MUNICIPAL SOLID WASTE COLLECTION ROUTE OPTIMIZATION USING GEOSPATIAL TECHNIQUES: A CASE STUDY OF TWO METROPOLITAN CITIES OF PAKISTAN

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Title

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

DOCTOR OF PHILOSOPHY

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ABSTRACT

The population growth in many urban cities and its activities in developing countries have resulted in an increased solid waste generation rate and waste management has become a global environmental issue. Routing of solid waste collection vehicles in developing countries like Pakistan poses a challenging task. In the process of solid waste management, collection and transportation play a leading role in waste collection and disposal, in which collection activities contributed the most to total cost for solid waste collection activities. Therefore, this study describes an attempt to design and develop an appropriate collection, transportation and disposal plan for the twin cities of Pakistan by using Geographic Information System (GIS) and Remote Sensing (RS) techniques to determine the minimum cost/distance/time efficient collection paths for the transportation of the solid wastes to the landfill sites.

In addition to this, identification of solid waste disposal sites and appropriately managing them is a challenging task to many developing countries and Pakistan is no exception to that. The existing landfill sites for the twin cities are not technically viable and environmentally acceptable and are thus damaging to the environment due to their location and the type of waste dumped. Therefore, the second aim of our study was to find out the suitable landfill sites for the twin cities and the study employed Multi-Criteria Evaluation (MCE) methods to combine necessary factors considered for landfill site selection for the twin cities. Hence, our present study has proved that GIS is a tool that can be used in integration with other techniques such as MCE for a identifying new landfill sites and it can help decision makers deal with real-world developmental and management issues.

Finally, the study has developed a Wed-Based Decision Support System (DSS) via Application Programming Interface (API) which will help decision-makers to search for cost-

effective alternatives and it can be operated by people who don’t have knowledge of GIS. The proposed study can be used as a decision support tool by the municipalities of the twin cities for efficient management and transportation of solid wastes to landfill sites, managing work schedules for workers, etc.

ACKNOWLEDGEMENTS

The process of writing this thesis was a wonderful learning experience in my academic life, which was filled with challenges and rewards. The completion of the present study leads a new beginning and a step forward towards my future and when writing this preface, a quotation by the famous **Scottish Physicist James Clark Maxwell** came to my mind. Maxwell once stated **"What is done by what is called myself is, I feel, done by something greater than myself in me".** The question is justifiable. Did I really do this? Did I really manage to get it all together?

First, I would like to express my sincere gratitude to my thesis supervisor, **Dr.Joseph Szmerekovsky** for his valuable supervision, never-ending support, encouragement and good nature during the process. I am very thankful to him, that he has given me this pleasure to use his valuable comments, feedbacks and suggestions during the time that I have been working on this thesis and he has presented a new world for my further academic research. I believe that one of the main gains of my PhD program was working with Dr.Joseph Szmerekovsky and gaining his guidance and trust. I am greatly indebted to him for his continual encouragement and support. Apart from a wonderful professor he is great human being and I respect him from the depth of my heart.

Secondly and most importantly, I would like to dedicate this dissertation to my **mother** who has always supported and encouraged me in all walks of life. She has devoted her life for my disciplined training and upbringing. I offer special thanks for her boundless love and sincerity, which hearten me to achieve success in every sphere of life. Without her encouragement and moral support, the present study would have been a mere dream. Her emotional involvement during the thesis writing kept me on my toes. My mother is my angel; my role model and my best friend I ever had. I owe her much. I would like to thank my younger sister **Arooj** for her support and love during some of the most challenging moments of thesis writing process. My sister was through thick and thin as well. **Arooj** thanks for being my little sister.

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Lastly, my sincere thanks also go to all my committee members of for their input, help, guidance, valuable feedbacks and support during my dissertation.

DEDICATION

I dedicate this dissertation to my loving husband Jehanzeb Khan for all his love, care, support and sacrifices during this PhD program.

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LIST OF ABBREVIATIONS

ASTER ……………Advanced Space-borne Thermal Emission and Reflection Radiometer

API ……….……..…Application Programming Interface

CDA ……….…..……Capital Development Authority

CAD ……...………Computer-Assisted Drafting

DBMS……..……… Database Management Systems

DEM …….….……Digital Elevation Model

DSS ………......……Decision Support System

GIT.... …………..…Geo information technology

GIS ………......……Geographic Information Systems

GDEM ……………Global Digital Elevation Model

GE ………….…..…Google Earth

GNI ……….…...…Gross National Income

GCP …………..…Ground Control Point

GPS ….……………Ground Point Survey

HTML ….…………Hypertext Markup Language

ICT …………....…Islamabad Capital Territory Administration

KML ………..……Keyhole Markup Language

KMZ …….………Keyhole Markup Language Zipped

LULC …………Land Use/Land Cover

MIS ………………Management Information Systems

MCE ………………Multi-Criteria Evaluation

METI ……………..…Ministry of Economy, Trade and Industry of Japan

MSWMS…..……..… Municipal Solid Waste Management Systems

MCDA …………..……Multi Criteria Decision Analysis

MCDM……………..… Multi Criteria Decision Making Method

MSW ………………Municipal Solid Waste

NASA……………… National Aeronautics and Space Administration

NA……………….… Network Analyst

RMC ……………..………Rawalpindi Municipal Corporation

RS …………………..…Remote Sensing

SWM……………… Solid Waste Management

VRP ………………..…Vehicle Routing Problem

1. INTRODUCTION & BACKGROUND

The environment is at risk due to unsustainable waste disposal. In recent years, this has become a critical issue concerning serious environmental problems and challenges. Despite that, there has been growing awareness in both developed and developing countries regarding solid waste management followed by the development and adoption of new technologies such as GIS for the improvement of solid waste management systems (Heywood et al., 1998 and Ramasamy SM, et. al., 2003). GIS is one of the new technologies which have contributed a lot to waste management in a very short time (Heywood et al., 1998 and L. Narayan., 1999). In many developed countries of the world, geographic information system (GIS) is used as a vital and decisive tool in resource management, regional planning, and economic development. Unfortunately, the practical use of GIS in many developing countries of the world such as Pakistan, is hindered by the scarcity of accurate and detailed geo-spatial data and other concerns such as political and management issues. A study by Mennecke and West (1998) built on the work of Yapa (1991) makes the case that GIS is important as an appropriate administrative technology for developing countries. A major and basic difference in research and data collection between developed and developing countries is the degree to which existing organizations help to collect and manage data, and the current study encountered the same challenges. Furthermore, the nature of spatial data makes collection efforts for the researchers difficult in developing countries such as Pakistan as compared to the developed nations such as USA, UK, etc. As a result, only a limited amount of spatially referenced data is available to support current researchers, analysts and decisions makers working in developing parts of the world, such as Pakistan. This problem was expressed by Gerland (1996, p.9) “The problem remains that very little of this information is spatially referenced and organized, making it difficult or even impossible for analytical studies, monitoring, planning, and decision-support to take place". Therefore, our present study is no exception to that. Many challenges were faced during the spatial and non-spatial data collection for the current study in contrast to those in the developed world such as:

- There is a scarcity of geo-spatial data and the current geo-spatial information available in Pakistan is not atomized and is not updated both in terms of quality and quantity.
- Unlike in the developed world, Pakistan is devoid of proper methods for SWM such as optimal routing for the collection and transportation of solid waste from collection points to the landfills and no urban settlement synchronization with the current/existing landfill sites.

Therefore, our current study has employed the approach to developing GIS physical data by digitizing existing paper maps and satellite imagery obtained from Google Earth (GE) in order to get the data. Imagery is useful to identify physical features such as roads, villages and natural resources etc. (Wang, Treitz, & Howarth, 1992). Furthermore, the study used modern Global Positioning System (GPS) technology to record positions such as collection points etc. Dugger (1997) also showed in his study how GPS and ground surveys could be used in the creation of boundary maps depicting the location of solid waste disposal sites in the remote areas of Thailand. Similarly, Hightower et al. (1997) used GPS technology in his study for the collection of land use data in the Lake Victoria region of Africa. Hence, the collection of spatial data can be expensive in developing countries but our proposed study used strategies and techniques which reduced the overall data collection problems, costs and efforts and thus we opted to use GIS technology for SWM in Pakistan for our current study. In particular, our current study addresses the following three general research questions:

- RQ1: In a developing country like Pakistan, how practical is it to assess the present waste management strategies, analyze the urban land and identify new appropriate landfill sites using GIS and Remote Sensing technology?

- RQ2: How to obtain the pattern of location of communal waste depots and how they can be managed in terms of better urban planning using Remote Sensing and GIS technology?

- RQ3: How beneficial will it be to develop the optimize routes for economical and time saving purposes and to develop an online DSS as a waste collection optimization tool for the policy/decision makers?

This study concludes a three-research question sequence on the use of GIS and RS for SWM in Pakistan. A study by Mennecke & West (1998) showed how GIS data has the built in potential of serving as an integrated decision support system (DSS) in most of the economic and planning areas. The combination of geo-spatial data with non spatial data by employing GIS has benefits ranging from the individual research study level to national policy making. Despite the challenges of data acquisition, it is appropriate to conclude that the potential, opportunities, and contributions of GIS are worth the effort requisite to ensure successful and practical implementation in the developing part of the world. This is a rich area for conducting research on the adoption and dissemination of GIS integrated with other useful information technologies. Our study should is for highlighting many of the important variables that influence this process in developing countries such as Pakistan.

1.1. Broad Overview

Global urbanization, rise in population, economy and life style change in recent years have resulted in increased amounts of solid waste generation (Beede and Bloom, 1995; Minghua et al, 2009) and ultimately towards the problem of solid waste management (SWM) (Sumathi et al, 2008). In the current era, waste is dumped directly without any proper inspection and monitoring which results in severe environmental pollution causing a tremendous growth in health related problems. Therefore, one of the key challenges being faced by the urban areas of the world is the management of solid waste. The reason behind this is the aggregation of human settlements which has the potential to generate massive amounts of solid waste whether they are of low or medium level wastes; they are causing environmental pollution and have become a constant problem for mankind (Ramasamy SM, et. al., 2003). The Municipal solid waste generation rate was estimated at more than one and a half billion metric tons per year in 2000 and is expected to rise to five billion by 2030 (Beede and Bloom, 1995; Hoornweg and Thomas, 1999). If this situation is not handled in a proper manner within time it will lead to worse consequences on a global level. In most of the countries much emphasis is being laid on solid waste management and many new technologies have been developed for improving solid waste management systems. GIS is one of the new emerging technologies which have contributed much to the waste management society in a very short time. The Geographic Information System (GIS) helps to manipulate data in the computer to simulate alternatives and to make the most effective decisions (L. Narayan., 1999).

1.1.1. What is Solid Waste?

Waste comprises all the items which are not of any use to people and which they intend to get rid of or want to discard. In short, waste can be defined as the items which are no more in use and are not expected to be used in the future.“Solid waste is the term used to describe non-liquid waste materials arising from domestic, trade, commercial, agricultural, industrial activities and from public services.”(S. Palnitkar, 2002). Further examples of waste are sewage mire, household rubbish, wastes from manufacturing activities, packaging items, discarded cars and electronic devices, garden waste etc. Thus all our daily activities can give rise to a large variety of different wastes arising from different sources. Wastes generated from residential, commercial, industrial, or institutional construction, as well as from demolition processes and municipal services are also an example of solid wastes (MoEF, 2000). Solid waste varies from country to country and the type of solid waste in every country depends on the lifestyle and the use of the products and commodities by the people.

1.1.2. Background

Daily human activity in urbanized areas generates huge amounts of waste. In the present era, annual production of solid waste in the world is about 1.6 billion metric tons and a significant amount of money is used in the management of massive amounts of solid waste. In the 1990s, Asian countries alone spent about US$25 billion on solid waste management per annum and this figure is expected to rise to US$50 billion by 2025 (Hoornweg & Thomas, 1999). These figures illustrate that SWM has become a complex, huge and expensive service. In general, the production or generation of waste is directly proportional to the economic growth, increase in population and the changes in lifestyle of the people (Hoornweg & Thomas, 1999). As the world is developing and progressing, waste amounts are also increasing and it has become a major concern at a global scale.

The impact of waste on public health and environment, such as emissions to air, water and the soil contamination, land degradation and habitat deterioration, has encouraged engineers and scientists to explore waste management solutions with more favorable environmental footprints (Ackerman, 1997). Domestic, industrial and other wastes are also the reasons for environmental pollution (Dipanjan et al, 1997). As a result, municipal solid waste management systems (MSWMS) are important for the sustainable development of developing countries. MSWMS deal with generation of the municipal solid waste at the source until its final disposal, which includes many operations in between. The problem is especially severe and a major issue in most of the developing countries having rapid urbanization, poor planning and scarce resources (Mato, 1999 and Mwanthi et al., 2010) and almost one third of the total waste generated in developing countries is not collected or disposed off (Mahar *et al*, 2007). According to Senkoro (2003), in developing countries solid waste management arose as the second most important problem after water quality and only 27% of the urban populations have access to proper and regular garbage removal.

Solid waste disposal sites are found everywhere in urban areas of developing countries and have become the main sources of contamination due to flies, mosquitoes, and rodents which are disease transmitters and affect the health of the local population (UN Environmental Protection Agency, 2006). This type of situation can cause gastric, dermatological, respiratory, genetic, and other health diseases. According to Marshal (1995), dumping sites have a very high economic and social cost in public health services, and have not yet been addressed and estimated by governing bodies. The UNEPA (2006) states that people are at risk because of these open dumps of solid waste, especially infants, waste pickers, sanitary workers and workers in facilities producing poisonous and infectious material and people who are living near to a waste dump and those whose water supply has become contaminated (either due to waste dumping or leakage from landfill sites). According to M. K. Virk, et al., (2004) “The decaying matter provides suitable material for mosquitoes and flies to thrive and rapidly causing diseases.” The exposed and accumulated garbage invites massive problems in the locality.

One of the consequences of global urbanization is increasing volumes of solid waste and the management of municipal solid waste (MSW) is one of the major challenges worldwide (Sandec/Eawag, 2008). Back in 1990, It is estimated that about 1.3 billion metric tons of municipal solid waste was generated globally (Beede and Bloom, 1995). In 2002, 2.9 billion urban residents produced around 0.64 kg per capita/day. In 2012 3 billion residents generated 1.2 kg per capita/day and it is estimated that by 2025 this will probably increase to 4.3 billion urban residents producing around 1.42 kg of municipal solid waste per capita/day (Hoornweg and Bhada-Tata, 2012). The amount of waste generation rate varies and is dependent on the lifestyle of the people, income and on their spending and consumption patterns. A correlation between the amount of municipal solid waste produced and gross national income (GNI) is shown in Figure 1.

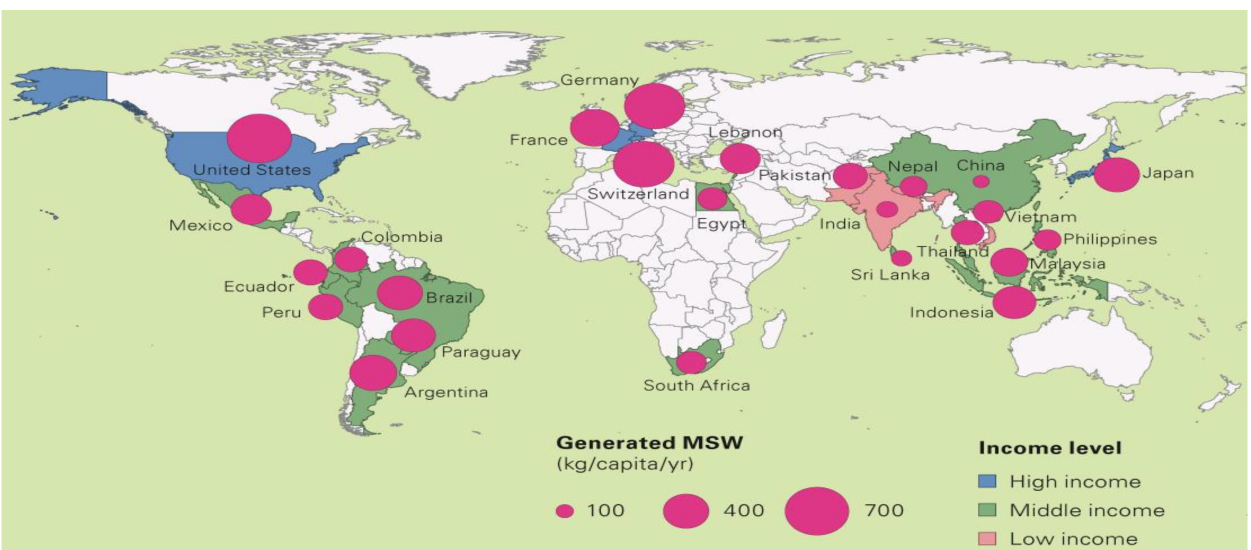


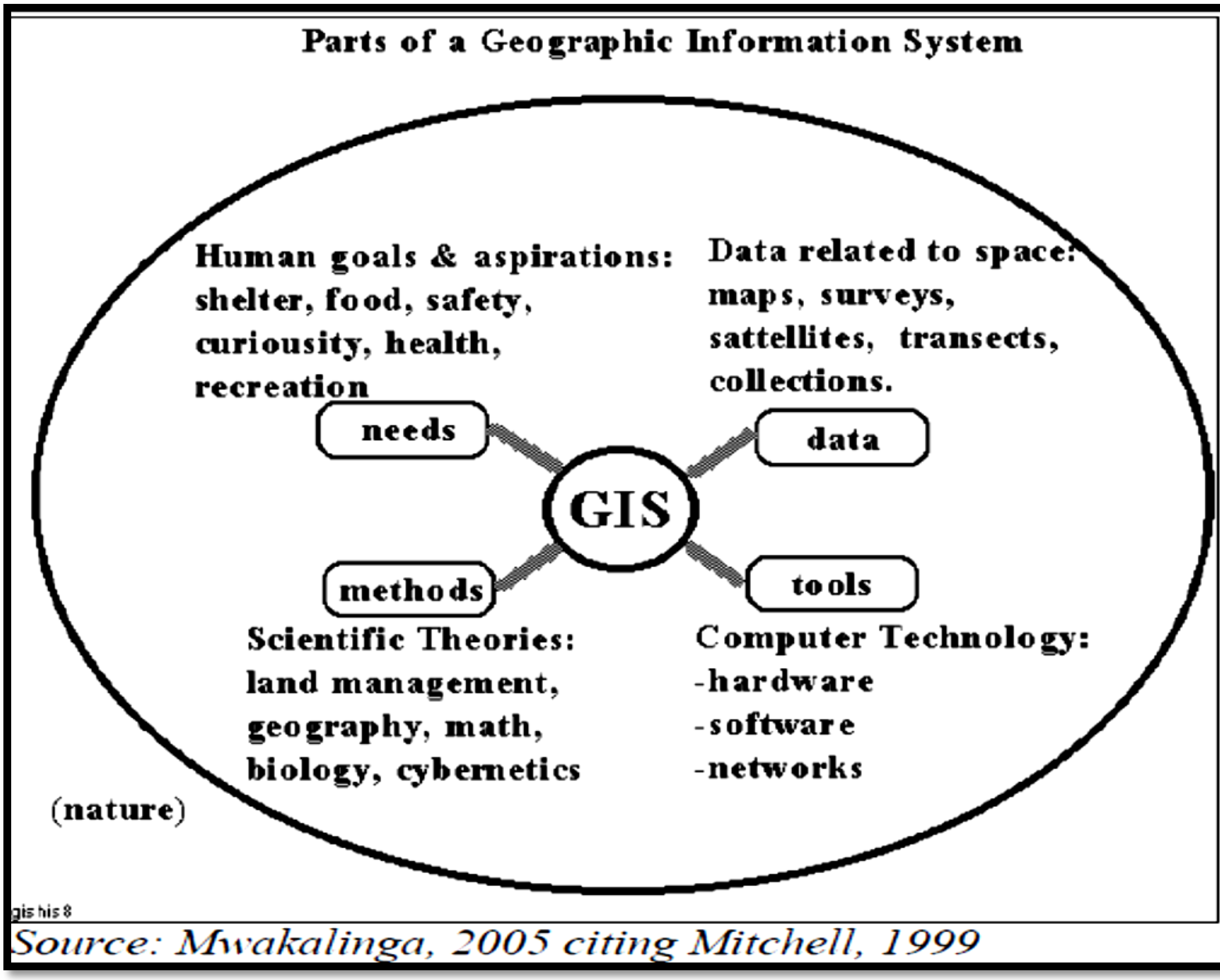
Figure 1: Average Municipal Solid Waste Generation (kg/capita/year) in 25 Countries Grouped According to their Gross National Income (GNI)
Source: (Sandec/Eawag, 2008)

Poor management of solid waste causes hazards to residents (Mahar and Naseem, 2007). The environment becomes vulnerable to infectious diseases because of the open dumpsites. Obnoxious odors are emitted from dumpsites due to gases produced during decomposition and burning of waste. Burning of waste at open dumps is another major issue which significantly contributes to air pollution and causes illness to people living nearby. Dumpsites are a source of airborne chemical pollution due to transportation of gases and chemicals adhering to dust (Wilson and Vincent**,** 2007). Researchers have detected volatile chemicals in the air of homes nearby dumpsites and it is very common that pollutants leach into soil under and near the open dumps (Wrensh, 1990). It may cause the contamination of the ground water as well as surface water bodies (Warith and Sharma, 1998 and Hayder et al.2012). This contamination further extends to vegetables growing in the area and enters the food chain. It was discovered that many diseases including respiratory problems, irritation of the skin, nose, and eyes, gastrointestinal problems, psychological disorders, and allergies are related with these contaminations (MSDS, 2009). According to many researchers emissions of volatile organic compounds can cause a nuisance. Dolk (1997) states that dump sites nearby residential areas are always feeding places for stray dogs and cats that, together with rodents carry diseases to the nearby population where they move. Dumpsites being unhygienic and unsightly are prone to seasonal effects which are extremely harmful for environmental, climatic conditions and human life (Marshal, 1995). Most of the developing countries, like Pakistan and India, use such dumpsites instead of properly managed, well protected and environmentally safe landfills. Lack of proper budget, poor government policies and availability of sufficient resources regarding waste management contribute to such conditions. Therefore, there is considerable public apprehension over the likely bad effect of dumpsites on the health of the residents living nearby. Dumping of solid wastes in open areas without careful planning and administration can present a danger to the environment and the people (Wang et al.2009 and UEPA, 2009). The safety of human life requires cleanliness and a pollution free environment and therefore, waste should be properly managed and disposed of at all costs to limit its effects on the environment (US Environmental Protection Agency, 2006).

In most of the developing countries like Pakistan and India, only 55% of the waste is actually collected and the uncollected waste lies in the empty plots, across the roads, streets, drains, topographic depressions and open sewers within overall urban areas (Das et al., 2002 and Sharholy et al., 2007). SWM is one of the major causes of environmental degradation in Pakistan and lack of capital and poor governance enhances the dilemma. Pakistan is facing serious environmental challenges in MSWM which is threatened by a number of problems like inadequate management, lack of technology and human resources, shortage of collection and transport vehicles and inadequate funding (KOICA-World Bank, 2007). The solid waste management process in Pakistan generally involves primary and secondary collection of waste followed by open dumping of more than 85% of the collected waste (Das et al., 2002 and Batool and Nawaz, 2009). In broad-spectrum, an effective SWMS should consist of collection of waste, transportation and transfer, intermediate treatment, (3R) activities such as reduce - reuse – recycle and disposal (Agarwal et al., 2005). The collection of waste followed by transport and transfer methods used depends solely on the particular site situation; amount of generated waste; manpower; vehicles and road distribution network, and it is further ensured that MSWM disposal is environmentally sustainable, acceptable and safe (). Disposal means final placement of wastes, excess and scrap by using a proper process under official influence with no intention to retrieve. Disposal may be accomplished by abandonment and destruction, therefore, the need arises for a suitable and efficient waste disposal scheme to be incorporated for proper waste management (Hotta, 2007).

In Pakistan, none of its cities has a proper solid waste management system starting from the solid waste collection up to its proper final dumping. Currently, no adequate planning for collection, transportation and disposal or dumping of solid waste in Pakistan has been carried out regardless of the size of the city; therefore the environmental and sanitary conditions in those cities are becoming more serious each year. In Pakistan, urbanization and economic growth have been advanced drastically in recent decades and more people have migrated into urban areas. The expansion of the urban population in present-days seems to be growing at a rate from 3.7% to 7.4% in cities while the overall population growth rate in Pakistan is only 2.8% (JICA, 2005). The amount of solid waste generated in urban Pakistan is more than 55,000 tons per day, and the current average waste collection in cities is only 50% of waste generation (PRB, 2012). It is estimated that, in the next ten years, the population of major cities will double and correspondingly, the waste generation will also double (Mahar et al, 2007). Moreover, none of the municipalities are managing proper landfill sites even in one of the highly populated provinces of Pakistan (Punjab) and only two Lahore and Faisalabad municipalities out of the nine considered in this study own lands where solid waste is being dumped. It is known that uncollected waste is placed in or beside common places or roads and because of the lack of sufficient disposal sites most of the collected waste finds its way into dumping grounds, open plots and rivers. There is no official or scientific dumpsite for the safe disposal of solid waste in most of these areas. Furthermore, dump sites in Pakistan are mostly set a fire in order to lessen the volume of accumulated waste (Rehan et al, 1998). Environmental degradation in Pakistan is not only getting well advanced but it is also getting increasingly worse with the rise in the population, urbanization and industrialization. This concern has led to a growing appreciation that the economic growth, welfare and health of the people of Pakistan are dependent on the enhanced environmental management and safety (ISWA, 1998 & IUCN, 2004).

According to Howard and Irwin (1978), a perfect or model waste disposal site is one which is located reasonably close to the source of the waste, is not situated in a floodplain, has a proper road network and is underlain by geologically strong, stable and competent rock material. It is therefore imperative that many factors must be incorporated into landfill siting and therefore, Geographic Information System (GIS) is an ideal tool for this type of study or research, keeping in view its ability to manage large volumes of spatial data from a wide range of sources (Heywood et al., 1998). Being a computer based system the rationale behind using GIS is that it is one of the most exciting technologies available to geographers today and it provides support for making decisions using spatial data. This rationale can be achieved through organizing, visualizing, combining, querying, or analyzing data. GIS has evolved into essential tools of urban planning and administration, zone detection, business planning, natural resource management, and other areas as shown in Figure 2.



Source: Mwakalinga, 2005 citing Mitchell, 1999

Figure 2: Parts of GIS

The ultimate objective of using a GIS is a useful tool for landfill site selection and route optimization of solid waste management, i.e. from collection to dumping of solid waste (Sumathi *et al*, 2008; Rahman and Hoque, 2006). The use of GIS and RS techniques in environmental assessment gives a low cost and generates digital data (Sumathi *et al*, 2008). Although waste reduction, reuse and recovery are considered important for landfill siting, route optimization is the usual practice (Dipanjan *et al*, 1997). GIS is being used for selection of solid waste dumping sites worldwide; for example, Ghose *et al*. (2006) found that efficient solid waste management is possible by optimizing the routing system for collection and transportation of solid waste. The integration of a GIS with Remote Sensing (RS) has been widely applied and recognized as a powerful or useful tool in monitoring the environment. RS data often comprises a significant part of the data base introduced into a GIS because of its intrinsic digital nature and it can be used as the base over which to overlap other data (Carver, 1991 and Jankowski, 1995). RS data is a useful source of information to obtain different data or information, including recognition of roads, tracks, land use, land cover, topography, slope, aspect, presence of surface water and drainage system. The use of RS data is effective at cutting costs and the time spent on studies.

1.2. Research Aims and their Significance

Solid waste disposal is a serious problem in urban areas because most solid wastes are not dumped in suitable areas. The overall aim of this proposed study is to develop a Decision Support System (DSS) which will be applied to two metropolitan cities i.e. Islamabad and Rawalpindi to find the optimal routes for solid waste disposal and select potential sites for dumping. The main data used for this project will be high resolution satellite images with a spatial resolution of 0.5 m Digital Elevation Model (DEM) with 30 m spatial resolution, Ground Control Point (GCP), collected by Ground Point Survey (GPS) and topographical maps of the study areas. Maps will be prepared by overlay suitability analysis using GIS, RS Techniques and MCE Methods. The capabilities of GIS and RS technology for identification of the suitable solid waste dumping sites will minimize the environmental risk and human health problems.

The main aim of this research is to apply GIS/RS techniques to evaluate communal solid waste depots in Islamabad and Rawalpindi. For this purpose, it aims to:

- Assess the present waste management strategies in two Metropolitan /Mega Cities of Pakistan.

- Analyze the urban land use of two Metropolitan/Mega cities using RS and GIS technology.
- Obtain the pattern of location of communal waste depots and how they can be managed in terms of better urban planning using RS and GIS technology.
- Develop the optimization of routes for economical and time saving purposes.
- Prepare maps of suitable sites for solid waste dumping by overlay and suitability analysis of GIS, RS and MCE.

GIS and RS technology will be used for the effective identification of suitable solid waste dumping sites by digital image analysis techniques using object oriented classification methods for generation of a geo-database to be used in various GIS based analysis. The images will be downloaded from Google images and updated by minimum surveys for the methods to be cost effective both in terms of labor and time. This component links with the technical aspects of the study. The RS will overcome the paucity of geographic data which hinders appropriate supply chain management. One of the added advantages is categorization of the solid waste and suitable categories of solid waste can help municipal administrations to identify areas from where they can obtain raw materials for:

- Electricity generation
- Fertilizer materials, such as compost

The whole effort will minimize the environmental risks and human health problems. The dumping sites will be easily accessible, manageable and more cost effective due to accurate optimization route finding in GIS and RS technology. The decision makers will also be able to use this system for appropriate management of urban resources.

1.3. Research Objectives

Given the background, this study is focused on analyzing the following major research questions:

1. Rout optimization for solid waste collection, its storage and disposal with the help of RS and GIS techniques for two metropolitan cities of Pakistan i.e. Islamabad and Rawalpindi.
2. Analyzing the current dumping sites and finding optimal sites (landfill sites) for solid waste disposal for two metropolitan cities of Pakistan i.e. Islamabad and Rawalpindi.
3. Developing an online DSS as a waste collection and transportation optimization tool for the policy/decision makers.

The dissertation examines these research questions empirically on the macro-level by making use of the aggregated data. The choice of the dissertation topic has been made in order to allow for the possibility of finding results, so as to provide a DSS to the municipal administration for efficient management of the daily operations for solid waste management. Other spatial data can be added in the future to enhance the utility of this research, such as generation of capacity of various residential areas, types of dumping vehicles and an enhanced road network for operations. Therefore, the current research is going to contribute to the environmental and socio-economic aspects in the decision making process for sustainable location of landfill sites and optimal routes for waste collection by the use of GIS and a DSS.

1.4. Potential + Innovative Contribution of the Research Methodology

The proposed study has the following potential and innovative methodological contributions:

1.4.1. Methodological Innovative Strengths

1.4.1.1. Analyzing the Urban Land Use with GIS Technology and Remote Sensing

The methods to be used in the current study for this component are innovative as those do not rely on conventional i.e. (supervised or unsupervised) classification methods. Instead, it is proposed to use the object oriented classification techniques using high resolution satellite imagery. The object-oriented approach will offer new possibilities that will exceed the traditional visual interpretation of aerial photography. It will offer new quantitative analysis for detecting change and implementing GIS with the use of automatic feature extraction. Furthermore, the whole image analysis process will be divided into two principal workflow steps, segmentation and classification. Firstly, the segmentation will be done by grouping the picture elements and building blocks for classification will be created in order to compare different object features like color and size and then will be classified using rule-based expert methods. Rule-based expert methods have played a significant role in modern intelligent systems and their applications in strategic goal setting, planning, design, scheduling, etc. Their application in our research methodology is very innovative and helpful for achieving the desired output.

1.4.1.2. Optimization of Routes

The current study is set out to examine how GIS technology could be used to help reduce overall costs for collection and transportation of residential solid waste for two cities of Pakistan. The current study used Arc-GIS 10.0 Network Analyst (NA) GIS software and its route optimization solvers. This is an innovation of the research methodology in Pakistan as no one has used this methodology earlier for calculating the optimized routes for solid waste management for the two cities in Pakistan. The optimization of routes for the two cities of Pakistan i.e.

Islamabad and Rawalpindi would be done by using the road infrastructure and urban land use map through Network Analysis.

1.4.1.3. Web-Based DSS

The DSS which is being produced is capable of performing various analyses on the geospatial data regarding solid waste management.

1.4.2. Potential Contributions as Organizational Benefits

1.4.2.1. Identification of Suitable Sites for Solid Waste Dumping

This area is innovative in the way that it combines the nature of solid waste being spatially produced, land characteristics, and land use to identify optimal dumping sites. The benefits would be utilization of waste for various purposes ranging from compost to electricity generation. Thus the proposed study does not only rely to produce optimal routes but also to manage the solid waste being produced.

1.4.2.2. GIS Technology as a Solid Waste Collection Optimization Tool

In the current study, GIS technology is used for the development of a methodology for the route optimization for two cities in Pakistan and it is a new methodology ever used in Pakistan for solid waste management route optimization. The proposed methodology is chosen to find the optimal route which is more efficient in terms of fuel consumed, distance covered, and time used, and it will offer savings for gas emissions and fuel consumption. Therefore, this study will analyze GIS technology as a waste collection optimization tool which is capable of guiding decision making for the decision makers. GIS is a tool that can provide both spatial and non-spatial information for improved urban planning and management, natural resource management and business planning. This will in turn improve the service efficiency. In addition to this, GIS and RS techniques are proficient, inexpensive and low cost tools for the present study and they help to select optimal routes and appropriate dumping sites which will facilitate the decision making process. Therefore, this will lead to contribute to the protection of the environment, public health safety and reduce obligations to future generations by limiting the production of open dumps.

1.4.2.3. Identification of City Routes for General Services

The two cities proposed for the dissertation provide various services to inhabitants and hence GIS technology can be used to help improve performance and reduce costs. This current study can be used as a guideline for configuring route optimization for many services that are within the two cities such as school bus, delivery, public transportation routes, street sweeping, or any other services within the cities which have multiple stops along the network.

1.4.2.4. GIS- As a Decision Support System (DSS)

The web based GIS system enables the various stake holders who do not have capabilities to use GIS to perform various analyses by using interactive graphic user interface. The user would be able to perform buffer analysis, calculate distance, manage vehicles, and many other geospatial operations. This gives the user a better understanding of the terms, procedures, and techniques used throughout the route planning and optimization and the results from the GIS analysis aid the decision maker on where and to what level the problem is. GIS application will be used as a decision support tool by municipal authorities for the efficient management in waste collection, transport, load balancing within vehicles, managing fuel consumption, and generating work plans for the workers and fleet vehicles. In addition to this, municipal workers, sanitation officers, government bodies and fleet vehicle workers may find interest in the overall concept and may reap the benefits of the current study.

1.5. Constitution of the Study

This study is structured into five chapters. Chapter 2 provides background and review of the solid waste generation and its management in different countries of the world. It presents a brief overview of literature on the subject and it highlights general factors affecting the rise of solid waste management. The chapter further discusses extensively the existing studies in the area of solid waste management and how GIS has been used as a DSS in the previous literature. The chapter reviews the current use of GIS in developed and developing countries of the world and gives examples of the potential usefulness and application of GIS techniques for developing effective waste management strategies and plans and in enhancing the waste management process. Furthermore, the chapter clearly focuses on the importance and role of GIS for managing the solid waste in an effective and proficient manner.

Chapter 3 empirically discusses the methodology applied to carry out this research. It also explains the choice of the research method – Geographic Information Systems (GIS) and Remote Sensing techniques. The sources of data and materials are also explained in chapter 3.

Chapter 4 empirically discusses the methodology applied to carry out this research, both the study analysis of different waste management problems and their analysis and the way GIS has been used to deal with waste management issues in different situations. It presents the methodological framework that is used to address the research questions as well as a description of the data and provides solutions to some of the research questions. This chapter will further explore the nature and basic principles of GIS systems, including components, analysis and applications in the context of SWM.

Chapter 5 aims to analyze the data with the help of GIS and RS techniques thus providing a comprehensive picture of solid waste management in Pakistan. Furthermore, it will present the development of a Wed-Based DSS which will help decision-makers to search for cost-effective alternatives. Moreover, Chapter 5 reviews the use of GIS in relation to waste management and offers a number of potential applications for effective waste management strategies.

Finally, Chapter 5 sets out the main conclusions/summary and presents the limitations. It also highlights recommendations for future research.

2. BACKGROUND & LITERATURE REVIEW

The environment is likely heading towards risk of a serious health and environmental problem because of poor waste disposal management. In today's world waste is not properly dumped and it is causing severe environmental issues and health related problems. If this situation is not handled in a suitable way within time it will lead to severe consequences on a global level. The awareness regarding waste management has increased in many countries of the world and most countries have adopted new technologies such as GIS, which have contributed a lot to the SWM in a very short period of time. The waste management societies and municipalities have a dire need to cut operational costs of their fleet vehicles and to look for cost effective measures. Therefore, cost sensitive decisions makers and planners intend to use GIS technology in order to cut costs and keep their budgets level. The use of GIS technology aids decision makers to manipulate data in order to generate options and to take wise cost efficient decisions. "By assessing the location of something and then combining it with what's around it, you're able to make a decision you were never able to make before," said Erich Seamon, GIS manager for San Francisco (Wired News Publication website, 2004).

According to Jack Dangermond, ESRI, "The application of GIS is limited only by the imagination of those that use it". Hence, this chapter reviews the past literature on how municipalities can optimize the route for collection and disposal of municipal solid waste (MSW); identification of suitable landfill site; the development of DSS in solid waste management and other related fields and what current technologies are available and how they are employed.

2.1. Literature Review

Consumption of resources and generation of waste are inbuilt in the living process of a human being (Kumar, 2002). Human activities alter all waste composition conditions and pose a challenge in waste management (Wang et al. 2009). Ineffectively managed waste creates threats of contagious diseases, air pollution and contamination of groundwater besides space constraints, odor and problems (Kumar 2002 and UNDP, 2004). The situation is worse in municipal waste management where waste variety ranges from biodegradable organic wastes to toxic, infectious and perilous wastes generated from various sources (Tchobanoglous, 1993). Solid wastes are usually classified with respect to their source of origin. Table 1 shows the source and types of waste that are generated in today's era.

Table 1: Sources and Types of Waste

Source	Types of Waste
Residential (Single and multi-family homes)	Food wastes, rubbish, ashes, special wastes, yard trimmings, cans and bottles, clothing, newspaper etc.
Commercial (Office buildings, restaurants, wholesale establishments and retail.	Food wastes, rubbish, office papers, yard trimmings, paper napkins, ashes, disposable tableware, demolition and construction wastes, special wastes, etc.
Institutional (Prisons, schools, libraries, hospitals)	Food wastes and rubbish, office paper, yard trimmings, classroom wastes and cafeteria trash can waste.
Industrial (packaging and administrative wastes)	Food wastes, rubbish, demolition and construction wastes, special wastes, hazardous wastes and wood pallets.
Treatment plant sites	Treatment plant wastes (left over sludge).
Agricultural	Special food wastes, rubbish, agricultural wastes and hazardous wastes.

Source: Tchobanoglous, 1993; UNEP 2003 & 2004

Poor waste management contributes to poor environmental and hygienic conditions that interfere with health and life quality for urban dwellers (EPA, 2010). For example, over the years efficient management of solid waste has been a major crisis in the city of Kampala and throughout Uganda. This is because the location of a landfill is a major determinant of the extent to which the landfill will pose an environmental risk (EPA, 1998). Municipal solid waste management is a problem that is experienced by almost all countries of the world (UNEP, 2001). It is an issue mostly witnessed by urbanized people due to a high surge in the population growth rate and increased per capita income, thus posing a threat to environmental quality and human life (UNEP, 2005 and Javaheri, 2006).

Over last ten years, experimental testing and field pilot research have been carried out to develop and improve landfill techniques and manage the negative effects of landfill sites on the environment (Siddiqui et.al 2001; Kontos et.al 2003 and Kao and Lin, 1996). There are many advantages of enhancing solid waste degradation like minimizing the time period of leachate treatment, growing methane production and accelerating the subsidence of waste. (Warith, 1999 & Barlaz, 1990). Currently Uganda's urban areas are characterized by "careless and indiscriminate open waste-space-dumping" (EPA, 1998). The most common air pollution resulting from burning dumps was highly visible clouds of particulate matter and incompletely burned gases, as well as the smell of smoldering garbage (EPA, 2010a).

Sanitary landfills started to appear in the 1930s with organized deposition, compaction, and burial of refuse, but open dumps still persisted until the 1960s and 1970s (EPA, 2010b). Landfills are the largest anthropogenic source of methane and municipal solid waste landfills, accounting for approximately 93 percent of total landfill emissions (EPA, 1998). A municipal solid waste landfill is a discrete area of land or an excavation that receives household waste and that is not a land application unit, surface impoundment, injection well, or waste pile, as those terms are defined in law (Chang et.al 2008 and UNEP, 2003). Household waste includes any solid waste, including garbage, trash, and septic tank waste (EPA, 1993).

