informal	1	1	-	1	1	3	2	-	9
Focus Group	2	1	-	2	2	4	2	-	13

Source: Author

5.2.3 Focus Group Discussions

As shown in the table 5.1, I conducted 13 focus group discussions, from all of the tehsils except, Kahuta, which I intentionally skipped due to the strategic importance of the area and the high security in place there. Due to my position as an Assistant Professor of Geography at Bahawalpur University for a long time, I had good opportunities to contact some of my ex-colleagues, class mates, and some students as well, who were currently working in the Rawalpindi region. These highly educated people, who we can legitimately refer to as “Research Assistants”, are embedded in the communities of their respective areas and helped a lot in arranging the focus groups discussions. They facilitated for the researcher his entry into the local communities by introducing him to the town officers, local patwaries, local councillors, Revenue officers and many other officials. In fact, these RAs were a great source of help for the researcher, as they performed every duty, from seating arrangements to taking videos, photographs, meeting notes, arranging and serving refreshments during the FGDs and even sometimes arranging a night’s stay for the researcher in the area. Fig. 5.3 illustrates the role of RA’s in the research. The researcher is discussing with HOD of Geography Department, Government College Rawalpindi, the arrangements for FGD, to be held on 19th March at Ashgar Mall Scheme, Rawalpindi in the vicinity of Govt. College Rawalpindi.

In the tehsils of Rawalpindi, Murree, Gujjar Khan and Taxila, these RAs introduced the researcher to the local representatives and leaders, who further served as gatekeepers for the selection of participants of the FGDs. In the remainder of the tehsils, the researcher himself found the gatekeepers during participant observation, perimeter walks and personal contacts. As for as sampling techniques for these FGDs are concerned, two sampling strategies were used. First, the initial contacts were done through snowball sampling, while entry into the communities was gained through local community leaders as ‘gatekeepers’ who were identified through purposeful sampling (Cameron, 2000). Prior to the FGDs, it was found imperative to identify the groups and also to resolve some of the methodological issues associated with the formation of the focus groups. Among these was the issue of ‘lack of representativeness’ (Bedford and Burgess, 2001, cited in Koti, 2004) and second was ‘lack of homogeneity’ (Cameron, 2000). Bedford and Burgess (2001) borrow from Lunt and Livingstone (1996) to argue that the problem of representation can be overcome by ‘running’ as many groups as it takes to ensure that the stories used have all been heard effectively. Based on the above issues and the author’s own experience, it is recommended that pilot surveys are useful to plan a strategy for holding FGDs. A total of 96 people participated in the focus group discussions in all, conducted in six tehsils of Rawalpindi, excluding Kahuta.

All efforts were made to have representation of both genders equally, but still the proportion of men was greater in all cases, i.e. 60: 40 in FGDs and 80: 20 in the individual interviews of officers. Just to check the significant difference in the proportion of gender between two groups, a chi square test was performed at 5% of significance level. The calculated value of X^2 as 0.267 was not significant and it can therefore be accepted that the two groups were reasonably homogeneous on the basis of gender and there is no effect on the results. As discussed earlier, the participants of the FGDs were selected using “snowball sampling”, keeping many things in mind such as the age of the participants, their familiarity with the area, their socio-political background, and of course their consent as well. Since the participants of all FGDs were important informants, some basic information about them was gathered beforehand on a specified form, such as gender, age, residential status, occupation, and education. The age and sex structure, education, employment patterns and residential characteristics of the focus groups are given at appendix 5.4. The information collected from all of the participants on the “Participants’ information form” suggests that 95% of the them were educated, 50% were either serving in the government or semi government sector, 35% were self-employed, among whom 15% were volunteer social workers, and 5% were living a retired life. Further analysis shows that approximately 70% of the participants originally came from the area and only 30% of them were migrants into the areas where they were currently residing.

Figure 5.2: Discussion meeting between the Researcher and RA regarding arrangements of FGD

These incomers were in the majority from nearby cities in the Punjab and the adjacent province of Khyber Pukhtunkhwa, and some from central Punjab, but the total distance from the place of their origin was never more than 500 Kilometres in any case. Before conducting FGDs in neighbourhoods, the researcher initially visited each neighbourhood with a research assistant (RA), and was introduced to a local community leader in a popular place like a tea restaurant, park or in the drawing room (s) of the leader. After a brief introduction and a short gossip of community issues, mostly residential problems in the area, an appointment was made for the focus group discussion, and the Research assistant or any prominent figure of the area would announce the group meeting to the local residents well in advance. Before the beginning of each FGD, the RAs were assigned their roles of making seating arrangements, refreshments, recording conversations, taking photographs and making a video (with the permission of the participants). All the materials were arranged, including a statement of confidentiality, discussion checklist, recording devices, transportation, and refreshments. After initial introductions, the researcher explained the purpose of the research and read the statement of privacy and confidentiality. The procedures for the discussions were clearly explained in Urdu and sometimes in Potohari[42] (Bracken & Oughton, 2006), thereafter the discussion commenced by asking the group members to identify their key issues of concern. It is important to mention here that, every participant was told that he/she could leave the meeting any time, but the discussions were so interesting that none of the participants during the 13 meetings left the halls/rooms where the discussions were conducted. The questions discussed in detail in these group discussions are annexed as appendix 5.2.

[42] Local language spoken in the study area

Following the sequence of the questions prepared beforehand, group members discussed the local issues, residential problems, resource access and use, historical urbanization, land use/land cover changes due to urban and peri-urban expansion, the inward and outward movement of the people, the establishment of the colonies and political corruption, delivery of social services, physical infrastructure and housing conditions, traffic congestion problems, and many other issues. During the discussion, the researcher mostly kept silent, but effectively guided the discussion and played the role of a facilitator (Cameron, 2000) or moderator (Bedford and Burgess, 2001). As the discussion progressed, it was interesting to observe the synergistic effect of the discussions as one issue led to another. During the mid of the discussions the research assistants served refreshments. Interestingly the debates continued during the refreshments. Importantly some very important issues from shy participants tended to emerge during break times. Since the participants knew about the time required for each question, yet many times the discussions were prolonged due to underestimation of the involvement of the participants. Thus the discussion went on until there were no new ideas coming out; a point Mahiri (1998) calls the 'level of saturation' of the discussion. The most important part of the FGD was when participants were asked to identify the features from the satellite images and some Google Earth maps drawn on big poster size papers. That was a particularly interesting activity, and is called by some researchers a "mental mapping". Almost all participants took a great interest in it and even were thankful to the researcher to provide them an opportunity to see how their areas looked from the space. FGDs in all places lasted 90-100 minutes, consistent with Bedford and Burgess's (2001) recommendations. After the end of every meeting, a signed statement of confidentiality and the researcher's contact information was passed to the participants. The data was further analysed to seek answers to the research questions with reference to the specific objectives.

5.2.4 Participant Observation

To gain in-depth knowledge of the area to confirm the issues arose during the focus group discussions; to enhance the quality of data and to strengthen the interpretations, the author availed the opportunity to personally live these experiences. The purpose was to understand the "tacit" elements of social realities that may not surface during the interview and FGD. In fact, in this research participant observation was used as a confirmatory method for challenging issues such as differential access to resources, agricultural problems, deforestation, house shortage, water and electricity supply problems, under-representation of low and middle class in decision makings and many other issues. For example, people living near the bank of the Nallah Lai claimed that they were never consulted when decisions about new drainage systems were being made, and that they only learned of such decisions when they were ordered to move from the land they occupied.

The author himself witnessed the poor services that were experienced on a daily basis by local communities, such as chronic water shortages, long blackouts due to non-availability of electricity, the low quality of drinking water, inadequate housing, solid waste management problems, hazardous wastes generated by rapid industrialization, poor infrastructure, broken roads, a poor sewerage system or lack thereof and last but not least the unemployment of highly educated young people.

All these experiences were recorded in an "*observational protocol*" (appendix 5.2) that Arthur & Nazroo (2003) called "logging data". The above story of learning through participant observation was also saved through videography of the area. It is pertinent to mention here that all parts of the study area never presented such chronic situations cited above; it was only in the peri urban and rural areas which were being neglected by the district authorities. In many parts of the study area first class facilities are provided to the citizens. But, here again the question of social disparity arises. By way of example, below are some paragraphs from the researcher's field book insinuating a story?

> *I captured a picture of the houses constructed on the bank of the "Nallah Lai". Small houses of one/two rooms with dumped floors, no showers inside, sewerage water is being mixed with the government water supply lines. Indeed they are houses of mosquitoes, but are in the heart of the city, just 300-400 yards away from posh houses. How come these people live there? Are they living there by their own will or forced to live there? Many questions in mind---------- (OK. I'll first ask these questions to school children)*
>
> (Research field note: March 20, 2011)

> *Azhar continued to write (his own notes about community photos) but he didn't want me to look at what he was writing. He said again, "I am confused! I don't know what I am doing." At the same time he was vigilant too, to note what I was doing? His relatives lived there. Does he want me not to do field work here? Or ----------Even I don't know what I'm doing*?
>
> (Research field note: April 17, 2011)

On one pleasant evening, the researcher sat near the well, and chatted with the residents as they came and left. I discussed with the residents about their families, household size, their activities, and many relevant issues. In the night, sketches were made to keep a fresh memory of events and to provide a visual context for subsequent analysis. During Focus group discussions I was told by the participants about the heaps of garbage at Khaybban-e Sir Syed, New Katarian Road, Pir wadhai and at many other places of Rawalpindi Tehsil which lies in the heart of the capital city Islamabad and is the core of political activities. The author also noted that some time exaggerations were also made by the participants about the area, deforestation, land holdings size, commercial use of residential area, water shortage, nevertheless, my video and photographs witnessed the actual story of the conditions of the people of this area.

With the help of semi-structured interviews, focus groups, perimeter walks, and participant observation, the researcher was able to know much about the study area, its street politics and most importantly these methods helped the author to understand the land cover changes over the last forty years, size of agricultural land holdings, agricultural practices and patterns, important crops of the area, loss of agricultural land, deforestation, illegal colonies in the slums and heart of the city, and transportation and water problems. The results were more comprehensive than if had I employed only one of these methods. Each one revealed different information and helped to fill gaps in understanding left by the others.

On the one hand the semi-structured interviews with the officers showed their point of view as stake holders, which helped to illuminate differences in land use over years, while the semi-structured interviews with representatives of the community told a different story of the same phenomena. Focus groups spoke more about structural and planning issues of the region, but provided a forum for fruitful discussion and an opportunity to refine questions. In addition, focus groups were a logistically practical outcome of the group nature of the urban and peri urban areas situated in Rawalpindi district in which I was researching. Participant observation was used as confirmatory methods for contested issues which provided background and context to the interviews and focus groups and helped the author gain a deeper appreciation of the region. Transect walks provided additional meaning to the spoken story, by allowing for direct observation of land cover and land use practices, and for providing concrete examples for the residents to talk about.

The above four methods helped the author gather mostly qualitative data from the urban, peri-urban mauzas of Rawalpindi district. At the end of the field work, I began to understand the area, regarding its historical development, the pros and cons of urbanization, agricultural practices, crops grown, crop rotations, irrigation sources and practices, conversion of farmlands and forest into built up areas, and the establishment of the housing schemes over the years. I also came to know about the role and working practices of the "Qabza mafia" (illegal holders of plots) who, with the help of local Members of Provincial Assembly (MPA's) and Members of National Assembly (MNA's), force people to sell their agricultural land at a nominal rate for the establishment of expensive housing colonies to earn millions of rupees after spending only thousands. I also began to grasp the sheer scale of poor housing conditions and housing shortages, water shortages and flooding problems, the big unmet promises of the government leaders, and many other important legal and illegal land use practices within the area. On returning home, I carefully reviewed my interview notes and certain lasting impressions from the field which helped me to decide where to focus the analysis of my results. The following section discusses some of the results obtained from the use of these four qualitative field methods, focusing specifically on the theme of land use.

5.3 Results of the Qualitative Methods: The Importance and Meaning of Urban Expansion

This section illustrates the important links between urban expansion and land cover and land use practices in the region of study. I first present the results of individual interviews concerning the main causes of urban expansion, urban differentials and effects of urbanization on the natural environment. I then discuss the local people's perceptions of urban expansion, and their views about the main issues connected with urbanization and mental mapping of remote sensing images. For a better understanding of the results of the one to one interviews and focus group discussions, some demographic characteristics of the tehsils are shown in Table 5.3. The next two sections will focus on two important aspects, first longitudinal urban expansion and resulting causes of deforestation, and changing cropping patterns and the resulting loss of agricultural land, followed, second, by a discussion of the size of the land holdings and land prices in the different areas, and their impact on inward migration and industrialization.

Table 5.3: Some Important demographic characteristics of Rawalpindi District (1998)

Indicator	**Tehsils**						
	G.Khan	**Kahuta**	**K.Syedan**	**K. Sattian**	**Murree**	**R.Pindi**	**Taxila**
Mauzas	373	140	92	56	112	309	55
Housing units	69793	48000	6010	14100	23000	122000	14545
Average House hold size	7.1	5.9	5.6	5.8	7.5	6.1	6.9
Room density	4.2	3.8	5.1	4.1	5.6	5.8	3.9
Literacy rate (%)	63	71	56	69	71	73	62

Source: Government of Pakistan, 1998b

5.3.1 Important Issues of the Study Area

In the beginning of each focus group discussion or individual interview exercise, respondents were asked one lead question: to list three important issues they considered to be important to the residents of the area. The most recurrent issues in all the discussions and interviews were; (1) water; including water shortage, water borne diseases, and sewerage leakage; (2) electricity outages, and (3) high house rents, and their order of importance. Other residential development-related issues raised included social amenities, cultural issues, sanitation, pollution, infrastructure, neglect by the local authorities, and exposure to risk. The researcher then moderated the discussions and interviews towards in-depth discussions on urban expansion and related issues revolving around these issues.

5.3.1.1 Spatial Disparities

Water shortages seemed to be a chronic problem in many tehsils of Rawalpindi district, although interviewees and FGD participants in the different neighbourhoods seemed to have different opinions about the causes of these shortages. There was a general consensus that water was supplied preferentially to large industrial establishments and on a 24 hours a day basis to high class residential areas. There was also said to be overuse of water at governmental offices and a discriminatory policy of distribution. Old water pipes leakage at many points and, of course, the deep water table and the high cost of boring wells were major reasons, and communities had to seek alternative water sources for their daily use by payment. For example, many people said that this artificial shortage is sometimes created by the employees of the respective municipal corporations in order to boost the price of water sold from tankers. In some areas, residents reported that water was available to them for only for one or two hours in 48. Government representatives admitted that water shortages had increased in the last 10 years but they were of the view that the main reasons were the excessive demand for water due to over-population and large family sizes due to the lack of family planning that comes with illiteracy, water leakages in people's houses, and the illegal storage of water. In an emotional contribution during a focus group discussion, one middle-age participant resident of Tipu Road in Rawalpindi tehsil remarked:

> *The biggest problem here is water supply. We have spent more than a hundred thousand rupees to build a toilet in our house. Is there any benefit of constructing the toilet? We cannot use the toilet because we do not have enough water even to drink. Look at these people waiting for water around a single tap outside! – If they had water in their houses they could be doing some other works. Worse still, some people return from their jobs after working 10-12 hours, and instead of taking a rest they have come here to queue up for water, sometimes for more than two hours. Do you say there is something else to talk about?*
>
> (Focus group discussion, April 2011)

I had no answer, and the whole group asked why this problem is not in the Cantonment areas and other newly built posh colonies? One of them replied, "my friend: this is called social disparity". They insisted that none of the problems which local municipal governments explained existed there; some commented that the state of the physical infrastructure has deteriorated. Though these internal differences based on lived experiences are beyond the scope of this research, yet the researcher believes that in future, a GIS analysis of this crucial information about residential quality could be very helpful to portray the picture efficiently and effectively.

The unchecked urban growth and old narrow diameter sewer pipelines are among the basic issues specifically in the urban areas of Rawlpindi tehsil. In most parts of the Khayban-e Sir Syed, Pir Wadhai, New Katarian, and Tench Bhatta of the study area, this study reveals that sewer lines have been laid down, but are blocked, burst, or simply dysfunctional. I saw heaps of rubbish in the drainage system, blocking the flow of water. At the end of the FGD at Khyaban-e Sir Syed, the researcher and FGD participants took a transect walk and witnessed the burst sewer pipes which had remained a nuisance to the communities for more than three months. Referring to the problem of garbage heaps and blocked sewerages, an active participant forced the gathering to laugh saying:

We are so used to the smell coming from Nullah Lai that we are convinced that this is not smell. Only problem is with our visitors.

Regarding the water and sewer network in the town, the participants narrated a fascinating story in which they implied that local resources are only availed to them whenever ‘important people’ or higher social status groups locate in their neighbourhoods. However, in their interviews, none of the officers accepted this.

There was a big debate among the people whether the third big issue is traffic congestion, and resultant pollution, or housing. The majority of the interviewees and half of the FG participants mentioned high rent charges, inaccessibility to housing by low social status groups, and the rise of spontaneous squatter settlements as the third big issue of the area. Both the FG participants and key responsible officers were of the view that the urban housing market in Rawalpindi, faced with a rapidly growing population, has failed to meet housing demand. The government representatives gave the whole blame to the prolonged army rule in the near past, which was non representative and had its own motives. Contrary to above, the FGs were of the view that to them all governments including the present one were same, as none of them thought for their future.

In terms of housing conditions, surprisingly, this was not raised by the inhabitants of the low income housing schemes, despite the obvious differences in housing condition and status in the town. People were also less concerned about the size of the houses however they were more concerned having a small house of their own, rather than a big rented house. The majority wanted the provision of basic facilities like water, electricity, a good sewerage system and suitable solid waste management. A participant said:

> *It does not matter to us to have a big house if it’s not our own. But no electricity, no water, no sewerage, no cheaper public transport, no employment, poor public health facilities, impassable roads, heaps of garbage everywhere and a factory on your doorstep making your children sick every day, has made our environment unattractive (Focus group discussion, April 2011).*

She shouted saying had these ‘high’ people should face these problems, and then they would change the neighbourhood in a single day.

The Participant observation, key informants and Focus group participants revealed that squatter settlements, Timber mafia, unattended broken roads, insufficient urban transport and complete blackouts are the serious problems of most of the towns particularly Murree and Kotli Sattain. In a light moment, during a perimeter walk, a young man joked:

Bao je (gentleman), how would you feel if your car punctures and you take a bus which drops you near chasma (spring) at night, and you have to walk in the darkness to your house which is not less than six furlongs. He maintained that he does it every day, but he made me realized that this not an easy job, but Tehsil administration despite knowing this, never felt the severity of the issue. (October, 2, 2011).

5.3.2 Urban Expansion in Rawalpindi (A Chaos)

Urban expansion has been rapid in Rawalpindi district during the last two decades, particularly in Rawalpindi tehsil. Much of the growth has been in the peri urban periphery where it occurred in a rapid and unplanned manner. The rate at which the cities grew is of vital concern, because by definition urbanization changes the basis of people's livelihoods. Urban expansion has occurred more rapidly in certain directions, based on the land available for its encroachment. The people of the area were of the view that it most specifically engulfed the agricultural land of the peri urban compared to the forests, as most of the forests were owned by the government.

Though urbanization has the potential to increase economic development and improve livelihoods by expanding opportunities in entrepreneurship and emergence of new markets and trading, at the same time the scale and speed of urbanization in the district has created many challenges, including access to resources, and the destruction of agrarian employment without providing reliable substitutes. Many scholars agree that urbanization leads to changes that affect livelihoods at the household level, but the nature of the relationship is in dispute. Thus it is necessary to examine the nature of processes involved in detail, particularly how changing urbanization has altered the land use/cover and how the neighbourhood context mediates such impacts. In the context of Rawalpindi, increased macro-scale economic growth has some impact at the local/household level, but the rapidity of the urbanization has challenged these households' ability to adjust. Without doubt, the rate of urbanization during the last four decades has definitely affected access to assets/resources, and economic and social strategies at the household scale. In the following paragraphs let us see how the actors (responsible for planning) and affected (local people) shed the light on this spatially uneven process of urban change. A similar question regarding urban expansion was asked both of key officers during interview and of people living in the area during the focus group discussion and informal discussions.

Question: To which extent would you say there has been an expansion in the urbanization during the last forty years?

Response(s): One key official very proudly started answering the question in his bureaucratic style (the answer was like a professional speech) addressing the researcher: “Gentleman, time and progress is never stopped, so with the passage of time increase in population and extension of urban areas is always natural” (researcher said, agreed sir). “Mr---- (addressing the researcher) urbanization is on-going process throughout the world, no doubt it is more rapid in developing countries, but nevertheless it’s a reality. How can Pakistan and Rawalpindi be an exemption? I’ve been living in ------------ (he started his own story)”. I kept listening for a long time. At last I asked, ----- “but sir, I wondered to know the level of extent--------“(I was not allowed to complete my sentence.) “Gentleman, I’m coming to that point. In nutshell, this official told me nothing relevant except just trying to impress me with his knowledge and indeed by his position within the government”.

The above paragraph may be irrelevant to a reader, but researchers from the developing countries can better smell these kinds of hazards, which definitely they’ll have to face during interviews with officials known as the cream of the civil bureaucracy.

One well-informed official confirmed that Rawalpindi had witnessed big changes during the last forty years. He emphasised a number of factors, posing great challenges particularly in the last couple of decades: the shifting of the capital from Karachi to Islamabad; the establishment of the marble industry; the high population growth rate of the area; rural to urban migration because of poor facilities in the rural hinterland of Rawalpindi; migration of people from adjacent cities because of the presence of better educational institutions; and, last but not least, an influx of Afghans either directly from Afghanistan or from Peshawar and Swat. He admitted that urban expansion development into peri-urban Rawalpindi is the result of rich people, who have built very big farm houses there on acres of land. He asserted that now there is a big trend of outward migration of people, who gets some prosperity and feel less space for their families. The business families, who have been living in the core of the city in one or two room houses for ages, have started moving out towards the peri-urban areas. This trend has encouraged the builders to develop illegal colonies in a haphazard manner without planning, to provide plots to the above people. This residential sprawl is strongly linked with unauthorized land developments and the erection of buildings without approval of the competent authorities making it difficult to control the rate and nature of urban development. He admitted that for the last two decades the Rawalpindi Development Authority has not announced a single colony to provide the legal shelter for the people.

Another official discussed in detail that due to great encroachment of peri-urban areas into the urban areas; the nearby mauzas of Rawalpindi (those adjacent to Islamabad in particular) grew most rapidly and become the part of Rawalpindi. He asserted his answer by giving the mauza-wise population (plus/minus) statistics of Rawalpindi during the years of 1981, 1998 and 2010. He requested not to quote his name anywhere, and after this was agreed, he told the researcher how in Murree tehsil of Rawalpindi beauty of the area was destroyed by the timber mafia, local politicians and some builders in collusion with the Tehsil Municipal Administration (TMA) and high ranking officers of the Punjab government. He said that 2007 should be written in history as the year of deforestation in Murree.

An officer from the Rawalpindi Development Authority (RDA) commented on the overall urban expansion under the following main categories:

- Planned Satellite towns, Bahria towns, Korangi Towns, Chak Shazad, Sir Syed Scheme Chaklala scheme and Lalazar
- Badly planned Iqbal colony, Dhoke khaba, Tipu Road, Gulshan colony, Fazia colony and Khayaban Sir Syed
- Unplanned Farasat colony, Muh Noor colony, Pandoora, New Kattarian and many others)
- Illegal/squatter The settlements/slums along the banks of Nallah lai, Pir wadhi bus stand, near Margalla Railway Station , near Faizabad, and Panoora)

He maintained that nearly one fourth of the people living in the area are very poor, with a monthly income not exceeding Rs. 6,000 ($ 70) and the average income of a further 35% is less than Rs. 20,000 ($235). Thus there has been a dire need of the people for micro-financing and housing finance facilities, particularly low income housing finance and the launch of low income housing schemes on a priority basis. But unfortunately this has never been fulfilled. As a result, there has been a major unplanned expansion and sometimes low income people have been forced to construct houses illegally on barren government land and sometimes private land as well. He explained that this illegal possession could never be successful without the involvement of the officers of Railway/ highway and local politicians.

Some ex-servicemen in their interviews shed light on the problem that resettling people displaced by the Mangla and Tarbela dams in Rawalpindi district was not wisely managed and that there has been a lot of corruption in the allotment of land ever since independence. They suggested that housing shortages should have been dealt with as a priority and that housing projects should have been launched both by the government and public/private partnerships. They asserted that demand was met by individual self-help and that is why everywhere one can see unplanned expansion. In response to the above question, FG participants explained the longitudinal expansion in the following manner. For them, demographic pressure is the main indicator of unbounded spatial increase. In particular, urban demographic growth exacerbated the problem of inadequate housing, street lights, roads, water supplies, offices and urban councils. One participant pointed out that from 5500 hectares in 1972, the total urban area of Rawalpindi increased to 23,000 ha by the end of

2010. This is a fourfold increase in 38 years. He said that this phenomenon has challenged the sustainability of urban livelihoods.

One participant pointed out that beyond the military fortress, many urban quarters of Rawalpindi have grown up from village status and been assimilated or swallowed up by the town. He talked of the "agglutinated expansion" when villages are gradually engulfed by the urban. This began with linear development linked to road facilities and moved on to nuclear settlements related to the multiplication of housing and infrastructure during the last thirty years. Many respondents pointed out how Rawalpindi has been subdivided by the politicians from 4 to 7 administrative units. Some were of the view that this splitting was closely linked to demographic growth. They were particularly voluble about the creation of "shanty towns" in the vicinity due to irregular and unexpected flooding in the Nallah Lai. Commenting on urban expansion on the cost of green spaces (forests/farmlands), the headmistress of a school (a participant in a FGD at Murree) observed that:

> *In a single day, a human being breathes oxygen equivalent to three cylinders. Each oxygen cylinder on an average costs Rupees 700, so in a day each of us uses oxygen worth Rs. 2100 and for a full year that is worth Rs. 766,500. Considering 65 years as an average life span, the cost of oxygen we use works out to be a staggering sum of Rs. 50,000,000. All this oxygen comes free-of-cost from the surrounding trees. I don't know why so few people look at trees as a critical resource, and there is rampant tree-cutting going on everywhere in the country, which must be stopped. She shouted, I'm afraid we are not only going to lose the big source of oxygen soon but also our lives*."

The above statement shows that people of the study area are very vigilant. A focus group participant from Taxila explained that the increased encroachment of peri-urban areas into the urban areas was due to an increase in the number of "influential affluent people who had been moving out from the core of the city to the peri-urban areas, due to legal/illegal increases in their household income". According to him, between 1970 and 1990, one quarter of the increased sub-urbanization in Rawalpindi can be explained by people getting richer (Glaeser and Kahn, 2003). Thus, compared to the people who live in the core of the cities, those who had moved out to become sub-urbanities have been living in larger houses on larger lots with all modern facilities and using their automobiles more often.

The shifting of these "influential elites" on a large scale to peri-urban areas, forced the city governments to provide all facilities of the same type as in the urban areas at their door and even construct the roads from their houses to the cities as well. Since these people belonged to the high social class which is comprised of serving and retired army personnel, retired and serving civil servants, the judiciary and members of the National and Provincial assemblies, the cities of the Rawalpindi district in general and Rawalpindi city in particular have expanded well beyond their limits. Thus increased peri-urbanization in Rawalpindi from 1980 to 2010 can be partly explained by increased demand for larger plots of land per inhabitant, i.e. greater land consumption. The other alternative reasoning as to why growth of the suburbs has come about is because these people have fled the social problems of the inner city.

5.3.3 Socializing the Pixel: Identification of Land Features from Satellite Imagery

Oral histories combined with archived information like satellite maps provide a rich source for contextualizing development in urban and peri-urban places. The focus group discussions with different social status groups of the region provided an opportunity to map local community perceptions about the urban development through the identification of land features from the satellite images. In fact this was a poignant event for the researcher and his team when many people identified the location of their farms, houses and orchards, which were no longer there. Some of them become sad and started cursing their family members. The participants easily identified their mauzas and different types of land cover (chapter 6) from the satellite images of different years and discussed at length about the ownership, cropping patterns, land prices and many other things. During the FGDs for instance, participants identified various qualitative aspects of spatial change, which had not been captured by traditional approaches. This helped the researcher to suggest reasons for spatial change which are discussed in the following chapters.

During this interesting segment of FGD, people were able to differentiate between the Rawalpindi and Islamabad areas, growing settlements, bare land and urban land, wetlands and water bodies, and farmland. Many people could even recognise the local roads and the motorways. For instance participants could easily differentiate between the M1 & M2 and the other roads leading to their homes/towns. With the help of satellite images they easily recognised the historical changes that occurred during these years in the various mauzas of the district. People recognised the forest which once covered major parts of the area and knew about the periods of clearance. They were aware of industries such as rubber and plastics factories, and hosiery. They also spotted the big plazas and famous colonies established by property developers. They also helped the researcher to understand the location of some major industries in Rawalpindi and Taxila, like the marble industries, cement industries, oil refinery, and electric cables, with respect to location of mauzas. The people could identify the heavy mechanical complex at Taxila and the University of Engineering and Technology, Taxila, from the satellite images of 2010. Some unplanned residential areas surrounding a “Mechanical Complex” in a south-easterly direction along the railway track were also recognised by them. The FGD participants from Rawalpindi could pick out the National park, Nawaz Sharif Park, Army golf stadium, airport, and Qasim base, the Morga oil refinery and Liaqat Bagh.[43] They also recognised the areas of high congestion like Raja bazaar, Sadder, Committee Chowk, Chandni Chowk and many other areas. People also commented on the recently rapid urban expansion that has been taking place along the Murree road (Rawalpindi), GT road (Gujjar Khan and Taxila), Murree-Islamabad road (Murree), Murree-Kotli satian Road (Kotli Sattian) and Gujjar Khan-Kallar Syadan road (Kallar Syadan) in a south-westerly and north-easterly direction.

All these comments were recorded during the discussion and will be the basis of further discussion in the coming chapters. Since it was the first time that most participants had seen satellite images, they were very anxious to use them for their personal knowledge as well. The important aspect of this mental mapping was that participants even identified the illegal slums and the large scale destruction due to flooding in different years, which showed their vigilance and interest about their homes and environment. The FGDs identified areas of incidents where ethnic tensions sparked off conflict over land. These local communities also identified areas of water shortage, broken sewerage lines, heaps of garbage in the heart of the cities and areas along the bank of Nallah Lai where the city government and Rawalpindi development authorities had colluded to forcefully to remove nomad people from places where they had lived for many years, so as to give way for modern developments. These local communities were also asked to map various residential dynamics, and what they felt about uneven and illegal development, matters which are not found in conventional planning maps. Thus with their great help, some maps were produced during these FGDs based on their perceptions and the recognition of the satellite imageries showing environmental vulnerability, historically cultural areas and quality of life. These mental maps after further reconciliation proved to be good "reference data" for the accuracy assessment of land use classification.

5.3.3.1 Loss of Agricultural Land

The rugged topography, limited irrigation facilities, and poor farm mechanization are the main factors which go against the growth and flourishing of agriculture sector in the study area. The proportion of cropped area of the district has been diminishing for the last two decades. In the plain areas of Gujjar Khan, Rawalpindi and Taxila tehsils, Rabi (winter crops) and Kharief (summer crops) are the main two seasons while the mountain areas mostly have a single crop. Wheat is the major crop followed by barley, bajra, gram, sunflower, maize, groundnuts and a large variety of vegetables. Apples, apricots, bananas, guava, peaches, pears and plums are the main fruits. The key officials confirmed the changing land use and cropping patterns of the area. They were of the view

[43] The assassination place of three Prime ministers of Pakistan: Liaqat Ali Khan, Zulfiqar Ali Bhuto & Benazir Bhuto. The last two were father and daughter.

that cultivated area in the study area has decreased for many years. They were further of the view that human settlement density and the intensity of cultivated land both decrease with the distance from the urban areas. But with the decrease of agricultural land/farmlands in the peri-urban areas, the pressure on the occupiers of the remaining agricultural lands has increased, i.e. either to produce more intensively to raise incomes, or sell the agricultural land. Comparatively, this pressure is still less in the rural areas. The builders have been exerting a lot of pressure on the agriculturalists of the peri-urban areas to sell their land, which anyway is of a low productivity. The small land holding size and further division of the land between the children and wider family is key factor which has been encouraging farmers to leave their profession. The holding of agricultural land in the peri-urban area is now not considered as a wise accomplishment as many FG participants were of the view that more income can be generated by selling it to the industrialists or builders. Many asserted that the people in the peri-urban areas, who were still holding the agricultural lands, are either holding out for an attractive offer or thinking that they have an historical obligation to their forefathers.

Based on the above assumptions, many officers told the researcher that during the study period the expansion of cities was on agricultural land alone. Some were of the view that at least half of the cultivable land has been converted into the built up area during the last three decades. This land transformation in Rawalpindi is clearly the result of urban land market operations, the most important and relevant of which for the present study are land values. Thus land values in peri-urban areas are a major factor responsible for the conversion of farmland into residential or industrial zones. Since peri-urban areas have high land values, therefore farmers take advantage of it and sell at what they perceive to be high rates.

The focus group participants also told the same story by commenting that unplanned residential areas have at least doubled in extent during the last two decades, gaining land from agriculture, vacant land and plantations.[44] They were also of the view that commercial developments, institutional establishments and industry have increased many folds in the study area, but mainly capturing land from agriculture, as these developments are mostly away from the city centre. Some participants told the researcher that they were still waiting payment for their agricultural lands which were taken by the government at the time of construction of motorways. Addressing the researcher one participant commented:

> *The Government only cares about those areas where the "influential" people live. The politicians' only think about us when it comes to voting …then politicians shows us big dreams. But my friend, since last elections nothing happened and so far they have been neglecting us, tired of us and indeed they don't want us to live anymore.*

[44] When farmlands/forests are cleared, they are often kept for some time unused to attract builders and industrialists for their future plans.

Their slogan is to eradicate poverty, and they mean it in a sense by killing all the poor. So if there'll not be poor, how come there'll be poverty".

(Focus Group Discussion, May 2011)

Nadeem (FG participant) attracted the attention of the researcher saying:

"*Don't you see that the government simply want to get rid of us, but they don't know how? They have taken our golden lands at very low rates, thrown us in darkness, waterless and dirty environment, hoping that we can finally all die …"*

(Focus Group Discussion April 2011)

Both the interviewees and the FGD participants agreed unanimously that urbanization at the cost of agricultural land has been most incisive in areas where local politicians and the "Qabza mafia[45]" are active. According to local people Rawlpindi, Taxila and Murree tehsils expanded most rapidly outwards, without following any regulations, as compared to other tehsils. Mostly this was either the local people moving from core of the city to outer areas into larger houses or migrants from other cities coming for the better education of their children. The respondents knew that, due to the loss of green spaces, congestion of buildings, waste heat from large automobiles, the use and misuse of air conditioners in big houses, offices and plazas, establishment of factories, erection of tall buildings/plazas, and displacement of natural surfaces has decreased the amount of evapotranspiration, thereby increasing the temperature of the urban area (the urban heat island effect) at least two degrees centigrade. FG participants maintained that urban planning has become a political activity, and that politicians in Rawalpindi only support planning as long as the planners provide support for their purposes and priorities. When planners oppose political power or raise questions about its objectives, they are frequently overridden and sometimes disciplined. Some were of the view that an increased number of actors having contradicting goals and conflicts of interest have fundamentally challenged the "rules of the game" and badly reshaped the urban process in the study area.

5.3.4 Land Prices and Growth of Slums

The author's formal and informal interviews and discussions with officers, real estate brokers, and local people, suggested that land prices in the urban areas of Rawalpindi district have been increasing very rapidly during the last decade, creating an affordability problem for low and middle income people. An officer in-charge of the "revenue record" told me that the officially declared price of a plot size of 5 marla (125 metre^2) increased tenfold between 2000 and 2010. Unofficially these prices were three or four times more than this. Many people commented that in the newly

[45] A group of people who take illegal possession of the lands of the actual tenants, and use different tactics to keep them away from their lands.

developing colonies having the poorest facilities, the price of one Marla (25 square meters) ranges between 200,000 to 500,000 Pakistani Rupees.

A statistician (participant of FGD) told the researcher that if calculated against the current GDP of Pakistan, the cost of a 125 metre² plot ranges between 5 and 11 times per capita GDP. Moreover the construction cost is high relative to people's ability to pay, which is nearly 10 to 14 times GDP. This means that that the growth of property prices is exceeding that of the growth of the economy. The high rates of urban growth in Rawalpindi combined with the restrictive environment for provision of land and housing, have resulted in escalating land prices and increasing infrastructure and urban development costs while diminishing housing affordability. The local communities in Rawalpindi also shared a different opinion as far as access, ownership, development and distribution of resources are concerned. Focus group discussions revealed that land ownership is the preserve of 'big capital', and those who are well connected politically. Although the participants of the FGD agreed that the city/ provincial government always notifies them about available land for allocation for residential development, but at least seven discussion groups concurred that the conditions set by the government for acquiring land are unattainable for 'ordinary' citizens. They criticized the role of the Government in providing cheap land to build houses as not satisfactory. They asserted that when housing schemes are launched on the demand and pressure of the people, because of procedural hurdles, many poor and illiterate people are unable even to submit their applications. Sharief (43 years old) a FG participant responded:

> *"We are given very short notice to apply for land and are deliberately asked for too much money as a down payment for the land. Moreover they give us only three to five years to put up a permanent structure; otherwise we are threatened with cancellation of the plot. They know we cannot meet those conditions, so they just want to show publicly that everyone has had equal chances to get land, and then give it to those with access to credit that can develop it and rent it back to us for more money"*

(Focus group discussion May, 2011)

The growth rate of the urban population is rising day by day and decade by decade. At the same time the growth of the existing population also requires more housing facilities. With few financial resources, the drastic option of illegally occupying a vacant piece of land to build a rudimentary shelter is the only choice available to the people who choose to live in big cities. This phenomenon has caused the emergence of squatter settlements (Katchi Abadis). Thus, the low-income people have continued building katcha- rudimentary houses of cheap makeshift materials affordable to them. This phenomenon has taken the shape of mushroom growth of squatter settlements on public or private land lying vacant adjacent to the major urban centres in the study area. Some participants maintained that the people from rural areas and small towns rush towards big cities for adequate employment opportunities as well as for a better quality of life. But as soon as they enter the city, the first problem they have to face is appropriate shelter to live, which has caused the emergence of squatter settlements. They were of the view that further rapid growth will also result in deteriorated and low quality infrastructure, large slum and squatter settlements, and high household expenditures. Both interviewees and FG participants believed that there had been a large influx of population in the area during the last two decades due to the unemployment and low urban facilities at source, and industrialization, better private job/business opportunities and the existence of excellent educational institutions both in Rawalpindi and Islamabad (the destinations). For some, the high rate of migration from rural areas of Rawalpindi and nearby smaller cities has caused the proliferation of slums and squatter areas as well as an unhealthy environment.

A spokesman for the district administration told the author that Katchi abadis are only acknowledged by the government if over 100 dwelling units in a cluster are located on government land, while slums can be located on public or private lands but they are not legally acknowledged by local, provincial or federal governments. According to him, katchi abadis are a subset of slums—ones whose existence is acknowledged by the government. Squatter settlements are again another subset of slums and refer to settlements where the occupants have unilaterally occupied land without permission or payment. Thus to get the status of being legally accepted as "katchi abadis" the residents of illegal slums sometimes manoeuvre things with the help of politicians. Usually with the help of lower government staff, these slums are shown in the government records as the dwellings that were growing very fast to force the district administration to give them the status of legal Katchi abadis, and further, after getting this status, to include them within the jurisdictional limits of city. In this way the urban limits of any city increases legally or illegally. While government interventions such as land regulations, property rights, and taxation and infrastructure investments are necessary for residents of urban areas, these slums, which are exempt in the sense of being outside the system, become serious obstacles to the development of cities. All of the participants admitted that the socio-economic conditions of the inhabitants of these squatter settlements are quite different from those of normal settlements. Some FG representatives, who belonged to big slums of Rawalpindi such as Shah Jewan colony, Sawan colony, Sadiq colony, Ahmadabad and Quaid-i-Azam colony, responded to my question about how life is in slums as follows: "*Life is not treating us very kindly*." A woman (Rashida) during a visit to slum responded "*Although life here's not fair, but we do not have any other option".*

Rawalpindi lies in proximity of the capital Islamabad. The people of Rawalpindi can see the best possible service standards in the capital. The residents of Rawalpindi want a share of the capital resources among them, which is not possible. This situation fuels their grievances. On the other hand the resources of Rawalpindi are fully utilised by the capital Islamabad. In a short term, the local residents also felt that the location on the fringe of Islamabad gives the local residents access to employment. In the long term, they were of the view that relocation of industrial resources, and commercial activities in the nearby capital was driving land value and housing rents to prohibitive costs for the local residents. During the transect walks the researcher himself witnessed the miseries of life of inhabitants of many slums, but they yet were very hopeful, trusting that one day their all problems will be solved.

The qualitative methods used in this research investigated how the agricultural areas of peri-urban Rawalpindi have been utilised by the builders of Islamabad to erect tall plazas to accommodate the growing population of Islamabad and Rawalpindi, particularly the government employees working in the offices of Islamabad.

5.4 Summary of Field-based Results

The results of the field based qualitative methods component of this thesis reflect a complex picture of urban expansion in terms of scale and time period. Social histories from focus group discussions were combined with local community mental maps, remote sensing interpretation, GPS-based transect walks, oral narratives of land use and relevant archival material. The study culminated with the integration of traditional expert and community local knowledge for a more robust representation and understanding of uneven urban and peri-urban expansion. The local people of the area during informal interviews, focus group discussions and transect walks from all tehsils emphasised that there have been a lot of changes over four decades. They witnessed that due to a large influx of population from the rural areas of Rawalpindi, from the other districts of the Punjab province and from other provinces of Pakistan, the urban areas have increased many fold. They maintained that shifting the capital from Karachi to Islamabad, the establishment of small and large industries, the provision of better employment opportunities both in public and private sector, the existence of excellent educational facilities at Rawalpindi and Islamabad, on the one hand attracted a large population, and on the other hand caused unplanned and unexpected urban expansion. This unexpected expansion caused over-utilization of resources, over-consumption of water, resulting in water shortages in many areas, the conversion of farmlands and forests into the residential areas, the reduction in green and open spaces, traffic congestion and pollution problems, resulting in rising temperature due to the urban heat island effect, and extinction of many plant and animal species.

Using multiple qualitative methods, the researcher tried to establish some concepts about the extent of urbanization, the direction of expansion, the main indicators of urban growth and expansion, and the main issues related to urban expansion during the last forty years. An effort has been made to know from the planners their policies and strategies in coping with the challenges of urban expansion, their explicit attempts to regulate urbanization, and hurdles they faced from the local people and politicians in implementing urban policies.

5.5 Working with Remote Sensing and Field Methods Together

Land use is the "series of operations and associated inputs on land, carried out by humans, with the intention to obtain products and/or benefits through using land resources" (McConnell and Moran, 2006). Since land cover change is the result of overlapping multiple land use processes, therefore there is not a one-to-one relationship between land use and land cover, and it is a strong possibility that a single piece of land will have only one land cover but may have many land uses (Cihlar and Jansen, 2001). Because of this complexity, research into the patterns, processes and impacts of land use and land cover therefore requires multiple disciplines and employs a range of methods, including remote sensing, census data analysis, and qualitative field based methods. The main focus of this chapter has been to study urban expansion and land cover change of a rapidly urbanizing district. Following paragraphs throw light on how the combination of RS and field methods can help research to move across scales, ultimately providing data that is more useful to policy- and decision-makers. Whereas the satellite data provided extent and coverage i.e. answered the "what & where" questions but human geographers are also interested in "why" it happened. Thus field work and qualitative method such as participant observation; interviews, focus group discussions and perimeter walks, all have quenched the thirst of the researcher regarding the integration of local perceptions of land cover and land use directly into the remote sensing portion of the analysis. In fact the field work has provided the researcher with an opportunity for his own mental mapping of the area based on remote sensing and local human knowledge. Thus it can safely be said that qualitative field-based methods helped the researcher a lot to gain insights into the multiple meanings of land cover and land use that were hidden using remote sensing methods. Likely remote sensing helped the people to recognise their area. For instance, in this research many participants and interviewees had difficulty in recalling the changing use of the area, land prices at different periods of time, the industrialization process of the area, etc. Ultimately, with the help of satellite images, they were able to recall and recognise many features.In a nutshell, in this research, qualitative and remote sensing data both were used as a system of checks and balances on each other, providing a multi-layered picture of urbanization and its land uses.

5.6 Conclusion

The chapter has fully narrated the story of the researcher's field work and the qualitative methods employed. It explores how qualitative methods have been used to add meaning to the remote sensing data. The chapter starts with a brief review how the author was able to use the above methods in the field. Moreover it also throws light on the interviewees, participants' interests and responses, the bureaucratic style of officials, and working with interpreters and research assistants during the field work. In the next sections the researcher has concentrated on the real issues and discussed the people's perceptions about urban expansion in the study area during the last four decades, and its effect on the deforestation and loss of agricultural land. An important element of this section is the "mental mapping" of the area with the help of local community. Next section describes the views of the local community and actors about land prices, growth of squatter settlements, and shortage of houses has also briefly been discussed. Final section presents the summary of the field based results.

6 LAND COVER CLASSIFICATION AND ACCURACY ASSESSMENT

6.1 Introduction

Mather (1993) describes the classification process as the identification of the patterns associated with each pixel's position in an image in terms of the characteristics of the objects at their corresponding positions on the Earth Surface. Spectral separation forms the backbone of most classification activities. Hence the main objective of the chapter is to analyse the land cover types that existed during the different intervals of time, and evaluate it with the other ancillary field reconnaissance data. The principal data sets used in the study were Landsat MSS and Landsat Thematic Mapper (TM) imagery.

Two strategies have been chosen for multi-temporal image processing for detecting and analysing changes in urban dynamics. First, changes in multi temporal images are detected by applying appropriate image enhancing techniques, and then specific comparisons of individual images have been made (chapter 2). Secondly image classification is used to extract the land cover types of the study area. This chapter documents the results of the image processing based on the above two analyses.

