Hydrological Analysis For Urban Water Management

A Thesis Submitted in the partial fulfillment for the award of the degree of

"***Master of Technology***"

In

"***Civil Engineering***"

WITH SPECIALIZATION IN

WATER RESOURCES ENGINEERING

Under The Guidance and supervision

Of

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MAY 2015

NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA

CERTIFICATE

This is to certify that the thesis entitled, **"Hydrological Analysis for Urban Water Management"** submitted by **RANJIT KUMAR SAHU** in partial fulfillment of the requirements for the award of Master of Technology Degree in **CIVIL ENGINEERING** with specialization in **"WATER RESOURCE ENGINEERING"** at the National Institute of Technology, Rourkela is an authentic work carried out by her under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Date:

Place: **Prof. (Dr.) R. Jha**

ACKNOWLEDGEMENT

A fascinating journey has begun with the imagination and objective in mind, kept on going with wide exposure of information, instrumentation, knowledge and application and finally reaching the destiny of completing our project report. It has become possible due to the direct and indirect contribution of many well-wishers, who have provided us all the support to stand determined, motivated to move forward, strength to overcome the obstacles in reaching our goal.

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This leaf would remain incomplete; if we do not record our appreciation of understanding, inspiration and support we received from our parents and all family members and friends who have taken a lot of pain for this project venture. We consider ourselves extremely fortunate to be blessed with such loving family who have always supported and encouraged us to achieve our goal.

Ranjit Kumar Sahu

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ABBREVIATIONS:

CWC: Central Water Commission, India

DEM: Digital Elevation Model

IDW: Inverse Distance Weighted

USGS: United States Geological Survey

TIN: Triangulated Irregular Network

Abstract

Abstract— Urban Water Management is the practice of managing freshwater, wastewater, and storm water as components of a basin-wide management plan. It builds on existing water supply and sanitation considerations within an urban settlement by incorporating urban water management within the scope of the entire river basin. The pervasive problems generated by urban development have prompted, in the present work, to study the spatial extent of urbanization in Golden Triangle of Odisha connecting the cities Bhubaneswar (20.2700° N, 85.8400° E), Puri (19.8106° N, 85.8314° E) and Konark (19.9000° N, 86.1200° E)., and patterns of periodic changes in urban development (systematic/random) in order to develop future plans for (i) urbanization promotion areas, and (ii) urbanization control areas. Remote Sensing, using USGS (U.S. Geological Survey) Landsat8 maps, supervised classification of the Urban Sprawl has been done for during 1980 - 2014, specifically after 2000. This Work presents the following: (i) Time series analysis of Hydrological data (ground water and rainfall), (ii) Buffer Analysis and other soft computing techniques for Urban Water Management, and (iii) Uncertainty analysis of model parameters (Urban Sprawl and correlation analysis). The outcome of the study shows drastic growth results in urbanization and depletion of ground water levels in the area that has been discussed briefly. Other relative outcomes like declining trend of rainfall and rise of sand mining in local vicinity has been also discussed. Research on this kind of work will (i) improve water supply and consumption efficiency (ii) Upgrade drinking water quality and wastewater treatment (iii) Increase economic efficiency of services to sustain operations and investments for water, wastewater, and storm water management, and (iv) engage communities to reflect their needs and knowledge for water management.

Keywords— Land use change, Buffer Analysis, Uncertainty analysis and Urban Sprawl.

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Chapter 3 **The Study Area And Methodology**

Chapter 4 **Results and Discussion**

Chapter 1

INTRODUCTION

1.1 GENERAL

Urban Water Management is the practice of managing freshwater, wastewater, and storm water as components of a basin-wide management plan.

It builds on existing water supply and sanitation considerations within an urban settlement by incorporating urban water management within the scope of the entire river basin.

1.2 ORIGIN OF PROJECT

More than six decades after independence, India's Urban Water quality is worse than before. At presvent, there is absolutely not a single good reason as to why the urban population of India cannot have access to clean water which can be drunk without treatment from taps, wa stewater cannot be properly treated before being discharged to the rivers, and monsoon rains cannot be promptly drained so transportation systems are not paralyzed.

The imperative of sustainable economic development demands sound water manage ment and more research on hydrological processes.

In order to manage water resources in a sustainable manner, it is essential to study the hydrological processes associated with the water problems to understand the causes of the existing vulnerability of water resources and to try to increase water safety.

1.3 RESEARCH SIGNIFICANCE

1. Improve water supply and consumption efficiency.

2. Upgrade drinking water quality and wastewater treatment.

3. Increase economic efficiency of services to sustain operations and investments for water, wastewater, and storm water management.

4. Utilize alternative water sources, including rainwater, and reclaimed and treated w ater.

5. Engage communities to reflect their needs and knowledge for water management.

1.4 About Remote Sensing

Remote sensing is the art, science and technology of acquiring information about physical objects and the environment through recording, measuring and interpreting imagery and digital representations of energy patterns derived from noncontact sensors (*Colowell, 1997*). Remote sensing has traditionally been the colony of earth scientists and national security com munities and urban questions have been largely marginalized (*Sherbinin et al., 2002).*

With recent innovations in data, technologies, and theories in the wider arena of Earth Observation, Urban remote sensing, or urban applications of remote sensing, has rapidly gained the popularity among a wide variety of communities. First, urban and regional planne rs are increasingly using remote sensing to derive information on the urban environment in a timely, detailed and cost-effective way to accommodate various planning and management activities (*e.g., Sugumaran, Zerr and Prato, 2002; Alberti, Weeks and Coe, 2004; Mittelbach and Schneider, 2005; Santana, 2007; Bhatta, 2010).* Second, more urban researchers are using remote sensing to extract urban structure information for studying urban geometry, and models of urban morphology (*e.g., Batty and Longley, 1994; Longley, 2002;* which can help develop theories for studying urban geometry, (*Herold, Scepan and Clarke, 2002; Yang, 2002; Lo, 2004, 2007; Rashed et al., 2005; Batty, 2008; Schneider and Woodcock, 2008).*Third, environmental scientists are increasingly relying upon remote sensing to derive urban land cover information as a primary boundary condition used in many spatially distri buted models (*e.g., Lo, Quattrochi and Luvall, 1997; Lo and Quattrochi, 2003; Arthur-Hartranft, Carlson and Clarke, 2003; Carlson, 2004; Stefanov and Netzband, 2005; Hepinstall, Alberti and Marzluff, 2008).* Lastly, the global change community has recognized remote sensing as an enabling and acceptable technology to study the spatiotemporal dy namics and consequences of urbanization as a major form of global changes (*e.g., Bartlett, Mageean and O'Connor, 2000; Small and Nicholls, 2003; Auch, Taylor and Acededo, 2004; Small, 2005; Turner, Lambin and Reenberg, 2007; Grimm et al., 2008)*, given the facts that more than half of the global population are now residing in cities (*UN-HABITAT, 2010*) and urban areas are the home of major global production and manufacture centers (*Kaplan, Whe eler and Holloway, 2009*).

1.5 REMOTE SENSING AND URBAN STUDIES

The technology of modern remote sensing began with invention of the camera more than 150 years ago, and by now a wide variety of remote sensing systems has been developed to detect and measure energy patterns from different portions of the electromagnetic spectrum. Remote sensing can help improve our understanding of urban areas in several ways, although the realistic potential for making these improvements is often challenged by the complexity in the urban environment.

Remote sensing provides several major benefits for urban studies. First, perhaps the largest benefit of remote sensing is its capability of acquiring photos or images that cover a large area, providing a synoptic view that allows identifying objects, patterns, and human-land interactions. The unique perspective is highly relevant to the interdisciplinary approach we advocate to study the urban environment.

Second, remote sensing provides additional measures for urban studies. Urban researchers frequently use data collected from field surveys and measurements. This way of data collection is considered to be accurate but can introduce potential errors due to the bias in sampling design (*Jensen, 2007*). Field measurements can become prohibitively expensive over a large area. Remote sensing can collect data in an unbiased and cost-effectiveness fashion. Moreover, remote sensors can measure energy at wavelengths which are beyond the range of human vision; remote sensor data collected from the ultraviolet, infrared, microwave portions of the electromagnetic spectrum can help obtain knowledge beyond our human visual perception. For example thermal remote sensing can measure spatially continuous surface temperature that is useful to examine the urban heat island effect (*e.g., Lo, Quattrochi and Luvall, 1997*). Data fusion from different sensors can improve urban mapping and analysis.

Third, remote sensing allows retrospective viewing of Earth's surface, and time-series of remote sensor data can be used to develop a historical perspective of an urban attribute or process, which can help examine significant human or natural process that act over a long time period. Examples include time-series land use/cover data used for examining suburbanizing process; increasing gross primary production (GPP) that may be linked with vegetation carbon sequestration due to urban growth; historical land use changes affecting upon near-surface air temperature during recent extreme heat events; and urban growth and landscape changes affecting biodiversity.

Fourth, remote sensing can help make connections across levels of analysis for urban studies. Urban science disciplines and sub-disciplines have their own preferred levels of analysis and normally do not communicate across these levels. For example, urban planners tend to work at street and neighbourhood levels; regional planners deal with a larger environment such as several districts, one or more metropolitan areas, or even a whole state; urban meteorologists and ecologists tend to work at levels defined by physiographical features or ecological units. On the other hand, the temporal scales used by these different urban researchers vary greatly, from hourly, daily, weekly, monthly, seasonally, to annual or decadal basis. Remote sensing provides essentially global coverage of data with individual pixels ranging from sub-meters to a few kilometres and with varying temporal resolutions; such data can be combined to allow work at any scales or levels of analysis, appropriate to the urban phenomenon or process being examined. Therefore, remote sensing offers the potential for promoting urban researchers to think across levels of analysis and develop theories and models to link these levels.

Last, remote sensing integrated with relevant geospatial technologies, such as geographic information systems, spatial analysis and dynamic modelling, offers an indispensable framework of monitoring, synthesis and modelling in the urban environment. Such frameworks support the development of a spatio-temporal perspective of urban process or phenomena across different scales and the extension of historical and current observations into the future. They can also be used to relate different human and natural variables for developing an understanding of the indirect and direct drivers of urban changes and the potential feedbacks of such changes on the drivers in the urban environment.

Nevertheless, urban environments are complex by nature, challenging the applicability and robustness of remote sensing. The presence of complex urban impervious materials, along with a variety of croplands, grasslands and vegetation cover, causes substantial interpixel and intrapixel scenic changes, thus complicating the classification and characterization of urban landscape types. Moreover, it is always difficult to integrate remote sensor data with other types of geospatial data in urban social or environmental analyses because of the fundamental differences in data sampling and measurement.

1.6 OBJECTIVES OF THE PROJECT

To Analyse:

- Time series analysis of Hydrological data.
- Application of Buffer Analysis and other soft computing techniques for urban water management.
- Uncertainty analysis of model parameters.

1.7 ORGANIZATION OF THE PROJECT REPORT

The present project report is divided into six chapters. The general introduction to Ground Water, Urban Water, Remote Sensing, its present application and the objective of present work is outlined in **Chapter1**. The existing literature relevant to the present investigation is presented in **Chapter 2**. The critical observation on the available literature and scope of the present work is also outlined in this chapter. The details of study area and their topology and also the soft computing methodology for all the program that is being carried out during the present work are presented in **Chapter 3**. Results and discussions of all the methods using different soft computing techniques, ground water and urbanisation and also a comparative study between them in timeline is mentioned in **Chapter 4**. The conclusion drawn out of the present research and the future scope of works are summarized in **Chapter 5**. Finally, a list of references cited in this project report is provided in **Chapter 6**.

1.8 SUMMARY

This chapter presents the general introduction to Ground Water, Urban Water, Remote Sensing, present applications and international status. The objective of the present work is also outlined. Finally, the organization of the project report is presented.