2.1.1. Unsanitary Landfill or Dumping

In developing countries, MSW is collected and mostly disposed off in open areas or in unsanitary landfills (UNEP, 2002). This is in addition to the irregular collection of wastes and its transportation in many cities, which leaves MSW on the streets. (Kreith, 1994). Unsanitary landfilling pollutes and contaminates ground and surface waters, emits green house gases, organic aerosols and pollutes the air (Wang et al.2009). Pests feeding on improperly disposed of solid waste are a nuisance which provides a breeding ground for disease causing organisms. Leachate, a liquid which is a byproduct of moisture, rain, snow and dew, percolates through the waste in a landfill or dump (Magrinho et al. 2006). While migrating through the waste, the liquid dissolves salts, picks up organic constituents, and leaches heavy metals, such as iron, mercury, lead, and zinc from cans, batteries, paints, pesticides, cleaning fluids, and inks. The organic strength of landfill leachate can be 20 to 100 times the potency of raw sewage (Jefferis, 1993 and Vienna, 2006). Indiscriminate dumping of waste and leachate from landfills contaminates land resources, surface and groundwater supplies and the environment (Allen, 2001). It also blocks sewers and drains which leads to floods. Landfills can be of different shapes and sizes which can impact the environment in many different ways (Barrett and Lawler, 1995). Some dump sites may be as small as a few barrels of waste oil, while the largest of industrial waste landfills may occupy huge amount of waste oil (Hayder, 2012). For example, Hong Kong has a population close to 6 million and it generates huge quantities of waste very day. Millions of tons of waste are added to landfill every year and this has been the foremost source of impact on the surroundings (Hong Kong Environment Department, 1993).

2.1.2. Landfill Gases

Methane (CH4) is the principal gas formed from the decomposition of organic solid waste (about 50% by volume) with carbon dioxide, nitrogen, oxygen, and non-methane organic compounds making up the remainder (EPA, 1993 & Nas et al 2010). For instance, a total of 13 potential landfill sites were recognized in and around the Subic Bay Freeport Zone. In order to determine the suitability of each site as a landfill, the Project team evolved a criteria of site selection through the team's personal experience in landfill siting, “Sanitary Landfill Design and citing Criteria” developed by Sandra Cointreau-Levine provided in the Terms Of Reference (TOR) document, the “Landfill Site Identification and Screening Criteria for Local Governments” by DENR, and from the Handbook of Landfill Operations by Neal Bolton (P.E, 1995). At times the main objective seems to be to get rid of solid waste in strategic sites, though this has not been effectively done as there are many illegal dumpsites. It is clear that there is no adequate plan for proper waste collection and disposal of wastes (Lasisi, 2007).

2.1.3. Site Selection Criteria for the Landfills

Several countries (like Australia, Malaysia, Nigeria, Philippines, Uganda, and some states of the United States such as North Dakota) have set up rules for selecting suitable sites for sanitary landfills (EPA, 2010a & 2010b). These guidelines act as the primary mechanism used to protect the host community and the environment at large. There are some important factors that several researchers have discussed in their studies and these are:

- The location must comply with the requirements of the existing governmental regulations and at the same time must minimize economic, environmental, health, and social costs (Siddiqui, 1996 and Johnson et.al 2002). In assessing a site as a possible location for solid waste land-filling, many factors should be considered (Savage, 1998).
- No Highway, River, Lake or Pond should be constructed with in 200 m of a landfill site. No landfill should be constructed within wetlands (Despotakis, 2007 and Nas et al.2010). Maps may be available for some wetlands, but in many cases such maps are absent or are incorrect (Sumathi, et al.2008 & Savage 1998).

- Research has shown that as the distance from residential areas increases, the issues of public opposition to siting of waste disposal facilities diminishes (Diaz et al. 1997; Baban and Flannagan, 1998 and Nast et al, 2010).
- Weather is one of the environmental components that may influence the frequency and intensity of odor (Magrinho, 2006).
- The wind orientation and pattern is not known to be subject to any legal restrictions but based on the premise that a landfill site should not be in the direction of the wind (Kontos et al. 2002 and Lunkapis, 2003).
- The road network in the city consists of major roads, minor roads and others. The waste disposal sites should not be too close to road networks (Lunkapis, 2003 and Lasaridi, 2009).

An example of site selection comes from Kenya, where the use of open dumps for MSW makes environmental pollution highly probable. Both surface water and groundwater remain vulnerable to MSW pollution because disposal dumps were chosen for convenience rather than based on environmental safety considerations (Blight, 1995 and Henry, 2006). Studies of the odor from landfill operation have been carried out in many developed countries such as USA, Europe, Japan and Korea (United Nations Environment Program, 2005). Most of the research is focused on approaches to the measurement of odor as exemplified by the studies of Nicolas (2006), Robbat (1997) and Capelli, (2008). For proper identification and selection of appropriate sites for landfills; systematic procedures need to be adopted and followed (Hehn et al. 2000). Wrong siting of a landfill many result in environmental degradation followed by public opposition (Allen et.al 2001).

2.2. Role of GIS

Recognition of the of GIS in landfill site selection and route optimization studies clearly seen in the previous literature as GIS is capable to store, retrieve and analyze a large amount of data (Allen et.al 2001). GIS technology is playing a significant role in the field of siting of waste disposal sites (Sumathi et al. 2008). Advantages of applying a GIS in the landfill-siting process include selection of an objective zone exclusion process according to the set of provided screening criteria (Sumathi, 2007 & Malczewski, 2004). Analysis for selection of a suitable site can be improved by using GIS technology (Zamorano et al.2008). GIS technology is an apt tool for site selection because it has the capability to manage large amounts of spatial data that come from various sources (Malczewski, 1999 and Bhushan and Rai, 2004). Large amounts of spatial data can be processed using GIS techniques, potentially saving time that would normally be spent during selection of an appropriate site (Daneshvar, 2005). GIS technology has emerged as a very important tool for land use suitability analysis in the recent past (Sener et al 2006). GIS can recognize, correlate and analyze the spatial relationship between mapped phenomena, thereby enabling policy-makers to link disparate sources of information, perform sophisticated analysis, visualize trends, project outcomes and strategize long-term planning goals (Malczewski, 2004 and Sener et al.2006).

Furthermore, the use of GIS technology provides researchers with network-based spatial analysis and assists them in modeling practical network situations such as height restrictions, turn restrictions, one-way roads, speed limit, and different travel speeds based on the local traffic for route optimization studies (ESRI, 1995 and Heywood et al, 1988). The use of GIS has been very successful in a wide range of applications such as urban planning and management; transportation; geology; zone detection; health sciences; environmental modeling and engineering etc. (Higgs, 2006 and Sener et al.2006) The study of waste management with respect to landfill site selection and optimizing of routes for waste collection and transportation has remained a favored field of GIS applications from the introduction of the technology.

2.3. Geographic Information System

2.3.1. History of GIS

GIS is one of the leading information technologies that have changed the ways for scientists and planners to carry out research and add to society (Higgs, 2006). GIS have had a significant impact on research methods and techniques specific to certain disciplines along with in general ways in which researchers communicate (Foote and Lynch, 2000). These methods/systems allow people to examine information very quickly as compared to traditional research techniques. The real world comprises many objects and events which are located at different places and these events or objects don't occur in space alone and there are many other objects with them which are mutually related and influence each other directly or indirectly (Walter, 1993). Therefore, it is very important to understand both the location and spatial relationship between these particular objects in order to solve the problems which occur in the world (Alpin et.al 2001). In the real world, we need to know information both about the object and also about its position/location and these types of data is basically referred to as spatial data and they can therefore be maintained by GIS (Yaakup et al. 2005and Alpin et.al 2001).

The decision-making process has become very quantitative, and the use of mathematical models has become very common since 1960's and hence, the application of various information technologies in the field of geography started several years ago and will continue to grow and expand in the future as well (Timothy, 1997; UNEP, 2003 and Kontos et al.2003). Methods of statistical modeling were developed and first RS data was made possible in 1970s (Batty et al.

1997). In addition to this numerous sophisticated mathematical models were also developed in the 1970s (Chrisman N., et al, 1997). The world was fortunate when the first commercial available software for GIS was introduced in the late 1970s by Ian McHarg (1920-1981) the “Father of GIS”, the same time which incited many experiments and the first best outcome of these experiments was the development of the first microcomputers in the early 1908s (Coppock J.T. & Rhind D.W., 1991). In the context of these advancements, geographic information emerged as an integrating and powerful technology because it let the researchers and geographers incorporate their methods and information in various ways that supported traditional forms of geographic analysis. For instance, map overlay analysis and all types of analysis and modeling that were not possible with manual methods. GIS has made it possible for researchers to map, model, query, and analyze massive amounts of data together within a single database (Lopez et al.2008). Therefore, this term GIS reinforces this movement from maps as images to mapped data (Steinitz, 1993 and Timothy, 1997). The advancements and innovations made in many different disciplines such as Geography, Cartography, Remote Sensing, Geodesy, Civil Engineering, Statistics, Computer Science, Operations Research, Artificial Intelligence, Demography, and many other branches of the social sciences, natural sciences, and engineering have all contributed to the development of GIS (Tomlinson R.F., 1987).

2.3.2. Mechanism of GIS

GIS can be defined by considering the component parts of the term separately i.e. Geographic in GIS refers mainly to spatial features; Information in GIS represents the large volumes of data which are dealt with, and the term System is used to represent the system approach taken by GIS as a whole (Geo Data Institute, 1993 and UNEP, 2004). In simple words, A Geographic Information System comprises computer software and hardware; data and personnel and these three components make it possible to enter, manipulate, analyze or evaluate and present information that is attached to a location/position on the surface of the earth (Armstrong, 2004).This is shown in Figure 3.

Figure 3: A Working GIS Integrates Five Key Components

GIS operates on hardware and software. The software runs on a wide range of hardware types and GIS software are very friendly by proving all the required features and functions to input and store the query tools in order to display the spatial information in the form of maps and reports (G. J. Lunkapis., 2004). The computer has provided a way for the efficient handling of huge data followed by effective spatial analysis capabilities (S. Upasna & M. S. Natwat., 2003).

The second component of the GIS, which is very important and costly, is data and it has two types of digital formats in GIS i.e. vector and raster. Spatial data/geographic data consist of spatial/geographic features and their attribute information is entered in GIS with the help of the digitizing technique (Jovicic, et al., 2011). The Vector data are in the form of x and y coordinates and they are classified into three geographic features such as points, lines and polygons. Vector data format is ideally suited to provide accurate representation of an object and it incorporates topology and other spatial relationships between the individual entities representing linked networks such as road systems (ESRI, 2006 ArcGIS). Map digitization and data collected via GPS are examples of the vector data format. In contrary, raster data is an array of grid cells that cover the surface of the earth. Rater data is ideal for representing traditional geographic features that carry continuously over space such as elevation, slope or precipitation (S. Upasna & M. S. Natwat., 2003). While capturing large datasets such as polygons and topographic curves, the process of digitization becomes time consuming and dull. Therefore, users can obtain much of the GIS data easily from government agencies and commercial operations that is mostly available for free or for purchase from the data provider (Ogra, A., 2003).

Over the past several years, computers have become very accessible and affordable for schools, companies and organizations to use and the real power of GIS comes from the people who use it (Dangermond, 1991 and Chang, 2007). In today's world, GIS is used as a tool in a variety of fields and is making it easy for people to perform their jobs efficiently (Chang, 2007). For instance, biologists protect their plants and animals by making use of GIS, instructors teach lessons such as geography and engineering with the help of GIS, the police use GIS to solve crimes, Emergency 911 operators use GIS to send emergency personnel to a person in distress etc (UNEP, 2002 & 2003). The number of GIS users in the 21st century continues to grow and from here we can see that no one can deny the importance of GIS this current world and furthermore, the user being the key to successful GIS applications (Modak, 1996).

2.3.3. Definitions of the Term

Different researchers have defined GIS in different contexts by emphasizing various aspects of GIS. Conversely, some of the authors missed the true ability of GIS to generate information and be a powerful tool for decision makers. The most well-known definitions are the following:

Star and Estes (1990) is definition of GIS in their book Geographic Information Systems: An Introduction (Englewood Cliffs, NJ: Prentice-Hall, 1990), page 2-3:

> "A geographic information system (GIS) is an information system that is designed to work with data referenced by spatial or geographic coordinates. In other words, a GIS is both a database system with specific capabilities for spatially-reference data, as well [as] a set of operations for working with data . . . In a sense, a GIS may be thought of as a higher-order map."

A definition quoted in Huxhold’s (1991) in his Introduction to Urban Geographic Information Systems. (New York: Oxford University Press), page 27, from some GIS/LIS '88 proceedings is the most complete and traditional definition of GIS starting:

> “The purpose of a traditional GIS is first and foremost spatial analysis. Therefore, capabilities may have limited data capture and cartographic output. Capabilities of analyses typically support decision making for specific projects and/or limited geographic areas. The map data-base characteristics (accuracy, continuity, completeness, etc) are typically appropriate for small-scale map output. Vector and raster data interfaces may be available. However, topology is usually the sole underlying data structure for spatial analyses."

Tomlin's (1990) definition taken from Geographic Information Systems and Cartographic Modeling (Englewood Cliffs, NJ: Prentice-Hall), page xi states that:

"A geographic information system is a facility for preparing, presenting, and interpreting facts that pertain to the surface of the earth. This is a broad definition . . . a considerably narrower definition, however, is more often employed. In common parlance, a geographic information system or GIS is a configuration of computer hardware and software specifically designed for the acquisition, maintenance, and use of cartographic data."

Environmental Research Institute (1990) page 1.2 uses the following definition in Understanding GIS: The ARC/INFO Method:

A GIS is "an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information."

Monroe County (2008) defines GIS as a mapping tool for mapping visualization and geographic analysis.

"Geographic Information Systems are computer based tools for mapping and analyzing features and events on earth. GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps" (Monroe County, 2008).

2.3.4. GIS Vs Contemporary Computer Techniques

Geographic Information Systems are usually computer-based systems with an overall aim to preserve and make use of spatial data's inherent characteristics by handling both components of spatial data i.e. the physical position in space and the set of characteristics associated with that position/location (Rhind et al. 1991 and Maguire 1991). The great interest in GIS would be in its technical basis for implementation of integration methodologies and as Muller 1985 states: "The application of GIS, if successful will upgrade the image of geography by demonstrating both the advantages of a multidisciplinary, holistic approach and the irrelevance of clear delimitations between geography and other connected disciplines".

In contrast to GIS, there are many other computer programs which can use spatial data such as Statistics Packages, Computer-Aided Design or Computer-Assisted Drafting (CAD) and Database Management Systems (DBMS) but they are typically not able to combine spatial and attribute information together (Dangermond 1991; Maguire 1991 and Eastman 1992). Furthermore, they do not comprise the added ability to perform spatial operations, but GIS enfolds an additional ability to perform spatial operations (Cowen, 1988 and Chang, 2007).

CAD systems (Computer-Aided Design or Computer-Assisted Drafting) replace manual drafting with an automated process and are a combination of hardware and software for input, display and visualization of spatial data. These systems are used mainly by architects and engineers and were proposed for drafting and design (Bozdoc, 2003). They handle spatial/geographic data as graphics rather than as information and CAD data normally covers small geographic area as compared to GIS. Furthermore, high-quality maps can be produced with CAD but they are competitive to produce complex spatial analyses and they lack coordinate systems (Cowen, 1988 and Bozdoc, 2003). Overall, GIS and CAD have similar data content but have different fundamental philosophies such as CAD perceiving the world as a cube whereas GIS perceives the world as a sphere (Foote and Lynch, 2000). Database Management Systems (DBMS) consist of methods for the representation of data in digital form followed by measures for system design and to handle great volumes of data, ensuring that data is updated, organized and remains easily accessible whereas the two elements of spatial features are handled separately in GIS (Beynon, 2004 and Foote &Lynch, 2000). Furthermore, attribute information is stored in a database and the spatial relationships are represented graphically in GIS (ESRI, 2006 and Chang, 2007). Abler (1987) illustrated the potential and importance of GIS technology and predicted its future usage in geographical analysis or study in the world: “GIS technology is to geographical analysis what the microscope, the telescope, and computers have been to other sciences.... (It) could therefore be the catalyst needed to dissolve the regional-systematic and human- physical dichotomies that have long plagued geography and other disciplines which use spatial information,” GIS thus needs the ability to relate the attribute information to the spatial locality (Maguire 1991). Table 2 below gives a brief overall reflection of GIS versus other contemporary computer technologies.

Table 2: GIS Vs DBMS & CAD

Database Management Systems	DBMSs can store and manage different types of data including geographic data. On the other hand, DBMs do not offer spatial analysis and visualization tools as GIS offers.
CAD Systems	CAD systems are developed to create engineering infrastructure plans. GIS systems have better utility for the management of big geographic databases and offer wide spatial analysis capacity.

Parker (1988) suggested that “GIS should be viewed as a technology, not simply as a computer system”. Therefore, GIS technology filled the gap left by CAD, DBMS and other contemporary computer systems.

2.3.5. GIS - An Innovative Technology

GIS grew out of computer technology because advanced technological development such as hardware and software development gave birth to GIS and it is a spatial information science which has maintained various links with the previous geography science and is developing very quickly (ESRI, 2006). GIS can likely link other sciences such as social sciences with geography easily and one can employ GIS with the current technologies like computer science and RS (Malczewski, 2004). This usage of GIS with other technologies has immensely helped geography all over the world to cross over in other fields e.g. resource management, anthropology land use planning, ecology, etc (Chang, 2007). Several years ago, the insinuation of linking a wide range of sciences dealing with spatial information was expressed and the most persuasive example of this is a remarkable book by McHarg (1969) named "Design with Nature". GIS have facilitated the vision of McHarg to become a reality and has the potential to integrate and incorporate large quantities of information regarding the environment and offers a powerful range of analytical tools to explore them. GIS enjoys an immense potential as a research and decision making technological tool because it has the capability to split information in layers and then join it with other layers of information (Katpatal and Rao, 2010).

The field of GIS has incessantly provided innovations and technologies that drastically changed the world. Technological innovation occupies a significant position in the field of GIS discipline development and is closely associated with the present information technological development (Khan and Samadder, 2014). Since the development of GIS in the 1960s, it has emerged as a very useful technology and it has a wide range of applications across many different sectors benefiting different organizations in almost every industry (Timothy, 1997). GIS technology serves as a backbone to support traditional geographically associated fields such planning of urban areas, mapping of technology and cartography (Malczewski, 2004). There is an escalating awareness of the economic and strategic value of GIS for a wide range of other sectors and the development of GIS has been more evolutionary. GIS serves as a possible tool to improve local planning by visualizing the probable impacts of a variety of transformations such as climate change around the globe, economic growth per annum and regional information such as climatic zones or population development in different regions of the world (Malczewski, 2004 and Singh & Ohri, 2009). The use of GIS technology in present intelligence system and defense has became incredible as increasingly spatial information is required whether it is a command decision to attack an enemy or a strategic intelligence and acumen decision to determine terrorist intention. Today, many homeland/national securities in USA use ESRI GIS to support the tasks and responsibilities for national security (Mei-Po and Jiyeong, 2005).

GIS is persistently used in the public health sector for epidemiological studies and the public health sector was an early adopter of GIS (Hanchette, C.L. (2003). With the help of GIS, the sources of diseases are easily tracked and the health sector professionals can promptly respond to prevent disease from spreading with the help of targeting and identification of the population at risk (Hanchette, 2003 and UN, 2004). In addition to the public health sector, the use of GIS in the private health sector has grown significantly in the last fifteen years (Hanchette, 2003). Here we will consider an example of one of the foremost medical research centers in the world i.e., Loma Linda University Medical Center which employs a GIS-based system titled “Patient Location and Care Environment System” (PLACES) to see the physical bed location of each patient and to get demographic and clinical information (Raper, 2000 and Lang, 2000). Public and private health care companies make use of GIS technology in order to improve their management practices followed by enhanced customer service. For example, with the help of dynamic maps one can easily get the information regarding the location of services at Web and Arc Logistics Route adds to better health services delivered to the patients at home by scheduling and optimizing routes between patients (Lang, 2000 and ESRI, 2006).

In addition to this, GIS is extensively used for well planning in the petroleum sector because of the increase in important resources such as coal-bed methane and shale gas and oil. The unique spatial analytics of GIS can be employed to optimize the drilling patterns in order to calculate the best most drilling configuration (Ryan Carlyle, 2014). Another promising use of GIS is in sensor technology where it helps to gather high resolution images on demand across a particular location or field which is used for surveying. This aspect of GIS is very helpful to cut the costs for capturing expensive satellite data and hence it allows companies to identify, examine and manage sites on a regular basis (Winther, 2014). The other important and notable areas of the petroleum sector where GIS technology is effectively used are data index maps, block ranking, land management, environmental monitoring, pipeline routing, vessel tracking, emergency response and pipeline monitoring (ESRI, 2006). All major oil companies in the world use GIS technology to manage their location-based information. The business world is also employing GIS in advertising, marketing, sales and the logistics of where to locate businesses (ESRI, 1995). Furthermore, the importance and role of GIS cannot be denied in water resource management, crowd management, location based services and governments, educators, scientists, conservation organizations, natural resource groups and utilities (Chang, 2007 and ESRI, 2012). The world demands particular requirements for the use of GIS technology across a variety of sectors because the techniques and concepts in GIS are very important for the creation of frameworks that ensures all entities in the area of interest are properly handled (Ming-Hsiang, 2004). This becomes significant and of utmost importance because proper understanding is achieved when the information system is supportive enough for analysis across numerous sources of information (Chang, 2007). Therefore, GIS has gained significant attention from most of the research areas in the world and they are supporting it in return through of various geospatial applications (Tomlison, 1990 and Yaakup et al. 2005).

GIS has helped several industrial sectors and consumer service enterprises to manage their resources and personnel in an effective way. The use of GIS for different industrial, agricultural, ecological, research and planning sectors in the world will continue to grow and its role will always remain significant and indispensable because of its ability to integrate a broad range of data starting from legacy systems to image data and to make complex data very easy to comprehend (ESRI, 2004 & 2006 and Chang, 2007). GIS has given an immense business gain to the companies where it has been used.

2.4. Importance of GIS in Solid Waste Management Systems and Route Optimization

GIS is a part of the Geo information technology (GIT) and Management Information Systems (MIS) and has been adopted in solid waste management in many countries of the world. The adoption of GIS is very common among developed countries such as USA and the UK. and other developing countries such as China, Ghana, South Africa, Mexico, Kenya, Malaysia (NEERI, 1994 and UN, 2000). A GIS is an information system for capturing, storing, analyzing, managing and presenting data which is spatially referenced. It consists of a geo-referenced spatial database and it also includes all required parameters for MSWM. These parameters involve city maps, collection points, transfer stations, collection and transportation road networks, location and capacity of disposal sites (Foote & Lynch, 2000 and Nas et al. 2010). MapInfo software has the capability to input and store the geographic (coordinate) and tabular (attribute) data, to find specific features based on location or attribute value, to answer questions regarding the interaction between multiple datasets, to visualize geographic features using a variety of symbols and to display the results in a variety of formats, such as maps and graphs (ESRI, 2006). In addition, it can be used to display, edit, create and analyze GIS data and to browse, find and present geographic information (Tomlin, 1990 & Environmental Research Institute, 1990).

Recently, the use of GIS technology as a tool for data collection, data analysis and result display has increased tremendously in research (Star and Estes, 1990). Ghose et al. (2006) used a GIS to create an optimal routing model to establish minimum cost/distance efficient collection paths for waste collection and transport. Wilson et al. (2007) used GIS to estimate the delay time of waste transfer stations. GIS applications have been used to analyze existing maps and data was generated to give efficient information concerning static and dynamic parameters of MSWM problems (Sharholy et al. 2005). Development of a master plan for waste management is a difficult job for planners. Optimization of the operational efficiency for collection, transport and transfer of solid waste becomes a significant element of an effective MSWM system (Sahoo, et al. 2005). For example, in the study by J. Energy Env, (2009), an assessment to estimate the operational efficiency of waste collection, transport and transfer was conducted and an MSWM model applying GIS as a decision support tool for municipal authorities to efficiently manage waste collection, waste transport, waste transfer, load balancing within vehicles, fuel consumption, and generation of work schedule was proposed (Chang et al. 1997 and Keenan, 2008).

Assortment and haulage of solid waste frequently accounts for a considerable portion of the total budget that include labor costs (Dogan and Duleyman, 2003; Ghose et al., 2006). Fuel expenditure plays a dominant role in the costs of MSWMS because of the emission of a significant level of undesirable atmospheric pollutant by vehicles, which include carbon dioxide (CO2) and nitrogen oxide (NO), both of which are of major concern due to their contribution to the greenhouse effect and to acid rain (EPA, 2010a). MSWMS provide a public service and therefore, return investment and profit margins are not major priorities. However, because waste management is a costly activity, it is vital to justify the investment in terms of environmental, technological and economic feasibility in order to achieve the required level of efficiency (Morrissey, 2004 & Tavares, 2009). Therefore, optimization of waste management is a problem that needs attention in the management of routing networks for waste collection and transportation (Sahoo et al, 2005). Several studies have optimized particular (non-routing) operations related to waste management. For instance, Magrinho and Semiao, (2007) and (2008) have studied the effects of both the screening method and humidity content on recycling rates. They have also explored the possibility of increasing recycling rates for packaging materials while still keeping open the option of incinerating residual waste. Furthermore Baetz (1990) and Bhat (1996) have proposed the idea of adapting simulation modeling for best possible solid waste management planning. Clark and Gillean (1974) have used analytical approaches to achieve the same desired target and several other authors such as Cordeau et al. (2002) and Simonetto and Borenstein (2007) have investigated route optimization and used operation research methodologies to build up computer tools for vehicle routing optimization.

Morrissey and Browne (2004) reviewed the first models that dealt with specific aspects of route optimization as applied to waste assortment and shipping. Tung and Pinnoi, (2000) and Angelleli and Speranza (2002) performed optimization of vehicle routing for waste collection using operation research methodologies. In addition to this, Badran and El-Haggar (2006) used operational research to develop a computer system based on a fusion of quantitative techniques, such as simulation of discrete events and heuristics for vehicle allocation. Everett and Riley (1997) presented a model to work out time taken during waste collection. It operated on the basis of total distance travelled and also took into account shut down times. Their work led to numerous economic analyses. Sonesson (2000) extended the aforementioned research and also estimated the energy and fuel consumed during haulage and waste compaction. It is now overwhelmingly accepted in this arena that effective decision making requires the execution of vehicle routing techniques. Since routing models make extensive use of spatial data it is possible to take advantage of new technologies such as GIS (Keenan, 2008).

GIS is able to provide effective handling, display and manipulation of both geographic and spatial information, as reported by Keenan, (1998) and Armstrong and Khan, (2004). In related work, Ghose et al. (2006) proposed a model for MSW collection that includes distribution of collection bins, load balancing of vehicles and generation of optimal routing based on GIS. The generation of route heuristics using GIS was performed by Viana (2006), focusing on the vehicle routing problem (VRP) applied to the optimization of solid waste assortment systems. GIS object classes were used to model the transportation networks (Truitt et al, 1969, Esmaili, 1972). Supporting their study on GIS tools for road transportation, Ericsson et al. (2006) proposed a model to guess possible fuel savings and reductions in carbon dioxide emissions. Route optimization was considered to mean increasing fuel economy, rather than reducing time (Keenan, 2008). Optimization metrics were calculated using tentative fuel consumption values recorded from specific segments of the road network (Psaraftis, 1995). Moreover, the supplementary effect of real-time information about traffic disturbance events was also taken into account. More recently, Salhofer et al. (2007) proposed an evaluation of the environmental effects produced by multifarious waste management systems, where their work applied a life cycle based approach. For each selected product and waste stream, a life cycle analysis was conducted with an emphasis on waste transport and related vehicle emissions (Tung and Pinnoi, 2000). They considered different collection schemes, distances to management or disposal locations, means of haulage, and vehicle loads. As surmised above, two-dimensional travel distance is a widely used methodology for assessing the optimal routing for vehicles that collect and transport waste (Keenan, 2008). Some additional problems, such as speed, lifting of collection bins, waste compaction or traffic have also been taken into account. However, engine performance and efficiency are also influenced by a third spatial dimension that quantifies road slope, resulting in a variation of the engine power requirement and, thus, yielding different fuel consumption and vehicle emissions (Bertsimas and Simchi-Levi, 1996). Therefore, it would be useful to address road slope when determining the fuel consumption of trucks that collect and transport MSW (Ghose, 2005). Such an approach is innovative and would provide the system an additional degree of freedom, the vertical direction, which would produce a more realistic cost function that takes into account both fuel consumption and related emissions (Ericsson et al. 2006 and ESRI,2012). In the present work, I propose a GIS-based model that allows for the relief of the terrain to calculate fuel consumption of vehicles that collect and transport MSW. Based on this scenario, it is possible to set up a best possible optimal route for waste collection and transportation. According to Keenan (1998), the optimal route is defined as the one that minimizes fuel expenditure, but which does not essentially correspond to the shortest travelled distance   Indeed, depending on the slopes of the roads, it is possible for a longer route to become optimal in terms of fuel consumption (Dogan and Duleyman, 2003, Ghose et al., 2006). Such a model can be used as a decision support tool to improve the efficiency of waste management systems and thereby reduce the cost of waste collection and transportation to dumping sites (Densham, 1991).

GIS technology can be used for the development of routing models, because they need spatial data (Batty and Howes, 1996). Geographical and spatial data can be handled, displayed and controlled by using GIS technology (Armstrong and Khan, 2004). For example, a model for municipal solid waste collection, including distribution of collection bins, load balancing of vehicles and generation of optimal routing was developed based on GIS technology (Ghose et al, 2006). Possible fuel saving and reduced emission of carbon dioxide were estimated, using a model by Ericsson et al. (2006). Life cycle based ecological effects of a waste management system were evaluated by Salhofer et al. (2007).

The process of solid waste management is very important and it demands many aspects such as its planning and operations which are highly dependent on spatial data and in this context the role of Geographic Information Systems (GIS) cannot be denied (Tomlinson, 1987, Dangermond, 1991). GIS plays a significant role in maintaining account data to aid collection process, speed customer service, scrutinize optimal sites for transport, plan optimal routes for vehicles and locate and monitor landfills/dumpsites (Sener et al, 2006; Keenan, 2008; Kyessi and Mwakalinga, 2009, ESRI, 2012). GIS is a computer-based tool that offers a digital data base for examining potential sites for future purposes and it cuts costs and reduces the amount of time for the selection of an appropriate site (Kontos et al. 2003; Sarptas et al. 2005; Sener et al. 2006, Kassim, 2008). In today’s world, no one can deny the importance and ease of usage of GIS technology in the solid waste management (Sener et al. 2006). Here we will shed a light on the Malaysian companies which have adopted GIS for solid waste management and have allocated a handsome budget for the process. For example, Alam Flora Sdn. Bhd. (AFSB) is a company which has taken an initiative to setup GIS such as ArcInfo and ArcView as prime components for the management of information and is responsible for the collection, transportation and disposal of 75% of solid waste in Malaysia (Keir, 1997).

Furthermore, we will consider another example of the municipal waste management in the context of GIS in Pudong city of China, where most of the municipal waste was burnt (PSWAO, 2006). GPS sets facility was used for 200 trucks. Trucks were observed by uploading the coordinate data and integrating it into GIS (Minghua et al. 2009). Similarly GIS was used for spatial data creation to select a site for land-filling. Atmosphere, surface water, ground water, soil and human health were considered as environmental factors for this purpose (Zamorano et al. 2008). In addition to this, in another developing country like Pakistan, Batool and Nawaz, (2009) used the ArcView software of GIS to show the exact location of communal storage centers of Data Ganj Baksh Town (DGBT) of Lahore. They showed that in DGBT, waste is collected with the help of 129 containers of 5 cubic meter capacity, 120 containers of 10 cubic meter capacity and 380 skips of 2.5 cubic meter capacity. For determination of efficient collection routes with minimum cost for solid waste transportation to landfills, a GIS optimal routing model was proposed (Ghose et al, 2006). Tavares et al. (2009) used 3D route modeling software for waste collection and transportation. This system has an additional benefit of lessening the fuel consumption. Furthermore, Cordeau et al (2002) and Simonetto and Borenstein (2007) optimized vehicle routing by developing computer tools with the help of operational research methodologies. Time taken for waste collection was calculated using a model by Everett and Riley (1997). Energy and fuel consumption during stoppage and waste compaction was estimated by Sonesson (2000). For example in the Klang district of Malaysia, integration of GIS and Multi Criteria Decision Making Method (MCDM) was used for suitable landfill site selection (Din et al, 2008).

2.5. Importance of GIS in Landfill Site Selection Process Using Multicriteria Evaluation Technique (MCE)

Multi criteria decision analysis (MCDA) and overlay analysis were used with the help of GIS to select a landfill site. Furthermore, GIS is used in conjunction with other important techniques such as MCE and AHP for waste management planning in the landfill site selection process. According to Malczewski, (2004) MCE is commonly applied to land suitability analysis. Novel information can be attained to select landfill sites by uploading an information data base (Din et al, 2008). With reference to their relative importance weights were assigned to different factors (Sumathi et al.2008). Standard GIS software was used for development of thematic maps (Sumathi et al. 2008). While 178 thousand polygons of information layers, maps and satellite images were used to recommend landfill sites (Lotfi et al., 2007). The Raster model was utilized due to its speed and efficiency while a vector model was used for generating cartography and initial model variables by using MCE techniques (Zamorano et al., 2008).

Siddiqui et al. (1996) were first to use GIS, MCE and AHP techniques to help in the site selection process. Sener et al. (2006) integrated GIS and MCE technique to solve the landfill site selection problem and developed a ranking of the potential landfill areas based on a variety of criteria. Similarly, Chang et al. (2008) integrated GIS with MCE technique for landfill sitting in the suburban area of the Harlingen City. Pokhrel and Viraraghavan (2005) carried out an evaluation of solid waste management in Nepal relating to the sitting of landfills. Charnpratheep et al. (1997) used fuzzy set theory integrated with GIS in Thailand for the screening of landfill sites.

Batool and Nawaz (2009) used GIS to coordinate residential and commercial areas for solid waste disposal sites and converted the location coordinates and container types into spatial and attribute data. Sumathi et al. (2008) developed an amalgamated air quality index map to locate polluted, moderately polluted, heavily polluted and seriously polluted areas. Rahman and Hoque (2006) suggested that suitable sites for disposal of solid waste must meet criteria such as a distance of 100 meters from drainage, 200m from socio-cultural institutes, 200m from hotels, markets and shopping centers, 500m from banks, 200m from any water body and 1km from educational institutions, health establishments and administrative sites.

For example, in the Jiangsu province of China, five landfills were selected randomly, a GIS database was established and data was checked for its suitability with reference to human health and the environment. Organic and inorganic materials were found to be leaching out from landfills (Yang et al, 2008). For the disposal of waste to landfill sites a GIS based optimal routing system was recommended for Asansol municipality (Ghose et al, 2006). GIS was used for management and presentation of spatial data and grading the maps from one to five, prospective sites were classified as best, good and unsuitable (Guiqin et al, 2009). Al-Jarrah and Abu-Qdais (2006) considered several factors for landfill siting like geology, topography, socio-cultural aspects, natural resources, safety and economy. To optimize and reduce the fuel consumption, GIS system 3D modeling software was used for waste collection and transportation (Tavares et al, 2009). Rapid spread out of urban areas has created the waste management problem (Fiorucci, et al. 2003). There is a lack of an all encompassing solid waste management system in three mega/metropolitan cities of Pakistan i.e. Rawalpindi, Islamabad and

Lahore due to unavailability of a GIS based solid waste collection, disposal and transportation system; therefore this study plans to address this problem.

Pakistan is a developing country that is experiencing good and sustained economic growth. The estimated population of Pakistan in July 2009 was 180,800,000 and by 2015 it is estimated to be 200,846,310 (PRB, 2009, PRB, 2010). In Pakistan, 35 percent of the population resides in cities and urban solid waste generation is estimated to be 55,000 tons/day (JICA, 2005). In the few larger cities the average rate of waste production varies from 1.896 kg/house/day to 4.29 kg/house/day, from all types of municipal controlled areas (Pak-EPA, 2005). It is estimated that, in the next ten years, the population of major cities will double and correspondingly, the waste generated will be double (Mahar et al, 2007). Batool and Nawaz (2009) reported that in Lahore solid waste is scattered in open places and present landfills are not based on a scientific basis. Municipalities play a major role in waste collection in Pakistan with efficiencies ranging from 0 percent in low income rural areas to 90 percent in high income areas of large cities (Pak-EPA, 2005). Three types of solid waste are found in Pakistan: biodegradable, non-biodegradable and recyclable (Mahar et al, 2007). Solid waste management is collectively used for control of generation, storage, collection, transfer, disposal and processing of municipal solid waste, keeping in view the principles of public health, economics, engineering, aesthetics and other environmental factors (Daskalopoulos et al, 1999).

A great challenge for Pakistan is the establishment of an integrated and reliable MSWMS that ensures methodical treatment and disposal of waste. The amount of generated waste has been increasing considerably as a result of urban pressure, demographic growth and other economic activities (HBP, 1999). Despite efforts at state government and municipal levels, development of solid waste urban planning remains inadequate (Pak-EPA, 2005). The existing waste management system and planning are still very basic and characterized by an inefficient collection system. The collected waste is disposed of in uncontrolled open landfill sites with subsequent local burning for volume reduction. This results in a negative impact on the environment and civic health of the people nearby (Batool et al, 2009). However, industries and traders, particularly wholesalers and retailers, handle their own waste collection and transport it directly to the landfill sites. In the urban areas of Lahore, Rawalpindi and Islamabad waste is collected at returnable bins spread throughout the entire city. These bins are emptied into compaction vehicles. All collected waste is deposited in open uncontrolled landfill sites, where no further treatment is given to this waste, though there is a project in progress for the thermal treatment of MSW by incineration. It is expected that the plant's substantial capacity will allow for the treatment of all waste collected from all the municipalities of Islamabad and Rawalpindi.

Keeping in view the progressive role of GIS in SWM in developed part of the world and current SWM practices in Pakistan, the present study discovered a fair amount of research relating to GIS applications in certain areas of solid waste management, routing and landfill siting specifically. However, an overwhelming majority of the published literature was related to solid waste management in European nations, United States and in many other countries of the world. In Pakistan modest amount of research is carried out in different areas using GIS. Most of the previous available GIS-related research in Pakistan focused on broad environmental issues, such as irrigation sector, ground waster prevention etc. Therefore our current research is different from the previous research in a way that it has both scientific and socio-economic contributions.

a. Scientific Contribution of the Research

- Urban area mapping using high resolution satellite imagery and state of the art object classification techniques.

- Integrated use of mobile-desktop-web-based DSS.

b. Socio-economic Contribution of the Research

- The output of current research will enhance the managerial and administrative capabilities of the municipality agencies of the twin cities.
- The output of route optimization for SWM will serve enormous amount of time and money and will reduce carbon dioxide emissions.
- The indentified potential zones for new landfill sites keeping in view the current urbanization rate will help in urban planning and management.

The choice of the dissertation topic has been made in order to allow for the possibility of finding results, so that they can help municipalities and decision makers in order to reap the benefits of route optimization and potential candidate sites for landfill for future effective management and improved environmental and economic conditions. Therefore, the main objective of this study is route optimization for waste collection, its storage and transportation with the help of GIS and RS for the two mega/metropolitan cities of Pakistan. Furthermore, the present study will identify potential candidate sites for landfill.

2.6. An Overview of the Previous Literature on DSS

DSS is deeply rooted in the previous literature and it was first proposed in Morton in (1971) when he completed his PhD dissertation about the role of computers followed by analytical models in helping the managers and decision makers in the decision making processes (Dangermond, 1991). From there, DSS emerged in the mid 1980s when technological advancement enabled computers to process spatial information. Since then, the amount of research performed in the area of DSS has increased dramatically. DSS's are very helpful in aiding decision makers and planners to solve complicated spatial problems (Buede, 1996). The importance of DSS in the past and present literature remains indispensable.

Hasstrup et al. (1998) has developed a DSS for urban waste management in Italy. The DSS was used for the review of a service organization's policies for the collection of waste and for the identification of an appropriate location for a disposal site and to categorize sites from the best to the worst. Likewise, MacDonald (1996) has developed an accessible; interactive spatial decision support system that was used for helping municipal solid waste decision makers in the solid waste management process.

Furthermore, Fiorucci et al.(2003) and Costi et al. (2004) have developed a DSS for managing solid waste in urban areas to assist decision makers or planners of municipalities. Amouzegar and Moshirvarziri in (2001) presented a DSS which was used to analyze the environmental policies in order to deal with environmental issues. A study was carried out in Boyle and Baetz in (1998) which developed a sample decision support system for managing industrial waste. The primary purpose of this sample DSS was to assist and train managers so that they can determine all the options for waste management of industrial plant and for recycling options in order to cut costs and contribute to environmental stability. Similarly, another DSS was formulated by Simonetto and Brenstein (2007) for the management of solid waste. It helped decisions makers in operational planning of solid waste collection and transportation systems. Sufian and Bala (2006) developed a wonderful computer tool to estimate the rate of solid waste generation and its collection in the urban city of Daka, Bangladesh.

Wang et al. (1996) presented a solid waste management simulation package based on Excel. Repousis et al. (2009) and Bhargave (1997) have developed a decision support system for waste management via standard web browser to give user easy access to the system and the database. In today's era, since all decision support related operations are performed on network servers, the use of web-based DSS has gained tremendous praise and implementation in the research work for planning (Togia, 2003). A Web-based recycling DSS was created by Bhargava and Tettelbach (1997) to tackle disposal and recycling of waste. Furthermore, Chang et al. (2008) developed a DSS which comprised two stages i.e. GIS and MCE for landfill site selection and to rank the potential areas for the landfill site based on the selected criteria. Quintero et al. (2005) and Jajac et al. (2009) developed a DSS in order to manage the urban infrastructure and to develop adequate criteria set in terms of maintenance.

Table 3 shows some other researchers who have developed DSSs in order to solve problems regarding urban management.