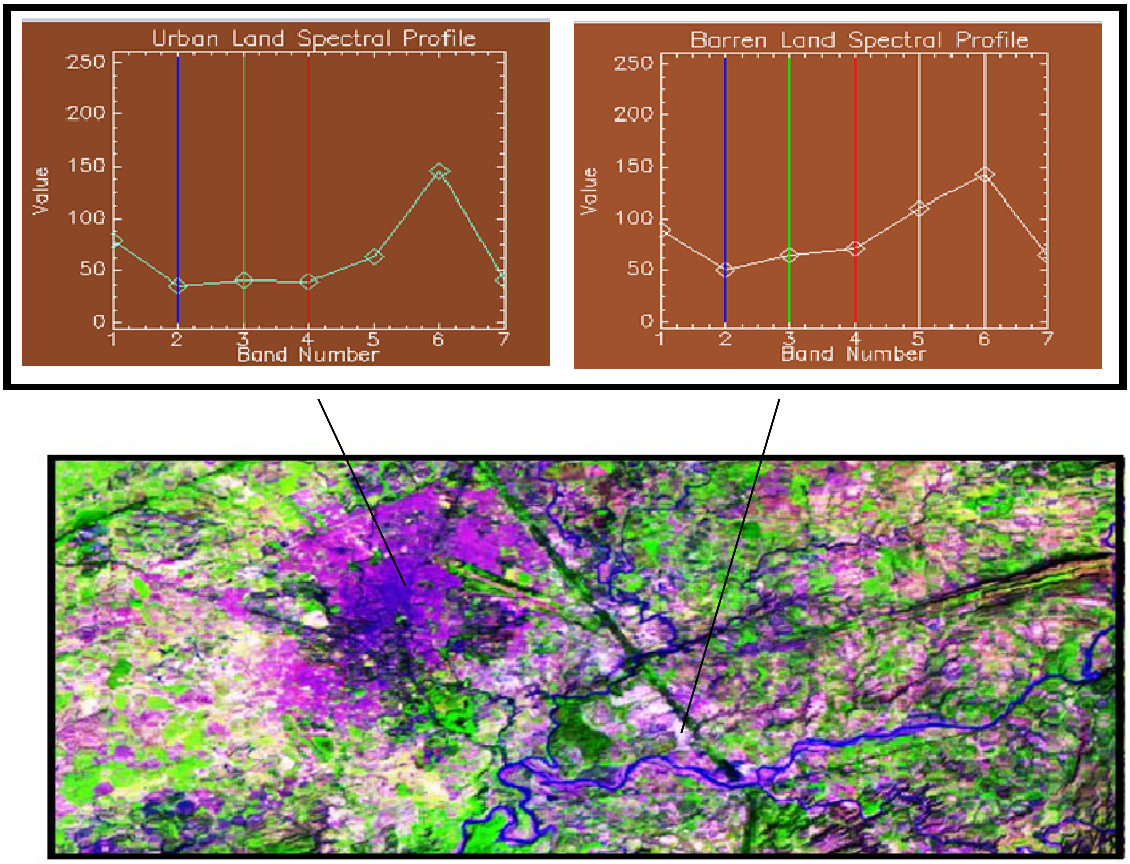
This chapter can be broadly divided into two major sections. The first section deals with the visual interpretation of land cover, and then land use and land cover classification. It describes the objectives of digital classification, land cover classification systems, selection and application of different classification schemes and classifiers, and it also describes the generation of training samples from unsupervised clustering and field reconnaissance visits and the evaluation of training samples. The second section of the chapter deals with accuracy assessment. Three major operational phases of accuracy assessment, i.e. response design, sampling design and analysis design, has been applied in this section. Producer's, user's, and overall accuracy of the classifiers are calculated and Kappa statistics applied for the interpretation of the agreement between classified and reference data. Moreover the comparison of different classifiers has been made on the basis of accuracy assessment statistics.

SECTION-I

6.2 Land Use/Cover Interpretation

Image classification is a major part of land use/cover mapping in remote sensing, as the accuracy of resultant land use maps mainly depend upon this part. In fact classification is a form of spatial and spectral pattern recognition. The spatial pattern analyses size, shape, texture and location, while the spectral pattern involves digital analysis of reflectance measurements of each pixels over different wavebands. The main aim of the land cover mapping is to group all pixels of the image into land use /cover classes and produce thematic maps. Since the aim of the classification is to find a decision rule with the help of which each pixel in the image can be assigned to a corresponding class of land cover. Before using the conventional methods of classification, i.e. unsupervised and supervised classification, the visual interpretation and classification of remote sensing data was performed by extracting various features sets, using band wise land cover statistics, and application of band ratios and through principal component analysis. Fig. 6.1 displays the false colour composite of Landsat TM image of 1992, along with the spectral profile of urban and bare land.

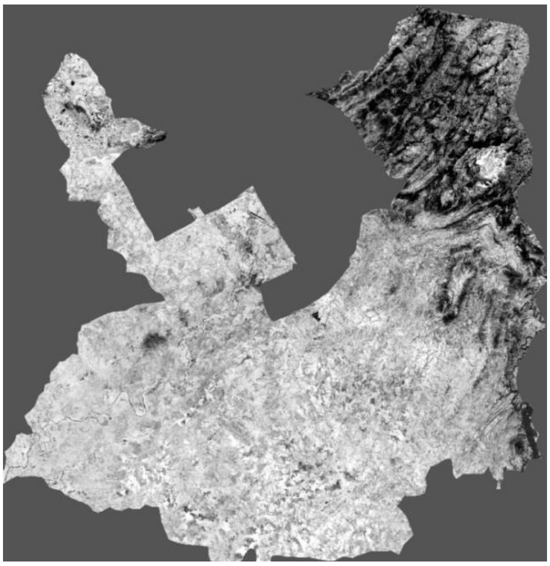
Figure 6.1: False Colour Composite of 1992 Image using band 5, 4 and 3 (RGB) combinations



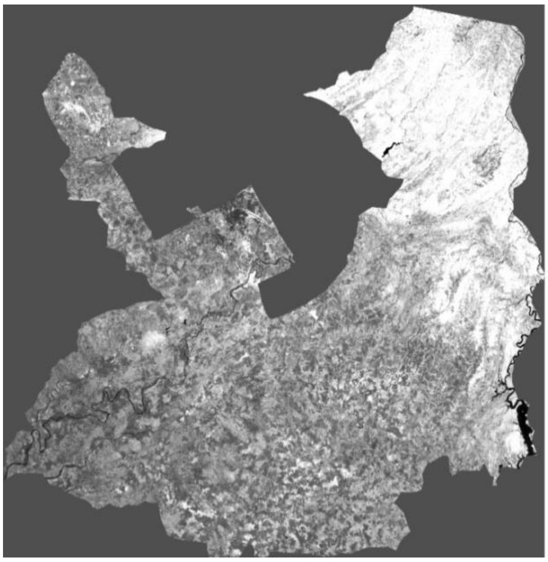
Urban shows bands 234 very similar whereas the bare land shows red NIR reflections are higher - may be due to influence of exposed soil. Note that band 6 is Thermal infra-red and is not used in spectral analysis or image classification. For the purpose of Spectral statistics of different land covers, different samples from the multi temporal images were collected to derive and discover the features and to some extent to frame some rules for specific land use. Fig.6.3.shows the spectral curves of different land covers based on the results of training samples of land cover types in the images of 1972, 1979, 1992, 1998 and 2010. Figure 6.2 shows the NDBal, NDBI and NDVI

Figure 6.2: Application of different Indices on Landsat TM 1998

NDBal

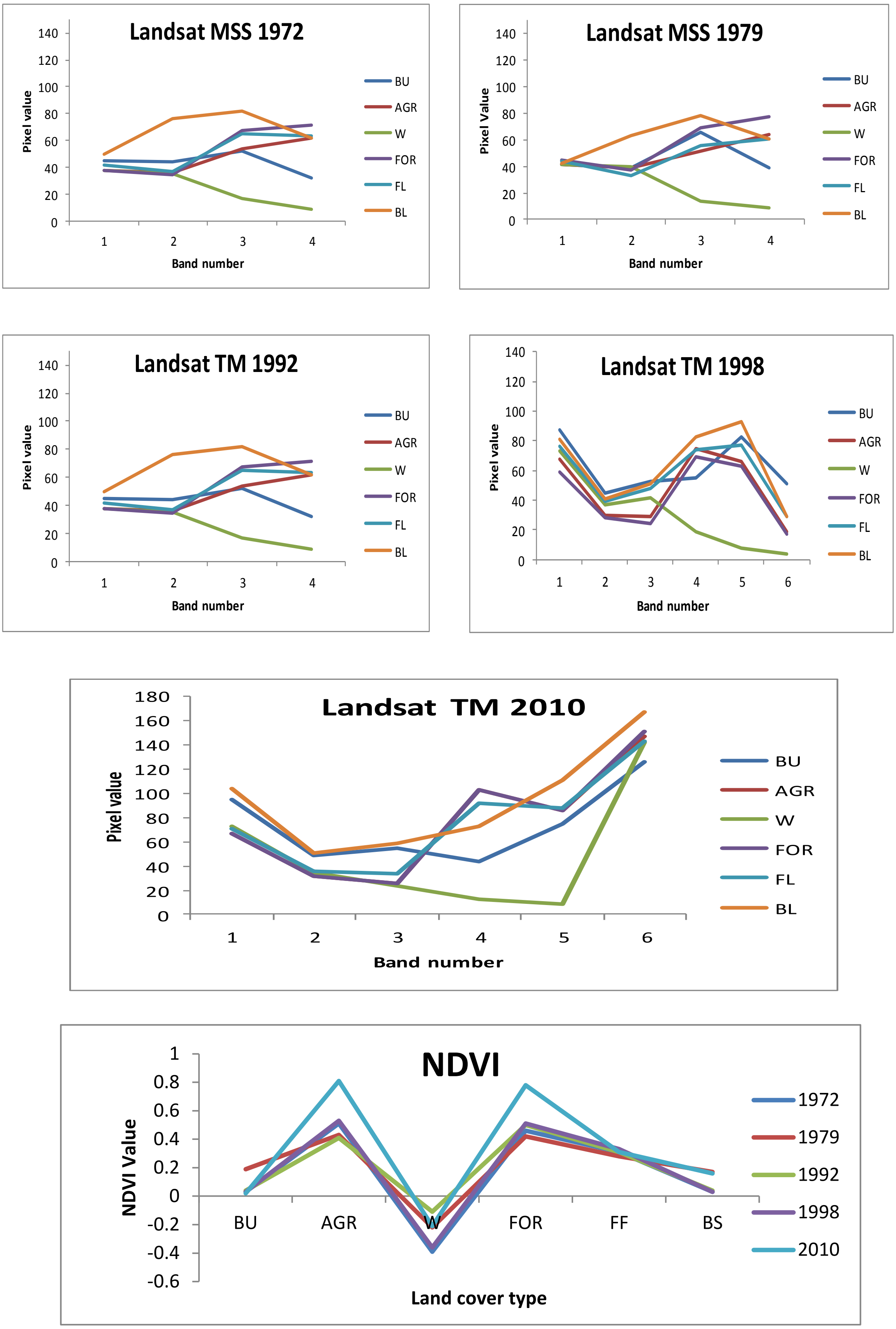


NDBI



NDVI

Figure 6.3: Spectral curves of land cover of various images showing DN and NDVI values



BU=Built-up area, AGR =Agriculture, For = Forested area, W = Water, BL = Bare land, FL = Fallow land, Images to explore the image ratios, as discussed in the methodology chapter, for the purpose of land cover identification and comparison. Figure 6.2 is an example of the application of these indices on Landsat TM image of 1998 year. These indices were applied to all images. The basic idea of taking spectral statistics, NDVI values, as part of the classification strategy sketched in Fig. 6.11, was to use different input features to investigate the spectral features of different land covers types and finally to select effective features sets as evidence of classification. For instance NDVI can be used to distinguish the vegetative classes i.e. forested, agricultural areas grasslands and other vegetation's from other land cover types. Similarly the researcher applied different combinations such as NDVI, Principal Component 2 statistics to discriminate the different classes. For example B2, B3, NDVI, PC2, is effective in differentiating forested and agricultural areas and B3, B5, PC2 and Brightness statistics in distinguishing built-up areas and fallow farmlands. In nutshell, these successful pre classification processes were followed by identification of training sites for classification process.

6.2.1 Land Cover Classification Scheme

A Classification scheme effectively defines the legend that is used for the final map. One place to start was to look at some classification schemes. There are large numbers of classification schemes used for land cover/land use classifications throughout the world. Some of the more common schemes are Global Terrestrial Observing Systems (GTOS), Food and Agriculture Organization (FAO) land cover classification systems, United States Geological Survey (USGS) and United States Department of Agriculture (USDA) Systems. Land use classification scheme of this study was derived from the general land use maps developed by SUPARCO[46] Pakistan and Survey of Pakistan which are mainly based upon the Anderson et al (1972) Level II classification developed for USDA[47]/USGS[48]. Therefore on the basis of the general information from different sources, human activities in the study area and mainly prior knowledge of the author about the study area, and by using the modified version of Anderson's classification (Table 6.1) six broad land cover/land use classes were identified and mapped using the maximum likelihood algorithm.

A modified version of Anderson land cover/use classification level 1 was found suitable for Landsat MSS and TM images, and therefore was adopted to examine the multi temporal land cover/ use changes in the district of Rawalpindi. The six separable land cover/use classes identified in this study were: agriculture, bare land, built-up, forest, fallow land/ grassland and water bodies.

[46] Space and Upper Atmosphere Research Commission
[47] United States Department of Agriculture/
[48] United States Geological Survey

Table 6.1: Land use and Land cover classification system

Anderson et al (1972)		This study
1: Urban or built-up land	11 Residential 12 Commercial and Services 13 Industrial 14 Transportation, Communications, and Utilities 15 Industrial and Commercial Complexes 16 Mixed Urban or Built-up Land 17 Other Urban or Built-up Land	Built-up area
2: Agricultural Land	21 Cropland and Pasture 22 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas 23 Confined Feeding Operations 24 Other Agricultural Land	Agriculture
3: Rangeland	31 Herbaceous Rangeland 32 Shrub and Brush Rangeland 33 Mixed Rangeland	Fallow land/ grassland
4: Forest Land	41 Deciduous Forest Land 42 Evergreen Forest Land 43 Mixed Forest Land	Forest
5: Water	51 Streams and Canals 52 Lakes 53 Reservoirs 54 Bays and Estuaries	Water
6: Barren land	71 Dry Salt Flats. 72 Beaches 73 Sandy Areas other than Beaches 74 Bare Exposed Rock 75 Strip Mines Quarries, and Gravel Pits 76 Transitional Areas 77 Mixed Barren Land	Bare Land

Source: Anderson et al., 1972

Following the recommendations of world land use survey, and in order to have a systematic and uniform colour scheme for the presentation of LULC information in map format, the following colour scheme was used for the purpose of Supervised Classification of all Landsat data.

1. Agriculture — Green
2. Bare land — White
3. Built-up — Red
4. Forest — Dark Green
5. Fallow-land — Gold
6. Water — Dark blue

It is important to mention here that since this project focuses on the urban expansion and land use / land cover change, particularly the loss of green space and conversion of bare land into built up areas, therefore only above six broad categories were taken into consideration which were directly related to the research project.

6.2.1.1 Collection and Analysis of Training Data

In supervised classification the quality of the training samples is one of the important factors that affect the accuracy of the classified images. Since an effective SC entirely depends upon separating land cover types of interest into sets of spectral classes, therefore training samples selected for this purpose were sets of pixels which represented what was recognized as a discernible pattern of land cover classes. While training data selection the following criteria was taken into consideration:

- The land cover types that were selected for training were identified both on ground and the satellite images
- The training sites represented the thorough variation within each stratum, and were collected from all strata of the image in question.

In the light of the foregoing, the training areas were chosen from different locations on a stratum basis and a sufficient number of training areas for each land cover type were taken.

Training sites for signature generation were identified from the 1972, 1979, 1992, and 1998 images (for the six classes based on the following sources, besides the personal knowledge of the researcher about the study area.

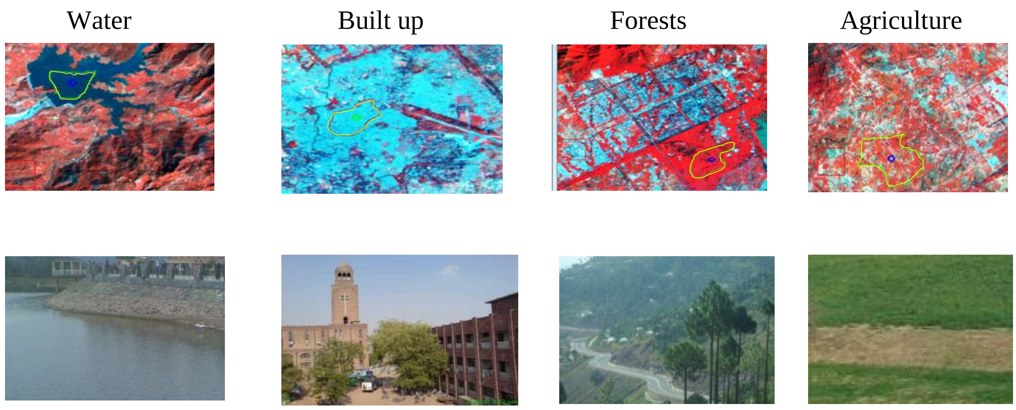
- Land use maps of the district during these periods
- Topographic map of the study area
- District Map of Rawalpindi
- Interviews from the residents and policy makers
- ISODATA classification
- Reflectance values of pixels of individual land cover classes (spectral profile of land covers; Fig.6.4)

For the Landsat image of 2010, the identification of training sites was mainly aided by GPS-based Field survey and Google Earth Images of the study area, in addition to the some of the above sources. It is pertinent to mention here that training areas collected by different methods mentioned above were divided into two sets:-

a) Training areas for SC
b) To validate the classifier i.e. accuracy assessment of the classification performed

As discussed above, the training samples were extracted from spectral classes corresponding to the classification system, with the help of field data and the other sources mentioned above, which were used as aids to identify patterns on the images before onscreen digitization. Before the application of the relevant classifier, the training samples were evaluated and those having the similar characteristics were merged to form composite training samples. Fig. 6.4 shows training data of some land covers along with photographs taken during field work.

Figure 6.4: Land covers types and field photographs



Source: Landsat TM 2010 and Field photographs

Signature separability is a statistical measure of the distance between two signatures and it can be calculated for any combinations of bands that are used in the classification to rule out any band not found useful for classification (ERDAS 2010). There are four methods of computing separability and distance between training samples. These methods are: *Euclidian Distance, Divergence, Transformed Divergence (TD) and Jefferies-Matusita Distance*.

During the literature review it was found that all four methods have been applied by the researchers in their studies,(Al Ali, 2011; Duadze, 2004; Shueb & Atkins, 1994) but according to Ringrose et al (1997); Jensen (1996) and ERDAS (2010), Transformed Divergence has been found to be the most efficient method of the four techniques. Keeping in view the above studies, Transformed Divergence was used in this study. Congalton and Green (2008) and Jenson (1996) observed that although the scale of the TD may range from 0 to 2000, however if the values are more than 1700, the separability is considered as “fairly good”, values between 1500 to 1700 may be considered as “acceptable” and values below 1500 show the poor separability. Table 6.2 generated by the software shows the separability of training samples and minimum and average separability among the classes of Landsat TM 1998 and Landsat TM 2010. The comparison of two years that is T3 and T4 was done to show how different signatures were separable in the latest images, having comparatively good reference data. The best average separability for Landsat TM 2010 and TM 1998 was 1913.78 and 1890 respectively, which according to the above standards can be taken as fair. Further to the average, the signature separability computation takes into account the separability of the individual classes as well. It shows that in 2010 Landsat images, apart from two classes i.e. (Forests and Fallow lands) and (Built-up areas and bare land) the separability values among all other classes were almost equal to 2000, which means that all classes were separable except the above two classes. In 1998 image the separability between the same two classes was also very poor showing confusion between these classes, as compared to other classes which were fairly separated. In the light of the TD separability table, those signatures were rejected which showed poor separability.

Table 6.2: A comparison of Transformed Divergence Separability distance computation values for Landsat TM 1998 and Landsat TM 2010

Signature name		**water**	**Agriculture**	**Forest**	**Built-up**	**Bare land**	**Fallow land**
1:Water	2010	0	2000	2000	2000	2000	2000
	1998	0	2000	2000	2000	2000	2000
2:Agriculture	2010	2000	0	1951.04	2000	2000	1991.19
	1998	2000	0	1997.47	2000	2000	1999.88
3: Forest	2010	2000	1951.04	0	2000	2000	785.766
	1998	2000	1997.47	0	2000	2000	584.674
4: Built-up	2010	2000	2000	2000	0	1597.18	2000
	1998	2000	2000	2000	0	1607.33	2000
5: Bare land	2010	2000	2000	2000	1597.18	0	2000
	1998	2000	2000	2000	1607.33	0	2000
6: Fallow land	2010	2000	1991.19	785.766	2000	2000	0
	1998	2000	1999.88	584.67	2000	2000	0

Source: Signatures evaluated in ERDAS

6.3 Utilization of Supervised Classification

After the evaluation of the signatures, and selection of bands, 5, 4, and 3 (through the signature comparison process), Maximum Likelihood classifier (MLC) was applied to all strata of Landsat images of 1972 (T1), 1979 (T2), 1992 (T2.5) and 1998 (T3). However for Landsat TM 2010 (T4), three different supervised methods which include Maximum Likelihood Classifier (MLC), Mahalanobis Distance (Mh.D) and Minimum Distance (MD) were applied for comparison purposes. This makes a total of 16 classification combinations for 1972, 1979, 1992, and 1998 years (four strata, four years x 1 classifier) and 12 combinations for Landsat TM 2010 (four strata x 3 classifiers).

Fig. 6.10 (a) displays the classified images of Rawalpindi stratum of Landsat TM 2010, produced by applying three classifiers i.e. MD, Mh.d, and MLC. Fig. 6.10 (b) shows distance files of above classifiers respectively. It can be noticed from the Fig. 6.10 (a) that to some extent both MLC and Mh.D methods agreed with land truths in terms of Land cover/Land use in the study area, as their predictions of distributions of classes were reasonable, however the MD method underestimated the urban class. Unlikely, Mh.D overestimated some classes. Overall it was found that application of MLC comparatively improved the classification results.

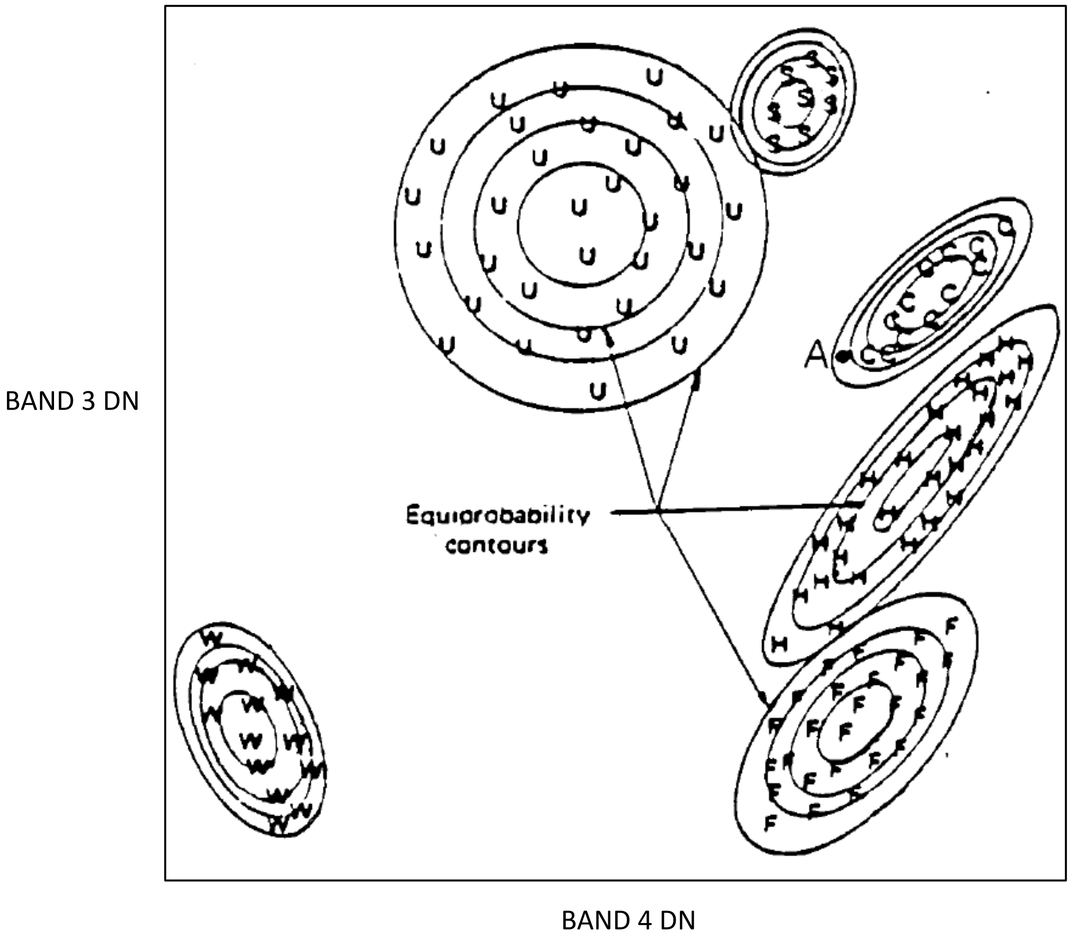
The minimum distance to mean classifier is the simplest classifier which performs three simple tasks. First, it calculates the mean DN of a class in the training data for all variables (this is termed as mean vector); second, allocation of pixels to be classified to the classes of their nearest vector, and third, creation of data boundary around the mean vector. Its main limitations are its insensitivity to variance in the spectral properties of each class.

Unlike MD, the Mahalanobis Distance classifier takes into account the variability of the classes, however this method tends to over classify signatures with relatively large values in the covariance matrix. Moreover since Mh.D highly relies on the normal distribution of the data in each input band, it needs more computational work.

The maximum likelihood classifier is the most popular one which addresses the short comings of the previous methods as it quantitatively evaluates both the variance and covariance of the category spectral response patterns when classifying an unknown pixel (Lillesand et al. 2010). To do so, it makes an assumption that the distribution of the clouds of points forming the category training data is normally distributed. The principle of MLC is that it delineates ellipsoidal and equal probability contours in n-dimensional space (Lillesand et al. 2010; Jensen 1996, Curran, 1985).

The likelihood process is performed individually for each pixel and every class. MLC, from knowledge of the prior probability of an allocation to each class, calculates a conditional probability for each pixel according to spectral values of that particular class and then compares it to the class conditional probability density functions, estimated from each training set, for each class (Donoghue and Shennan, 1986). Finally the pixel is assigned to that most likely class for which it had the highest probability of membership, otherwise labelled as unknown if the probability values are below the pre-set threshold. In essence, MLC draws equiprobability contours around each class of the training points in n-dimensional space, as shown in Fig. 6.5. The shape of equiprobablity contours reflects the sensitivity of the likelihood classification to inter band correlation (Lillesand et al 2010). Because of this sensitivity, pixel A would be appropriately assigned to C category. As discussed above, MLC uses probabilistic discriminant functions in order to assign each pixel to pre-defined groups according to the statistical parameters estimated from the covariance matrix of each training set.

Figure 6.5: Equiprobability Contours defined by maximum likelihood classifier



Source: Lillesand et al., 2010

Figure 6.6: (a) Supervised classification: three methods applied to Landsat TM 2010 (T4) (Rawalpindi Stratum)

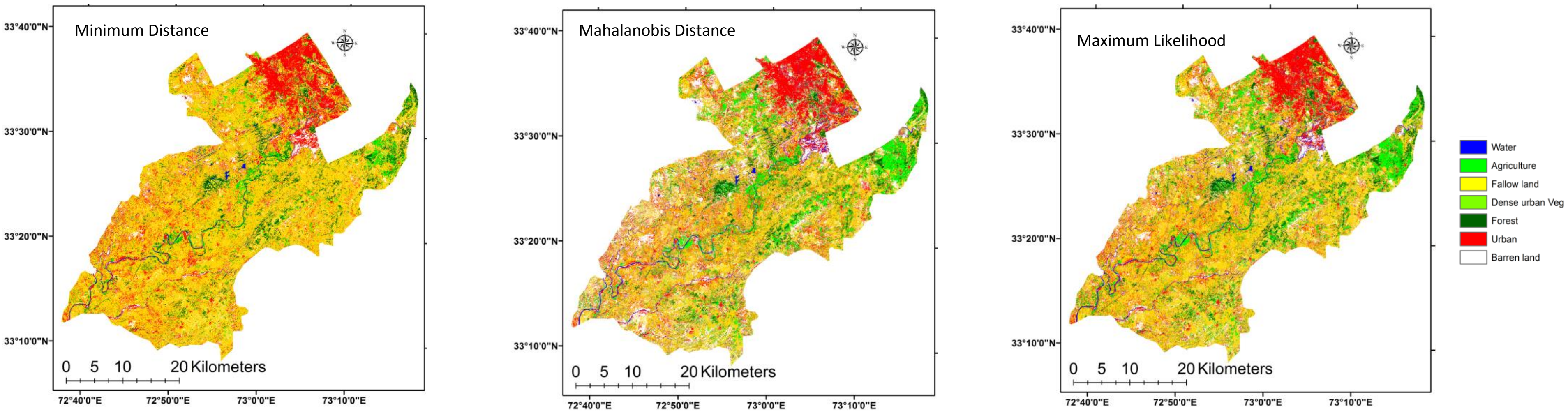
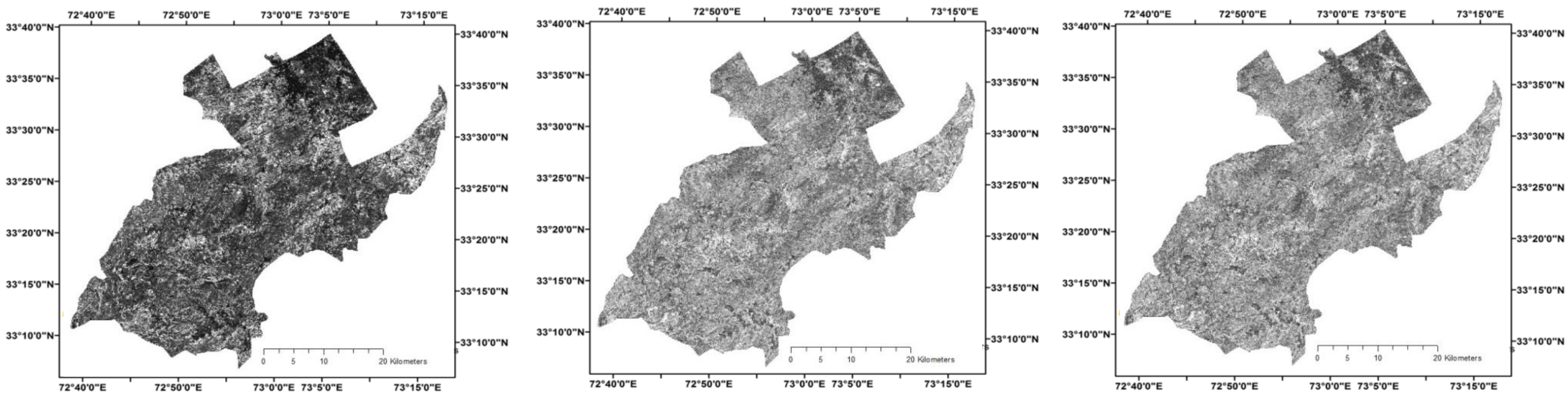


Fig.6.6 (b): Distance files of supervised classification methods



To summarize, MLC was performed to all strata of multi-temporal Landsat images according to the following steps (Richards & Jia 1999).

1. Display the three band overlay colour composite (CC) image
2. Look carefully at the available features , and decide the set of classes into which image is to be segmented
3. Choose representative training samples (TS) from the CC image for each of the desired classes (use box cursor)
4. By comparison, use the result of ISODATA and K –means
5. Estimate the mean vectors and covariance matrixes for MLC (use TS). The final discriminant function g(x) is taken as:

$$g\ (x) = 1n\big((\textstyle\sum_i)\ - (x - m_i\ )\ \big)^t \textstyle\sum_i\ (x - m_i\ ) \qquad (1)$$

Where m_i and $\sum_i$ are mean vector and covariance matrix of the data in class($_i$) N is the number of bands.

6. Apply decision rule for MLC algorithm
7. Get the classified image
8. Calculate statistics of classes
9. Compare the results

Figures 6.7 to 6.11 display the results of supervised classification of multi temporal satellite data by applying the Maximum likelihood classifier (MLC).

Figure 6.7: Supervised classification of Landsat MSS 1972 of the study area -Rawalpindi district (MLC applied)

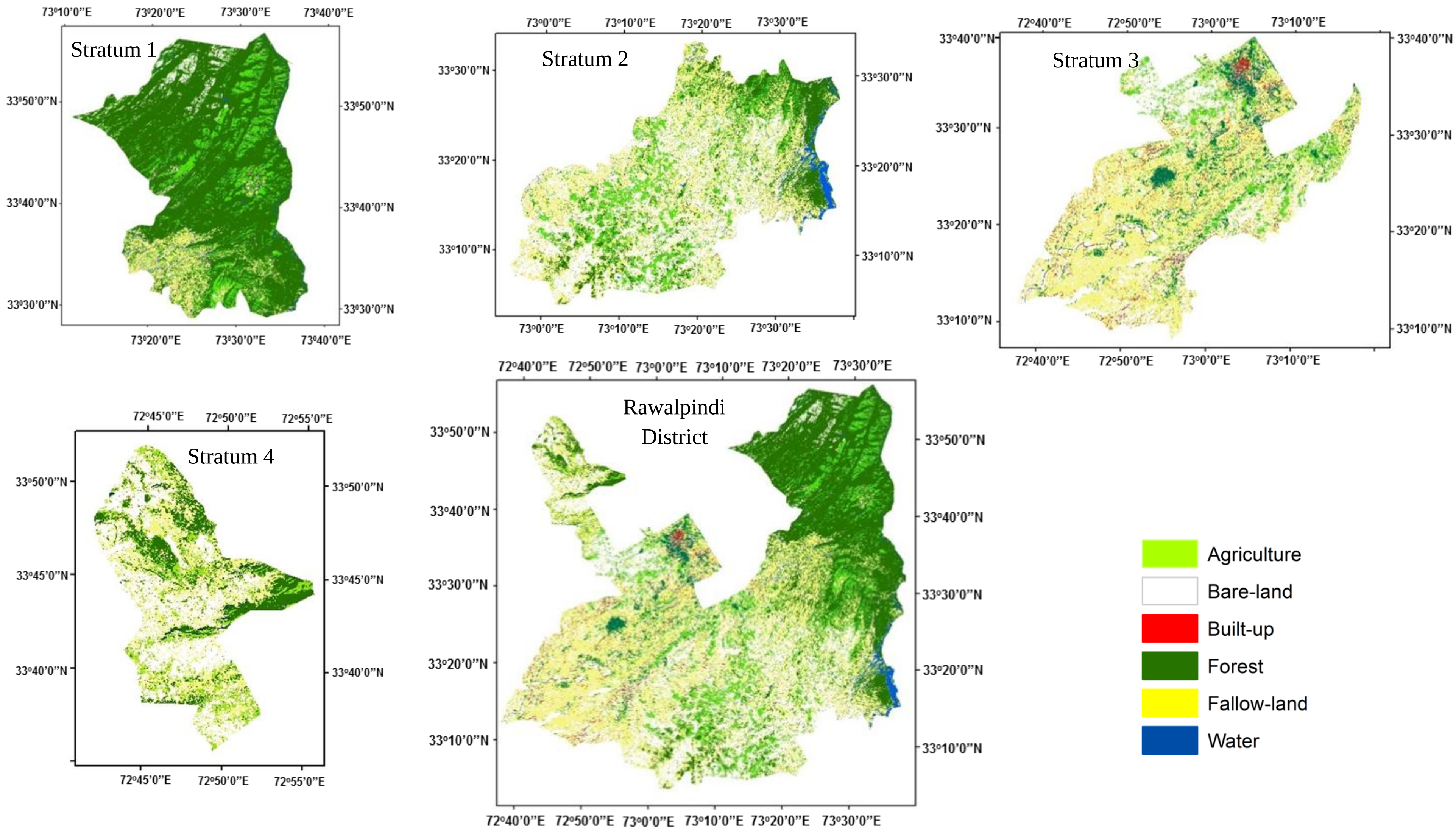


Figure 6.8: Supervised classifications of Landsat MSS 1979 of the study area -Rawalpindi district (MLC applied)

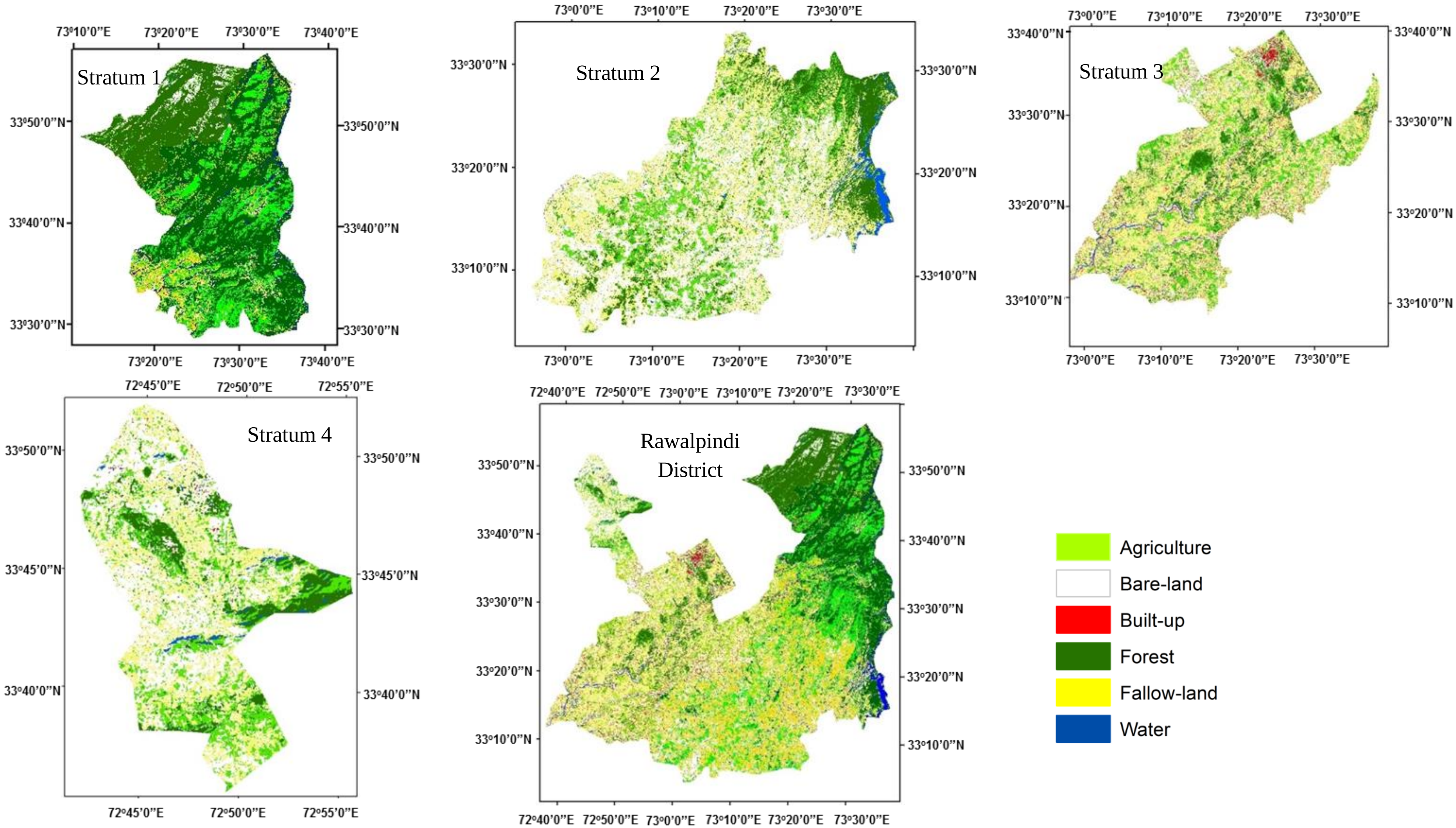


Figure 6.9: Supervised classifications of Landsat TM 1992 of the study area -Rawalpindi district (MLC applied)

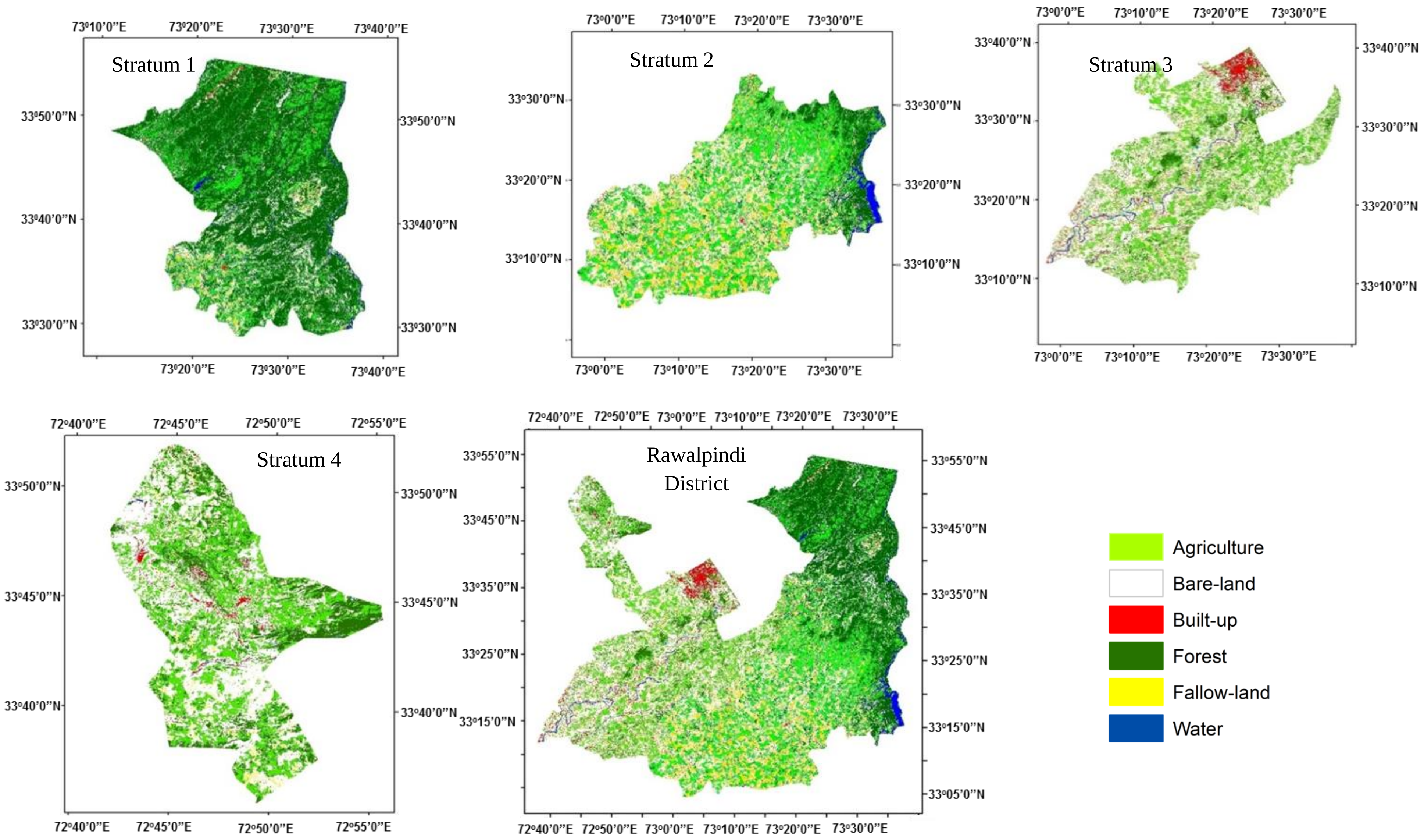


Figure 6.10: Supervised classifications of Landsat TM 1998 of the study area -Rawalpindi district (MLC applied)

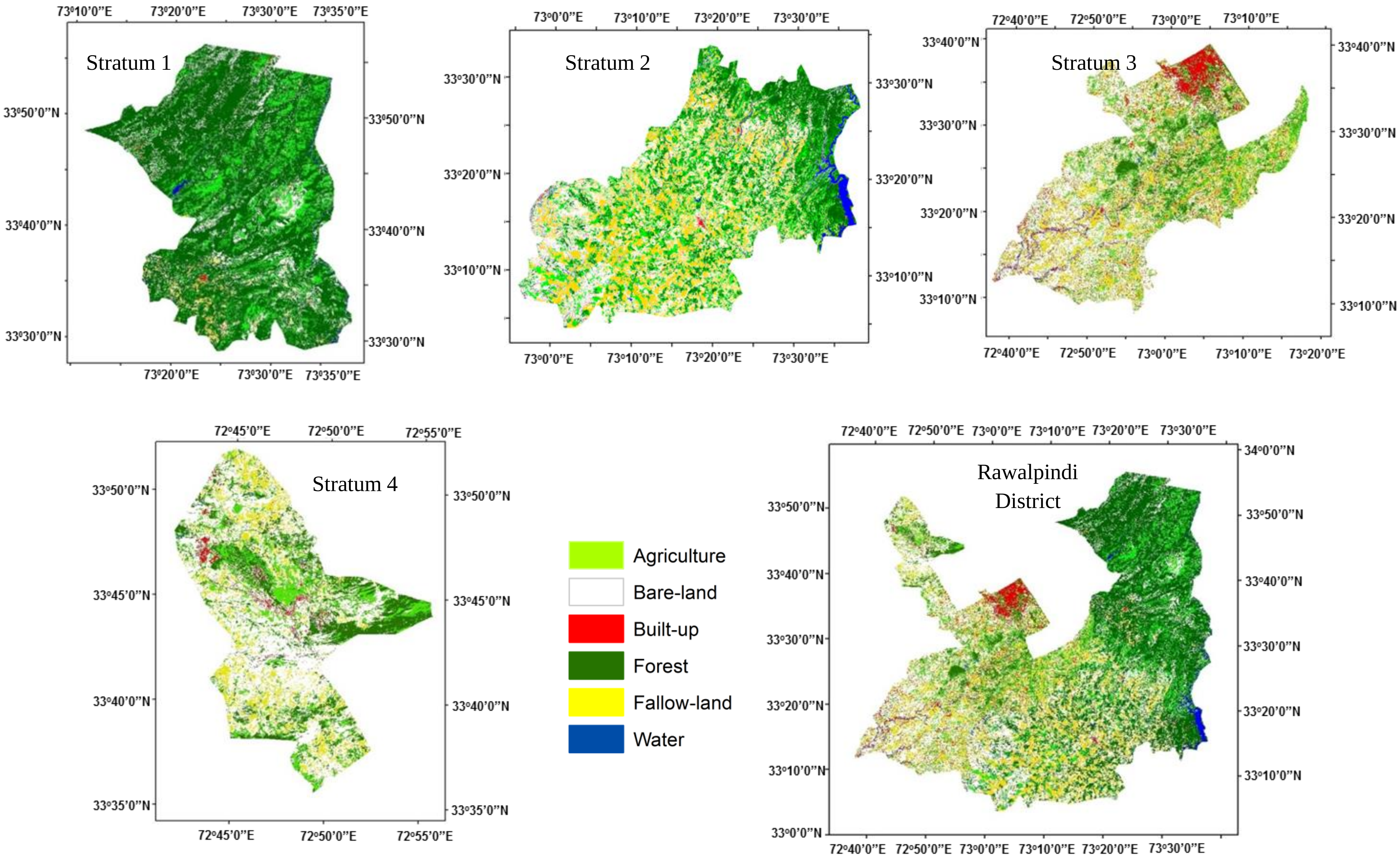
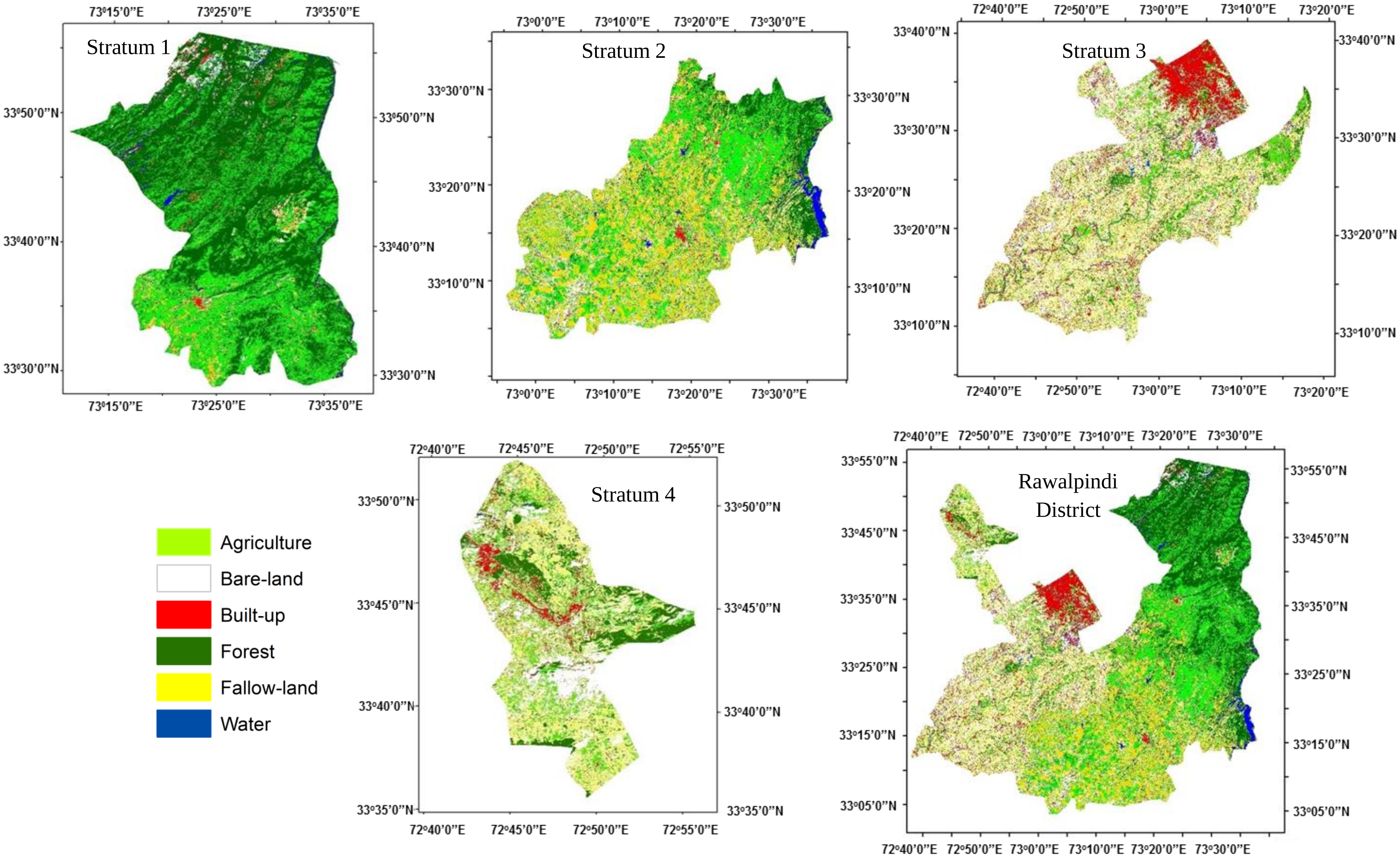


Figure 6.11: Supervised classifications of Landsat TM 2010 of the study area -Rawalpindi district (MLC applied)



SECTION-II

6.4 Evaluation of Classification

Evaluation of anything is generally considered a challenging work; particularly in the field of remote sensing the map generated from any remotely sensed data needs to be assessed whether it has been classified accurately or not. Moreover land cover is a critical variable that links the human and physical environments; therefore accurate and up to date information is required for a plethora of applications such as land resource planning, environmental change and biodiversity conservation (Foody et al., 2004). Evaluations of classification usually have the following objectives:

- to check the data's suitability for a particular purpose
- to learn more about errors in the data and improve the mapping process
- to verify conformance to production standards
- to compare various techniques and algorithms applied

Besides the above, the best reason which attracted the author is that of Congalton and Green (2008). According to them the simplest reason of evaluation is the "curiosity" the desire to know how good something is. This section therefore describes the methods and procedures to get the knowledge about the errors in the classified data for further improvement of the mapping procedures and also to make the data sets suitable for the future users for particular applications.