Chapter 2

REVIEW OF LITERATURE

2.1 GENERAL

The major achievements and results reported in this literature are highlighted in this chapter. All kinds of experimental, theoretical as well as numerical studies on Ground Water and Urbanisation are presented in this review of the literature.

2.2 REVIEWS ON GROUND WATER AND URBAN RESEARCH

Experimental, numerical as well as theoretical studies on use and properties of Ground Water have been contributed by the following researchers. The brief literature reviews of these studies on Ground Water are as follows:

Srivastava and Bhattacharya (2000): In their work the satellite data of IRS-IB-LISS-II was used to determine the presence of groundwater in the rock and various zone of ground water. Bargarh district of Odisha has been taken as the study area covering the 680sqkm of land mass. For the preparation of geological-cum-lineaments, drainage areas and land used satellite information are applied. GIS is used to integrate many thematic image and to demarcate less groundwater potential zone to higher one. Pumping test was carried over the case area. The results explain that the lineaments and drainage plays important part for the ground water potential among the various geomorphic units.

Srinivasan et al. (2010) integrated different components of the urban water system to develop a unified hydrologic-economic model to simulate the dynamic interactions responsible for urban water supply in Chennai. They integrated different components of the urban water system: water flowing into the reservoir system; diversion and distribution by the public water utility; groundwater flow in the aquifer beneath the city; supply, demand, and prices in the informal tanker-truck-based water market; and consumer behaviour. Both the economic and physical impacts of consumers' dependence on multiple sources of water were quantified. The model was calibrated over the period 2002−2006 using a range of hydrologic and socio-economic data. The model's results highlight the inadequacy of the reservoir system and the buffering role played by the urban aquifer and consumers' coping investments during multiyear droughts.

Burns et al. (2012) have evolved management paradigms from the initial objective of flood prevention, to more recently, pollutant load reduction.

Pathy and Panda (2012): The reason for speed rate of spatial growth sprawl are the growing industrialization and urbanization and the development of current urban centrals. The increase of centres leads to high population in slum areas also results in conversion of lands in a high-scale. Growing urbanization were mainly seen over the hazards and limited areas of the countries yet to develop, this increased the accumulation of squatters and were regular effect of floods, experiencing health issue. In developing countries like India, such problem were observed over the cities of different states e.g. Bhubaneswar is the capital of Odisha, which was dealing with same kind of problem for the urbanization. It is due its location sites with river bank, low-laying grounds, with valleys surrounding. Considering the issue and development of Bhubaneswar, they had taken as the case study for the present work. The rapid urbanization has been noticed over the past years since it was planned in 1954. The work kept focus on monitoring and developing methods to control the growth and development of urban areas through GIS and Remote sensing information data. The study also included the present rapid growing pattern of Bhubaneswar.

Reddy & Jha (2012): In order to conserve forest over tropical region, one must control the deforestation for the global importance. In India within past years they have noticed drastic alteration of the forest land due to the government policies and because of the population growth. Their study delivers the spatial change of forest area and the nature of the forest in Odisha state for the last 75 years. The graphs for the year 1924-1935, 1975, 1985, 1995 and 2010 shows the forest area for 81,785.6 km^2 (52.5%), 566,661.1 km^2 (36.4 %), 51,642.3 km^2 (33.2 %), 49,773 km^2 (32 %) and 48,669.4 km^2 (31.3 %) of the investigation location. The study disclosed the annual mean rate of deforestation as 0.69% annually, reducing 40.5% of the whole forest mass for period of 1935-2010. During the period of 1995-2010 the annual rate of deforestation reduced to 0.15%. According to the forest cover type, the deforestation results in large area of deciduous dry forest. For the various years landscape analysis was done which showed the different number of patches for forest were 2.463 in 1935; 10.39 in 1975; 11.89 in 1985. These value indicated large pressure of anthropogenic over the forest.

The mean sqkm patch area of forest reduced from 33.2 in 1935 to 5.5 in 1975 and 3.2 by the year 2010. The work showed the loss in quantity of forest cover and landscape while managing the long period variation of forest.

Aguilar and Dymond (2013) gave guidance on calibrating a model to assist storm-water managers by providing a geographic information system (GIS) workflow supported by Python scripting that produces a geographic database of storm-water infrastructure that can subsequently be used to create a fully parameterized hydrologic/hydraulic model. Guidance on calibrating this model was provided with suggestions for measuring discharge in storm sewer systems. The application of the objectives was demonstrated in a watershed in Blacksburg, Virginia, where a unique municipal-academic partnership fostered the development of their work.

Naik and Jha (2013) analyzed the ground water depletion of Bhubaneswar city due to Urban Sprawl, using Entropy, Buffer Analysis and GIS Applications.

Wakode et al. (2013) Hyderabad is one of the fastest growing mega cities in India and it is facing many economic, social and environmental problems due to rapid urban growth. For the better planning of resources and to provide basic amenities to its residents, it was necessary to have sufficient knowledge about its urban growth activities. Also, it was necessary to monitor the changes in land use over time and to detect growth activities in different parts of the city. To accomplish these tasks with greater accuracy and easiest way, remote sensing and geographic information system (GIS) tools proved to be very advantageous. Their study makes an attempt towards the mapping of land use classes for different time periods and analysis of apparent changes in land use using the Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM) data for the urban agglomeration of Hyderabad, India. In their study, three different time periods viz. 1989–2000, 2000–2005 and 2005–2011 were chosen for the analysis. The results have shown that high density urban area had grown during 1989–2011 by encroaching into other land use classes. The urban growth had also affected water resources both, qualitatively and quantitatively in the region. The transformation of other land use types into urban area dynamically continued in the North-East and Southern parts of the city. In the North-East direction, the urban growth was mostly due to growth in industrial and residential area and in Southern part, mostly due to residential growth.

Anu and Ashwani (2014): There were involvement of large forces when the land cover changes due to calamities. The paper present the natural resource management by extracting the data of alteration occurred. The data or information can be quantitative or qualitative even both. The change in the land surface cover were mainly observed around the coast. For the case study Odisha, an eastern India was considered with the coastal region of 480 km frequently affected by cyclone. In this the dynamic variation of land surface was examined by the application of remote sensing satellite data and GIS. The aim of the research was to get the land cover variation along the coastal region of Kendrapara. Previous data of landsat ETM+ image of year 2000 and 2006 were collected and used for the coast of Kendrapara. Methods of unsupervised classification and a post-classification comparison technique was used to classify the images and to record the recognised alteration of the images. With going investigation, they observed the growing agricultural land and vegetation areas but minimising the unfertile land, soil and water bodies.

Javaid and Asima (2014): Provincial urban periphery is the most element region lying between the city and country zone. The dynamic nature of the periphery can be identified by watching the adjustments in the city and bad habit versa. The progressions at rustic urban periphery depended up on the capacity and size of the city. The state of the periphery belt changes from city to city, taking into account the physical, social, and monetary identity of the city. Its shape is continually changing in correspondence offices. It is a process which serves to change the provincial wide open into urban units. As the urban focus grow, the periphery belt does not stay static, it goes progressively changed over into a provincial urban periphery and afterward converge with the guardian urban focus. Rustic urban periphery implies both urban and country attributes. The way of periphery, as it neither absolutely takes after with the town characters nor with country characters and the same time relates to both. The better approach to distinguish the dynamic way of periphery range is regarding social, social, demographic also, arrive change at distinctive time periods. Urban infringement is one of primary issue winning in the earth of rustic urban periphery. The urban effect has not just changed the financial and demographic profile of the rustic urban periphery additionally the area utilization example of the region

Nagarajan and Basil (2014) A study was conducted by Nagarajan and Basil to estimate the runoff in urbanized zone using Soil Conservation Services Curve Number (SCS-CN) method through remote sensing and GIS techniques. In this study, the region they identified as

Cochin Corporation (Kerala State, India) with an aerial extent of 96.44 km^2. They collected spatial and non-spatial data from different sources, and the thematic layers of soil hydrologic group and prepared land-use maps and overlaid with one other. The overlaid output results were assigned by curve numbers with respect to soil and land-use categories, and prepared the CN map with the help of Visual Basic (VB) language in ArcGIS platform. Through supervised classifications, 13 different land-use classes were identified from Quickbird data for the year of 2005 and 2010. The most prominent land-use classes were water bodies, residential, mixed crops, commercial and industrial, and 3 types of soil hydrologic groups were identified namely A, B, and C categories. The B group was most prominent occupying 60 km^2 of the study area. The CN map showed the ranges that 92–100 was the major CN area with high runoff potential zone of the study region. At the final stage, the runoff was estimated by the maximum successive rainfall received in the study area in two different years—2005 and 2010 along with their land-use pattern. The runoff model applied was for temporal variation in land-use change, and impact of runoff was studied. The study area showed significant changes in land-use pattern between 2005 and 2010 particularly in the land-use change from agricultural into industrial, commercial, and residential (high density).

Prabhu and Hrushikesh (2014): The Rajnagar Block of Odisha has been considered for the study of sub-surface ground water system and involving the location sampling of aquifer in the mentioned areas. To determine the natural factor like habitats and their interrelationship with the ground water that affecting the anthropogenic, we look over the topography and hydrological data of study area. For the examination purpose 53 distinct point are taken on the ground which shows the similar characteristic of ground water with same chemical formation as found from the available geological data obtain from the Geological survey of India.

2.3 Critical Observation

- Remote sensing is a fruitful technique for urban analysis.
- The ground water and urban sprawl can be linked together for better research.
- Ground water depletion is directly related to urbanisation.
- Potential areas for development can be found out through land use and land-cover analysis over the timeline.

Chapter 3

THE STUDY AREA AND METHODOLOGY

3.1 STUDY AREA

The problems generated by urban development have prompted, in the present work, to study the spatial extent of urbanization in Golden Triangle of Odisha connecting the cities Bhubaneswar (20.2700° N, 85.8400° E), Puri (19.8106° N, 85.8314° E) and Konark (19.9000° N, 86.1200° E).The study area includes more than 200 Ground Water Station Points including Khordha and Puri Districts.