Table 3: Urban Management by Employing DSS

References	Concentration
(Values and Manoliadis, 2002)	Lndfill side selection
(Kuwata et,al., 2002)	Evalutaion of decision support system for emergency management
(S. Jaun, Quangong, Ruijun & Wenlan, 2002)	Forage selection
(Adenso Diaz, Tuya, & Goitia 2005)	Evaluation of alternatives in waste water collecting System Design
(Ahmed Abrishamchi, 2005)	Applications of multi criteria decision making to urban water supply
(C.K. Makropoulos, 2008)	Sustainable option selection in integrated urban management
(Bani et,al., 2009)	A review on development of decision support system for waste management
(Yilmaz & Harmancioglu, 2010)	Decision making for water resource management
(Z.Li, Madanu, S.Zhou, B.Wang, Y.Abbas, M, 2010)	Selecting Highway investment alternatives
(Jaffery Shelton, 2010)	Prioritizing transportation Project
(A.R. Karimi, 2010)	Waste water treatment process selection

Source: Farzad et.al 2012

Hence, waste management has remained an important aspect of the urban management issue and it is a very complicated process as it consists of various issues that interfere with social and environmental aspects (De Oliveira and Borestein, 2007). The biggest issue always remained the location of proper landfill sites and choosing proper optimal transportation routing which can reduce cost and save time (Fiorucci et al, 2003). In such scenarios, DSS remained very helpful in combating these complexities and as has been shown in the past and current literature.

2.7. An Overview of Solid Waste Management in Pakistan

Pakistan is the second largest country in South Asia ranking sixth largest in the world with a population of 180 million. Like other developing countries of the world, Pakistan is also facing severe environmental issues. During the last thirty years, the global population has increased drastically, because of this solid waste management has became a very important issue in the life of individuals living in any corner of the world and in this case Pakistan is no exception.“Solid Waste Management is the generation, separation, collection, transfer, transportation and disposal of waste in a way that takes into account public health, economics, conservation, aesthetics and the environment and is responsive to public demands”.

SWM is an amalgamation of all those actions and behavior that can best protect both the community and the environment. “Good municipal solid waste management practices require collection of critical information which is not just for keeping the records up to date but is used effectively for taking corrective measures as well as proper planning for the future.” (Ramachandra and. Saira, 2003). Solid waste generation in Pakistan ranges between 0.283 to 0.612 kg per capital per day and growth rate of waste generation per annum is 2.4 percent (CDA, 2012).

In most of the urban cities of Pakistan poor collection and transportation of municipal solid waste is reported. In Pakistan, numerous government owned and private operating service companies are responsible for the solid waste collection and they currently collect only 50 percent of the total waste generated (ESMAP, 2010). However, for the country to be clean, at least 75 percent of waste should be collected (Daskalopoulos et al, 1999, Sener et al. 2006). To a large extent, most of the uncollected waste ultimately finds its way into vacant plots, agricultural land, pits and rivers/ponds. This situation creates a perfect atmosphere and environment for mosquitoes and moth to inhabit and become harmful for the people, animals and plants nearby by transmitting acute diseases (JICA, 2004). The process of SWM in Pakistan has been executed in an inappropriate manner and the condition is worsening with every passing day and failure of the MSWMS also has severe environmental implications such as air pollution, water pollution in natural streams, blocked drains and land pollution (IUED/SDPI, 1996).

Some of the important features of solid waste management demonstrate that the composition of solid waste in Pakistan comes from a variety of sources comprising a higher proportion of organic waste and this waste has not been collected out in an adequate and appropriate manner, thereby leaving the sanitary and environmental condition of the country at greater risk with every passing year (UNDP, 2000 and GOP/FBOS, 1998).

The scope of the problem regarding SWM in Pakistan is very broad and involves the following factors such as the rate of urbanization, composition and amount of waste, scavenging for recyclable segregation and the capacities of existing municipalities for SWM which includes collection, transport and dumping/disposal (Islamabad Census Report, 1998). SWM comprises primary and secondary collection of the waste that is carried out from household to dust bin sites manually and is done mechanically from dust bin sites to landfill sites, respectively, as shown in Figure 4.

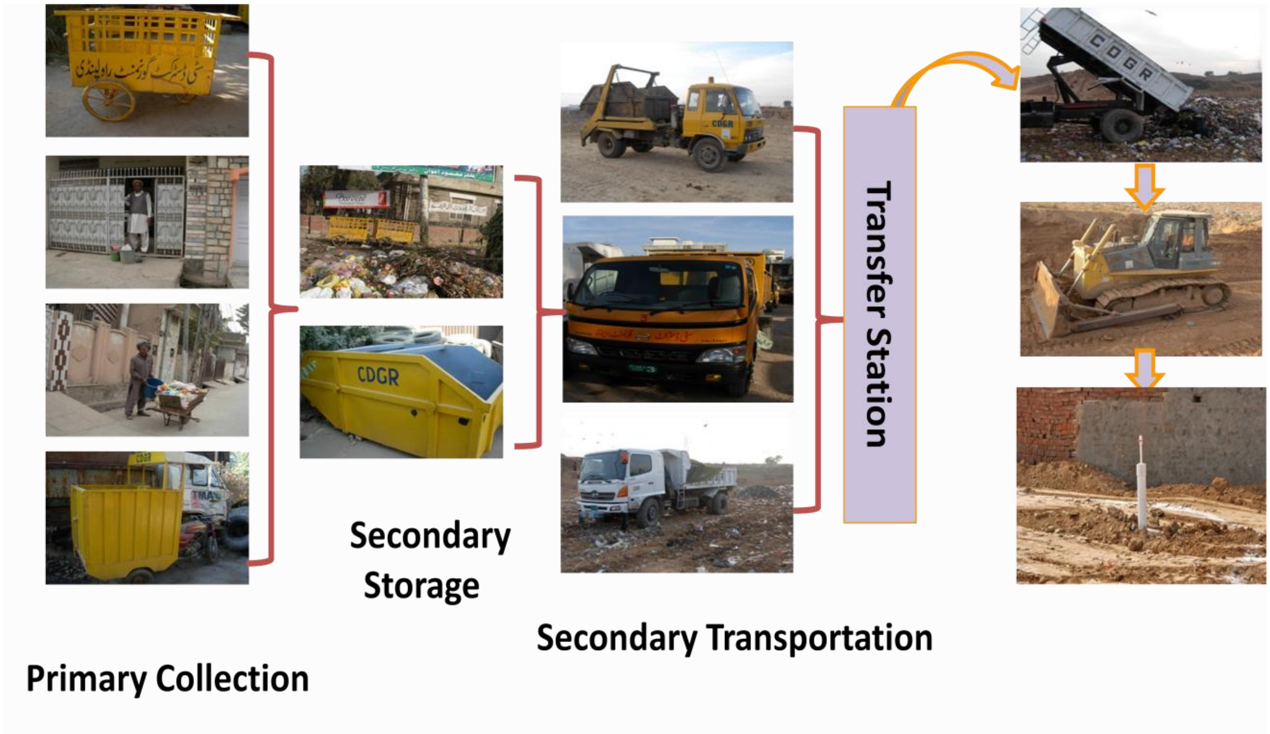


Figure 4: Existing SWM System in Pakistan for Islamabad and Rawalpindi

The total amount of municipal and harmful waste generation in Pakistan is estimated to be 54,888 tons/day. In major cities of Pakistan, waste collection services are much better as compared to medium and small cities and towns and rural areas of the country which are deprived of waste collection services and in rural areas waste is often dumped or burnt at the border of villages. One of the other problems of the SWM in Pakistan is that the vehicles used for the collection of the municipal waste are often not appropriate for the containers used and they are rarely suitable for collecting waste on unpaved roads or in the narrower streets (Islamabad CDA, RMC).

In a developing country like Pakistan, waste disposal has emerged as a problematic and worthy concern in almost all the major cities of Pakistan due to scarce land and improper controls on dumping measures resulting in odor, litter and smoke as well as posing health risks to nearby communities.

2.8. Two Mega Metropolitan Cities

2.8.1. Islamabad

Islamabad is the national capital city of Pakistan located within the Islamabad Capital Territory. According to a 2012 estimate by the Census Department, the population of Islamabad including its surrounding territory has increased to 2 million. Together with its neighboring twin city of Rawalpindi, the Islamabad-Rawalpindi metropolitan area is the third largest conurbation in Pakistan with a population of over 4.5 million inhabitants (PRB, 2009 and PRB, 2010).

Islamabad is located at 33.43°N 73.04°E at the northern edge of the Pothohar Plateau and at the foot of the Margalla Hills in Islamabad Capital Territory (PRB, 2009, PRB, 2010). Its elevation is 540 meters (1,770 ft). The modern capital and the ancient Gakhar city of Rawalpindi stand side by side and are commonly referred to as the Twin Cities where no exact boundary exists between the two cities. To the northeast of the city lies the hill station of Murree, and to the north lies the Haripur District of Khyber Pakhtunkhwa. The Kahuta District lies on the southeast, The Taxila, Wah Cantt, and Attock Districts to the northwest, The Gujar Khan, Rawat, and Mandrah District to the southeast, and the metropolis of Rawalpindi to the south. Islamabad is located 120 kilometres (75 mi) SSW of Muzaffarabad, 185 kilometer (115 mi) east of Peshawar, 295 kilometre (183 mi) NNE of Lahore, and 300 kilometer (190 mi) WSW of Srinagar, the capital of Indian Kashmir. The city of Islamabad has expanded to an area of 906 square kilometers (350 sq mi). A further 2,717 square kilometer (1,049 sq mi) area is known as the Specified Area, with the Margala Hills in the north and northeast. The southern portion of the city is an undulating plain. It is drained by the Kurang River, on which the Rawal Dam is located.

The main administrative authority of the city is the Islamabad Capital Territory Administration (ICT) with some help from the Capital Development Authority (CDA), which oversees the planning, development, construction, and administration of the city. Islamabad Capital Territory is divided into eight zones: Administrative Zone, Commercial District, Educational Sector, Industrial Sector, Diplomatic Enclave, Residential Areas, Rural Areas and Green Area. Islamabad city is divided into five major zones: Zone I-V. Out of these, Zone IV is the largest in area. Zone I consists mainly of the developed residential sectors while Zone II consists of the under-developed residential sectors. Each residential sector is identified by a letter of the alphabet and a number, and covers an area of approximately 2 km × 2 km (1 1⁄4 mi × 1 1⁄4 mi). The sectors are lettered from A to I, and each sector is divided into four numbered sub-sectors. Series A, B, and C are still underdeveloped. The D series has seven sectors (D-11 to D-17), of which only sector D-12 is completely developed. This series is located at the foot of the Margalla Hills. The E Sectors are named from E-7 to E-17. Many foreigners and diplomatic personnel are housed in these sectors. The F and G series contain the most developed sectors. The F series contain sectors F-5 to F-17 out of which some sectors are still under-development. The H sectors are numbered H-8 through H-17. The H sectors are mostly dedicated to educational/health and other government organizations. The I sectors are numbered from I-8 to I-18. With the exception of I-8, which is a well-developed residential area, these sectors are primarily part of the industrial zone. Currently two sub-sectors of I-9 and one sub-sector of I-10 are used as industrial areas. Zone III consists primarily of the Margalla Hills, National Park and Rawal Lake. Zones IV and V consist of Islamabad Park and rural areas of the city. The Soan River flows into the city through Zone V. Islamabad is the hub of all the governmental activities while Rawalpindi is the center of all industrial, commercial, and military activities. The two cities are considered sister cities and are highly interdependent.

2.8.2. Rawalpindi

Rawalpindi, commonly known as Pindi, is a rapidly growing city in the Pothohar region of northern Punjab, Pakistan. It is situated at an elevation of 508 m above MSL & at 33.6000° N latitude & 73.0333° E longitude and is located only 1 kilometer south from the capital city of Islamabad, in the province of Punjab. Rawalpindi is the fourth most populous urban area and is in the list of most populous metropolitan areas in Pakistan (PRB, 2009, PRB, 2010). The Rawalpindi/Islamabad metropolitan area is ranked the third highest in the country. Due to the high interdependence and intertwined areas of the two cities, they are known as the twin cities of Rawalpindi/Islamabad. In the 1950s, Rawalpindi was smaller than Hyderabad and Multan, but the city's economy received a boost during the building of Islamabad (1959–1969), during which Rawalpindi served as the national capital. Rawalpindi is in the northernmost part of the Punjab province, located 275 km (171 mi) to the north-west of Lahore (Pakistan Bureau of Statistics, 2009). The Headquarters of the Pakistan Military, known as GHQ is also in this city. Many tourists use Rawalpindi as a stop before entering into the northern area. Numerous shopping plazas, parks and a cosmopolitan population attract shoppers from all over Pakistan and abroad. The city is home to several industries and factories. Islamabad International Airport and Chaklala Airbase are both located in Rawalpindi which provides travelling facilities to local as well as international passengers.

3. RESEARCH METHODOLOGY & DATA

The collection of data is an imperative task and is the backbone of any research work. The accuracy of the research results is highly dependent on the appropriateness of the data. The database for this research is prepared on the basis of the information collected from different sources and then it has to be transferred into the GIS database. In this study the information was collected from different sources and then was integrated to form a database. The acquired information proved very useful in the data preparation process. This chapter details the methodology undertaken to carry out this research. It is organized as follows: the next section presents the data sources and method of constructing the database. Results of the research conducted (using GIS, RS and MCE Techniques) then get presented, including an analysis of results and corresponding discussions followed by an online web-based decision support system via Application Programming Interface (API).

3.1. Choice of Research Method

There are several techniques, which could be used to carry out the research based on the research problem area. When dealing with a research problem, one can use any of the three classification of research i.e. exploratory, explanatory or descriptive (Yin, 1994). Methodologists and science philosophers have centered their research on two different but essential paradigms namely the quantitative (positivist) and the qualitative (phenomenological) approaches (Smith, 1998 and Shaw, 1999). In the quantitative approach, results are based on numbers and statistics that are presented in figures, whereas in the qualitative approach the focus lies on describing an event with the use of words. Qualitative research emphasizes the importance of looking at variables in the natural setting in which they are found (Jacob, 1988). This differs from quantitative research, which attempts to gather data by objective methods to give information about relations, comparisons and predictions and attempts to remove the investigator from the investigation (Smith, 1983). It is important for researchers to realize that qualitative and quantitative methods can be used in conjunction with each other.

The research on Municipal Solid Waste Collection Route Optimization using Geospatial Techniques with a case study of two metropolitan cities of Pakistan is very extensive and broad. Thus to gain a deeper understanding of the research topic in the Pakistani context, this research is conducted as a qualitative and quantitative by employing new evolutionary techniques i.e. GIS, RS and MCE techniques. First, using the qualitative approach in the first half of the research has provided rich and forensic details for exploring viewpoints in the early stage of research. Second employing the evolutionary new techniques in the second half of the research will yield the final results.

Considering the nature and main objectives of this research, GIS, RS and MCE techniques have been adopted. GIS are used to collect, store, manipulate, process and analyze large volumes of spatial data from a wide variety of sources and this property of GIS has made it an ideal tool for the current research work (Sener et al. 2006). Furthermore, GIS can be used in conjunction with other important techniques such as MCE for waste management planning in the landfill site selection process (Vatalis and Manoliadis, 2002). The method of multicriteria analyses and evaluation is used for identifying locations of elements of a waste management system in the GIS (Malczewski, 1999) and is very important for the current study as well.

The integration of GIS with other techniques such as GPS, RS and MCE are used for analysis and cartographic representation and integrated GIS technology has been recognized as one of the approaches to mechanize the process of waste planning and management (Kontos et.al 2003; Chang et.al 2003 and Sener et.al 2006). An extensive use of GIS for solid waste management lies in the areas of landfill site selection and the optimization of routes for waste collection and its transport (Sonesson, 2000; Higgs, 2006 and Sener et.al 2006). Therefore, these methods/techniques get selected for the purpose of this research to identify optimal routes for solid waste collection and transportation, for identifying new landfill sites and to develop a web-based decision support system in order to support the decision makers who don't have much knowledge about GIS.

3.2. Map of Study Area (Islamabad and Rawalpindi)

The cities of Islamabad and Rawalpindi are normally referred to as twin cities and are commonly viewed as one unit. Islamabad is the capital of Pakistan, and is the tenth largest city in Pakistan. The Rawalpindi/Islamabad metropolitan area is the third largest in Pakistan with a population of over 4.5 million inhabitants according to the 2012 census. On the other hand, these twin cities with separate ancestry and distinct personalities are far from being the same. Figures 5 & 6 below show the maps of the study area without and with the street and road network.

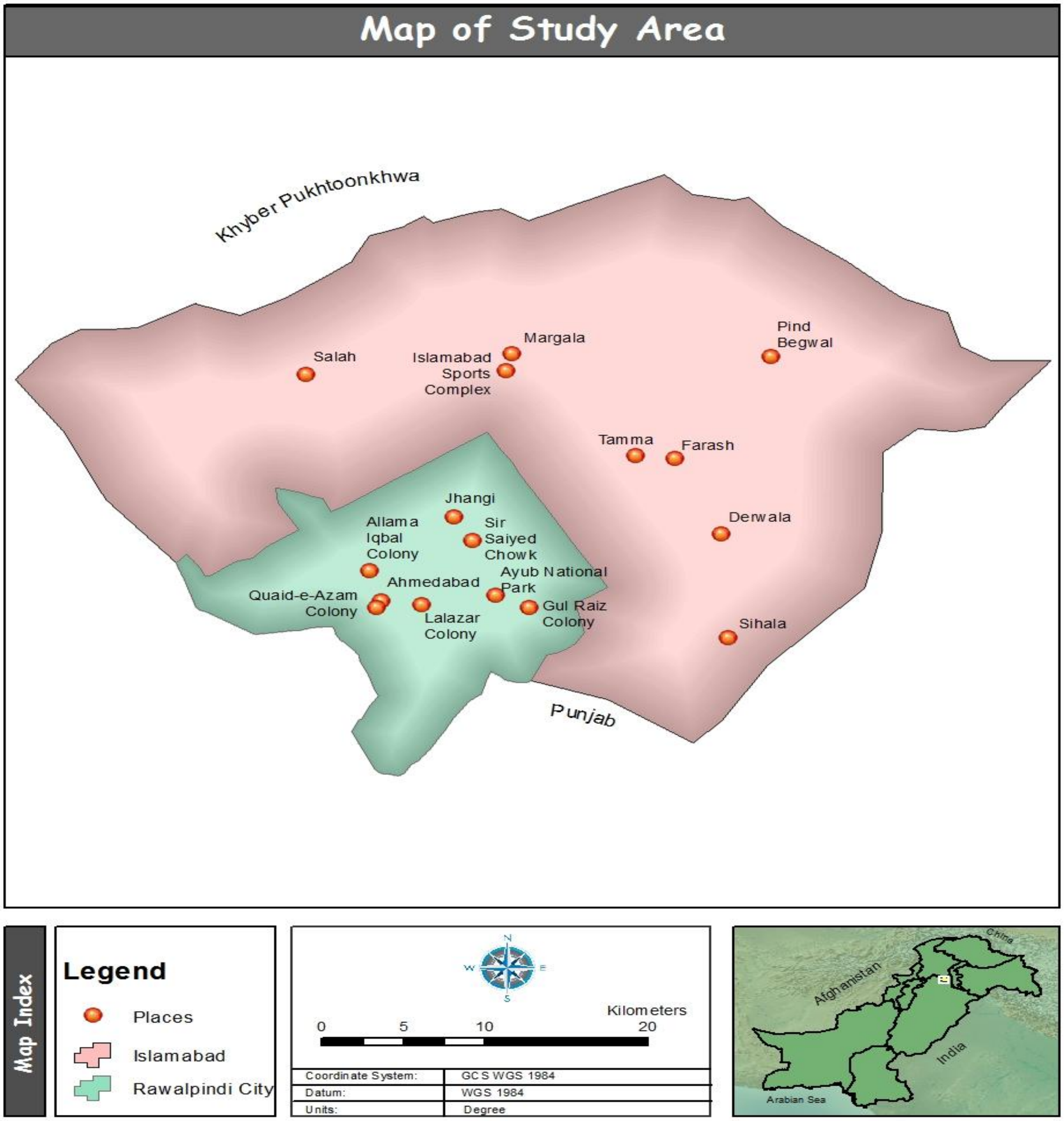


Figure 5: Study Area Map of Islamabad and Rawalpindi with Places

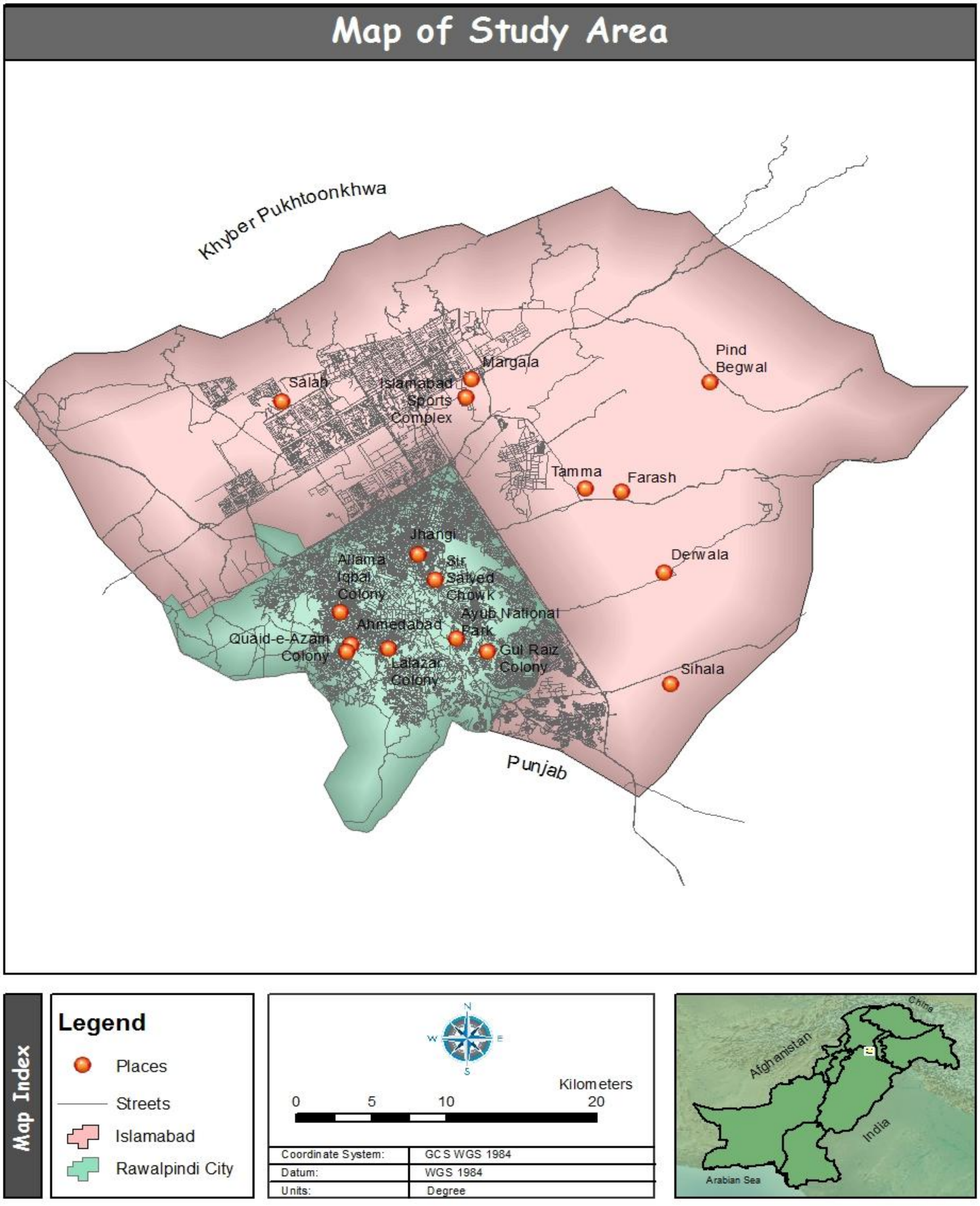


Figure 6: Study Area Map of Islamabad and Rawalpindi with Places and Streets

3.3. Methodological Framework

This research has three main studies and will be guided by the following research questions/objectives (RQs):

- RQ1: To assess the present waste management strategies in two metropolitan cities of Pakistan i.e. Islamabad and Rawalpindi.
- RQ2: To analyze the urban land use in two metropolitan cities using RS and GIS technology and to identify new appropriate landfill sites.
- RQ3: To obtain the pattern of location of communal waste depots and how they can be managed in terms of better urban planning using RS and GIS technology.
- RQ4: To develop the optimization of routes for economical and time saving purposes and to develop an online DSS as a waste collection optimization tool for the policy/decision makers.

3.4. Model Development and Specification

3.4.1. Urban Area/Residential Area Map

The urban area map will be developed by making use of high resolution satellite imagery (Geo Eye, Quick Bird and World View) downloaded from Google earth and existing boundary extents which will be obtained from the Population Census organization of Pakistan and Tehsil Municipal Administration of Islamabad and Rawalpindi.

3.4.2. Road Network

The Road Network of Islamabad and Rawalpindi City will be generated using vehicle N-route tracking with Global Positioning System (GPS) and satellite imagery by vectorization tools using ArcInfo. The Digitized road network (including all main roads and streets) of the study area will be from Geo-referenced high resolution satellite images of Islamabad and Rawalpindi.

3.4.3. Collection Points/Dump Sites

The collection points of solid waste will be mapped by high resolution GPS devices. The latitude and longitude for each collection will be recorded and mapped in ArcGIS using the add XY data tool.

3.4.4. Digital Elevation Model (DEM)

The Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) was developed jointly by the United States National Aeronautics and Space Administration (NASA) and Ministry of Economy, Trade and Industry of Japan (METI). The ASTER GDEM is the single DEM that entirely covers the land surface of the Earth at high resolution. The most important and fundamental geophysical measurements of the Earth are the topography of the land surface which is a dominant controlling factor in almost all physical processes that occur on the surface of land. Therefore, topographic information has remained very important and useful across the entire continuum of earth sciences and Global DEM has always remained as the first. For our current study, ASTER GDEM was downloaded from available online sources at: http://www.jspacesystems.or.jp/ersdac/GDEM/E/4.html.

3.4.5. Existing Routes of Collection

Existing solid waste collection routes will be obtained by mobile GPS.

3.4.6. Mapping Landfill

The collection points of solid waste will be mapped by high resolution GPS devices. The latitude and longitude for each landfill site will be recorded and mapped in ArcGIS using the add XY data tool.

3.4.7. Route Optimization by Distance

Collection routes will be worked out by using NETWORK ANALYST in Arc/Info GIS software with the planned infrastructure (urban areas, road network, collection points and landfill sites) to find the shortest or minimum impedance path.

3.5. Data Collection and Spatial Database Description

In order to efficiently manage the municipal solid waste system, detailed spatial information is required (Chang, et al. 2007). This information is related to the geographical background of the area under investigation as well as to special data related to the waste collection procedure. This proposed study will be carried out to estimate the waste collection, transport and transfer system to find out problems from those activities and then to propose the solutions by using GIS application. For collection and transport system, surveys will be conducted on waste collection vehicles as handcarts and waste transport vehicles as trucks by using manual GIS application

In co-operation with the municipality a database of waste management data for the period 2005- 2012 will be collected and statistically analyzed, regarding the static and dynamic data of each existing collection program: population density; waste generation rate; number, type and positions of waste bins; the road network and the related traffic; the current routing system of the collection vehicles; truck capacities and their characteristics; and, the geographic boarders and characteristics of the waste collection sectors. Thus, for the optimization of the collection process the following data will be generated (data source in parentheses):

- ➢ Study area boundary (Municipality Corporation of Islamabad and Rawalpindi).
- ➢ Satellite image of the municipality (Google Earth)
- ➢ Detailed urban plan of the municipality (Official Toposheet Plan)

- Population density distribution (Pakistan Bureau of Statistics, PBS)
- Land use of the study area (Pakistan Bureau of Statistics, PBS)
- Road network and road class information of the present study (Official Toposheet Plan, Municipality Corporation of Islamabad and Rawalpindi).
- Location, Time schedule for the collection process and capacity of waste bins (Municipality Corporation of Islamabad and Rawalpindi and Field work).
- Existing collection routes and vehicle speed, fuel consumption, CO_2 emissions of the compactors (Municipality Corporation of Islamabad and Rawalpindi and Field Work).

For the optimization of the collection process a spatial geodatabase will be designed and implemented, using a standard commercial GIS environment (ESRI, ArcGIS). This choice ensures compatibility with the available data from the municipality of Islamabad and Rawalpindi and access to many network analysis routines available from the software. Previous spatial data for road network, existing routes, bins and building parcels will be obtained from the municipality of Islamabad and Rawalpindi. These data along with other non spatial data such as road name, road type, vehicle average speed, travel time, bin type/capacity and bin collection time will be updated with field work.

3.6. Interview/Meeting with Sanitary Officer

A detailed meeting with the sanitary officer of Islamabad Municipality (CDA) and the sanitary officer of Rawalpindi Municipality Corporation was carried out and an informal interview was conducted in order to gain insight of the solid waste management process of the twin cities, the amount of waste generated per capita per day in both the cities, modes and methods of waste collection and transportation, schedule of waste collection and transportation, number of garbage/waste bins; vehicles and sanitary staff in the waste management teams of the twin cities. The detailed description of the minutes of the meeting / interview is appended below:

3.6.1. The Waste Management Process of Islamabad and Rawalpindi Municipal Corporation

The Municipal solid waste is managed by the Municipal Corporation of Islamabad and Rawalpindi. The municipal corporation of Islamabad is also called Capital Development Authority (CDA). The working system in practice is such that the whole city has been divided into several areas such as Zone, Sector, Sub-Sector and Beat Levels and for each area a team of members are appointed to maintain waste.

Zonal Team: There is a sanitation team for every Zone and its composition is given in Figure 7. There is a Chief Sanitary Inspector for every Zone who is overall in-charge of supervision of all teams in the particular zone.

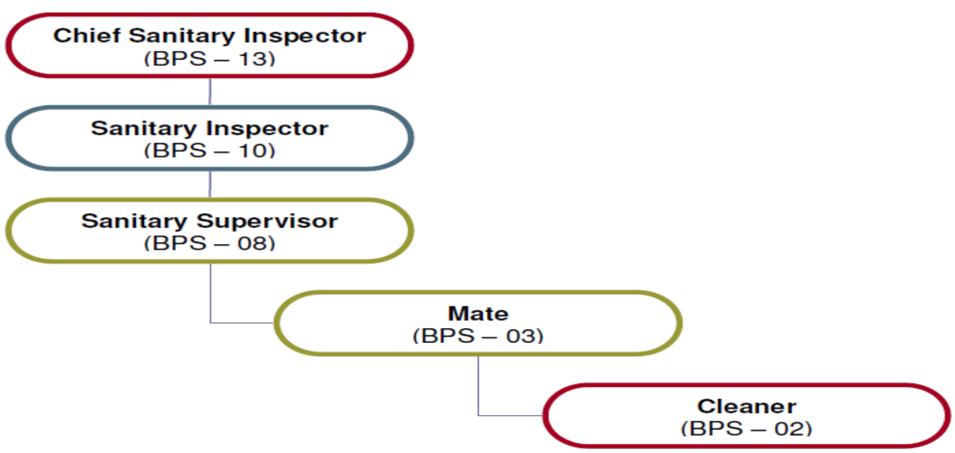


Figure 7: Composition of Sanitation Team of Islamabad

The allotment of vehicles and employees to a chief sanitary inspector is based on the size of the area and amount of waste generated in that particular area. Each team acts as an individual cell and has responsibility to maintain the waste in a particular area. This includes collection of garbage from waste bins, residences and waste collected from the sweeping of the area and dumping it into the landfill site where the waste of the whole city is dumped.

Sector Team: There is a team for every Sector comprised of one sanitary inspector, five sanitary supervisors, ten mates and 150 cleaners.

Sub-Sector Team: There is also a team for every Sub-Sector comprised of one sanitary supervisor, two mates and thirty cleaners (fifteen cleaners per mate). Figure 8 shows the waste management process practiced by the municipalities of Islamabad and Rawalpindi

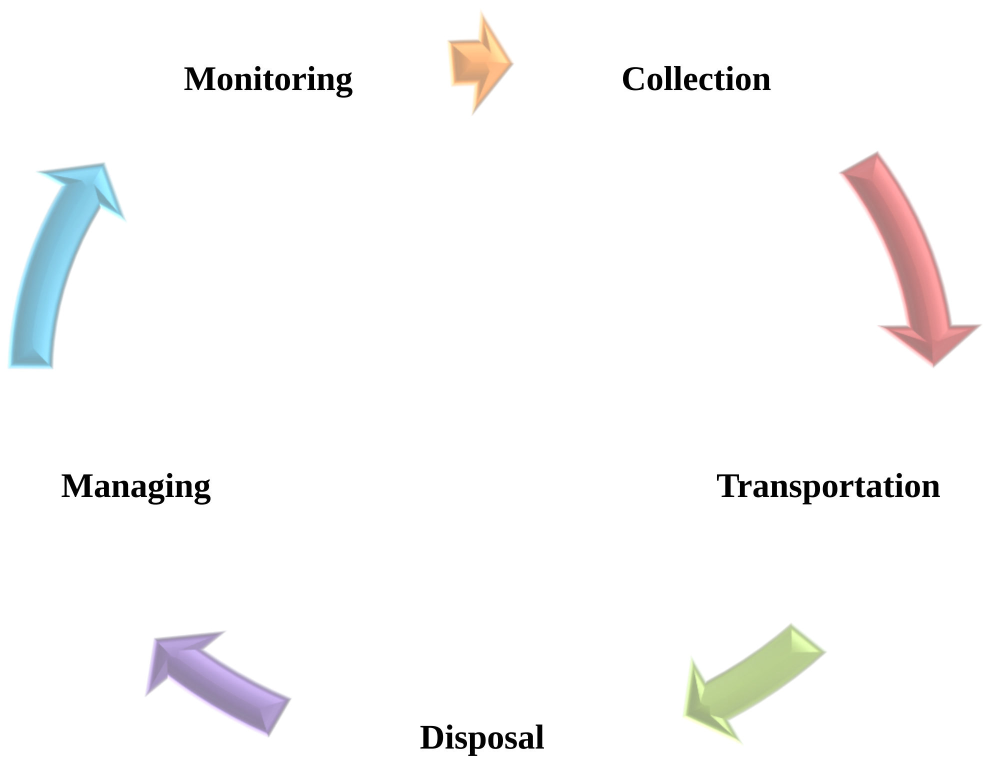


Figure 8: Waste Management Process of Islamabad and Rawalpindi Municipalities

3.6.2. Methods Used for the Collection of Municipal Solid Waste in Islamabad and Rawalpindi

There are three methods which are generally in practice in Islamabad and Rawalpindi Municipal Corporation.

a. **<u>Road sweeping</u>** is carried out on a daily basis. Road sweeping is done daily and collected waste is combusted or dumped into bins; sweeping and combusting is done by municipal appointed employees.

b. **<u>Door to door garbage collection</u>.** Garbage collected door to door is put into the nearest waste bin. Collection and dumping of waste into bins is done by municipal appointed employees.

c. **<u>Public dumping</u>**. This is done by the citizens themselves by throwing/dumping waste in the bins in their close proximity on their own.

3.6.3. Islamabad and Rawalpindi Schedule for Cleaning and Transference of Waste to the Bins from the Different Sources

The cleaning process of streets and the collection of wastes from the residential areas are from 6:30am to 1:30pm in summer from April through October and in winter it is from 7am to 2pm from October through April year round. However, the timing and schedule for the transportation of solid waste/garbage to final landfill site is from 8am to 4pm. Generally, hand carts are used to carry the swept waste and the door to door collected waste to the waste bins. In addition to hand carts; tempos, auto rickshaws (three wheeler carrier vehicles) are also used.

3.6.4. Number of Vehicles in Islamabad and Rawalpindi Municipal Corporation Waste Management System

- The Islamabad CDA has 192 dustbins/collection points and 43 vehicles for shifting waste to the dumping site with 1,603 sanitary workers.
- The Rawalpindi Municipal Corporation (RMC) has 113 dustbins/collection points and 29 vehicles for shifting it to the dumping site with 1,756 sanitary workers.

3.6.5. Brief Description about the Type of Wastes, Amount of Waste Generated and Current Waste Disposal Techniques Used in Islamabad and Rawalpindi

The main administrative authority of the city is the ICT with some help from the CDA which oversees the planning, development, construction, and administration of the city. The daily average waste collection for Islamabad Municipal Corporation is about 1000 tons daily and for RMC is 900 tons per day. The amount of municipal waste per capita is calculated as 1.896kg/house/day for Islamabad and for Rawalpindi it is 0.8 kg/house/day. The waste generated is mixed type of solid waste and comprises municipal/kitchen/green/domestic waste, commercial, building material and other scrap. The composition of waste matter generated in the municipal limits of Islamabad appears in Figure 9.

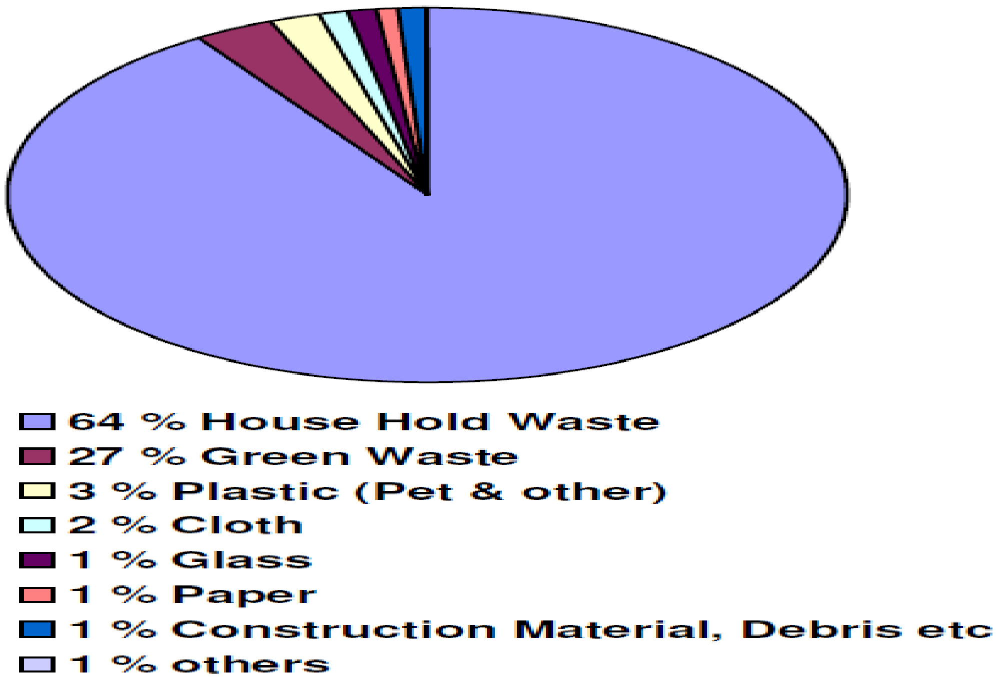


Figure 9: Composition of Waste in Islamabad
Source: Waste Characterization Study for CDA's Project, CERES February 2006 (Annexure C')

3.6.6. Spatial Division of Work of CDA/Municipal Corporation of Islamabad and Rawalpindi

In order to ensure provision of efficient and well managed sanitation services, Zone 1 of Islamabad, which falls within the spatial jurisdiction of the Directorate of Sanitation, is further divided into three zones keeping in view the work load, resources available and the supervision requirements. The total land area of Islamabad city is 906 km² with a population of 1.5 million. The spatial division of Islamabad comprises:

Zone-1: Bari Imam; Constitution Avenue; Aiwan-e-Sadar; PM House; Saidpur Village; Blue Area and Sectors= 06 i.e. G-5, F-5, G-6, F-6, G-7 and F-7.

Zone-II: Model Villages= 04,i.e. Margalla Town, Shehzad Town, Rawal Town and Humak; Sectors=03,i.e. I-8, I-9 and I-10; Islamabad Highway, Police Lines and Garbage Containment Site in Sector H-10; Public Places such as Rawal Lake Promenade etc.

Zone-III: Sectors=07 i.e.G-8, F-8, G-9, G-10, F-10, G-11 and F-11; Faisal mosque and Fatima Jinnah Park.

Zones IV and V are in the developmental phase. Figure 10 shows the classification of Islamabad city by zone.