6.4.1 Accuracy Assessment

Accuracy assessment (AA) is a process of comparing the classification with geographical data i.e. how an estimate is true to its true value. In fact the accuracy assessment reflects the difference between the classification and reference data. If reference data is highly inaccurate, the assessment will show the classification poor. So it is better to get fewer, but more accurate and precisely reflecting land cover reference data. Particularly in the last few years with the widespread integration of remote sensing and GIS, and use of RS data as GIS layers, the need for such an assessment has become even more critical (Luneeta et al 2010). The history of the accuracy assessment of remotely sensed data dates back to 1975. Before this time, although "field checks" were applied as part of interpretation process but no quantitative measures of quality were used. Congalton & Green (2008) divides the history into four development epochs.

First stage:	No real accuracy, rather map “looks good- -mentally prevailed
Second Stage:	Epoch of non-site specific assessment Overall acreage comparison of ground estimates and map estimates without regard of location
Third stage: (1975 to 1980)	Epoch of Site specific assessment Actual ground places were compared to the map places and overall accuracy was computed
Fourth stage (1980 to data)	Epoch of Error matrix Application of significant statistical techniques— Kappa statistics etc.

Several formal and informal project reviews conclude that accuracy assessment is the strength of any project and land cover inventory. While the scientific literature provides a good guidance on field campaigns, sample design and other statistical techniques, the methods that are specific to urban land cover are less often addressed. The present study is an effort to introduce the accuracy assessment in the field of urban land cover analysis. According to Congalton and Green (2008) accuracy assessment data collection requires the completion of the following three steps using both the reference data and the map being assessed.

- The accuracy sample site must be located both on reference data and the map
- Sample units must be exactly the same area on both the reference data and map
- Reference and map data must be collected for each sampled unit

Since the errors in the classification may exist due to misidentification, excessive generalization, mis-registration and mis-assignment of informational categories to spectral categories, therefore based upon the literature review cited above, there were many reasons why this assessment was important for this project, including:

a) to perform self-evaluation and learning and rectifying mistakes
b) to compare methods/ algorithms/analysis work
c) the desire to use the results at home country in planning and decision making.

6.4.1.1 Specific Areas of Activity

The scope of this work was to conduct an assessment of different land covers and urban and non-urban change estimates, therefore specific areas of activity include:

(a) to enhance the methodology to assess the urban and non-urban change

(b) to frame a methodology for accuracy assessment, i.e. to outline *sample design*, *response design* and *analysis design*

The accuracy of the classified maps was assessed by using the following well established procedures.

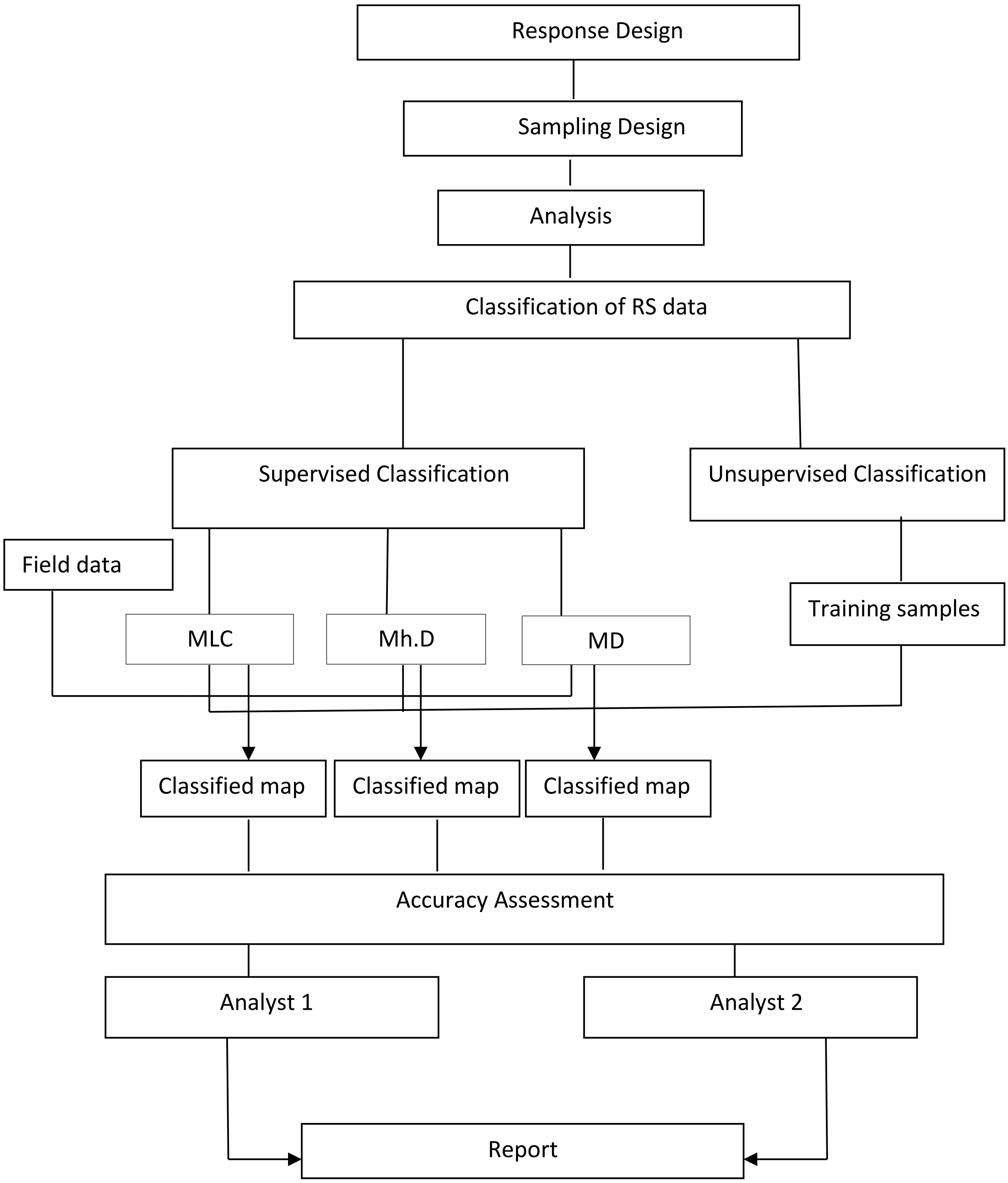
(a) determine the number of sample areas to be assessed
(b) select the sampling procedure
(c) overlay a sampling grid
(d) conduct sampling
(e) error matrices formation

Three major operational phases of thematic accuracy assessment: response design (field methods), sampling design, and data analysis was observed in order to compare the results of the three classifiers used for supervised classification with a goal to derive a statistically robust and quantitative assessment. Fig. 6.12 illustrates the methodology adopted for the accuracy assessment. In order to maximise the degree of independence of accuracy assessment best practice is that this important work should be independently done by some experts not involved in the classification. But in this study, it being the Ph.D. project, it was not completely possible to adopt this rigorous procedure. Despite time and financial constraints, the researcher hired some field assistants to help him in maintaining the field book. Moreover the accuracy has been assessed by two analysts i.e. the researcher and his colleagues (who were also actively involved in data collection and maintain the field book along with the researcher).

6.4.1.2 Response Design

The response design refers to an assessment methodology that produces reference data which can be assumed as having significantly higher accuracy than the map itself. That's why the methodology used in the response design in the study was kept independent from the mapping results that were assessed. As stated above the response design is a kind of field campaign to collect the data at reference sites, therefore the response design summarizes the data sources used for validation of the land cover maps and methodology adopted for the collection of the reference data. Thematic accuracy was assessed using field observations by the researcher and his field assistants as reference sources of higher accuracy.

Figure 6.12: Methodology of Accuracy Assessment



MLC = Maximum Likelihood Classifier; Mh.D = Mahalanobis Distance and MD= Minimum Distance classifier

Although the detailed field strategy has been discussed in the methodology chapter, however for the purpose of this section some important steps are discussed here.

a) Engaging field staff
b) Meeting the local people and government officials to coordinate field campaigns operational needs and restrictions
c) Training the field staff
d) Recording land cover types in the field book using field key and site positions
e) Computing field positional and attribute data into a GIS format

Efforts were made that reference data should be correct and updated which can be independently used to evaluate the results of land cover mapping; realizing that a critical component of any accuracy assessment exercise is the need for appropriate reference data (Powell & Matzke 2004). But sometimes the reference data itself is not up to the mark, which produces results well below the gold standard (Foody 2010; Powel & Matzke 2004). Therefore a key aspect of the response design was to collect and use that reference data that allows the land covers of the study area to be classified with certainty

As this is a PhD project, therefore the digitizing, mapping and all the related work was done by the researcher himself. However during the field campaign, the two field assistants helped the researcher to record the reference data. It is pertinent to mention here that the field assistants mostly helped the researcher to drive into the study area, to familiarize him with the area and locate site positions of various land covers. This was done to avoid the collection of inappropriate reference data. As rightly pointed out by Lunetta et al. (2006) there are numerous examples in the literature documenting collection of improper or inadequate reference data, therefore every effort was made to collect reference information that was true representation of the mapped area. For this purpose video recording of all events at places which were felt to be secure (the security and data protection constraints) were also done with the help of field/ local people. Table 6.3 summarizes the data sets used to validate the occurrence of different land covers, specifying the area covered by each and agency which provided. Fig. 6.13 is a picture of Sharli mauza of Gujjar Khan tehsil, from where some reference data was also collected.

For the purposes of consistency, an accuracy assessment was carried out by a team of two analysts i.e. by the researcher and by another field assistant who is a qualified Engineer and had also maintained his field book while working with the researcher. The results of both analysts are discussed later in this chapter. Although there are no hard and fast rules for an “acceptable accuracy assessment” an overall and class wise accuracy of +80 % was our set standard (for the point estimates of the sample means).

Table 6.3: Data Sources used for validation of land covers of Rawalpindi

Application	Data set used	Date of acquisition	Area covered	Provider/facilitator
Urban and Vegetation Change	SPOT Image (20m)	2008	Jhelum and some parts of Gujjar Khan of Rawalpindi district	SUPARCO, Islamabad
	Google Earth	2011 and 2012	Rawalpindi district	Google Earth
	Landsat TM and Landsat ETM+	2012 and 2011	Rawalpindi	Landsat
	Land use Map of Rawalpindi Tehsil	2005	Rawalpindi city	Survey of Pakistan, Rawalpindi
	District Map of Rawalpindi	2010	Rawalpindi	Survey of Pakistan, Rawalpindi
	Topographic maps of Rawalpindi	1984	Rawalpindi	Survey of Pakistan, Rawalpindi
	Participant Observation (Transacts walks)	2010, 2011 and 2012	Rawalpindi district	Self, and District administration
	Focus group discussions, Interviews	2010 and 2011	Participants from all tehsils	Self, and District administration
	Mauza boundary map of Rawalpindi	2010	Rawalpindi district	Government of Pakistan
	Forest Reports of Rawalpindi	2010	Rawalpindi district	District Forest Office Rawalpindi
	Agricultural statistics of Punjab	2010	Rawalpindi district i	Government of the Punjab, Pakistan
	Development Statistics of Punjab	2009 and 2010	Punjab province including Rawalpindi	Government of the Punjab, Pakistan

In general, the accuracy assessment was considered an important and rigorous component of the project, but time and cost constraints were also of great concern. Nevertheless the researcher has tried to put his best efforts into achieving the best results. No doubt the researcher encountered some problems while applying field observations and methodology in the study area (due to the strategic and administrative sensitivity of the area being very close to the capital) and applying field keys to the more than 450 individual sites which might have led to a gap between expectations and results, but in hindsight some predictions about the overall performance were probably not reasonable given the time, limitations and expertise of the researcher.

Figure 6.13: A typical rural view of Sharli mauza of Gujjar Khan Tehsil

Source: Fieldwork, 2011

In fact response design is primarily tactical and requires a high methodological rigor to produce an acceptable level of accuracy. Moreover the accuracy assessment is influenced at large by the setup of the land covers, reflectance resemblance of the land covers, and the type of the classifier applied. For instance in the beginning, despite all efforts, a class wise accuracy of bare land and built-up area could not be achieved, mainly because of the confusion of the reflectance resemblance of the two lands covers by the classifiers.

6.4.1.3 Sampling Design

Accuracy assessment requires sampling and sampling requires a specific design. In fact the selection of a proper and efficient sample design to collect valid reference data is a big challenge for a researcher; nevertheless it is an important component of any accuracy assessment, because it has to be ensured that the information displayed in the error matrix is a true representation of the map being assessed. Congalton and Green (2009) have observed that several considerations are critical for designing an accuracy assessment sample, such as:

a) How is map information distributed?

b) What should be the size of the sample?
c) How many samples are to be taken?
d) How will samples be taken?

In short, sampling design deals with all methods to select the locations, choosing, and taking of appropriate samples. Although a number of methods are applied for drawing samples from a population, the most commonly used methods are random, stratified sampling, stratified random sampling, systematic sampling, cluster sampling and subjectively representative sampling (Thomson, 2002). Rosenfield & Fitzpatricklins (1986) suggest a stratified systematic sampling procedure to identify the land cover categories in the first stage. Congalton (1991) simulated five sampling strategies using a different number of samples over maps of a forest, with the aim of ascertaining the effect of different sampling schemes on estimating map accuracies. He concluded that great care should be taken in using systematic stratified sampling as these methods could lead to bias, for instance they can overestimate population parameters. Todd et al (1990) argued that cluster sampling can be a good and cheap method to check each sample unit on the ground. Story & Congalton (1986) argued that number of samples may be related to two factors in accuracy assessment.

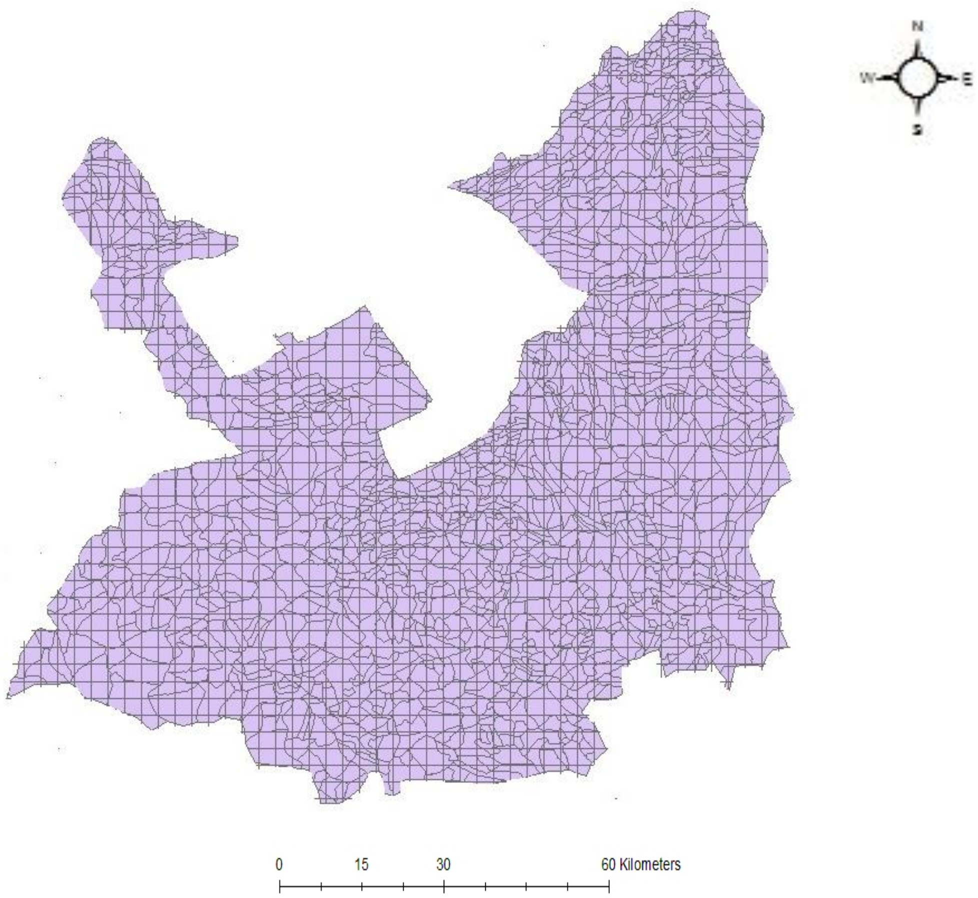
1) Which number of samples is required in order to reject a map as being inaccurate
2) The number of samples required to determine the accuracy within same error bounds for a map

Based upon the above research, to assess the changes in the different land covers, the following sampling design strategy was adopted for the present study.

a) Decide the classes which are to be included or excluded from assessment
b) Decide the area of all classes to be included in the assessment
c) Determine sample size for each class
d) Determine individual class inference area
e) Allocate site to individual class inference area
f) Find site coordinates from field book
g) Load coordinates

The sampling design employed in this research is stratified random sampling. A sufficient number of observations (25 to 40) for each class from each stratum (except water) were taken to make a clear-cut statement about the accuracy of each class. Prior to the individual class accuracy, a short sample total of 30 observations were also chosen to validate the entire map and to evaluate the overall map accuracy for acceptance or rejection of a map. To take appropriate samples through a methodology of stratified random sampling, first a square grid of 3 kms x 3 kms in size was created within the spatial extent of the Rawalpindi District boundary of the study area. A total of 1120 grid squares were created; but 845 squares were included in the designs which were within the boundary of the study area (Fig. 6.14). Secondly the tehsil boundary containing mauzas were overlaid on the classified map. Since the details of land cover and population statistics were available for each mauza and moreover average size of each mauza was also between 2.5 km, therefore the mauza boundary was considered to be a second grid on the classified map.

Figure 6.14: A grid of 3x 3 km in size created within the district boundary of Rawalpindi



As the built-up area is clustered around a small area as compared to other land cover which are spread over the whole area, therefore a stratified sampling frame work was adopted. Based on mauza statistics and geographical boundaries of the mauzas, grids were stratified according to the factors closely related rural areas and urban and peri urban areas. Two main stratum i.e. urban areas and rural areas were thus created and random samples for each land cover were taken proportionally. With each grid square a systematic sample of a land cover appropriate to that grid was selected from both strata. Table 6.4 summarizes the area represented by each stratum.

Table 6.4: Area represented by each stratum of Rawalpindi District

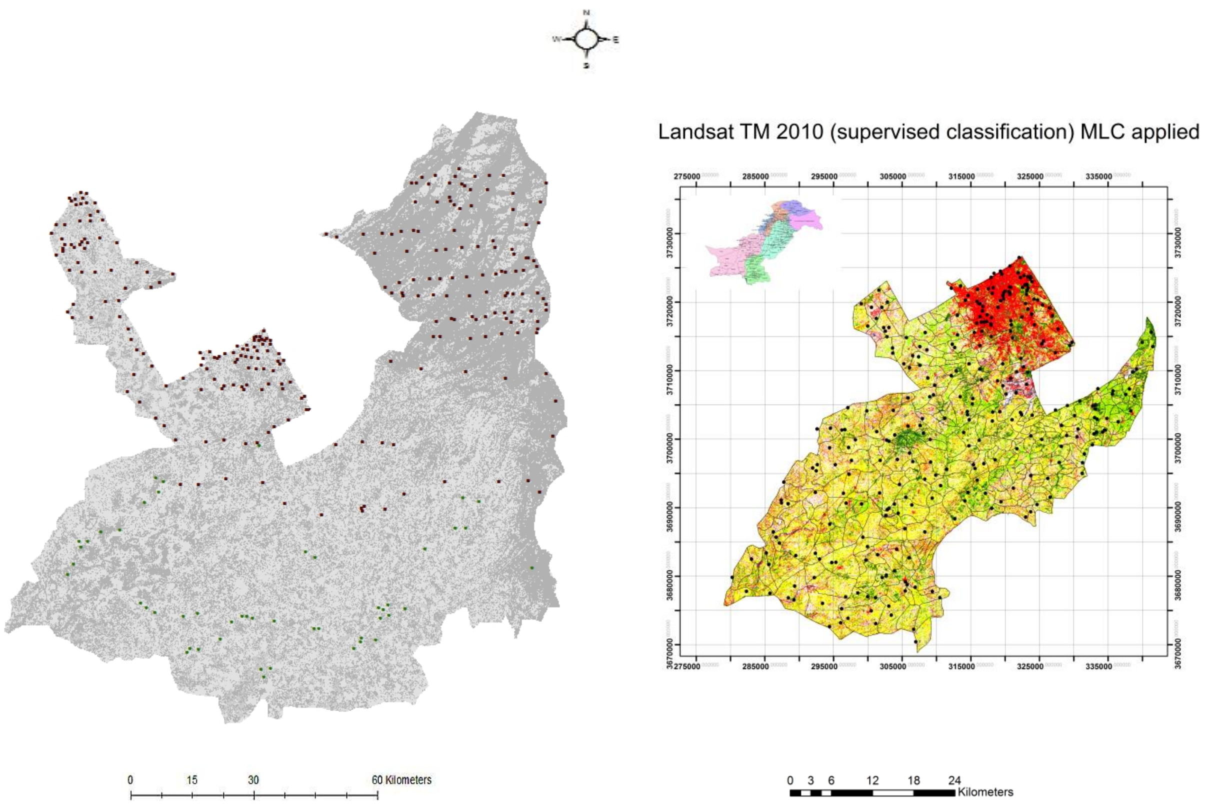
Stratum	Total number of squares	No. of samples collected	Per cent of the stratum
Total District	845	410	100
Urban and peri urban Stratum (taken from each tehsil)	400	300	75%
Rural stratum	445	110	25%

Source: Author

As shown in the Table 6.4, a total of 845 square grids were selected for sample collection. The urban and peri urban stratum contained 400 squares which were nearly 47% of the total grids, while the rural stratum contained 53% of the grids. Since the land use map suggested that rural stratum has a low probability for loss of vegetation as compared to the urban and peri urban areas, therefore urban and peri urban stratum was considered as *high vegetational loss risk areas* and rural stratum as *low vegetational loss risk* areas respectively. Samples were selected according to the importance of the region, and supplementary samples of all land covers were collected from the high risk stratum. The table suggests that the proportion of the two regions is 47: 53 respectively, but keeping in view the accessibility, the loss of agricultural and forested land in urban and peri urban areas, time and financial constraints, a total of 410 samples were taken from both strata.

A random sample of 300 grid squares was collected from the high risk stratum which constituted exactly 75% of the grids of the stratum and 35 % of the total grids. 110 samples were collected at random from low risk i.e. rural grids which were 25% of the stratum and 13 % of the total grids. Stratum 3 (Rawalpindi tehsil) is headquarters of the district and expanding very rapidly. Almost 80 % of the built-up area of the total study area falls in this tehsil. Therefore an accuracy assessment of this stratum was done independently as well. 212 samples were taken randomly from this stratum using the same procedure as adopted for Rawalpindi District. Fig.6.15 illustrates the sampling stratification strategies of both regions i.e. Rawalpindi district and the Rawalpindi tehsil. Red dots in the fig. 6.19 show high risk of conversion and green dots show low risk.

Figure 6.15: Sampling stratification map



Rawalpindi District (Study Area) Stratum 3 (Rawalpindi Tehsil)

6.4.1.4 Analysis and Estimation

The accuracy assessment of 2010 images of the study area was done using the data given in Table 6.3. During the FGD and interviews with local inhabitants, farmers and policy makers questions were asked about the past land use and preliminary classified maps of the study area were corrected accordingly with help of the local people, this data along with the past maps and other sources were used for accuracy assessment of 1972, 1981, 1990, and 1998 imageries. The accuracy assessment procedure for Landsat TM 2010 for both Rawalpindi district and tehsil is given in the following paragraphs.

The accuracy assessment was done in two ways.

1) The accuracy assessment of LULC data of Rawalpindi district as a whole. In this study 410 randomly selected reference points collected from field visits and other reference data were used for accuracy assessment.

2) The accuracy of LULC data of a single stratum comprising of Rawalpindi tehsil was assessed using the three classifiers i.e. Maximum likelihood, Minimum Distance and Mahalanobis Distance.

The classified maps are employed in a wide array of applications such as assessment of land cover changes and an input of land use planning decisions. But no land classification project is completed until an accuracy assessment method concisely assesses the land cover changes. Thus the analysis is the procedure of validation of reference points within each grid square. The stratum wise recorded data was used to generate a cross tabulation between reference data and the classified data. And the error matrix has been adopted to summarize and describe accuracy of land cover changes (Biging et al., 1998; Macleod and Congalton, 1998; Van Oort, 2007; as cited in Stehman, 2009).

The quality of the classified images of Rawalpindi strata using MLC, MD and Mh.D classifiers was assessed with the use of an error matrix (also called a confusion matrix or contingency table). This error matrix calculates the accuracy of the classified classes with respect to the reference data. The error or confusion matrix is a square array of numbers that express the number of sample units assigned to a specific category in one classification relative to the labels of samples assigned to a specific category in another classification (Congalton and Green 2009). Usually the columns are assumed to be correct and termed as reference data while the rows are usually used to display the classified data. The major diagonal of the matrix represents the agreement between the two data sets, i.e. reference and classified data. Error matrices are very effective representatives of map accuracy, as the individual accuracy of each class is plainly described with both the errors of inclusion and errors of exclusion. Error of inclusion or *commission error* and error of exclusion or *omission error*, both occur due to misclassification error of the classifier, therefore both are also known as misclassified error. A *commission error* occurs when a classifier assigns a label to those samples which actually belonged to other category. Whereas an *omission error* occurs when a sample is excluded or omitted by the classifier from the category to which it actually belonged (Congalton and Green 2009). The columns of the error matrix defined the classes in the reference data, rows defined the classified classes of the image and the diagonal elements of the matrix indicated correct classification. Congalton and Green (1993) recommended the error matrix or contingency table as a jumping-off point for identifying sources of confusion and not just error in the remotely sensed classification. Table 6.5 shows the error matrix of the classification of Landsat TM 2010 of S3 (Rawalpindi tehsil) used to calculate the commission error, omission error, Kappa Index and Overall accuracy.

Table 6.5: Error matrix of classified image of Landsat TM 2010 of (S3) Rawalpindi Tehsil

	Class image	**Reference data**							**Column Total**	**User's Accuracy (%)**	**CE (%)**
		W	**FL**	**Ag**	**DUV**	**F**	**Bup**	**BL**			
Classified data	W	**9**	0	0	0	0	0	1	10	90.00	10.00
	FL	0	**28**	2	0	0	0	0	30	93.33	6.37
	Ag	0	1	**31**	2	0	0	0	34	91.18	8.82
	DUV	0	0	1	**31**	2	0	0	34	91.18	8.82
	F	0	1	0	4	**34**	0	0	39	89.47	10.53
	Bup	0	0	1	0	0	**29**	4	34	85.29	14.71
	BL	1	0	0	1	0	12	**17**	31	54.84	45.16
Column total		10	30	35	38	36	41	22	212		
Producer Acc. (%)		90.00	93.33	88.57	81.58	89.47	70.73	77.27	**Over all accuracy: 84.43**		
Omission error		10	6.67	11.42	18.42	10.53	29.23	23.73	**Over all Kappa coefficient: 0.8117**		
Kappa for each class		0.81	0.89	0.89	0.89	0.87	0.82	0.50			

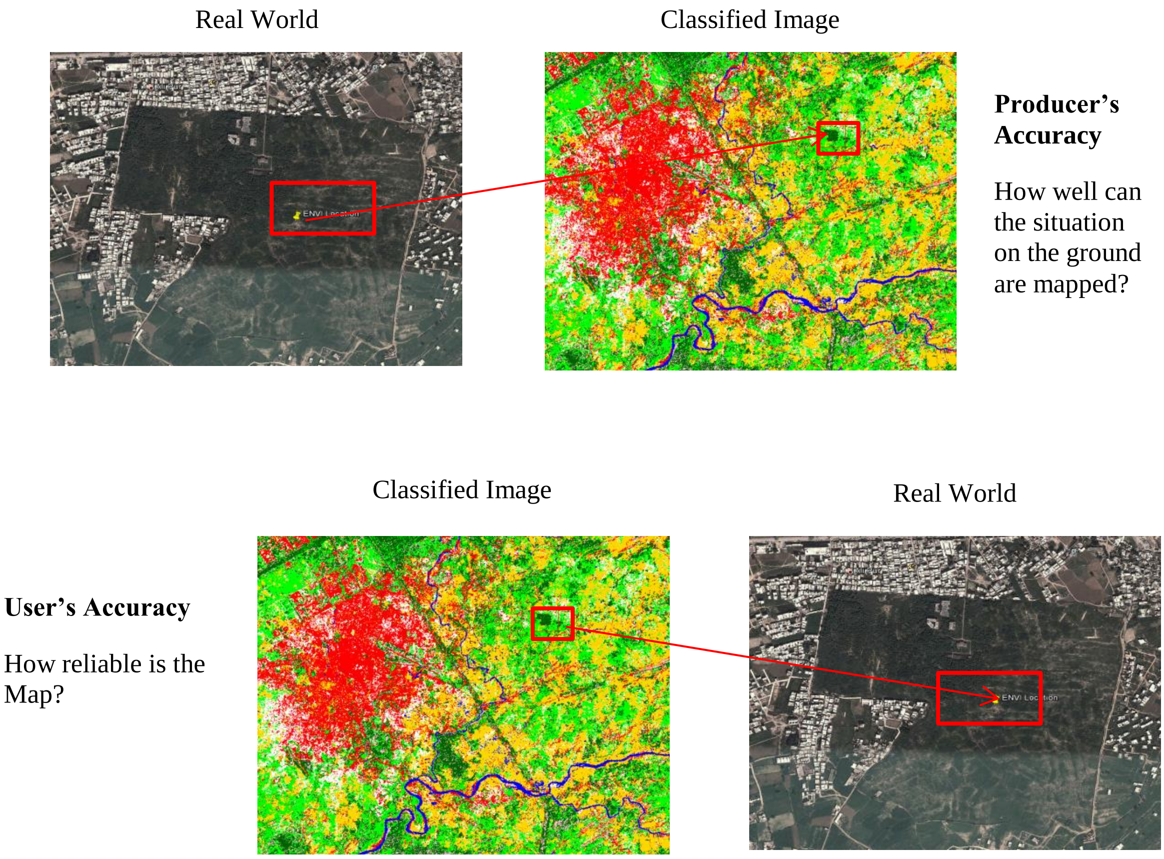
(W= Water, Ag. = Agriculture, DUV = Dense Urban Vegetation, F = Forests, FL = Fallow-land, Bup= Built-up, BL = Bare land, CE=Commission Error)

The diagonal elements of the matrix indicated a correct classification. Therefore an overall accuracy of the classification was calculated by dividing the sum of correctly classified sample units, i.e. values that lie on the diagonal (bold values) by the grand total number of sample units in the entire matrix. In this case (9+28+31+31+34+29+17) /212 = 0.84.43 or 84.43 %. The overall accuracy can be mathematically expressed as:

$$Oveall\ accuracy = \frac{€(\text{total of sample units along the diagonal})}{€(\text{values of all sample units in the matrix})}\ x\ 100$$

This index is however known as a crude measure of accuracy, as it results is often misleading due to the fact that a certain number of correct classifications may occur by chance (Congalton, 1991). Moreover an overall accuracy does not tell anything about the individual classes. However to solve this problem per class accuracies can also be extracted from the error matrix and can be useful if differentiated into producer's and user's accuracies. Producer's accuracy, also referred to as error of omission, calculates the probability that how exactly a reference sample has been classified correctly. It is defined as the ratio between the number of correctly classified sample units and total number of units in that column. User's accuracy, which represents the commission error, is the percentage of pixels labelled in an incorrect class. This is calculated by finding the ratio between number of correctly classified sample units and the total samples in that row (reference data). Producer's accuracy is an important measure of how well the situation on the ground can be mapped while the user's accuracy on the other hand measures how reliable the map which has been produced is compared to the ground truth or real world. Fig. 6.16 further illustrates the general concept of the both types of accuracies.

Figure 6.16: Conceptual framework of Producer and User's accuracy



Source: Adopted from Al-Ali, 2011

The commission error and omission errors are simply calculated as follows:

Commission error = $1 - Consumer's\ or\ User's\ accuracy$

Omission error = $1 - Producer's\ accuracy$

The Kappa coefficient (K) uses all elements of the matrix and not just the diagonal one. It statistically measures the relationship between beyond chance agreement and expected disagreement, and is an indicator of the extent to which the correct values of an error matrix are due to “true “agreement versus “chance” agreement. In other words K is the proportion of agreement after chance agreement is removed from consideration. The value of K ranges from 0 (worst) to 1 (best). Landis and Koch (1977) divide the Kappa into three groups: a) a value greater than 0.80 represents strong agreement, b) a range value of 0.40 to 0.80 represents moderate agreement; and c) a value less than 0.40 represents poor agreement. Kappa analysis provides following two statistical tests of significance (Congalton, 2009).

1) Whether a land cover map generated from satellite data is significantly better than a map generated by randomly assigned labels to area
2) Comparison of two matrices to see the difference of methods/algorithms/analysts

The Kappa coefficient on the basis of the values given in Table 6.5 has been calculated with the help of following formula. Table 6.6 shows the Kappa statistics of error matrix calculated for classified image of Landsat TM 2010 for S3 (Rawalpindi Tehsil).

$$K = \frac{\text{Observed Correct} * - Expected\ correct}{1 - Expected\ correct}$$

* observed correct = Over all accuracy

Table 6.6: Kappa Statistics of error matrix of Landsat TM 2010 (S3-Rawalpindi Tehsil)

	W	FL	Ag	DUV	F	Bup	BL		
W		0	0	0	0	0	1	0.047[49]	0.002225
FL	0		2	0	0	0	0	0.142	0.020025
Ag	0	1		2	0	0	0	0.160	0.026477
DUV	0	0	1		2	0	0	0.160	0.028747
F	0	1	0	4		0	0	0.184	0.031239
Bup	0	0	1	0	0		4	0.160	0.031016
BL	1	0	0	1	0	12		0.146	0.015174
	0.047[50]	0.142	0.165	0.179	0.170	0.193	0.104		**0.154904**

P expected correct = (0.047 x 0.047 = 0.002225) + (0.142 x 0.142= 0.020025) + (0.160 x

[49] Row total/ total reference points
[50] Column total/total reference points

0.165=0.026477) + (0.160 x 0.179 = 0.028747) + (0.184 x 0.170 =0.031239) + (0.160 x 0.193=0.031016) + (0.146 x 0.104 = 0.0151740)

P expected correct = 0.15904

$$K = \frac{0.84-0.1590}{1-0.15904} = \frac{0.15904-0.84}{1-0.15904} = 0.8117$$

Diagonals represent the sites classified correctly according to the reference data while off-diagonals show misclassified. Tables 6.5 & 6.6 demonstrates that out of the 10 water samples only one sample was misclassified as bare land. Similarly out of 30, 34, 34 and 39 samples of fallow land, farmland, dense urban vegetation, and forest, 28, 31, 31 and 34 samples were correctly classified in their corresponding classes. However, great confusion occurred in classifying the bare land and built-up areas. For instance out of 34 samples of built-up areas, 29 were classified as built-up and 5 samples were misclassified. Among the misclassified samples, 80 % belonged to bare land. The reference samples of bare land showed a different story. Out of the 31 samples the classifier wrongly classified 12 samples as built-up areas. This means that almost 40% of the samples which actually belonged to bare land were wrongly classified as built-up areas thereby increasing the proportion of the built-up area of the classified map. This confusion occurred due to the reflectance resemblance of these land covers. Moreover the building material bricks, rock blocks and mud bricks used in the construction of buildings is another reason. Although the correspondence of 84.43 % overall accuracy demonstrates an acceptable agreement between the mapping and sampling units, because of some broad classes, yet the variation occurred in the individual classes.

The producer's accuracies for water, fallow-land and forest were almost the same as their correspondence user accuracies. However for agriculture and dense urban vegetation their producer's accuracies were slightly lower than the user's accuracy. By analysing the off-diagonal element, major spectral confusion was found between bare land and built-up areas which affected the accuracies of both classes. The producer's accuracy of the built-up area was less than the user's accuracy. Unlike all other classes the producer's accuracy of bare land was much higher than its user's accuracy. The Kappa statistic was calculated from the results of the land cover classification, with seven classes shown at the bottom of the confusion table. This implied that the K value of 0.8117 and a variance of 0.1888 represented a probable 81 per cent accuracy resulting from a maximum likelihood classification. According to the Kappa agreement scales discussed in the preceding paragraphs, the classification denotes good agreement. On the basis of above calculations, the accuracy assessments classifications of all images i.e. T1, T2, T2.5, T3 and T4 were done which is shown in section 6.7

6.5 Consistency

As discussed above, the validation team consisted of the two people (the researcher and his highly qualified colleague). Both of us visited the study sites and actively participated in collecting field data, maintained our independent field books and agreed upon the definitions of the different land cover types. Moreover both of us were familiar with the satellite images, topographic maps and other sets of data which were used for validation. A blind replication of the same area was used by both of us, and on the basis of our independent field books both of us analysed the grids independently. The results of the author have already been discussed above. Table 6.7 shows the comparisons of the results of the second analyst with the researcher. It is important to mention here that the second analyst was not aware of the reference data used by the researcher as training samples; therefore there was a probability that he might have used some reference points which were already used as training samples.

Table 6.7: Agreement among interpreters

Class	Interpreter 1			Interpreter 2		
	Producer's accuracy	**User's accuracy**	**Kappa Coefficient**	**Producer's accuracy**	**User's accuracy**	**Kappa Coefficient**
Water	90.00	90.00	0.93	98.00	92.00	0.95
Fallow land	93.03	93.33	0.91	89.00	87.00	0.87
Agriculture	88.57	91.18	0.89	77.00	80.00	0..76
Forest	81.85	91.88	0.89	76.00	88.00	0.81
Dense urban veg	89.47	89.47	0.85	91.00	88.00	0.87
Built-up	70.73	85.29	0.76	62.00	78.00	0.73
Bare land	77.27	54.84	0.47	62.00	63.00	0.41

(The overall accuracy of the interpreter 1 and interpreter 2 was 84.5 and 83.7 respectively.)

Secondly the researcher used stratified random sampling procedure, but the second analyst used a simple random sampling technique. Thirdly the researcher used 212 samples while the second analyst used 150 samples, 15 for water, and 20 each for fallow land, forest, and dense urban vegetation, 25 each for, agriculture, bare land, and built-up classes. This exercise was done with a view to check that how location, total number of samples and individual number of samples within each class effects the accuracy results. The results demonstrate that it is difficult to achieve a level of accuracy assessment that is better than 90 %. The consistency comparison demonstrates that introduction of the second and independent analyst can help in future studies to reduce interpreter's bias. However it would again need a good set of data and sufficient training of the interpreters. This comparison of consistency did not allow attributing any error value to the reference data.

6.6 Comparison of Three Classification Methods

Based upon the classification results of the Rawalpindi stratum, some refinements were made in response and sample design for accuracy assessment of the one stratum of Rawalpindi district (study area). In this comparison first of all the efficiency of all three classifiers were checked comparatively on the smaller area. Secondly the samples were chosen proportional to the land cover area, from the classified map of MLC classifier. Thirdly a random size of 4000 pixels was fixed for all land cover classes, for the accuracy assessment of the classifiers. As for as change in the data sets used for validation is concerned, in this comparison only those reference points were used for accuracy assessment of the classification which were directly collected from the field during the field campaign. The error matrix and the associated accuracies were computed by three classifiers used for supervised classification for the single stratum (Rawalpindi tehsil) which produced three error matrices. Table 6.8 describes the summary of the thematic maps produced using the three methods (see Fig. 6.6). The error matrices for the three classifiers have been shown in Tables 6.9 (a-c).

Table 6.8: Tabular Summary of thematic maps produced using MLC, MD and Mh.D classifiers

Classes	MLC		MD		Mh.D	
	No. of pixels	Area (ha^2)	No. of pixels	Area (ha^2)	No. of pixels	Area (ha^2)
Water	38995	3545	54014	4910	39212	3565
Agriculture	186021	16911	234062	21278	182043	165476
Fallow land	649286	59026	756202	68746	810216	73656
Dense urban veg.	13442	1222	36010	3274	9002	818
Forest	119042	10822	72019	6547	117031	10639
Built up	291500	26500	576154	52378	320485	29135
Bare land	502194	45654	72019	6547	338490	30772

From Table 6.8 it can be seen that the land cover calculations from the three classifiers are varying. Water pixels were identified almost the same by both the MLC and Mh. D classifiers, but MD estimated more. Agriculture and forest categories were also classified by both the MLC and Mh.D classifiers in the same manner, however bare land was underestimated by Mh.D as compared to MLC but on the other hand MD calculated bare land as 7 times less than MLC. Built up areas was overestimated by MD. On the whole MLC and Mh.D calculation are with some exceptions similar, but the MD calculations for all categories are not only different to other two classifiers but also against the ground truth data.

Table 6.9: Accuracy Assessment error matrix of (a) Maximum Likelihood (b) Mahalanabis Distance and (c) Minimum Distance Classifiers on Rawalpindi Tehsil (Landsat TM 2010)

(a) Maximum Likelihood Classifier

Class name	**Producer's accuracy**	**Omission error**	**User's accuracy**	**Commission error**
Water	90.00	10.00	90.00	10.00
Fallow land	93.33	6.67	93.33	6.337
Agriculture	88.57	11.42	91.18	8.82
Dense urban veg.	81.58	18.42	91.18	8.82
Forest	89.47	10.53	89.47	10.53
Bare land	70.73	29.23	85.29	14.71
Built-up	77.27	23.73	54.84	45.16
Over all classification accuracy		84.43		
Over all Kappa Statistics		0.812		

(b) Mahalanabois Distance Classifier

Class name	**Producer's accuracy**	**Omission error**	**User's accuracy**	**Commission error**
Water	90.00	10.00	90.00	10.00
Fallow land	88.18	11.82	92.18	7.82
Agriculture	86.00	14.00	81.00	19.00
Dense urban veg.	82.15	17.85	85.67	14.33
Forest	87.50	12.50	89.13	10.87
Bare land	74.50	25.50	78.56	21.44
Built-up	85.00	15.00	62.50	37.50
Over all classification accuracy		77.13		
Over all Kappa Statistics		0.691		

(c) Minimum Distance Classifier

Class name	**Producer's accuracy**	**Omission error**	**User's accuracy**	**Commission error**
Water	90.00	10.00	90	10
Fallow land	75.33	24.67	71.23	28.77
Agriculture	69.00	31.00	69.23	30.77
Dense urban veg.	72.00	28.00	58.3	41.7
Forest	83.00	17.00	53.51	46.49
Bare land	51.00	49.00	61	39
Built-up	62.50	37.50	35.56	64.44
Over all classification accuracy		63.18		
Over all Kappa Statistics		0.512		

It can be seen from the analysis of the Table 6.9 a-c, that best overall classification method is the Maximum Likelihood, with an overall accuracy of 84.43 % and Kappa statistics of 0.81 showing a very good agreement among classified data and the reference data. As discussed in the preceding sections that Mahalanobis Distance works almost on the same patterns of MLC and calculates the same statistics, therefore it was the second best with an overall accuracy of 77.13 and Kappa statistics of 0.691. The Minimum Distance Classifier showed the worst results, having an unacceptable overall accuracy of only 63.18 and Kappa agreement statistics of just 50 %.

6.7 Accuracy of the Classifications

6.7.1 Accuracy of the Classification 1972

The results of the assessment of the classification accuracy showed in Table 6.10 yielded an overall accuracy of 75.16 % with an overall Kappa of 71%. The producer and User's accuracies for the various land cover categories are shown below.

Table 6.10: Accuracy Assessment of the Classification map derived from Landsat MSS 1972

Class Name	Classified Total	Correct Classified	Producer's Accuracy (%)	User's Accuracy (%)
Agriculture	34	25	80.6	73.5
Bare land	30	17	54.8	56.7
Built-up	30	24	68.6	80.0
Forest	30	25	86.2	83.3
Fallow land	30	22	78.6	73.3
Water	15	14	100	93.3

6.7.2 Accuracy of the Classification 1979

The results of the assessment of the classification accuracy showed in Table 6.11 yielded an overall accuracy of 72.5 % with an overall Kappa of 69%. The producer and User's accuracies for the various land cover categories are shown below.

Table 6.11: Accuracy Assessment of the Classification map derived from Landsat MSS 1979

Class Name	Classified Total	Correct Classified	Producer's Accuracy (%)	User's Accuracy (%)
Agriculture	40	31	91.1	77.5
Bare land	39	21	56.8	53.4
Built-up	36	24	66.7	57.1
Forest	25	23	92.0	95.8
Fallow land	32	23	62.2	71.8
Water	17	15	100	86.4

6.7.3 Accuracy of the Classification 1992

The results of the assessment of the classification accuracy showed in Table 6.12 yielded an overall accuracy of 80.5 % with an overall Kappa of 73%. The producer and User's accuracies for the various land cover categories are shown below.