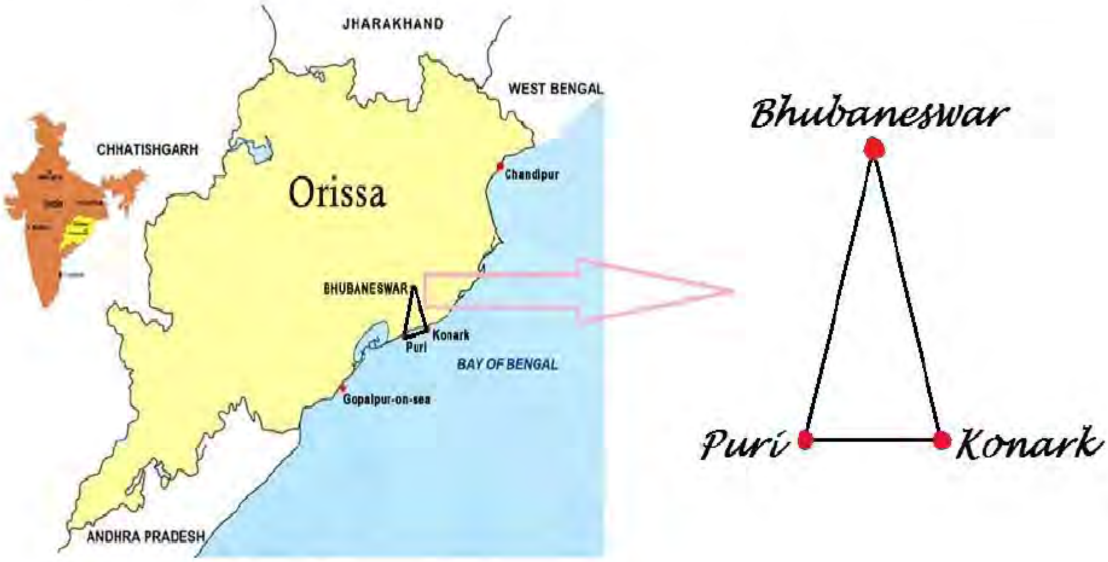


Figure 3.1: The Study Area of Research

3.2 METHODOLOGY

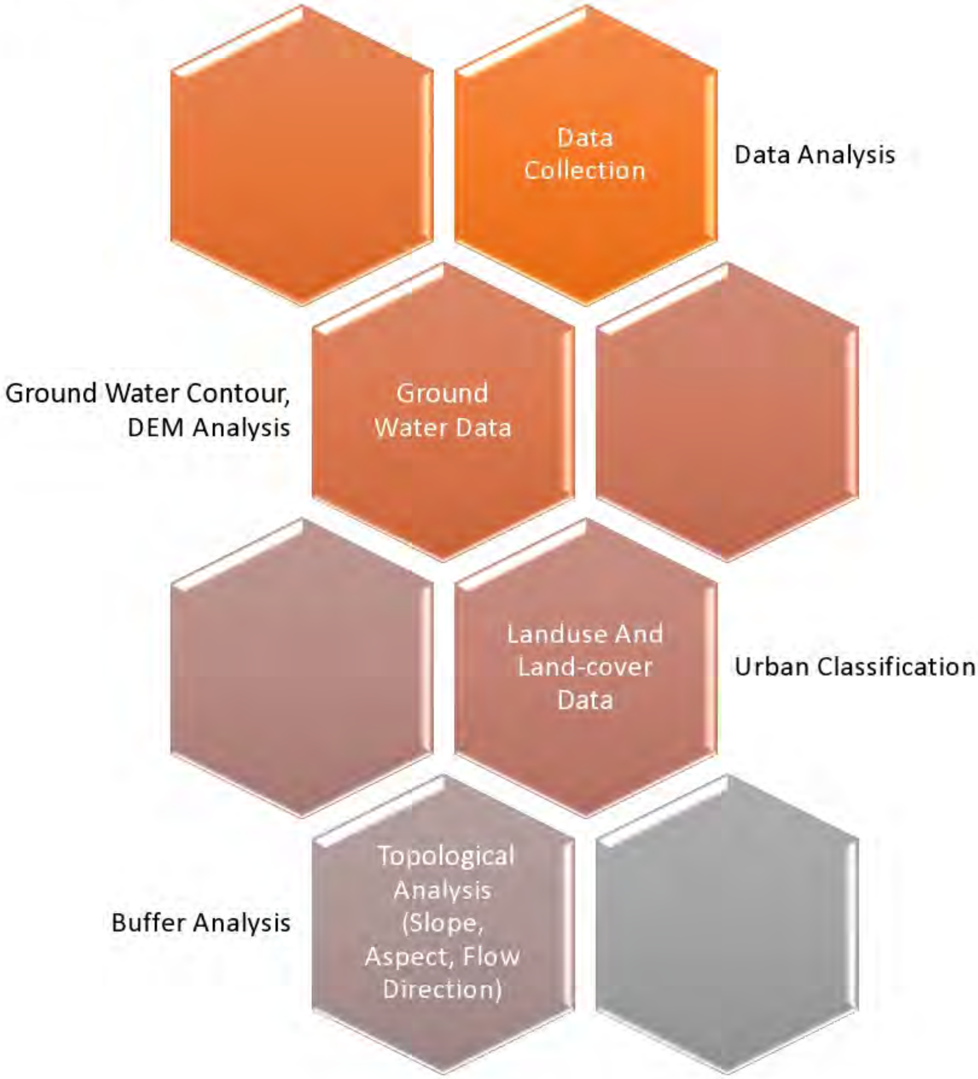


Figure 3.2: The Methodology Sequence

3.3 DATA COLLECTION

Various Data requirements have been met through online and off-line sources depending on the availability and feasibility of data. Most of the data were freely available through various websites for the research work. Along with the data requirements other research works by various researchers have also been an immense help for the project.

3.4 Data Analysis

After collection of the data, first they were verified as original and true to the knowledge then they were processed for further works. Missing and other erroneous data have been checked and taken care off.

For better analysis the whole two district maps' shape file has been created in ArcGIS Tool and monitored for results and analysis.

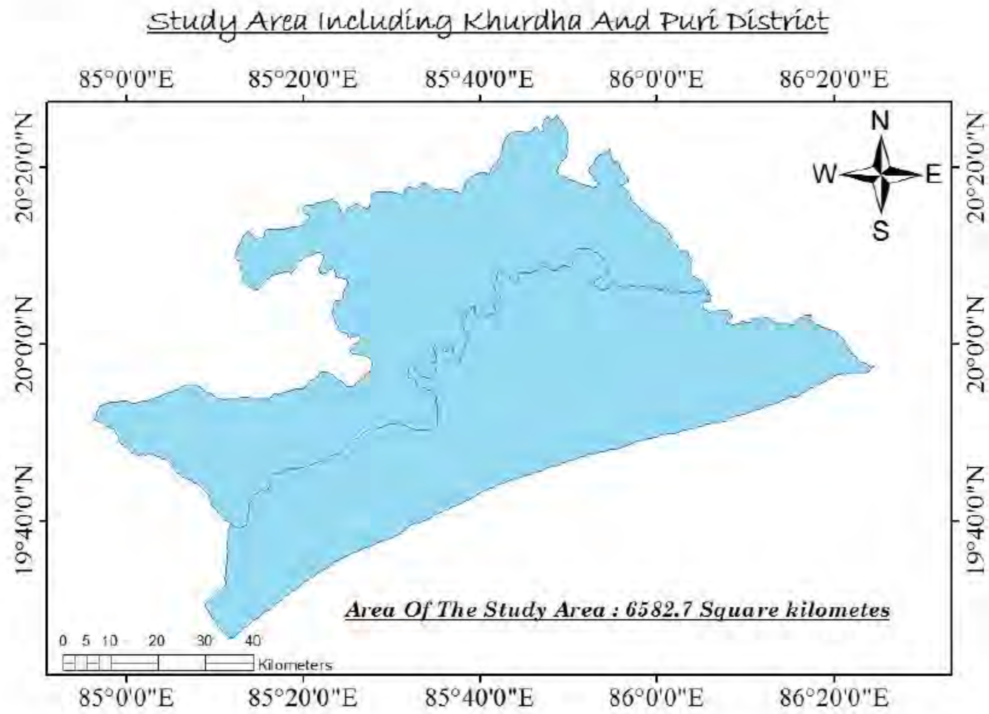


Figure 3.3: Study Area

3.5 Ground Water Data

The Ground Water levels have been accessed through Central Ground Water Information System of CWC. The Ground Water Levels were available from year 2008 to 2013. And year wise the number of stations for recording of the Ground Water Levels have increased from 116 to 173 in the study area.

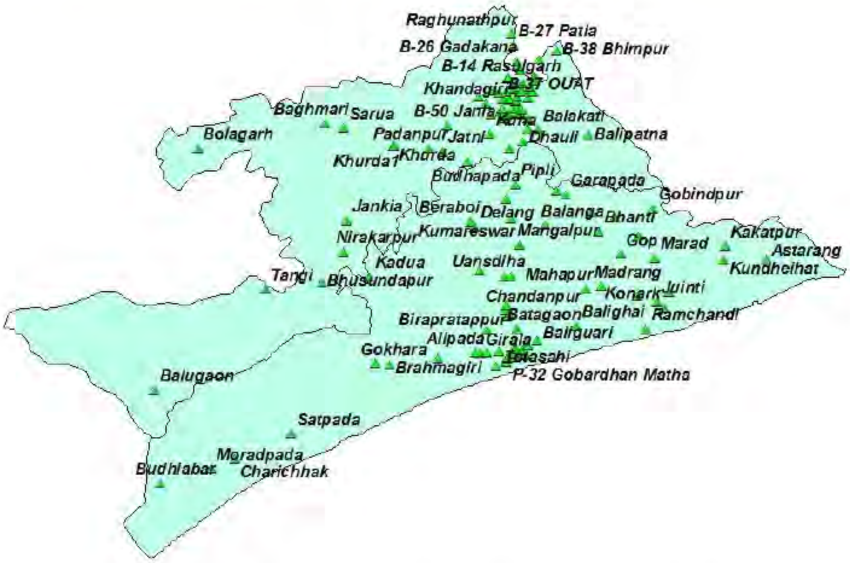


Figure 3.4: The Ground Water Stations in the Study Area

3.6 Ground Water Data Analysis

After collection of the Ground Water levels, the data were properly organised. Then Latitude and Longitude for the ground water stations were located by the use of Google Maps, then projected over the study area and verified by superimposing the generated map on Google Earth.

3.6.1 Contouring

Contours are lines that connect locations of equal value in a raster dataset that represents continuous phenomena such as elevation, temperature, precipitation, pollution, or atmospheric pressure. The line features connect cells of a constant value in the input. Contour lines are often generally referred to as isolines but can also have specific terms depending on what is being measured. Some examples are isobars for pressure, isotherms for temperature, and isohyets for precipitation.

The distribution of the contour lines shows how values change across a surface. Where there is little change in a value, the lines are spaced farther apart. Where the values rise or fall rapidly, the lines are closer together.

After getting exact coordinates of the ground water stations and their year-wise water level, the values and fields are added to the ArcMap for Contouring.

After contouring the values of contours are interpolated to interpret better results of contouring.

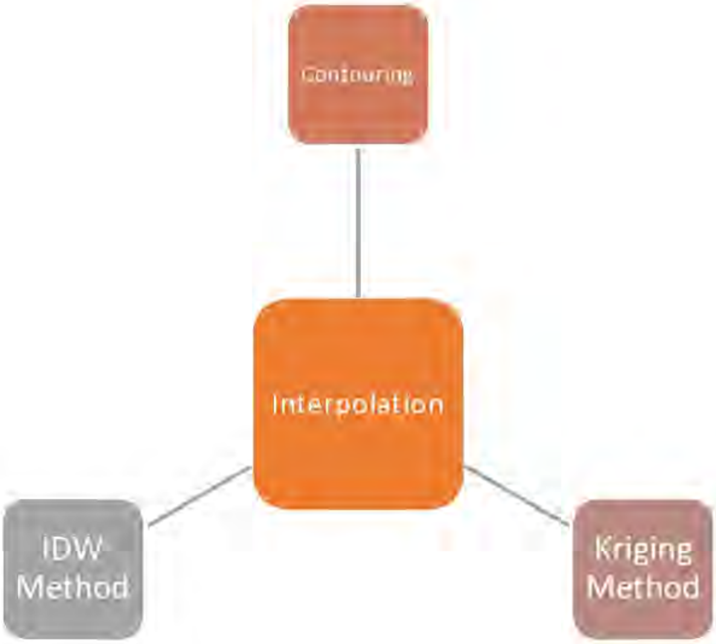


Figure 3.5: Contouring Used In Study Area

About IDW Method:

Interpolates a raster surface from points using an inverse distance weighted (IDW) technique. The IDW (Inverse Distance Weighted) tool uses a method of interpolation that estimates cell values by averaging the values of sample data points in the neighborhood of each processing cell. The closer a point is to the center of the cell being estimated, the more influence, or weight, it has in the averaging process.

- The output value for a cell using inverse distance weighting (IDW) is limited to the range of the values used to interpolate. Because IDW is a weighted distance average, the average cannot be greater than the highest or less than the lowest input. Therefore, it cannot create ridges or valleys if these extremes have not already been sampled (Watson and Philip 1985).
- The best results from IDW are obtained when sampling is sufficiently dense with regard to the local variation you are attempting to simulate. If the sampling of input

points is sparse or uneven, the results may not sufficiently represent the desired surface (Watson and Philip 1985).

- The influence of an input point on an interpolated value is isotropic. Since the influence of an input point on an interpolated value is distance related, IDW is not "ridge preserving" (Philip and Watson 1982).