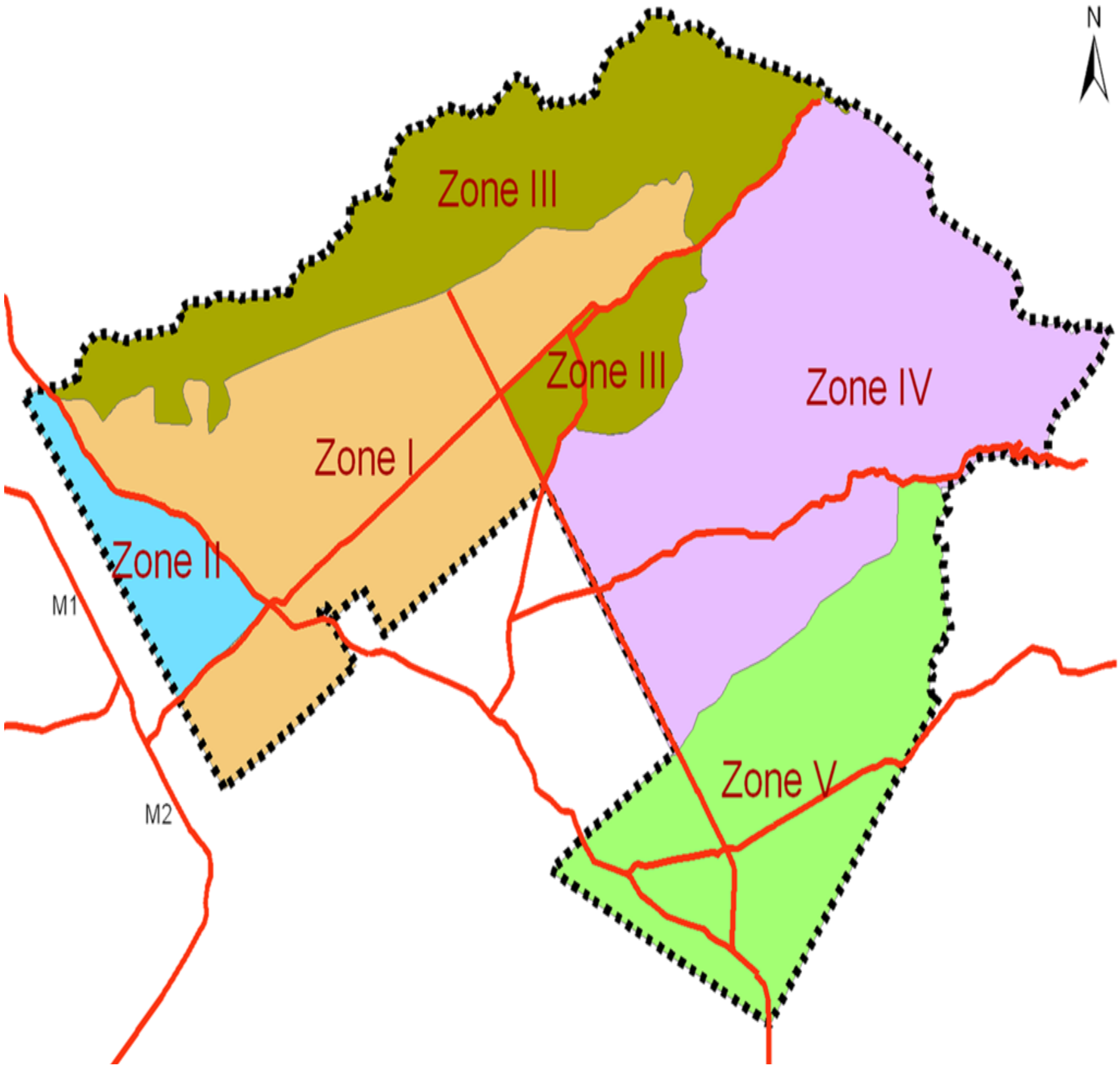


Figure 10: Classification of Islamabad with Different Zones

The total land area of Rawalpindi city is 5,286 km² with a population of 3 million. Rawalpindi city has three major areas i.e. Rawal Town, Potohar Town and Muree. These three major areas are based on 59 Union Councils. 46 Union Councils from Rawal Town, 12 Union Councils from Potohar Town and 1 Union Council from Muree. Figure 11 gives detailed information regarding the service area for solid waste management in urban and rural union councils of Rawalpindi city and shows the mapping of the sectors with their respective areas.

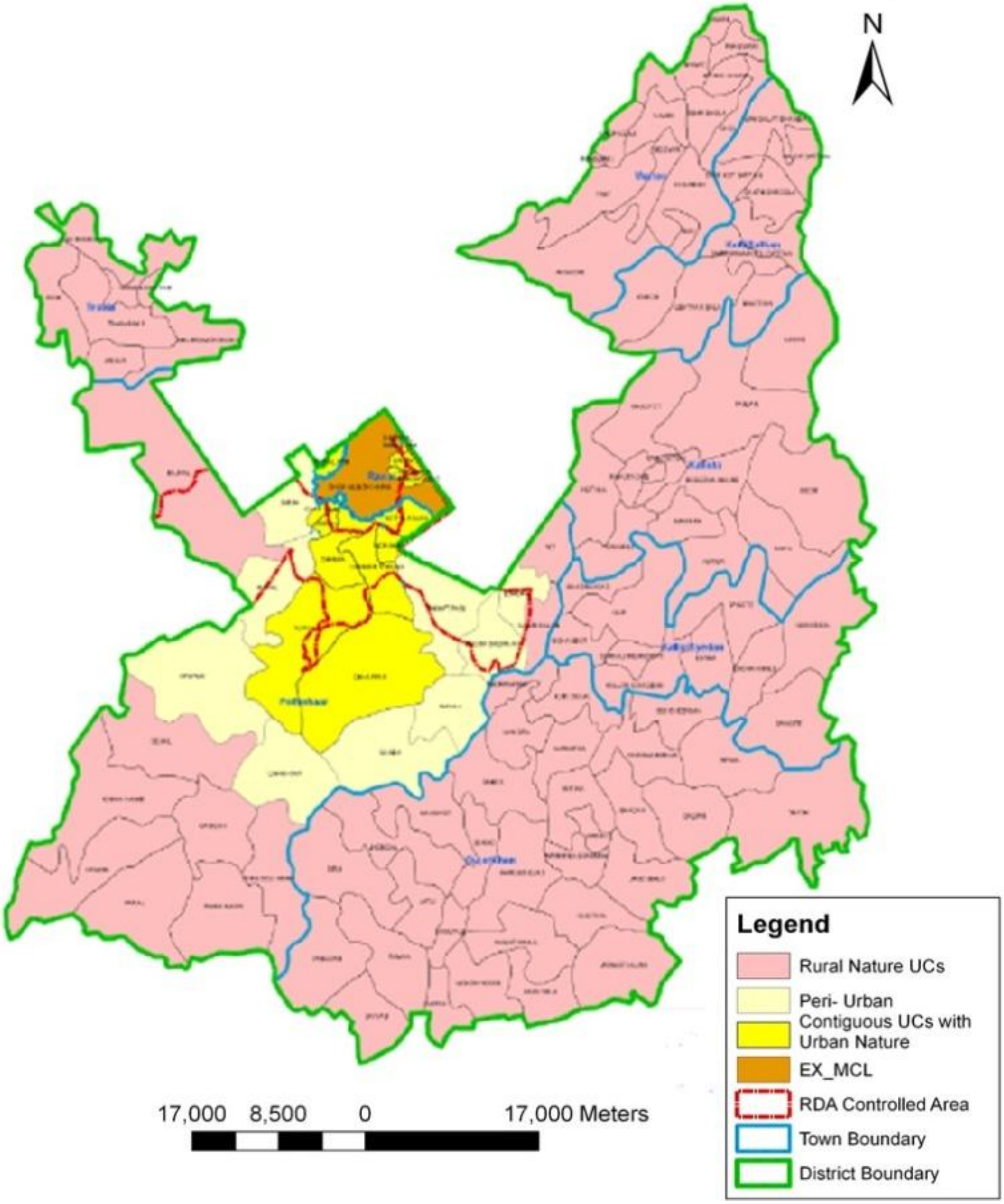


Figure 11: Urban and Rural Areas of Union Councils of Rawalpindi City Covered by RWMC

The Table 4 below shows different sectors and areas of Rawalpindi city in which solid waste management process is carried out by RMC.

Table 4: Sectors of Rawalpindi City with their Respective Areas

Sector	Area
A	Satellite Town
B	Mukha Singh
C	Banni Chowk, Ganj Mandi
D	Khayaban e Sir Syed
E	TMA Pothohar Town

3.6.7. The Problems Associated with the Current Landfill Sites of Islamabad and Rawalpindi and what is the Reason for that?

The Islamabad CDA is currently dumping waste in Sector I-12, but will not do so for long. The current open-dump site of Rawalpindi city was located at Kuri and has now been shifted to Losar Landfill near Rawat (an aerial distance is five kilometers from sector G-5 which is known as the nucleus of capital city Islamabad) but under the current planning exercise, RMC has decided to close this site and to find new sanitary landfill sites for the city. The areas in close proximity to landfill sites are getting contaminated. The air pollution caused results in a bad odor. People complain about health problems like malaria and fever, there is frequent illness amongst nearby residents. Also there has been an increase in the rate of mosquitoes, flies and other insects. The reason behind the inconvenience is due to the improper maintenance of the dumping sites. Waste is not segregated and there is no technical approach to it. There is a lack of properly managed landfill sites for the twin cities. There should be technically sound landfill sites. All the waste is simply dumped without segregation.

3.6.8. Complaint Registration System in Islamabad and Rawalpindi

There is 24/7 complaint registration cell or helpline where the people can set up complaints. Islamabad and RMC clear these complaints within three hours. Furthermore, there is a complaint register in the office to receive complaints and note down the complaints made by the public in person. These complaints are always attended to almost on the same day.

3.7. Methodology

The key point of the proposed study is GIS technology. GIS provides an effective mean to import, manage and analyze spatially based data. Methodology that will be used in this proposed study is described stepwise as follows:

- Geo-referencing the satellite imagery and topo-sheet (by using RS Technology) was done by using coordinates (Lat / long) of the known points in ArcMap 10.1.
- Data such as population density waste was generated; municipality boundary, road network, storage dustbin and collection vehicle details was digitized from high resolution satellite imagery and was also collected from the municipalities of Islamabad and Rawalpindi.
- Topo-sheet was collected from Survey of Pakistan for rectification of municipality map and road network map according to latitude and longitude.
- Feature class was created by digitizing urban areas / residential areas as well as the road network dataset from high resolution satellite imagery and then combining the Network Dataset with N-route vehicle tracking output. Digitizing is the process of converting features into the digital format and it is the one way of creating new data but there are

many ways to digitize new features such as automated digitization, heads-up digitization. We used the most common and interactive method of digitization i.e. heads-up digitization. In this method we displayed an aerial photograph or satellite image on screen as a base map and traced features such as roads, parcels and buildings from it.

- The network layer was created using the Build Network tool of NETWORK ANALYST in ArcGIS. In ArcMap, network dataset is displayed as a network layer. This network layer is responsible for storing symbology for edges, junctions, turns and system junctions and turns are only displayed if the network dataset supports the turns. Furthermore, network datasets can be previewed in ArcCatalog and in ArcMap, they can be displayed, symbolized, and queried.
- Geo-coding was performed on the network dataset and then roads were split to mark the junctions. The process of transformation of the location's description e.g. coordinates; name or address of a place into a location on the surface of the earth is called geo-coding. Geo-coding can be done by entering the description of one location at a time or by providing many locations at once in a table. The resulting locations are called geographic features with attributes and they can be used for spatial analysis or creating maps. One can easily and promptly find different kinds of locations through geo-coding such as house numbers with postal codes or street numbers and street intersections.
- Important locations such as landfill sites and collection points were mapped using hand held GPS. These will be used as "origin - collection point" and "destination - landfill sites" to find the shortest routes. Furthermore, the number of closest destinations from origin to destination was found.

- The optimized route/model for solid waste collection and disposal was developed with the use of Arc GIS 10.0 Network Analyst (NA) GIS software. It consists of the waste collection routing optimization for minimum time, distance, fuel consumption and gas emissions.
- Cost analysis and comparison with existing expenditure of the municipalities will then be analyzed. In the end, the Solve tool will be used to show the shortest paths for destinations.

The aforementioned steps and their sequence in the operations are shown in Figure 12.

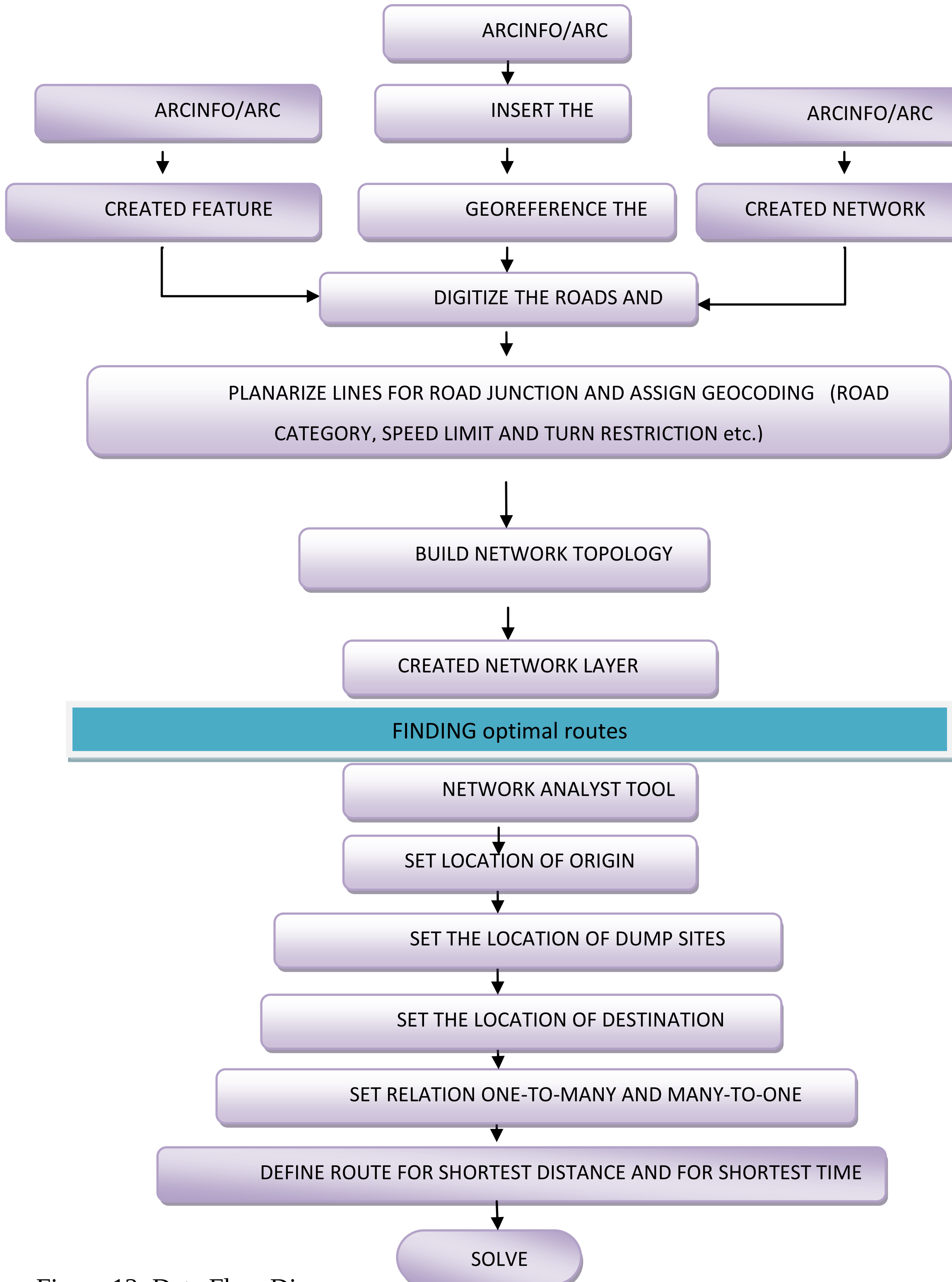


Figure 12: Data Flow Diagram

3.8. Statistical Analysis/Network Analysis

The collected data from waste collection and transport activities is examined as follows:

- The amount of time spent during each activity and in the particular route.
- Each vehicle per quantity of waste
- Speed of the vehicles and the distance the vehicles travel.

For time spent analysis, the operations of waste collection and transport are classified as follows:

- Running forward to the first collection point from the facility, e.g. parking.
- Loading of waste and moving between waste discharge points. Furthermore, running back from the last collection point to a facility or parking area and then unloading waste.

The time of operations was recorded manually by the defined classification. MapInfo was used to map and integrate the position data of disposal sites and transfer stations. For examination of the efficient operations of transfer stations that are focused on delay time, the evaluation was carried out e.g. arrival times of the vehicles and the relation between the vehicle arrivals and time spent in each activity.

3.9. Decision Support System

The quickly increasing generation of municipal solid waste has made a great impact on the environment; therefore various processes for waste management have been developed by researchers. It is essential to select economically viable and environmentally friendly methods for waste management (P. Haastrup, et al. 1998). The application of a DSS has become common in many applications relative to the growing study and research of DSS and has resulted in the development of a wide range of scientific problem-solving and model based methods for many decision problems (Chang & Wang, 1996). Diaz et al. (2006) defines DSS as a new generation of information system, the goal of which is to try to discover what would happen if a series of decisions are taken, or going further, by automatically providing the decision or suggestions that assist the users. In this study a decision support tool will be developed to assist the economic calculation of municipal solid waste management, using Application Programming Interface (API) to compare alternatives and select the best possible solution. In this field, many researchers Kunsch et al. (2002) have done much work generating a lot of outcomes; but currently very few of the outcomes concerning evaluation are developed based on computer technology. Since the development of information technology various applications using computer-aided systems or computer databases for municipal solid waste management have been established over many years (Fiorucci et al. 2003; Costi et al. 2004). Over the past many years, DSSs have been developed and successfully implemented in many subjects. However, the rapid increase of internet applications and technologies has opened new avenues for improving the traditional DSS (Amouzegarn & Jacobsen, 1998). In the present study, the DSS is meant primarily for economic evaluation of considered alternatives and is applied to select and evaluate different options for waste management. This last objective is achieved by an online DSS for the policy makers so that they can benefit from the power of GIS even if they don't have basic/prior knowledge. For this purpose, website has been launched where the users can be logged in and determines various factors which are important for decision making purposes. The website will be linked with API The user can log into the website which asks for the user name and password, after entering the correct user name and password, one can further view the "HOME PAGE" of the website. On the home page, there is a tab option to click to view the main page of the site. Therefore, the DSS provided with GIS helps planners to understand the spatial nature of particular programs and how they may impact the public and the environment.

3.9.1. Structure of Decision Support System

The structure for the web-based DSS for SWM is as follows:

3.9.1.1. Data Conversion

Firstly, all the input data and the output of previous objectives was converted from shape-files, which are non-topological format for storing geometric location and attribute information of geographic features, to Google support Keyhole Markup Language Zipped (KMZ) with a compressed version of Keyhole Markup Language (KML). KMZ files contain placemarks featuring a custom name, the longitudinal and latitudinal coordinates for the location. KMZ files can be opened by Google Earth or unzipped with a compression utility such as Winzip on Windows, MacZip for (Macintosh users) and Zip and Unzip for UNIX systems. Furthermore, Google Earth provides a drastic improvement over previous inventions of geospatial visualization applications and a significant application of Google Earth is the KML. This is a format in which users can provide their own data so that it can be visualized in the Google Earth application. Thus, it will give the advantage that geospatial data will be easily visualized for our current study.

3.9.1.2. Web-Based System

Secondly a website will be developed from where the Google Application will be launched. The user of the online DSS does spatial queries to find areas of interest such as existing routes, optimized routes, collection points, existing landfill sites and proposed landfill sites. The user is also able to upload his/her geospatial dataset and measure distances online. This component helps incorporate the development in residential and road networks in the particular area. Additionally, an algorithmic model, built with the use of Excel spreadsheets was constructed and embodied in the DSS tool for the estimation of the generated quantities of categorized solid waste from a building. This information can be used by the power and fertilizer generation companies.

3.9.1.3. Online Analysis Functionality

Lastly, online functionality is provided to the users (with no practical GIS knowledge) of this proposed system to perform analysis on the spatial data presented. The functionalities are draw, measure buffer analysis and upload locational data. The user is able to draw lines, polygons, free hand polygons and ellipse on various places on the map shown and is able to o obtain distances and areas with a single click as shown in the Figures 13-15.

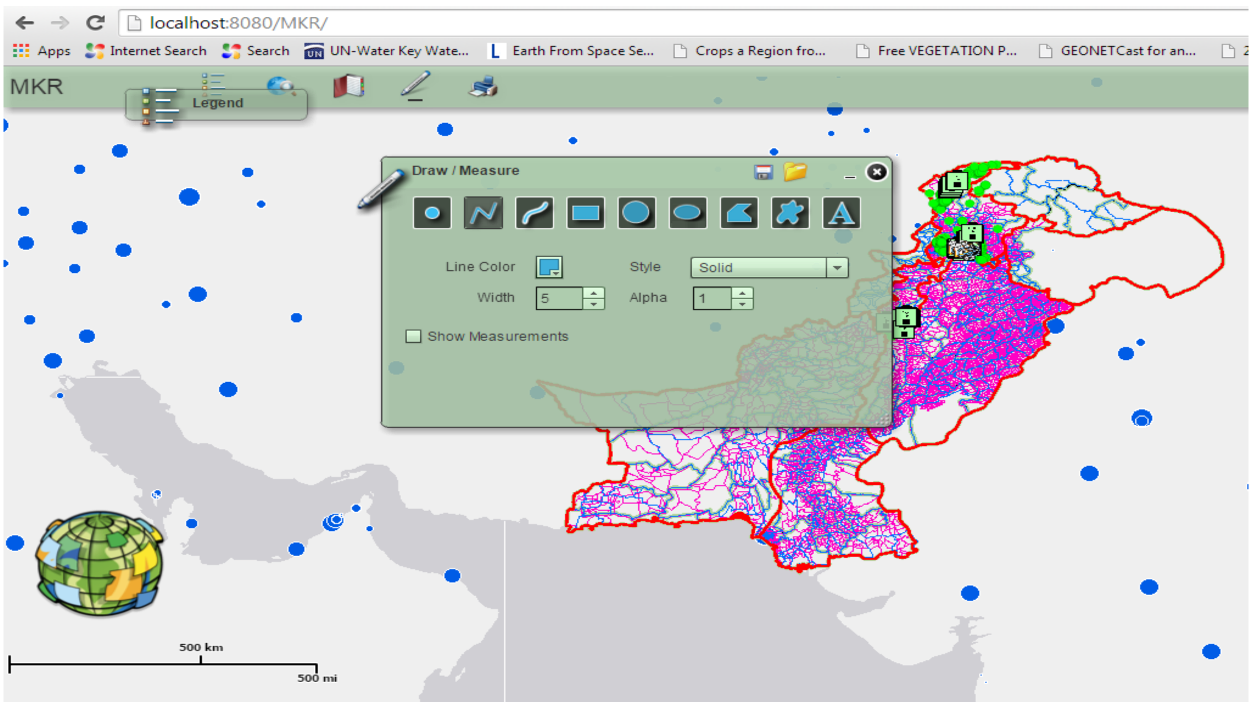


Figure 13: Proposed Draw/Measure Functionality

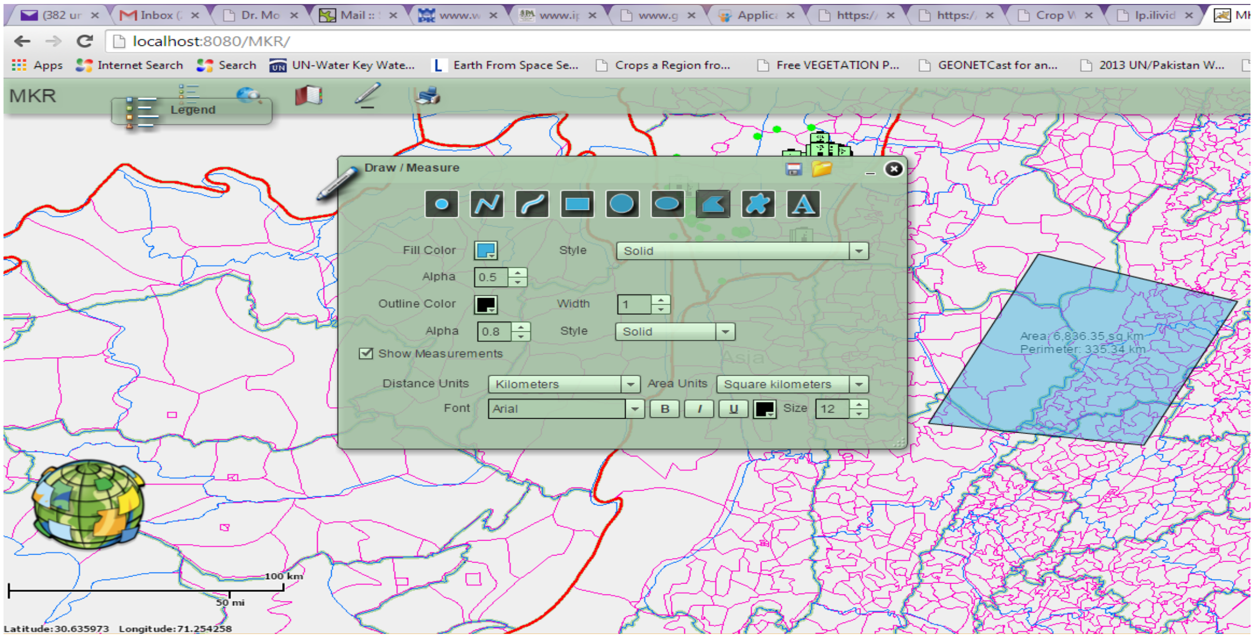


Figure 14: Calculating Area of a Polygon

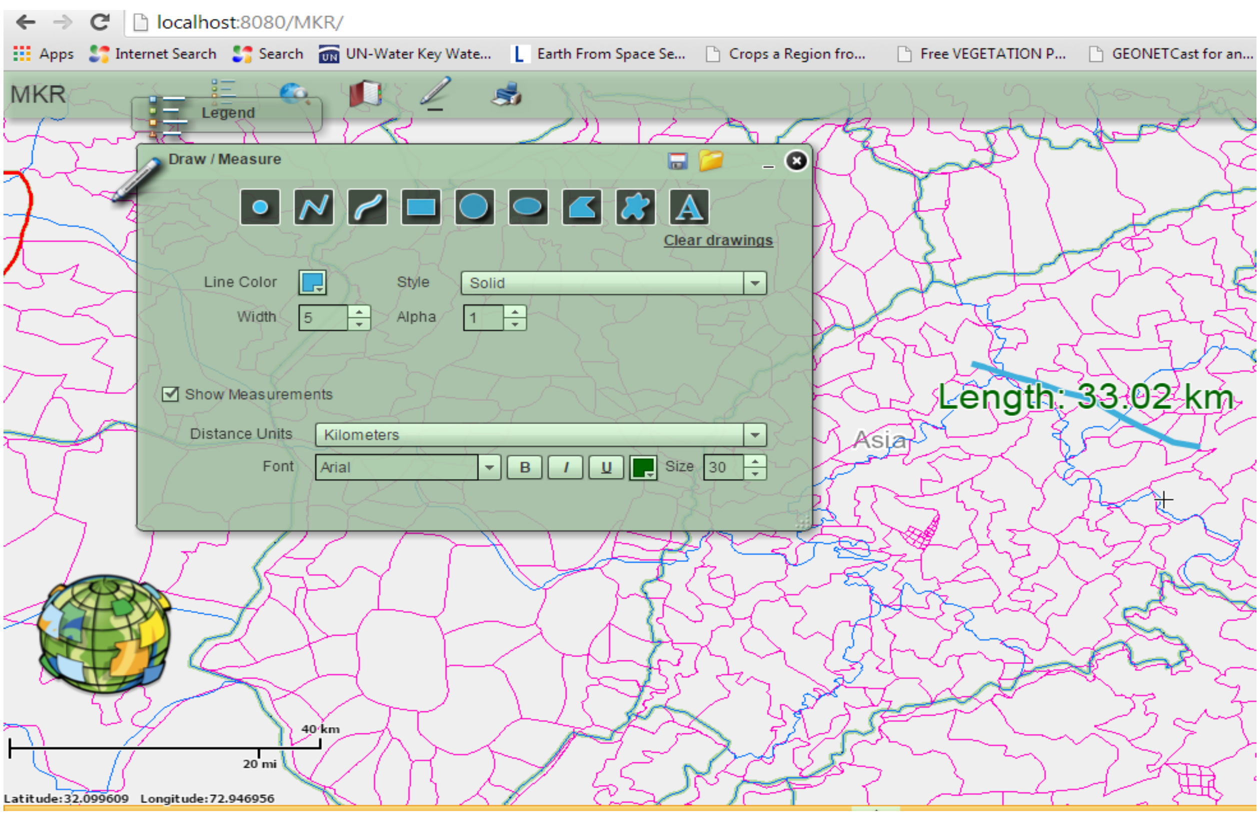


Figure 15: Calculating Length of a Line Feature

The interdependencies of the aforementioned structural components are captured in the following proposed conceptual model of the online DSS in Figure 16.

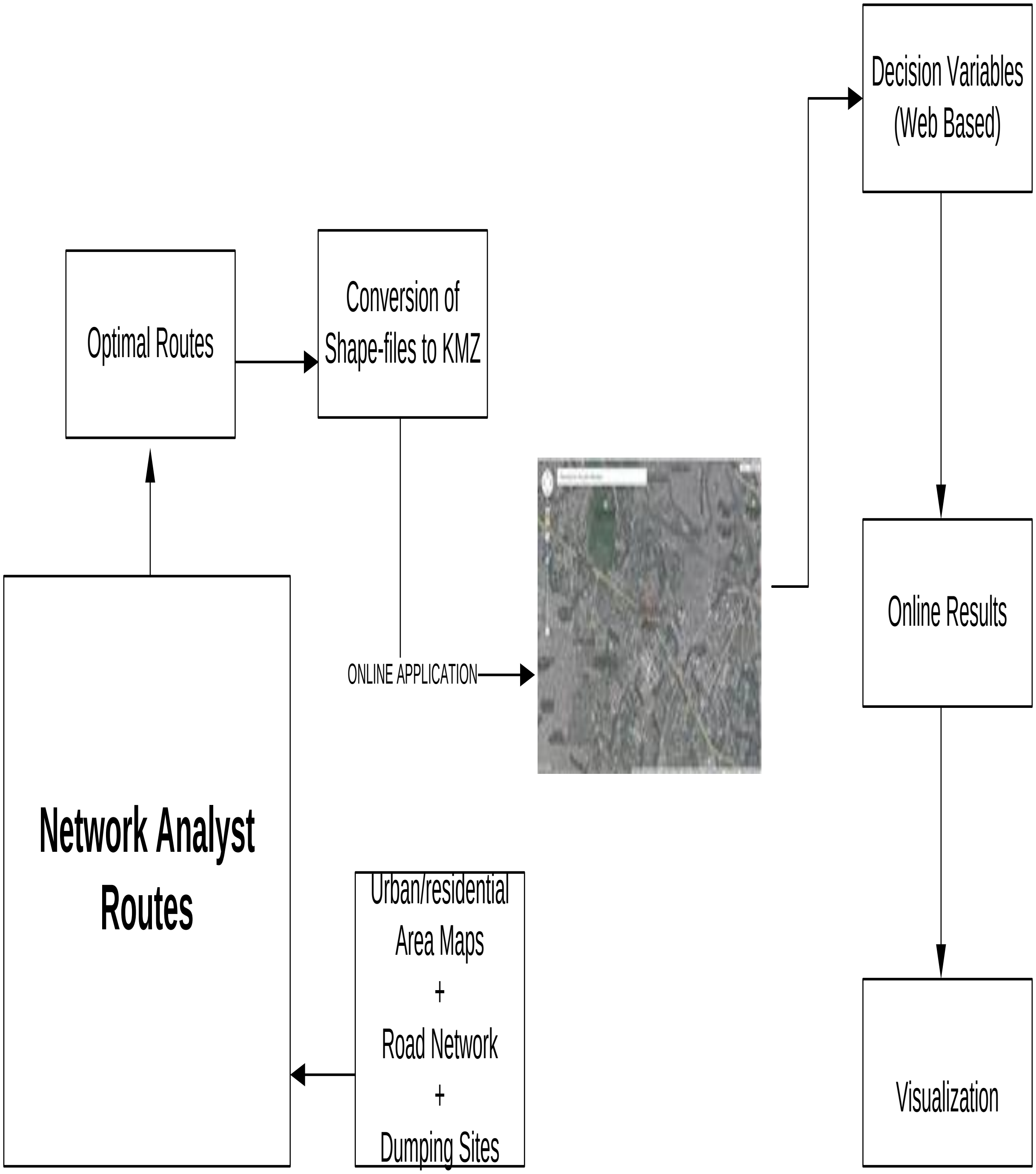


Figure 16: Framework of Online DSS

4. RESULTS & DISCUSSION

This chapter discusses overall results of the current study and shows how the municipalities of Islamabad and Rawalpindi and decision makers might benefit from the generated results and information. The rest of the chapter analyses and describes the data. It attempts to shed light on the contextual purpose and issues addressed by the study. The following sections of this chapter highlight different issues of solid waste management in the twin cities. Firstly, the results from configuring and running the Network Analyst of ArcGIS for new and existing routes are reviewed and are further compared for cost effective purposes regarding time and distance. The findings from this study were mapped and provided a comparison of the results obtained from both scenarios. Secondly, our present study has proved that GIS is a tool that can be used in integration with other evolutionary techniques such as MCE for a number of different planning tasks such as identifying new landfill sites and it can help decision makers deal with real-world developmental and management issues. Furthermore, this chapter emphasizes the role of GIS in urban growth management and land-use planning for effective decision making. The use of GIS for evaluation of future waste disposal sites in the current study has been shown to save time when there is a need for fast evaluation. Thus, GIS-based technology provides high-tech analytical tools to analyze the data spatially and to make more informed decisions.

Finally, the study has developed a Wed-Based Decision Support System (DSS) via Application Programming Interface (API) which will help decision-makers to search for cost-effective alternatives and it can be operated by the people who don't have knowledge of or background in GIS.

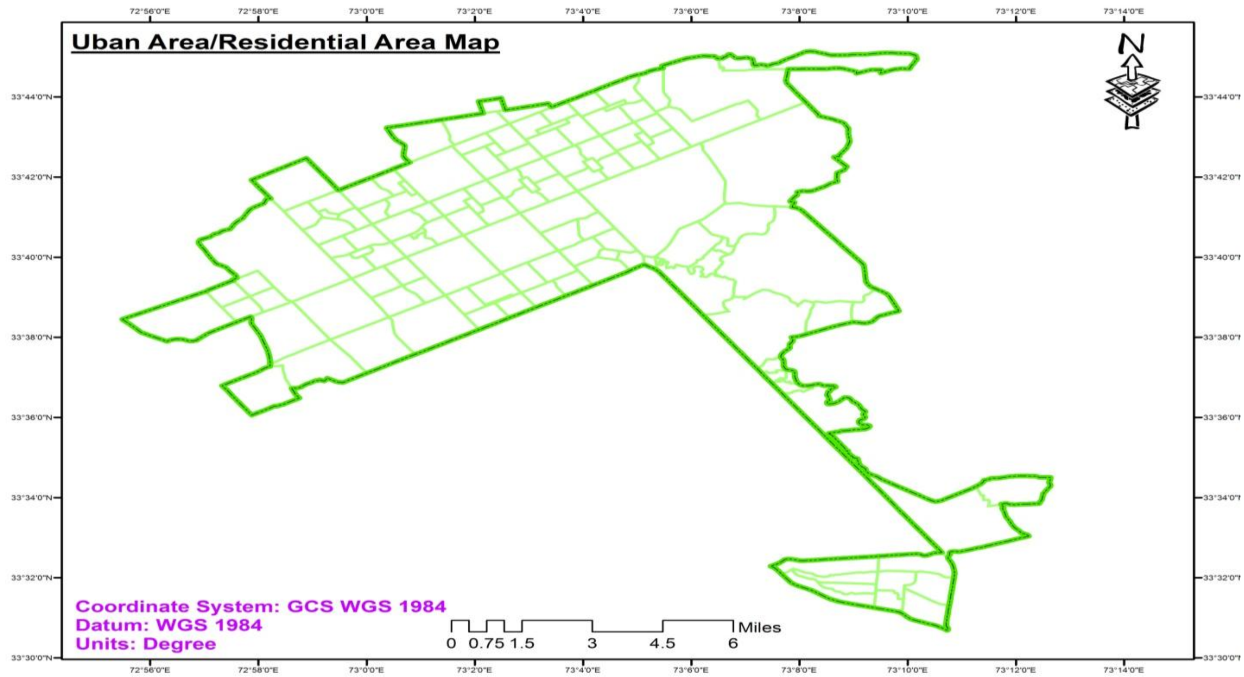
4.1. Result 1-Route Optimization of Collection and Transportation of Waste

4.1.1. Urban Area/Residential Area Map

The United Nations Centre for Human Settlements, 2003 reports that "more than one billion people in the world live in slums and squatter settlements without adequate shelter and basic services. Worldwide, slums are considered to be residential areas in urban geographic areas that are inhabited by the poor. Because of these characteristics, urban planners can use GIS to manage geographic data about slum areas to show relationships, elevations, landmarks, slope, water sources, and other attributes that affect these urban populations".

Therefore, an urban area map for Islamabad and Rawalpindi was developed using high resolution satellite imagery (Geo Eye, Quick Bird and World View) downloaded from Google Earth and existing boundary extents which were obtained from population census organization of Pakistan; CDA of Islamabad and Municipal Corporation of Rawalpindi. The global high resolution satellite imagery was developed during the cold war for military use and today professionals are reaping the benefits of satellite imagery for a wide range of applications such as emergency response planning, airport mapping; homeland defense and national security; urban planning and development; land use mapping, planning, change detection and zoning administration and land cover. Google Earth (GE) collection represents a quick and cost-free resource for mapping urban areas. The Quick bird satellite, a high resolution commercial satellite launched in 2001, is the primary source for high-resolution GE imagery (Potere et.al, 2009). Therefore, our study has made use of the satellite imagery for mapping the urban/residential areas of Islamabad and Rawalpindi city. Thus, the generated urban area map of Islamabad city and Rawalpindi city are shown in Figure 17(a) and Figure (b).

(a)



(b)

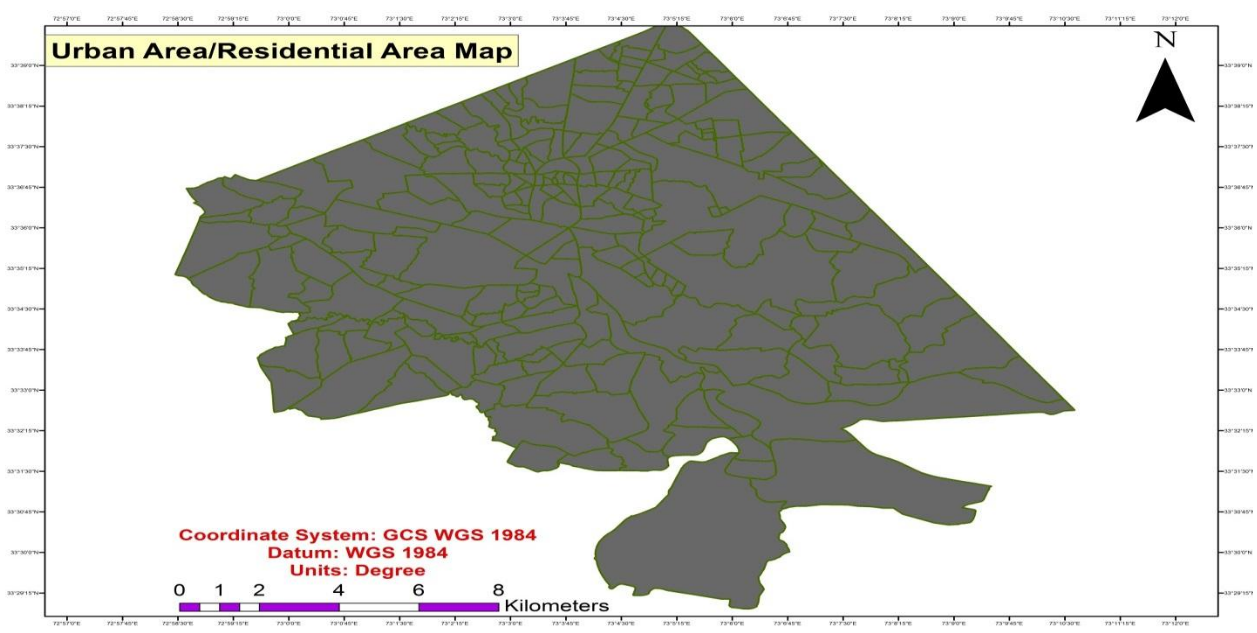
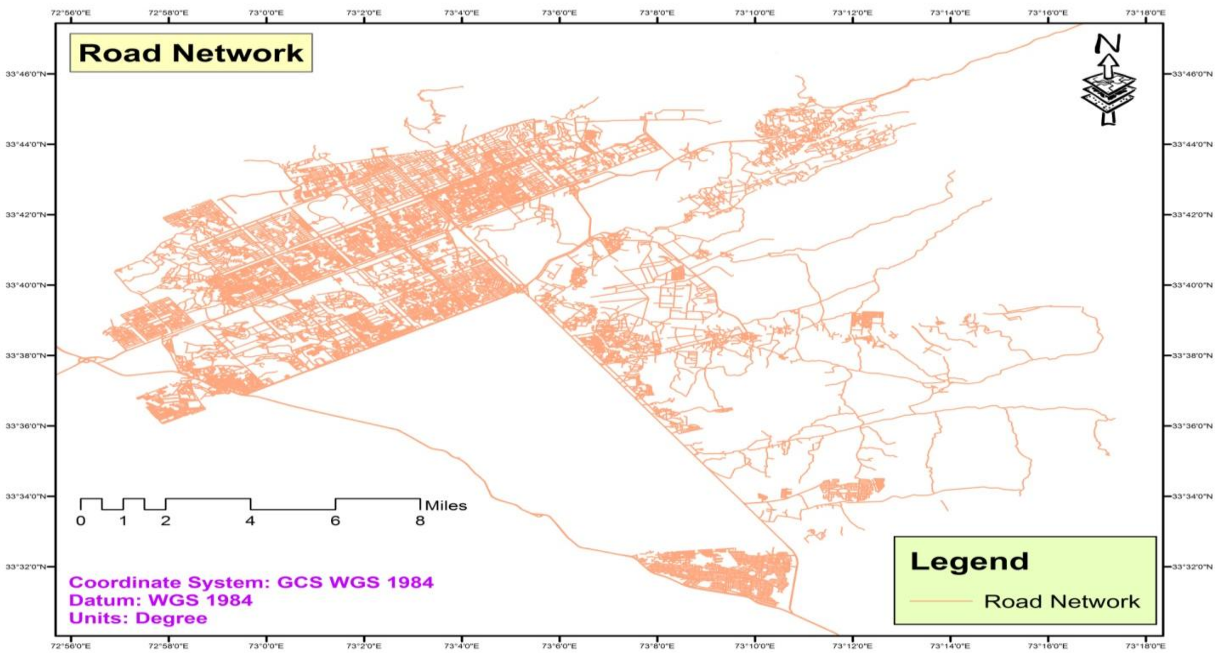


Figure 17: (a) Generated Map of Urban/ Residential Areas of Islamabad, Pakistan; (b) Generated Map of Urban/ Residential Areas of Rawalpindi, Pakistan

4.1.2. Road Network

The road network was the most essential data required for the study. The road network of Islamabad and Rawalpindi city was generated using vehicle N-route tracking with Global Positioning System (GPS) and satellite imagery by vectorization tools using ArcInfo. GPS is based on a constellation of 24-48 satellites orbiting the earth at very high latitude and GPS can be taken into the field to record data. Recent advances in GPS technology are very effective in cutting costs and reducing time in field data collection over-the-road travel distances are measured precisely by GPS. Therefore, digitized road networks (including all main roads and streets) of the study area are from geo-referencing high resolution satellite images of Islamabad and Rawalpindi. Images were used as a background for vector files and transparent overlay, for verification of the digitization results. After digitization of road networks we created topology networks to remove errors incurred during digitization. The generated road networks of Islamabad city and Rawalpindi city are shown in Figure 18(a) and 18(b). When the road network was planarized during topology creation, the junctions of all roads in the networks for Islamabad and Rawalpindi city were generated and are shown in Figures 19(a) and 19(b) respectively. These junctions are those points where the lines or roads, intersect and hence are important variables in the present study as these are turns, roundabouts and ramps.