Table 6.12: Accuracy Assessment of the Classification map derived from Landsat TM 1992

Class Name	Class Name	Classified Total	Correct Classified	Producer's Accuracy (%)
Agriculture	47	42	92.8	88.6
Bare land	45	30	60.0	67.5
Built-up	41	29	72.1	71.6
Forest	34	32	96.7	93.8
Fallow land	41	31	76.6	76.6
Water	21	20	100	93.6

6.7.4 Accuracy of the Classification 1998

The results of the assessment of the classification accuracy showed in Table 6.13 yielded an overall accuracy of 84.5 % with an overall Kappa of 80%. The producer and User's accuracies for the various land cover categories are shown below.

Table 6.13:: Accuracy Assessment of the Classification map derived from Landsat MSS 1998

Class Name	Classified Total	Correct Classified	Producer's Accuracy (%)	User's Accuracy (%)
Agriculture	40	38	100	95
Bare land	40	25	69.4	62.5
Built-up	37	31	70.5	73.8
Forest	32	32	96.7	100
Fallow land	32	26	83.9	86.7
Water	20	18	94.8	81.8

6.7.5 Accuracy of the Classification 2010

The results of the assessment of the classification accuracy showed in Table 6.14 yielded an overall accuracy of 87.1 % with an overall Kappa of 83%. The producer and User's accuracies for the various land cover categories are shown below.

Table 6.14: Accuracy Assessment of the Classification map derived from Landsat TM 2010

Class Name	Classified Total	Correct Classified	Producer's Accuracy (%)	User's Accuracy (%)
Agriculture	80	74	90.1	91.1
Bare land	80	45	77.2	54.8
Built-up	80	73	71.6	85.3
Forest	70	68	91.9	97.3
Fallow land	65	64	90.9	93.3
Water	35	33	91.0	90.0

The Accuracy assessment for the years 1972 (T1), 1979 (T2), 1992 (T2.5) and 1998(T3) was computed based on the random reference points collected from topographic maps, district maps, interviews, focus group discussions and various other sources mentioned in the chapter six. The accuracy assessment of the 2010 (T4) classification was based on the stratified reference points mostly collected during the author's field survey, and other data sources which has been described in Table 6.3 above.

The above tables show the agreement between the reference points and classified data. It is pertinent to mention here that accuracy of the classification of Landsat MSS (1972 and 1979) was lower as compared to Landsat TM. The main reason was the spatial resolution of two sensors. In general the similarity of spectral reflectance of some land use classes e.g. bare land and built-up land; agriculture and fallow land; bare land and fallow land was one of the reasons for not having a higher accuracy.

As shown above, the lowest accuracy was of the 1979 classification, which was 72.5 %. The highest accuracy was of 2010 classification which was 87.1%. The overall accuracy of 1972 classification was little bit higher than 1979, but both were less than 80%. The overall accuracies of 80.5%, 84.5%, and 87.1 % for 1992, 1998, and 2010 classifications showed a good agreement between classified and reference data. However a constant confusion of 20 to 30 % between bare land and built-up persisted in all classifications, which suggested a degree of overlap between these classes. This confusion was comparatively greater in MSS images and occurred because of the spectral similarity of the two classes.

Confusion was also seen between agricultural and fallow-land/grasslands in some classifications. This can be explained by the fact that the farming system in the region consists of the growing of crops in rotation, leaving some land fallow to retain the fertility. But this land contains some green material from the last crop. Moreover in these fallow lands grass grows very quickly due to frequent rainfall. Another reason is that sometimes in these fallow lands farmers intentionally leave some roots or stubble of old crops, which they later burn in the fields to make the land fertile. For the reasons some of the farmlands/bare-lands/fallow-lands are likely to be underestimated since some might been mapped as agricultural fields, which was possibly over estimated.

The most accurately classified land cover was water bodies, with over 90 % both producer's and user's accuracies. This was followed by forest, which had Producer's accuracy of 86.2%, 92%, 96.7% 96.7%, and 91.9% and user's accuracy of 83.3%, 95.8%, 93.8%, 100%, and 97.3% in 1972, 1979, 1992, 1998, and 2010 classifications respectively. The producer's and user's accuracy figures for built-up category for the above five classifications were 68.6% & 80%; 66.7% & 57.1%; 72.1% & 71.6%; 70.5% & 73.8%; and 71.6% and 85.3% respectively. While bare land was the least accurate category having producer's and user's accuracies of 54.8% & 56.7%; 56.8% & 53.4%; 60% & 67.5%; 69.4% & 62.5%; and 77.2% & 54.8% in the above five time periods. The "agriculture" class was also well separated having producer's and user's accuracies of 80.65% & 73.5%; 91.1% &77.5%; 92.8% & 88.6%; 100% & 95%; and 90.1% & 91.1% respectively. The fallow-land/grassland category was classified at 78.6% & 73.3%; 62.2% & 71.8%; 76.7% &

76.7%; 83.9% & 86.7%; and 90.9% & 93.3% producer's and user's accuracies in 1972, 1979, 1992, 1998, and 2010 years.

6.8 Conclusion

This chapter explained the land cover mapping using digital classification and accuracy assessment of the classifications of all time periods. The first section described the land cover mapping using unsupervised and supervised classifications. The results of unsupervised classification showed that it cannot be used to identify urbanization. Therefore, the adopted approach was supervised classification. The collection and analysis of the training data, the signature separability, and Anderson et al.'s (1972) modified scheme of classification were discussed in detail in this section. The application and comparison of different classifiers (within the supervised classification), on the study area as a whole and on individual strata is also an important topic of this section. The results of the different classifiers indicated that the Maximum Likelihood is the best classifier. The main outputs of this section were the classified land cover maps of the study area (stratum wise and as a whole) compatible to the census years around which the whole thesis revolves.

The second section dealt with the accuracy assessment of the thematic maps. In this section the detailed discussion has been made on the response design, sampling methodology and analysis techniques. The error matrices were generated for the assessment of the classified images of 1972, 1981, 1992, 1998, and 2010 and overall, producer's and user's accuracy and Kappa coefficient has been estimated. The comparison of the different classifiers used in supervised classification was also made on the basis of the confusion matrices and the producer's, user's and overall accuracies of the classifiers respectively. The results showed that every classifier could not easily differentiate the bare land and built-up areas. Nevertheless the Maximum likelihood classifier was found to be most satisfactory as its results were up to the mark. To make the results more consistent, the accuracy assessment exercise was also performed by another interpreter. The results showed good agreement between both Researcher and his colleague interpreters.

Both sections make the basis for quantifying land cover and urban land cover change in the study area from 1972 to 2012.

7 DYNAMICS OF LAND USE/COVER CHANGE

7.1 Introduction

This chapter describes the assessment of land use and land cover changes of Rawalpindi district during the period of 1972 to 2012. The relationship between this chapter and rest of the study has already been illustrated in Fig. 3.1 (Chapter 3), which shows the major steps in the methodology used for the overall study.

The maps produced from the Landsat classifications of 1972, 1979, 1992, 1998, and 2010 are used to ascertain the extent and distribution of land cover changes in the study area (Objective 3-Table 1.1). What are their quantities and how are they distributed across the area? Since there are variations in the landforms, population growth rate and economic activities, this study also sought to answer the question as to whether there are variations in the intensity of changes across the various subunits of the study area.

In this study there were two reasons to select images from years 1972, 1979, 1992, 1998, and 2010 images for change detection analysis. First, the census records of 1972, 1981, 1998 and 2012 allow this research to examine the change and relate it with the population estimates calculated from the censuses reports. Secondly, as noted above the 1998 census were not held at a decadal interval and there were delays of 17 years (1981-1998), therefore irregular gap between these two censuses did not portray the true story of change. Hence to bridge this big gap an additional image of 1992 has been used. The selection of the 1992 image in addition to 1972, 1979, 1998 and 2012 would not only allow the change to be estimated approximately at an equal interval, but would also enable the identification of trend and growth of different land covers types at an approximate equal interval. This will throw some light on what would have happened had the censuses been held after every ten years, as planned.

The analysis recognises that satellite-based mapping can be subject to error (Sannier, 2000; Foody, 2004). Since these errors are transferred into the change analysis (Congalton and Green, 1999; Coppin et al., 2004), there is also need to analyse the errors, which may in turn improve the estimates as well (Biging et al., 1998; Pontius and Lippitt, 2006; Van Oort, 2007). Therefore while calculating the areas of land cover classes the error envelope of each classification has been taken into consideration.

This chapter is divided into four sections: The second section describes the changes of each land cover according to regions and location of intensive change. It further provides summary estimations of land covers and changes, both stratum-wise and for the whole study area. Land cover transition matrices for inter-censal periods such as 1972 to 1981 (T2-T1), 1981 to 1998 (T3-T2), 1998 to 2012 (T4-T3) and 1972 to 2012 (T4-T1) are presented in this section for the analysis of persistence, loss, gain and swap of each land cover that occurred for pairs of classifications. Moreover change detection error matrices are also presented in this section for computing change detection and transition detection accuracies of different classifications. Since the major and abrupt changes have occurred in the Rawalpindi tehsil of the study area, therefore the fifth section throws light on the land cover statistics of the Rawalpindi tehsil only. The final section concludes the whole story of land assessments of the study area during the last four decades.

7.2 Analysis of Land Use Areas Change

This section analyses the changes in land use from a general perspective by looking at each of land use category and their transitions. The area of each land use has been calculated from the classification results (Chapter 6). The classified land use/ cover maps of Rawalpindi for the years 1972, 1979, 1992, 1998, and 2010 are shown in Fig. 6.11-6.15(Chapter 6). While calculating the areas of land cover classes took into account 1) the error envelope of each classification; 2) Calculated the areas in square hectares based on counts of pixels; 3) calculated the minimum and maximum land areas based on error envelope. The calculations of error are based on the accuracy of every classification.

The study area as a whole and stratum-wise is taken into consideration while identifying different signals of change during the forty years period i.e. 1972 to 2012. The analysis has been carried out at Inter-censal level. Following main elements of land cover change analysis, as described in detail in the methodology has been applied in the next section:

Persistence: The area of a land cover that remained unchanged between the two time periods, i.e. between T2 & T1; T3 &T2; T4 & T3; and T4 & T1.

Net Gain: When the difference between area of land cover of a time period and the preceeding time period was positive.

Net Loss: When the difference between area of land cover of a time period and the preceeding time period was negative.

Gain: The difference between the area of a land cover in the second time period is less than the area that persisted between two time periods under analysis.

Loss: The difference between the area of a land cover in the first time period is less than the area that persisted between two time periods under analysis.

Swap: The area of a land cover lost in the first time period and gained in the second time period.

Absolute net Change: It is difference between gain and loss in two successive periods.

Percentage Gross Change: It is the sum of the net changes

7.2.1 Inter-censal Land Cover Distribution

The study area Rawalpindi witnessed important land use/ cover changes during the last four censuses. The percentage gross change (sum of the net changes) from T1 to T2 was 38,287 hectares (7.43%), T2 to T3 was 25,131 hectares (4.87%) and T3 to T4 it was 26,560 hectares (5.14%). The overall a gross change of 79,559 hectares (15.44 %) was seen during the last forty years (T1 to T4) (Table 7.10). The fallow land had a net loss of 13.41%, while the agricultural land and built-up categories both gained approximately 30,000 hectares each, during the last forty years.

In the T1 (1972- census and image) the area under agricultural fields was 70,906 ± 17,613 hectares (13.73%); bare land 120,503 ± 29,940 (23.63%) hectares; built-up 7,017 ± 1,743 hectares (1.36%); forest cover 136,878 ± 34,001 hectares (26.51%); fallow land[51] 171,535 ± 42,540 hectares (30.5%); and water bodies 7,574 ± 1881 (1.47%). This means that out of 242,441 ± 60,222 hectares of cultivable land[52], only 29 % (70906 ha) was cultivated. The area under forest was high as compared to the other districts because of the high amount of rainfall at the mountainous areas, which supported the natural and planned growth of forests. Moreover the trend of clearing the forest was also smaller as compared to the following years.

Data are also analysed by stratum wise for reasons of sampling design in accuracy assessment. Tables 7.11 to 7.14 summarizes stratum wise detail of area of land covers in 1972, 1981, 1998 and 2012 census periods. The stratum one (S1) which comprised three mountainous tehsils (Murree, Kotli Sattian and Kahuta), contained 19,231 ± 4,760 hectares of agriculture; 3,200 ± 792 hectares of bare land; 314 ± 78 hectares of built-up land; 72,085 ± 17,841 hectares of forest; 14,342 ± 3,550 hectares of fallow-land and 1,865± 462 hectares of water bodies. The percentage of each land cover as per the total area of the Rawalpindi district was as follows: agriculture: 3.7 %; bare land: 0.6%; built-up area: 0.1 %; forests 14.1%; fallow land: 2.7 % and water bodies: 0.4%. It is pertinent to mention here that out of the total forest cover of the study area, over half was contained by stratum 1 (Table 7.11).

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[51] It is a cultivable land but not cultivated and left fallow to retain the fertility. Grass/shrubs naturally grow on this land.

[52] Fallow-land + Agricultural land.

Table 7.1: Area of land Covers for the census years 1972, 1981, 1998 and 2012

Class	**Area (Hectares)**				**Change T1 to T2 (h)**		**Change T2 to T3 (h)**		**Change T3 to T4 (h)**		**Change T1 to T4 (h)**	
	1972	1981	1998	2012	Net loss	Net Gain	Net loss	Net Gain	Net loss	Net Gain	Net loss	Net Gain
Agriculture	70906	99310	112633	102305		28401		13323	10328			31339
	(13.73)	(19.23)	(21.81)	(19.81)		(5.50)		(2.58)	(2.00)			(6.08)
Bare-land	120503	124636	125960	136720		4106		1324		10760		16190
	(23.63)	(24.44)	(24.7)	(26.81)		(0.81)		(0.26)		(2.11)		(3.18)
Built-up	7017	11764	22238	36220		4747		10474		13982		29203
	(1.36)	(2.28)	(4.31)	(7.02)		(0.92)		(2.03)		(2.71)		(5.66)
Forest	136878	132179	128823	126397	4699		3356		2426		10481	
	(26.51)	(25.60)	(24.95)	(24.48)	(0.91)		(0.66)		(0.46)		(2.03)	
Fallow-land	171535	137949	116263	102457	33586		21686		13806		69078	
	(33.3)	(26.78)	(22.57)	(19.89)	(6.52)		(4.21)		(2.68)		(13.41)	
Water	7574	8604	8614	10253		1030		10		1639		2679
	(1.47)	(1.67)	(1.67)	(1.99)		(0.20)		(0)		(0.32)		(0.52)
Gross Change					**38287 hectares (7.43 %)**		**25131 hectares (4.87%)**		**26560 hectares (5.14%)**		**79559 hectares (15.44%)**	

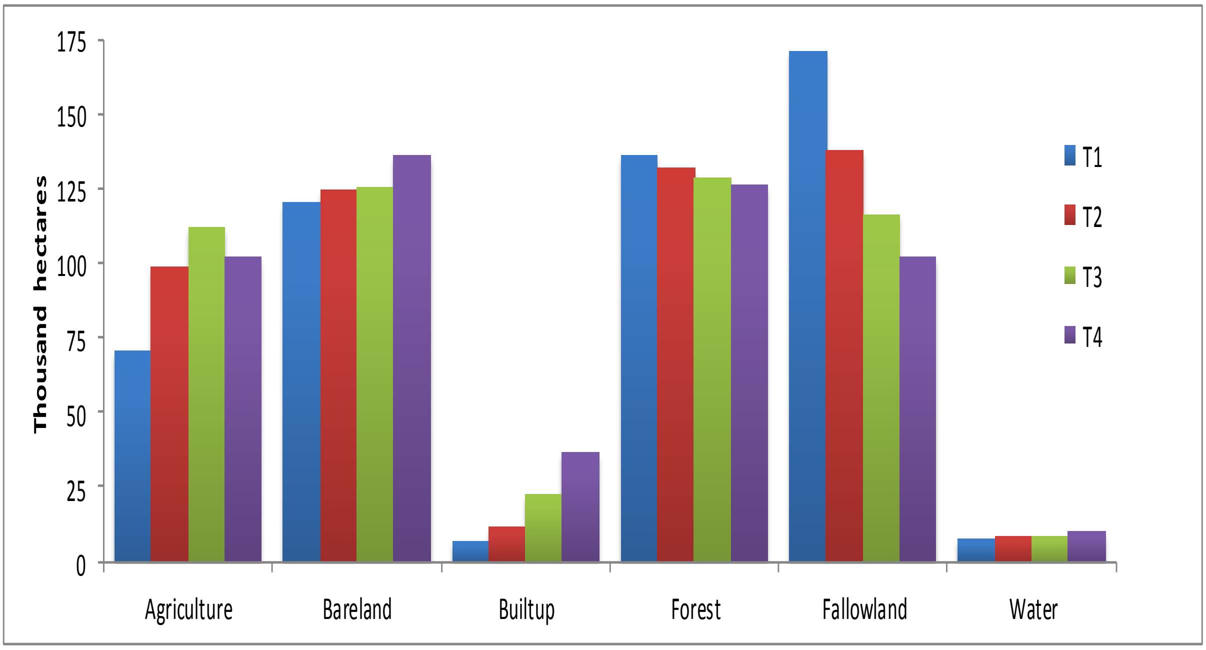
Note: The figures in brackets are the percentage equivalent

The stratum two (S2) which comprised the tehsils of Kallar Syyedan and Gujjar Khan, having some of their areas under mountains and rest the plain area, had 33,248 ± 8,229 of hectares (6.5%) under agriculture; 57,124 ± 14,138 hectares (11.1 %) under bare land: 864 ± 214 hectares (0.2 %) under built-up area; 45,231 ± 11,195 (8.8 %) hectares under forests; 68,194 ± 16,878 hectares (13.3%) under fallow-land; and 3,915 ± 9,692 (0.8%) hectares under water bodies.

The stratum three (S3) Rawalpindi tehsil, which is the main focus of this study had 13,795 ± 3,425 hectares (2.7%) of its area under agriculture; 48,606 ± 12,084 hectares (9.4%) under bare-land; 5,600 ± 1391 hectares (1.1%) in the built-up category; 15,624 ± 3,884 hectares (3.1%) under forests; 78,876 ± 19,609 hectares (15.3%) under fallow-land; and 1,564 ± 387 hectares (0.3%) under water bodies. This tehsil alone contained 80 % of the total built-up land of the study area. That is why after general land cover distribution of the study area in different years, the detailed distribution of land cover of Rawalpindi has been discussed in detail. Moreover this tehsil has also been selected to study in detail due to extra ordinary urban expansion during the last forty years.

The stratum four (S4) Taxila tehsil of the study area contained 4,632± 1146 hectares (0.9%) of agricultural fields; 11,573 ± 2,864 hectares (2.25) of bare-land; 212 ± 52 (0.04%) hectares of built-up land; 3,938 ± 975 hectares (0.8 %) of forests; 10,123 ± 2,505 hectares (2%) of fallow land; and 230 ± 57 hectares (0.04%)of water bodies.

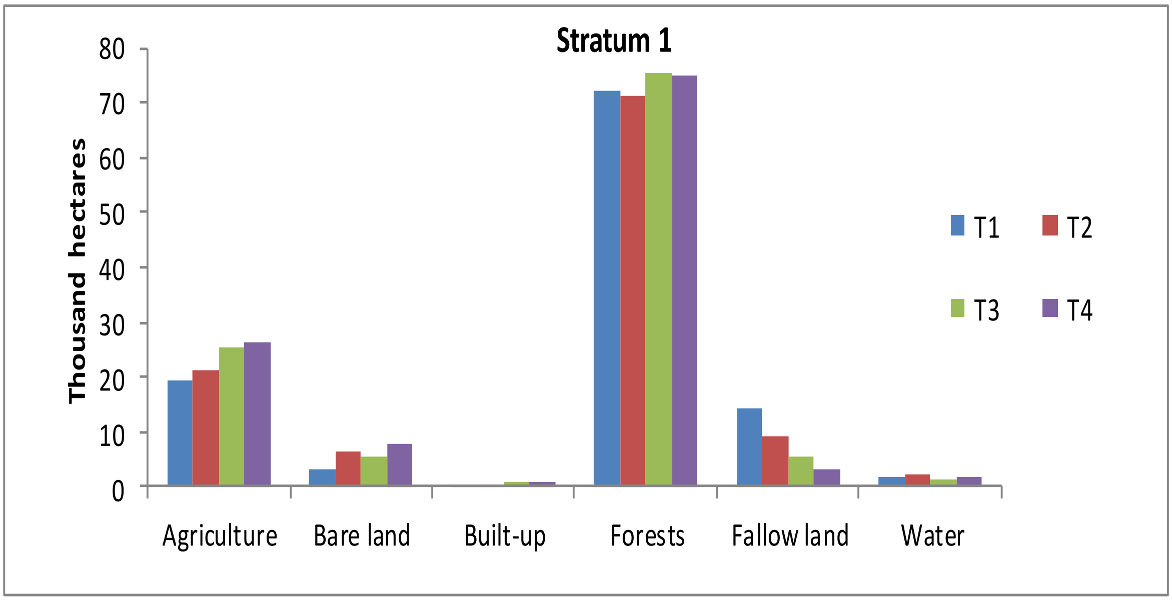
Figure 7.1: Rawalpindi: Land covers change of the study area T1 to T4

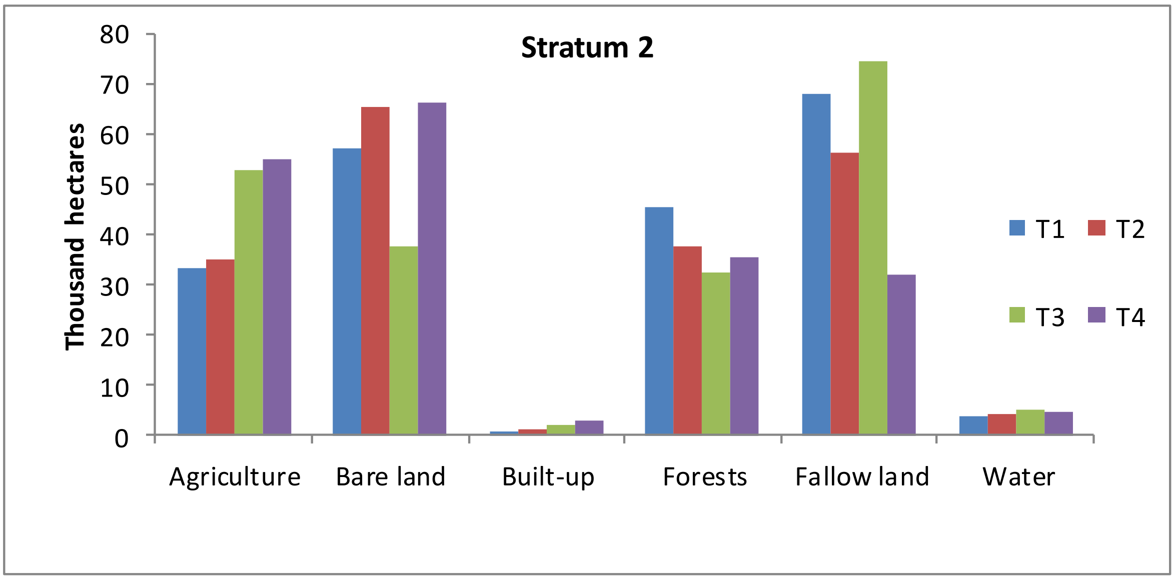


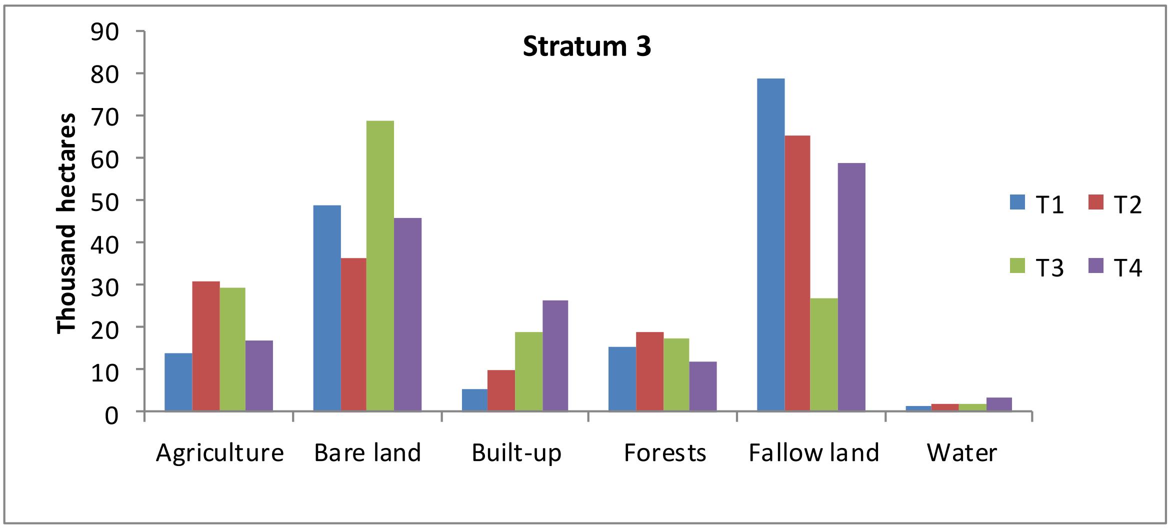
The 1979 classification, which has been correlated with the 1981 census i.e. (T2), showed different results. The agricultural area of the study area increased from 13.73 % to 19.23 % with a net increase of over 28000 hectares (5.5%), bare-land slightly increased from 23.63 % to 24.44 %, built-up area increased from 1.36 % in 1972 to 2.28 % in 1981 having a net increase of 4747 hectares 1% approximately (see fig. 7.1), forested area decreased from 26.51 % to 25.60 % with a loss of 4699 hectares (1% approximately), fallow land decreased considerably i.e. 33586 hectares (6.52 %) and there was an increase of over 100 hectares in the water resources.

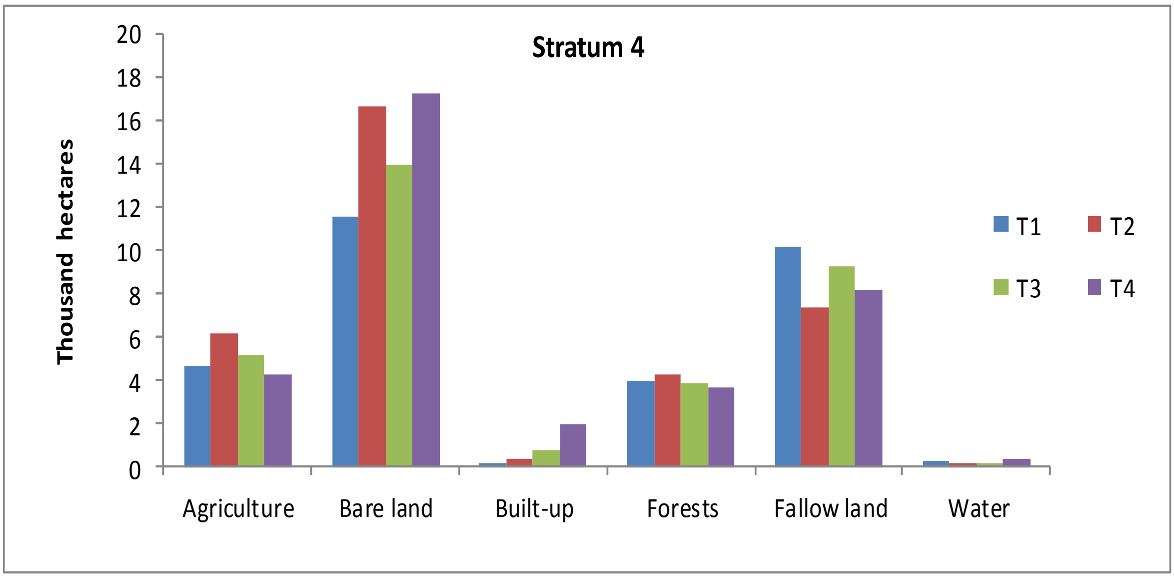
Three important changes are notable: 1) agricultural area increased, (2) Forested area decreased, and (3) built-up area increased. Although the increase in the agricultural area occurred in the whole study area, the maximum increase was witnessed in S3. It is likely that the forested portion of the study area decreased, but at the same time its percentage increased in S3 and S4. The increase in the agriculture area was due to cultivation on the vacant patches by the people who were migrated from other areas to S2 and S3 of the study area. Besides cultivating the uncultivable areas the people also gave attention towards growing forests on the uncultivable lands. Another reason of increase in forest resources of S3 and S4 was the district's government policies of reforestation in both stratums to retain the scenic beauty and preserve natural forests. Although the built-up area increased in all tehsils/strata, but the major increase was in S3 (Rawalpindi tehsil).The built- up increase was related to high population growth and high inward migration, Thus decrease in the fallow land caused the increase in the farmland, forests in S2 and S3 and an overall increase in the built- up area in the whole study area, particularly in S2 and S3.

Figure 7.2: Rawalpindi: Stratum wise Land covers change of the study area from T1 to T4




Stratum 2
Thousand hectares
80
70
60
50
40
30
20
10
0
Agriculture
Bare land
Built-up
Forests
Fallow land
Water
T1
T2
T3
T4

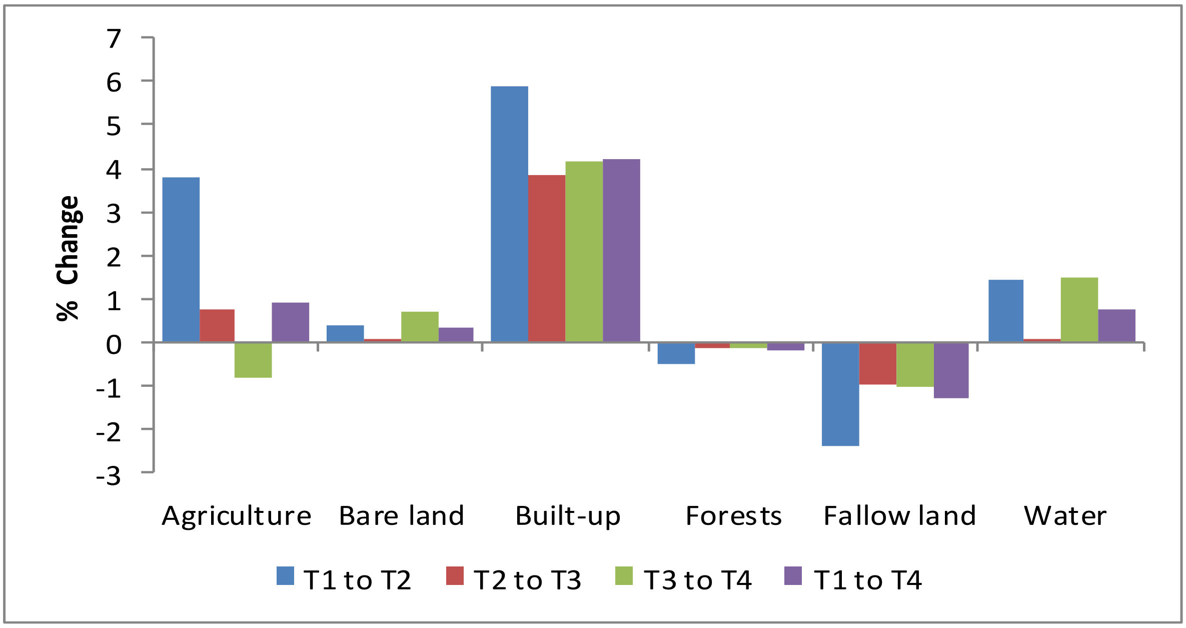

Stratum 3
Thousand hectares
90
80
70
60
50
40
30
20
10
0
Agriculture
Bare land
Built-up
Forests
Fallow land
Water
T1
T2
T3
T4


Stratum 4
Thousand hectares
20
18
16
14
12
10
8
6
4
2
0
Agriculture
Bare land
Built-up
Forests
Fallow land
Water
T1
T2
T3
T4

1998 census and classification (T3) showed a further increase of 13,323 hectares in the agricultural area of Rawalpindi as compared to the 1981 census. But this time the increase was less than half of the 1972-1981 period. The percentage of bare land also increased very little i.e. 24.44 to 24.77% having a negligible net gain of 0.26%. The built-up area almost doubled from 1981 to 1998, from 2.28 % to 4.31 % (10,474 hectares). Again, this increase mostly came from S3. The area under forest decreased from 25.60% in 1981 to 24.95 %. This time the decrease was 0.66 %. Actually in Murree, Kotli Sattian and Kahuta tehsils (S1) the area under forest cover increased, lessening the effect of the overall decrease in the whole study area. The percentage of fallow land decreased from 26.78% in 1981 to 22.57% in 1998, a net decrease of 4.21%. This cultivable area was converted to bare land due to less rainfall in that particular year.

In 2010 Classification (T4), the agricultural area decreased considerably. The loss of agricultural land was over ten thousand hectares, which was mainly in the S3. It is important to note here the cropped area of the S1 and S2 increased while S3 and S4 it decreased. The cropped area of the S3 (which was formerly the main contributor of the agricultural area) decreased 100%. The overall agricultural area of the study area decreased from 21.81 % to 19.81% (Fig. 7.2). This loss of agricultural land increased the percentage of bare land from 24.7 % to 26.81%. The amount of bare land increased (10,760 hectares) was almost equivalent to loss of the agricultural land. During the inter-censal period of 1998-2012, the built-up area of the study area increased from 4.31% of the total area to 7.02%, having a net increase of 2.71%, which was more than the increase/decrease of any other land cover.

Figure 7.3: Inter-censal Percentage Annual Change in land use types during 1972 to 2012



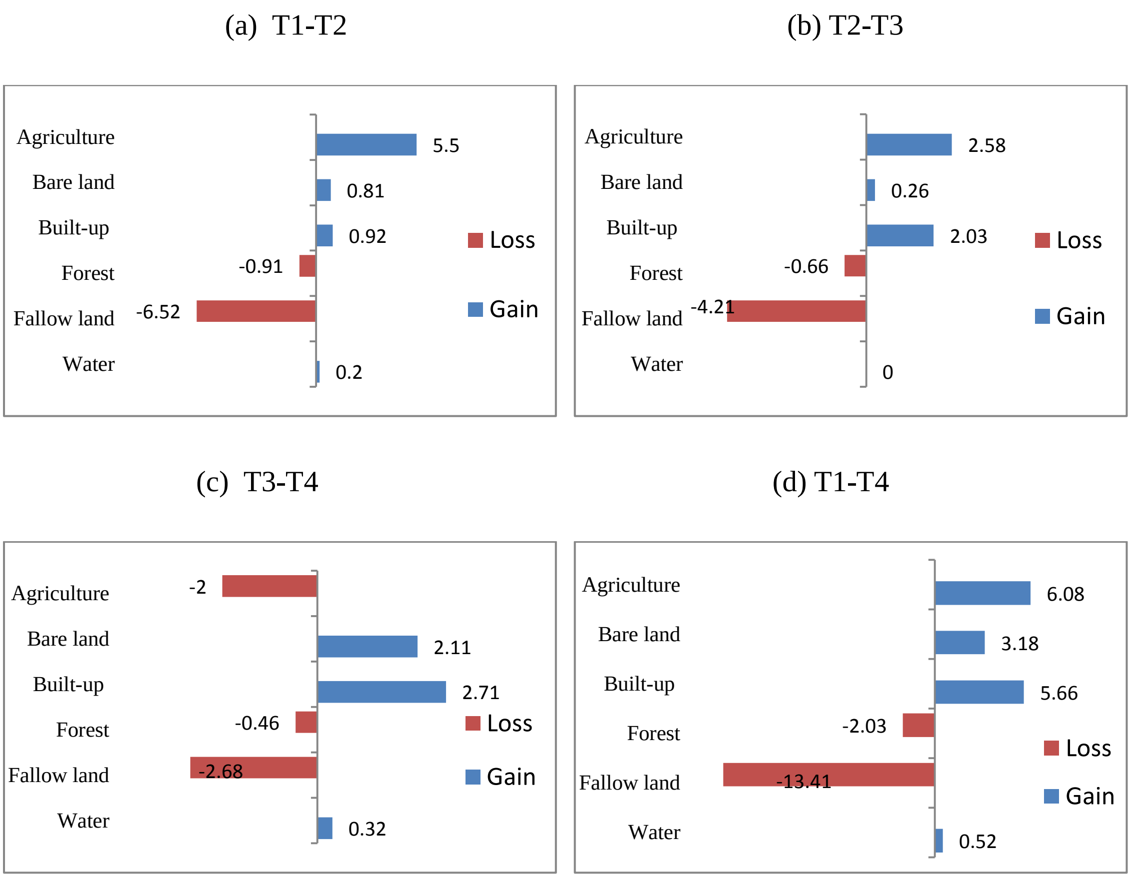
This increase was seen in all tehsils, but the most in Rawalpindi (S3) and Taxila tehsils (S4). The built-up area of S3 alone increased more than 7500 hectares in 12 years, and this increase was approximately 40% of the city's built-up area. In S4, an increase of 140% in built-up area was seen. A gradual trend of decrease in forest cover could not be stopped in 2012, the forest cover of the study area decreased from 128,823 hectares to 126,397 hectares, with a net loss of 2,426 hectares, which was approximately 2 % of the total forest cover. If we see both Table 7.10 and Fig. 7.2 it is obvious from both that although built- up area increased maximum during the 1998-2012 period , but annual per cent change was maximum in 1972-1981. In fact after 1972 the Rawalpindi started to expand and in a span of nine years it expanded almost double. Fig.7.3 throws light on the net change percentage of total area of land use/land covers in the Rawalpindi district during the inter-censal periods i.e. 1972 to 1981, 1981 to 1998, and 1972 to 2012.

In nutshell, during the 1972 to 1981 census period the cropped area of the study area increased at a rate of 4000 hectares per year. This rate of increase decreased to 900 hectares in 1998. It is pertinent to mention here that although the cropped area increased from 1972 to 1998, yet the *cultivable waste* decreased, and there are possibilities that the cultivable waste was converted to cropped area. For instance in 1972, the amount of cultivable but not cultivated area (cultivable waste) was 290,500 hectares, which decreased to 257,678 and 231,838 hectares in 1981, and 1998 respectively. The rate of decrease showed a similar pattern to that of the rate of increase of the cropped area.

In 2012 the cropped area decreased and the annual rate of decrease was 860 hectares per year, and there is possibility that this area was lost to (swap) to built-up category, as most of the decrease was in S3, where the built-up area increased to its maximum. The forest cover decreased to 525 hectares per year during 1972-1981; 197 hectares per year during 1981-1998, and 202 hectares during 1998-2012 inter- censal periods. Over all during the forty years it decreased 276 hectares per year. This rate of deforestation was very high for a single district where electricity and gas were available for cooking and heating and so there was less need for the forests being cut for fire wood. In terms of annual deforestation rate it was 0.51 %, 0.15%, 0.16 % and 0.21 % during 1972-81, 1981-98, 1998-2012 and 1972-2012 inter- censal periods respectively.

The built-up area increased steadily. The pace of increase was 527 hectares per year during the 1972 -1981 inter-censal period; 617 hectares per year during 1981-1998; and approximately 1165 hectares per year during the 1998-2012 census periods. Overall in forty years the annual increase was 769 hectares per year, which was much higher than many metropolitan cities of developed countries. Inter-censal growth rate of built up category was 5.91%; 3.82%; 4.15 %; and 4.41% during 1972-81, 1981-98, 1998-2012 and 1972-2012 inter- censal periods respectively.

Figure 7.4: Net change percentage of total area of land use/land covers in the Rawalpindi district during (a) T1 to T2; (b) T2 to T3; (c) T3 to T4 (d) T1 to T4 periods

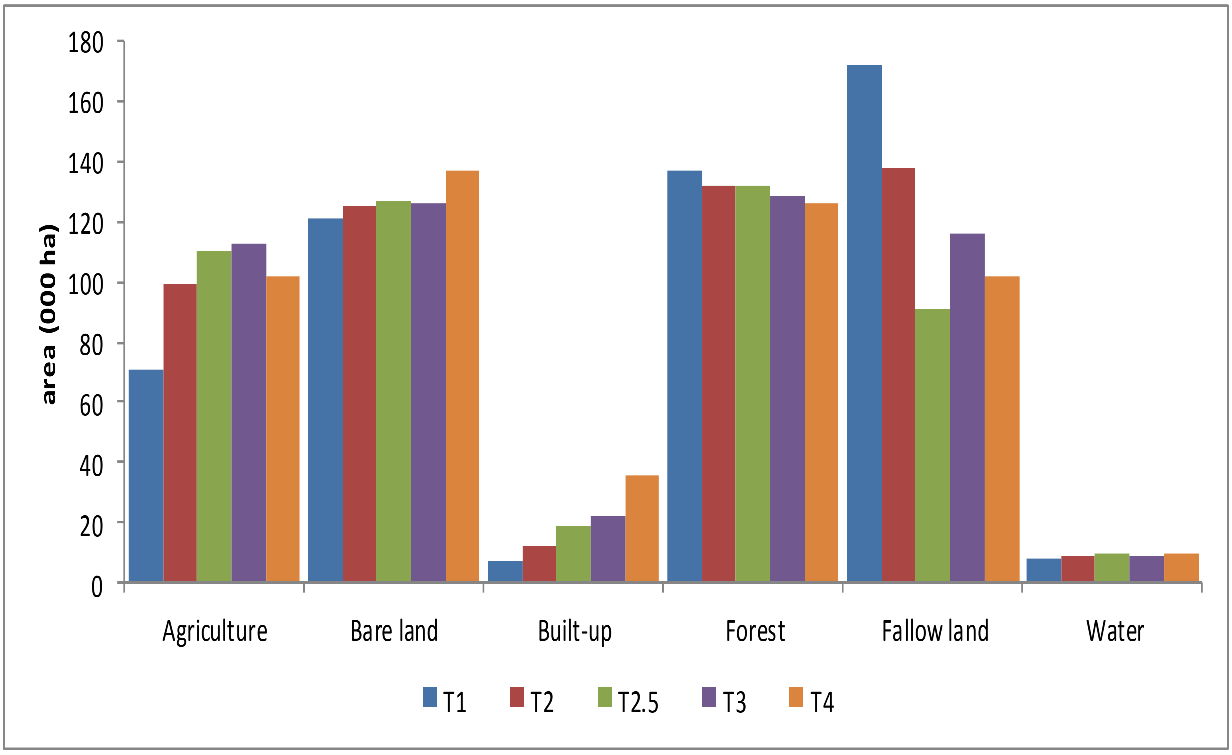


Source: Classified maps of the study area

During the last 14 years there has been a trend of loss in agricultural land and forests, and increase of built-up area. It is important to mention here that due to less urban expansion in other tehsils of the study area, the rate of deforestation and loss of agricultural land was controlled. Had there been the same pace of urbanization across all tehsils the rate could have been very high.

As discussed earlier, the census organization in Pakistan has not been able to operate at decadal intervals; therefore the irregular gaps particularly between 1981 and 1998 may not depict a true picture of change. To facilitate the reader, the researcher has also tried to explain with the help of fig. 7.5 what would have happened had the census been held in 1992.Hence to bridge the big gap between two censuses, another time interval T2.5 (1992 image) has been added, and results has been compared accordingly. As obvious from fig.7.5, the trend of increase in built up area continued in T 2.5. Moreover there was little increase in the bare-land which probably swapped to built-up area in T3. The most important change was the loss of fallow-land (cultivable waste), which was converted to agriculture in T3.

Figure 7.5: Rawalpindi: Land covers change at an interval of 10 years from 1972 to 2012



7.2.2 The Land Cover Changes

In the above sections the land cover distribution was analysed from a general perspective by looking at each of the land cover categories and their transition (Ponitus et al., 2004). In this section the transition matrices for T1 to T2, T2 to T3, T3 to T4 and T1 to T4 are computed from the classification results (Chapter 6) and are presented in the form of Tables 7.2 to 7.5. The diagonal entries of the above tables indicate the total amount of persistence, the bottom rows show the quantity gained and the right hand columns show the quantity lost. The matrices are computed for each land cover for each pair of census periods. The area that persisted (sum of the diagonal) between 1972 and 1981 was 236,665 hectares or 46% of the total area; between 1981 and 1998 it was 178,631 hectares or 35%; between 1998 and 2012 it was 198,637 hectares or 39% and between 1972 and 2012, the area that persisted was 179,787 hectares or 35% of the total study area.

Table 7.2: Land cover change matrix T1 to T2 census period (%)

T2 ↓	T1 →						Total (T1)
	Agriculture	Bare land	Built-up	Forest	Fallow land	Water	
Agriculture	5.01	3.05	0.13	2.52	2.93	0.04	13.73
Bare land	2.95	9.17	0.76	2.32	7.77	0.37	23.33
Built-up	0.07	0.34	0.20	0.31	0.38	0.05	1.36
Forest	4.90	2.25	0.16	17.01	1.82	0.36	26.51
Fallow land	5.81	9.32	0.99	3.15	13.74	0.22	33.22
Water	0.05	0.31	0.04	0.28	0.14	0.64	1.47
Total (T2)	19.23	24.44	2.28	25.60	26.78	1.67	100.00

Table 7.3: Land cover change matrix T1 to T2 census period (%)

T3 ↓	T2 →						Total (T2)
	Agriculture	Bare land	Built-up	Forest	Fallow land	Water	
Agriculture	5.16	3.31	0.07	4.90	5.81	0.05	19.23
Bare land	5.69	7.74	1.13	2.18	7.36	0.33	24.44
Built-up	0.41	0.43	0.95	0.30	0.13	0.07	2.28
Forest	5.23	2.32	0.49	14.14	3.14	0.28	25.60
Fallow land	5.32	10.44	1.55	3.15	6.03	0.28	26.78
Water	0.10	0.42	0.12	0.28	0.09	0.66	1.67
Total (T3)	21.81	24.70	4.31	24.95	22.57	1.67	100.00

Table 7.4: : Land cover change matrix T2 to T3census period (%)

T4 ↓	T3 →						Total (T3)
	Agriculture	**Bare land**	**Built-up**	**Forest**	**Fallow land**	**Water**	
Agriculture	5.06	7.55	0.82	5.25	2.98	0.15	21.81
Bare land	7.23	7.18	2.94	1.93	4.42	0.57	24.27
Built-up	0.56	0.87	1.64	0.21	0.92	0.11	4.31
Forest	3.10	1.71	0.60	15.98	3.28	0.28	24.95
Fallow land	3.68	9.14	0.84	0.90	7.86	0.15	22.57
Water	0.18	0.15	0.17	0.21	0.22	0.74	1.67
Total (4)	19.81	26.60	7.01	24.48	19.69	1.99	0.00

Table 7.5: : Land cover change matrix T1 to T4 census period (%)

T4 ↓	T1 →						Total (T1)
	Agriculture	**Bare land**	**Built-up**	**Forest**	**Fallow land**	**Water**	
Agriculture	5.06	2.93	0.13	2.50	3.05	0.05	13.73
Bare land	7.23	5.89	2.13	1.41	6.20	0.48	23.33
Built-up	0.53	0.35	0.25	0.11	0.06	0.05	1.36
Forest	3.10	4.10	1.67	15.05	2.32	0.27	26.51
Fallow land	3.70	13.06	2.75	5.13	8.05	0.51	33.22
Water	0.18	0.27	0.08	0.28	0.15	0.51	1.47
Total (4))	19.81	26.60	7.01	24.48	19.69	1.99	100.00

The analysis of persistence, loss, gain swap and net change of each land cover that occurred between pairs of classifications for the two dates were done with the aid of Tables 7.2 to 7.5. Tables 7.6 to 7. 9 summarize the proportion, gain, loss, swap and net change of each land cover during 1972-2012 periods. During the 1972-81 census bare land, agriculture and fallow land experienced more gain, whereas fallow land experienced the highest loss in near 20% of the landscape, followed by bare land and agriculture. In terms of absolute change, fallow land was on the top followed by agriculture. Actually this was the time when the population was increasing at a fast rate and immigration of the population from other parts of the country was also high due to the shifting of the capital from Karachi to Islamabad. Thus the bare patches of land were brought under management and agriculture flourished. At the same time the built-up area was also expanding at a rapid rate. The gain-to-loss ratio of 1.8 was highest for built-up land indicating that built-up areas gained almost two times more gain than loss and expanded at higher rate than any other land cover. The gain-to-loss ratio of agriculture was 1.6 indicating expansion of the agricultural frontier in response to population increase. At the same time forest experienced more loss than gain. The loss-to-gain ratio of forest was 1.1 showing a relationship between deforestation and expansion of the area of built- up land due to population increase.