A general form of finding an interpolated value u at a given point x based on samples $u_i = u(x_i)$ for $i = 1, 2, ..., N$ using IDW is an interpolating function:

$$u(\mathbf{x}) = \begin{cases} \dfrac{\sum_{i=1}^{N} w_i(\mathbf{x}) u_i}{\sum_{i=1}^{N} w_i(\mathbf{x})}, & \text{if } d(\mathbf{x}, \mathbf{x}_i) \neq 0 \text{ for all } i \\ u_i, & \text{if } d(\mathbf{x}, \mathbf{x}_i) = 0 \text{ for some } i \end{cases}$$

Where, $$w_i(\mathbf{x}) = \frac{1}{d(\mathbf{x}, \mathbf{x}_i)^p}$$

is a simple IDW weighting function, as defined by Shepard, $\mathbf{x}$ denotes an interpolated (arbitrary) point, $\mathbf{x}_i$ is an interpolating (known) point, is a given distance (metric operator) from the known point $\mathbf{x}_i$ to the unknown point $\mathbf{x}$, N is the total number of known points used in interpolation and P is a positive real number, called the power parameter. Here weight decreases as distance increases from the interpolated points. Greater values of assign greater influence to values closest to the interpolated point, with the result turning into a mosaic of tiles (a Voronoi diagram) with nearly constant interpolated value for large values of p.

About Kriging Method:

Kriging is an advanced geostatistical procedure that generates an estimated surface from a scattered set of points with z-values. More so than other interpolation methods, a thorough investigation of the spatial behavior of the phenomenon represented by the z-values should be done before you select the best estimation method for generating the output surface.

- Kriging is a processor-intensive process. The speed of execution is dependent on the number of points in the input dataset and the size of the search window.
- Low values within the optional output variance of prediction raster indicate a high degree of confidence in the predicted value. High values may indicate a need for more data points.
- The Universal kriging types assume that there is a structural component present and that the local trend varies from one location to another.
- The Advanced Parameters allow control of the semivariogram used for kriging. A default value for Lag size is initially set to the default output cell size. For Major range, Partial sill, and Nugget, a default value will be calculated internally if nothing is specified.
- The optional output variance of prediction raster contains the kriging variance at each output raster cell. Assuming the kriging errors are normally distributed, there is a 95.5 percent probability that the actual z-value at the cell is the predicted raster value, plus or minus two times the square root of the value in the prediction raster.
- Some input datasets may have several points with the same x,y coordinates. If the values of the points at the common location are the same, they are considered duplicates and have no effect on the output. If the values are different, they are considered coincident points.

The various interpolation tools may handle this data condition differently. For example, in some cases, the first coincident point encountered is used for the calculation; in other cases, the last point encountered is used. This may cause some locations in the output raster to have different values than what you might expect. The solution is to prepare your data by removing these coincident points. The Collect Events tool in the Spatial Statistics toolbox is useful for identifying any coincident points in your data.

3.6.2 Ground Water DEM

The most common digital data of the shape of the earth's surface is cell-based digital elevation models (DEMs). This data is used as input to quantify the characteristics of the land surface.

A DEM is a raster representation of a continuous surface, usually referencing the surface of the earth. The accuracy of this data is determined primarily by the resolution (the distance between sample points). Other factors affecting accuracy are data type (integer or floating point) and the actual sampling of the surface when creating the original DEM.

After contours are being extrapolated the ground water DEM is generated through various step processes like TIN model generation and raster file generation.

TIN Model of the Study Area (2013)

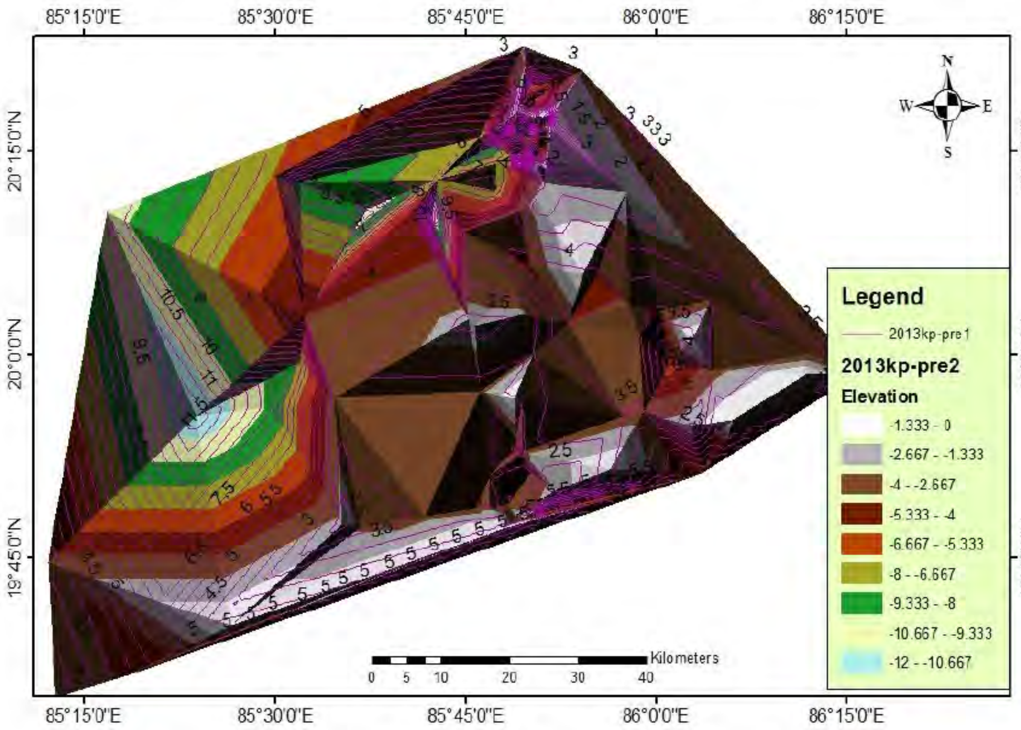


Figure 3.6: TIN Model of the Study Area

3.7 LAND USE AND LAND-COVER DATA

The landuse/land cover pattern of a region is an outcome of natural and socio-economic factors and their utilization by man in time and space. The terms "land use" and "land cover" are often used simultaneously to describe maps that provide information about the types of features found on the earth's surface is called as land cover and the human activity that is associate with them. Land cover is an important input parameter for a number of agricultural hydrological and ecological model, which constitute necessary tools for development planning and management of natural resources in the territory. In order to use the land optimally and to provide as input data in modeling studies, it is not only necessary to have information on existing land use/ landcover but also the capability to monitor the dynamics of land use resulting out of changing demands. If the site is small and easily accessible a suitable land cover may be based on ground observation and surveys.

However such methods are quickly become less feasible, if the site is large or difficult to access. Toposheets may be useful for reference but are generally outdated and too coarse for detailed analysis. With the improvement in software and hardware and decrease in the cost of imagery, satellite remote sensing is being used for more and more studies particularly at the landscape level.

For land use and land cover maps, L8 satellite bands are downloaded from USGS website. Then after pre-processing used for various classifications.

3.8 URBAN CLASSIFICATION

The goal of classification is to assign each cell in the study area to a known class (supervised classification) or to a cluster (unsupervised classification). In both cases, the input to classification is a signature file containing the multivariate statistics of each class or cluster. The result of each classification is a map that partitions the study area into known classes, which correspond to training samples, or naturally occurring classes, which correspond to clusters defined by clustering. Classifying locations into naturally occurring classes corresponding to clusters is also referred to as stratification. The Image Classification toolbar provides an integrated environment to help with the multi-step workflow that is necessary for performing a classification.

3.8.1 Geo-Referencing:

Base map is taken, which is the map of Odisha taken from the survey of India. Geo-referencing is the process in which a given map which doesn't have specified units is aligned with the natural coordinates. This can be done if the coordinates of at least four points in the map are known and the geo-referencing tool is used to specify the unit of the map.

3.8.2 Creation of shape files:

This process is also called digitization of the map, in this process a part of the map which is required for the analysis can be converted to raster by making shape file of that portion using data management tools present in the Arc Catalog menu. This gives the polygon map for study area.

3.8.3 Extraction by mask:

Aerial image of the study area for the years 2005 to 2012 captured by LANDSAT 8 are obtained from http://earthexplorer.usgs.gov/. Bands 1, 2,3,4,5 and 7 are added to the ArcMap and then the shape file data superimposed on it, extraction by mask tool is used to extract from LANDSAT image, only the area required for analysis.

Figure 3.7: Extracted Base Map of the Study Area from L8 Bands

3.8.4 Supervised classification:

This is a process where the masked data is worked upon to differentiate various land use types. This process includes: creation of training samples; creation of signature file; supervised classification.

Various land use types taken in to consideration are –

1) Forest
2) Urban
3) Agricultural
4) Waste land
5) Water bodies

1) Forest – Land area covered by dense plantation and a habitat for wild animals is classified as forest area.

2) Urban- The build-up area except the villages and industrial ones which is used by people for residential purpose, recreational buildings, malls, office spaces etc.

3) Agricultural – Land area where crop is grown and also the plantation areas present in the study area.

4) Waste land –Land which is not used for any purpose yet.

5) Water bodies – Area which is covered by water resources, it includes: River, Pond, Lake Etc.

3.8.4.1 Maximum Likelihood Classification:

Cells in a class are rarely homogeneous. This is especially true with training samples taken for a supervised classification. If hardwoods in the shade, for instance, have a reflectance signature that resembles conifers in the full sun, both types of tree will end up in the same class. Any location in a training sample taken from a habitat where you would expect to find bears could contain sub-locations that bears avoid.

The maximum likelihood classifier calculates for each class the probability of the cell belonging to that class given its attribute values. The cell is assigned to the class with the highest probability, resulting in the term "maximum likelihood."

Assumptions are made for the maximum likelihood classifier to work accurately:

- The data for each band are normally distributed.
- Each class have a normal distribution in multivariate attribute space.
- The prior probabilities of the classes are equal—that is, in the absence of any weighting of attribute values, all classes are equally likely.

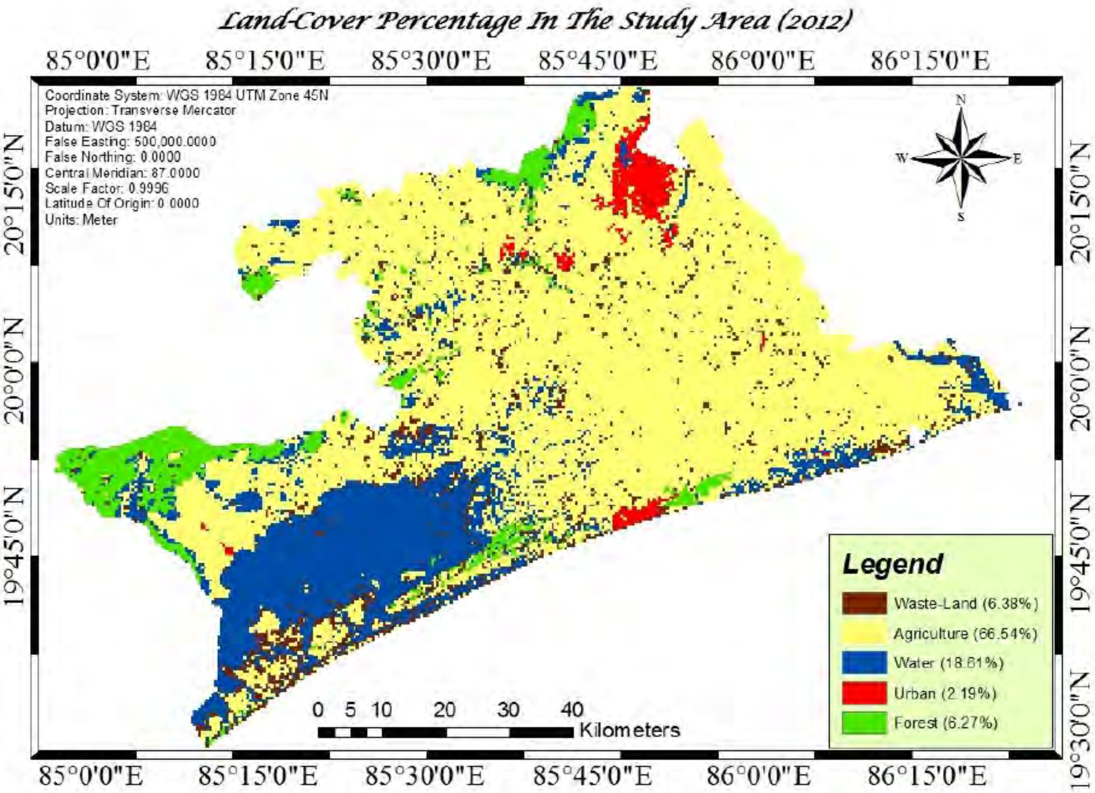


Figure 3.8: Land use and Land-cover Map of Study Area

3.9 Topological Analysis

In here the topological analysis has been done through DEM, slope map, Flow Direction Map and Aspect Ratio Map of the study area.