(a)



(b)

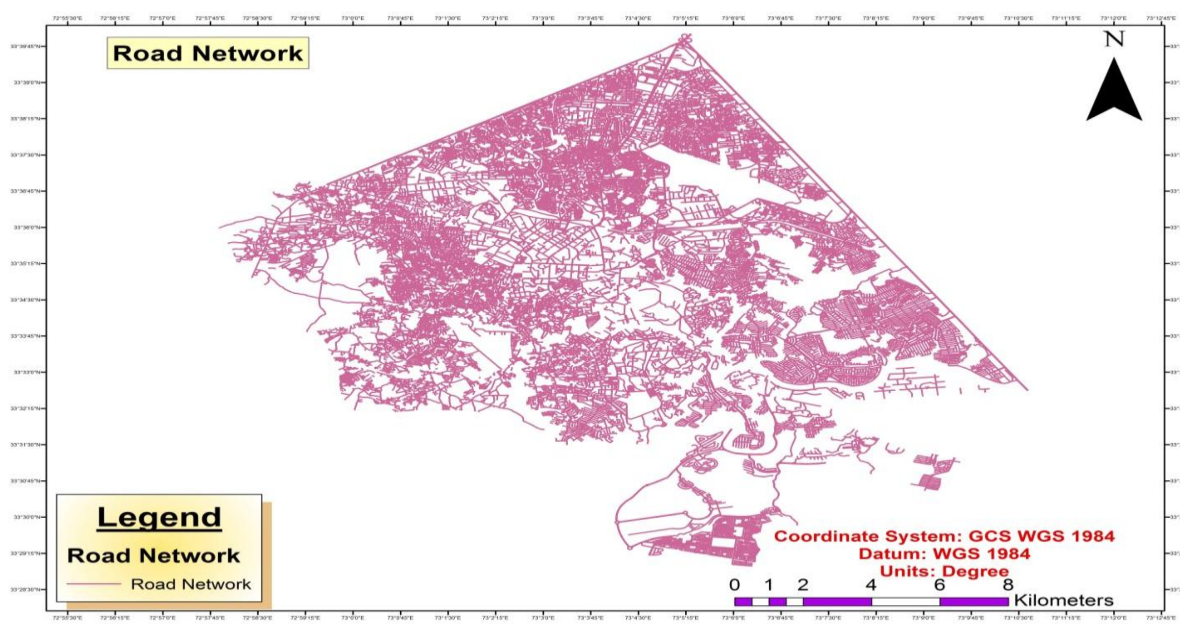
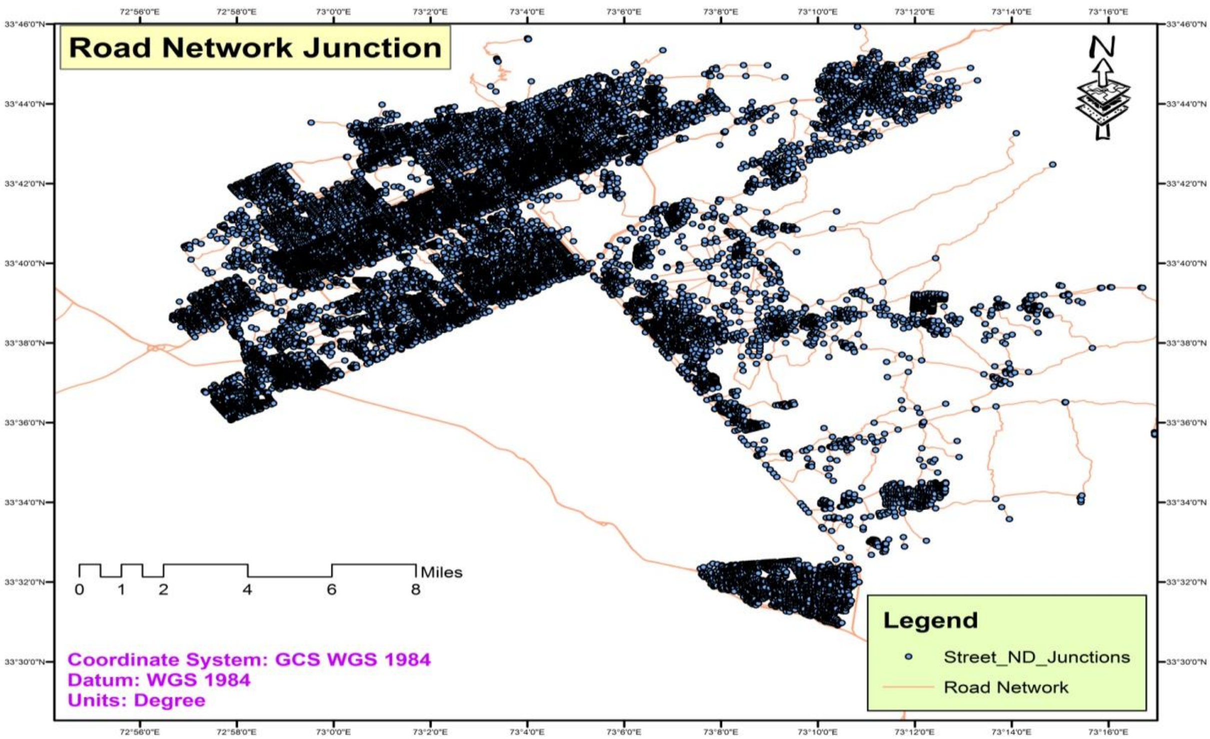


Figure 18: (a) Generated Road Network of Islamabad, Pakistan; (b) Generated Road Network of Rawalpindi, Pakistan

(a)



(b)

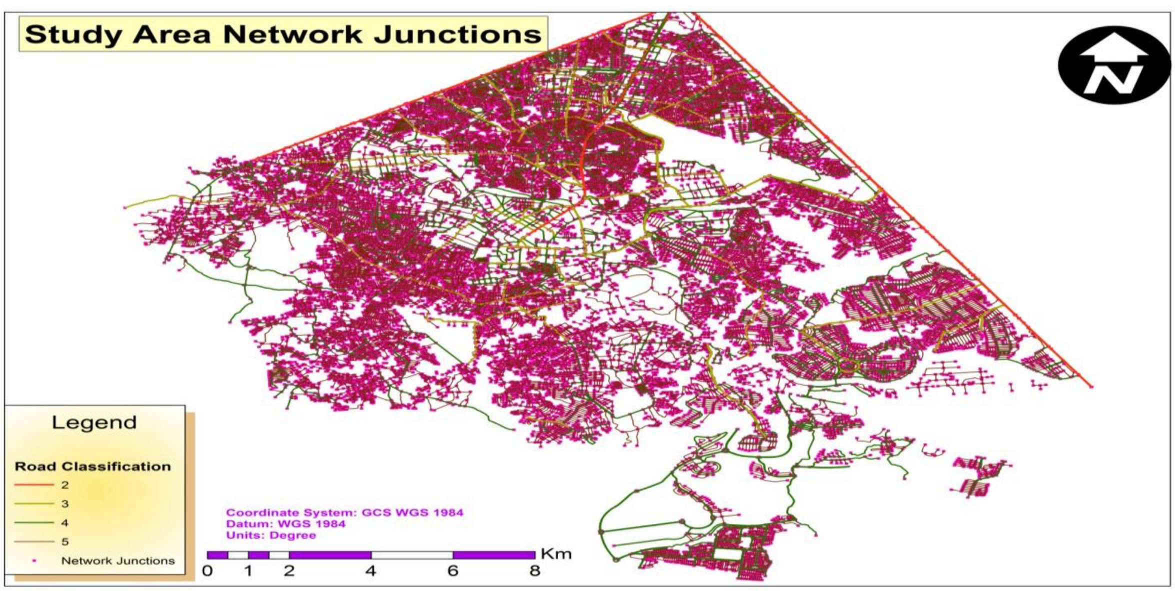


Figure 19: (a) Road and Street Junctions of Islamabad, Pakistan; (b) Road and Street Junctions of Rawalpindi, Pakistan

4.1.3. Road Classification/Functional Class

A Functional Class defines a hierarchical network used to determine a logical and efficient route for travelers are appended below in the Table 5:

Table 5: Functional Class Levels for Islamabad and Rawalpindi

1.	**Level /Class1**	Motorway
2.	**Level /Class 2**	Highways / City Main Arteries are all Highways passing through the city and will remain the part of the Main Classification.
3.	**Level /Class 3**	All Regional Roads /for inside cities: normal roads connected to city main arteries.
4.	**Level /Class 4**	1-way and 2-way Roads in Cities where traffic volume is < (Level 3 Main Arteries in City).
5.	**Level /Class 5**	Level /Class 5 comprise all roads within colonies, towns and sectors which are not used by outsiders.

4.1.3.1. Functional Class Usage

This can be used to determine sets of links that form connected graphs. The arterial network is connected. Each link has at least one connection in the network to every other link with the same Functional Class via a link with the same or higher functionality.

4.1.3.2. Functional Class 1

Roads allow for high volume, maximum speed traffic movement between and through major metropolitan areas. This class is applied to roads with very few, if any, speed changes. Access to the road is usually controlled.

4.1.3.3. Functional Class 2

Roads are used to channel traffic to Functional Class 1 roads for travel between and through cities in the shortest amount of time. This Class is applied to roads with very few, if any speed changes that allow for high volume, high speed traffic movement.

4.1.3.4. Functional Class 3

This class will be applied to roads which interconnect Functional Class 2 roads and provide a high volume of traffic movement at a lower level of mobility than Functional Class 2 roads.

4.1.3.5. Functional Class 4

This class will be applied to roads which provide for a high volume of traffic movement at moderate speeds between neighborhoods. These roads connect with higher functional class roads to collect and distribute traffic between neighborhoods.

4.1.3.6. Functional Class 5

This class will be applied to roads whose volume and traffic movement are below the level of any functional class. In addition, walkways, truck only roads, bus only roads, and emergency vehicle only roads receive Functional Class 5.

4.1.3.7. Speed Category

Speed Category classifies the general speed trend of a road based on posted or legal speed and is provided to enhance route calculation and the timing of route guidance. Speed Category values represent the combination of several factors besides legal speed limit (e.g., physical restrictions or access characteristics) and are shown in the Table 6:

Table 6: Speed Limits for Respective Functional Class Levels

Functional Class	**Speed Limit**
Function Class 1	120 KPH
Function Class 2	70-100 KPH
Function Class 3	50-65 KPH
Function Class 4	40-50 KPH
Function Class 5	30-40 KPH

4.1.3.8. Direction of Travel

Direction of Travel identifies legal travel directions for a navigable link.

- B - Both Directions
- F - From Reference Node
- T - To Reference Node

Usage: Direction of Travel enables correct route calculation, route guidance, and map display. For example, display of one-way icon.

Specification: The Direction of Travel is determined based on each individual link as shown in the Table 7. Links within the same one-way road may have a different Direction of Travel value because of the relative positions of the reference and non-reference nodes. Figures 20(a) and (b) show the directions of travel in the road network of Islamabad and Rawalpindi cities.

Table 7: Direction of Travel

Direction of Travel	**F**	Is applied when the direction of travel is one way from the reference node to the non-reference node.
Direction of Travel	**T**	Is applied when the direction of travel is one way to the reference node from the non-reference node.
Direction of Travel	**B**	Is applied when travel is allowed in both directions between the reference and the non-reference nodes.

(a)

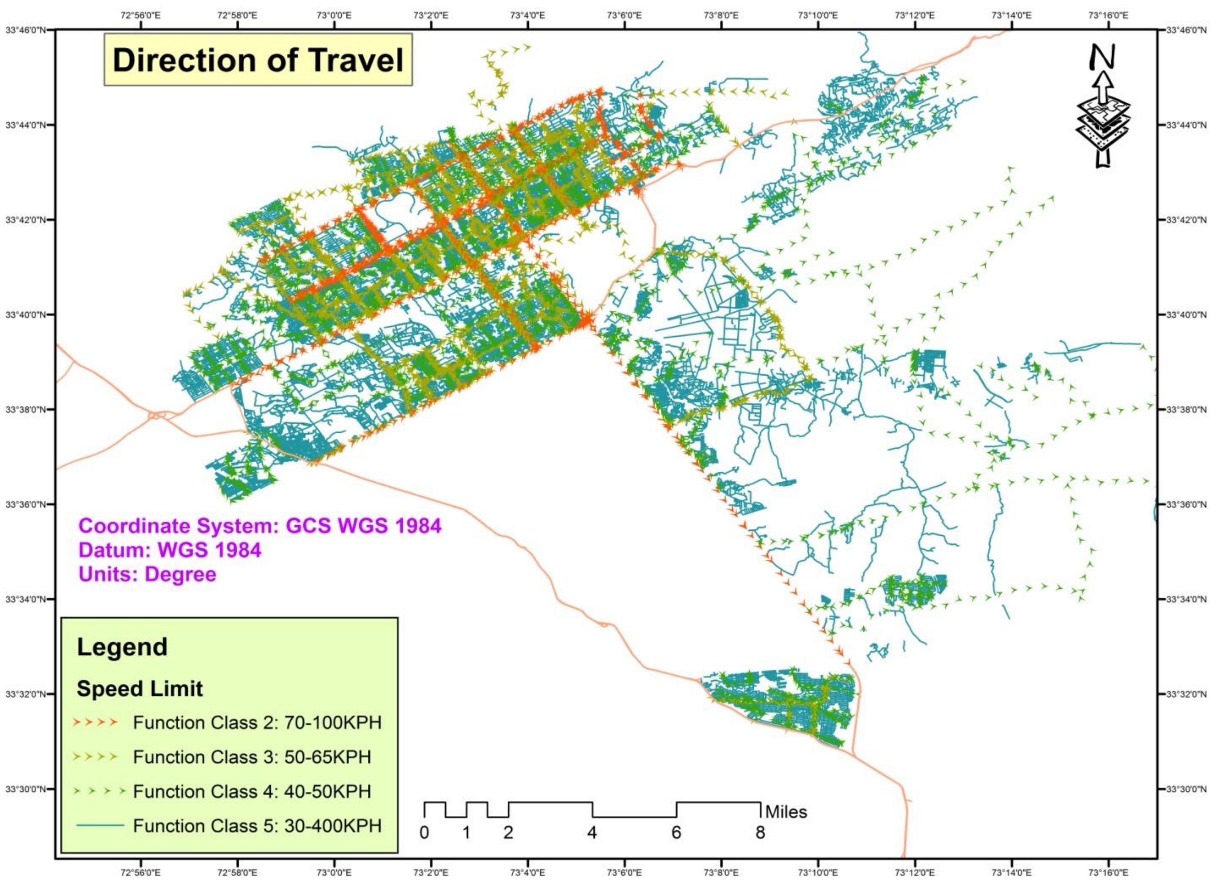


Figure 20: (a) Road Network of Islamabad, Pakistan According to Direction and Speed of Travel; (b) Road Network of Rawalpindi, Pakistan According to Direction and Speed of Travel

(b)

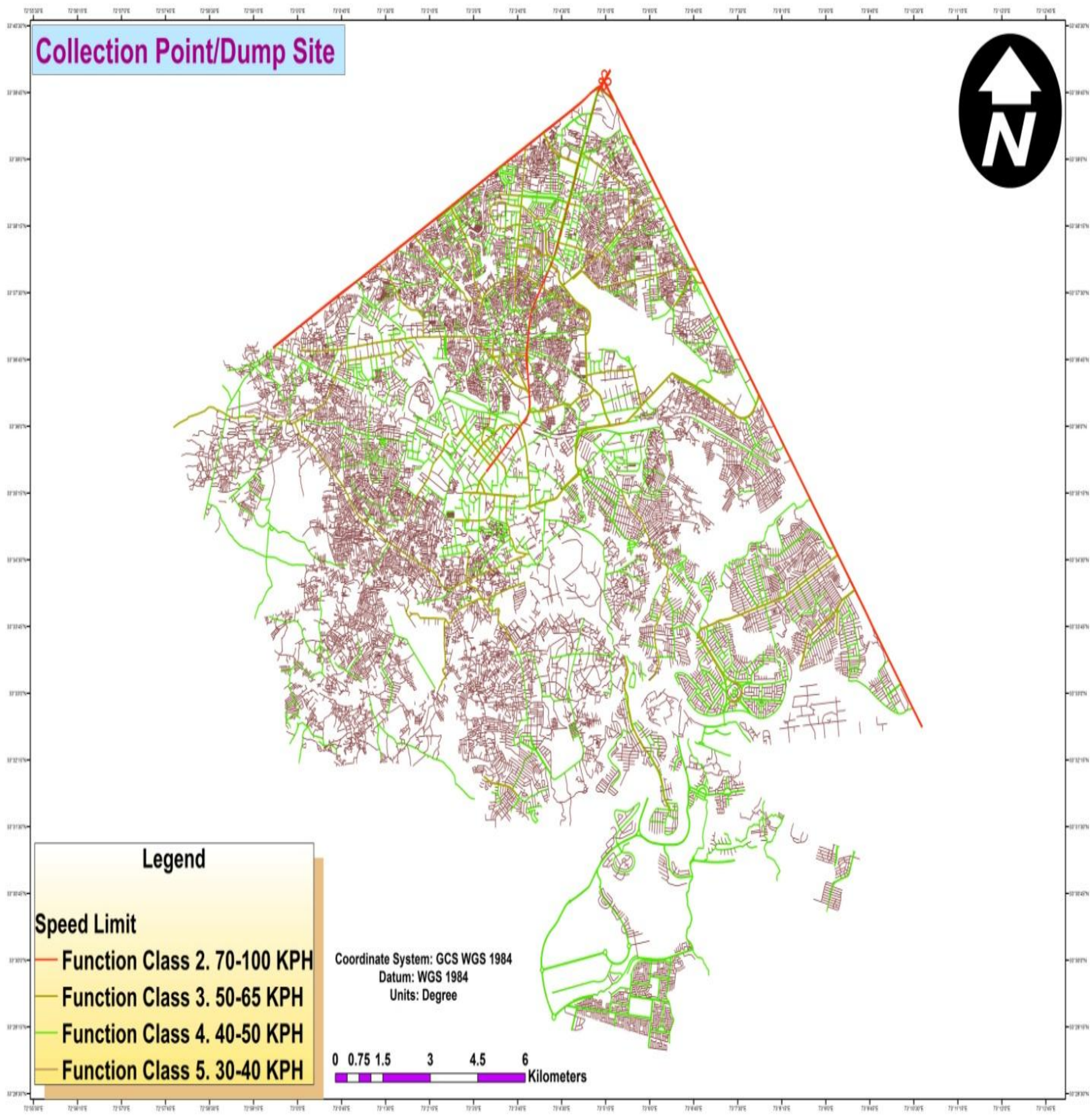


Figure 20: (a) Road Network of Islamabad, Pakistan According to Direction and Speed of Travel; (b) Road Network of Rawalpindi, Pakistan According to Direction and Speed of Travel (continued)

4.1.4. Collection Points/Dump Sites

The collection points of solid waste were mapped by high resolution GPS devices. The latitude and longitude for each collection were recorded and mapped in ArcGIS using add XY data tool. The collection points in Islamabad and Rawalpindi cities are shown in figures 21 (a) and (b).

(a)

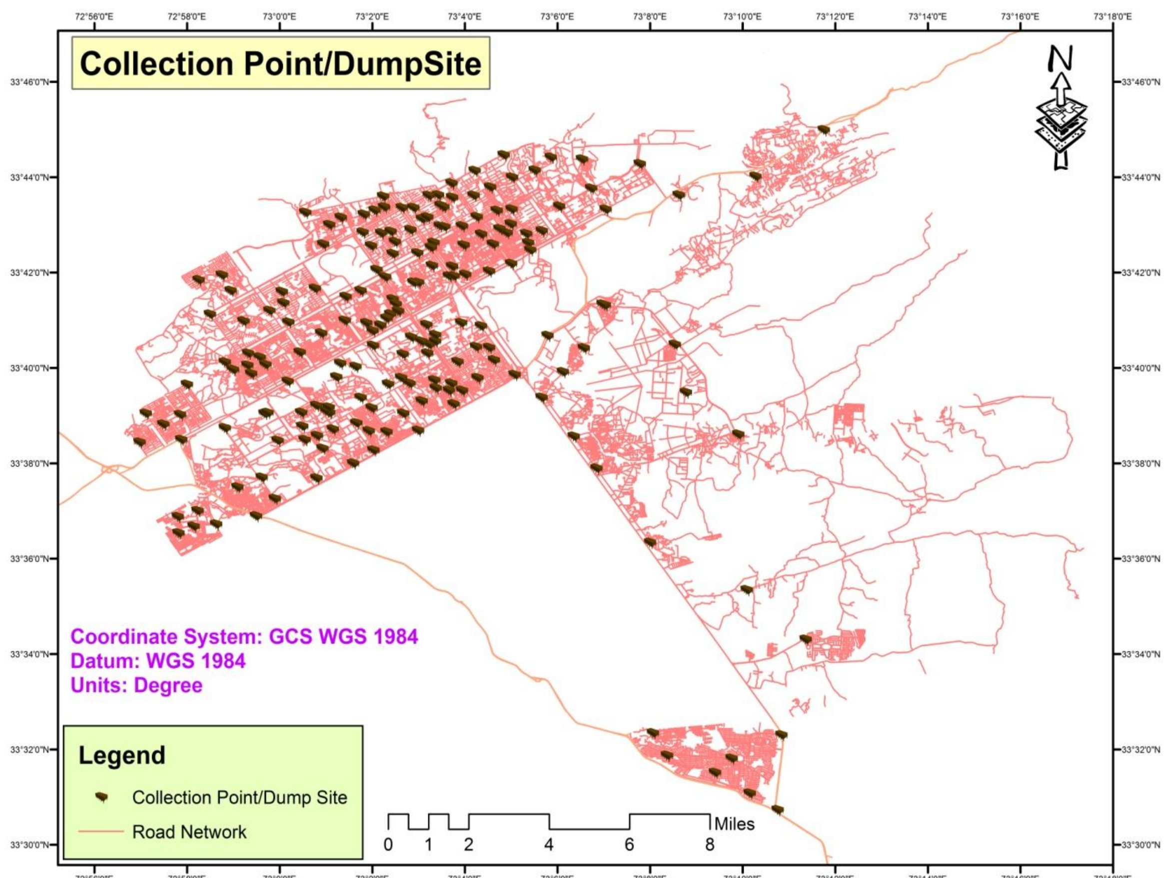


Figure 21: (a) Map of Solid Waste Collection in Islamabad, Pakistan; (b) Map of Solid Waste Collection in Rawalpindi, Pakistan

(b)

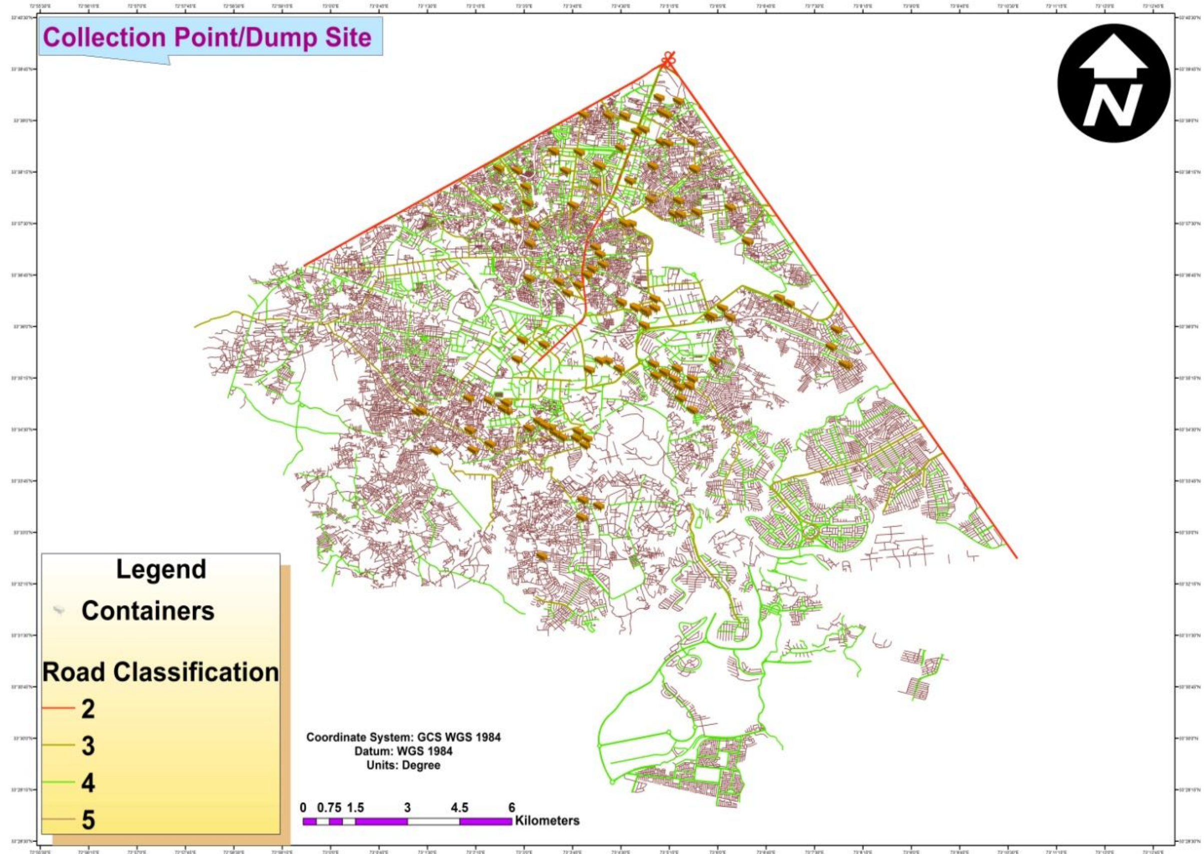


Figure 21: (a) Map of Solid Waste Collection in Islamabad, Pakistan; (b) Map of Solid Waste Collection in Rawalpindi, Pakistan (continued)

4.1.5. Mapping Landfill

The collection points of solid waste were mapped by high resolution GPS devices. The latitude and longitude for each landfill site were recorded and mapped in ArcGIS using add XY data tool. There are two dump sites in Islamabad and Rawalpindi shown in figures 22a and 22b.

(a)

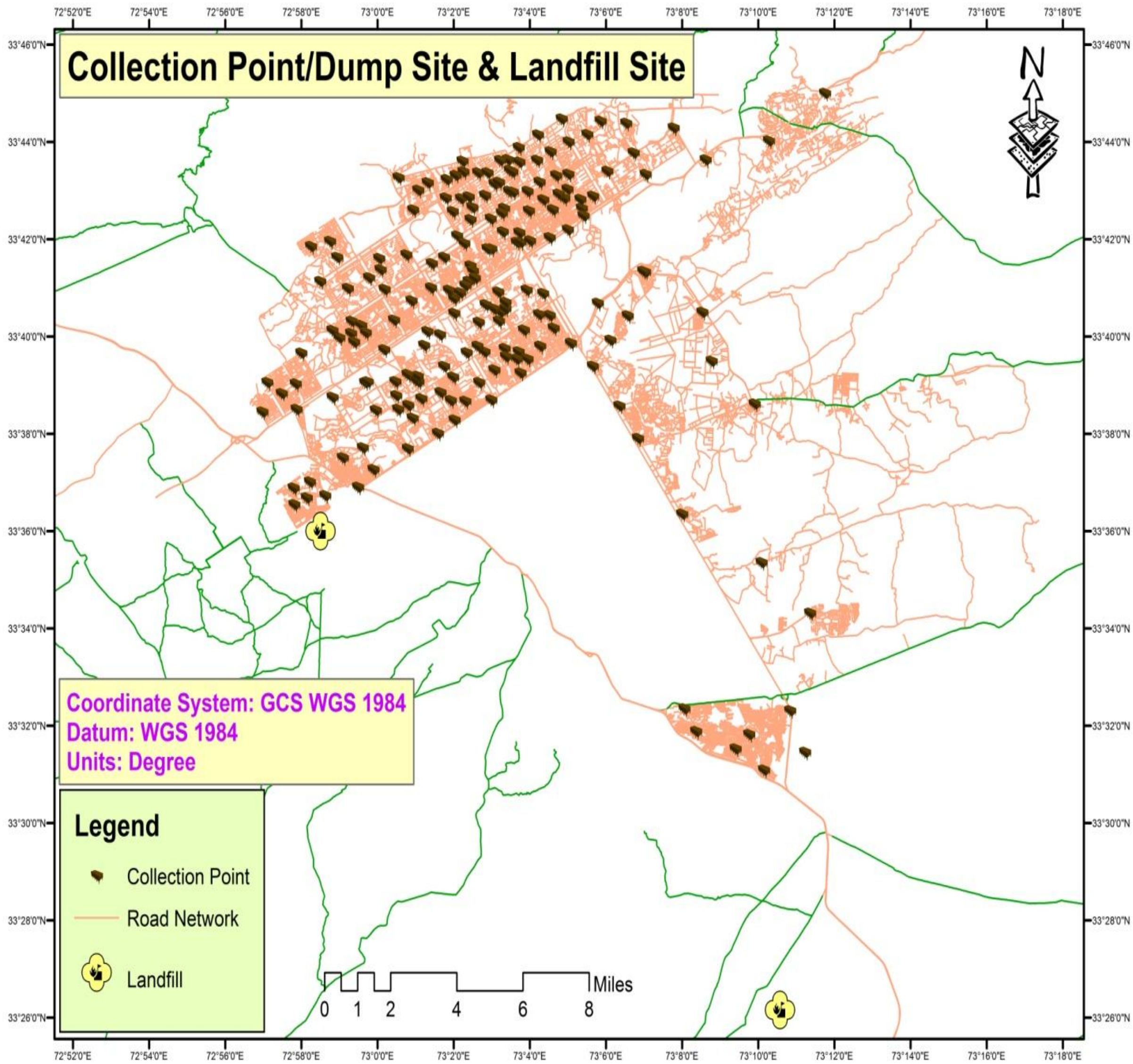


Figure 22: (a) Map of Solid Waste Collection Points and Landfill Sites in Islamabad, Pakistan; (b) Map of Solid Waste Collection Points and Landfill Sites in Rawalpindi, Pakistan

(b)

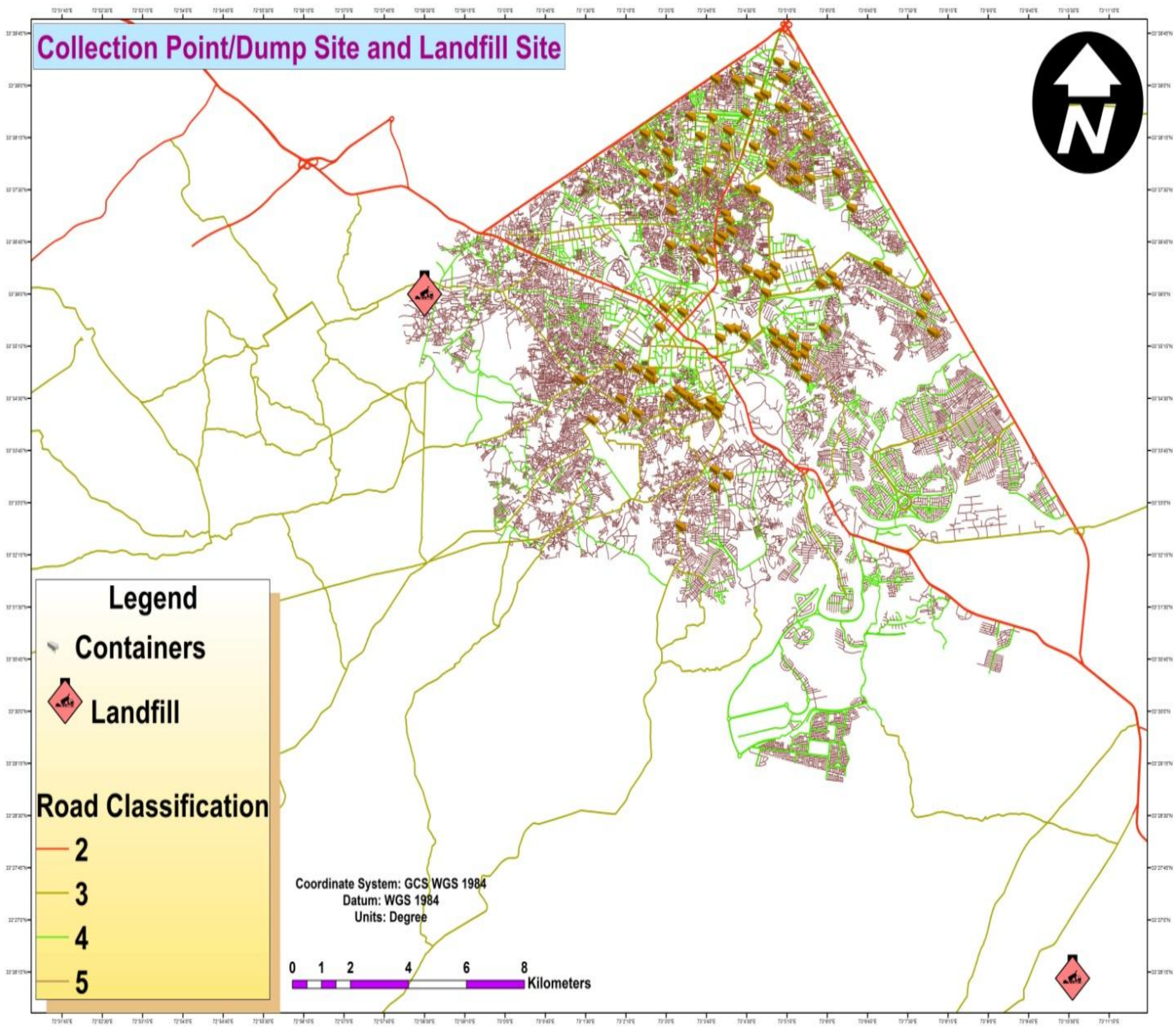


Figure 22: (a) Map of Solid Waste Collection Points and Landfill Sites in Islamabad, Pakistan; (b) Map of Solid Waste Collection Points and Landfill Sites in Rawalpindi, Pakistan (continued)

4.1.6. Route Optimization by Distance

4.1.6.1. Routing

"It has been estimated that, of the total amount of money spent for the collection, transportation, and the disposal of solid waste, approximately 60-80% is spent on the collection phase" (Karadimas, Doukas, Kolokathi, & Defteraiou, 2008, p. 2022). This provides an immense and big prospect for the current study to be conducted and to come up with better and reduced costs for the solid waste management procedures. Local municipal authorities have duties for the collection and disposal of waste. However, solid waste management consists of the production, collection, transport, treatment, and disposal of solid waste from a facility (Modak, 1996). All these factors are very important both for the people and environment. Municipal authorities have to make important decisions in order to manage household waste and these decisions impact expenditures. The expenditure sale comprised of high costs to operate and maintain the municipal fleet, exhaust gas emissions such as carbon dioxide, fuel consumed and the number of miles driven which in turn leaves a negative impact on the environment. In order to overcome these problems and cost, the municipal authorities are suppose to make effective decisions which can influence the quality of service in a positive manner offered to people and in return the environment can be protected from the waste pollution in the future. These positive decisions will come from the route optimization for the solid waste collection by using GIS and different types of mathematical algorithms. For measuring, path length is mainly used by the routing algorithms in order to determine an optimized route or an ideal route to a defined destination. Routing means finding the quickest, optimal or shortest path depending on the type of impedance, e.g. time or cost, we choose to solve for. Hence the best route can be defined as the route that has the lowest impedance. Any valid network cost attribute can be used as the impedance when determining the best route. The optimal routes are then determined by comparing the different paths.

4.1.6.2. Network Analysis

Network Analyst is a powerful extension of ArcGIS that provides network-based spatial analysis comprising travel directions, routing to the closest facility, and service area analysis.

With the help of Network Analyst users are able to dynamically model realistic network conditions e.g. speed limits, height restrictions, turn restrictions and traffic conditions during the different times in a particular day (Lakshumi et al 2006). Therefore, in terms of distance and time criterion, the final result will be an optimal solution. The Network Analyst allows a user to perform Find Best Route in order to solve a network problem by finding the least cost impedance path on the network from one stop to one other stop or from one stop to many stops (Stewart 2004).

The Network Analyst extension helps users to do the following:

- Find efficient travel routes and decide which facility is nearby
- Create travel directions and find a service area around a site.

Network Analyst key functions include:

- Establish a network with current GIS data.
- Detect closest facilities.
- Produce a travel network cost matrix.
- Define optimal facility positions using location allocation.
- Use time windows in vehicle scheduling.
- Establish shortest routes to travel.

In this research, Network Analyst will be used to find the optimal route for the collection of waste. The ArcGIS Network Analyst extension uses the routing solver based on Dijkstra's Algorithm developed by Edgar Dijkstra which is an efficient algorithm that finds the shortest or lowest cost path between two points or determines the best optimal path (Dijkstra, 1959).

This section discusses how the Network Analyst tool was used to build new collection routes and explain in detail the workflow, properties, settings and data used for route analysis and construction. At present, many other routing algorithms such as Simulated Annealing, Tabu Search and Genetic Algorithm have been developed, but Dijkstra's algorithm is the simplest path finding algorithm as compared to other contemporary algorithms because it reduces the amount of time and effort required to find the optimal or best path (Sivanandam, et al 2009). The Network Analyst tool is comprised of routing solvers such as Route, Closest Facility and OD Cost Matrix solvers and all of these solvers are based on the Dijkstra's algorithm for finding shortest paths (ESRI,2006) . Dijkstra's algorithm solves a shortest-path problem on an undirected, nonnegative, weighted graph and calculates length of the shortest path from the source to each of the remaining vertices in the graph (Goldberg, 1989, Ravindra et al. 1993). Dijkstra's algorithm uses the following notation:

G= {V, E} a directed weighted graph (digraph).

"V" = set of vertices

"E" = set of ordered pairs of vertices, called directed edges, arcs, or arrows.

There are two special vertices s and t in V, where s is the source and t is the link. Further for each edge e in E, Edge Cost (e) is the length of edge e.

Figure 23 gives an example of the weighted digraph and shortest path by Dijkstra's algorithm (Ravindra et al. 1993 and ESRI, 2006 & 2008).