In 1981-1998 census period agriculture again experienced more gain, but it also lost 14.17% of the area having an absolute increase of 2.58%. Bare land and fallow land also experienced more gain but at the same time they also lost the area at a high rate. The gain-to-loss ratio of built-up area continued increasing and during this inter-censal period it was 2.53 indicating a higher increase than loss as compared to the previous inter-censal period. However the deforestation rate was almost similar to the last inter-censal period, as the loss-to-gain ratio was same.

During the 1998-2012 inter-censal period, agriculture, bare land, fallow land and forest experienced more loss as compared to gain. Only built-up areas and water bodies experienced more gain than the loss. During this inter-censal period due to the population increase, demand for housing increased which put a lot of pressure on the agricultural and “cultivable but not cultivated” land of the peripheral urban areas. In response people sold their agricultural land at highest rates to the house building companies which erected tall residential and commercial buildings to cope the demand of residence and business. In sum during the last forty years of the study period i.e. 1972 to 2012, agriculture, bare land and built-up areas experienced more gain, whereas fallow-land experienced the highest loss in over 25% of the District, followed by the forests at about 11.5% of the District.

Table 7.6: Summary of landscape Changes during 1972 to 1981 (%)

Class	Total 1972	Total 1981	Gain	Loss	Total Change	Swap	Absolute Change
Agriculture	13.73	19.23	14.17	8.67	22.84	17.34	5.5
Bare land	23.33	24.44	15.27	14.17	29.44	28.34	1.1
Built-up	1.36	2.28	2.08	1.15	3.23	2.3	0.93
Forest	26.51	25.6	8.58	9.49	18.07	17.16	0.91
Fallow land	33.22	26.78	13.04	19.48	32.52	26.08	6.44
Water	1.47	1.67	1.03	0.82	1.85	1.64	0.21
Total	100.00	100.00	54.17	53.78	107.95	92.86	**15.09**

Table 7.7: Summary of landscape Changes during 1981 to 1998 (%)

Class	Total 1981	Total 1998	Gain	Loss	Total Change	Swap	Absolute Change
Agriculture	19.23	21.81	16.65	14.07	30.72	28.14	2.58
Bare land	24.44	24.70	16.95	16.69	33.64	33.38	0.26
Built-up	2.28	4.31	3.36	1.33	4.69	2.66	2.03
Forest	25.6	24.95	10.81	11.46	22.27	21.62	0.65
Fallow land	26.78	22.57	16.53	20.74	37.27	33.06	4.21
Water	1.67	1.67	1.01	1.01	2.02	2.02	0
Total	100.00	100.00	65.31	65.3	130.61	120.88	**9.73**

Table 7.8: Summary of landscape Changes during 1998 to 2012 (%)

Class	Total 1998	Total 2010	Gain	Loss	Total Change	Swap	Absolute Change
Agriculture	21.81	19.81	14.75	16.75	31.5	29.5	2
Bare land	24.70	26.60	19.43	17.1	36.53	34.2	2.33
Built-up	4.31	7.01	5.37	2.67	8.04	5.34	2.7
Forest	24.95	24.48	8.5	8.96	17.46	17.0	0.46
Fallow land	22.57	19.69	11.82	14.7	26.52	23.64	2.88
Water	1.67	1.99	1.25	0.93	2.18	1.86	0.32
Total	100.00	100.00	61.12	61.11	122.23	111.54	**10.69**

Table 7.9: Summary of landscape Changes during 1972 to 2012 (%)

Class	Total 1972	Total 2010	Gain	Loss	Total Change	Swap	Absolute Change
Agriculture	13.73	19.81	14.75	8.67	23.42	17.34	6.08
Bare land	23.33	26.60	20.71	17.44	38.15	34.88	3.27
Built-up	1.36	7.01	6.76	1.11	7.87	2.22	5.65
Forest	26.51	24.48	9.44	11.46	20.9	18.88	2.02
Fallow land	33.22	19.69	11.63	25.16	36.79	23.26	13.53
Water	1.47	1.99	1.48	0.98	2.46	1.96	0.5
Total	100.00	100.00	64.77	64.82	129.59	98.54	**31.05**

Loss in the forested areas is most likely due to clearing of forests for residential purposes and making the land available for agricultural activities in the mountainous area where terrace cultivation is common and native people are always in search of the bare land/plain forested areas to use for growing vegetables. The gain in the forested areas was due to regrowth and governmental policies for reforestation particularly in the mountainous areas. The gain-to-loss ratio was highest for the built-up class indicating that built-up areas experienced over six times more gain than loss which was associated with continual increase of population, expansion of residential areas in the peri urban locations, loss of agricultural and forested areas and decrease of "cultivable but not cultivated" land. The loss of agricultural areas was perhaps due to the abandonment of fallow-land. This also appears true, if we look at the loss-to-gain ratio of fallow-lands which constitute the "cultivable waste". This ratio for fallow-lands is 2.16 which are much higher and scattered over the landscape.

Changes in all land covers except water bodies consist both swap and net change, whereas change in water bodies seems nearly pure swap type change. The net change is highest for built-up (approximately 72% of the total change of built-up); whereas the change attributable to location (swap) is highest for forest and bare land (above 90% of total change for forests and bare-land both). The swap land dynamics for 1972 and 2012 years accounted approximately 75 % of the total District's change.It is important to mention here that the amount of gain or loss could be different for a number of reasons. For instance it may be due to changes in the spatial determinants of land use distribution such as population growth, economic growth, industrialization, soil fertility and even the opening of new roads. Therefore certain locations may have suitable factors for a given land cover. Moreover a given quantity of land cover lost at one location may be accompanied by the same quantity of gain at another location, which is termed as a "swap". Hence "a net change" in the quantity of a category indicates a definite change. Table 7.18 indicates that a net change of 31% has occurred in the landscape of the study area during the last forty years.

7.2.3 Persistence of Land Covers

The diagonal entries of Tables 7.2 to 7.5 indicate the total amount of persistence, about which many authors claim is important (Mertens and Lambin, 2000; Geoghegan et al., 2001). It is important to note that the in developing countries like Pakistan, with high rates of population growth the amount of persistence tends to be small compared to countries where population growth is low and persistence is high. The proportion of land cover that was static between different inter-censal periods mentioned above are shown in the diagonal (highlighted grey) of Tables 7.2 to 7.5. In the Rawalpindi district, which is renowned for rapid population growth, there has been 35% persistence over the last forty years. About 15% of the land cover that was forest in 1972 remained unchanged in 2012. Among the cultivable land and waste, agriculture experienced the lowest persistence in about 5% of the study area and fallow-land experienced the highest of the District (8%).

Looking at persistence in different inter- censal periods can portray the pace of landscape change. During 1972-81 (Table 7.2) there has been 46% of persistence showing the slow pace of change as compared to the 1981-98 inter-censal period, which is considered to be the period when great changes have occurred in the landscape. The amount of persistence in 1981-98 (Table 7.3) inter-censal periods was 34.68% followed by 38.46 in 1998-2012 (Table 7.4) showing a slowing down of the change.

To assess the vulnerability of the land classes to transitions, Braimoh (2006) used the loss-to-persistence, and gain-to- persistence indices. According to him a value of Lp above 1 indicates a higher tendency of land covers to transition to other land classes than persistence. Table 7.10 summarizes the gain to persistence, loss to persistence and net change to persistence ratios of the land classes in different inter-censal periods. It is apparent from Table 7.10 that Lp for all the classes except forest is higher than 1 in all census periods. Thus it can be presumed that there is higher tendency to loss than persistence. It means that during the passage of time the proportion of forests decreased but the persistence of forest was also greater than any other land cover. This is an indication of the District government's policy of reforestation at various locations. The persistence of forest is widespread in S1 and S2 where population density is low. However the loss has mostly occurred in the high population density areas.

Remarkably the gain to persistence ratio for all land cover classes except the forest is also greater than 1 indicating that all land classes except forest experienced more gain than persistence. For instance in 1972-81 census period built up gained the highest Gp (10.41) whereas in T2-T3 and T3-T4, it was moderate i.e. 3.5 and 3.2 respectively.

Table 7.10: Gain- to-persistence (Gp), Loss-to-persistence (Lp), and Net- change-to persistence (Np) ratios of land classes during T1-T2; T2-T3; T3-T4 and T1-T4

LAND CLASSES	T1-T2			T2-T3			T3-T4			T1-T4		
	Gp	**Lp**	**Np**	**Gp**	**Lp**	**Np**	**Gp**	**Lp**	**Np**	**Gp**	**Lp**	**Np**
Agriculture	2.80	1.71	1.09	3.23	2.73	0.50	2.92	3.31	-0.40	2.92	1.71	1.20
Bare land	1.67	1.55	0.12	2.19	2.16	0.03	2.71	2.38	0.32	3.52	2.96	0.56
Built-up	10.40	5.75	4.65	3.54	1.40	2.14	3.27	1.63	1.65	27.04	4.44	22.60
Forest	0.50	0.56	-0.05	0.76	0.81	-0.05	0.53	0.56	-0.03	0.63	0.76	-0.13
Fallow land	0.95	1.42	-0.47	2.74	3.44	-0.70	1.50	1.87	-0.37	1.44	3.13	-1.68
Water	1.61	1.28	0.33	1.53	1.53	0.00	1.69	1.26	0.43	2.90	1.92	0.98

Overall, over a period of forty years the Gp was 27.04 and Lp was as low as 4.4 showing the highest 22.60 net change to persistence. The net change to persistence for forests has been negative in all census years indicating a continuous deforestation at various locations, whereas for agriculture it was negative only in the T3-T4 periods indicating a loss of cropped land in the foresaid inter-censal period. Figures 7.5 to 7.7 focus on the changes in the forest, agriculture and built-up categories from T1 to T4 periods.

The dark green colour in Fig. 7.6 shows persistence of forests and the blue colour shows persistence of non-forest. White shows deforestation and red shows forest regrowth. As can be seen in Fig.7.6 there is net loss of forests (more white than red). The proportion of gained forest (Reforestation) and lost forest (deforestation) varies *inter* stratum and *intra* stratum. For instance in stratum 1 more red area than white area shows the reforestation. In S3 and S4 there is net loss of forests as there are more white areas compared to red ones. Within the stratum the variations are more complex. For example the north western portion (Murree tehsil) of S1 experienced more reforestations, whereas the southern and eastern portion experienced more deforestation.

Figure 7.6: Change in the forest category between T1 to T4

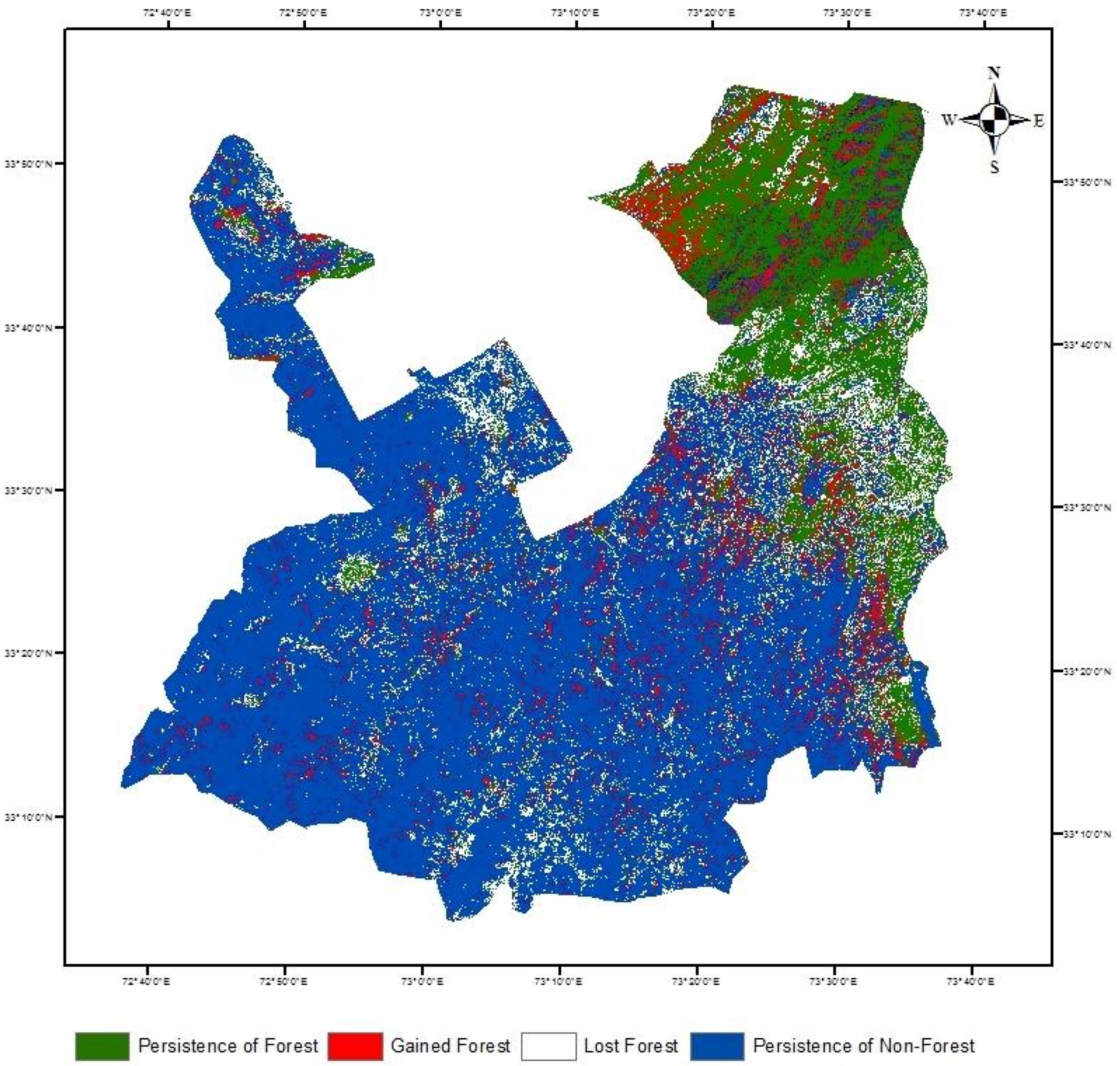


Fig. 7.7 shows the change in the *builtup* category. Built-up land accounts a small proportion of the landscape as compared to the forest and agriculture categories and characterized with a net increase with almost no loss and hence very little swapping. Moreover in S 3 (Rawalpindi tehsil) the gain of built-up land is clustered around the persistence, whereas there are also scattered patches over the whole stratum. In S4 a long strip of gain of built-up land can be seen. Except in S3 the persistence of non-built-up land is greater in the whole study area.

Figure 7.7: Change in the *builtup* category between T1 to T4

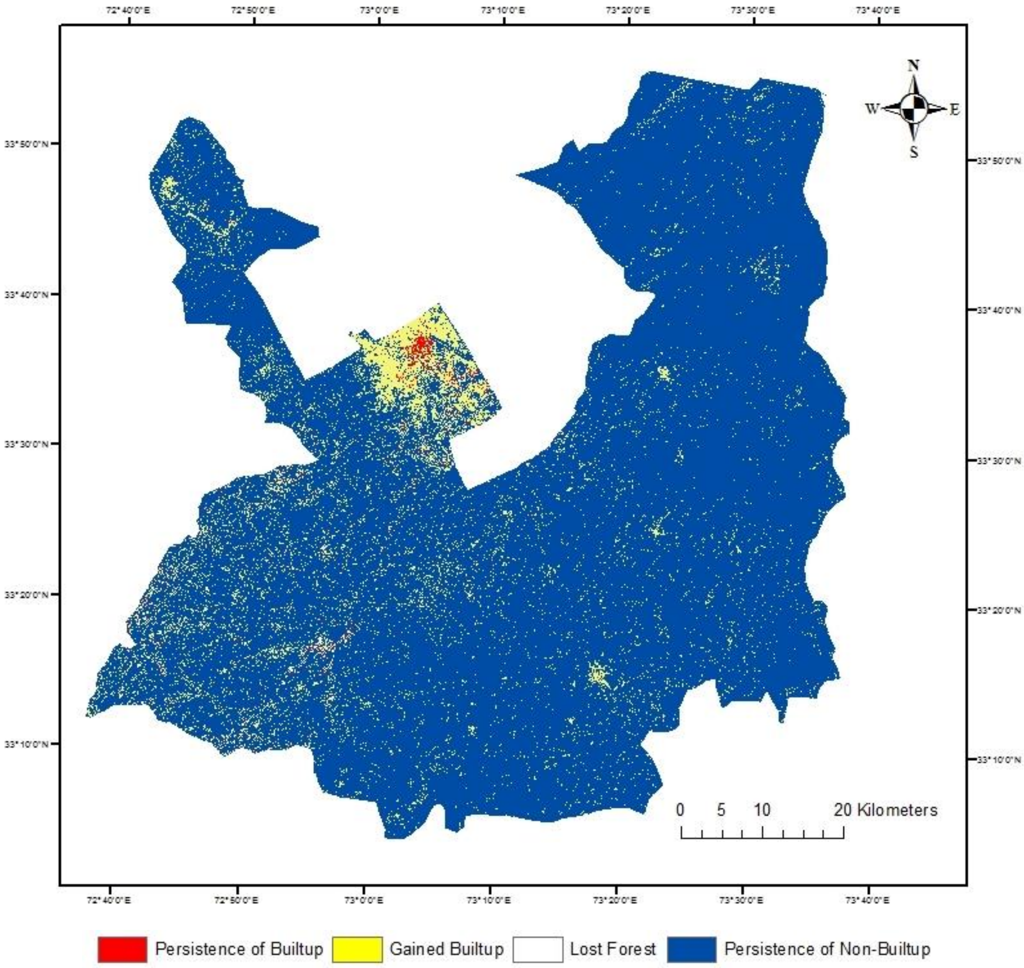
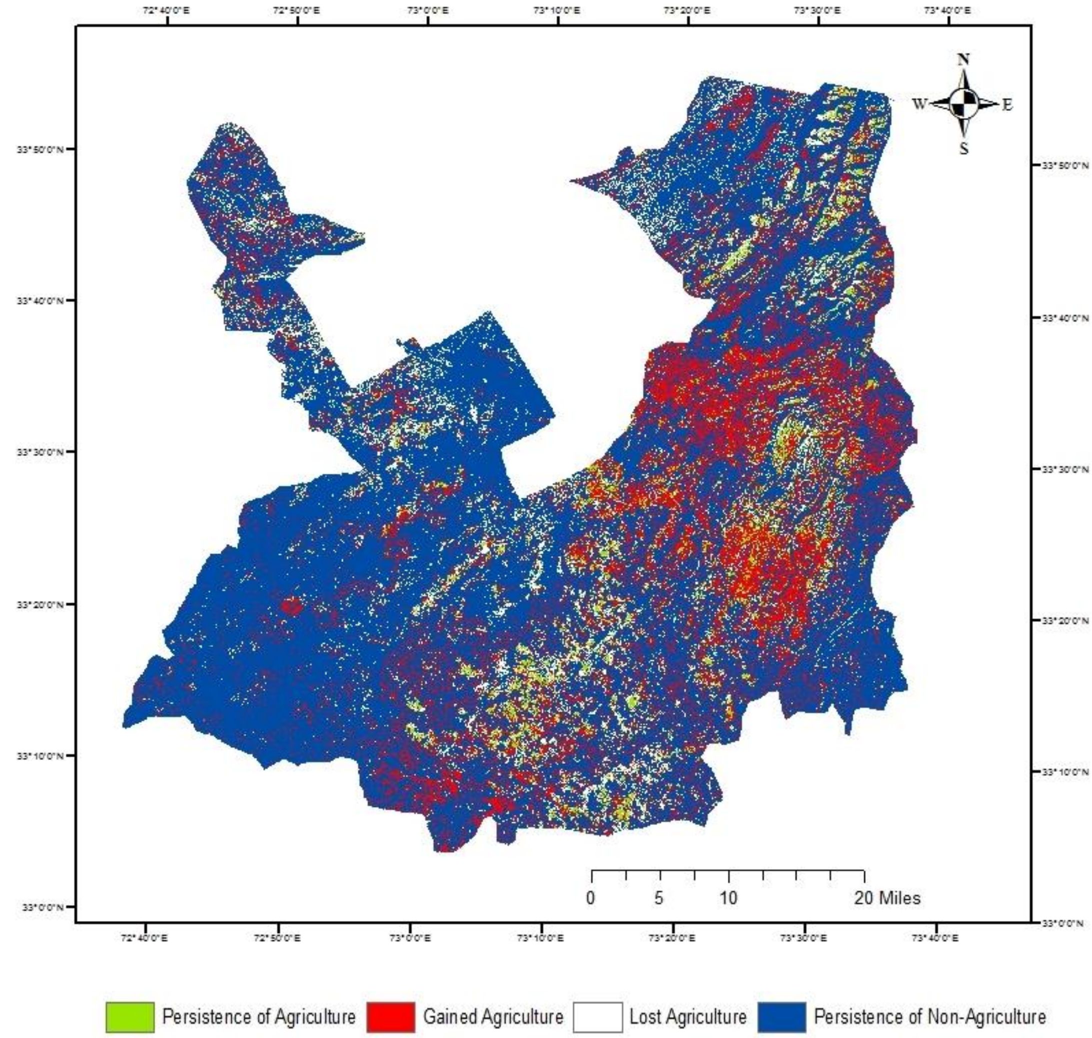


Fig.7.8 shows the change in the agricultural land cover from 1972 to 2012 i.e. T1 to T4. The light green colour shows persistence of agriculture and the blue colour shows persistence of non-agricultural land. White areas show the loss of agricultural land and red shows the areas gained by agriculture. Also notice that patches of gain are mostly clustered in the Kahuta tehsil of S1 and Kallar Syeddan tehsils of S2. The gain in agriculture in these tehsils may be associated with the increase of population and fulfilment of demand for food. Therefore, the cultivable waste land has been utilized. Whereas in S3, the higher demand for houses resulted in the loss of agricultural land, therefore white patches are seen more in the peri urban zones. However in the interior of the S3 (Rawalpindi tehsil village areas) some clusters of gain are also found. On the whole during the 1972 to 2012 period agriculture areas expanded more as compared to loss. Loss of agricultural land is a recent phenomenon. In sum, the study area (Rawalpindi district) has undergone a remarkable expansion of growth and developmental activities. Most striking change is increase built up areas and decrease in forest land area.

Figure 7.8: Change in the Agriculture category between T1 to T4



The many fold expansion of built up areas, construction of new roads, widening of existing roads to cope the pressure of population increase, urbanization and anthropogenic activities caused the loss of prime agricultural fields and forested areas during the study period. But it is important to note that within the study area the gravity of these changes were different at different locations. In some tehsils if there were loss of agricultural land, in other tehsils there has been a gain in the amount of agricultural land. As discussed in Chapter 4 the role of urbanization has been more crucial in two tehsils [Rawalpindi (S3) and Taxila (S4)] of the study area. In fact due to the large developments in these two tehsils, the other tehsils remained backward in terms of urbanization and are still considered as semi urban areas. To analyse the impact of urbanization on the loss of vegetational cover, in the study area in its real sense, there is a need to look in detail land cover statistics of the Rawalpindi tehsil of the study area (Section 7.4).

7.2.4 Change Detection Error Matrix

By using a post classification method as a change detection method (as in this research), there is a tendency of overestimating the change (Van Oort, 2007). Among the main sources of error, the acquisition of data, image registration, the land cover classification definitions and data processes and analysis are the main factors (Congalton and Green, 1999; Mundia and Aniya, 2005). The transitional error matrix compares the two confusion matrices, for instance for Year 1 and Year 2, (section 3.8). In other words it compares the classified and reference data of one year of a particular location to the classified and reference data of the same location in year two. The matrix which is similar to the confusion matrix (Biging et al., 1998) is a useful tool to produce the normal change /no change matrix, and condensed transitional matrix.

The confusion matrices and transition matrices are two main tools of analysing error in any remote sensing classification. The confusion matrices for all classifications were used to judge the classifications (chapter 6). In this section transitional error matrices have been constructed for T2 to T3 and T3 to T42 periods, according to the procedures described earlier in methodology chapter and change detection and transitional detection accuracies for these periods were computed. From the tables 7.11 (a & b) and 7.12 (a & b) the change detection accuracies of 59 % and 62 % and transitional detection accuracies of 51 % and 54 % were computed for T2 to T3 and T3 to T4 periods. The results of the transition error matrices indicated large transition errors related to the transitions between the *bareland* and *builtup* categories, where many of the built-up pixels were incorrectly classified. Other similar problems were identified in the spatial analysis of the fallow land and agricultural land where some of the pixels were wrongly classified as fallow land.

Table 7.11 (a): Change /no change error matrix for 1981 to 1998 classification

		Reference Data	
		No Change	**Change**
Classified Data	**No Change**	14403	6234
	Change	8567	6901
Change detection Accuracy = (14403+6901)/36105 = 59 %			

Table 7.11 (b): Condensed transition error matrix for 1981 to 1998 classification

		Reference Data			
		No Change		Change	
		Correct	Incorrect	Correct	Incorrect
Classified Data	No Change	12097	2306	6234	
	Change	8567		6320	581
Transition detection Accuracy = (12097+6320)/36105 = 51%					

Table 7.12: (a) Change /no change error matrix for 1998 to 2010 classification

		Reference Data	
		No Change	Change
Classified Data	No Change	9238	2667
	Change	4316	2170
Change Detection accuracy = (9238+2170)/18391 = 62 %			

Table 7.12 (b) Condensed transition error matrix for 1998 to 2010 classification

		Reference Data			
		No Change		Change	
		Correct	Incorrect	Correct	Incorrect
Classified Data	No Change	8338	900	2667	
	Change	4316		1594	576
Transition Detection accuracy = (8338+1594)/18391 = 54%					

The transition error matrix was used to analyse the errors associated with the transition. As discussed above, the main problem in this research was associated with the bare land class. This error could partly be attributed with the timing of some images. However the analysis presented here largely represented what happened in the area especially for the other land covers, other than the bare land class.

7.3 Land Use and Land Cover Distribution of Rawalpindi Tehsil

As discussed in the preceding sections that major changes have occurred in the S 3 (Rawalpindi tehsil) of the study area, therefore this section focuses on the land use assessment of the Rawalpindi tehsil only during the last four censuses. Table 7.13 presents class area and percentage cover for different land cover classes during the four time periods i.e. T1, T2 T3 and T4.

While Agriculture, Built-up and water bodies increased spatially during 1972 to 1998 (T1 to T3), forest, bare land and fallow land decreased in extent. The boundaries of forest were assumed not to have changed spatially during 1972 to 1998, though subtle changes do occur within them. However in 2012 the most obvious change occurred in the amount and boundaries of the forest land. Table 7.13 shows that the per cent gross change that occurred in the Rawalpindi tehsil from T1 to T2 inter-censal period was 16%, which was more than double the average of the study area as a whole (Table 7.10). During the inter-censal period of 1981 to 1998 (T2 to T3), the per cent gross change was, 25.3% followed by almost the same percentage in 1998 to 2012 (T3 to T4) inter-censal periods. During these periods the rate of change of Rawalpindi tehsil was almost more than double that of the District. The built-up area had a net gain of approximately 13%, and fallow land had a net loss of 12% between T1 to T4. The changes in each of the land use and land cover categories are discussed separately below.

7.3.1 Agriculture

As shown in the Table 7.13 and figure 7.9, Agricultural land increased spatially from 13,795 ± 3,429 hectares in 1972 to 30,692 ±8,440 hectares in 1981 census, having a net increase of 16,897 hectares (10.35%) at an ever highest inter-censal annual growth rate of over 9%. Figure 7.9 shows change in Agricultural area during last four censuses. However during the inter-censal period 1981-1998 due to increase in Population, inward migration and rapid urbanization, the agricultural area decreased. This decrease was approximately 1,400 hectares in 17 years, an indication that there is pressure of developmental activities and extension of residential areas on agriculture.

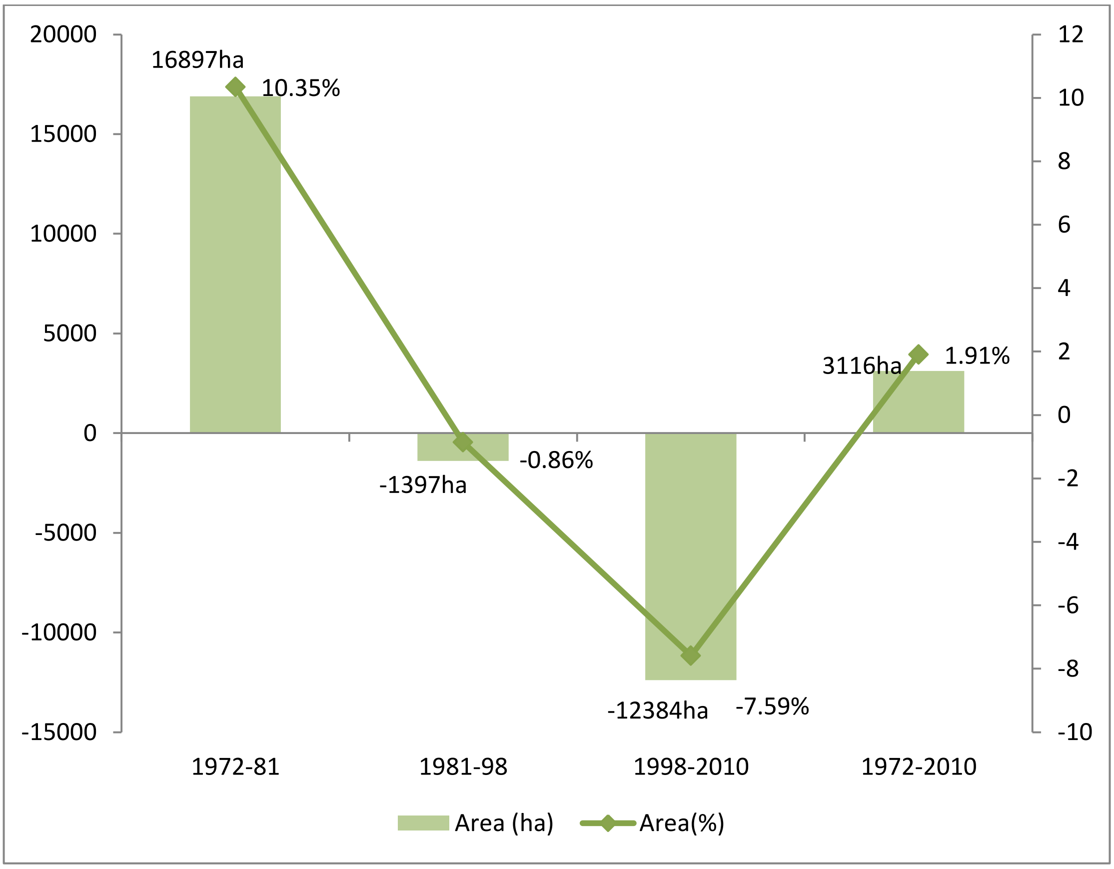
Table 7.13: Rawalpindi Tehsil: Area of land Covers for the census years 1972, 1981, 1998 and 2012

Class	**Area (Hectares)**				**Change T1-T2 (ha)**		**Change T2-T3 (ha)**		**Change T3-T4 (ha)**		**Change T3-T4 (ha)**	
	T1	**T2**	**T3**	**T4**	**Net Gain**	**Net Loss**	**Net Gain**	**Net Loss**	**Net Gain**	**Net Loss**	**Net Gain**	**Net Loss**
Agriculture	13795	30692	29295	16911	16897			1397		12384	3116	
	(8.4)	(18.8)	(17.9)	(10.4)	(10.4)			(0.9)		(7.6)	(1.9)	
Bare land	48606	36302	68959	45654		12304	32657			27305		2952
	29.8	22.2	42.2	28.0		(7.6)	(20)			(14.3)		(1.8)
Built-up	5600	10044	18966	26500	4844		8922		7534		20900	
	3.4	6.1	11.4	16.2	(2.7)		(5.5)		(4.6)		(12.8)	
Forest	15626	19117	17295	12044	3491			1822		5251		3582
	9.6	11.7	10.6	7.4	(2.1)			(1.1)		(3.2)		(2.2)
Fallow	78876	65195	26826	59026		13681		38369	32200			19850
land	48.3	39.9	16.4	36.2		(8.4)		(23.5)	(19.7)			(12.2)
Water	1564	1896	1906	3545	352		10		1639		1981	
	0.96	1.16	1.17	2.17	(0.2)		nil		(1.0)		(1.21)	
Gross Change					25984 (16%)		41589 (25.5%)		44840 (25.3%)		25997 (16.2%)	

Note: Figures in brackets are percentage equivalent

The agricultural area further decreased to 16,911 hectares in 2012, having a net decrease of 12,384 hectares (7.59%). This decrease was also the highest ever with an annual rate of about 4.5%. Overall in forty years the increase was 3,116 hectares (1.09%) having an annual growth rate of 0.5%.

Figure 7.9: Change in Agricultural area during last four censuses



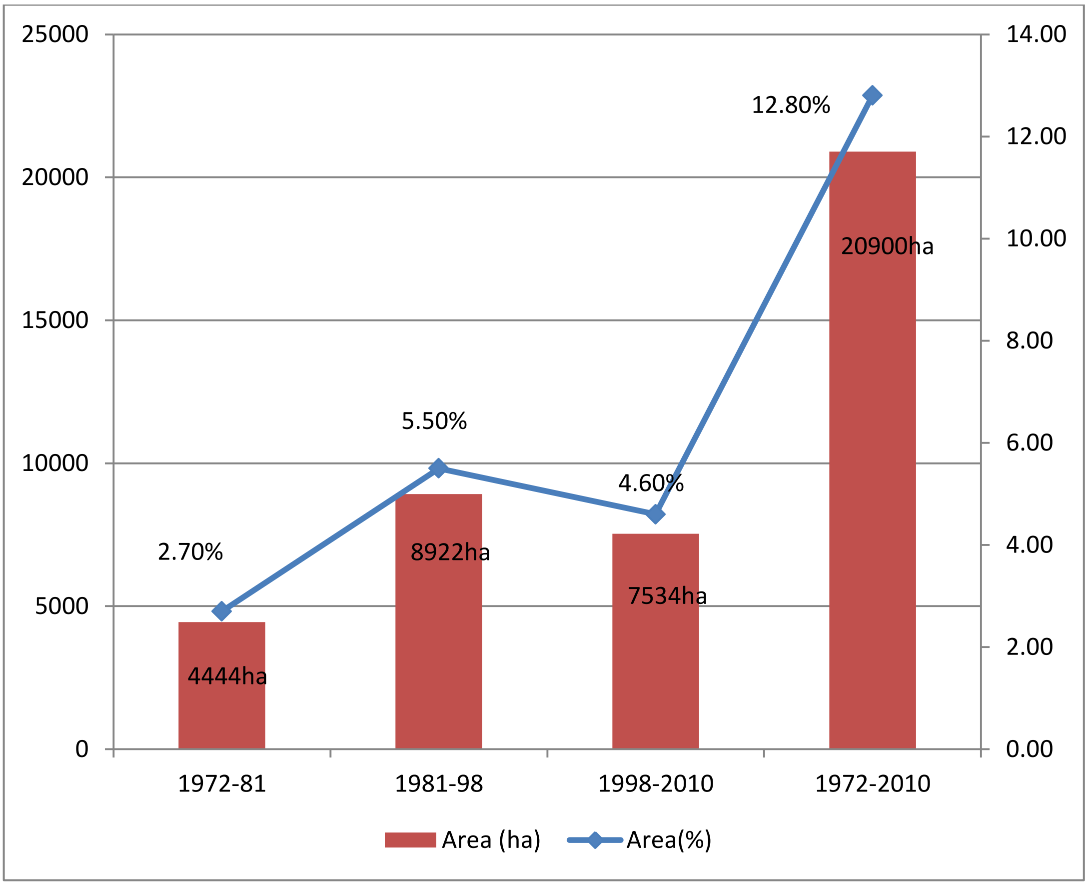
NB: Time spans are different for different censuses

7.3.2 Built-up Area

Built-up areas, often referred to as "impervious area" (Yang et al., 2003) contain structural information about the urbanized land, and have a significant impact on the ecosystem, biodiversity, local climate, which can result in negative aspects such as the urban heat island phenomenon (Kiran and Joshi, 2013).

As demonstrated by the results obtained for the Rawalpindi tehsil shown in Fig. 7.10, the built- up land cover increased several times. For instance in 1972 the built-up area constituted only 3.2% of the total landscape increased to over 16% in forty years. In terms of amount and percentages the built up area increased spatially from 5,600 hectares in 1972 to 10,044 hectares in 1981, which was an increase of 4,444 hectares. It increased further to 18,966 hectares in 1998 and 26,500 hectares in 2010, which was an additional increase of 8,922 hectares (5.5 %) and 7,534 hectares (4.6%) in 1998 and 2010 respectively.

Figure 7.10: Change in Built-up area during last four censuses

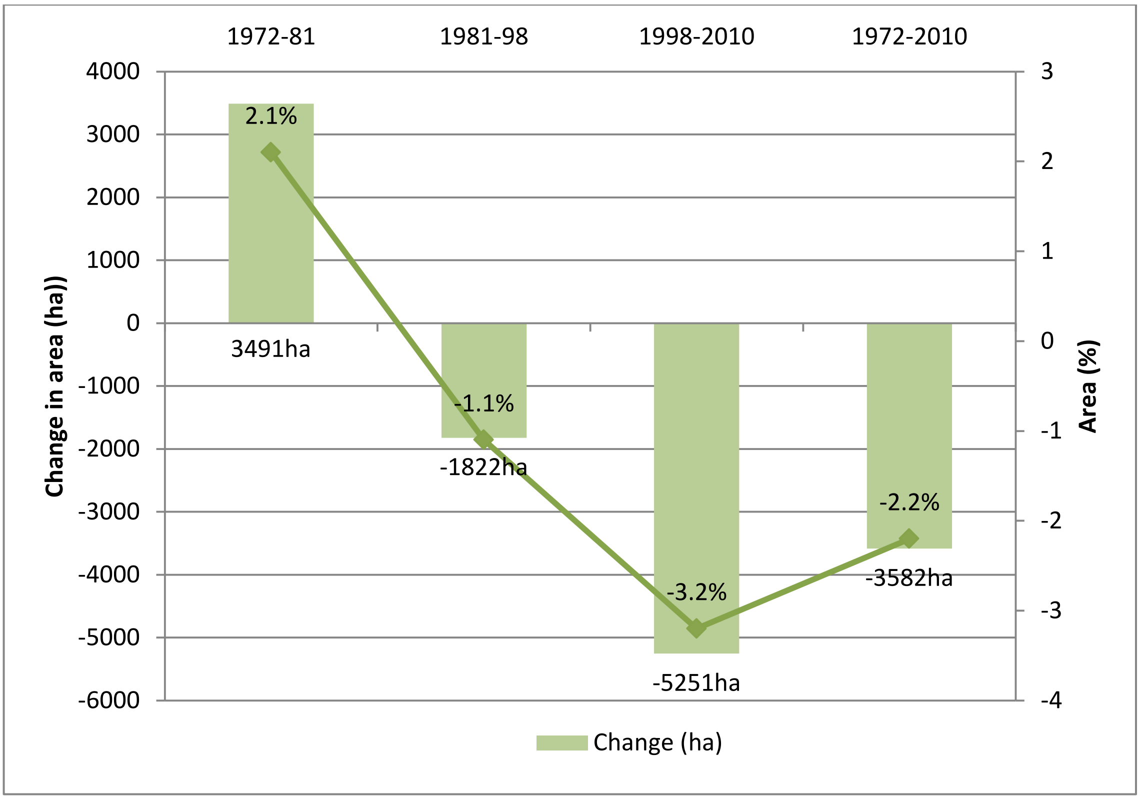


NB: Time spans are different for different censuses

7.3.3 Forest

The forest area of Rawalpindi tehsil as shown in Figure 7.11 increased during the 1972-81 inter-censal period. It increased from 15,626 hectares in 1972 to 19,117 hectares in 1981 with a net increase of 3,491 hectares (2.1%). The inter-censal growth rate was 2.92. However in 1998 a decrease of 1822 hectares (-1.1%) was seen in the forest cover. It decreased further to 5,251 hectares (-3.2%) in 2012. Overall the forest area decreased during 1972 to 2012, from 15,626 hectares to 12,044 with a net decrease of 3,582 hectares which was 2.2% of the region.

Figure 7.11: Change in forested area during the last four censuses



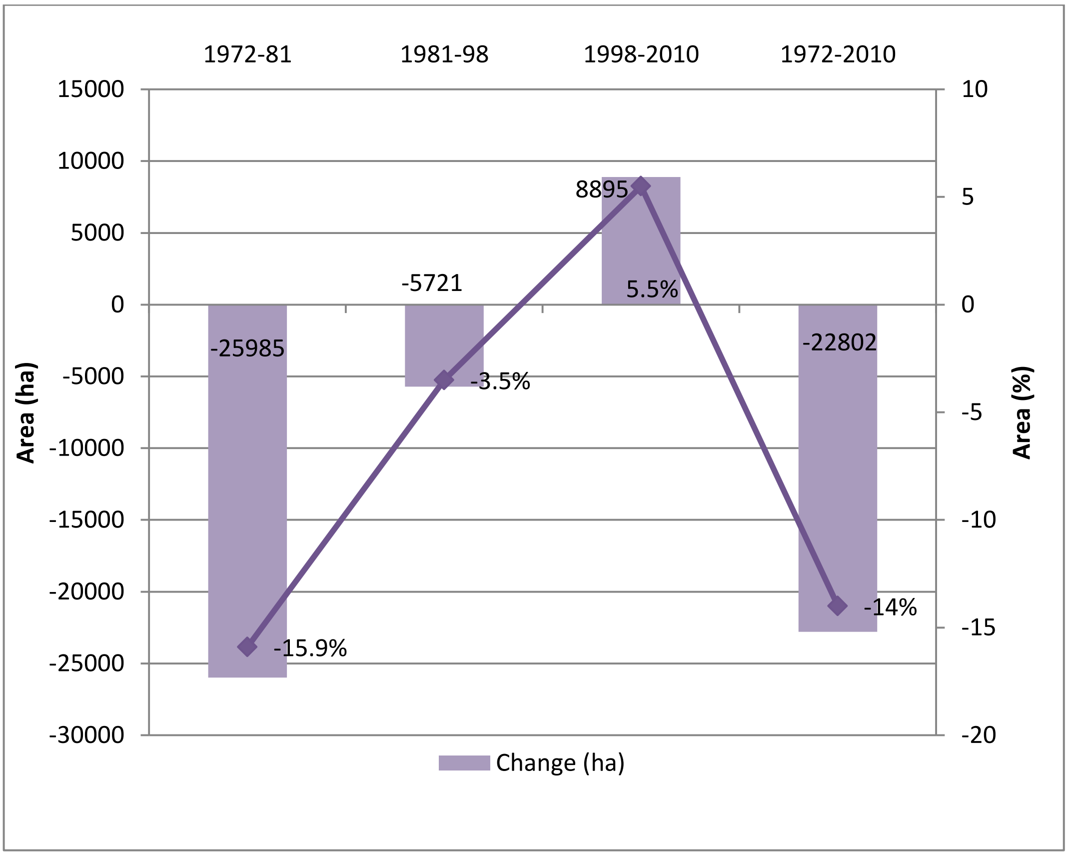
NB: Time spans are different for different censuses

7.3.4 Cultivable Waste (Bare land+ Fallow land)

Like the fallow land which is actually the cultivable land, almost 80 of the bare land of the Rawalpindi tehsil comes directly either from the agricultural land or from the fallow land and only less than 20% land is bare rock or uncultivable land. Therefore, the changes in the bare land and fallow land are shown collectively in Figure 7.12, and termed here as "*cultivable waste*". This "cultivable waste" decreased during the inter-censal periods of 1972-81 and 1981-98. The decrease was 25,985 hectares (15.9%) in 1981, and 5721 hectares (3.5%). In fact, this decrease of cultivable waste was likely due to an increase in the agricultural land, forest cover and built-up area in the

1972-81 period and agricultural land and built-up areas in the 1981-98 periods. Due to the decrease of forest cover and agriculture land during the 1998-2012 periods, the “cultivable waste” increased to 8,895 hectares (5.5%). Overall during 1972 to 2012, this land cover decreased from 127,482 hectares in 1972 to 104,680 hectares in 2012. Thus change during the study period was a loss of 22,802 hectares (14%).

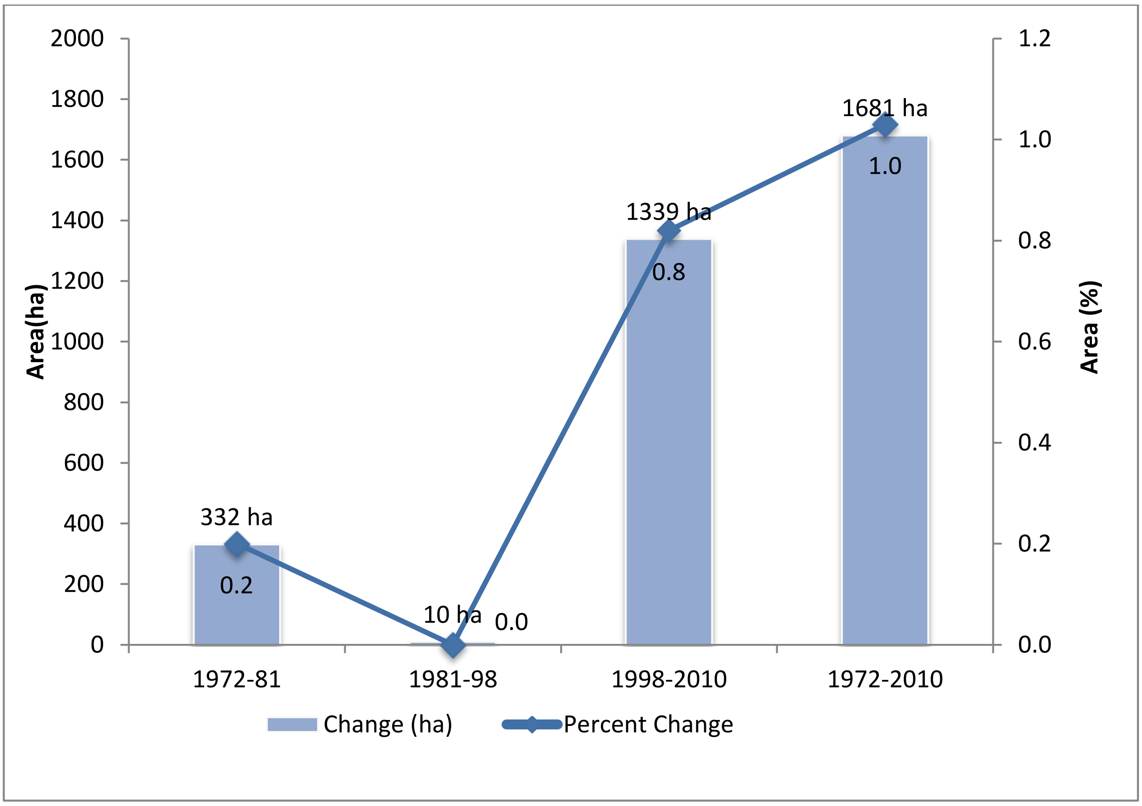
Figure 7.12: Change in Bare land and Fallow land during the last four censuses



7.3.5 Water Body

The analysis shows that from 1972 to 1981, the land surface covered by water increased little from 1,564 hectares (0.96% of the area) to 1,896 hectares (1.16%). During the 1981-1998, the area of water did not increase much, and increase was negligible (10 hectares only). However it increased to 3,545 hectares, having a net increase of 1,681 hectares (1.0%). This 100% increase in the water body area (Fig. 7.13) was not due to any addition of dams or reservoirs, but water bodies do change in response to climatic conditions in a given year and stagnation of rain water in the low-lying areas.