3.9.1 Flow Direction

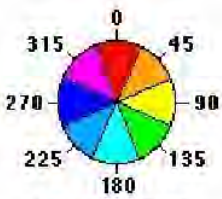
One of the keys to deriving hydrologic characteristics of a surface is the ability to determine the direction of flow from every cell in the raster. This is done with the Flow Direction tool.

This tool takes a surface as input and outputs a raster showing the direction of flow out of each cell. If the Output drop raster option is chosen, an output raster is created showing a ratio of the maximum change in elevation from each cell along the direction of flow to the path length between centers of cells and is expressed in percentages. If the Force all edge cells to flow outward option is chosen, all cells at the edge of the surface raster will flow outward from the surface raster.

3.9.2 Aspect

Aspect identifies the downslope direction of the maximum rate of change in value from each cell to its neighbors. It can be thought of as the slope direction. The values of each cell in the output raster indicate the compass direction that the surface faces at that location. It is measured clockwise in degrees from 0 (due north) to 360 (again due north), coming full circle. Flat areas having no downslope direction are given a value of -1.

The value of each cell in an aspect dataset indicates the direction the cell's slope faces.



Aspect directions

3.10 BUFFER ANALYSIS

The Buffer tool creates a new coverage of buffer polygons around specified input coverage features. Features can be polygons, lines, points, or nodes.

The Buffer tool is used to identify or define an area within a specified distance around a feature. For example, you may create a buffer to define an area around a river to identify land that can't be developed, or you may want to create a buffer to select features within a specified distance of a feature.

An item named INSIDE in the output polygon attribute table (PAT) identifies the buffer polygons. Polygons representing buffer zones have a value of 100; outside polygons have the value 1. Overlapping polygons with a common INSIDE value are merged.

The width of the buffer can be specified in one of three ways:

- With a fixed distance—specify a constant buffer distance to apply to all input features.
- With an item—specify a numeric buffer item from the input coverage. Each feature in the input coverage will be buffered according to its value in the buffer item.
- With a distance table—Specify a buffer item common to both the input coverage and a buffer table that contains a numeric item named DIST. Every feature with a common buffer item value will be buffered by the associated DIST value.

3.11 SUMMARY

This chapter discusses the overall computational program carried out during the process of completing the project work. This chapter contains the details of techniques used and their properties along with designating the different analysis.

Chapter 4

RESULTS AND DISCUSSION

4.1 GENERAL

The research program has been carried out in different phases as described in the previous chapter 3. In the first phase of the program, ground water analysis has been done through spatial analysis. The contour, DEM analysis has been done and results are presented along with the plots and discussions. In the second phase the urban classification along with top ography is presented. In the third phase of program buffer analysis has been done to interpret finer results.

4.2 GROUND WATER RESULTS

The ground water contours have been plotted and interpolated with the mentioned methods of chapter 3 and the results are as follows:

4.2.1 IDW Results:

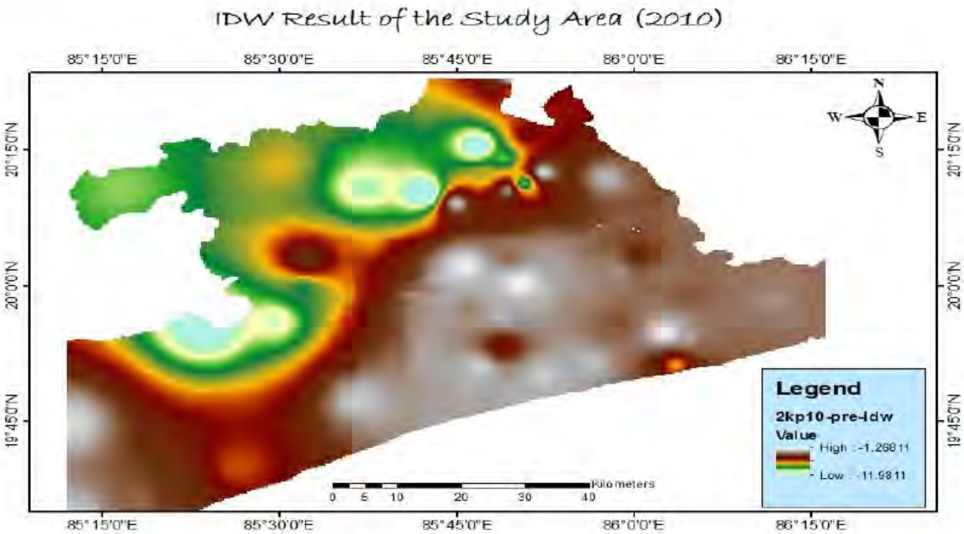


Figure 4.1: IDW result of the Study Area (2010)

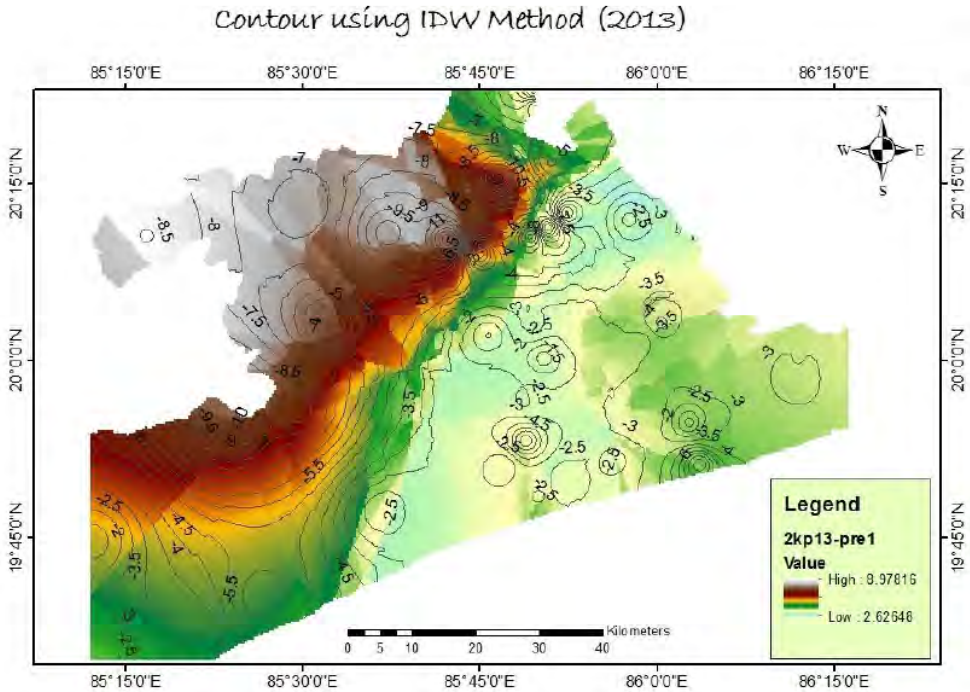


Figure 4.2: IDW result of the Study Area (2013)

From the above comparative results of IDW interpolation, which was done for interpolating ground water contour has been shown for the year 2010 and 2013.

The results from the time period shows higher level in urban areas like Bhubaneswar, puri and khordha, whereas a similar level in years where much of residential development has not taken place.

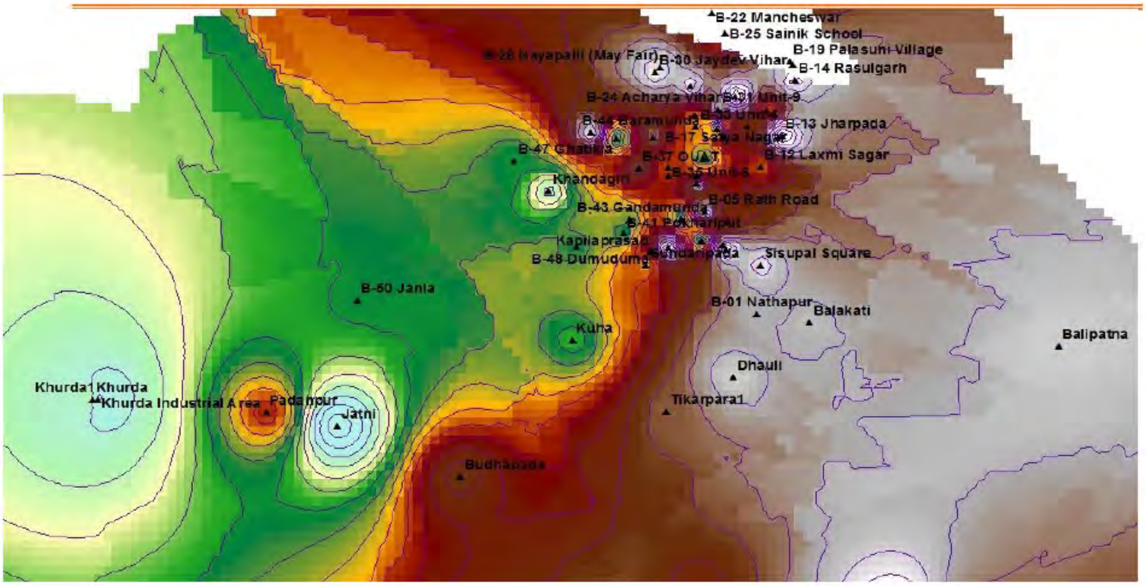


Figure 4.3: IDW result of closer look of Bhubaneswar of the Study Area (2013)

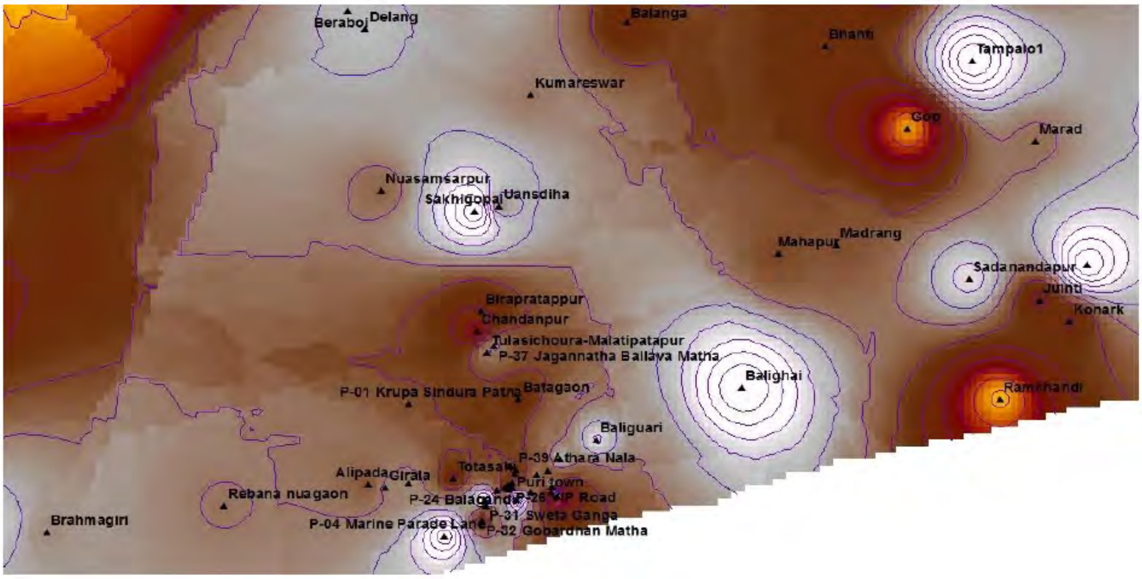


Figure 4.4: IDW result of closer look of Puri of the Study Area (2013)

The closer view of the two cities i.e Bhubaneswar and puri gives the brief idea that ground water levels are already higher for major city centres and have a nominal change of ground water levels. But those regions which are developing with time are also depleting the ground water levels with them.