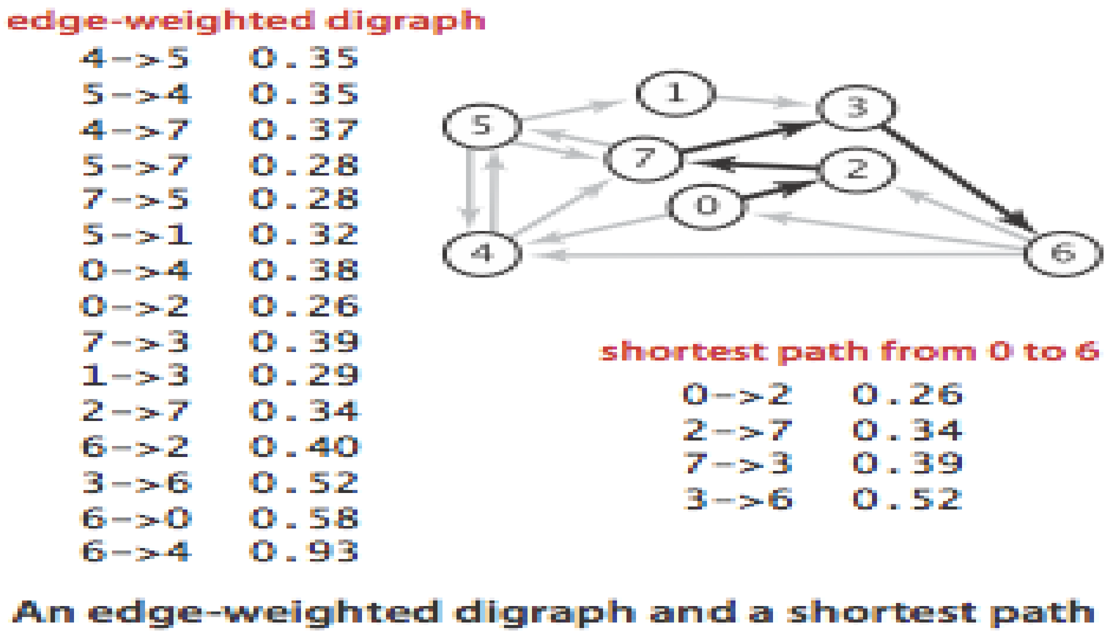


Figure 23: Dijkstra's Algorithm
Source: Ravindra et al. 1993 and ESRI, 2006

Paths are directed as shown in the above example and the shortest path must respect the direction of its edges. The weights are not always distances and the edge weights may represent cost or time (Ravindra et al. 1993). If t is not reachable from s. then there is no path at all and hence there will be no shortest path from s to t. in other words, it means that not all vertices will necessarily be reachable. In addition to this, we assume nonnegative edge weights because negative weights introduce complications (Goldberg, 1989 and ESRI, 2008). Furthermore, there can be multiple paths between vertices and the shortest path is necessarily unique (Ravindra et al. 1993). Hence in our present study for finding the optimal/shortest paths, Dijkstra's algorithm uses two criteria:

a. Distance criteria

The route will be generated taking into consideration only the location of the large waste items. In our present study, the volume of traffic on the roads will not be considered. Collection routes will be generated by employing ArcGIS Network Analyst software with the planned infrastructure such as urban areas, road network, collection points and landfill sites in order to find the shortest impedance path. No turn impedance will be used and the speed of the vehicle will be taken as the arc impedance. For the current study, the speed limit for all the vehicles will be assumed to be the same. However, for respective types of vehicles the user defined speed limit can be used in the model as the values of arc impedances. The shortest/minimum route from each collection point to the nearest landfill will be generated in the Network Analyst.

b. Time Criteria

For each road segment the total travel time in the route will be equal to the waste collection time of large items plus the runtime of the vehicle. The total time used by the vehicle to collect the waste from all the loading spots will be the collection of the large waste items. In order to calculate the runtime of the vehicle on each road, the speed of the vehicle on the road and the length of the road will be taken into account. Furthermore, width, length and the volume of traffic on each road segment will also be considered.

In order to compare the total travel time between these predefined time intervals several routes will be created during a random day. Using the time criteria, routes will be generated during the day time and night time in order to compare the total travel time in these different time intervals during the day. With the exception of the dead ends some important restrictions will be considered such as directions, u-turns and streets. Therefore, the best route is the route that has the least cost or the lowest impedance, where the impedance is chosen by the user (ESRI 2006). The Network Analyst tool of ArcGIS will be used to illustrate the outcome in meters. In order to find the shortest route the distance criteria will be selected and the stop-points will be reordered. In the end, the solve button of the Network Analyst will be used to generate the closest route for solid waste collection.

Collection routes are worked out by using NETWORK ANALYST of Arc/Info GIS software with the planned infrastructure (urban areas, road network, collection points and landfill sites) to find the shortest or minimum impedance path. The speed of the vehicle is taken as the arc impedance and no turn impedance is being used. For the present study, the speed limits for all the vehicles are assumed to be the same; however, the user defined speed limit for respective types of vehicles can be used in the model as the values of arc impedances. In NETWORK ANALYST, we generated the shortest route from each collection point to the nearest landfill site as shown in figures 23(a) & (b) and 24(a) & (b).

(a)

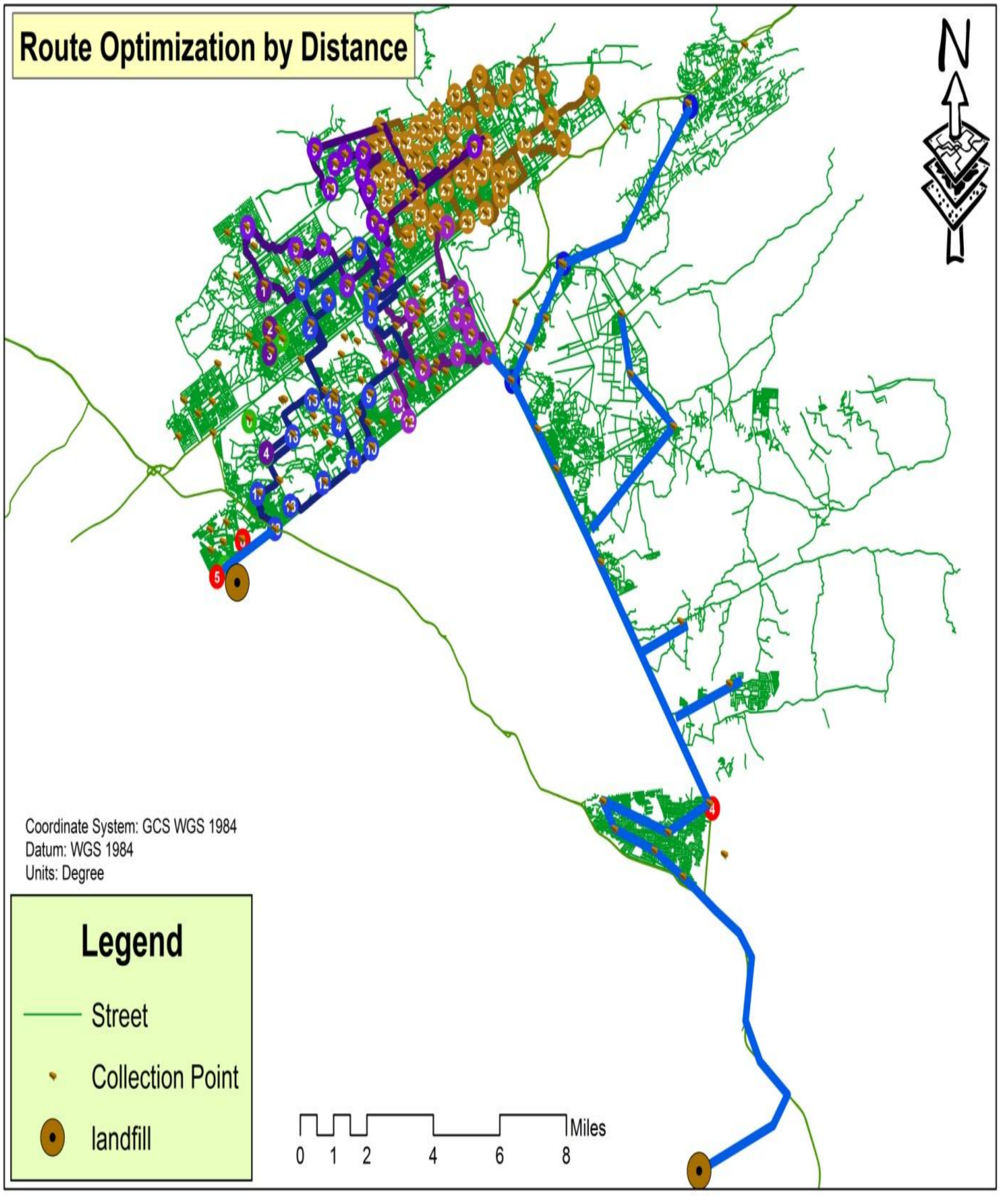


Figure 23: (a) Optimized Routes for Solid Waste Disposal in Islamabad with Overlay of Road Network; (b) Optimized Routes for Solid Waste Disposal in Rawalpindi with Overlay of Road Network

(b)

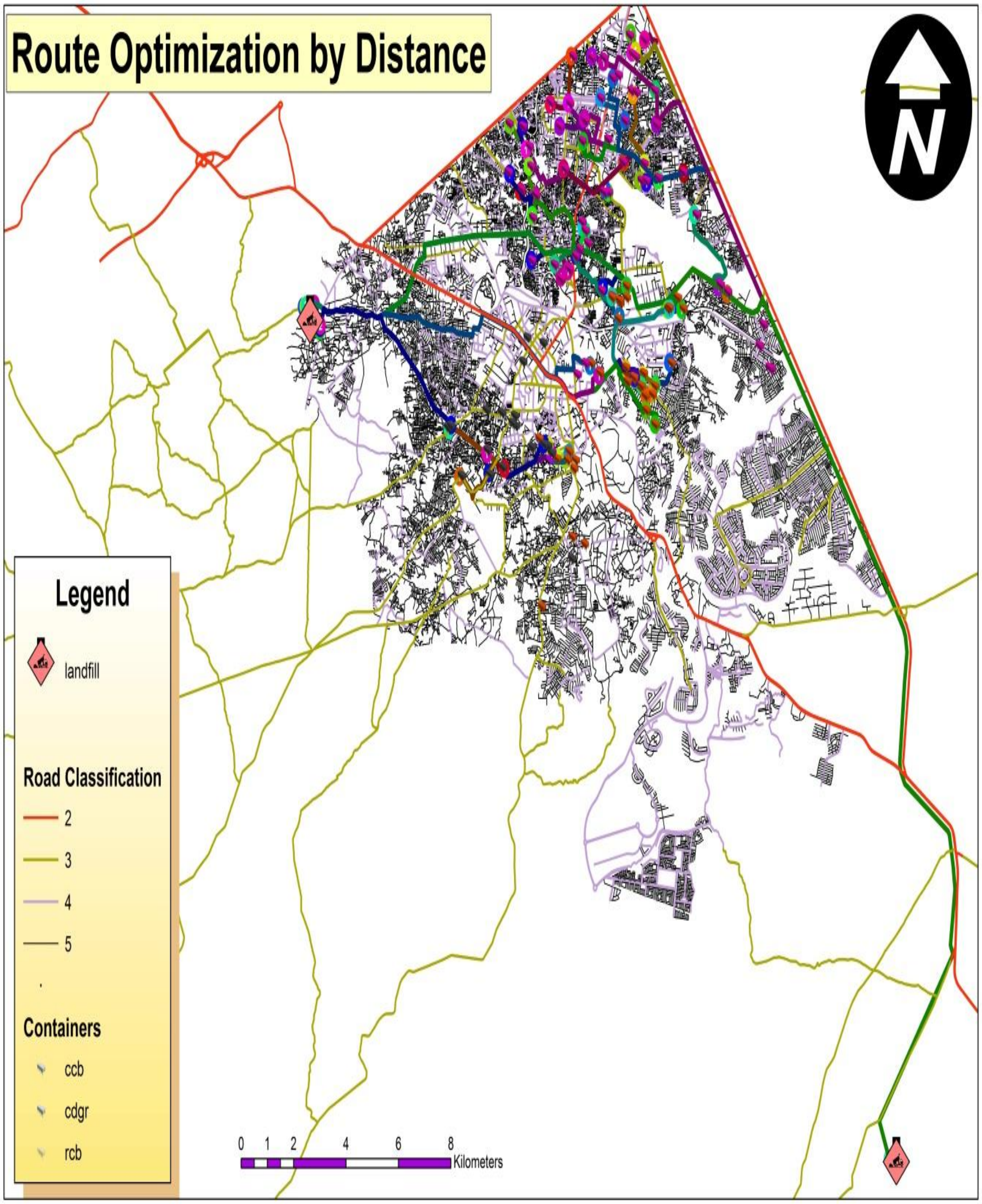
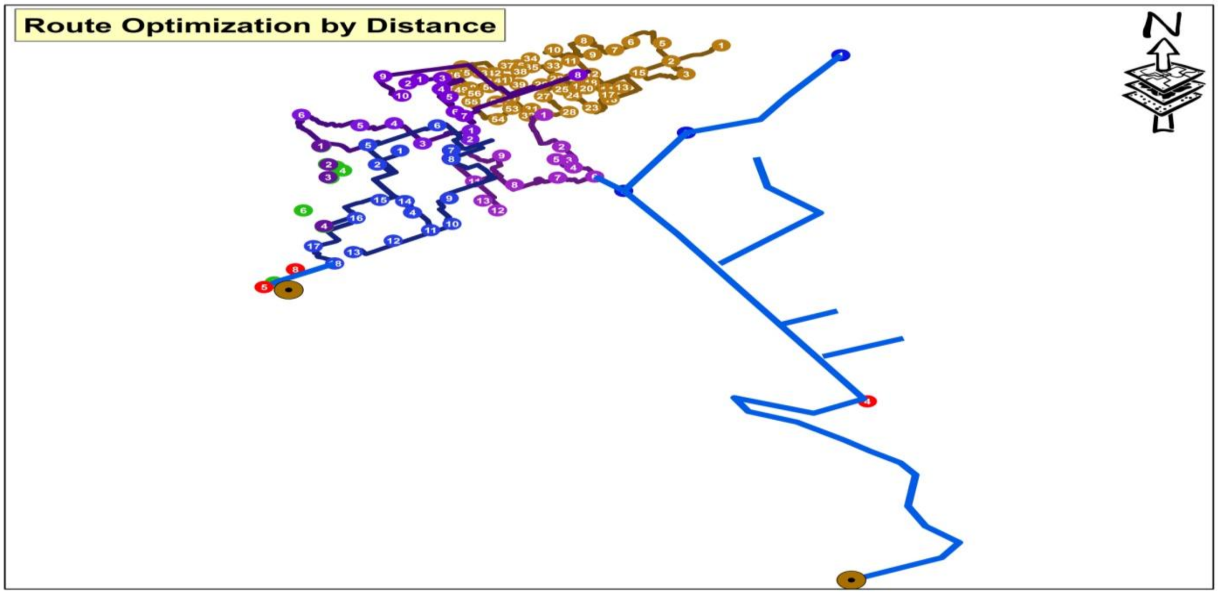


Figure 23: (a) Optimized Routes for Solid Waste Disposal in Islamabad with Overlay of Road Network; (b) Optimized Routes for Solid Waste Disposal in Rawalpindi with Overlay of Road Network (continued)

(a)



(b)

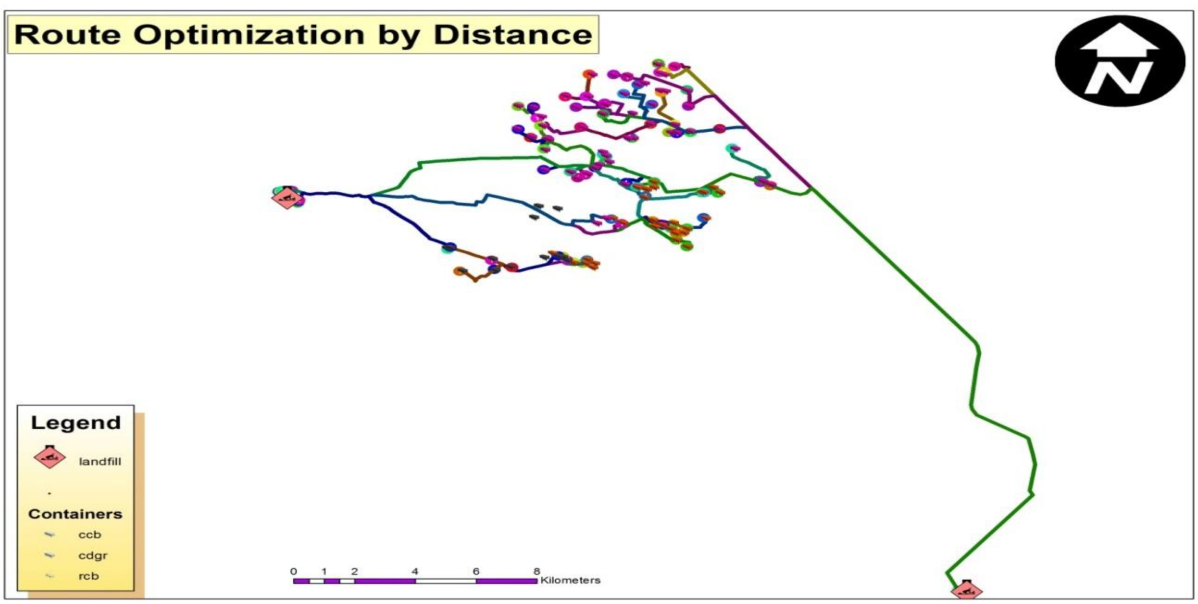
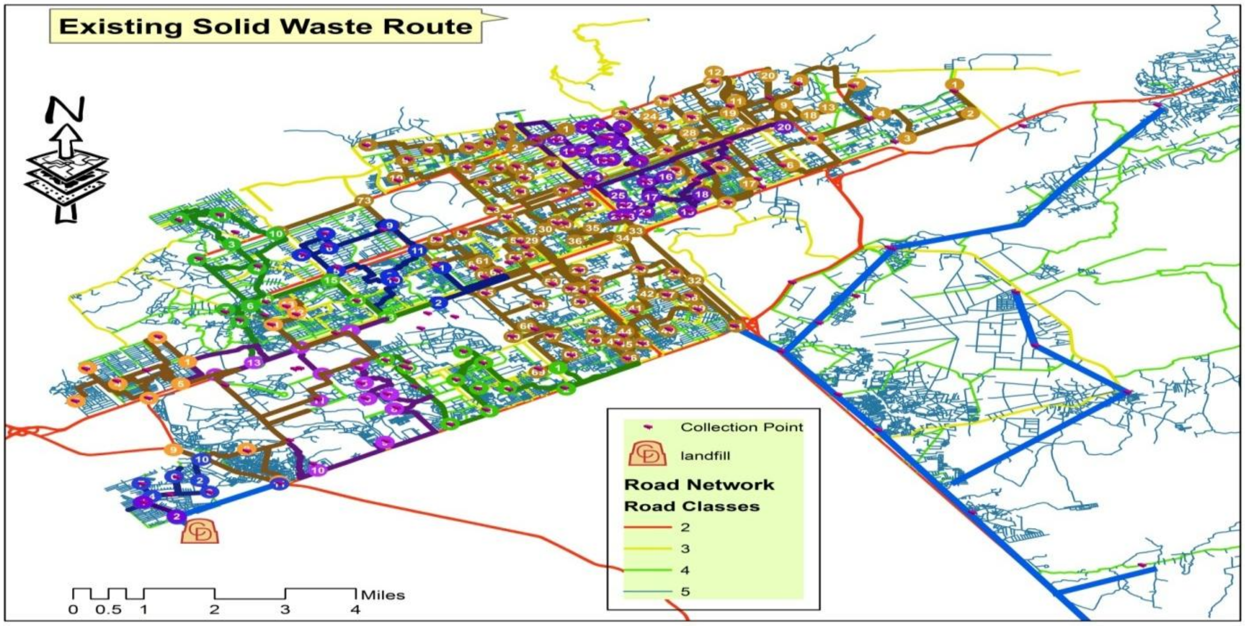


Figure 24: (a) Optimized Routes for Solid Waste Disposal in Islamabad without Overlay of Road Network; (b) Optimized Routes for Solid Waste Disposal in Rawalpindi without Overlay of Road Network

(a)



(b)

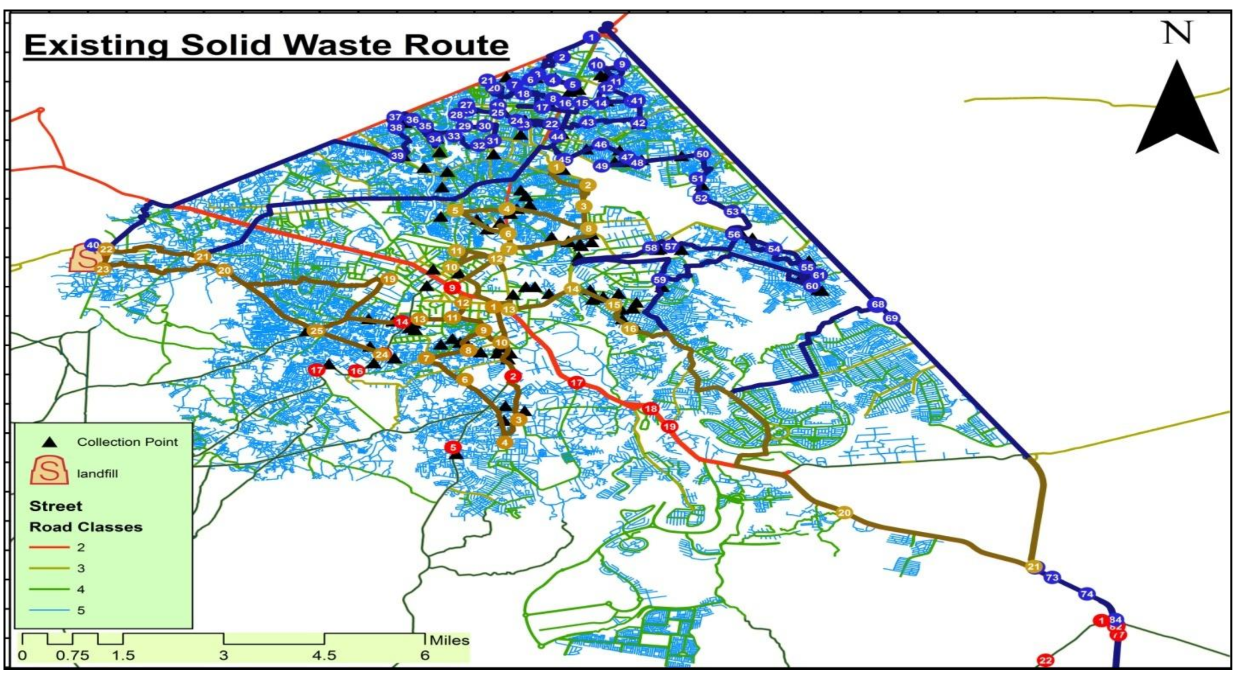
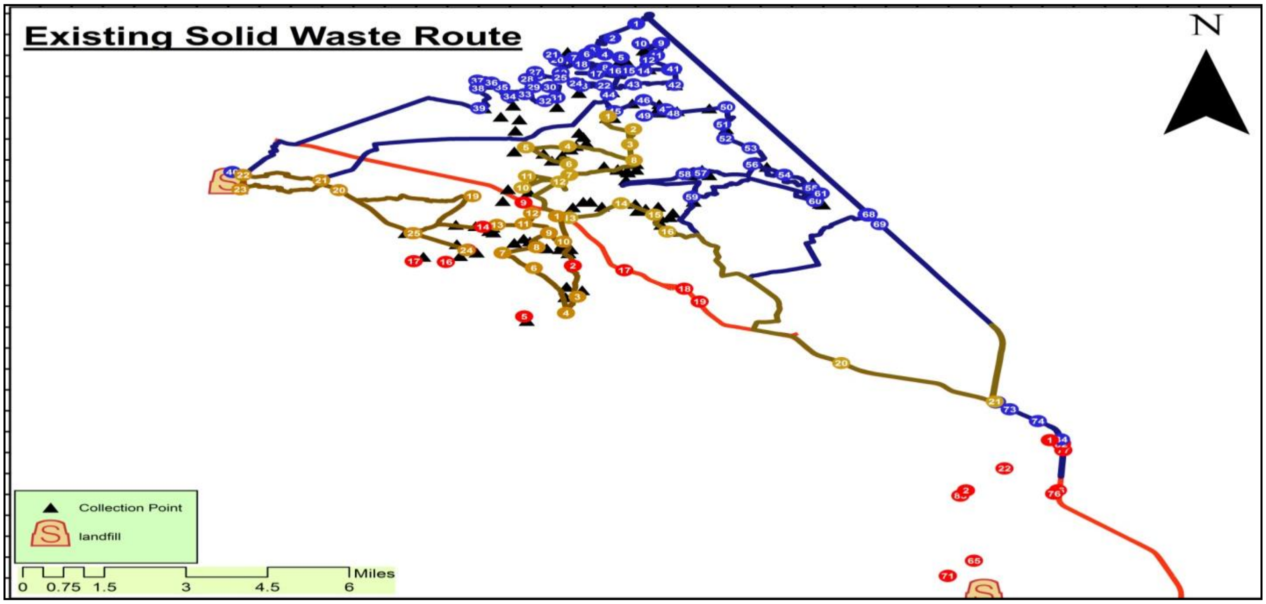


Figure 25: (a) Existing Routes for Solid Waste Disposal in Islamabad with Overlay of Road Network; (b) Existing Routes for Solid Waste Disposal in Rawalpindi with Overlay of Road Network

(a)



(b)

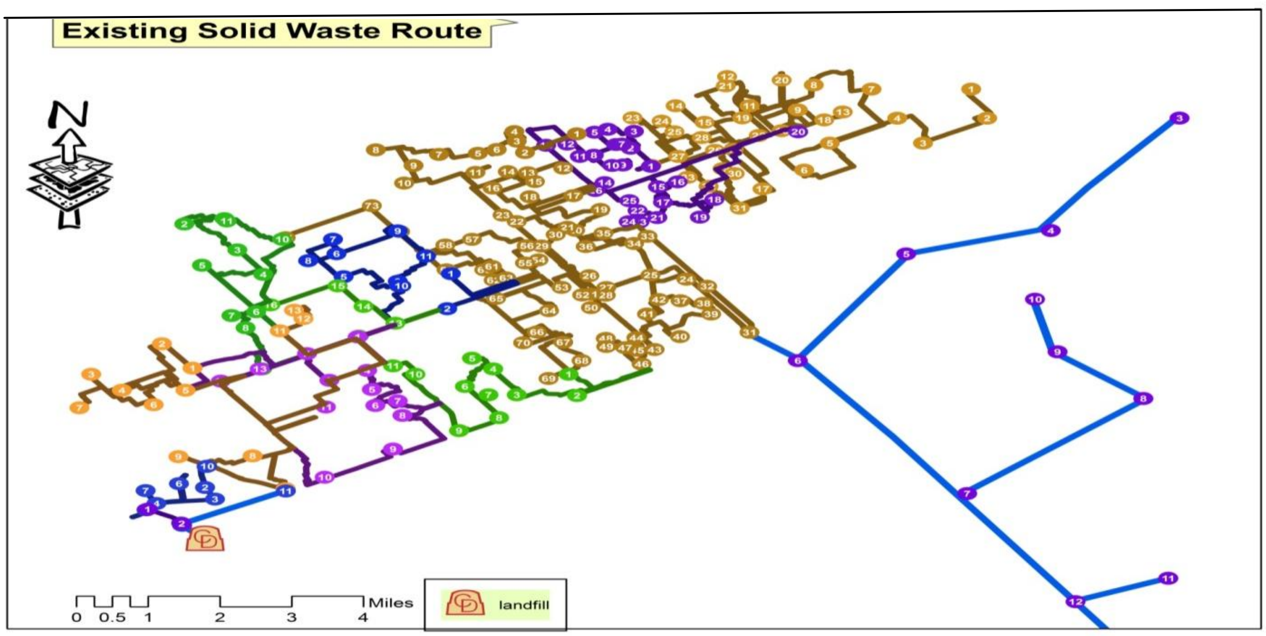


Figure 26: (a) Existing Routes for Solid Waste Disposal in Islamabad without Overlay of Road Network; (b) Existing Routes for Solid Waste Disposal in Rawalpindi without Overlay of Road Network

4.1.7. Comparison of Existing Routes Vs Proposed Routes

Speed limit classifies the general speed trend of a road based on posted or legal speed and is provided to enhance route calculation and the timing of route guidance. Speed limit values represent the combination of several factors besides legal speed limit (e.g., physical restrictions or access characteristics) and are shown in the Table 8 below for Islamabad and Rawalpindi:

Table 8: Functional Class with their Respective Speed Limits

Function Class 2	70-100 KPH
Function Class 3	50-65 KPH
Function Class 4	40-50 KPH
Function Class 5	30-40 KPH

Optimal route distance and time for Islamabad and Rawalpindi is calculated by an equation, i.e.

- Time = Distance / Avg. Speed
- T= d/s, Where'd' is the distance 'T' is the time and 's' is the avg. speed

Table 9: Existing and Proposed Routes for Islamabad with Distance and Time Criteria

Route No.	Existing Route Islamabad by Distance(s)	Proposed Route Islamabad by Distance(s)	Existing Route Islamabad by Time(T)	Proposed Route Islamabad by Time (T)
1	67767	82419	1.4	1.6
2	33500	26609	0.7	0.5
3	114983	24048	2.4	0.5
4	19626	14708	0.4	0.3
5	24197	49448	0.5	1.0
6	19141	50640	0.4	1.0
7	30359	45640	0.6	0.9
8	38664	141	0.8	0.0
9	7099	342	0.1	0.0
10	822	78	0.0	0.0
11	356158 meter	294073 meter	7.5 hour	5.8 hour
	356 km	**294 km**	**7.5 hour**	**5.8 hour**

Table 10: Existing and Proposed Routes Speed for Islamabad

Time Vs. Distance Factor Proposed (Islamabad)		**Time Vs. Distance Factor Existing (Islamabad)**	
Road Class	Avg. Speed	Road Class	Avg. Speed
Class 2	70	Class 2	75
Class 3	50	Class 3	52
Class 4	40	Class 4	45
Class 5	30	Class 5	30
Avg. Speed	**47.5**	**Avg. Speed**	**50.5**

Table 11: Existing and Proposed Routes for Rawalpindi with Distance and Time Criteria

Route No.	Existing Route Rawalpindi by Distance (s)	Proposed Route Rawalpindi by Distance (s)	Existing Route Rawalpindi by Time (T)	Proposed Route Rawalpindi by Time (T)
1	82418	76342	1.7	1.5
2	41925	43189	0.9	0.9
3	24048	29017	0.5	0.6
4	20561	18345	0.4	0.4
5	49848	56324	1.0	1.1
6	35219	19876	0.7	0.4
7	56981	44265	1.2	0.9
8	43521	35876	0.9	0.7
9	23456	21562	0.5	0.4
10	15492	13763	0.3	0.3
11	393469 meter	358559 meter	8.3 hour	7.2 hour
	393 km	**359km**	**8.3 hour**	**7.2 hour**

Table 12: Existing and Proposed Routes Speed for Rawalpindi

Time Vs. Length Factor Proposed (Rawalpindi)		**Time Vs. Length Factor Existing (Rawalpindi)**	
Road Class	avg. Speed	Road Class	avg. Speed
Class 2	70	Class 2	73
Class 3	50	Class 3	51
Class 4	40	Class 4	45.5
Class 5	30	Class 5	30
Avg. Speed	**47.5**	**Avg. Speed**	**49.875**

GIS based optimal routing was used for Islamabad and Rawalpindi waste management by using different parameters such as population density, waste generation rate, road network and road junctions, existing waste collection points, existing landfills and existing waste collection routes in order to find the new optimal routes for solid waste collection and transportation. The study was intended to plan cost efficient waste collection route for transportation of waste to the landfills. The research considered six day shifts for collection and transportation of solid waste per week in the twin cities. The ArcGIS geo-database was developed in this study which consists of raster photo images of the city, street network data, waste bin locations, current collection routes driven, service time to collect bins, truck type, and capacity. The original collection route length and time for Islamabad and Rawalpindi was 356km; 7.5h and 393km; 8.3h respectively, whereas the proposed collection route length and time for Islamabad and Rawalpindi came out to be 294km;5.8h and 359km; 7.2h respectively. The total distance covered and time consumed by Islamabad existing route for collection and transportation of solid waste per annum is 111, 428km;2,347h whereas for Rawalpindi is 123,009km; 2,598h. Hence with the proposed routes, the collection and transport vehicles will cover 92,022km in 1,815.4 hours for Islamabad and 112,367km in 2,253.6 hours for Rawalpindi each year. The detailed calculation for percentage change in the existing and proposed routes by distance and time for the twin cities are shown in the tables 13 and 14.

Table 13: % Change Calculation for Islamabad Existing Route Vs. Proposed Route by Distance and Time

Existing Collection Route of Islamabad by Distance /day	356 Km
Proposed Collection Route of Islamabad by Distance/ day	294 Km
Existing Collection Route of Islamabad by Time/day	7.5 h
Proposed Collection Route of Islamabad by Time /day	5.8 h
% Change in Existing Route Vs Proposed Route by Distance /day	**18%** (There is a drop of 18% in km per day).
% Change in Existing Route Vs Proposed Route by Time/day	**22%** (Time is saved by 22 % per day)
Existing Collection Route of Islamabad by Distance /year	111,428 Km
Proposed Collection Route of Islamabad by Distance/ year	92,022Km
Existing Collection Route of Islamabad by Time/year	2,347 h
Proposed Collection Route of Islamabad by Time /year	1,815.4 h
% Change in Existing Route Vs Proposed Route by Distance /year	**18%** (There is a drop of 18% in km per year).
% Change in Existing Route Vs Proposed Route by Time/year	**22%** (Time is saved by 22 % per year)

Table 14: % Change Calculation for Rawalpindi Existing Route Vs. Proposed Route by Distance and Time

Existing Collection Route of Rawalpindi by Distance /day	393 Km
Proposed Collection Route of Rawalpindi by Distance/ day	359 Km
Existing Collection Route of Rawalpindi by Time/day	8.3 h
Proposed Collection Route of Rawalpindi by Time /day	7.2 h
% Change in Existing Route Vs Proposed Route of by Distance /day	**9 %** (There is a drop of 9% in km per day).
% Change in Existing Route Vs Proposed Route by Time/day	**13.2 %** (Time is saved by 13.2 % per day)
Existing Collection Route of Rawalpindi by Distance /year	123,009 Km
Proposed Collection Route of Rawalpindi by Distance/ year	112,367 Km
Existing Collection Route of Rawalpindi by Time/year	2,598 h
Proposed Collection Route of Rawalpindi by Time /year	2,253.6 h
% Change in Existing Route Vs Proposed Route by Distance /year	**9 %** (There is a drop of 9% in km per year).
% Change in Existing Route Vs Proposed Route by Time/year	**13.25%** (Time is saved by 13.25 % per year)

This created a potential savings of 19,406 km driven and 531 hours spent each year for Islamabad city and 10,642km and 345 hours spent each year for Rawalpindi, based on the vehicle's schedule of six collections per week. Mostly, route optimization studies focus analysis on calculating the shortest distance or shortest drive times for the collection and transportation of waste. Likely, our research has shown that using advanced route solving software can return significant cost savings and this can be attained either by reducing fuel costs, decreasing mileage driven, or a drop in overall travel time. Therefore, our results have shown that there was a reduction in the kilometers driven to collect and transport residential waste to the landfills/dumpsites for the twin cities followed by a reduction in the overall vehicle drive time to collect and transport residential waste of the twin cities to the landfills/dumpsites. Our study can be a good decision support system/tool for waste transport, fuel consumption, work distribution amongst the vehicles for load balance and generation of work schedules for both employees and vehicles. Our research can be used as a decision support tool by the municipal administration for efficient management of the daily operations for solid waste management. Other spatial data can be added in the future to enhance the utility of this model such as generation of capacity for various residential areas, types of dumping vehicles, enhanced road network for operations, etc.

4.2. Result 2 -Indentifying New Suitable Landfill Sites

A GIS-MCE integrated analysis was a done suitable proposed landfill sites for landfill siting purposes. The use of GIS for evaluation of future waste disposal sites has been shown to save time when there is a need for fast evaluation. Local governments generally lack sufficient funds and experts to implement a complete siting process that doesn't cause significant damage to the environment. The application of GIS-based models for waste management in the twin cities is relatively new and the need to hire a technical workforce with adequate training is a must. In addition, the availability of detailed data in GIS ready format is limited or difficult to obtain because of bureaucracy or lack of regulations in developing countries like Pakistan as compared to the developed world. Some of the limitations to this kind of study and analysis in developing countries such as Pakistan are worth noting in comparison to the developed world. A landfill siting process requires evaluating many factors and criteria and processing much spatial information. First and foremost, any GIS analysis is obviously limited to the data availability and data accuracy in Pakistan. Six different thematic layers such as land use/land covers, streams network, water reservoirs, roads network, urban settlements and slope were considered in the analysis. There are certainly other factors, such as industrial areas, airports, wind direction, and other social and economic factors. At the end of the analyses, suitable areas for appropriate solid waste landfill sites are identified.

Our whole analysis has been done in vector-based GIS software package ArcGIS 10.0 and its extensions were used as the GIS tool since it is able to perform suitability analysis using multi-criteria evaluation analysis. An MCE analysis investigates a number of possible choices for a siting problem, taking into consideration multiple criteria and conflicting objectives. The available information for the study area was digitized and stored in the information system in order to use GIS for landfill site selection. The GIS model is based on Boolean operations. It involves the logical combination of binary maps resulting from the application of conditional operators. If the criteria and guidelines have been established as a set of deterministic rules, this method is a practical and easily applied approach. The output is a binary map because each location is either satisfactory or not. In practice, it is usually unsuitable to give equal importance to each of the criteria being combined. Factors need to be weighted depending on their relative significance and this can also be shown in the form of equations appended below:

$$Yij = (Xij - Xj\ min) / (Xj\ max - Xj\ min) \quad (1)$$

$$Yij = (Xj\ max - Xij) / (Xj\ max - Xj\ min) \quad (2)$$

Where: Yij = Standardized value for ith criteria and jth option; Xij = Scale value for ith criteria and jth option and Xj max, Xjmin= Maximum and Minimum Scale value for ith criteria and jth option respectively.

Hence, each location will be evaluated according to weighted criteria, resulting in a ranking on a suitability scale, rather than simply presence/absence. This method is known as index overlay. In this method, each factor map will be assigned ranks, as well as the maps themselves receiving different weights. All scored maps will be assigned to a common scale e.g., ranging between 0 to 9 in which 0 is restricted and 9 is suitable and with a weighted linear combination, factors are combined by applying a weight to each followed by a summation of the results to yield a suitability map as shown in the Equation 3.

$$S = Wi\ Xi \tag{3}$$

Where: S= suitability; Wi= weight of factor I and Xi= criterion score of factor i.

Weights are generally assigned to these maps to express relative importance. In order for the output map to be meaningful and consistent, map weights have to add up to 100% and the attribute scores have to be chosen using a scheme that is the same for each map. Table 15 shows the distance or proximity of a landfill from urban settlements, road network, land use/land cover (LULC), water reservoirs (lakes), water streams and slope and their weighting.

Table 15: Layer's Weights and Attribute Ranking for the Maps Used in the Landfill Site Selection

Layer/Sub-layer(Value)	**Ranking (Scale Value)**	**Weight-age (% Influence)**
Urban settlements		
0-1000 m	0	25%
1000-5000 m	3	
5000 -10,000 m	9	
10,000-15,000 m	5	
≥ 15, 000	1	
Roads		10%
0-500 m	0	
500-1000 m	9	
1000 -2000 m	5	
≥ 2000 m	1	
LULC		20%
Settlement	Restricted	
Water Bodies	Restricted	
Vegetation	5	
Soil	9	
Lakes		20%
0-1000 m	0	
≥1000 m	9	
Streams		20%
0-1000 m	0	
≥1000 m	9	
Slope (Degrees)		5%
0-4 %	0	
≥ 15%	1	

A landfill must be situated and designed so as to meet the necessary conditions for preventing pollution of the soil, groundwater or surface water and ensuring efficient collection of leachate. Similarly, a landfill site should be kept as far away as possible from population density, for reducing pollution impact on public health. On the other hand, the landfill site should be placed as close as possible to existing roads for saving road development, transportation, and collection costs. Furthermore, difficult or steep terrains are not appropriate for hosting landfills.

Six suitability criteria (distance from urban/residential , 1settlements, 2 road network, 3 lakes, 4 streams, 5 land use land cover , 6 slope) were used in this study and mostly based on the relevant Pakistani Government Regulations, in addition to international practices that account for economic, environmental, social, and technical viable factors. A map was created for each suitability criteria and a final composite map was produced by simple overlaying of the individual maps. The layers, buffer zones used, rankings and weights of layers are summarized in Table 15. The weights were assessed by taking into account the possibility of modifying the natural conditions of the sites by appropriate engineering interventions, so as to increase their suitability (Delgado et al. 2008). Likewise, criteria that are less important to the conditions of Pakistan and its climate were given less weight. For example, high weights were given to the urban settlements, road network and LULC. On the other hand, the drainage network and the slope were considered less important because of absence of water courses due to the climate of Islamabad. Furthermore, agricultural lands were neglected because the study area is a complete urban/metropolitan area.

4.2.1. Distance/Proximity from Urban/Residential Settlements

The landfill site should not be placed to avoid adversely affecting land value and future development and to protect the general public from possible environmental hazards released from landfill sites near a residential or an urban area,. At the same time, it should not be located too far to avoid extra transportation costs and environmental pollution (Baban and Flannagan 1998). A buffer of 1000 meter around urban/residential places was used to exclude the buffered areas in landfill site selection resulting in two classes suitable and unsuitable for the whole study area, as shown in Fig 27.