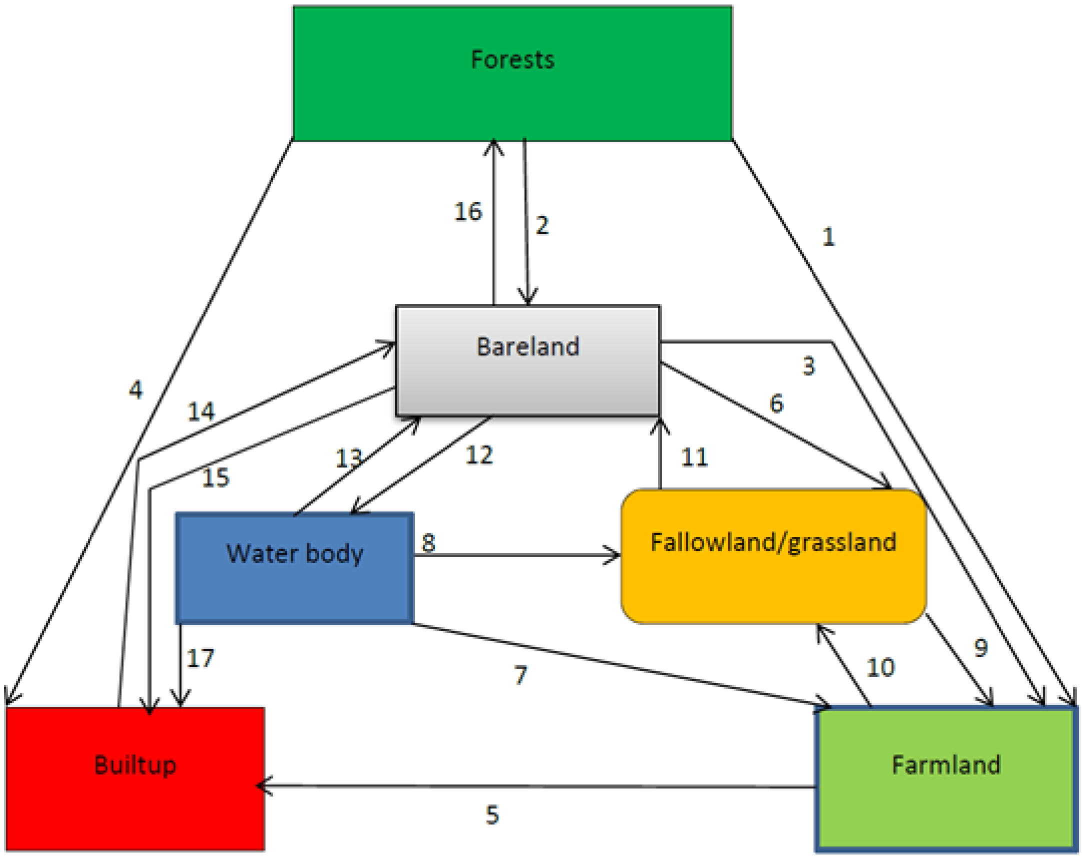
Figure 7.13: Change in water body during the last four censuses



The dynamics of land cover conversions and inter conversions are illustrated schematically in Fig. 7.14. In the scheme of intervention the forests are illegally cleared by the local inhabitants or farmers thereby either converting them into farmland (1) or into built-up areas (4) for residential or commercial purposes. Sometimes due to other events such as bushfire, or other forms of human interventions, the forests may convert into bare land (2).

More often than not, those farmlands, most possibly which would probably give low production, are sold by the owners to builders at good prices, who then build commercial and residential buildings (5). The farmland when left fallow (10) either for the purpose of retaining fertility or building houses, during the transitional period, it is converted into bare land (11). The bare land if it is located in the foothills or in the low lying areas converts temporarily into water bodies (12) due to the stagnant water accumulating after rainfall. When the water dries this land converts either into built-up areas (17) or if there is enough moisture, this water body is cultivated thus turning into farmland (7). It is also common in the area that when there is no or little water in the river, in other words if the river bed is dry, it is used for cultivation (7).

Figure 7.14: Land covers change dynamics in the Rawalpindi tehsil of the study area



Sometimes if bare land remains barren for a long time, due to sufficient rainfall it is converted into fallow land / grassland (6). After time when it regains the fertility, there are chances that farmers may cultivate (3) the crops on it under "crop rotation" arrangements. When the old or illegal constructed surfaces are demolished either to widen the roads or built parks, they temporarily convert into bare land (14), and if these buildings/ constructed surfaces were illegally built (encroachments) by clearing forests or on the government land then there is possibility that this bare land is used for reforestation purposes by the district government (16). There is also possibility that the bare lands if left unexploited for a number of years (which is rare) may revert to forests (16) naturally (Yang & Lo 2002).

In the light of the above discussion regarding the various land use and land cover classes in the Rawalpindi tehsil and the determination of the levels of change they have undergone, it is possible to have a look on the inter-censal change with the help of transitional matrices. The changes in land use and land cover described above are dynamic and consist of conversions and inter conversions. Cross tabulation matrices based on the supervised classification for the Rawalpindi tehsil images are generated: one for the T1 and T2 census (Table 7.14), one for the T2 and T3census (Table 7.15), one for the T3 and T4 census (Table 7.16), and one for overall period of T1 to T4(Table

7.17). Figures 7.15 to 7.18 illustrate the dynamics of these conversions during the different time periods, which is important to know particularly to analyse the landscape changes during the last forty years.

The area of land cover that did not change (persisted) in the 1972 to 1981 inter-census period was 64,272 hectares or 40%, in the 1981-98 period it was 43,018 hectares or 26%, between 1998 and 2012 it was 50,409 hectares or 31%, and between 1972 and 2012 it remained approximately 60,000 hectares or 36% of the region. The loss and gain quantities are presented in the transitional matrices. The gain is the difference between the total of the land cover (column total) less the unchanged portion and loss is the difference between the total of the land cover (row total) less the persisted portion.

Table 7.14: Rawalpindi Tehsil Cross Tabulation Matrix (T1 to T2)

		T1						
	Transition	**Agri-culture**	**Bare land**	**Built-up**	**Forest**	**Fallow land**	**Water**	**T1 Totals**
T2	**Agriculture**	4782	2558	402	1160	4883	10	13795
	(%)	2.93	1.57	0.25	0.71	2.99	0.01	8.45
	Bare Soil	8172	14731	3438	2135	19066	1065	48606
	(%)	5.01	9.02	2.11	1.31	11.68	0.65	29.77
	Built up	315	1470	994	853	1765	184	5581
	(%)	0.19	0.90	0.61	0.52	1.08	0.11	3.42
	Forest	3843	2181	462	6635	2446	57	15624
	(%)	2.35	1.34	0.28	4.06	1.50	0.04	9.57
	Fallow land	13555	15140	4658	8251	36912	361	78877
	(%)	8.30	9.27	2.85	5.05	22.61	0.22	48.32
	Water	25	222	90	82	927	218	1564
	(%)	0.02	0.14	0.06	0.05	0.57	0.13	0.96
	T2 Totals	30692	36302	10044	19117	65195	1896	163246
		18.80	22.24	6.15	11.71	39.94	1.16	100.00

Figure 7.15: Land use and land cover change during T1 and T2 inter censal periods

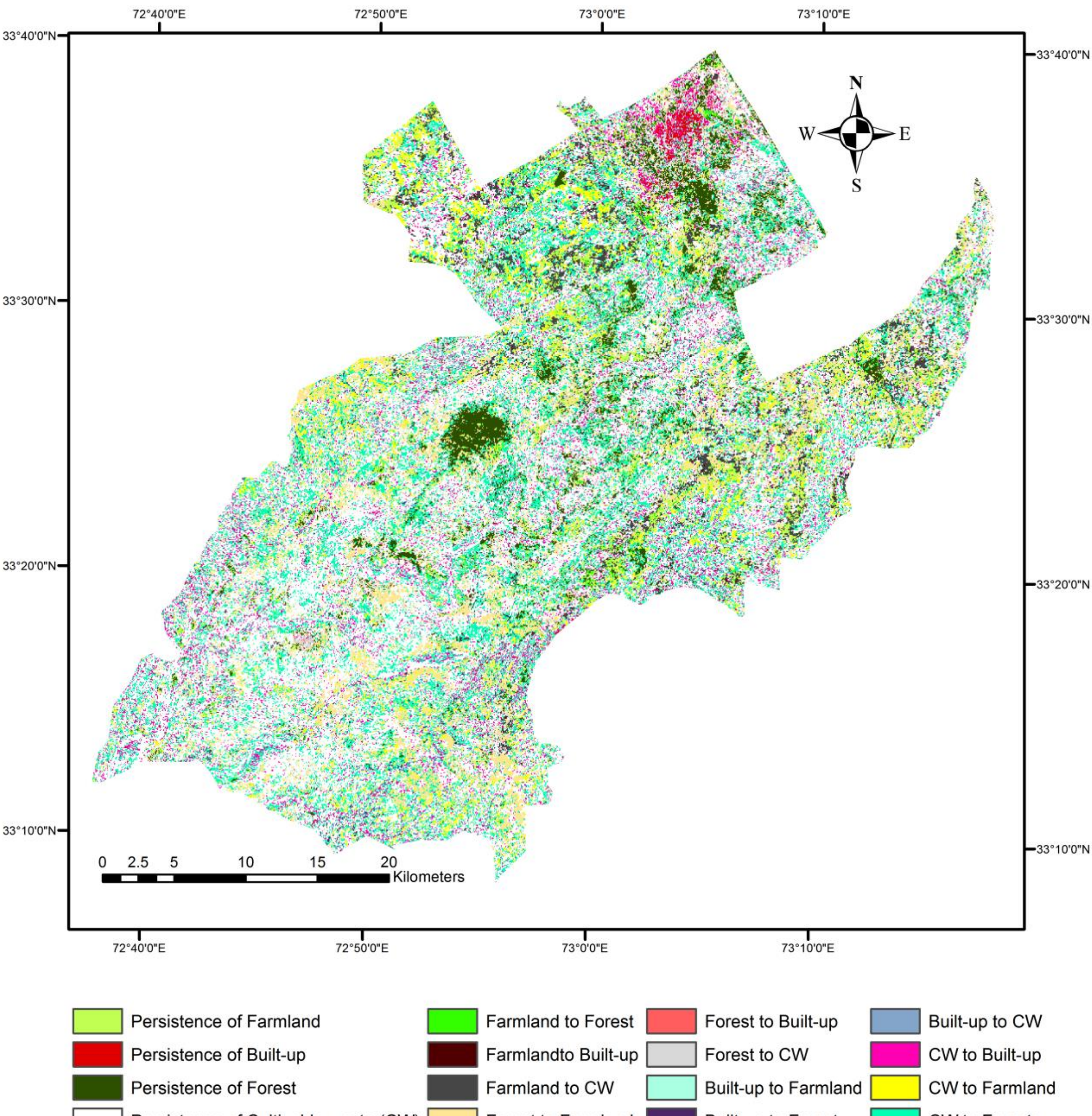
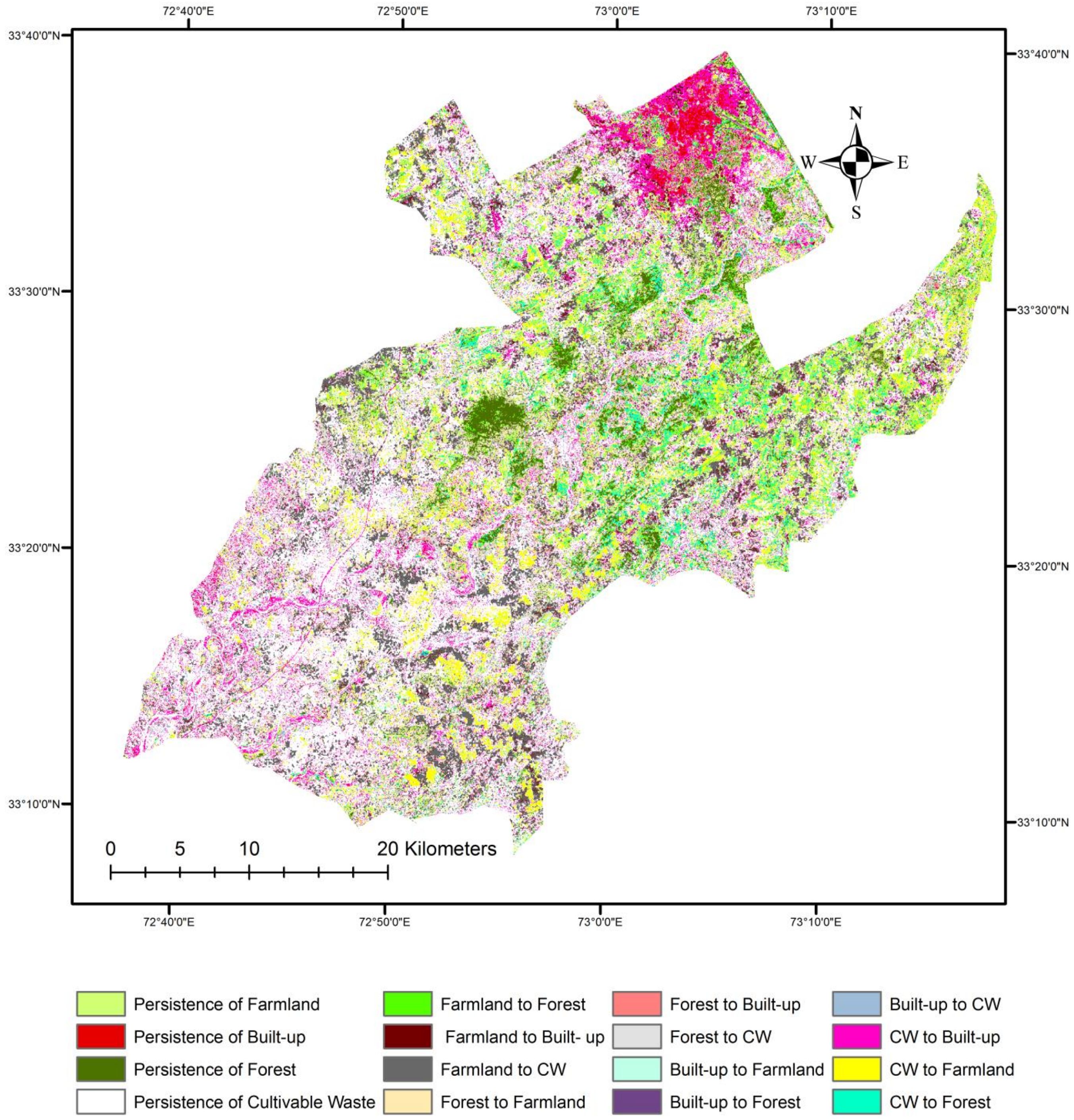


Figure 7.16: Land use and land cover change during T2 and T3 inter censal periods



In T1-T2 inter-censal period, the built-up area increased to 4,444 hectares. The majority of the urban area came from what was bare land and fallow land in T1 (8,196 hectares) comprising approximately 75 % of the total built-up area. The farmland almost increased more than twice at the expense of decrease in forests, bare land and fallow land. Much of the urban growth took at the periphery while the increase in the farmland was in the interior of the tehsil. The T2-T3 matrix showed almost a similar trend as the T1-T2 except the decrease (although negligible) in agriculture instead of increase. This period also witnessed an increase in urban area of 8,922 hectares which was over twice the increase seen from T1-T2. This may be indicative of the major land use conversions as described in (Malik and Hussain 2006) for Rawalpindi/Islamabad region. Because of the growth of the population, the need for extending the municipal boundary covering the large area was felt which not only expanded the city but also public transport system and other over-ground and under-ground utilities. As was true for T1-T2, bare land and fallow land were the major contributors to the increase in urban areas. Moreover the farmland and forest also uphold the burden of extension of built up areas.

Table 7.15: Rawalpindi Tehsil Cross Tabulation Matrix (T2 to T3)

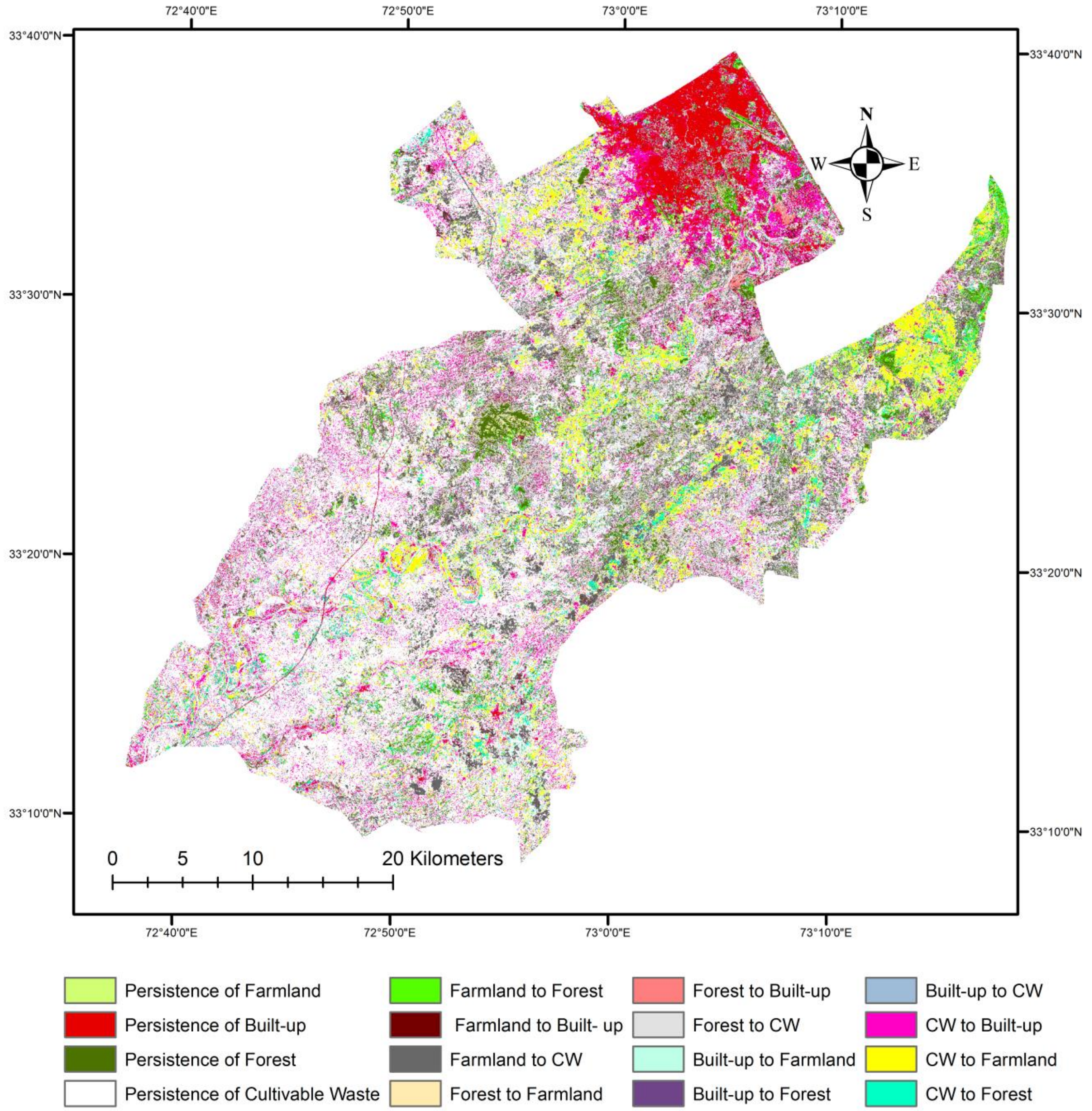
		T2						
	Transition	**Agri-culture**	**Bare land**	**Built-up**	**Forest**	**Fallow land**	**Water**	T2 **Totals**
T3	**Agriculture**	5404	12202	3287	2876	6845	77	30692
	(%)	3.31	7.47	2.01	1.76	4.19	0.05	18.80
	Bare Soil	6309	16763	4689	3130	4912	499	36302
	(%)	3.86	10.27	2.87	1.92	3.01	0.31	22.24
	Built up	1543	4237	2096	635	1294	239	10044
	(%)	0.95	2.60	1.28	0.39	0.79	0.15	6.15
	Forest	4540	4805	1585	6322	1753	111	19117
	(%)	2.78	2.94	0.97	3.87	1.07	0.07	11.71
	Fallow land	11446	30220	6886	4298	11899	446	65195
	(%)	7.01	18.51	4.22	2.63	7.29	0.27	39.94
	Water	52	730	424	35	122	534	1896
	(%)	0.03	0.45	0.26	0.02	0.07	0.33	1.16
	T3	29295	68958	18966	17295	26826	1906	163246
	Totals	17.95	42.24	11.62	10.59	16.43	1.17	100.00

As shown in Figures 7.16 and 7.17 and Tables 7.14 and 7.15, less than 1% of the Rawalpindi tehsil was built-up land cover which did not change between 1972 and 1981 and 1.3% between 1981 and 1998. There was approximately 6% gain over what persisted by 1981 and a loss of 3% what persisted in 1972, thus having a net change of 3%. There was a swap of 6% of the built-up area in the same period. Similarly the forest and agriculture land covers indicated a persistence of over 4% and 3%, respectively. The agriculture gained approximately 16% and lost only 6% having a swap of 12%. On the other hand forest land cover gained approximately 7 % and lost about 3% having a swap of 6% only. During 1981-1998 built-up land cover showed a gain of 10% over what persisted from 1981, and lost less than 5% having a net increase of almost double of the 1972-81 inter-censal period. The agriculture and forest land cover both lost more area as compared to gain. Thus persistence of agriculture and forest land covers during this period was 1.88% and 2.64 % respectively and a swap of 17% and 10% respectively.

Table 7.16: Rawalpindi Tehsil Cross Tabulation Matrix (T3 to T4)

		T3						
	Transition	**Agri-culture**	**Bare land**	**Built-up**	**Forest**	**Fallow land**	**Water**	T3 **Totals**
T4	**Agriculture**	3067	7371	2968	2962	12470	456	29295
	(%)	1.88	4.52	1.82	1.81	7.64	0.28	17.95
	Bare Soil	6165	24190	9828	2468	24514	1793	68958
	(%)	3.78	14.82	6.02	1.51	15.02	1.10	42.24
	Built up	1982	3870	7417	685	4534	477	18966
	(%)	1.21	2.37	4.54	0.42	2.78	0.29	11.62
	Forest	1156	3045	1676	4302	6527	590	17295
	(%)	0.71	1.87	1.03	2.64	4.00	0.36	10.59
	Fallow land	4378	6992	2836	1452	10680	489	26826
	(%)	2.68	4.28	1.74	0.89	6.54	0.30	16.43
	Water	163	185	327	175	302	753	1906
	(%)	0.10	0.11	0.20	0.11	0.19	0.46	1.17
	T4	16911	45654	25053	12044	59026	4558	163246
	Totals	10.36	27.97	15.35	7.38	36.16	2.79	100.00

Figure 7.17: Land use and land cover change during T3 and T4 inter censal periods

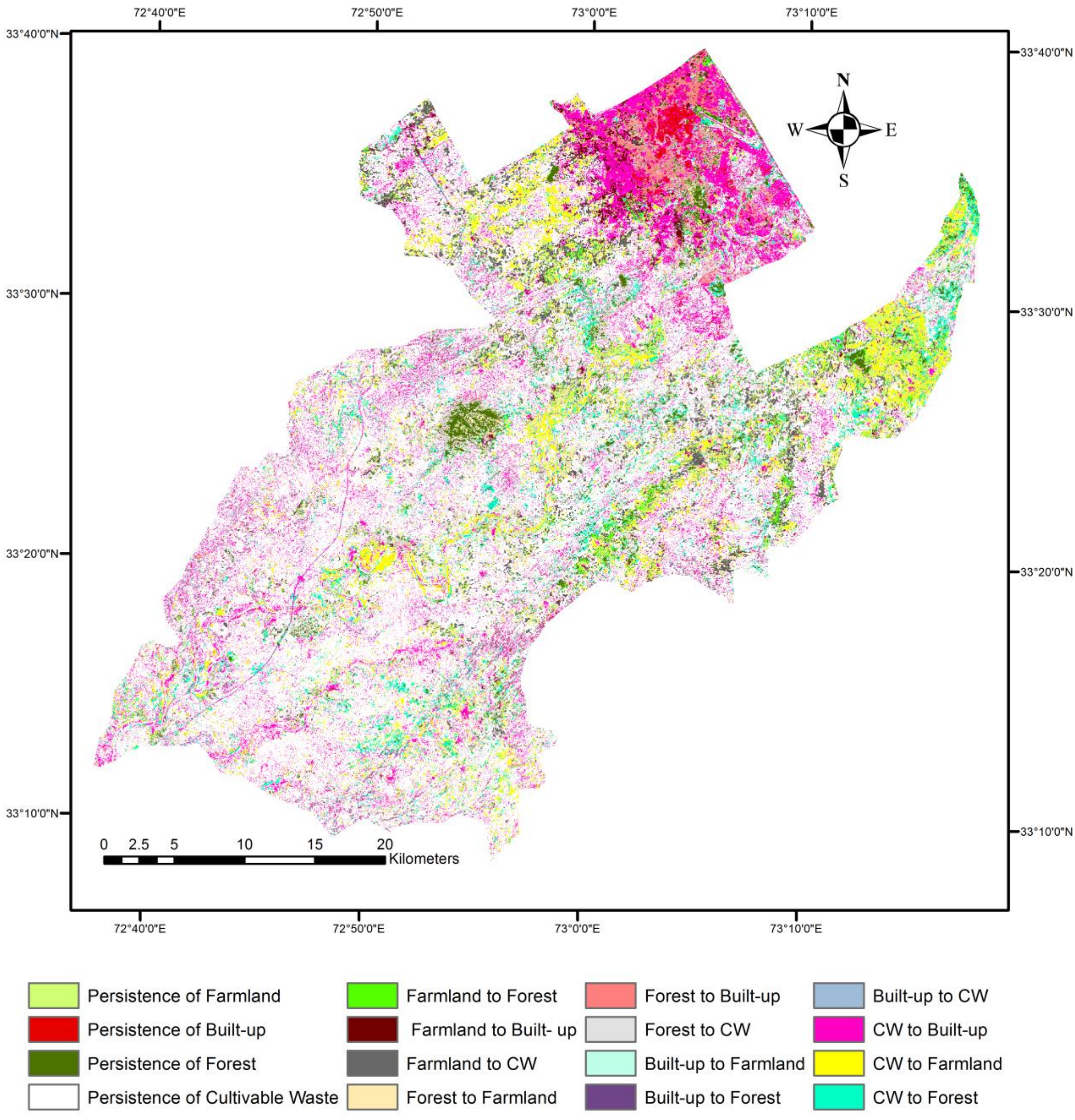


The built-up area continued to increase at the expense of loss of vegetation (forest and farmland) and cultivable (fallow land and bare land). During 1998-2012 period, an increase of over 6,000 hectares was observed which was more than 33% of the build-up area of 1998. The forest and farmland both decreased by 5,251 hectares and 12,384 hectares respectively, yielding a total forest cover of 7.38% and farmland 10.3%, both down by 3.21% and 7.95% respectively. The majority of the change in forest was to the grassland/fallow land whereas farmland changed to the bare land. The fallow land showed an overall increase of approximately 20% in this inter-censal period. From 1998 to 2012 the persistence of agricultural and forest land cover decreased to 1.88% and 2.64 % respectively, whereas the built-up increased to 4.54%. There was an approximately 11% gain over what persisted in the built-up in 2012 and a 7% loss from what persisted in 1998, thus having a net change of over 4% and a swap of 14%. Forest and agricultural land covers indicated a gain of 8.48 % and 4.74 %, losses of 16.07 % and 7.95 % and a net change (decrease) of 7.59 % and 3.21 % respectively and a swap of 9.48 % and 15.90 % respectively.

Table 7.17: Rawalpindi Tehsil Cross Tabulation Matrix (T1 to T4)

		T1						
	Transition	**Agri-culture**	**B-soil**	**Built-up**	**Forest**	**Fallow land**	**Water**	T1 **Totals**
T2	**Agriculture**	3395	3612	1779	1243	3675	92	13795
	(%)	2.08	2.21	1.09	0.76	2.25	0.06	8.45
	Bare Soil	4953	17919	7073	1818	15424	1418	48606
	(%)	3.03	10.98	4.33	1.11	9.45	0.87	29.77
	Built up	174	645	1708	410	2240	405	5581
	(%)	0.11	0.39	1.05	0.25	1.37	0.25	3.42
	Forest	1923	2182	3358	3426	4202	534	15624
	(%)	1.18	1.34	2.06	2.10	2.57	0.33	9.57
	Fallow land	6366	21234	10992	5074	33320	1892	78877
	(%)	3.90	13.01	6.73	3.11	20.41	1.16	48.32
	Water	101	62	142	73	166	218	763
	(%)	0.06	0.04	0.09	0.04	0.10	0.13	0.47
	T4	16911	45654	25053	12044	59026	4558	163246
	Totals	10.36	27.97	15.35	7.38	36.16	2.79	100.00

Figure 7.18: Land use and land cover change during T3 and T4 inter censal periods



The final T1-T4 matrix gives an overall view of the changes during the last four decades. The built-up area had a net increase of over 20,000 hectares. There is a possibility that fallow land alone contributed to approximately half of the increase of the built-up area, as there was a considerable decrease of 17,851 hectares in fallow land, whereas cropped area only increased to 3,216 hectares. Thus it seems that the fallow land has been converted into farmland, built-up area and bare land through a mechanism as described in Figure 7.8 above.

Forest area also had a net decrease of 3,580 hectares. Between T1 and T4, the persistence of agriculture, forest and built up was 2.08%, 2.10% and 1.05% respectively. There was an overall 8% gain in agriculture over what persisted in T4, and 6% loss from what persisted in T1, thus having a net positive change (increase) of 2% and a swap of 12%. The forest category lost more land (7.47%) as compared to gain (5.28%), having a net negative change (decrease) of 2.18% and it swapped approximately 11%. The maximum gain was in the built-up land (14.35) and a minimum loss of just over 2 %, having a net increase of over 12%. The swap for built-up also reduced to 4% compared previous inter-censal periods.

The interpretation of the gain and loss as described by Pontius et al. (2004) shows that when agriculture gained in area it replaced mostly fallow land, bare land and forest to some extent but not built-up and water. When it experienced losses it was replaced by bare land and fallow land and not forest. But in T2-T3 and 1998-2012 it was also replaced by the built-up, but not in 1972-81 inter-censal period. Whenever the bare land gained it mostly replaced fallow land, agriculture and forest, whereas when losses occurred it was mostly replaced by fallow land, agriculture and built-up area. In 1972-81 the built-up category gained in area mostly replacing fallow land and bare land but in 1981-98 and 1998-2012 it also gained area from agriculture and forest considerably. In the case of loss in 1972-81 it was mostly replaced by fallow land/grass; in 1981-98 by bare land; and in 1998-2012 by fallow land, bare land and agriculture. In 1972-81 forest mostly gained the area from the fallow land and the bare land but not from agriculture or any other category. In 1981-98 and 1998-2012 under a beautification programme some parks having dense vegetation were established by abolishing the cropped area, therefore, during this period the forest gained area from cropland as well. In 1972-81 forest was mostly replaced by agriculture and fallow land; in 1981-98 by agriculture and bare land and in 1988-2012 by fallow land and built-up area.

Whenever the fallow land/grassland experienced a gain in area, it was from agriculture and bare land whereas it mostly conceded to agriculture, bare land, forest and built-up areas. Water bodies when they gained area it was from fallow land and bare land and to some extent from built-up areas (in the case of flooding) but not from the forest and agriculture, whereas in case of loss it was mostly replaced by fallow land/grassland.

7.4 Conclusion

In this chapter the land cover statistics of the study area for the last forty years have been discussed in detail with the help of the tables and maps derived from the classifications of the Landsat MSS (1972, 1979) and Landsat TM (1992, 1998, and 2010) years. The above classifications were termed as T1, T2, T2.5, T3, and T4 respectively according to the dates of census organization. The area of each of the six land cover categories were first presented in descriptive form, i.e. the sum of the each of the land covers at each of the dates of census/image and thus estimating the change from their differences; and then in a transition matrix form which described the transition between land covers in terms of persistence, gain, loss and swap. The characteristics of the change were analysed graphically according to the strata of the study area, and for each land cover separately. A transition error matrix was used to compute the change detection and transition detection accuracies, which analysed the errors associated with the transition. The assessment of the land covers of the study area as a whole and stratum-wise not only exhibited important aspects of the areal differences, but also depicted the level of urbanization of the different strata of the study area.

The study area as a whole witnessed an overall gross change of approximately 80,000 hectares out of its over 500,000 hectares area during the last forty years, i.e. 1972 to 2012. The percentage gross change from 1972 to 1981 (T1 to T2) inter-censal period was 7.43 followed by 4.18 and 5.14 in 1981-1998 (T2-T3) and 1998-2012 (T3-T4) periods respectively. Both built-up and agriculture categories gained approximately equal area of 30,000 hectares during the last four decades. However the agricultural area increased mostly during T1 to T3 periods, and started to decrease in T3 to T4 period, whereas the built-up area expanded steadily from T1 to T2, and after that the increase was much more rapid in the following periods. The forested area has continuously been decreasing since 1972 to 2012 i.e. T1 to T4 periods. There had been a gross decrease of over 10,000 hectares of forests, thus indicating a negative change of over 13%. In Stratum 1(Murree, Kotli Sattian and Kahuta tehsils) and Stratum 2 (Kallar Syedan and Gujjar Khan), the agricultural areas are still expanding, but there is a trend of deforestation. The built-up areas of above strata/tehsils expanded, but not at the same pace as that of the Rawalpindi (Stratum 3) and Taxila (Stratum 4) tehsils. The built-up area of the Rawalpindi (Stratum 3) tehsil increased fivefold during the last forty years, whereas its forested area decreased considerably from 11.7 % in T2 to 7.4% in T4. In this region a continuous loss of agricultural and forested land indicated the pressure of population and urbanization. In a nutshell, this chapter provided a measurement and characterization of the land cover changes and set different approaches for analysing changes at different intervals of time.

8 INTEGRATION OF SATELLITE-BASED LAND COVER, CENSUS OF POPULATION AND QUALITATIVE DATA FOR ANALYSIS OF URBAN GROWTH

8.1 Introduction

This chapter deals with all the integration of satellite land cover data with official statistics on land cover and population, as well as qualitative data derived from fieldwork. These data are used to assess the urban growth over the period 1972-2012, particularly by comparing official statistical estimates of population and land cover with those derived primarily from detailed satellite observations in the study area. Both primary and secondary data have been included in the analysis. Primary data comprised remote sensing image analysis, interviews, focus group discussions, and participant observation. Secondary data included census figures, agricultural statistics and other related official statistics of land cover. The chapter focuses on the extent in which each type of data used in this study has facilitated the analysis and discussion.

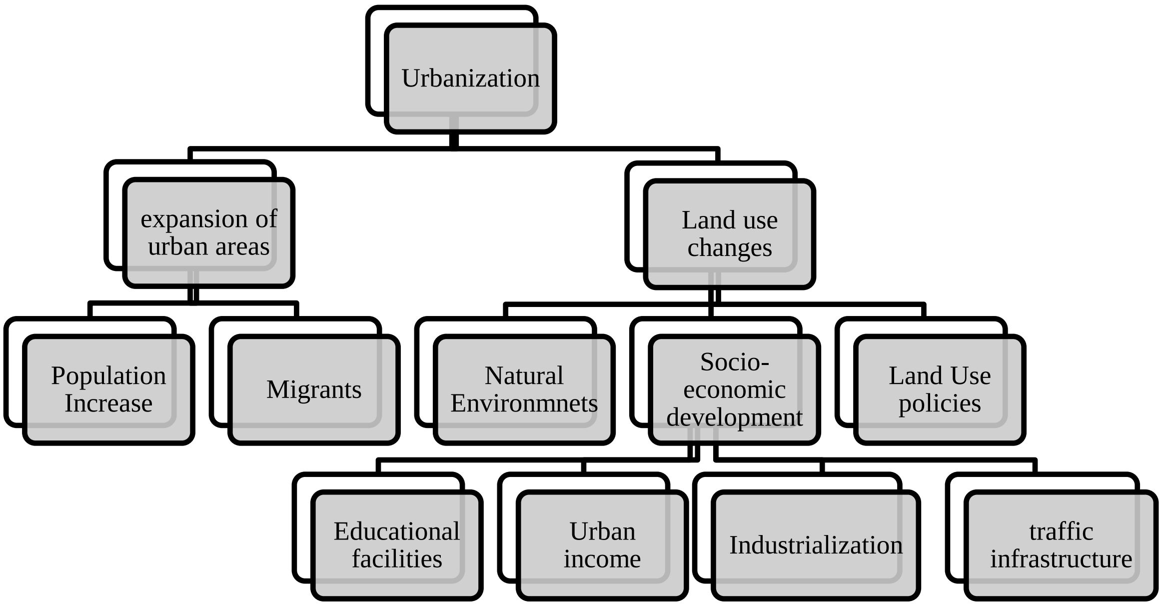
The chapter is divided into five main sections. The first section deals with the remote sensing analysis and its causal relationship with population and urbanization. It compares the urban expansion, built-up density and population density of the study area both at district and tehsil levels. It further throws light on the distribution of urban land according to the soils suitable for agriculture. The second section deals with the analysis of land cover change as perceived by the people of the study area. One of the strengths of using field data was to cross check the information from different resources. The third section illustrates how the government statistics were analysed in several ways in this land use /cover change investigation. The fourth section briefly throws light on the social change caused by the migration of the people due to land cover change. The last section explains how built up area estimated from remote sensing results can further be used to estimate the population.

8.2 Urban and Peri-urban land cover change

The population of Pakistan is over 180 million, over 41% of which is urban. The census estimates shows that out of the >100 million population of the province of Pujab, Rawalpindi District contributes nearly 5%, and Rawalpindi tehsil alone bears 60% burden of the District. The urban popualtion of Punajb is 38%, whereas the urban population of Rawalpindi district is approximately 60%. Rawalpindi tehsil alone has over 80% of the total urban population of the District. In 2000, the total built-up area of Pakistan as extracted from Landsat ETM images (Land Use Atlas of Pakistan, 2009) was 319,000 hectares which has reached to 430,000 hectares in 2012. This means that over 9,000 hectares of land is being converted into urban/built-up area annually. The built-up area of Pakistan is less than 1% of its total area, and 66% of it is occupied by the province of Punjab. Rawalpindi district covers nearly 13% of the total built-up area of Punjab. Patterns of land use in Pakistan are greatly influenced by environmental and physical factors such as landforms, soil, climate, water resources as well as human factors such as population size and growth patterns, cultural practices, and economic demands. Rawalpindi is not the exception. Inter provincial and inter district variations have an e influence of the above factors. For instance Kyber Pakhtankhah has the highest proportion of forest coverage (17%) as agianst Punjab (4%), Sindh (6%) and Baluchistan (1.5%). Rawalpindi, likely due to its high altitude and hilly areas, with relatively high rainfall, has almost 25% of its total area under forests, which is highest among all districts of the Punjab. On the other hand agricuture is over half of its total area of the Punjab, whereas Rawalpindi district has less than 20% of its area is under agriculture and this percentage has decreased from 1998 to onwards. This percentage is high in the other tehsils of the district as compared to the Rawalpindi tehsil, where it is slightly above 10 %.

The direct effect of urbanization, population concentration, and high inward mobilty involve, of course the conversion of land from rural to urban areas, thus causing extensive land use changes. Many researchers, such as Chen et al (2006); Chen et al (2007); Deng et al (2009); Grey et al (2003); Jat et al (2008); Kiran and Joshi (2013); Mundia and Aniya (2005) have reported in their research that land use changes occur as a result of the interaction of a number of environmental, demographic, and socio-economic factors. For instance if rainfall exerts a strong influence on the vegetation cover, the high population growth, economic development, and traffic infra-structure pushes the boundaries of the built-up areas well beyond the municipal limits of a city. Fig. 8.1 throws further light on the relationship between urbanization and land use changes. Factors such as administrative rights of land ownership, better economic development and manpower needs and industrialization all influence urban growth. Moreover, due to the large scale developments in the nearby city, Islamabad, the capital of Pakistan, a large number of skilled and unskilled workers moved to Rawalpindi during the study period increasing the total population and expanding urban areas and driving land use changes (see Figure 8.1). In short, urbanization contributes to the expansion of urban areas, and an increase in urban population on the one hand, and causes land use changes on the other hand which are affected by a number of factors mentioned above.

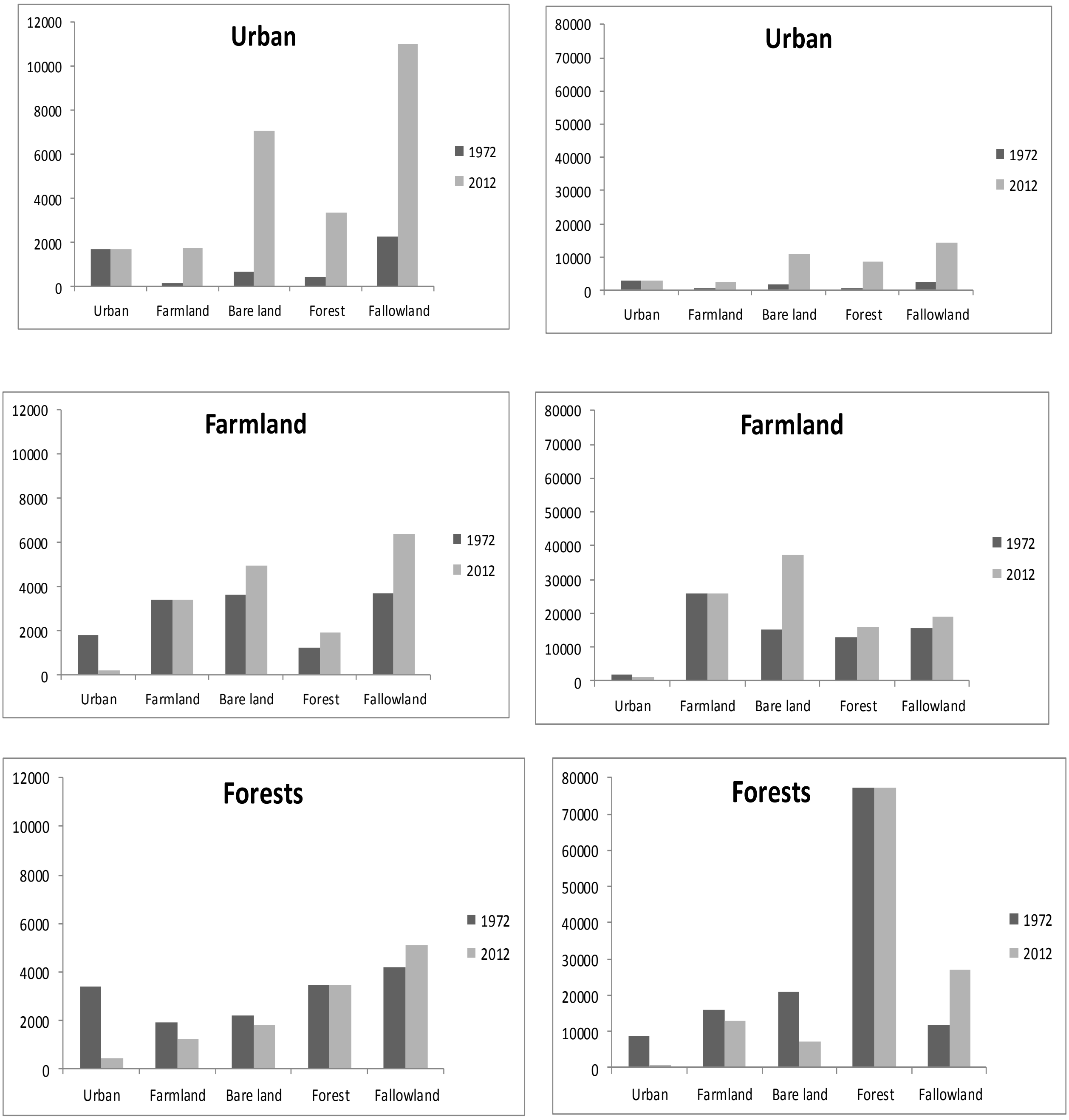
Figure 8.1: Outcome of urban growth)



The remote sensing analysis revealed that the biggest land conversion took place from cultivable waste to built-up areas. Comparing the classification maps as demonstrated in chapters six and seven, landscape changes are significant: the built-up areas/ urban regions have largely been broadened; the farmlands and forested areas have decreased; the farmlands/orchards/forests in the suburbs of the Rawalpindi in the southern and eastern side have disappeared.

Figure 8.2 establishes the conversion relationship among some major land use/cover types during the forty years (1972-2012) study period i.e. between T1 and T4, at the District and Tehsil level. Fig. 8.2 demonstrates the land use/cover conversion relationship more directly. For instance urban land (built- up area) both in the Rawalpindi District and tehsil shows a major increase from the bare land, forest and fallow land categories (fig. 8.2 a). In Rawalpindi tehsil, it can be seen that a considerable amount of farmland was also converted to urban. Thus in 1972 (T1), the trend of conversion of farmland, forests and bare land into built-up (urban) area was small, which means that these land cover categories persisted more in T1. With the passage of time (during T2 to T4 period), due to the establishment of industries and better job opportunities in Rawalpindi tehsil and nearby capital Islamabad, a large number of people moved to the urban areas causing an expansion of legal and illegal residential colonies. Moreover, the people of the area found it more profitable to change their professions from agriculture to business and service sector, which also caused a considerable decrease in the farm land, fallow land, and forest land covers.

Figure 8.2: The conversion relationship between some main land use types in Rawalpindi District (Right) and Rawalpindi tehsil (left)



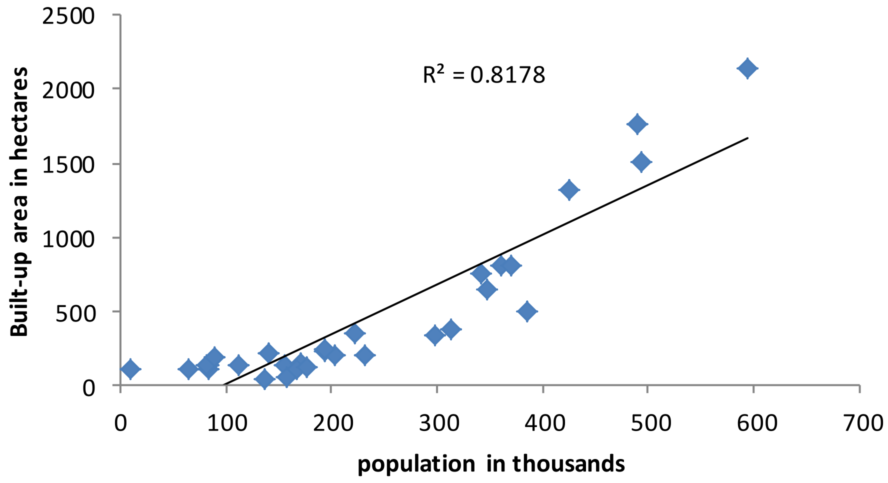
The change of farmland shows that a part of it decreased to urban land, although this decrease was more obvious in the tehsil of Rawalpindi, as compared to the District. Nevertheless it decreased in both regions. But due to high rate of agricultural land loss, those people who did not migrate to urban areas started to cultivate the vacant lying barren lands and some of them started clearing forests to bring them into cultivation. Therefore both in Rawalpindi district and Rawalpindi tehsil , a considerable amount of of bare land and forest land were converted to farmland during T1-T4 period (fig.8.2 b). Fig. 8.3 (c) shows that a large part of forests were converted for urban use, both in the District and Tehsil, and a smaller part of it was also converted to bare land and farmland. In sum, the loss of forests has mainly been converted to farm land. The peri-urban agricultural areas converted into built-up areas, whereas the bare land and fallow lands of peri-urban also converted into built up areas. In addition to it some of the bare land also convertd into fallow land /grass lands. This grassland was actually in response to the beautification strategies of the district authorities. So these grassland which appropriately be called" public green spaces" was an intended conversion of peri-urban bare lands and farm lands into grasslands.