4.2.2 KRIGING RESULTS:

Kriging interpolation is considered as one of the best available method for interpolation, thus its results are more vibrant.

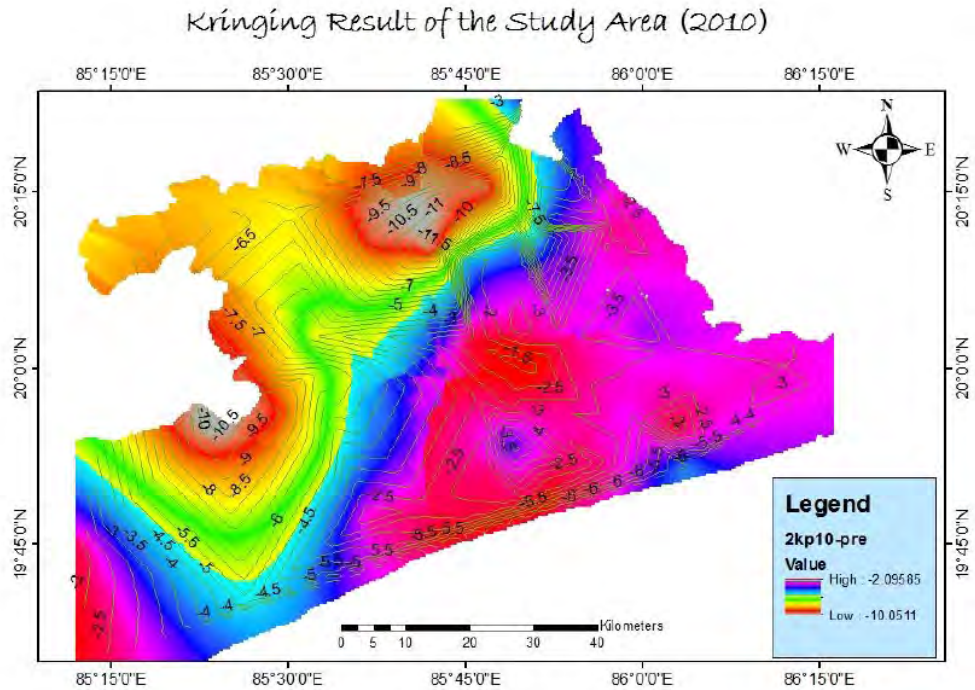


Figure 4.5: kriging result of the Study Area (2010)

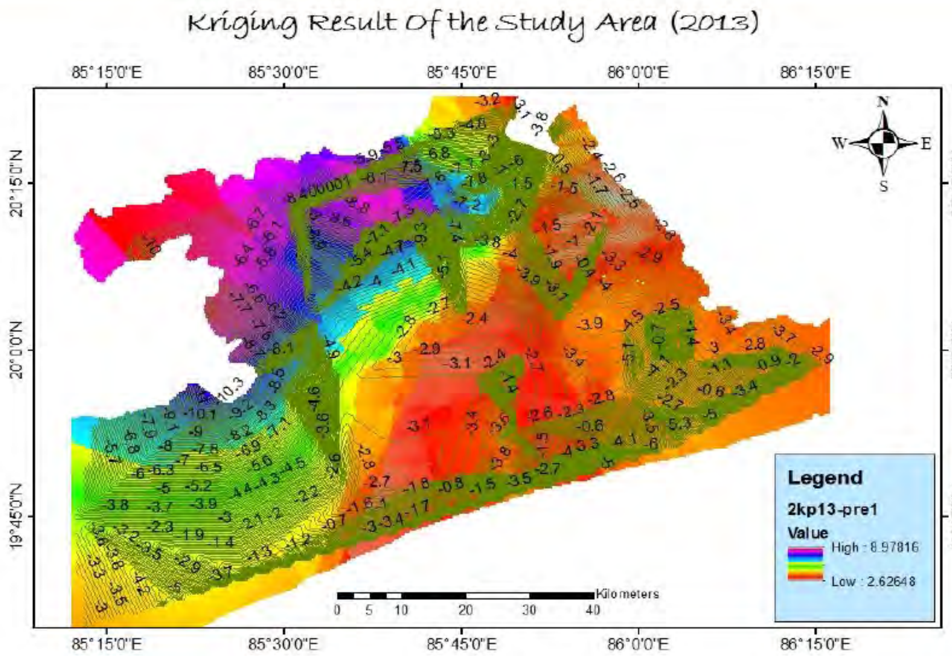


Figure 4.6: kriging result of the Study Area (2013)

The kriging results interpret the same as of IDW method, but it also shows the flow and changes of ground water along with the topology. As the regions vary, the ground water also flows from higher elevation regions to the lower ones and gradually near urban areas the levels are lower than its usual values over the time.

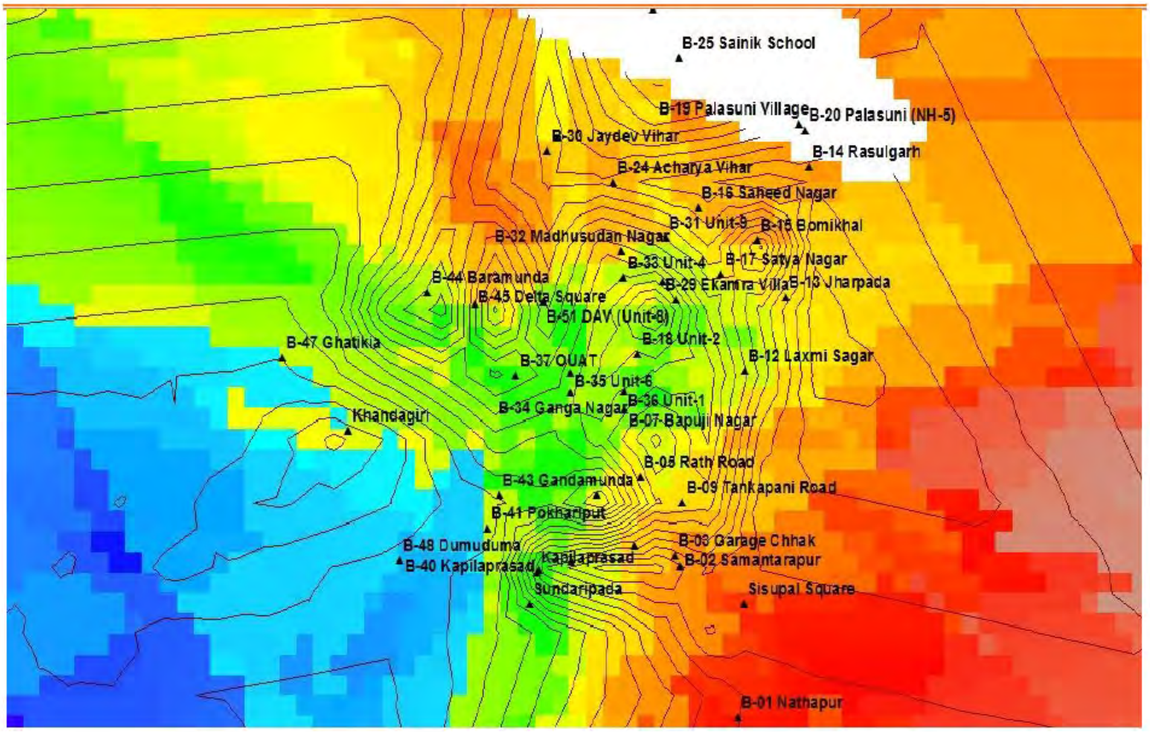


Figure 4.7: Kriging result of closer look of Bhubaneswar of the Study Area (2013)

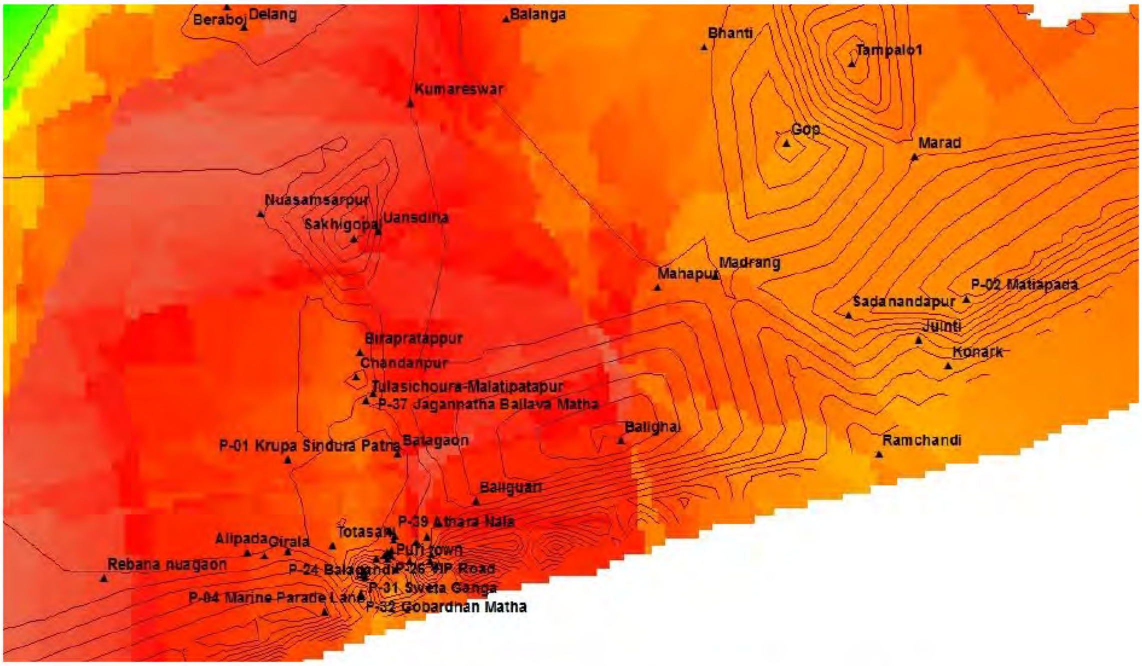


Figure 4.8: Kriging result of closer look of Puri of the Study Area (2013)