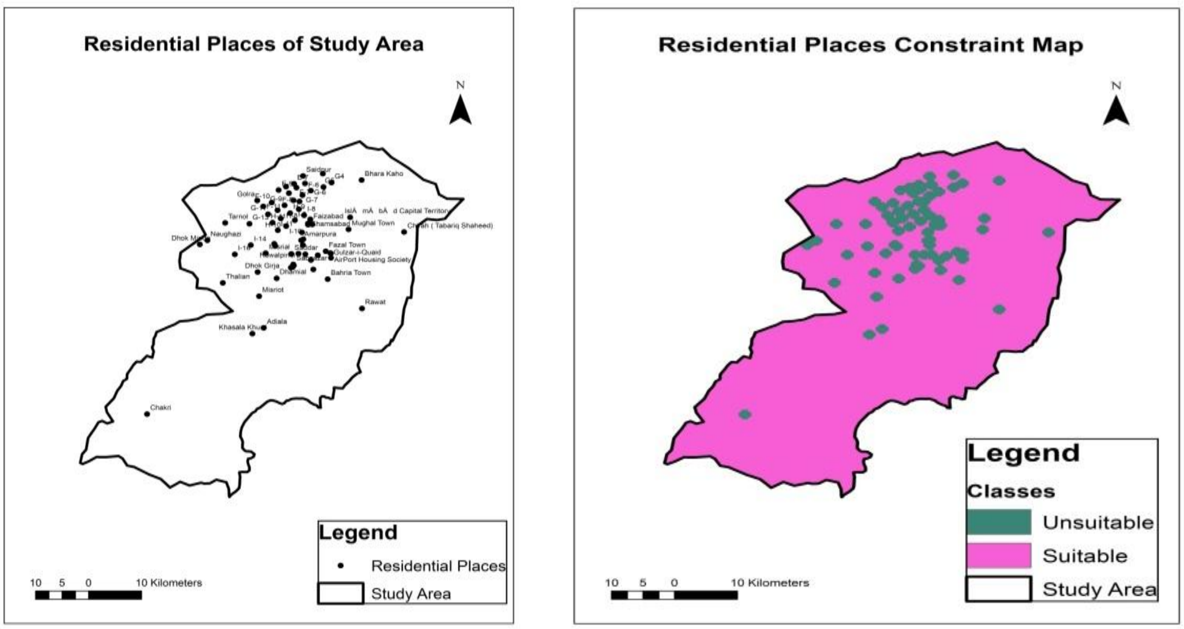


Figure 27: Urban Settlements and Constraint Map of Twin Cities

4.2.2. Distance from Road Networks

Aesthetic considerations are of good practice for good planning, and based on this rule, a landfill site should not be placed too far away from existing road networks, to avoid the expensive cost of constructing connecting roads. Table (1) shows the distances of a landfill from road networks and its weighting. A buffer of 500 meter around the road network was used to exclude the buffered areas in landfill site selection resulting in two classes suitable and unsuitable for the whole study area, as shown in Fig 28.

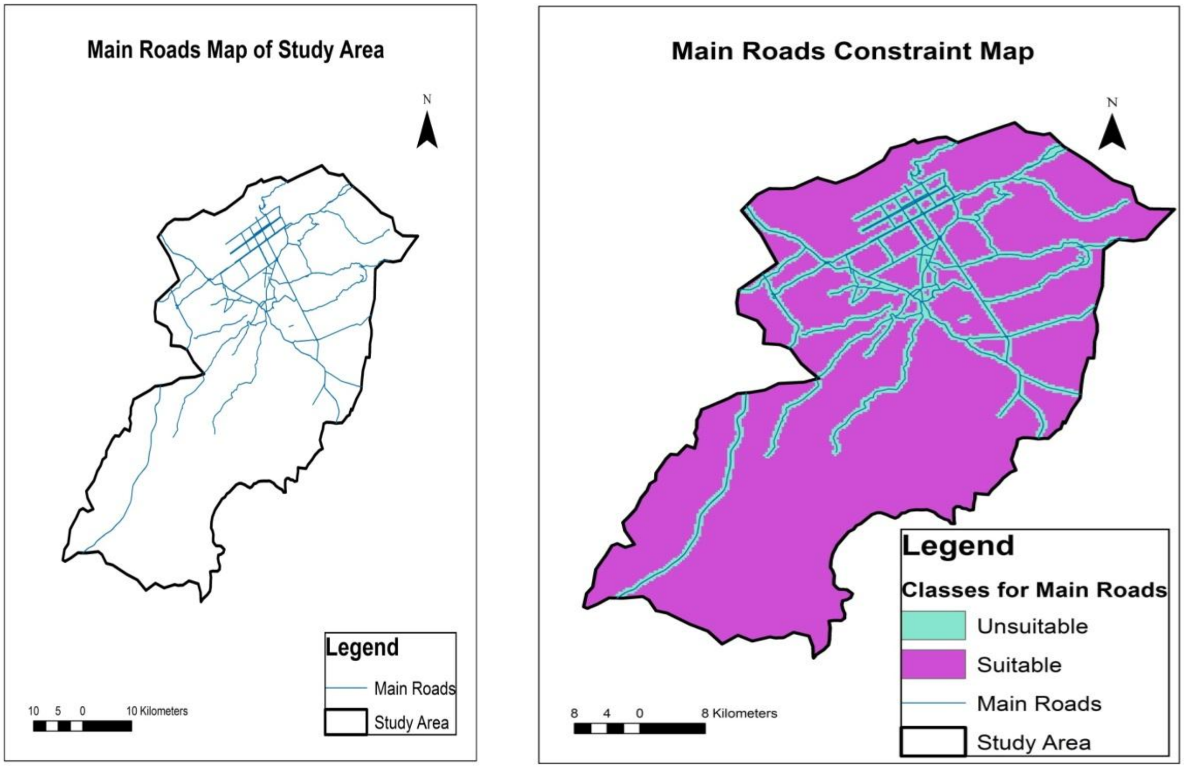


Figure 28: Road Network and Constraint Map of Twin Cities

4.2.3. Land Use Land Cover (LULC)

Land use and land planning requires knowledge of the current state of the landscape. Understanding current land cover and how it is being used, along with an accurate means of monitoring change over time, is very important to any organization/personnel responsible for land use and management. In our study we measured current conditions and how they are changing through land use land cover mapping in which build up area, water bodies, vegetation and soil are considered and as shown in the Figure 29.

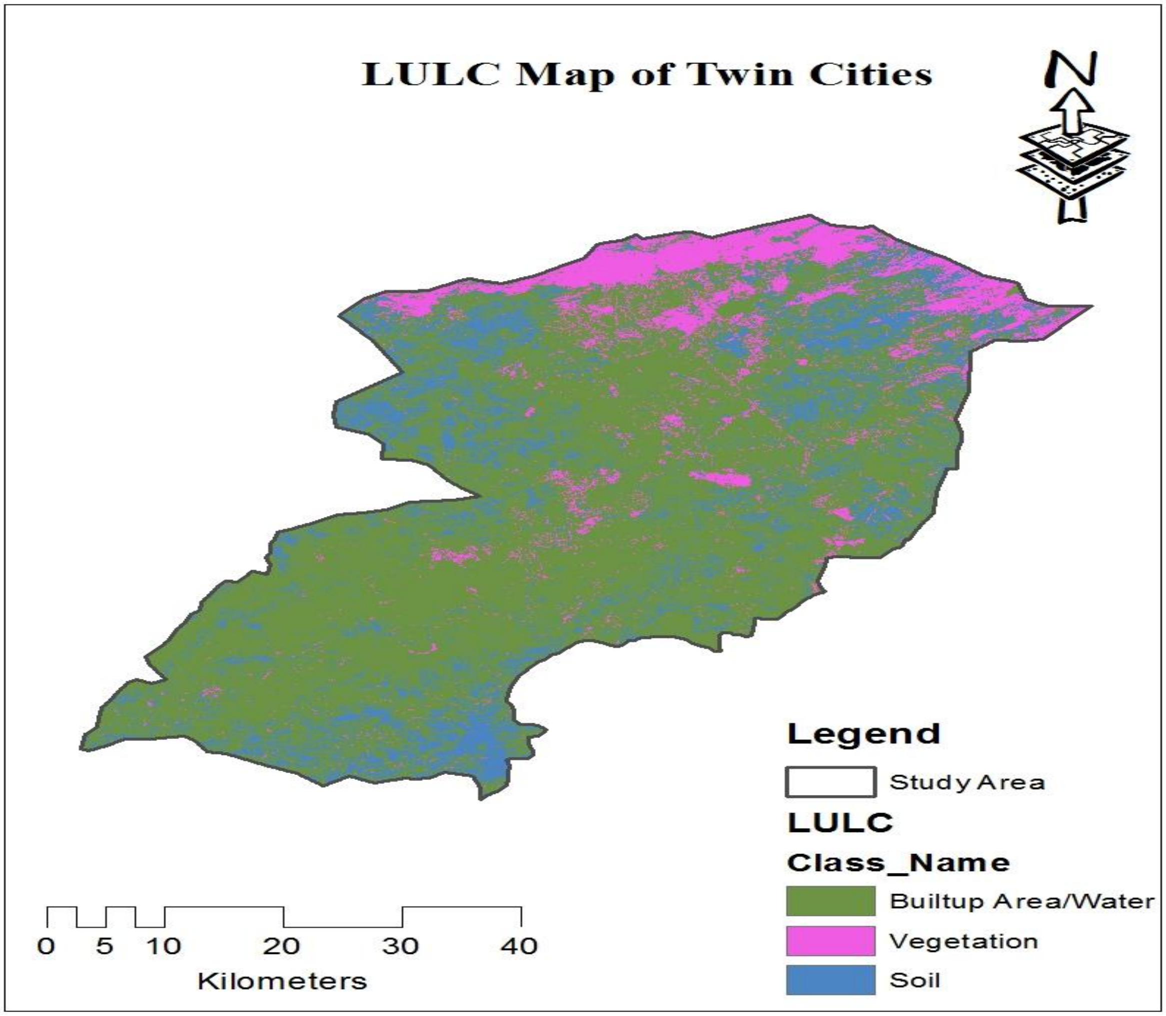


Figure 29: LULC Map of Twin Cities

4.2.4. Land Slope

The siting of a landfill requires many important parameters and in this regard the importance of land slope cannot be denied. According to the study by Lin and Kao (1998, 2005), an appropriate slope is 5-15% otherwise too steep of a slope will make it difficult for the construction and maintenance and too flat of a slope will adversely affect the overflow drainage. The slope layer is derived from the DEM layer in the GIS environment.

Slopes which are above 15% would have created high overflow rates for rainfall. With reduced penetration and a high overflow rate, contaminants are able to travel greater distances from the containment area and this makes a larger environment vulnerable, especially surface waters, to the dangerous chemicals produced within the leachate from the landfill. The study area is dominated by flat topography at the foot hills surrounded on three sides from the city, the slope factor is important as most of the feasible sites are located at the foothills and thus we assume that a feasible site should be located with < 9 degree slope. Therefore, a buffer of 4 % around land slope was used to exclude the buffered areas in landfill site selection resulting in two classes suitable and unsuitable for the whole study area, as shown in Fig 30.

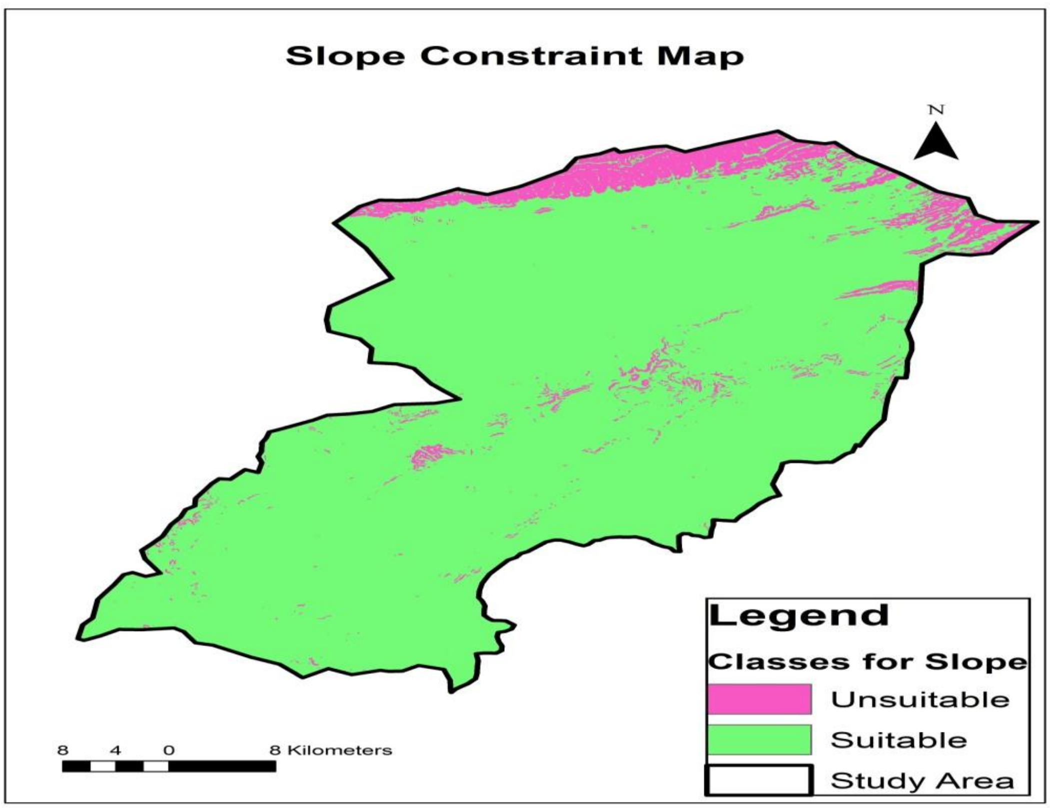


Figure 30: Land Slope Constraint Map of Twin Cities

4.2.5. Distance from Water Streams Network and Water Reservoirs

A landfill must not be located near any water streams, water reservoirs or wetlands. Proximity to water streams network and water reservoirs was an important criterion to accessing the landfill site. Landfills create noxious gases and leachate that make them unsuitable to be in proximity to water streams (Dorhofer and Siebert 1998). The water stream network layer and water reservoir layer were classified as suitable or unsuitable for a landfill site by assigning values 9 and 0, respectively. For this reason, a buffer of 1000 meter around water streams network and water reservoirs was used to exclude the buffered areas in landfill site selection resulting in two classes suitable and unsuitable for the whole study area is as shown in Figures 31 and 32.

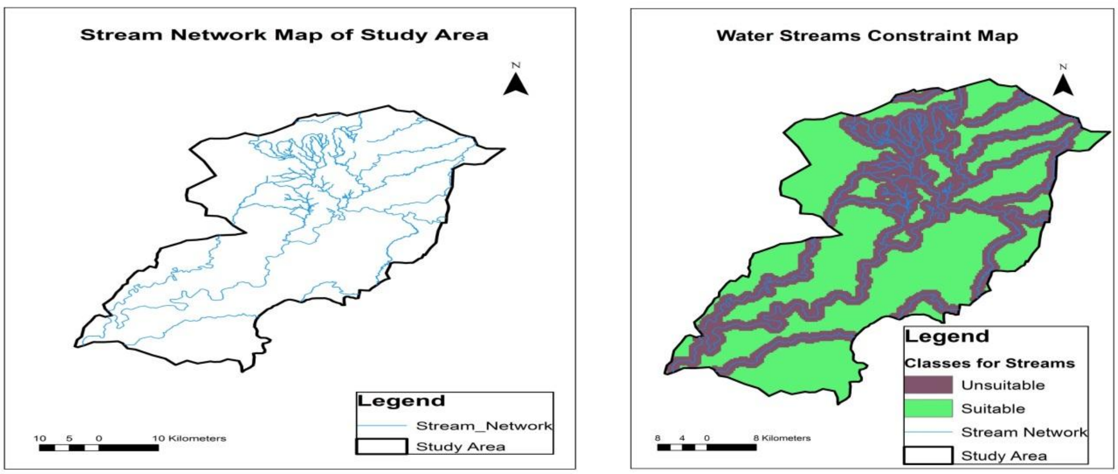


Figure 31: Water Stream Map and Constraint Map of Twin Cities

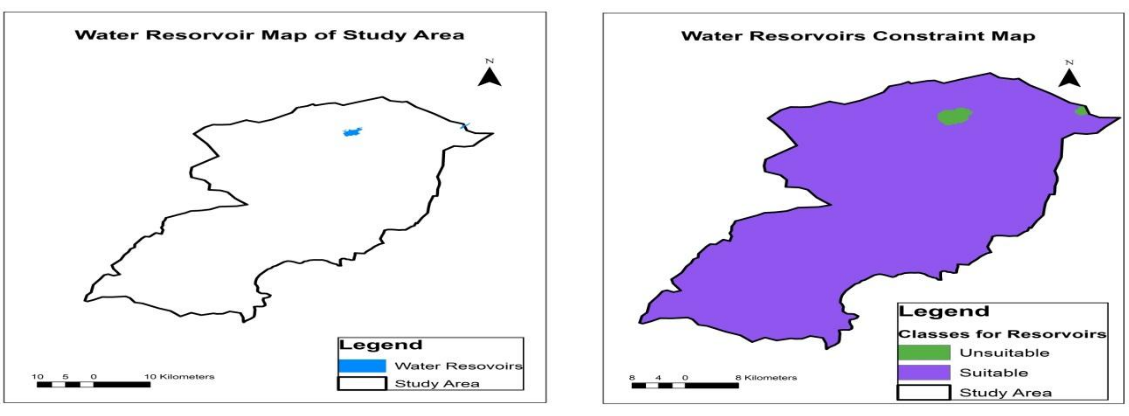


Figure 32: Water Reservoir Map and Constraint Map of Twin Cities

Finally, all constraints maps were combined to develop a final constraint map showing two classes suitable and unsuitable for the study area as shown in the Fig 33.

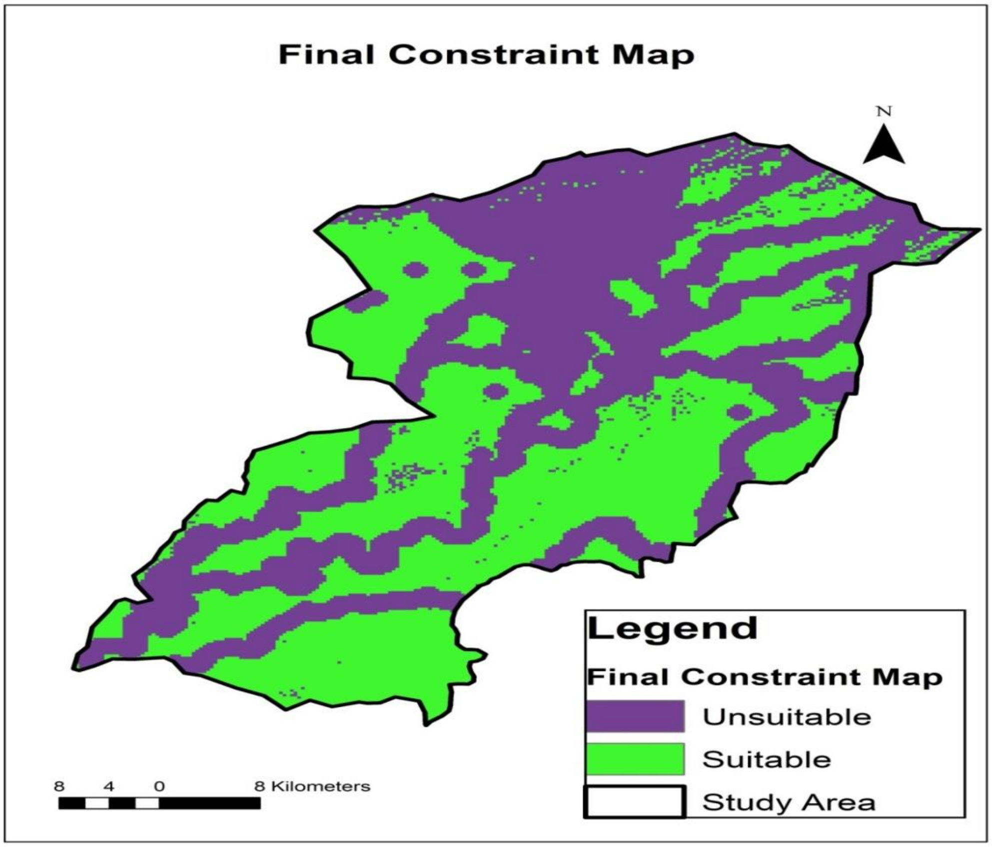


Figure 33: Final Combined Constraint Map of Twin Cities

The GIS spatial operation using map layers as specified in the constraint criteria worked very well using the ArcGIS 10.0 software. The GIS-MCE methodology presented here provided a more objective ranking of the appropriate sites. Figure 34 shows the final map generated when the constraint maps were subtracted from the map resulting from overlaying the ranked maps. A map was created for each suitability criterion and a final composite map was finally produced by simple overlaying of the individual maps. The layers, buffer zones used, and rankings are summarized in Table 15 and the definitions of the layer’s weights are also shown in Table 15.

The weights were assessed by taking into account the possibility of modifying the natural conditions of the sites by appropriate engineering interventions, so as to increase their suitability (Delgado et, al.2008). For example, high weights were given to the urban settlements, stream networks, water reservoirs and land use land cover class. On the contrary, road network and slope were considered less important, because they can be extended and modified, if required by a given project. The area belonging to “highly suitable” class to “unsuitable” class study area can be seen from Figure 34. The next step would be finalizing the location of the landfill site based on the integrated GIS-MCE analysis provided under this research. At the end of the analyses, appropriate MSW landfill sites are identified and proposed. These sites generally satisfy the minimum requirements of the landfill sites.

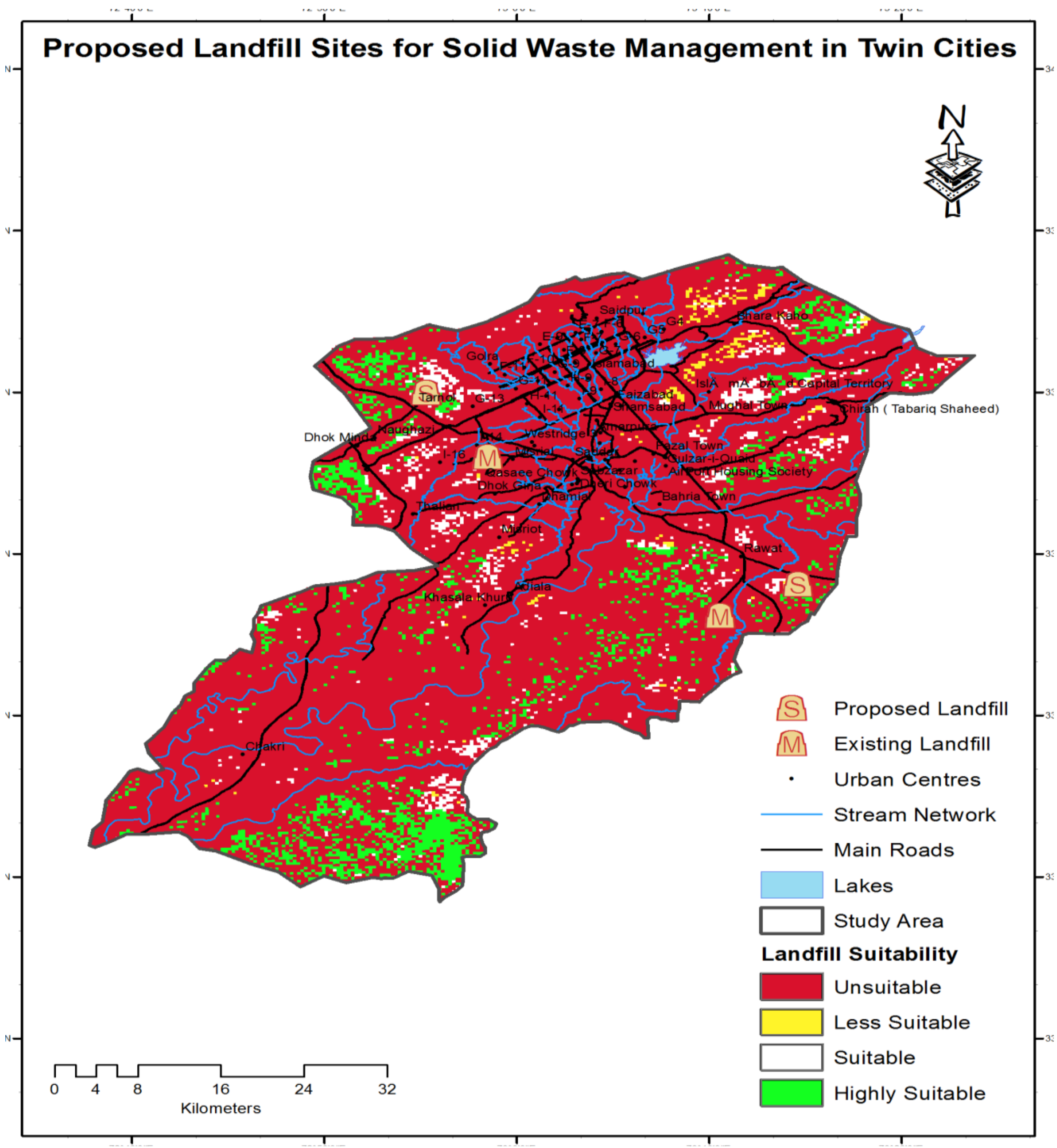


Figure 34: Proposed Landfill Sites for Solid Waste Management in Twin Cities

The results achieved by this study for identifying suitable landfill sites will afford policy makers of the twin cities by a variety of options being considered as sanitary landfill locations. The proposed landfill sites for the twin cities generally satisfy the minimum requirements for new landfill sites siting. However, potential/proposed landfill sites were selected through careful field research. Furthermore, the selection of the final proposed landfill sites, necessarily, requires further geotechnical and hydro-geological analyses towards the protection of groundwater as well as surface water in the future to be implemented. It must be noted that a more inclusive study on current and future land uses and the cost of the land as well as population growth and waste generation rate is recommended for future studies.

4.3. Result 3 -Developing a Web-Based Decision Support System (DSS)

The use of web based applications has increased dramatically on a global basis and it is used as a means of information circulation and sharing. The ease of information and easy access to that information has contributed to the growth of web based applications (Abel, Taylor, Ackland and Hungerford, 1998). The user can easily navigate the system and commune with the database with the help of web based user interface applications. Anyone with slight a understanding of the computer operation can use the application and achieve their desired objectives because the design of the application is very simple and user friendly.

A progressive amount of work has been carried out by the different organizations globally on web-based applications in natural resource management and environmental planning such as US National Environmental Data Index which is available at: http://www.nedi.gov/. It provides information online in the form of HTML (Hypertext Markup Language) pages with maps and images. Most such websites are being operated by different organizations worldwide to enhance the knowledge about the environmental issues by providing direct or indirect access to the information and environmental data. Recently, the main use of web based applications is the diffusion of information and its usage as decision support systems/tools. For instance, Bhargava & Tettelbach, (1997) has set up Recycling DSS for waste disposal and recycling and it was used as a wed-based decision support system in their study. It provided information to the users on locations; products to be recycled and the services that are used for recycling of the products in the Monterey Bay area; California, USA in order to develop a most favorable recycling plan via an integer programming model. Likewise, Jensen, Boll, Thysen and Pathak, (2000) developed a Web-based DSS named Pl@nteInfo which was helpful in providing information and decision support models to farmers about the management of crops. The database was comprised of certain important information such as field recordings of diseases and pests, weather information etc. Similarly, OWSimu is a Web-based system developed by Pan Hesketh and Huck, (2000). It was used to enhance the growth of plants for weeds and crops in varying soil and weather conditions. The web based system was used as a DSS for environmental planning. In addition to this, the use of web-based applications in environmental planning and natural resource management has offered decision system for the management and planning via the web.

Hence, from previous literature it is revealed that social, economic and environmental information are required to be concurrent with government policies and goals. There is currently no website in Pakistan designed explicitly to support solid waste management planning processes. In order to investigate the potential of the web to support the solid waste management planning processes, a web-based DSS was launched in the current study. The web-based application is user friendly and it was designed to accommodate users such (municipalities; general public; decision makers etc) of varying skills and competence in the area of computer usage and a well design user interface assists user with better understanding and knowledge of the system at large. It was designed as a central information resource on the web for solid waste management in Islamabad and Rawalpindi. Its main objectives are to join data and information in order to assist municipalities and decision makers in the evaluation and selection of different solid waste management options based on certain facts, up-to-date information, government policies and strategies and their own judgments.

4.3.1. User Interface

A well designed user interface provides users with better understanding of a system and a standard Web browser on a user machine serves as the user interface though which all resources and services of the web-based DSS can be accessed. The integration of the web with ArcGIS Server and internet mapping results in the web-based DSS. The user can interact with the map via zooming, panning and identifying such as selecting a map feature and recovering the attribute information about it. The web-based DSS will allow the users to access the information with ease and at their convenience. The users will be able to acquire required information whenever they need from a central information resource on the web, from their homes, offices, public libraries and other internet access points. It places minimal constraints on users' hardware and software environments and for accessing the web-based services requires only a simple computer network with a standard web browser. The architecture of the web-based DSS is shown in the Figure 35.

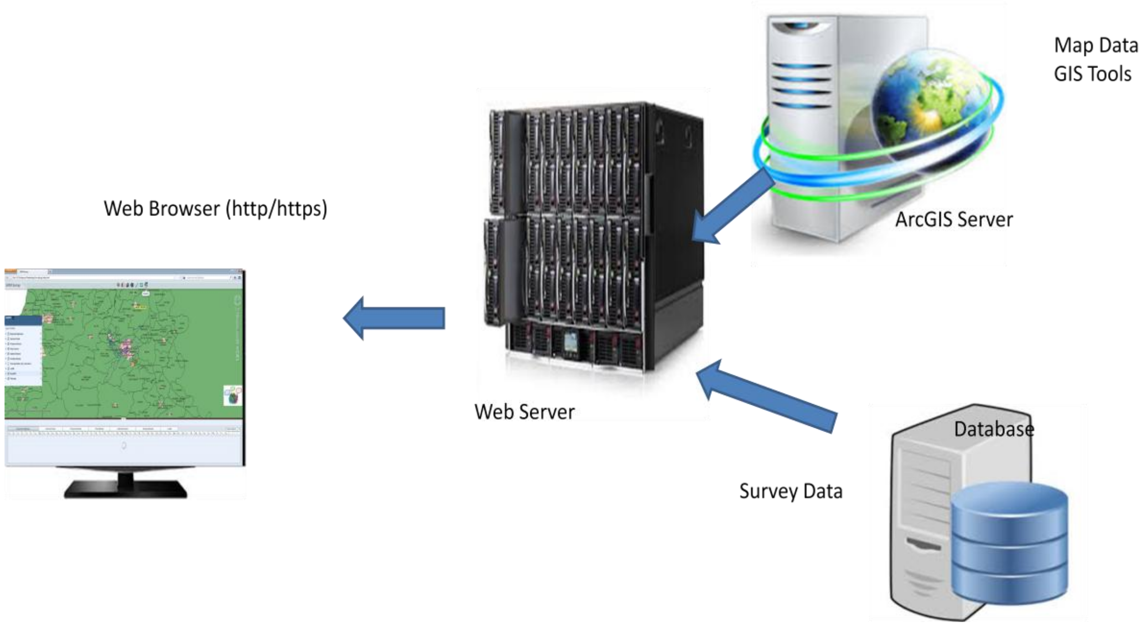


Figure 35: Architecture of the Web-Based DSS

4.3.2. Software Components of Web-Based DSS

The recent advancements in the GIS software's have simplified the process of development of WebGIS. ESRI supported ArcGIS software and it have options to develop WebGIS sites by using ArcGIS Server 10, ArcIMS, or ArcReader. ArcGIS Server simplifies access to GIS services to end-users without any GIS experience. The web-based DSS is a web-based decision analysis software tool/system for solid waste management. It is a GIS based optimal routing model based on the parameters such as residential areas, road network and the types of road, storage bins/collection points and landfill sites is developed and used to trace the minimum cost/distance efficient collection paths for transporting the solid wastes to the landfill. With the help of web-based DSS, the municipalities and decision makers can combine the accessible information and their value judgments to assess and priorities management options in their domain of solid waste management planning. It executes mulit-criteria decision making. The design of the web-based DSS comprises a web server and decision support tools/models that reside on this server and they are delivered to users as HTML documents through the internet. The web-based DSS is of comprises of the following technological components shown in the Figure 36.

Adobe Flex

Flex technology is being used to develop the web application for the tend user to view and for analysis. Flex provides a powerful development platform with logic programming function and visual presentation.

ArcGIS Server

ArcGIS Server is used to deploy shape files and roads network and make use of the Application Programming Interface (API) of ArcGIS in Flex for displaying the data view to the end user. One can stay in control of the content through centralized management of spatial data such as imagery with ArcGIS Server.

DataBase

Application need data base and employed MySQL is an open source database for the Web and is used for storing data in the Web-Based DSS. The choice of using these tools is because of their level of integration and the way it makes the use of the system easy to understand and manage by the end user.

Figure 36: Web-Based DSS Components

4.3.3. Implementation of Web-Based DSS

The web-based DSS is user friendly and it allows the user to navigate the system and communicate with the database. The web-based DSS is designed in a simple fashion that anyone with little knowledge of computer operation can use the system to achieve its overall objectives. it accommodate users of varying skills and competence in the area of computer usage, so with the employment of the specific tools and icons that represent the specific task that the user wanted to perform makes the system usage easy and convenient for all. The web-based DSS employs five tools and they are appended below:

- Geo Search Location-Based Tool
- Bookmark Tool
- Draw and Measure Tool
- Buffered Distance Tool
- Routing Tool

The main page of the Web-based DSS shows the base map of Pakistan as shown in the Figure 37 which contains the data till street level. The interface is supported by a standard web browser window where the base map of Pakistan occupies the central area. A bar with drop-down menus is displayed on the top of the map area offering five main tools The left side of the main page shows the different layers such as regional highways, seminar roads, streets, transportation junctions, road network, collection points existing routes, proposed routes and landfill sites of the twin cities added in the web-based DSS. At the top of the page there are seven icons that show different tools to carry out the operation/work at Web-based DSS. At the right side of the page there is "-"sign to zoom out and "+" sign to zoom in particular area you want to see on the map. The geo search tool is used to find new locations and point of interest such as if you select regional highways from the layers, it will show all the highways on the base map for the twin cities followed by the attribute table. It helps to find different locations, points of interest etc. In addition to this, if a user knows the particular street name and it enters the name of the street in the geo search tool and that street will be displayed on the screen. The attribute table tells us the different attributes of the highways or any layer selected such as its name, speed, length, functional class etc as shown in the Figure 38. Furthermore, the user can add or remove different layers of its choice as shown in the Figure 39.

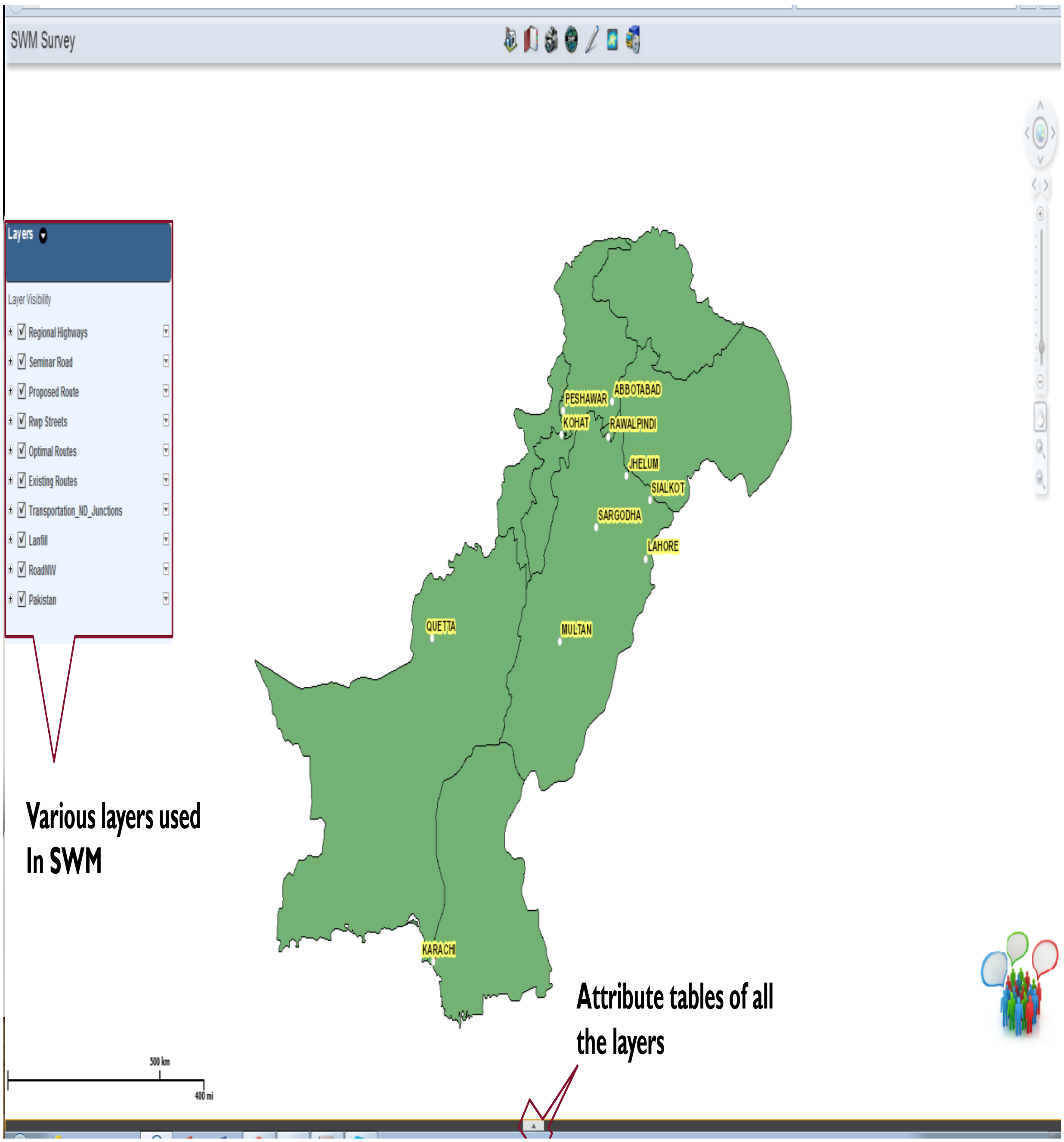


Figure 37: Base Map of Pakistan

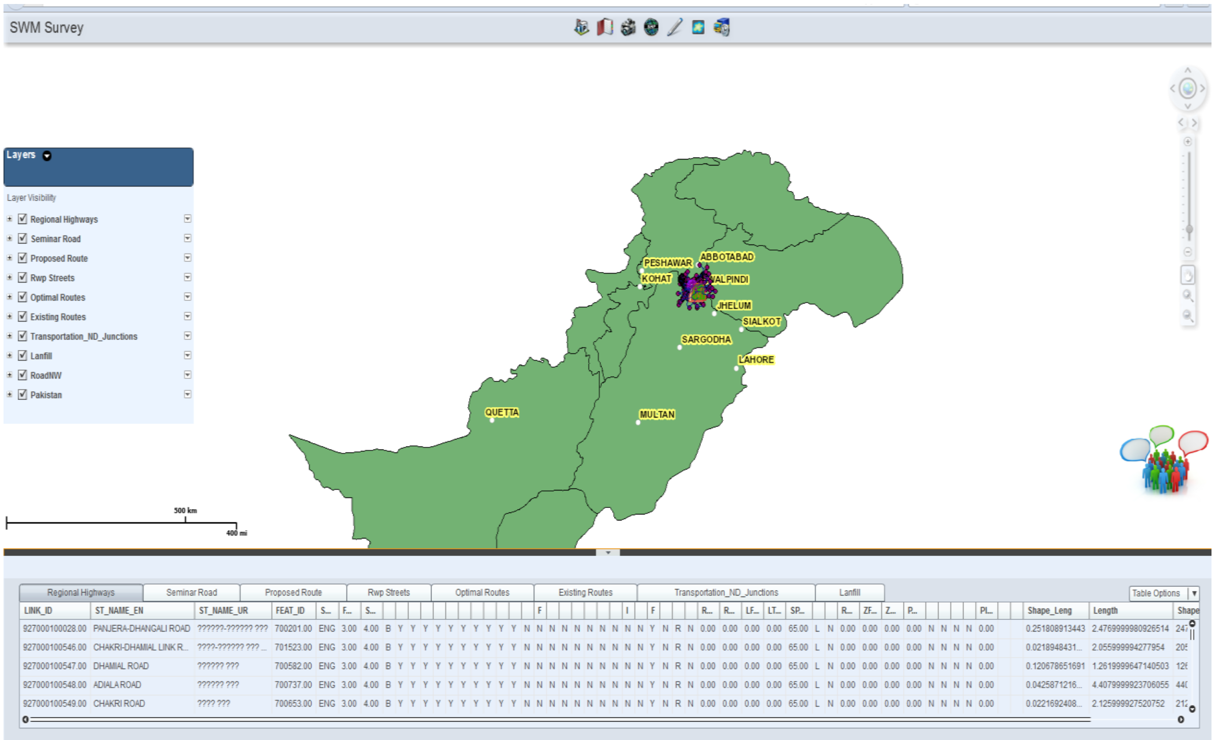


Figure 38: Base Map of Pakistan and Layer's Attributes

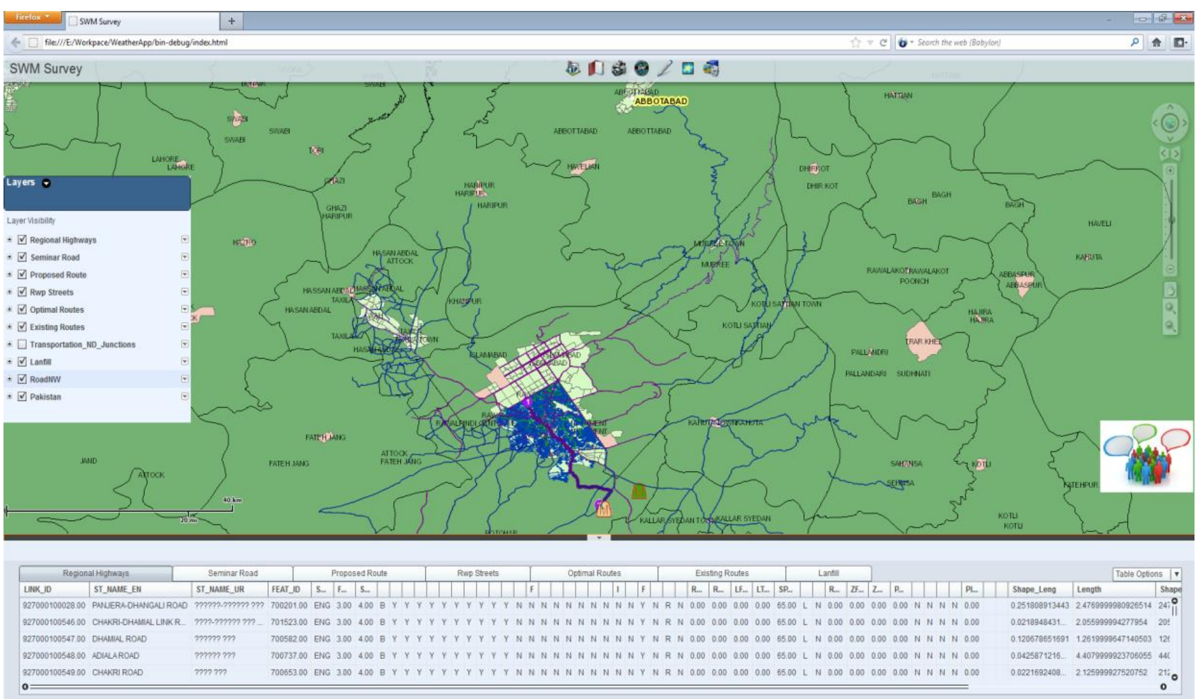


Figure 39: Layer's Attributes

The second important tool of the web-based DSS is the bookmark tool. It will help the user to do much clear research of the particular layer. For example, if the user is working on some important areas and it can bookmark those areas in order to return, reflect and really know where the user left off the last time when it was working with a specific area. The bookmark tool helps in focusing on the better research and getting things done in time. It helps the user to have a linear focused task of summing up the information that is available to it from what the user currently know, and can sort out in it later. The user can bookmark multiple locations while working on the web-based DSS and it is shown in the Figure 39 and 40.