8.3 Population Change and Urban expansion

According to the census records during the last four decades the mean urban population growth rate per annum in the study area and Rawalpindi tehsil was 2.8 and 3% respectively. The built up area of the study region increased at a rate of above 4% per annum during the last four decades. The relationship between population estimates derived from the official Census of population and estimates of built-up area land cover and area of transportation network is seen visually in Figures 8.3 and 8.4. Based on the observed linear trend, a least squares regression analysis was used to determine the relationships between Census data and satellite-derived land cover variables. All analyses are two-sided and statistical significance was considered at $p < 0.05$. Despite the fact that there are few observations, due to the decadal nature of Census and other government records, the coefficients of determination (R^2) measuring the strength of the relationships were found to be significant.

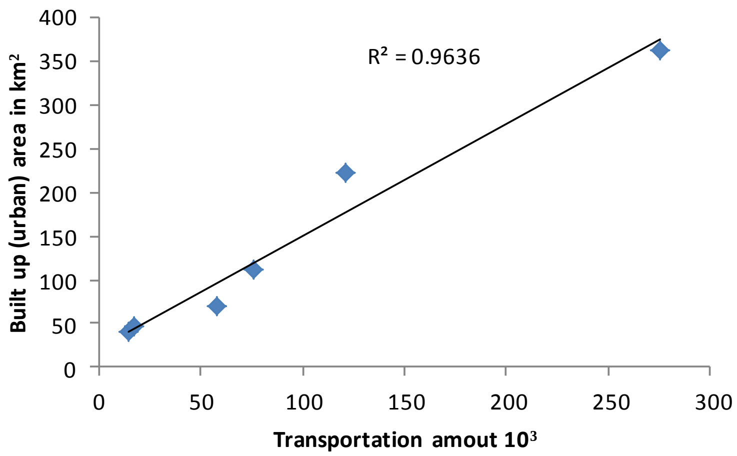
The increase in the built-up (urban) area from 1972-2012 strongly correlates (($R^2 = 0.81$) with the census population growth of the tehsils of Rawalpindi district during the last four censuses and the pattern of growth appears linear. This strongly suggests that satellite-derived urban area estimates can be used as proxy estimates for population.

Figure 8.3: The relationship between satellite-derived built-up area and census population data



Another possible proxy variable for urban development is the land area associated with number of vehicles registered to operate within the study area; to some extent vehicle numbers will be related to the physical extent of the transport infrastructure and the level of population. This idea is confirmed from interviews with governmental officials and local inhabitants. Figure 8.4 shows the relationship between the number of registered vehicles and the built-up area for all years where comparative data are available. The increase in the built-up (urban) area from 1971-2012 strongly correlates with the transportation network (R^2 = 0.9636) and a relationship indicates a pattern of linear growth.

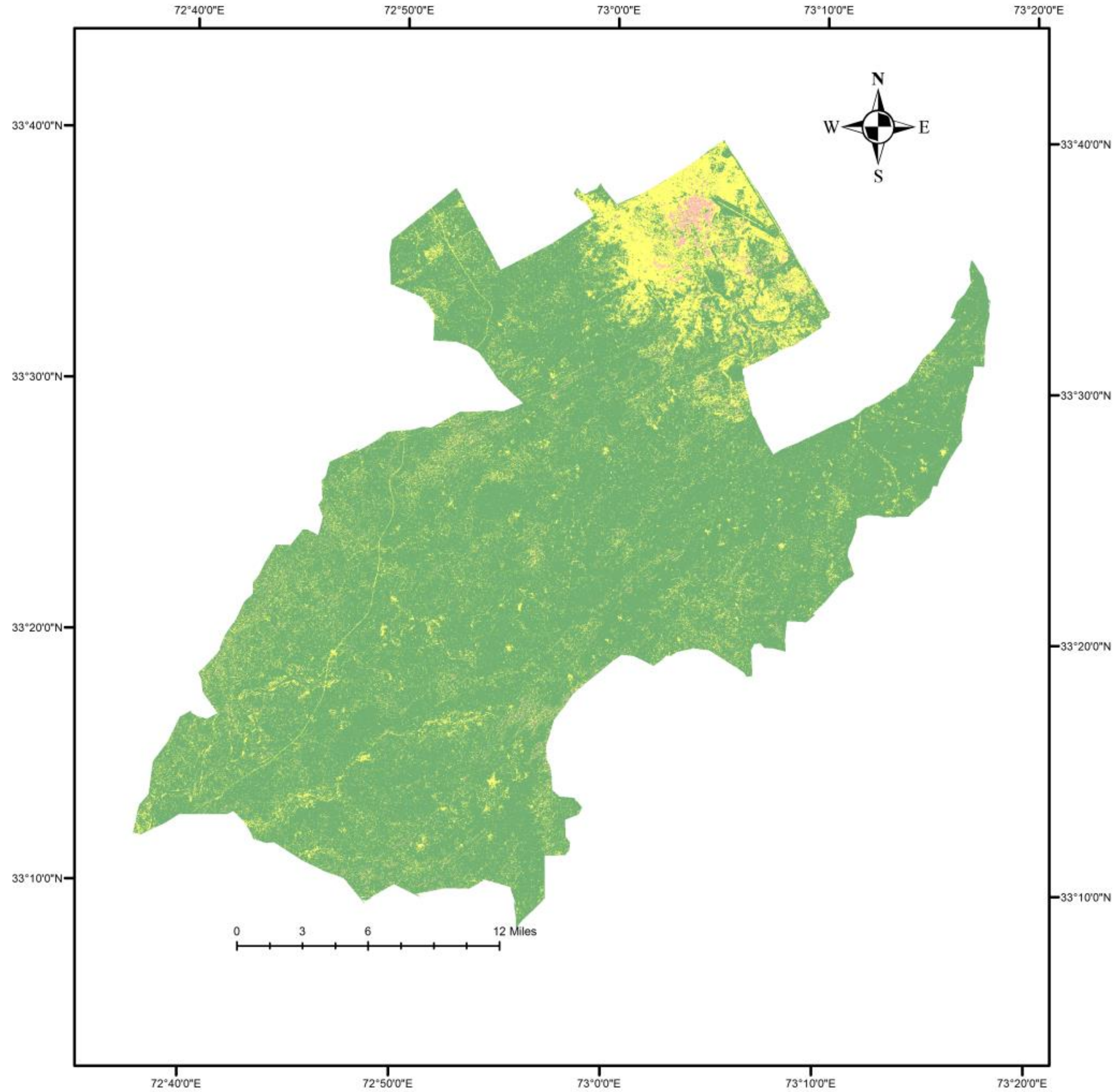
Figure 8.4: The relationship between satellite-derived built-up area and number of registered vehicles operating in the study area



It is pertinent to mention here that with the increase in the built up (urban) area of Rawalpindi district in general and Rawalpindi tehsil in particular, the demand for transportation also increased. Since the most of the urban expansion was in the peri-urban areas, therefore to facilitate the people living there, the transportation facilities increased many fold. These facilities were provided both by the public and private sector. FG participants and policy makers both admitted, that although amount of transportation vehicles operating on the roads have increased many fold, yet, this amount does not fulfil the requirements and in the peak hours, people has to wait many hours for transport facility. Moreover in many tehsils the movement of huge amount of transport vehicles on broken and narrow roads cause road side accidents and congestion of traffic is a routine matter, which in turn causes air pollution.

Exurban and peri-urban areas and even the villages near the city centres are subjected to continuing population pressure, as strong now as in 1972. At the same time suburbanization is continuing with a concomitant decline of the population in the core areas of Rawalpindi and an extraordinary extension of built-up areas due to the improved transport facilities to the peripheral of the city. This has favoured the establishment of housing colonies in the suburbs, increasing the built-up area, which can be seen as scattered particularly in the Rawalpindi tehsil (Fig.8.5 a & b). Some examples of how the District Government has turned a blind eye to the increase in the built-up area can be seen in the mushroom growth of illegal colonies in the outskirts, particularly in the western and southern areas of Rawalpindi tehsil. Currently there are more than 40 illegal colonies operating and responsible for the increase of built-up area in the district in general and in the Rawalpindi tehsil in particular. Moreover large military installations, the substantial presence of affluent residences and some heavy industrial complexes altogether have changed the land use of the study area.

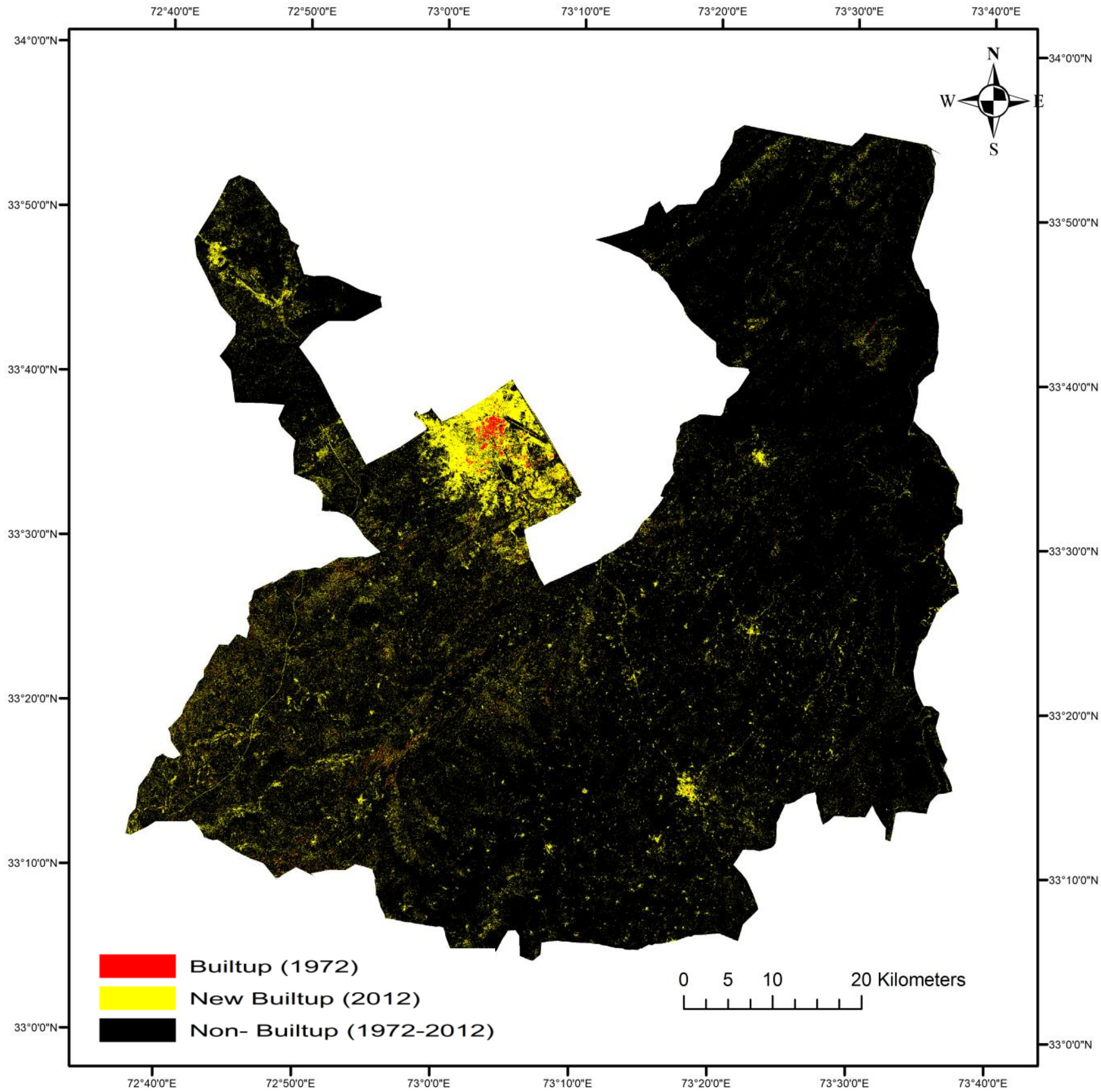
Figure 8.5 (a): Urban expansion in Rawalpindi Tehsil



Pink areas show the built-up area in 1972, Yellow shows built-up area. In 2012 and Green shows non-urban both in 1972 and 2012

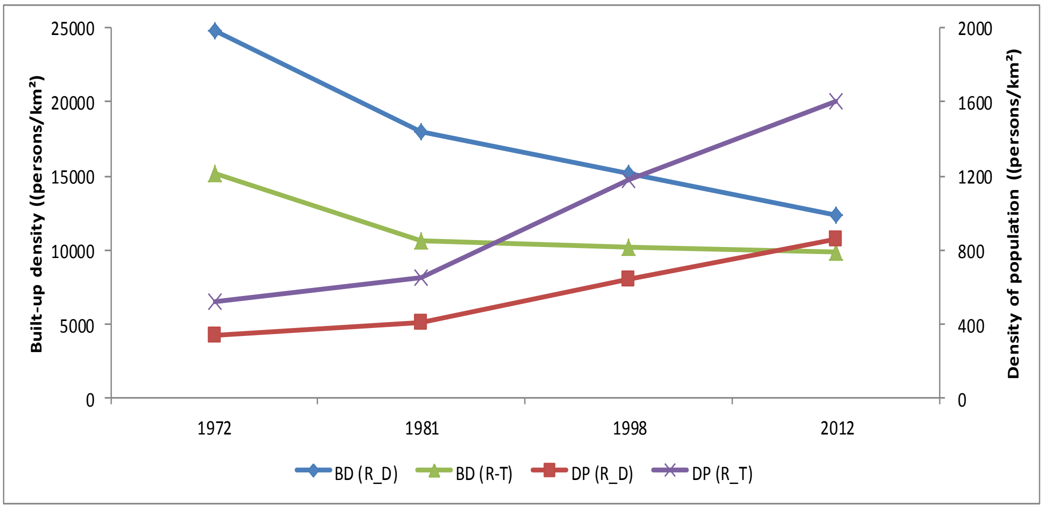
The density of population of the study area increased from 331 persons / km^2 in 1972 to 845 persons / km^2. The built-up density decreased from approximately 25,000 persons / km^2 in 1972 to 12,000 persons / km^2 in 2012 in the study area of Rawalpindi District. Whereas the density of population of Rawalpindi tehsil increased from 500 persons / km^2 in 1972 to 1600 persons / km^2 in 2012. The built-up density decreased from 15,000 persons / km^2 to less than10, 000 persons / km^2 approximately. The graph at Fig. 8.6 compares the density of population and built-up density of the two regions.

Figure 8.5 (b): Urban expansion in Rawalpindi District



The increasing trend of population density during the last four decades shows roughly the pressure of population over the area, which in the case of Rawalpindi tehsil is greater compared to the District, which is because of the greater portion of the population living in the tehsil of Rawalpindi. The decreasing trend of built-up density shows the large conversion of non-urban areas into urban areas and making the green lands available for people to live in. The lower ratio of built-up density of Rawalpindi tehsil shows that due to pressure of the population (high density of population), the built-up area of the region is expanding at a higher rate than the District.

Figure 8.6 Comparison of density of population and Built-up density of Rawalpindi District and Rawalpindi Tehsil



BD: Built-up density: DP: Density of Population; R_D: Rawalpindi District: R_T: Rawalpindi tehsil

The economic development in the study area, particularly in the Rawalpindi tehsil, reflecting the significant increase in the standard of living of the people in the last four decades, has contributed to the loss of agricultural, forest and cultivable land, leading to built-up and bare land. But at the same time the problems of water and power shortages, pollution, and traffic congestion have increased many fold (see the section 8.2). Rawalpindi has triggered a large amount of farmland and forest area to be converted into market-oriented land used for development. The commercial uses of residential purpose built-up areas in the study area particularly in Rawalpindi tehsil has encouraged the development of household enterprises, which has resulted in an increase of urban income. The data collected from the interviews and group discussions shows that there is positive relationship between household incomes (mostly coming from the working women) and small cottage industries.

Hence population growth and economic change are two important factors that influenced the land use changes and the distribution of agricultural and forested land. The existence of Rawalpindi in proximity to the capital of Pakistan, Islamabad has had a great effect on the land use changes and settlement patterns of the area. Those who work in Islamabad, but have less money to spend on renting a house, prefer to live in the suburbs of Rawalpindi tehsil which is close to Islamabad, and in this way, the farmland near the Islamabad has largely been converted into built-up areas. For instance during the last three decades (1981 to 2012) the annual loss of agricultural land has been over 700 hectares per annum. Due to which the built-up area has increased by over 500 hectares per annum and the rest of the farmland has been converted into bare land which ultimately will also be converted into built- up areas. Over 150 hectares per annum of the fallow land has both been converted directly to built-up areas or first into bare land and then into built-up areas.

Rawalpindi having a geo-political entity and having assumed charge of interim capital in the 1960s and 1970s eras retains many offices of the federal capital, due to which there is large demand for houses in the area, thus pushing the agricultural boundaries well beyond the previous limits. As seen in chapter 4, the population of those mauzas which are near to the urban areas, has increased rapidly. In a word, Rawalpindi almost overnight became villain with the shifting of capital from Karachi to Islamabad, and its eco-politics changed in the mid-1980s. The census records show that demographic displacement has had both plus and minus effects on the land use change.

While land use and land cover changes all have differentiated impacts on the environmental sustainability of the site, there has also been a lot of social change in response to the urbanization. For instance, the inhabitants of the area reported that they used to garden outside of their houses, because of large open space available, and they typically produce vegetables, such as potatoes, pepper, lady's finger, cucumber, and carrots. The production was all year round. But now, due to the scarcity of land, production has diminished as there are no lawns; all have been converted to the built- up areas. Interviewees were of the view that home gardening was not only a source of food for them, but they were able to utilize their leisure time properly. Now after office hours they feel imprisoned in their small houses with limited fresh air, causing many infectious diseases.

In some areas of the Punjab, where there has been a shift from an agrarian to industrial economy, abandoned agricultural and cultivable waste lands are often converted to urban lands; such areas that were grain exports became the importers (Weiss and Mughal, 2012). The same has happened with the Rawalpindi District. For example, until 1990 ground nuts and maize were produced in large quantities and exported to the nearby districts; production has decreased so much that it does not now fulfil local requirements (views of a participant of FGD).

Table 8.1 depicts the proportion of urban to non-urban land cover in Rawalpindi District and Rawalpindi Tehsil during the last four decades. The 2012 coverage resulted in a 13:1 ratio between non-urban and urban categories for the total area of Rawalpindi district. In 1972 it was 73:1; in 1981, this ratio was 41:1 and in 1998 it further decreased to 22:1.The non-urban/urban land coverage of Rawalpindi Tehsil was totally different to the district. It was 28:1(1972); 15:1(1981); 8:1 (1998) and 5:1 (2012). The percentage change for the district was +419 for urban and -6 for non-urban whereas for Rawalpindi tehsil it was + 376 and -13.25 for urban and non-urban categories respectively.

Table 8.1: Urban and Non- urban areas in Rawalpindi district and Rawalpindi Tehsil

Census Year	**Rawalpindi District**		**Rawalpindi Tehsil**	
	Urban (%)	**Non- Urban (%)**	**Urban (%)**	**Non- Urban (%)**
1972	1.36	98.64	3.4	96.6
1981	2.38	97.62	6.1	93.9
1998	4.31	95.69	11.4	89.6
2012	7.02	92.98	16.2	83.8
% Change	+419	-6.0	+376	-13.25

The greater percentage change of urban areas in Rawalpindi District is due to the rapid urbanization in the Taxila Tehsil of the district. In 1998 and 2012, as reported by the people during the interviews and FGDs, new areas of urban uses in Rawalpindi tehsil were mainly on soils with agricultural potential. However, in other tehsils this was less the case. Table 8.2 is based on the statements of the people and per hectare production, of those areas which were agricultural and now have been converted into the built-up areas. This throws light on the distribution of urban and non- urban areas relative to the soils suitable for agricultural areas. It is obvious from the table that new areas of urban use were higher on non-potential agricultural areas in Rawalpindi District whereas in Rawalpindi tehsil the potential agricultural soil converted to urban use was more than double in 2012 as compared to 1972.

Table 8.2: Distribution of urban and non-urban areas according to their suitability for agriculture

	Rawalpindi District		**Rawalpindi Tehsil**	
	Soils suitable for agriculture (%)	**Soils less suitable for agriculture (%)**	**Soils suitable for agriculture (%)**	**Soils less suitable for agriculture (%)**
Non-urban area (1972)	58	42	62	38
Non-urban area (2012)	76	24	51	49
Urban area (1972)	13	87	21	89
Urban area (2012)	11	89	43	56

Source: Field data (2011) and Agricultural statistics of Punjab, 1975 and 2012.

The establishment of educational institutions and health centres in the outskirts of the District and tehsil areas also had an adverse effect on agricultural land. The purpose of the establishment of these colleges on the agricultural lands was twofold. The main purpose was to provide the educational facilities to those located on the periphery of the urban areas, secondly to get rid of the illegal possession[53] by farmers of government agricultural land. Nevertheless a considerable percentage of the land suitable for agriculture was converted into built-up areas.

Urban areas usually refer to towns and cities. The urban environments of the study area contain numerous municipalities, mauzas and census tracts. But in some tehsils urban areas extend beyond the limits of a municipality. In other cases a considerable amount of "undeveloped waste" (e.g. cultivable but uncultivated land; ranch land, floodplains) exists within the areas that are urban. Weeks et al (2005) suggest that "urbaneness" needs to be viewed more as a continuum rather than a dichotomy of urban and rural.

In Pakistan the definition of an urban area for census purposes is "a cluster with a population of more than 20,000" (District Census Reports of Rawalpindi, 1951, 1962, 1972, 1981, and 1998). Built-up areas which are detected from satellite imagery as buildings, concrete asphalt and man-made structures, otherwise called "impervious surfaces" (Yang et al., 2003), also contain structural information about the urbanized areas; therefore here in this study built-up land has been taken as a proxy of urbanization. In Pakistan, the jurisdictional boundary of the municipality contains an area that is larger than the built-up area; therefore the official area of the municipality is not a very precise way to measure urbanization.

The urbanization which is a product of urban growth can be taken as the increase in built-up land. Other descriptions define it as "land conversion over time" or "the change in the spatial structure of an urban area over time" (Bhatta, 2010). Hence the pattern of land use/cover refers to the arrangement or spatial distribution of the built environment. Urban developmental patterns in the study area include residential lots, infrastructure, low density commercial developments, strip commercial, high density commercial developments and mixed peripheral urban developments with progressively increasing land consumption. As suggested by Herold et al. (2003), the expansion of the urban area of the study area started with a historical seed or core that grew and dispersed to new individual urban areas. This was just like a diffusion process which continues along a trajectory of organic growth and outward expansion until the spatial evolution transitions to a coalescence of the urban centres.

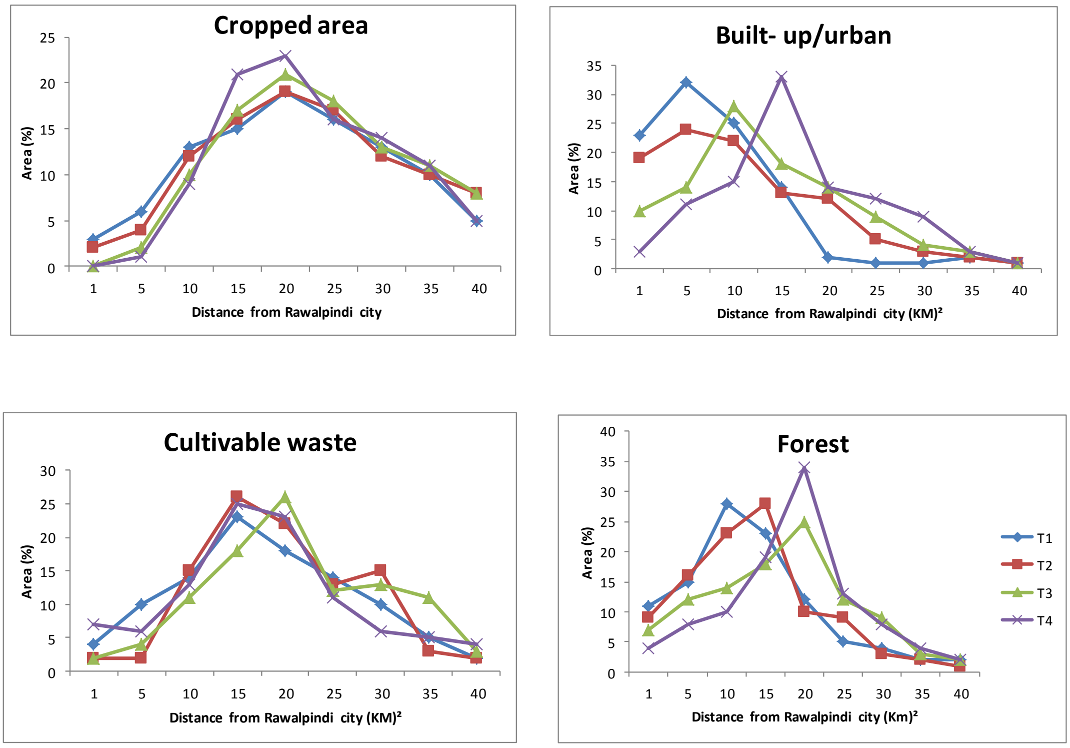
[53] Sometimes the local people start cultivating illegally on the government land near to their agricultural lands, which was purposefully left vacant by the government to establish offices/ parks in near future.

In general, as identified by Wilson et al. (2003), *infill*[54], *expansion*[55] and *outlying*[56] types of urban growth can be seen in the study area, Rawalpindi and Taxila tehsils mostly expanded through a process of expansion and outlying.. Figure 8.5 (a & b) suggests that most of the urban expansion has been seen in the tehsils of Rawalpindi and Taxila, although the other tehsils also expanded, but because of the areal differentiation, their expansion compared to the Rawalpindi tehsil was almost negligible. All tehsils expanded towards the north and northwest directions during the forty years of the study period. In case of Rawalpindi tehsil this was because of the proximity of the capital in North and for all other tehsils perhaps the reasons were adjoining to the main roads and motorways, as most of the transportation network is in the north of the tehsils. Thus the overall trend shows the expansion in all directions along major traffic routes between the existing urban centres, especially to the north and northwest.

The spatial distribution of urban expansion in 2012 was related to altitude, distance from existing urban centres, and distance from the main roads. The distribution of areas of urban change and no urban change were compared with respect to the altitude and it was found that areas of urban change mostly occurred in the low-lying areas, whereas areas of no change occurred at high altitudes. The development of new urban centres with respect to the distance from the old existing urban centres and from the motorways were found inclined to occur closer to the other urban areas, and also near the transport network. GIS-based spatial analysis of patterns of different land use/ covers in different time periods reveals that cropped areas and forests decreased within 25 kilometres of the main urban centre of Rawalpindi tehsils, whereas bare land also expanded more outside the city centre. This bare land encroachment deeper into the peripheral and rural areas is expected to give birth to new urban areas in the near future.

[54] Ellman (1997) defines infill growth as a development of vacant land in already built-up areas.
[55] Expansion-type development represents the expansion of existing urban land and mainly involves the urban fringe development.
[56] Outlying growth is described as change of non-developed land cover to developed land cover beyond the urban fringe.

Figure 8.7 Percentage of area under each land cover by distance from Rawalpindi city (T1-T4)



As can be seen from Figure 8.7, the curves representing cropped area shows a decreases near the city centres in 1998 and 2012 and increases near the areas located approximately at 15-25 km² i.e. in the interior of the tehsil of Rawalpindi particularly in those mauzas where the population was less and mostly engaged in agriculture, whereas the percentage of built-up land increased in the peripheral areas, and it was at a maximum in the buffer zones of 10-15 kilometres in 2012. In 1972, majority of the built-up area were within 5 km², which expanded mostly towards the north east in the preceding years. The forested areas also decreased near the city centres and expanded outward. The cultivable waste comprising bare land and fallow lands although increased in the zones of 15-20 km, but at the same time its percentage increased near the new urban developments and near the city centres which points out that in the near future this area will also convert to urban lands

From the above analysis it can be concluded that considerable land use changes have occurred in the study area particularly in the tehsils of Rawalpindi and Taxila. In terms of built-up areas it increased by over 29,000 hectares in the last forty years, resulting in a subsequent reduction of farmland and forested area, particularly near the urban centres. Socio-economic changes in the Potohar region in general, and in Rawalpindi and Islamabad in particular, during the last few decades, promoted changes in land use practices. This transformation from agrarian to industrial land use was noted by Brown & Starke (1996) in China, Japan, South Korea and Taiwan some 20 years ago. As seen in this study, in all these countries rapid industrialization led to the demand for residential, industrial and commercial areas and threatened agricultural lands because of their lowland locations and vulnerability to conversion to urban uses. Along with these land use changes, the study area experienced a rapid population increase and inward migration from the nearby centres due to its location, better employment opportunities, capacity to absorb people and low residential rents. This increase in the population resulted in an increase in the infrastructure, road facilities and demand for housing over the last forty years.

It has been noted that almost 60% of the new urban areas in Rawalpindi district between 1972 and 2012 occurred at the expense of the agricultural land. This percentage increased to 80 % in Rawalpindi tehsil. The analysis of the reasons for the conversions of agricultural land into built-up area shows that most of the area was near to urban centres and along the major roads. Thus the high road density of the study area, particularly in the Rawalpindi tehsil, is another reason for urban expansion at the expense of farmland especially along the Grand Trunk Road running between Lahore and Rawalpindi, the M2 motorway between Islamabad and Lahore, and the M3 Motorway running between Rawalpindi and Peshawar. A similar urban expansion along the major transport routes has also been documented by many authors, such as Dillman and Cousin (1982), Lopez et al (2001) and Yin et al (2011) in United States, Puero Rico and Shanghai respectively. In all studies approximately half of the agricultural land within 2 kilometres of the main transport routes has been converted to urban use. Although the loss of agricultural land at district or tehsil level has not seriously affected food availability, but at National level it might be very serious. Otherwise many countries have gone from being self-sufficient to net grain importers. The best examples are Japan, Korea and Taiwan where the increase of imports was a response to a reduction in production of food grains due to loss of potential farmland.

Urbanization has also had a negative effect on natural habitat and biodiversity. Cheng et al., (2009), Liang and Wang (2002), and Weng et al. (2008) have noted that many plant species have disappeared from various parts of China which have seen rapid urban development. Gong et al., (2009); Wu et al., (2011) noted that over-exploitation of ground water, high rise buildings and an extensive construction work in the cities has resulted in land subsidence. Urban development has also affected the surface run off, which can also be seen in the study area in case of Nallah Lai which causes floods every year and takes many lives. Moreover, the urban expansion has also caused an urban heat island effect in the study area.

8.4 Community Perspective

The semi-structured interviews and focus group discussions comprised questions about urban expansion, deforestation, decrease/ increase in farmlands, changes in the built-up area along the major roads, changes in the household size, what they thought caused the changes, and what they thought are the consequences. Further questions asked were about population growth, inward and outward migration, industrialization, water supply, sanitation, the urban heat island effect, and urban problems. This section correlates the responses of the people about urbanization and land cover change with the results derived from the remote sensing analysis discussed in section 8.1.

In all sites, there was a general perception that their surroundings had changed during the last forty years. For instance people reported that in early 1970s large patches of land (in the form of hills/mounds/dunes) were lying vacant (increased wilderness) under no control, having natural grass grown it, which they used for grazing of animals. Later on the people struggled hard to level the low hilly tracts manually and in some areas with the help of excavators, to bring it under agriculture and production. People were of the view that mostly initially it was started by migrants from the Kyber Pakhutunkhah (NWFP) province who were unemployed, but hard working Pathans[57]. Due to the high immigration and excavations, the cultivable area increased. Initially most of the area was levelled in front of the residences. During this levelling process people cut many trees. The governmental officials, especially from revenue department, proclaimed that the low hilly peripheral areas of Rawalpindi city were brought more under use of cultivation at large than any tehsil of the district. The local people also opined that a high population growth rate; increased mobility and large family size (Chapter 4) led the need from additional farmland and houses as well, which affected the extent of the woodlands and grasslands. This relates to the loss of grasslands (6.52 %), forests (1%), and increase of wilderness (1%), farmlands (5.5%) and built-up areas (0.91%) between 1972 and 1981 as seen from the 1972 and 1981 classification results (Table 7.10). Moreover Table 7.26 proves that out of 28401 hectares of increased farmland between 1972 and 1981, approximately two thirds lay in Rawalpindi tehsil alone.

Most of the people were of the view that due to the high growth rate, the establishment of industries and the development of the Rawalpindi city as a Central Business District, the attraction of the people for cultivation decreased. This was mostly due to the small size of agricultural land holdings near the city centre, which were no longer profitable for cultivation. And landowners thought it more profitable to sell their land to builders. Thus they were of the view that most of the commercial centres and tall plazas in the outskirts of the core city were built during mid-1990 and early 21st century. The builders by hook or crook (through golden dreams, high offers and

[57] A tribe mostly living in the mountains said to be very hard workers.

sometimes with the help of land grabbers locally called Qabza Mafia[58]) occupied the cultivable land of the poor farmers in instalments, established multi storied plazas and residential buildings and sold it to the immigrants at attractive rates. Both government officials and local people admitted that large conversions of cultivable land were near the main transport routes.

Although the multi-storey buildings cannot be seen from the remote sensing results, but as evident from Table 7.26, the cultivable land was converted into the built-up area, and there was a considerable decrease in the forests, grasslands and farmlands between 1998 and 2012. Unfortunately Pakistan is among those countries where the deforestation rate is very high. From 1990 to 2010 the forest change rate of Pakistan was -1.76 % according to FAO's Global Forest resource Assessment 2010. The FAO estimates for the period 2005-2010 gives an annual rate of deforestation of -2.37% supporting the data presented in this thesis that the rate of deforestation is increasing. Deforestation in the study area was calculated by using the Equation-1, adopted from Altamirano et al (2013).

Equation 1: Rate of Forest Change

$$q = \left(\frac{A_2}{A_1}\right)^{1/(t_2-t_1)} - 1$$ (Altamirano et al., 2013)

Pakistan ranks third in the world in terms of annual deforestation rate with only Uganda and Nigeria ahead (FAO Global Forest Resource Assessment, 2010). The deforestation rate of -2.97 % in Rawalpindi tehsil between 1998 and 2012 as seen through remote sensing results and witnessed by the local people is very high and alarming. It is more than the national rate. However, in the district it is very much controlled, because of the collaborative efforts of the forest departments in other tehsils. It is important to mention there that in the district, the district administration is spending huge sums on reforestation and on forest guards to protect the forest, yet there was a gradual decrease in the forest cover from 26.51 % in 1972 to 24.48 % in 2012. Surprisingly the government has turned a blind eye in the Rawalpindi tehsil, where forest cover decreased from 9.6% in 1972 to 7.4% in 2012.

In Murree tehsil people complained about government plans to establish a "New Murree Project" and thanked Chief Justice of Pakistan for taking action in the Suo Moto (Supreme Court of Pakistan, 2006) case to stop the project. Had it started, there would have been a further elimination of over sixteen thousand hectares forests, besides the destruction of the natural beauty of the mountain resort.

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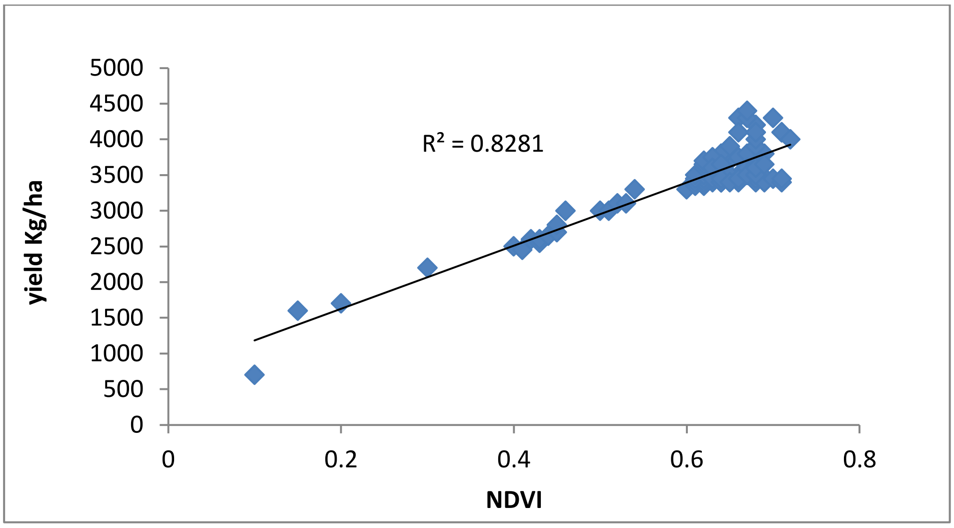
[58] Ref: Supreme Court of Pakistan's Suo Moto Case # 01/2011 regarding land grabbing in Bani Gala Rawalpindi and Suo Motu Case No03/2009 regarding destruction of forests and illegal acquisition of land

The expansion of the Taxila tehsil, especially Wah town, was explained by the people as migration of the people (federal government employees and skilled labour) from different parts of the northern areas, Pakistan army offices and residential colonies Heavy Mechanical Complex Taxila and University of Engineering and Technology Taxila and many other educational institutions in the vicinity. They asserted that Taxila tehsil has expanded because of its location on the major transport route between Rawalpindi and Peshawar, facilitating the people to easily move between Rawalpindi and Taxila.

The people recognised that a lot of changes have occurred in the area. Even they could count the plant species and area of the orchard that no longer exist. They recalled their farmlands, camel driven water wells, thick bushes and wild animals which were no longer there. In a sentence, the results point to the fact that the study area has expanded due to explosive population pressure and land cover changes are going on with implications that include loss of biodiversity, over-extension of built-up areas and the transport network (causing problems of water and power shortage, pollution and an urban heat island effect) and over-exploitation but uneven distribution of the resources causing conflicts among the different tehsils.

As discussed in chapter 5, people took great interest in remote sensing data. They were very anxious to know how RS data along can be used for various purposes, such as data inventory, stopping deforestation and bogus agricultural and illegal urban expansion. Taking the advantage of remote sensing data and participant observation, yield of the sunflower crop has been estimated. It clearly shows that remote sensing of crops can be an attractive alternative to the traditional methods (Basso et al., 2004). Remote sensing can be used effectively to provide information of yield per acre of the different crops and therefore spatial variations across the fields can be noted. A good and direct method for prediction of yield can be based on reflectance. In this study NDVI has also been used to predict yield. Fig 8.8 is a correlation graph between NDVI derived from an image of the Rawalpindi (Landsat TM 2010) taken at the time of flowering of sunflower crop.The data about yield per hectare was taken by the owners of the sample farms, during their informal interviews while staying with them as a “participant observer”. The graph suggests that there is strong positive correlation between NDVI value and yield per hectare. The low yield farms were noticed with the low value of NDVI and vice versa. In this study rather than predictions actual values were taken into account. However Jiang & Thelen (2004) have cautioned that the relationship of NDVI to yield can be dependent upon the normal gain filling conditions for the crops. As in some cases NDVI images results and those stories regarding yield of the wheat crop, told by the local farmers presented a different story, especially in the regions where spatial variability of soil texture and soil water uptake by plants was affected by drought in 2010 presented different scenarios from the one shown by NDVI.

Figure 8.8 Correlation between NDVI and yield of sunflower (per hectare)



Source: Landsat TM 2010 and field data.

8.5 Urbanization and Land Use Changes based on Governmental Statistics

Government statistics were used in several ways in this land use/ cover change study as discussed in chapter 2 and 4. The population data was obtained from the Population census reports and data about forest cover, agricultural land, and cultivable waste were obtained from various sources such as development statistics of Punjab and agricultural Census data. This section discusses the relationship between the governmental records and the remote sensing results. According to the official sources, in 1981, the total cropped area of the district was 100,000 hectares, cultivable but uncultivated land was 141,000 hectares, forests 130,000 hectares and the uncultivated area (hills, bare lands, water bodies, roads, houses and all kinds of land uses alien to agriculture) was 144,000 hectares (Table 8.3). Table 8.3 further shows that in 1998, both cropped area and uncultivated area increased, and there were decrease in fallow land and forested area. In 2012, the official records showed a decrease in the cropped area, fallow land and forests and an increase in the uncultivated area. Although in the agricultural statistics this area was not further broken down into the categories like bare land/ water bodies and built-up areas, yet there is a high probability that the increase in the uncultivable area was mainly due to the increase in the built-up areas particularly in the Rawalpindi tehsil. It is obvious from the Table 8.3 for different years that no big variations are found between the two sources and the governmental statistics are very much nearer to the results derived by the remote sensing classification (Tables 7.10). The relationship between areas of land covers estimates derived from the official resources and satellite base estimates is seen visually in

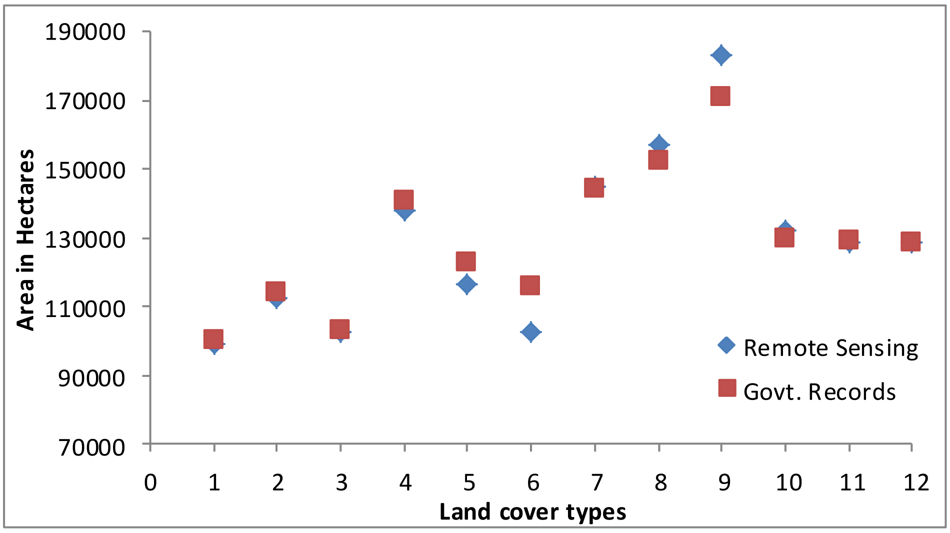
Fig. 8.9. Based on the observed linear trend of different land covers, a strong correlation (R^2 = 0.96) suggest that satellite derived estimates may be used independently.

Table 8.3: Comparison of area estimates of selected land covers by remote sensing analysis and Government records.

Land cover	Area in Hectares	
	Remote sensing	Government records
Cropped Area_T2	99310	100021
Cropped Area_T3	112633	114350
Cropped Area_T4	102305	103000
Fallow land_T2	137949	141000
Fallow land_T3	116263	123000
Fallow land_T4	102457	116000
Uncultivated_T2	145004	144000
Uncultivated_T3	156812	152480
Uncultivated_T4	183000	171000
Forest_T2	132179	130000
Forest_T3	128823	129170
Forest_T4	128823	128600

Landsat classification results and Government of the Punjab (2012)

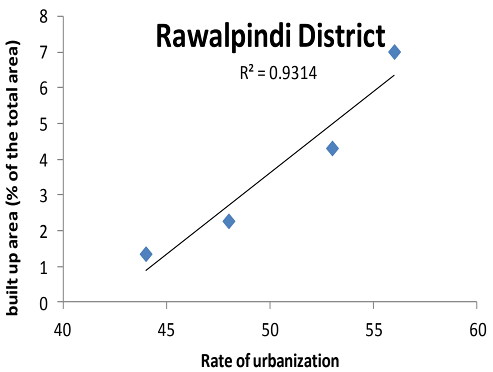
Figure 8.9: Comparison of Government Records (GR) and Remote Sensing (RS) estimates

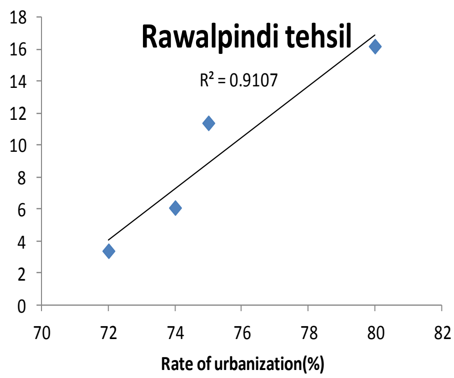


Land cover types: 1: Cropped Area_T2; Cropped Area_T3; Cropped Area_T4; Fallowland_T2;Fallow land_T3; Fallow land_T4; Uncultivated_T2; Uncultivated_T3; Uncultivated_T4; Forest_T2; Forest_T3; Forest_T4

The census data shows that rate of urbanization of the study area during 1972 to 2012 periods was 44 %, 48, 53 and 60 % during 1972, 1981, 1998 and 2012 respectively. The percent of urban change was 9, 10 and 6 during 1972-1981; 1981-1998; and 1998-2012 inter-censal periods respectively. In the tehsil of Rawalpindi, the percent urban change was 3, 4 and 3 during 1972-1981; 1981-1998 and 1998-2012 inter-censal periods. When related to the built-up area calculated from remote sensing classifications, there was found a strong correlation between percent changes of urbanization and built-up area extensions in both regions (Rawalpindi district 98% and Rawalpindi tehsil 0.92%). Figure 8.10 compares the relationship between urbanization and increase in the urban area. From the graphs it can be seen that the value of R^2 is high in the district (0.93) as compared to Rawalpindi tehsil (0.91), which shows that the increase in the built-up was comparatively more related to urbanization patterns as compared to Rawalpindi tehsil. This shows problems of housing shortage more in the Rawalpindi tehsil as compared to other tehsils. The field data (interviews, FGDs and participant observation) explains that in the district with the increase of urbanization, the built-up area increased horizontally, whereas in Rawalpindi tehsil it increased at both levels horizontally and vertically. Thus housing shortages were tackled by replacing the one or two storey houses with multi storey (6-10) apartments which have their own drawbacks such as water supply shortages, temperature rises, and shortage of open spaces.

Figure 8.10: Relationship between patterns of urbanization and increase in built-up area





The BUSI (built-up sprawl index) calculated for Rawalpindi district and Rawalpindi tehsil (chapter 6) further explains the patterns of increase in the built-up area of both regions. During1972 -1981, the BUSI value of Rawalpindi district and Rawalpindi tehsil was 0.0195 and 0.026 respectively, which showed that in Rawalpindi tehsil the rate of increase of built-up area was faster, as compared to the district. For instance at the district level the built-up area increased 4,747 hectares, and in the tehsil of Rawalpindi, (smaller in size more than 1/4th of the total area) the built-up area increased to nearly 5000 hectares. Actually this was the time when the shifting of the capital of Pakistan was in process from Karachi to Islamabad and a lot of shifting arrangements of offices were made in Rawalpindi city due to its closeness to Islamabad. Thus, as compared to population, the built-up area increased more due to the temporary shifting of federal offices/ institutions. At district level there was a slow expansion of the built-up area due to the increased population growth. During the 1981-1998 inter-censal period, the value of BUSI decreased for both regions, thus showing the pressure of population and demand of built-up area in both regions. This does not mean that the built-up area did not increase but in fact the population increased more, which increased the demand for built-up area. During the 1998-2012 inter-censal period, due to a considerable increase in built-up area in other tehsils such as Taxila, Rawalpindi and Kahuta, the value of BUSI increased at the district level (0.023), whereas it decreased in Rawalpindi tehsil, showing the high growth of population, as explained in the preceding paragraphs. The negative correlation between BUSI and Normalized Difference Vegetation Index (NDVI) values indicates an inverse relationship between built-up area and vegetation in the study area during the 1972-2012 period.