4.2.2 Ground Water DEM Results:

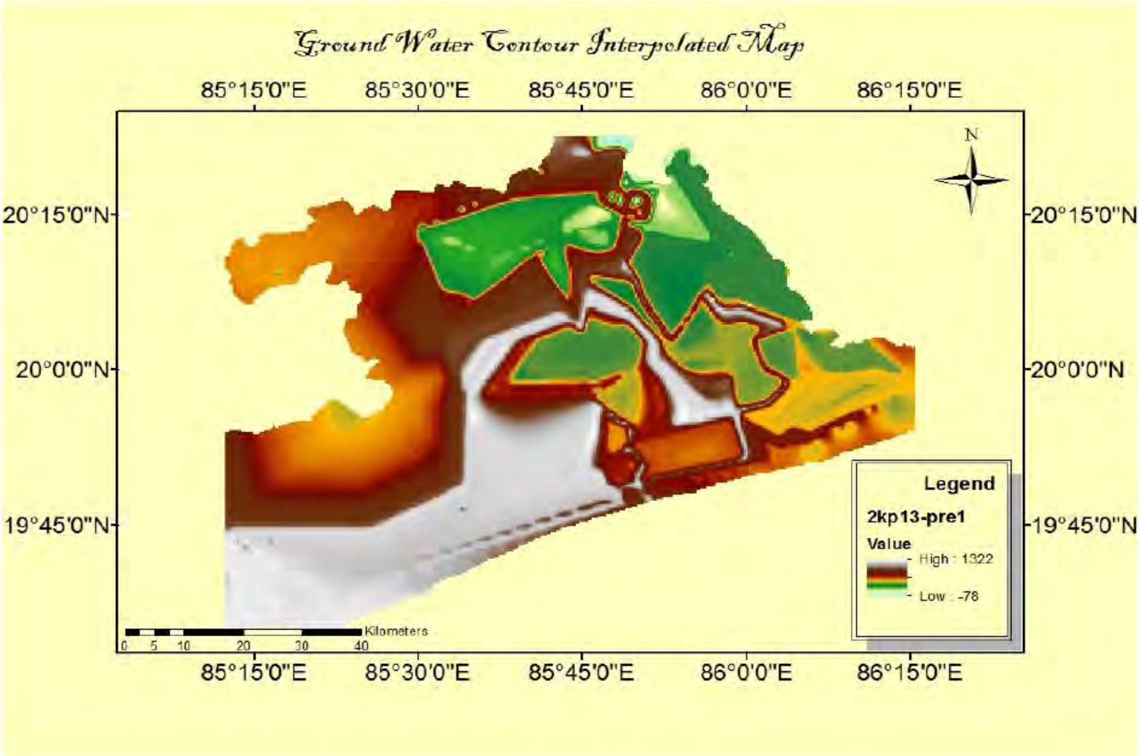


Figure 4.9: Ground water DEM of the study area

The above ground water DEM describes the availability of sub surface water i.e. low quantity ground water in the Bhubaneswar region and found to be high in the region of Puri.

4.3 Land Use And Land-cover Results

With the help of following results map we could see the percentage growth in the urba nization for the period of years taken into consideration. The wasteland and agricultural areas are found to decreasing with the passing years.

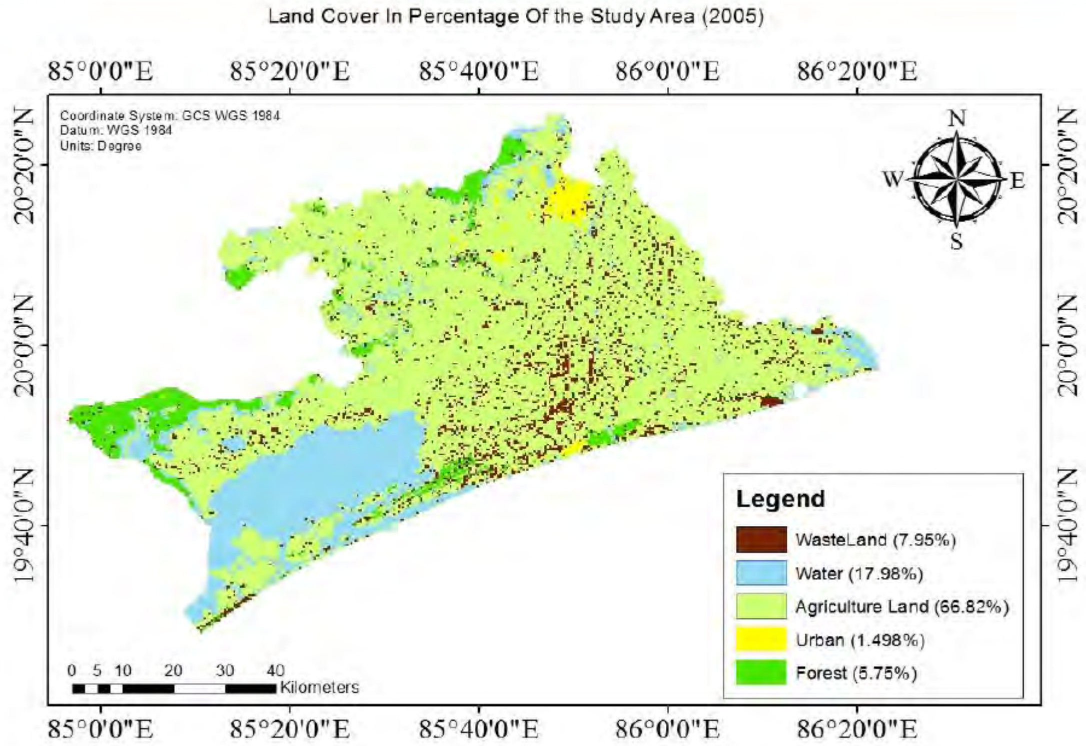


Figure 4.10: Land cover change in 2005

In the above map, the percentage land use has been evaluated and recorded for the year 2005 as 7.95% of total land cover was consumed by the waste land, 66.82% by agricultural land, forest 5.75%, water 17.98%, and urban 1.498%.