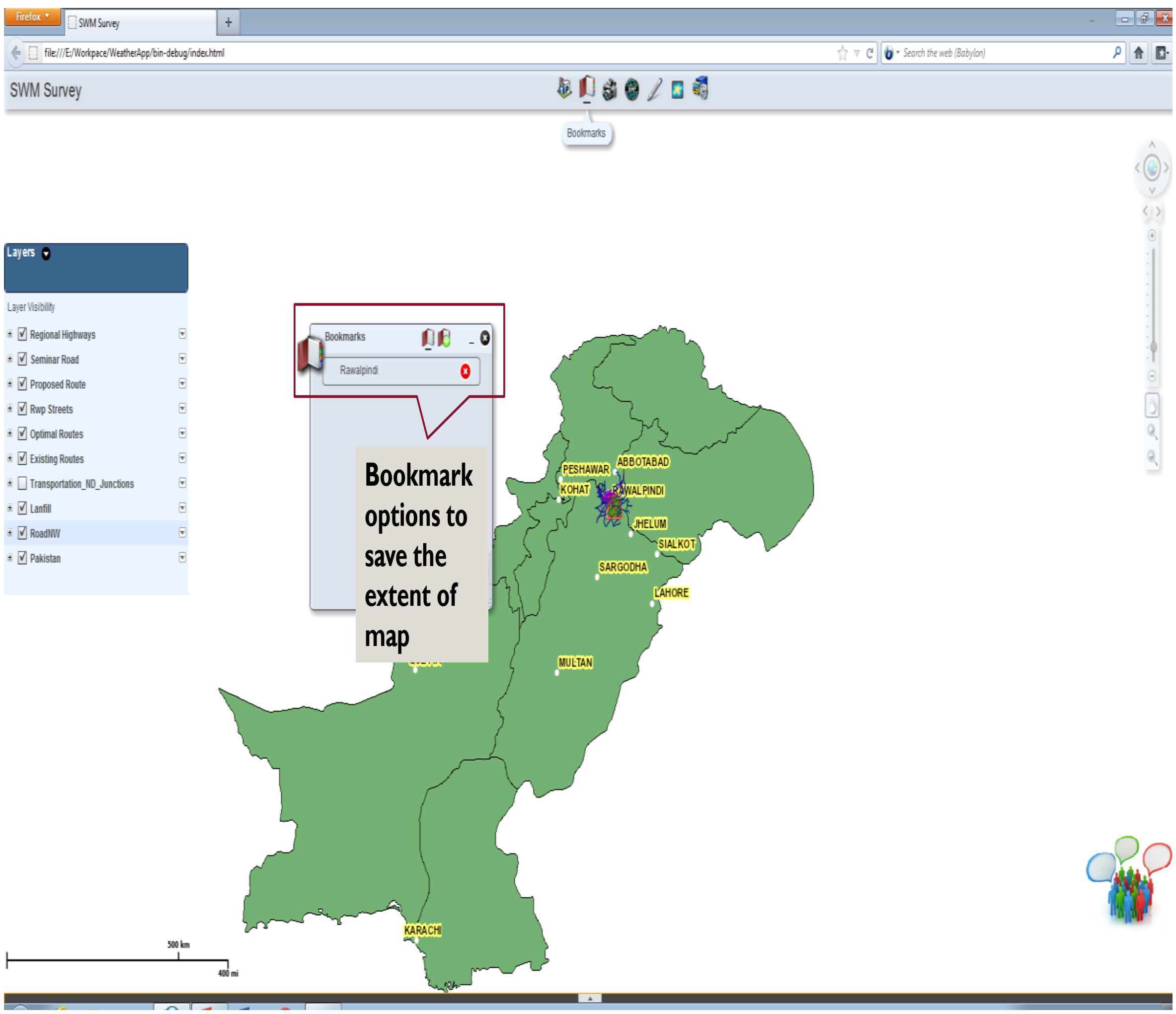


Figure 40: Adding Single Bookmark

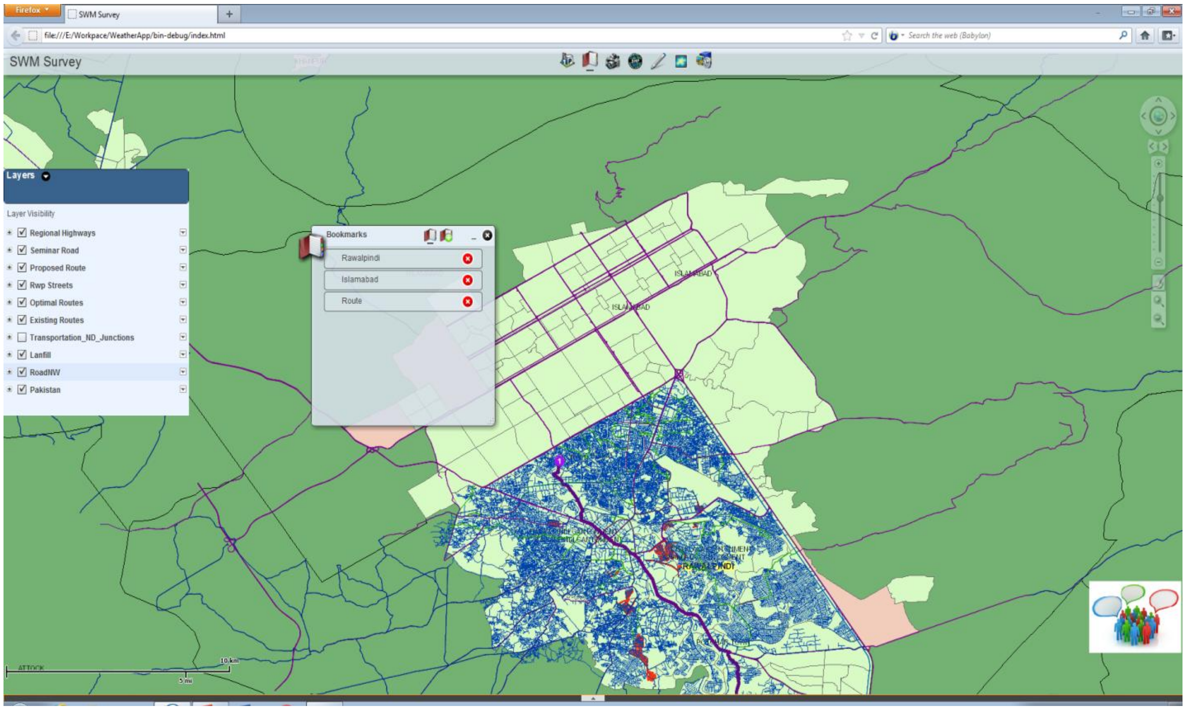


Figure 41: Adding Multiple Bookmarks

The third tool of our web-based DSS is drawn and measure tool. This tool is very important for the DSS and this tool lets user to draw on the map to measure distance, lines and areas. User can make use of this tool in many ways e.g., user can draw a line or polygon on the map and get its length or area. When the user will click the dialog box of the tool, it will allow the user to set different options of its choice such as whether to draw and measure lines, areas, point or features and can set units which will be reported. Therefore, user can choose one of the following options from the draw drop-down menu and draw on the map as shown in the Table 16.

Table 16: Drop Down Menu for Draw and Measure Tool

Point	Press once to create a point.
Rectangle	Press once to quickly create a rectangle or drag on the map to draw your own.
Circle	Press once to quickly create a circle or drag on the map to draw your own.
Polyline	Press to create two or more points to draw a line. Press twice to complete the line.
Polygon	Press to create three or more points to draw a polygon. Press twice to complete the polygon.
Freehand Polygon	Drag on the map to draw a freehand shape.
Freehand Polyline	Drag on the map to draw a freehand line.

To change the area units, the drop-down menu can be used to choose a new unit measurement and the result will update to reflect the new units of measurement. The draw and measure tool allows the user to draw a single-segment or multi-segment line in order to measure a specific area, shape or a linear path. Furthermore, the draw and measure tool has the ability to take into account the natural curvature of the earth to calculate the shortest path between two points such as if the user is measuring distance and location and the lines in the shape user drew may be curved. Hence, the draw and measure tool will represent the length, direction and position everywhere on the surface of the earth while taking into account the curved areas and it shown in the Figure 41 and 42. Furthermore, to measure another area, the user can press on the map and draw a new shape and the new measurement result will be updated and the last shape the user drew will be removed.

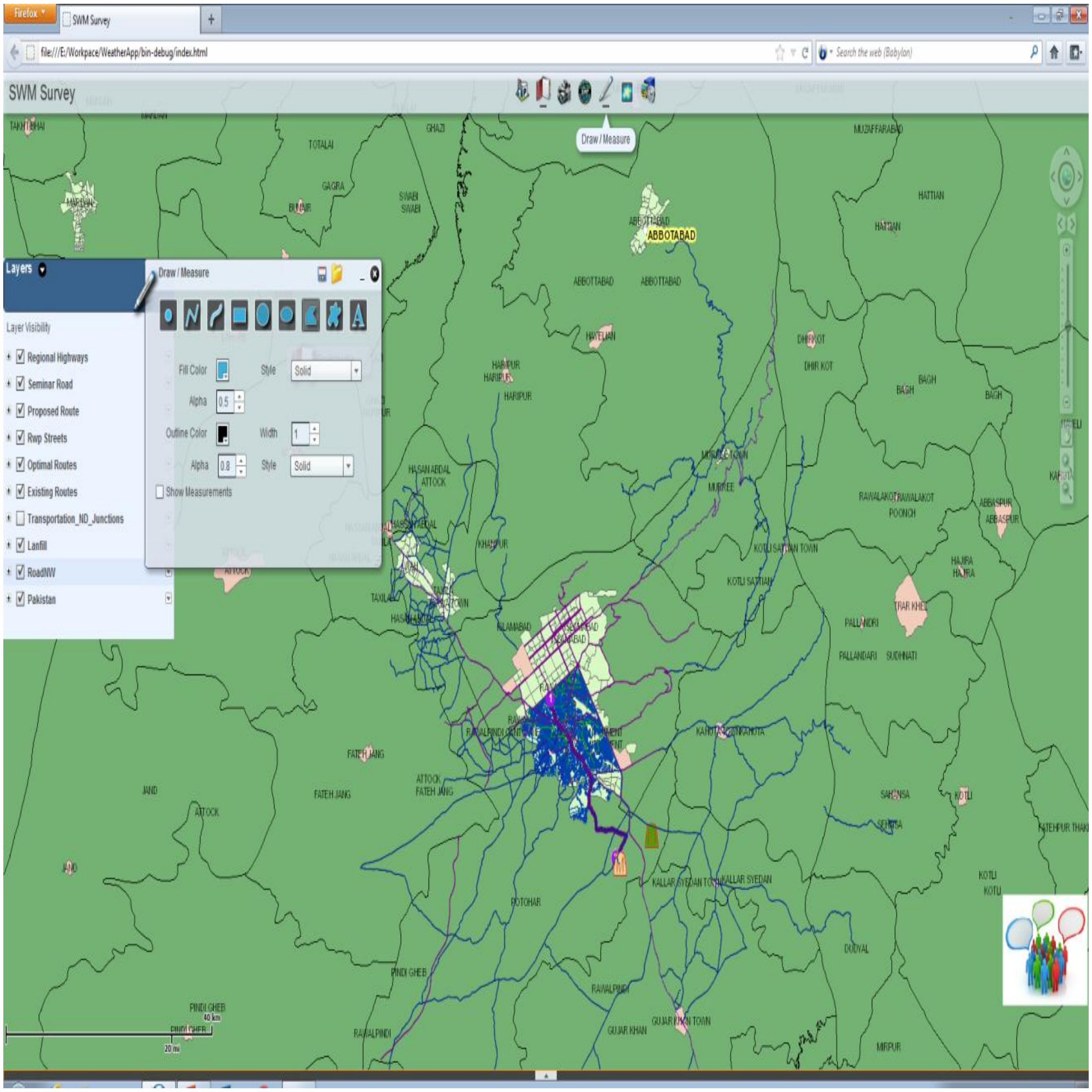


Figure 42: Draw and Measure Tool

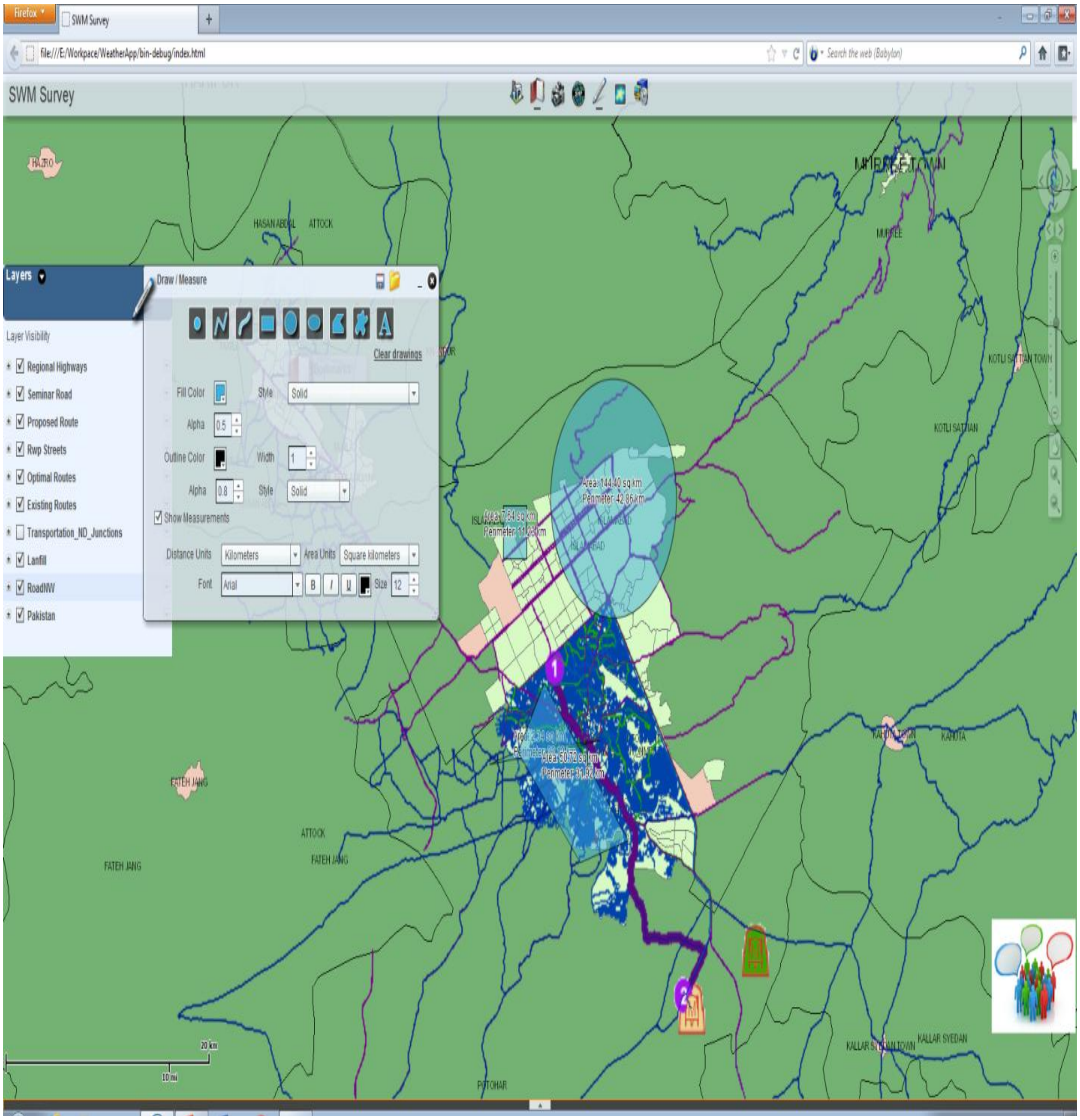


Figure 43: Measuring a Distance or Area Using Draw and Measure Tool

The next important tool of the web-based DSS is Buffered Distance Tool. It will allow the user to present the choice to create a buffer either for lines or for polygon. This tool will produce buffers that will measure the same distance from the feature in both the directions such as east-west and north-south. For example, if the user apply buffer of 500m on a specific area on the map to see the collection points of solid waste and the buffer tool will display all the places having solid waste collection points within that specific buffered area of 500m. The buffered tool allows the user to select features within the specified distance of their drawing and it is shown in the Figure 44.

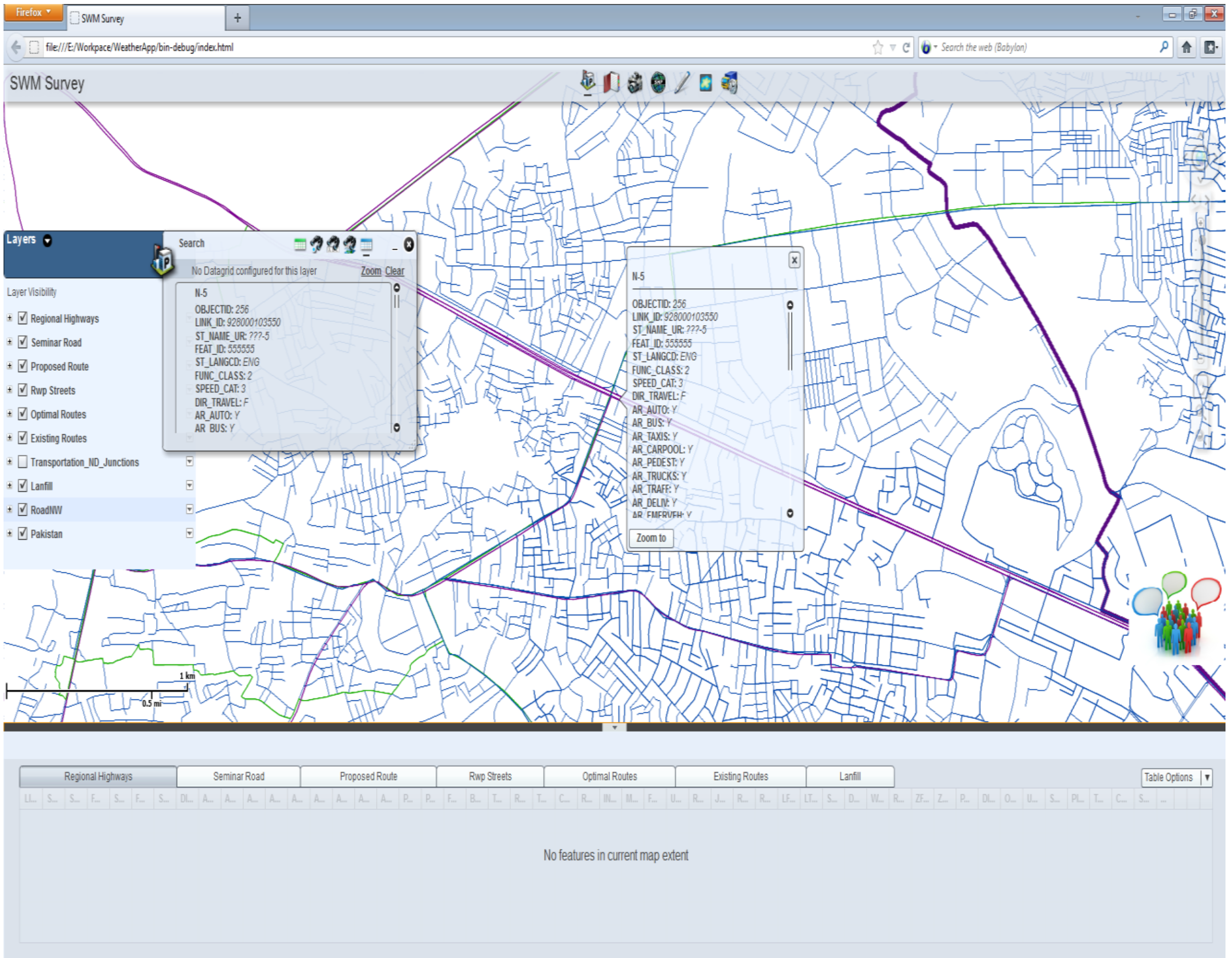


Figure 44: Applying Buffer on a Specific Area

The last important tool of our web-based DSS is a Routing tool. It helps the user to determine how a fleet of vehicles can visit a set of stops/ collection points in the least amount of time. The routing tool generates efficient routes for the user which saves time and resources followed by limiting fuel consumtption and vehicle pollution. The routing tool is defined on the basis of roads network, road junctions, landfills, streets etc. The web-based DSS will generate the best routing services for the user such as driving directions, services area (drive-time areas) or time driven and shortest route between the two points such as collection point/waste bin and landfill or the shortest route to the closest facilities. The user will click on the last tool of the toolbar i.e routing tool in order to generate the route as shown in the Fugure 45. After cicking the routing tool, the small tool bar will open with different options and the user can add two stops by clicking add stops as shown in the Figure 46. After the selection of the two stops, the interface will get the source point and final point and it will do auto routing by using artificial intellgencia and will come with the shortest route between the two points or stops added with travel directions as shown in the Figure 47.

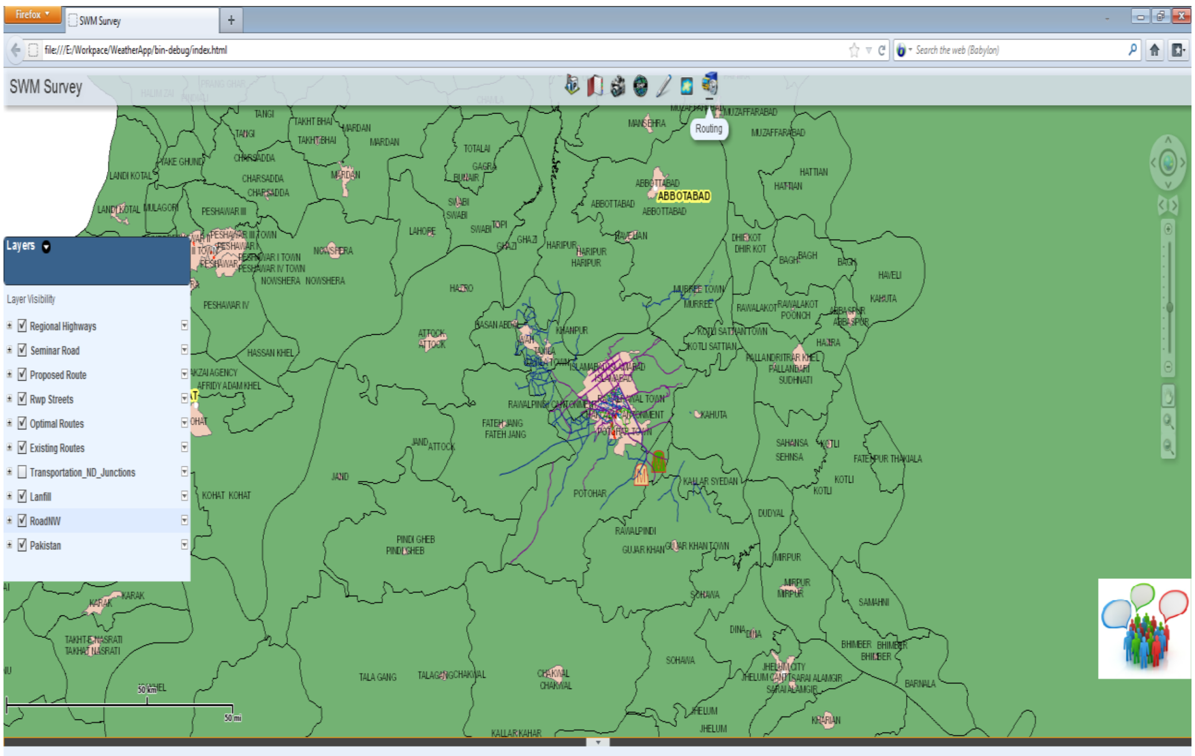


Figure 45: Selection of the Routing Tool

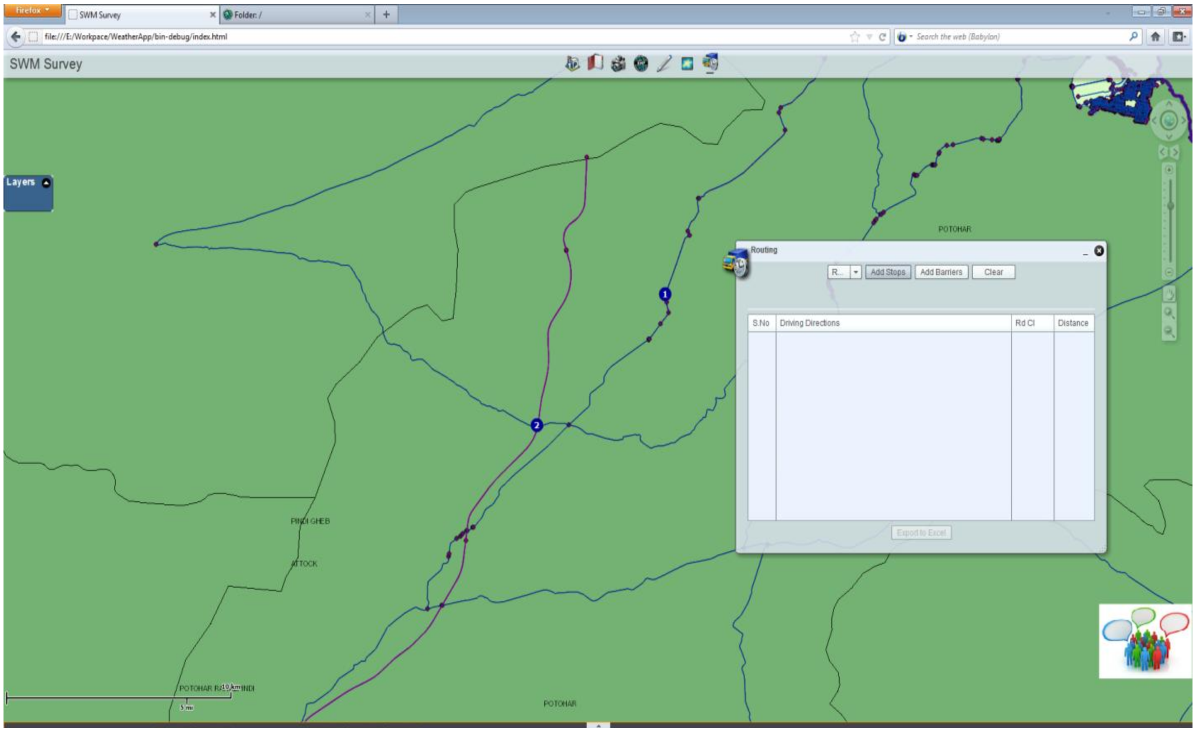


Figure 46: Selection of the Two Stops

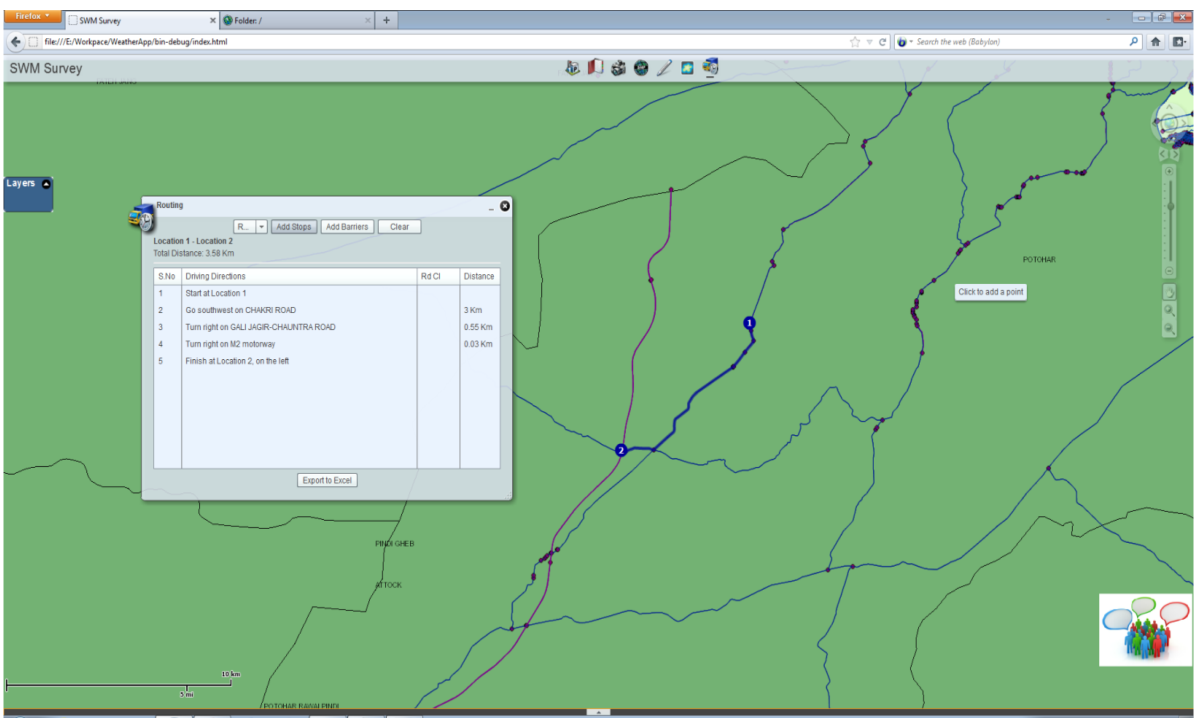


Figure 47: Shortest Route between Two Stops with Travel Directions

Furthermore, a user can perform the routing tasks on the web-based DSS comprising of the route solving task with barriers. A barrier denotes a point on the network that the route cannot pass through e.g. a barrier can represent an area of road construction, an area of accident or closure. If the user wants to apply a barrier between the two points, then the interface will select an alternative route with travel directions as shown in the Figure 47.

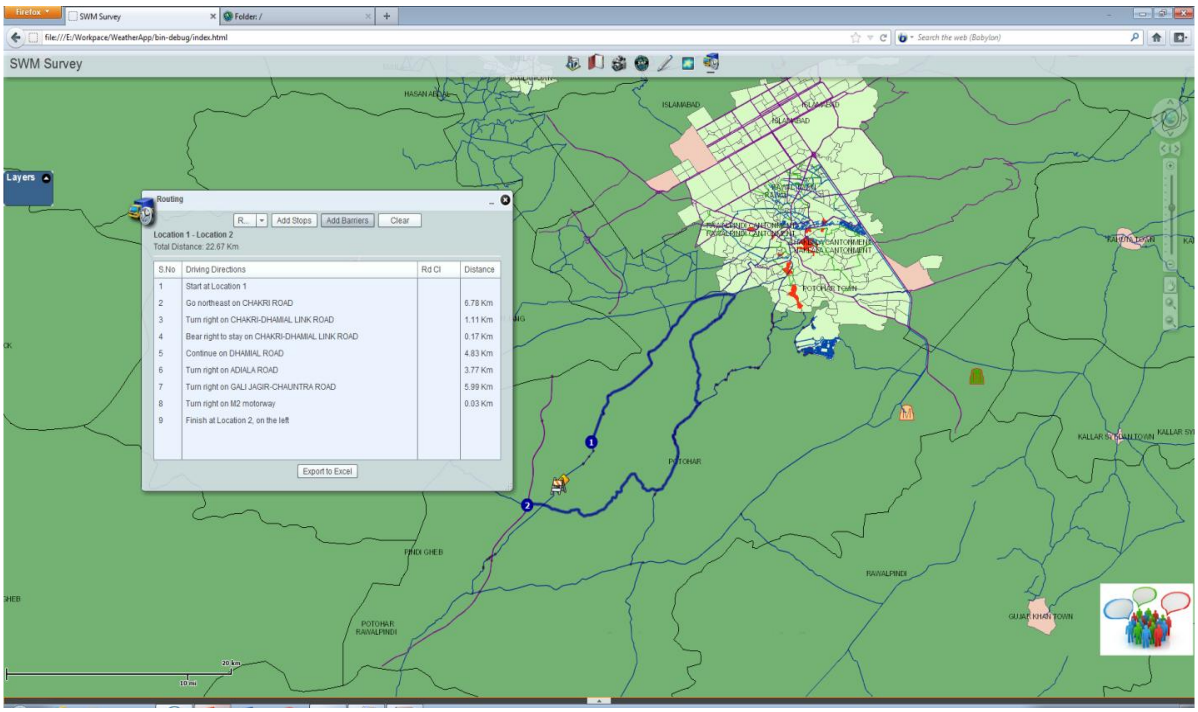


Figure 48: Alternate Route with Barrier Selected

The Web and related internet technology is growing rapidly at a global scale. Therefore, a web-based decision support system using Google Maps and survey data was developed for the proposed study. The DSS was designed to be entirely accessed via an Internet browser. It requires only an Internet browser to be used that allows remote access to cartography, networks data etc via the web. Furthermore, it accesses maps and streets network data provided by Google Maps and represents solutions i.e. routes with lists of directions and the sequence of streets as they are travelled by the vehicle, displaying accumulated length and time for the route as it progresses from one point to another point. There is a great prospective to improve the influx of information and knowledge about SWM to municipalities, decision makers, land managers and their wider community by the application of the Web technology. Since just a web browser is needed, it can be easily adapted to be widely used in many real world situations in Pakistan such as street sweeping, door-to-door collection of waste, delivery of goods, infrastructure, inspection of streets etc. Furthermore, the improved information and knowledge dissemination will ultimately improve awareness and enhance knowledge and commitment to suitable SWM in Pakistan and will satisfy goals for sustainable management in a regional sense. Furthermore, the DSS can read the time data on traffic situations for the future purposes.

5. CONCLUSION & FUTURE WORK

This proposed study set out to evaluate how GIS technology could be used to help reduce overall costs for collection and transportation of residential solid waste for the twin cities and the integration of GIS with other techniques such as MCE for identifying suitable landfill sites. The study focused on using Esri's ArcGIS Network Analyst software extension. The route optimization was done in ArcGIS version 10.0 and is designed to calculate the quickest collection/ delivery travel times for a fleet of vehicles. This chapter also discusses the future work that can be done from this current study.

5.1. Validation of the Research by the Municipalities of the Twin Cities

The twin cities of Pakistan face the issues of municipal solid waste management over the years. These wastes, if not completely managed, will create the environmental problems. Our current study is a dynamic model of municipal solid waste and is one of the waste management tools that were developed using GIS and MCE techniques. There is, however a need to validate the research results in order to be used in real situations. According to Finlay and Wilson (1987), the validation is coupled with two stages of modeling; one stage is associated with decision makers and the other with the model builders. Therefore, Validation is the ability to assess the usefulness of the research, its results and the recommendations deduced from it and it should be carried out in the context of the requirements and purpose of the decision makers. Therefore, the concerned authorities of the municipalities and decision makers of the twin cities of Pakistan validated our research results as they had a good understanding of the situation. The process of validation was carried out in terms of operational validation and logical validation. The municipalities and decision makers have validated the research results empirically and physically on ground as well. They have focused on analyzing the calculated the shortest distance or shortest drive times for the collection and transportation of waste. They acknowledged that by using advanced route solving software, one can return significant cost savings by reducing fuel costs, decreasing mileage driven, or a drop in overall travel time Our study can be a good decision support system/tool for waste transport, fuel consumption, work distribution amongst the vehicles for load balance and generation of work schedules for both employees and vehicles. Our research can be used as a decision support tool by the municipal administration for efficient management of the daily operations for solid waste management. Other spatial data can be added in the future to enhance the utility of this model such as generation of capacity for various residential areas, types of dumping vehicles, enhanced road network for operations, etc. Our results have given optimized routes both in mathematical numbers and in the map format which has made the validation of the research results easier for the decision makers and the municipalities of the twin cities.

Furthermore, the decision makers and the municipalities of the twin cities have visited the areas in person to see the suitability of the selected landfill areas in our research results. The validation of the suitability of the selected landfill areas was carried out on an international and domestic policies and standards such as the distance of landfill site areas from residential areas, road network, land use land cover etc. The validation of research suggested that the proposed landfill sites for the twin cities generally satisfy the minimum requirements for new landfill sites and potential/proposed landfill sites were selected through careful field research. Furthermore, the selection of the final proposed landfill sites in the future will requires further geotechnical and hydro-geological analyses towards the protection of groundwater as well as surface water in the future to be implemented. It must be noted that a more inclusive study on current and future land uses and the cost of the land as well as population growth and waste generation rate is recommended for future studies.

Hence, the research validation evaluated the appropriateness, accuracy and sufficiency of the findings/results to the problem solving process. It was shown by the validation of the research results by the municipalities and decision makers that the organization can plan for its implementation in the future for better economic, environmental and social prospects.

5.2. Conclusion

Rapid development of economic growth has forced the composition of solid waste. The changes in lifestyle, mostly in the urban areas, have led to more severe waste problems. Thus, the challenges of sustainable development are overwhelming, as cities in Pakistan are grappling with increased population, lack of infrastructure, industry changes, and intensifying environmental pollution. There has to be appropriate planning for proper waste management by means of analyzing the waste situation of the area. Protection of the environment from solid waste hazards is becoming a serious problem. The effect of solid waste in countries like Pakistan with limited financial and natural resources, inadequate infrastructure and expertise, and high population growth rate has become one of the most critical environmental issues. It is time to shift usage of emerging technologies such as GIS and RS to planning, management and decision making. Information and communication technology brings efficiency, transparency and accountability and results in better development. Though GIS and RS techniques are being used widely in developed and some developing countries, Pakistan is lagging behind. No study has been conducted to identify optimal routes for the landfill sites in Islamabad and Rawalpindi using emerging technologies like GIS and RS followed by DSS. To overcome these difficulties prudent management for solid waste is required. Therefore, in this study GIS and RS techniques are used for the development of a methodology for the route optimization of solid waste collection and transportation. Therefore, our study used Network Analyst of ArcGIS 10.0 version which provided efficient routing solutions in a simple and straight forward manner. Network Analyst gives the user the ability to produce a map and directions for the quickest route among several locations. The GIS technique identified the optimal route which was found to be cost/distance effective and less time consuming when compared with the existing route. In addition to advanced spatial analysis GIS tools, the study used various geographical data such as urban/residential area, road network, junctions, direction of travel, functional class usage, collection points and land uses. The proposed methodology is applied in the two metropolitan cities of Pakistan, i.e. Islamabad and Rawalpindi, to examine routing of the current system and proposed optimized routes in terms of less distance travelled and time consumed. The optimal routes were created in the current study and they are more efficient in terms of cost, collection time and distance travelled as compared to existing routes followed by the municipalities. These savings are highly related to gas emissions and fuel consumption savings.

Secondly, the proposed study used GIS integrated with other techniques such as MCE and it served as a great tool in finding potential sites for landfill siting for the twin cities. The proposed study has shown that the use of GIS for evaluation of future landfill disposal sites will save time when there is a need for quick evaluation. Furthermore, the study demonstrated the value of Web-Based DSS via API as a waste collection optimization tool, capable of guiding decision making. Development of a comprehensive and user friendly DSS for solid waste management in Pakistani social frame work appears very important to take full advantage of the planned solid waste management. A conceptual frame work for one such proposed decision support system, named DSS – API is presented. The complexity of issues in municipal solid waste management necessitates the development of new tools for processing data inputs of varying formats and expert opinions in multi objective decision making scenarios. DSS are among the most capable approaches to confront such situations. In our proposed study, the DSS – API is integrated with GIS to optimize the routes for the collection, transportation and disposal of the solid waste. This study aimed to present an overview of DSS in the area of solid waste management with specific reference to their development and applications in Pakistan.

5.3. Scope for Future Research

Future work should focus on sectorisation of wider waste collection areas based on spatial analysis as well as adaptation of the collection system to the introduction of separate collection schemes for different waste streams and quantification of fuel savings. One of the key areas for future progress is to reduce the amount of waste generated and sent to the open dumps. Recycling can make this possible and it is also very vital to improve and help organize markets for the recyclables.

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