Land consumption rate (LCR) indicates the ratio between built area and total population. The values of LCR increased gradually in Rawalpindi district, and sharply in the Rawalpindi tehsil. For the district LCR was 0.004 in 1972 census; 0.005 in 1981 census; 0.006 in 1998 census and 0.008 in 2012. The increase in LCR showed that the rate of increase of built-up area was higher than the rate of population growth. In Rawalpindi tehsil the value of LCR was higher than the district since 1972. Its value increased from 0.006 in 1972 to 0.010 in 2012 indicating the expansion of built-up area at a higher rate than the district. The land absorption coefficient, which is a measure of consumption of new built-up areas by each unit increase in urban population, was also significant for Rawalpindi tehsil, suggesting that the rate at which new lands are acquired for development is high. This trend has been seen in both in the 1981-1998 and 1998-2012 inter-censal periods, and there seems to be an expansion of the city centre towards the peri-urban areas. One reason is the congestion in the core of the city of Rawalpindi and also many of the government offices have been shifted to the outskirts.

8.6 Rural-Urban Migration and Social Change

In the last few decades, there has been a significant growth in Pakistan’s population, particularly in the Punjab. Many villages have been turning into small towns due to urbanization (Weiss and Mughal 2012). This has implications for the country’s city planning system, land management, and other geographic factors. Rawalpindi is not the exception. In the rural areas of the study area, the availability of agricultural land decreased as a consequence of increasing population. At a family level, the agricultural land was divided among multiple heirs and thus it became inappropriate for many farmers to cultivate a small piece of land given the cost efficiency and many other economic factors (Qureshi et al 1980; Haider 1981). Therefore, many farmers left agriculture and started to work in factories situated in the cities and some travelled overseas in search of better jobs. This brought about a shift from agriculture to the market economy. The process of social change with respect to urbanization and technological change can be explained in various ways. Social relationships based on class, caste, marriage networks, and other forms of mutual rights and obligations have been an essential part of the family and community in the study area, especially in rural areas. Social change in life of the people of the study area is reflected in the changing family patterns, from extended households to small nuclear units. Similarly, the caste-based patron-client relationships in the rural socioeconomic set up has been in flux due to less reliance on agriculture and a trend towards formal education and migration to the cities and overseas (Mughal 2008). Western-style clothing, television, mobile phones, the internet, English medium schooling, and international company branded products are some of the features to highlight the new economy and emerging trends in the study area's social organization. This change has brought an influx of people from rural to urban areas and small urban areas to the large urban areas. The people's wishes are fulfilled to some extent but the urban population and urban area has been extended in an unplanned manner.

8.7 Population Interpolation with Built-up Area Information

Nordbeck (1965) while studying the relationship between urban areas and population of US cities concluded that built-up area of a city is proportional to its population. Wu et al (2005) noted that the total population of an area can be estimated by multiplying the total number of dwelling units with the number of persons normally living in a dwelling unit. Green (1956) was probably the first to use the dwelling unit counts from aerial photographs for population estimation.

The built-up area extracted from remote sensing classification results has been used in this study to estimate dwelling units. After estimating the dwelling units, the population was estimated simply by multiplying the average household size with the total number of dwelling units.

For estimating the dwellings units from the built-up area, the built-up area has been split into two categories: residential and non-residential. This was done in accordance to the statistics provided by the government officials during the interviews. The researcher was told by high ranked officers that the ratio between residential and non-residential areas in 2011 was 40:30 and average size of a single dwelling was 350 square metres in Rawalpindi tehsil. The average household size of Rawalpindi tehsil estimated from the 1998 census in 2012 was 6 persons per house.

The total built-up area of Rawalpindi tehsil extracted from the 2010 image classification was 26,500 hectares; the residential built-up area calculated is 15,900 hectares. The total number of dwelling units was estimated by dividing the residential area by the average size of a single dwelling. Total number of dwellings calculated by this method is 454,285. Now simply by multiplying the total dwellings with the average number of people in one dwelling the author calculated the population which is 2,725,714. This population number is almost close to the figure estimated by the official records, which are 2,604,000. This statistical modelling approach for population estimation based on the satellite data can be a remedy for the shortcomings of the decennial census, such as high cost, labour intensity and low frequency. Moreover these methods can be applied to check the reliability of the census.

From the above discussion we have noted that there are no large variations between the land covers areal extents estimated by the government departments and one extracted from remote sensing results. So the remote sensing results can be applied for population, cropped area, and forest estimations. It has also been noted that many developed countries have stopped traditional census enumeration and with the help of sample surveys and satellite data they are estimating the population. The estimation of cropped and forested area from satellite data is very common in developed countries. Hence remote sensing methods may be applied in a country like Pakistan to assess the different land covers and population estimation.

8.8 Conclusion

This chapter has presented an evaluation of various data sources and their integration. In general, it creates a relationship between five categories of approaches, i.e. (1) image pixel characteristics, (2) population /urbanization patterns, (3) land use /land cover change, (4) people's perceptions and (5) governmental inventory.The remote sensing results of the land covers were validated with the field observations and official records. Similarly the secondary data about land covers such as agriculture and forest have been validated with the help of remote sensing data. Data obtained from remote sensing analysis provided evidence of encroachment of urban settlements on to agricultural land and forests. The field-based qualitative data witnessed the rapid urban expansion and explained the reasons behind the differential urban expansion in various tehsils of the study area. The incorporation of qualitative data from different sources (local people and local administration) with the remote sensing data presented a robust conclusion assessing the relative contribution of these factors in determining land use changes at district and tehsil level. The remote sensing data along with the qualitative data has been used to predict the yield per hectare, which opens the doors of scientific data inventory in a country where most of the works and data collection activities are done manually. Another focus of the chapter was to correlate the figures derived from government statistics and those derived directly from the image analysis. The analysis showed that there were no huge variations between the two assessments, indicating the possibility of replacing the manual data inventory with the remote sensing data, in future.

9 DISCUSSION AND CONCLUSION

9.1: Introduction

It is really thrilling to conduct an interdisciplinary research which combined both human and physical aspects. The broad view point of this research is that it combined the social science data and methods with satellite imagery and mapping. This study set out a methodology to understand the processes and impacts of urban expansion and land cover change by using a novel approach that combined remote sensing and GIS with census and field based qualitative data analysis. This study is first of its kind and to the best of researcher's knowledge no such study has been conducted in the global south which has demonstrated how longitudinal census data, remote sensing and qualitative field data can be used to gain a deeper understanding of land use and land cover change in response to urbanization over a period of forty years in the rapidly growing district of Rawalpindi, Northern Punjab, Pakistan. Census records provided aggregated population records within enumeration units. Satellite platforms provided Landsat MSS and TM images dating back forty years. Satellite reflectance data was transformed into land cover information using image processing techniques that mainly included supervised classification. Ancillary data along with field based GPS data was used to improve the accuracy of the classification. Drivers of land use and land cover change were inferred from the government records, social data and data collected through multiple methods of participant observation, focus group discussions and interviews of inhabitants and government officials. Integration of remote sensing, GIS, and qualitative data proved vital in detecting and quantifying changes in land cover and land use, monitoring urban growth, and analysing the district administration's policies and role.

Over half of the world's population now live in urban settings (UNPF 2008). Most of the world's population is concentrated in developing countries of the global south. As a consequence, the challenges of accommodating urban growth while simultaneously conserving natural resources will be felt around the globe particularly in developing countries such as Pakistan. This study has confirmed that the rates of urban growth in Rawalpindi are among the highest in the world and is associated with equally rapid natural resource depletion in the peri-urban zone. This and other studies imply an urgent need for public policies that recognise the impacts of rapid growth and possible land conservation measures. This study, using mixed methods, helps to identify both the scale and pattern of urban transition as well as incorporating information on its human dimension and social implications.

This chapter is divided into five main sections. After a brief introduction, the second section describes the main findings of the research; it follows through the research objectives and research questions. The third section throws light on SWOT (strengths, weaknesses, opportunities, threats) analysis as a means of evaluating different data sets used in the study. The fourth section outlines reflections on the study. The final section gives an insight into the directions for future study.

9.2: Main Findings

There is extensive literature on the use of remote sensing data including Landsat and its application in urban land use/cover analysis. However, there is less literature on the integration of census of population and social data with the remote sensing data for the detection of land use/ land cover change. The processes that have resulted in an increase in both population and urban land area have seriously affected the biophysical environment and there is a serious lack of formal government planning and regulation. This study emphasizes the effectiveness of the long-term archive of global Landsat data for evaluating urban and other land cover change in a rapidly developing region of Punjab over a period of forty years. Main findings of this research are discussed with reference to the research objectives.

Research objective 1: To undertake a spatial analysis of Pakistan Population Census data for 40 years, i.e. 1972 to 2012, to contextualize and interpret the process of urbanization.

Census data was analysed through statistical software to evaluate the trends of population change and urbanization; it was also integrated with the remote sensing data using the spatial analysis tools of GIS. Very old mauza maps of the study area have surfaced throughout this research as an ally of medium resolution satellite data. Population data was also available for each mauza in the census reports which facilitated the researcher in correlating land cover change in the study period in terms of the locations of different mauzas. Although Pakistan is rich in mauza maps which are usually drawn on white cloth (locally called Latha) and they are available in the revenue department, but these maps are restricted and researchers normally have no access to them. In the present study mauzas maps were acquired by the researcher personally from some departments, which helped analyse change at a micro-level. As noted by Jabeen (1985) and Rashid (2003) in their studies of land transformations in Pakistan and Bagladesh, this research has also shown that these maps can play a significant role in detailed planning of land management. Matching these mauzas with remotely sensed images, the forest, agricultural and built up areas can be monitored at the micro level. It is an additional resource in validating data collected manually by government officials. Integrating these mauza maps with the medium and high resolution remotely sensed images may play a significant role in several ways like monitoring agricultural change, urbanization, deforestation, flooding, environmental degradation, and settlement pattern analysis. In the researcher's opinion the government of Pakistan should take the initiative to start such surveys for better monitoring and planning. The analysis of census data shows that the total population of the study area increased from 1.74 million in 1972 to 4.5 million in 2012, with an average annual growth rate of 2.4%, and the urban population increased from 0.77 million in 1972 to 2.5 million in 2012, with an average annual growth rate of over 3%. Although the world's population increased from 3.8 billion to 7.1 billion during the above forty years period, but the average annual growth rate has been dropped from 2.1 % in 1972 to 1.05 % in 2012. Thus the world's population doubled over the past forty years and much of this increase was accounted for the developing countries of the Global South, particularly the most populous countries of the Asia such as China, India, Pakistan, Bangladesh and Indonesia. Pakistan's population almost tripled during this period and much of this increase was in the districts of Karachi, Lahore, Faisalabad, Rawalpindi, Gujranwala, Multan, Hyderabad and Islamabad. The world's urban population which was 1.5 billion in 1975 has reached near land mark of 4 billion. Interestingly Global North constitutes only 18% of the total world's population and 26 % of the total world's urban population. Asia and Africa are the fast urbanizing regions of the Global South. Pakistan is urbanizing rapidly. The current level of urbanization in Pakistan, above 41 %, though not high by global standards, is high in South Asia. The overall magnitude of the urban change can be gauged by the fact that from 1901 to 2012 the total urban population of Pakistan increased by 3.70% annually. The corresponding figures for 1972- 2012 are 4%. Such a massive growth in urban population, and overall, is unprecedented in the regions comprising Pakistan. The degree of urbanization of the study area is comparatively higher than other districts of Punjab. The higher arable density of population of Rawalpindi shows the pressure of population over the agricultural areas.

Due to the high population growth rate, from 1972 to 1998 in the peri-urban areas of the study area, intensive agriculture was being practised, possibly due to the fact that people anticipated that their land would soon be converted to urban uses and so they wanted to get the maximum financial returns. The cropping pattern, as witnessed by the local people, showed that areas near the cities were used to grow vegetables due to the developed transportation network from farm to market, while in the remote rural areas cereals and other food crops were grown. After 1998, the area of cultivated land started to shrink in the peri-urban areas, being replaced by urban developments, and cultivation is now mostly confined to those mauzas which are most distant from the urban areas. Due to social changes, the small size of land holdings, and the influence of the media have reduced people's interest in agriculture, and there is a probability that soon these outlying areas will also stop practising agriculture and maybe switch to industry. With the passage of time, the development of the transportation network, and changes in migratory labour patterns, these areas will develop into independent urban centres. This has already occurred in the tehsil of Taxila, where due to the establishment of a heavy mechanical complex, the population and built-up area are both increasing concurrently. The study has shown that the periods 1972-1998 and 1998-2012 had different patterns and mechanisms of transition. We have seen both the scale and some of the complexity of urban growth and development especially in the less developed parts/tehsils. The very small settlements in Rawalpindi are more in number and are located near to each other as compared to big towns. More than two thirds of the settlements are located within 2 kilometres from a main road, which clearly highlights the impact of the transport network on settlements. This has a great impact on the growth of Rawalpindi tehsil as link between Rawalpindi and its surrounding areas has forced Rawalpindi tehsil to emerge as a metropolitan city and negatively affected on the urban areas of other tehsils. This distribution pattern of urban localities shows that Rawalpindi tehsil is the primate city, and Taxila and other tehsils are still much behind it. This pattern also shows that due to the disproportionate rate of urbanization in the potohar region in general, and Rawalpindi district in particular, not so many urban centres have been developed during the last many decades. This has helped the Rawalpindi tehsil to emerge as the primate city. However the population of the peri urban areas is increasing rapidly.

Research objective 2: To acquire and analyse medium spatial resolution satellite data from the Landsat platform at intervals coincident with the population census data to map urban expansion and peri-urban land cover change

With advances in remote sensing techniques and the availability of median resolution data such as Landsat at little or no cost, it has become easier to obtain reliable land cover data in order to better understand urban growth. However, the processing and reliable interpretation of satellite images is highly technical and requires a considerable level of expertise and specialist knowledge. Moreover establishing the accuracy of land cover mapping, especially in heterogeneous environments, is problematic unless accompanied by appropriate ground truth data. Nevertheless satellite remotely sensed images are able to provide consistent data on temporal and spatial trends that would be impossible to obtain in any other way. The free availability of Landsat data is still not known to many private and government communities in Pakistan and so the present research will help to demonstrate its uses especially for monitoring the urban, agricultural and forest land and developing base line information for proper planning.

The visual analysis of the false colour composites allowed the identification of the main land cover classes within the study area before classification. Thus a general idea was perceived through visual interpretation about the land cover change over various periods, an approach also adopted by other studies (Shalaby and Tateishi, 2007). Supervised classification of images of 1972, 1979, 1998 and 2010 respectively was carried out by using a maximum likelihood classifier. The classification assessment results revealed that Landsat TM data showed a much higher accuracy than Landsat

MSS which is not surprising considering the differences between the sensors in radiometric and spatial resolution. The accuracy levels of Landsat MSS of 1972 and 1979 years are very close to those reported by Dewan and Yamaguchi (2009) and Malik and Hussain (2006). The relatively poor performance of Landsat MSS for mapping heterogeneous environments is not unexpected (Mundia and Aniya, 2005), however the relatively good performance of Landsat TM, seen in this study and also reported by Bahudar (2009); Deng et al. (2009) and Donoghue (1987) is encouraging and for a developing country like Pakistan where financial constraints are of major concern, Landsat TM and ETM+ data is a better source for research in land use change in response to urbanization. The *bareland* class was confused with the *builtup* class, and there is the probability that this confusion might have affected the results and hindered obtaining land cover statistics. Nonetheless, the approach used in this thesis was appropriate for a sample area situated in Global South, where financial constraints are an important consideration. Moreover with the launching of Landsat-8 with its improved radiometric precision and additional bands, should make the interpretation and land cover classification of images easier. In short, remote sensing has enabled the present research to calculate relatively unbiased land cover statistics, and results should be representative of the general land use cover changes in response to the rapid urbanization of this conurbation. The research has demonstrated the advantages of remote sensing data, such as being cost-effective, multiple date and ready to input into GIS (Aplin, 2004; Chen et al 2000; Donoghue et al 2005; Weng, 2001). There is a lack of studies of this kind from other districts of Pakistan to compare the results, however del Mar Lopez et al (2001); Fazal (2001), Fan et al. (2011) Weng (2001), Mundia and Aniya (2005) and Pauleit et al (2005) have reported in their studies that urban areas of Puerto Rico; India; Nigeria; China, Kenya and England have rapidly expanded at the expense of agriculture and forest lands.

Digital image classification coupled with GIS has demonstrated its ability to provide information on intensity, direction and locations of different land covers as a result of urbanization. The present research has recognised the usefulness of GIS in integrating remote sensing, census and social data from various sources – despite their different formats, resolutions, and projections – in assessing land cover change. In fact GIS helped a lot in mapping inter-censal land cover change, patterns of population and urbanization precisely.

The periodic availability of satellite data makes it ideal for change detection applications to determine the changes in land cover types (Xu, et al. 2000). Post-classification change detection techniques proved to be helpful in this research in order to produce the change maps with the help of cross tabulation or transitional matrices for the inter-censal periods of 1972-1981; 1981-1998; 1998-2012 and 1972-2012. Cross tabulation Matrices of different inter censal periods helped to correlate the statistical and social data with land covers results extracted from classified data. The confusion matrices and transition matrices were the two main tools of analysis. The confusion matrices were used to judge the classification errors whereas transition error matrices were used to judge the errors associated with transition (Van Oort, 2007). The analysis indicated that most of the transitional error occurred due to false errors related to the *bareland* and *builtup* categories.

Moreover conventional maps of the study area were transformed into digital format to analyse the image and population data in a meaningful way. It is important to mention here that although some researchers (Codjoe, 2007; Morton and Yuan, 2009) have used the census data along with remote sensing data to analyse the land use change, but there has not been any study found who has used the longitudinal census data of forty years. This research thus is unique in its nature which has used longitudinal Census data along with other sources.

The remote sensing analysis result showed that with the rapid population growth, urban expansion of Rawalpindi District of Pakistan has accelerated. The built-up area achieved a net increase of 29,203 hectares in the 40 year period 1972-2012. The built-up area in 2012 has increased by nearly 5.2 times over of that in 1972, with an annual average increase of 730 hectares per year. Rawalpindi tehsil showed the maximum increase in its built-up area. The density of population increased gradually while the built-up density decreased sharply during 1972-1981 inter-censal period, and then decreased gradually for the period 1981-2012, showing that during 1972-1981, due to make shift arrangements of national capital at Rawalpindi, the urban development rates were higher as compared to the other inter-censal periods. There has been a large increase in the residential area to accommodate the growing population of the study area, and this increase was particularly pronounced because it was unplanned. The increase in the built-up (urban) area from 1971-2012 strongly correlates with the population growth derived from the historical Census records. The pattern of growth appeared linear which strongly suggested that satellite-derived urban area estimates can be used as proxy estimates for population.

The forest area decreased continuously during the 1972-2012 period. A deforestation rate of 0.5% during the inter-censal period of 1972-81 was high as compared to 0.14, 0.16 and 0.22 for 1981-1998, 1998-2012 and 1972- 2012 inter-censal periods respectively. This shows large urban developments during the inter-censal period of 1972-81 at the cost of deforestation. Rawalpindi tehsil showed the highest deforestation rate of 0.65% during the 1972-2012 period. The deforestation rate of -2.97 % in Rawalpindi tehsil between 1998 and 2012 as seen through remote sensing results and witnessed by the local people is very high and alarming.

The cropped area of the study area decreased considerably during the inter-censal period of 1998-2012. The rate of decrease of cropped area in Rawalpindi District was 0.81% while in the Rawalpindi tehsil it was very high (4.47%) showing the rapid growth of urban area at the cost of lost agricultural land. Pakistan is an agricultural country and agriculture is practised on approximately 70% of the total of its land. In many districts of Punjab such as Sargodha, Jhang, Toba Tek Singh, and Bahawalpur many families possess thousands of hectares of agricultural land covering hundreds of mauzas. This study can be very helpful for the private agricultural landowners to inventory the vegetation cover and built area at the mauza level to monitor the land cover change of their big farms and estates.

Research objective 3: Urban expansion cannot be fully understood without considering the interrelationships of rural, peri-urban and urban land uses (Couch et al 2008; Herold et al 2003). This study will establish the quantitative relationships between population and land use using remote sensing land cover data as a proxy for land use and population density.

Urban expansion in the study area has involved the twin process of internal reorganization and outward expansion of the urban areas. It has been caused by both the population and the economic factors. Urban expansion has affected the agricultural and forest land in many ways. In the first phase of urban expansion, the agricultural areas of the peri urban though not completely diminished but started to shrink near the peri urban areas and moved in the interior, putting a pressure on the rural areas to increase the agricultural area. At the same time, the existing agricultural areas in the peri urban areas faced a lot of pressure to grow more. Thus intensification of agriculture has been seen in the peri urban areas because the farmers anticipated that their agricultural areas would soon become part of the urban areas, and at that time it would be more profitable for them to sell the land at higher rates. Because of this prediction they utilised the agricultural resources maximum, and grew those crops which were more profitable and of less duration. With the passage of time and higher population growth, the agricultural areas in the peri urban areas diminished and shrunk towards the remote areas. This phenomenon caused a great loss of agricultural land. The same kind of agricultural investigation and loss of agricultural land has been noted by the researchers of the neighbouring countries of India and Bangladesh (Dewan & Yamaguchi, 2009; Fazal, 2000; Rasul et al., 2004). The model of built-up expansion in almost all tehsils took the form of *radiation* centred on the old towns and then extending outward layer by layer and along the major traffic routes. The built-up area in Rawalpindi tehsil although it expanded in all directions, it was most pronounced towards the North and North West.

From the above analysis, the spatial pattern of built-up area expansion can be characterized as three spatial types: (1) *Special objective oriented*, (1972-1981), the expansion was governed due to government, military and associated factors: (2) *Socio-economic type,* (1981-1998), the expansion caused by rapid socio-economic development in the study area, (3) *Normal growth type,* (1998-2012), the expansion caused by continued economic development and population growth. However, the urban expansion in Rawalpindi differs from some large cities in Asia, such as Calcutta, Beijing, Karachi, and Tokyo, whose expansion was correlated with the growth of a Central Business District. This research therefore explored integration of census and field based qualitative data with remotely sensed (Landsat MSS and TM) data in order to obtain accurate land use/cover estimates and compare it with the archival sources collected manually. GIS techniques facilitated the statistical analysis and helped to display the data in the form of maps

Research objective 4: Qualitative data will be used to gain insights into the people, attitudes, behaviours, value systems, concerns, motivations, aspirations and life styles. Qualitative data involves the scrutiny of social phenomena and looks beyond ordinary every day of seeing social life and tries to understand it in novel ways. Qualitative research involves complex issues of interpretation.

Sometimes poor quality secondary data and unexplored remote sensing both cannot explain everything without field experience. The importance of field-based ancillary data has fully been recognised for improving land use/cover classification accuracy, particularly of urban areas, by many researchers such as Cihlar and Jansen (2001), Ellis et al. (2009), Lu and Weng (2007) and Rashid (2003). Field work in this research also played a very effective role in giving the micro details and context to the history of urbanization and land cover/ use changes. Field-based qualitative and GPS data used as reference data provided the training material for digital classification and gave a means to match them accurately.

Qualitative field methods revealed a different side of the story. Through interviews, focus groups and participant observation, a lot of information was collected. For example during *participant observation* the author observed terrace cultivation, cultivation in the dense forests, the small land holding size, grasslands in the mountainous areas, agricultural problems, and the construction materials used in building houses in cities and on uphill locations. The author’s observation helped provide an understanding of the reasons for spectral similarity between built-up land and bare land, between grasslands and agriculture, etc. Hence the lack of details in the remote sensing analysis contrasted strongly with the field-based qualitative data. The author fully utilised this experience and data and incorporated it into image processing at all three stages that is before, during and after classification, as suggested by Hutchinson (1982) and Lu and Weng (2007). Another utilization of interview data is the correlation graph between NDVI and yield per hectare (Fig. 6.8). During the flowering of sunflowers the data about yield per hectare was taken by the owners of the farms, the coordinates of the farms were recorded in the field book with the help of GPS and then in the laboratory it was correlated with the NDVI values. This example suggested that NDVI can be used to help predict the yield. However, Labus et al (2002) have cautioned that this relationship can be dependent upon the normal gain filling conditions of the crops. In short, remote sensing data provided the extent and coverage; the field and census data provided depth and detail.

9.3: SWOT analysis of Data sets

Each data set has certain areas of concern related to the rigour of the data. There were two areas of concern about rigour in Landsat data used in this research: (a) the coverage, and (b) traditional problem of classification accuracy, especially for MSS data. For the first type after several attempts, the researcher was able to download the images that covered approximately the whole area and were compatible to the census dates. Yet for the 1981 census, the author had to use the 1979 image, as no Landsat images of the study area in 1981 were available covering the whole study area. For the second type it was found that spectral confusion between some classes produced high errors of commission and omission, particularly in Landsat MSS images. However this accuracy was improved through increased ground truthing in Landsat TM images, particularly for Landsat 2010. However, there always remains some inaccuracy due to the inherent nature of the classification process itself (Shaban and Dikshit 2001).This leads to another area of concern about rigour in remote sensing methods.

Qualitative data showed different issues concerning rigour. For example talking to people about past activities, problems, planning issues, there was a question of recall error (Rindfuss et al 2004); exaggeration (Stewart et al 2007) and the bias of people (Burgess, 1996). Sometimes the researcher noted that interviewees and focus group participants changed their responses to “fit” into their problems. To improve this rigour, the author frequently verified the responses with the respondents to obtain a clear answer to a particular question. Moreover participant observation did prove to be important regarding the collection of information about water, sewerage, electricity issues, and many other issues related to urbanization, deforestation, loss of agricultural land, and the establishment of housing colonies in the study area.

The second issue in the qualitative data was related to the subjectivity of knowledge construction (Hellen, 2011). People see the world from specific embodied locations (Flowerdew & Martin, 2005; Valentine, 1997) and produce multiple realities of the world. In this research different people classified the land covers in different ways. For example, different people defined the forests, orchards, grasslands and agriculture in different ways. Moreover during the PPGIS phase they identified the land cover type from the images in different ways. However, again the author’s position contributed to the rigour, as the information was ultimately filtered through him and his colleagues (Smucker et al 2007). Another rigour in the qualitative data was the poor response of the civil servants and local bureaucracy, first in sparing time for an interview and secondly answering the questions appropriately.

Rigour in field data is related to GPS surveys, which were very tedious and risky. Due to the security reasons and situation of the study area very close to capital, and overall concerns of security in the country, it was difficult to conduct GPS surveys, and there was a continuous danger of investigation from the police and other agencies, for using GPS in highly sensitive area. Although the author had obtained prior permission for GPS survey and focus group discussions, yet many times he had to clarify his position to the agencies when conducting this research.

The irregularity in the organization of the censuses for political reasons was another issue of rigour in the census data. As noted in chapter 5 and 7, the last two censuses were not held at a decadal interval, and there were delays of 17 years (1981-1998) and 14 years (1998-2012), therefore the irregular gaps between censuses is not ideal. To improve this rigour, the author selected an additional image of 1992 and estimated the population for this time period from the nearest censuses, which threw light on what would have happened, had the census been held after every ten years.

In summary, although the data used in this research had certain unavoidable shortcomings as well as the nature of data themselves, yet the author tried to find the solution and improve the rigour.

By examining land cover/use change with the help of remote sensing classification, and ancillary data, the author concludes that no method was "impartial"; each method illuminated a particular element of the land cover change story. Each method was limited in the range of scale of investigation and addressed certain questions that other did not. For instance, on the one hand remote sensing provided data on the extent of land cover; on the other hand the multiple methods provided the evidences on the *how and why* of land cover change. By combining these methods, the story of land use and land cover change became more clear and relevant to spatio-temporal scales of operation (Walker and Peter, 2007).

9.4: Reflections

The impacts of intensifying urbanization and land use land cover change in the large areas are being felt both in developing and developed countries alike. Information about the changing patterns of land cover/land use in the large urban areas is not only important for the better management and planning of these areas, but also it helps to understand the human dimensions of landscape change at regional and global levels. Land use/ cover change in response to urbanization has been studied and analysed for the last four decades. The study area has undergone a noticeable change in terms of expansion of urban areas and loss of agricultural and forest land due to demographic and anthropogenic factors. This thesis was based in a part of the Global south where Land cover/use change has important impacts on everyday life.

This study demonstrated a methodology to help understand the processes and impact of urban expansion using a novel approach that combined remote sensing with population census and qualitative data analysis. The remote sensing data made it possible to enlarge the coverage and extent of the investigation in ways that would have been practically impossible with only field based qualitative methods and Census archives. More importantly remote sensing methods provided an insight into the spatial and temporal connectivity of the study area that was otherwise impossible to perceive. In other words this research provided an opportunity to a human geographer (researcher) to use remote sensing data to expand the field and scale of analysis of land cover/use.

The field based qualitative data provided the insight into multiple meanings and importance of urban expansion and land cover/use change that was not possible for only the remote sensing methods. Extensive ground truthing at one hand helped to correct the images and GPS data was further used as reference data, on the other hand extensive ground truthing in the form of participant observation, focus group discussions, perimeter walks and interviews with local participants and government officials enhanced the capacity of remote sensing analysis to distinguish between more complex land covers and land uses. Thus remote sensing and field based data served as a system of check and balance, each complementing the other while examining appropriate questions. In urban expansion analysis, an important data source is the population data. This research utilized the longitudinal population Census data published by the Government of Pakistan, at length, and compared it with the remote sensing and filed based data. Moreover the population data helped as an extra channel during classification stage. The population of mauzas in different inter-censal periods helped to explain the presence or absence of different land covers. In short, Census and participatory ground trothing enhanced the accuracy and detail of classification.

Availability of ancillary data such as population census data, agricultural data, analogue and digital maps and convenience of access were the main factors to choose Rawalpindi as a study area, besides the spatial characteristics of the area.

The methodology of mapping the land cover from a time series of Landsat images is based on adequate understanding of the landscape features and information extraction techniques employed. The study recognised that imperfect ground reference data may generate significant bias in estimates of land covers (Foody, 2010). Therefore ground data error and its impacts should be considered in the interpretation of land cover/land use change. Change detection in remote sensing can be simple as in many cases extent of change may be derived simply from a binary change detection matrix.

Landsat images can be used as a working base map for updating urban information for analysing built area densities and for the assessment of land covers. Although Landsat MSS images tended to over/ under estimate the areal extent of the land covers because of their lower spatial resolution (Altamirano et al., 2013), this research recognises the importance of Landsat TM. Moreover, with the recent launching of Landsat TM 8, with additional bands, it is expected that land cover classification will be improved. The image classification results show that Maximum Likelihood is the best classifier and accuracy of the classification can be enhanced with the help of suitable response and sample design.

The built up area extracted from remote sensing classification results has also been used in this study to estimate dwelling units and population of the study area. The population estimated was almost close to the figures that were derived by the official records. This statistical modelling approach for population estimation based on the satellite data can be a remedy for the shortcomings of the decennial census in Pakistan, such as high cost, labour intensity and low frequency. Thus these methods alongwith with Population sample surveys can either be an alternative of the census or at least can provide the population estimates, if population census is delayed. Moreover these methods can also be applied to check the reliability of the Census.

The results of the field based qualitative methods component of this thesis reflect a complex picture of urban expansion in terms of scale and time period. Social histories from focus group discussions, formal and informal interviews, and community mental mapping, all emphasised that there have been a lot of changes over four decades. People witnessed that due to a large influx of population in the study area, from different parts of the country, the urban population and the urban areas have increased many fold. This unexpected expansion caused over-utilization of resources, water shortages in many areas, the conversion of farmlands and forests into the residential areas, the reduction in green and open spaces, traffic congestion and pollution problems, resulting in rising temperature due to the urban heat island effect. The views of the local community on the growth of squatter settlements and establishment of illegal housing colonies on the government land, and data provided by the government officals regarding built up, agricultural and forst land of the study area during different inter censal periods, all supported the remote sensing results regarding increase of built-up land and loss of agricultural and forest land. Moreovver built up land cover data obtained from remote sensing analysis witnessed the local community's argument regarding encroachment of urban settlemnets on to agricultural and forest lands.

The present study recognises that although it is hard to stop urban expansion, nevertheless with proper management and planning it can be directed in a desirable direction, so protecting cropped areas and forests. Moreover, by providing basic facilities such as educational, health, gas, electricity and telephones to smaller towns and villages, the rural to urban and small urban centres to large urban centres migration can be reduced. In a broader sense, the results have also significance for conservation studies. For those natural resource managers and planners who are interested in the impacts of urbanization, this research can provide a model to help manage the potential changes in land cover and natural resources. Results of this study also can aid the development and implementation of urban growth-management plans.

This research further recommends that any economic activity in the area should only be allowed after assessing it in terms of land scarcity and land degradation, and its possible impacts on natural environment. To lessen the negative impacts of urban expansion, policy makers should come forward and take appropriate actions based on present and past land use and land cover changes.

Among the driving factors of urbanization and land use and land cover change, demographic pressure, provision of better educational and health facilities, better employment opportunities, developed transport network (both intra cities and inter towns/cities), Motorways (M1,M2 and M3) connecting Rawalpindi to main cities, pleasant climatic conditions, small and medium size industries in whole of the study area, cement and marble industries, cottage industries, cultural and social change in response to media are important.

The major impacts of urbanization in the study area are linked with environmental degradation. Some of the impacts are loss of vegetation and open spaces, water and air pollution, urban heat island effect, increased land sliding in mountainous areas, traffic congestions, water, and electricity shortfalls, shortage of housing facilities and unemployment.

The relationship between the land cover/use patterns and urbanization has a considerable effect on the intensity and spatial pattern of UHI effect in the study area, as argued by Chen et al. (2005). The radiant temperature data of different land covers showed a difference of 1-2 C^0 of temperature between built up areas and other land covers. The higher values of radiant temperature corresponded to an apparent UHI effect in the dense built up areas. It is pertinent to mention here that during the focus group discussions many of the participants were of the view that due to concrete/ block constructions in the study area at a large scale, the average temperature of the study area has been increased and duration of the winter season has also been shrunk. Many participants and interviewees told the researcher that during the last decade duration of the snowfall days has also been decreased in the Murree and adjacent mountainous areas. They were of the view that this was the effect of the long term deforestation in the study area. Deforestation in the mountainous areas of Kotli Sattain and Murree tehsils (S1) have made the soil vulnerable to soil erosion , and in these areas the problems of landslides was noticed by the author at many occasions during the field work .

An important impact of land use change resulting from urbanization is the degradation of the water resources, which were largely complained during the field work. In fact the increase in the impervious surface has altered the hydrologic conditions of the area. The outcome of these alterations is the increase in the volume and rate of surface run off during the heavy rainfall, and decrease in ground water recharge. Thus blocked drains are very common in Rawalpindi tehsil which lead to larger incidents of flesh flooding in the Nullah Lai, making the life of the local inhabitants miserable. Moreover during the rainfall the water comes out from the blocked drains making the situation difficult for pedestrians of the nearby households. Spread of infectious diseases due to the blocked and open drain holes is also common in the low-lying areas on the bank of Nullah Lai. Since the sewerage and water pipes run side by side, sometimes a small leakage has adverse effects. Open industrial disposed water also causes water pollution.

This interdisciplinary research has academic eminence and qualification of using GIS, Qualitative census and remote sensing data and tools to examine urban expansion and its aftermath monitoring with regard to land cover change. This monitoring has the potential to produce a cost effectual and efficient urban planning and development. Geographers, economists, urban planners and decision makers will be benefitted with the findings of this study and inter disciplinary research methodology.

- This research seeks to contribute to academic scholarship in three areas: First, contribution to theory comes from empirically testing the cross verging practices in the development process of a rapidly urbanizing district.
- Secondly, building an accurate GIS data base by utilizing remote sensing, field and census data in a developing country posing numerous challenges. But it was crucial for assessing response to developmental processes, rapid population growth, urban expansion, loss of agricultural land and deforestation. Issues and problems include the lack of cooperation between departments within the government, unawareness/ negligence of the government officials, and non-cooperation of the civil bureaucracy.
- Thirdly, construction of land cover data base for Rawalpindi demonstrated the use of RS and GIS techniques in formulating and monitoring policies towards the natural resources and urban expansion.

9.5: Future Study and Recommendations

There are number of recommendations for possible future research directions and follow-up applications.

1. The study of land cover and land use change at the scale of an administrative unit, like a District, requires reliable historical data to provide necessary context to understand change dynamics. The need for improved planning policies has already been noted and so detailed base line information should be established for the sustainable management of land resources; it is therefore recommended that government (provincial and district both)

should plan land use surveys at regular intervals. The inventory of these surveys will provide a mechanism to test the success or otherwise of land conservation policies and for future research. (It is pertinent to mention here that the author could not find a single land use map of the whole study area from any source).

2. A temporal analysis of land cover was derived from medium resolution imageries (Landsat MSS and Landsat TM); higher resolution imagery from systems such as SPOT, IKONOS, and GeoEye could help to determine the land conversion rate more precisely. This research focused on major land cover classes and gave an overarching idea of the gain or loss of agricultural, forest and built-up land over a forty year period. The use of fine resolution images may help to determine the agricultural patterns of Rabi and Kharief crops and deforestation up to a plot level in a mauza. Moreover the mapping of the built up area can further be split according to the structure (and function) of urban development; the spatial resolution of modern optical imaging systems should allow residential, commercial and industrial categories to be interpreted and perhaps automatically mapped using digital image processing. Thus the present research provides a valuable framework for future work with high resolution satellite data.
3. The methodology used in this research for mapping built-up areas is particularly practical for small districts. The procedures for assessing land cover and integrating population census data into the study are based on GIS overlay functions and, in contrast to conventional cartography, are not restricted to a certain scale. The development of more standardized methods for categorizing land consumption patterns, high and low-density developments will enable comparisons between different regions.
4. Further research is needed to fully understand rural-urban and urban-urban (small cities to large cities) patterns of migration. Moreover, a detailed study of push- and pull-factors of migration can and should be incorporated into future population studies.
5. Due to large temporal gaps in the acquisition and publication of the Pakistan Census of population, the analysis of change is not based on regular sampling periods. For instance the 1981-1998 inter-censal period was 17 years. Following the 1998 census, the census of 2012 has so far not been published, due to political reasons. Moreover, the census organization is laborious, costly and time consuming. This research recognises that certain key population variables can be estimated from the area of built-up land. A significant number of authors have argued for global mapping of settlements and estimation of population by using remote sensing including the use of night images showing emitted (anthropogenic) light (e.g. Elvidge et al., 1997; Imhoff et al., 1997; Sutton, 1997). By using night time images population variables such as density can be estimated, however, as this study has shown optical imagery can also be used to derive detailed land cover data that when suitably processed provides a consistent and systematic method for estimating and

modelling population trends. Thus instead of complete enumeration, it will be possible to conduct sample surveys, the results of which can be scaled up using satellite data. In this way a full population census can be avoided. However, it should be noted that optical satellite imagery is preferable to the use of night images in Pakistan, partly due to its better spatial resolution and interpretability and also because of known periods of electricity blackout and unlit urban areas in many parts of Pakistan.

6. The government of Pakistan spends huge sums of money on inventory of the agricultural, forest and fallow lands. A considerable number of field workers perform such jobs. Sometimes they make bogus entries, and just repeat record entries from previous years making these data somewhat unreliable. Future research can include the land cover change assessment with the help of satellite data to cross check the manual records.
7. The present research has noted that due to lack of planning, District government often fails to implement its own policies, and with the involvement of government officials, many residential colonies, industries have been established illegally. The commercial use of residential areas is very common in the study area. The possibility of using fine resolution satellite data to help update records and subdividing urban area according to its land use: residential, commercial and industrial would be very helpful for monitoring and for future planning as well.
8. Every year due to floods in Pakistan, hundreds of people die, thousands are displaced and at least one million hectares of agricultural land are affected. The mighty Indus River's flood can be monitored with the help of satellite data. This research recommends the use of satellite data for flood management. Moreover the potential use of high spatial resolution satellite imagery and Unmanned Aerial Vehicles (UAVs) during the time of high volume of water in rivers (August/September) could save many lives and help protect people's property.

APPENDICES

Appendix 5.1: Semi-structured Interview Schedule for Policy Makers

A. Urbanization – extent/drivers/causes

1. To which extent would you say there has been an expansion in urban areas in the last forty years?

   Prompts:

   - What are major population trends in urban areas?
   - Do you think number and size of urban areas are growing rapidly?
   - Are cities growing outward or upward?
   - What are the main indicators of urban growth and expansion?
   - What would you say are the main causes for the increase in urbanization?
   - Has urbanization been more incisive in some areas than others?

2. Do you think during the couple of decades average temperature of the area has been increased?

   Prompts:

   - wastes heat from a large number of automobiles, air conditioners, factories in the areas, tall buildings, and displacement of natural surfaces has decreased the amount of evapotranspiration
   - effect of "Urbanization" on INDUSTRIALIZATION
     - Increased pollution
     - Destruction of natural ecosystem for urban development
     - Negative impacts on health including increase in obesity & blood pressure & insomnia.
     - Increased Infra structure cost

3. What's your opinion on the following "smart growth tools"?

   Prompts:

Limits:	Limitizing urban growth boundaries ; Green belt around cities; Public review of new development
Zoning:	Promoting high density cluster housing developments: Uniform size of houses
Protection:	Preservation of existing open space Arranging new spaces Buying development rights Effective implementation of building codes
Taxes:	Taxes on lands and its use Taxes on value of actual use i.e. forests, agricultural land, Orchards
Tax breaks:	If owners agreeing not to build further
Revitalization:	Revitalizing existing towns and cities

Building well planned new towns within cities

B. Profile of urban dwellers

1. What is the demographic – socio-economic profile of urban dwellers [over time]

Prompts:

- Who are they - where have they come from? Do you think people?
- Are more prosperous now in comparison with ten, twenty, forty years ago?
- Prosperity across rural/urban areas?

2. What is the profile of the new urban dwellers that have come to inhabit the recently urbanized areas?

C. Challenges/Impact

1. What are some of the main challenges that urbanization/urban changes have been pressing?
2. Do you think that the local population growth rate was so high that it demanded to build more apartments and tall buildings?
3. Was it due to large influx of population from other parts of the country? From which parts [migrants?]
4. Do you think life is a desperate struggle for the urban poor?'
5. What is the role of political influence in the deshaping of cities and illegal schemes?

Prompt:

- Lessons from twin city of Islamabad:

D. Intervention/Regulation

1. Have there been any explicit attempts to regulate urbanization in some ways? How have these attempts been?
2. Should there be more initiatives of intervention from the State in the regulation of urbanization, or do you think urban regulation should be left to the civil society?
3. How important is land use planning? Do you think LUP can help to reduce uncontrolled sprawl, slow down the resulting degradation of air, water, land, biodiversity and other natural resources?
4. A growing number of urban planners think that the primary problem is not an urban growth; rather its administration's failure to make the urban areas more sustainable and liveable: please comment
5. Out of the following models of urban expansion, do you think which one applies to your area?
   A) Infilling
   B) Out Expansion
   C) Outlying
6. Do you agree that "micro financing "for providing apartments can control unplanned growth of dwellings?

Finally…

1. Could you please say some words about merits and demerits of urban life?
2. Which other organizations may contribute with relevant knowledge and expertise to respond to urban changes?
3. What was the primary use of this area before urban use?
    - A) Agriculture
    - B) Forest reserve
    - C) Fallow land
    - D) Commercial Use
    - E) Any other
        - o If Agriculture, average size of land holdings
        - o Crops grown:

          Prompt:
            - ▪ history of cropping
            - ▪ Cropping pattern (Rabi & Kharief crops)
            - ▪ Yield per acre/income per acre
            - ▪ Irrigation facilities
            - ▪ Population engaged in agriculture

4. Do you think after getting the status of "Urban area" the local population sold their land at very high rates?

   Prompt:

    - They absorbed in the area
    - Moved out: What about their employment?
    - What about their livestock?
    - Poultry farming?
    - Any other affect?

5. Do you think that during the last forty years a large influx of population moved in the area: Which parts of the areas the most moved? Why?

    a. Education of children
    b. Better employment opportunities
    c. Govt. Service
    d. Business
    e. Any other

6. From the following satellite images, what features of your area can you identify? How? What kind of changes has occurred during 1972, 1981, 1992, 1998, 2000 & 2010?

7. Do you think that it is more profitable to build tall buildings and rent them: How do you get money? Are there more property taxes on buildings to let?

8. Do you think that people, who had/has their land adjacent to city, find it more profitable to establish housing colonies: how do they get it approved?

    a. Basic facilities provided by local planners or govt.
    b. Issues of illegal colonies

c. Local people selling land to builders at very nominal rate
d. Builders sell/ sold/selling at very high rates
e. Political influence
f. Issues of housing colonies developed by different organizations
g. Town planner’s role in protecting biodiversity by preserving surrounding land, recycling and reuse of wastes

9. Why does high price of land in some areas higher?

    a. Due to intra city transport net work
    b. Provision of electricity/gas/phone/drainage facilities
    c. Location of the new colony
    d. Issues of council tax/property tax

10. In your opinion what is the annual deforestation rate/rate of replacement of agricultural land with impervious surfaces/industrialization?

    a. Issues of pollution
    b. Urban heat island
    c. Environmental problem

Appendix 5.2: Questions Asked during Focus Group Discussions

1. Which features of your area can you identify from satellite images of following years?
   1972, 1979, 1992, 1998, 2000, and 2010

2. (a): Do you think that local people sold their agricultural land at very cheaper rates to builders for establishing housing colonies?
   (b) Do you think that people, who had/has their lands adjacent to city, find it more profitable to establish housing colonies?

3. What is the role of the industries in the development of area? Do you recommend moving the industries out from urban areas?

4. What is the role of legal and illegal slums in urban expansion?

5. Have there been a lot of changes in the area over four decades? (Conversion of farmlands into built-up areas; establishments of educational institution, hospitals; construction of major roads/ motorways; and any major change you witnessed)

6. Do you think that during the last forty years a large influx of population moved in the area: which parts of the area the most moved and why?

7. What are the concerns/ problems you have regarding legal/illegal urban expansion?

8. Are you satisfied with the role of authorities in providing urban facilities in the area, how do you compare the life in urban /peri urban and rural areas?

9. What do you think could be done to address the concerns/ problems you have identified?

Appendix 5.3: Focus Group Guidelines

My dear friends,

Assalam o Alaikum!

I am really glad to see you all here and thank you for giving your precious time to take part in a focus group and contribute to the research! The discussion should take approximately 90 minutes (1hour 30 minutes).

To ensure that the discussion runs well, keeps to time and most importantly all participants are able to give their views we suggest a number guidelines here. These are as follows:

- Please respect other's views
- Have your say but give others chance to have their turn: you are requested to be patient, and not to over dominate discussion
- Please avoid talking each other while discussion is going, but do participate actively.
- No smoking
- You can leave the group at any point please do so discretely.
- Please respect the facilitator: we have limited time and a lot o discuss so facilitator will on occasion have to ask you to move on to new areas: please be patient at that time and respect this.
- Please fill the registration form before starting discussion

The facilitator will discuss these with you before commencing the focus group discussion.

Thank you very much for your cooperation.

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