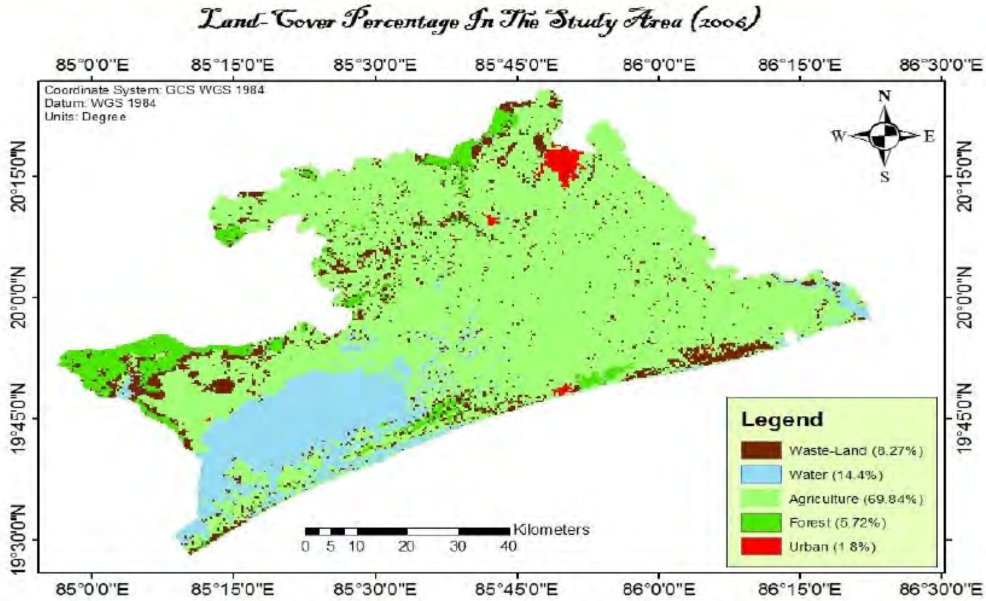


Figure 4.11: Land cover change in 2006

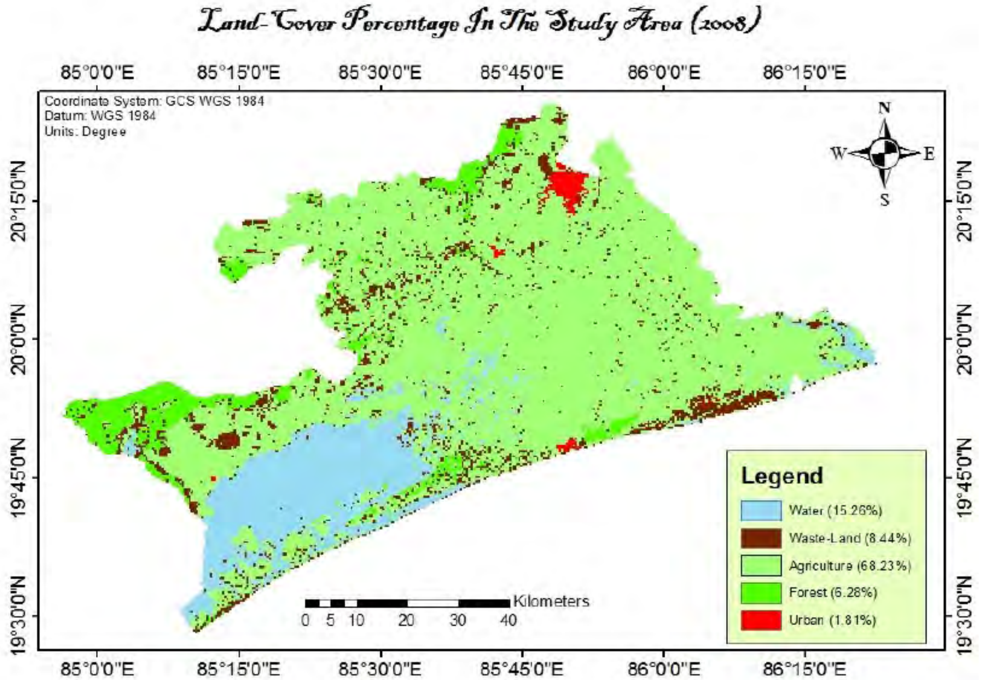


Figure 4.12: Land cover change in 2008

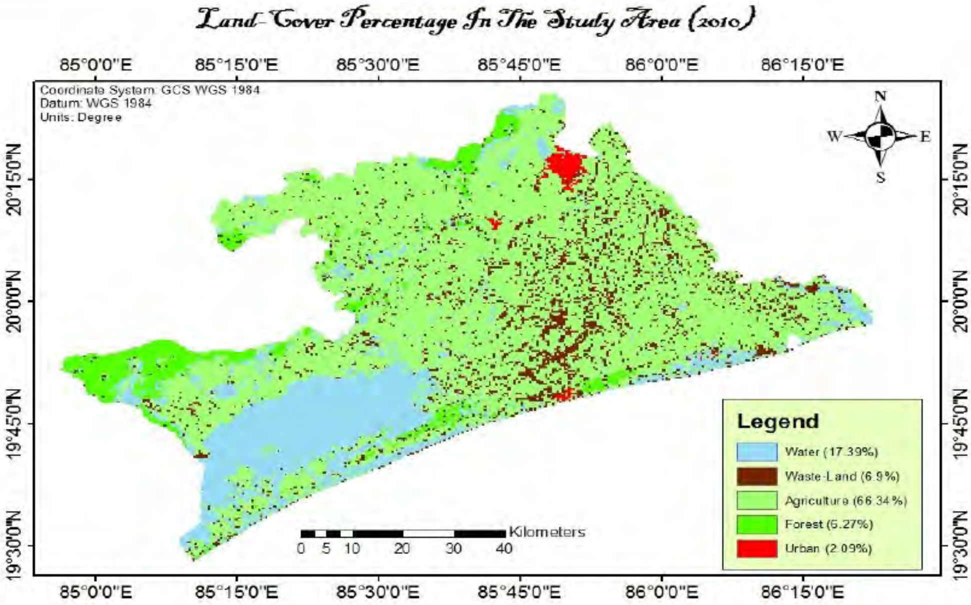


Figure 4.13: Land cover change in 2010

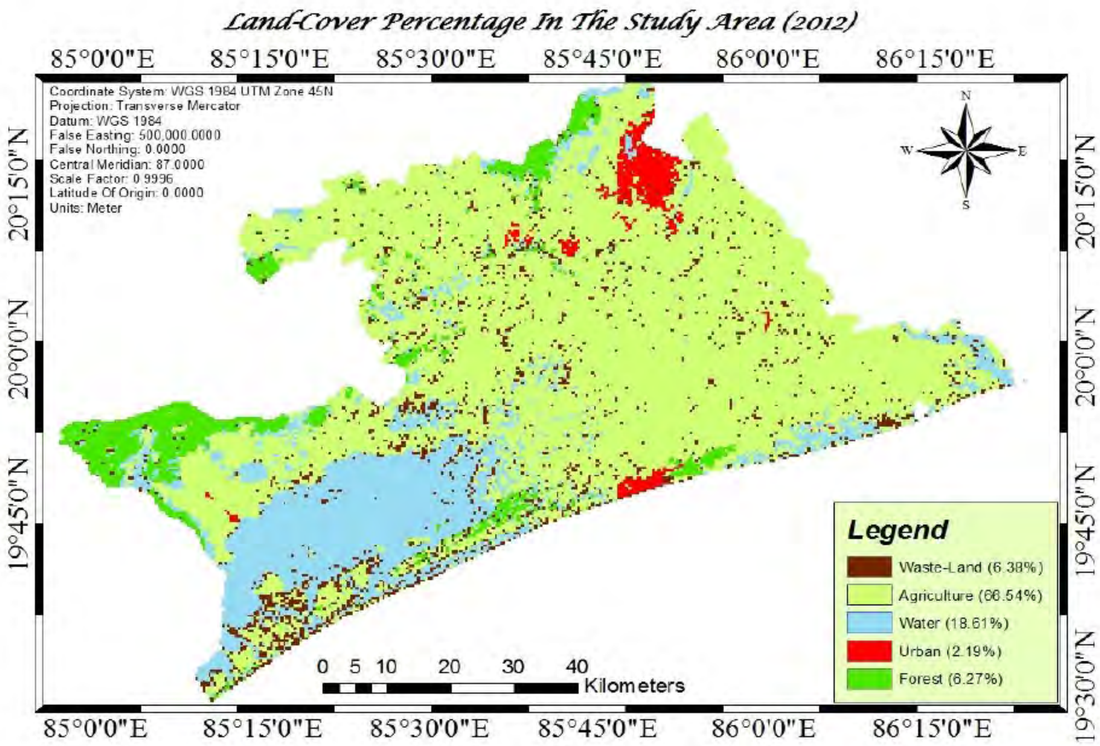


Figure 4.14: Land cover change in 2012

From the above supervised classification the results are graphically plotted for better understanding.

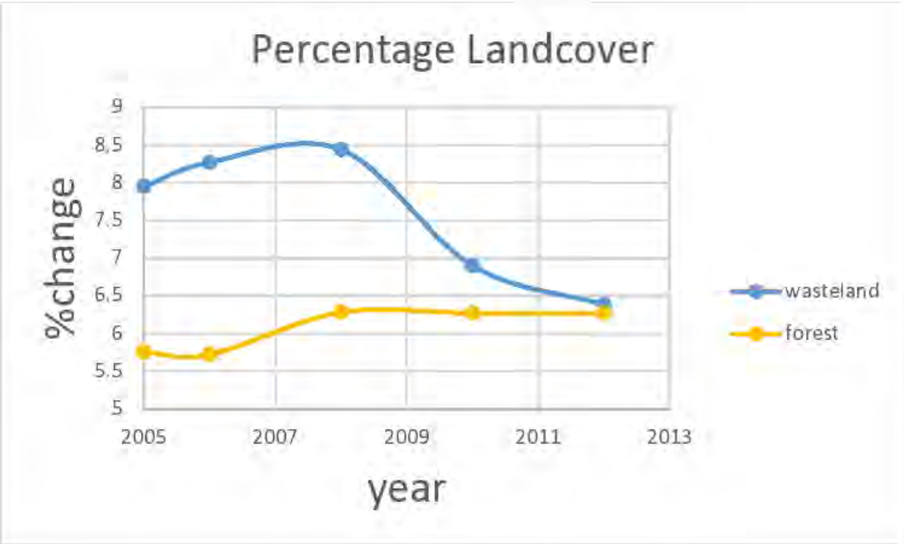


Figure 4.15: Change in percentage of forest and wasteland in the study area

The above graph shows the change in percentage of landcover over the study area in time. As it can be seen that the waste land is decreasing rapidly over time and the forest area is almost constant over the observed period of time.

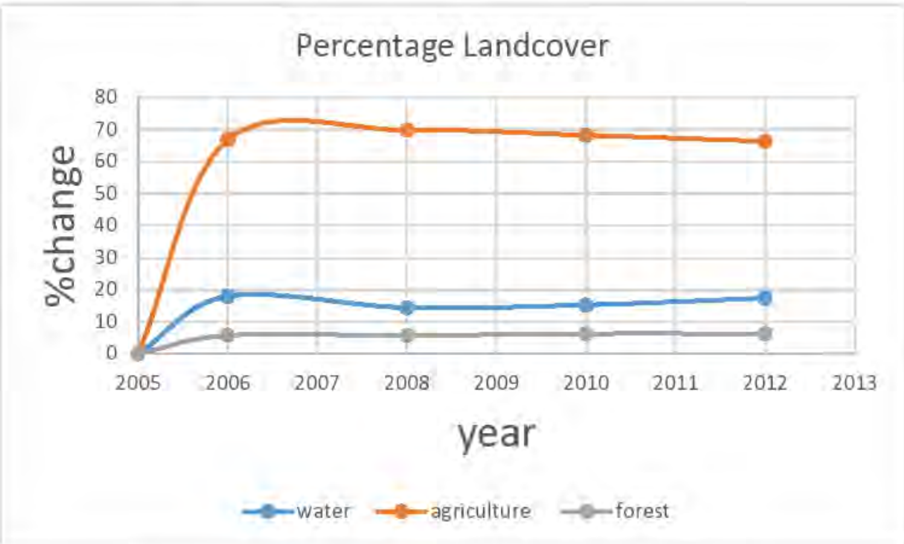


Figure 4.16: Change in water bodies, forest and agriculture land

The percentage change in water bodies and forest is almost constant over the time period but the agricultural land percentage is gradually slow decrease over the time.

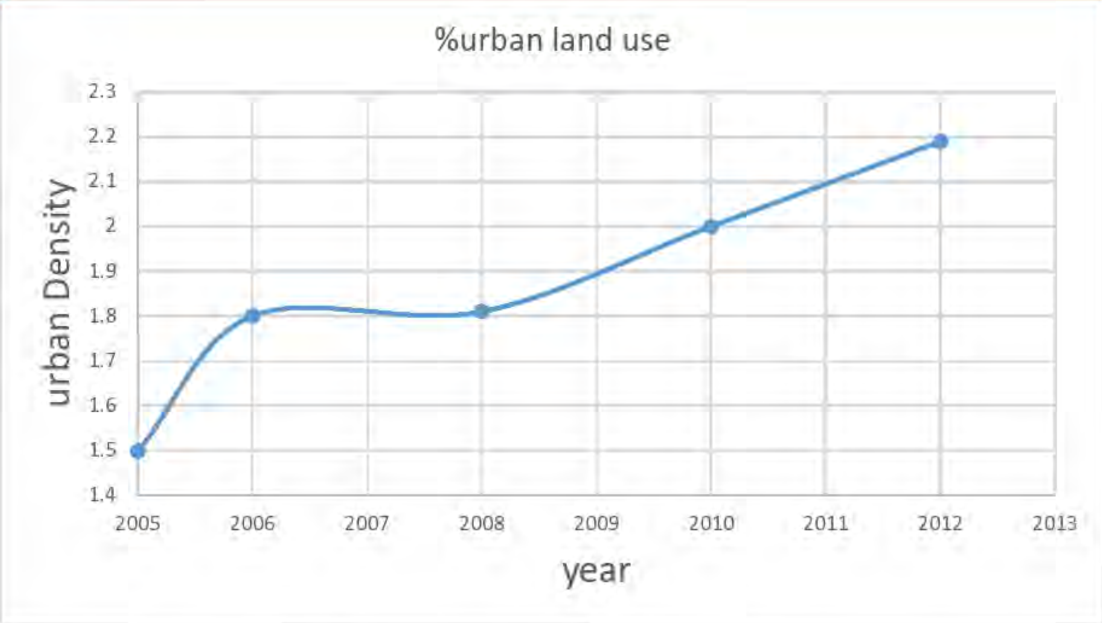


Figure 4.17: Urban land use change in percentage in the study area

The urban percentage is drastically increasing over the study area in the observed timeline.

The urban settlement has grown from 1.5 % in 2005 to 2.2 % in 2012 year. The percentage might be a small change but on a large study area of 6582.7 sqkm, this change is much bigger.

4.4 Topological Results

These results show the present topology of the study area.

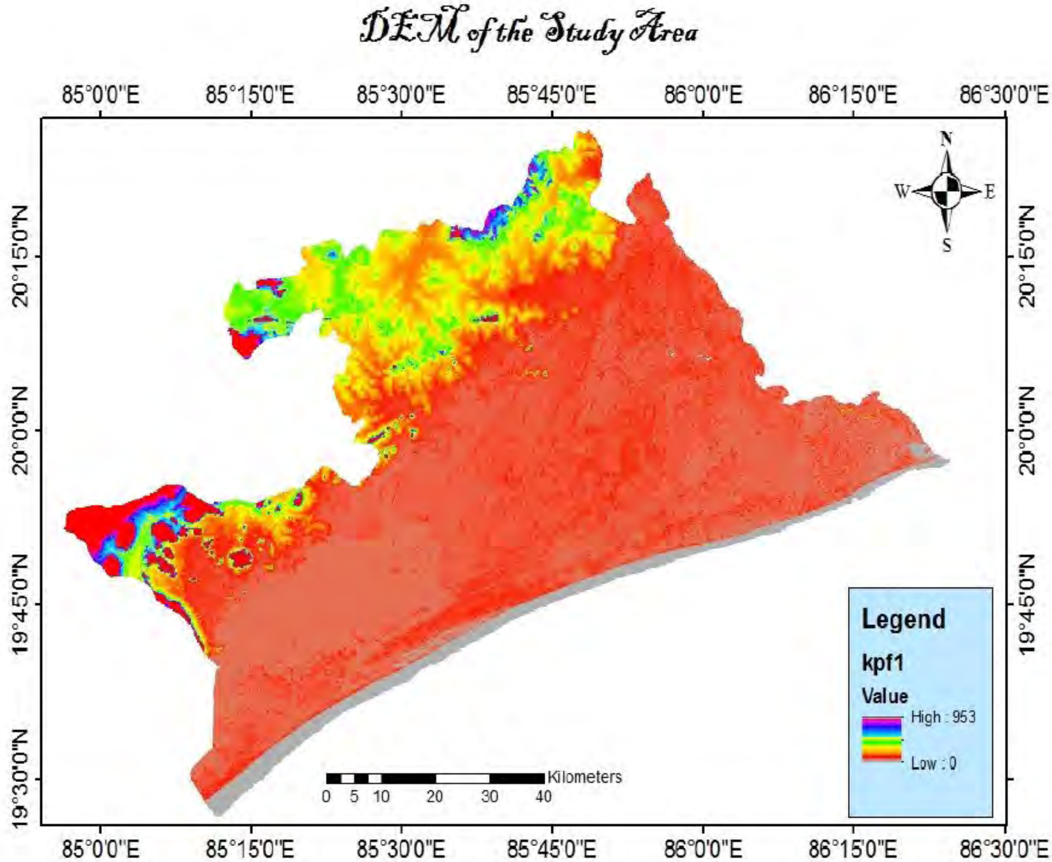


Figure 4.18: DEM of the study area

The DEM of the study area shows that the coastal line is plane area and has lower elevation that the central part of the study area. Whereas the area of Bhubaneswar has different elevation at different places. Thus the urbanisation also depends on the ground elevation for settlement.

Slope Map of the Study Area

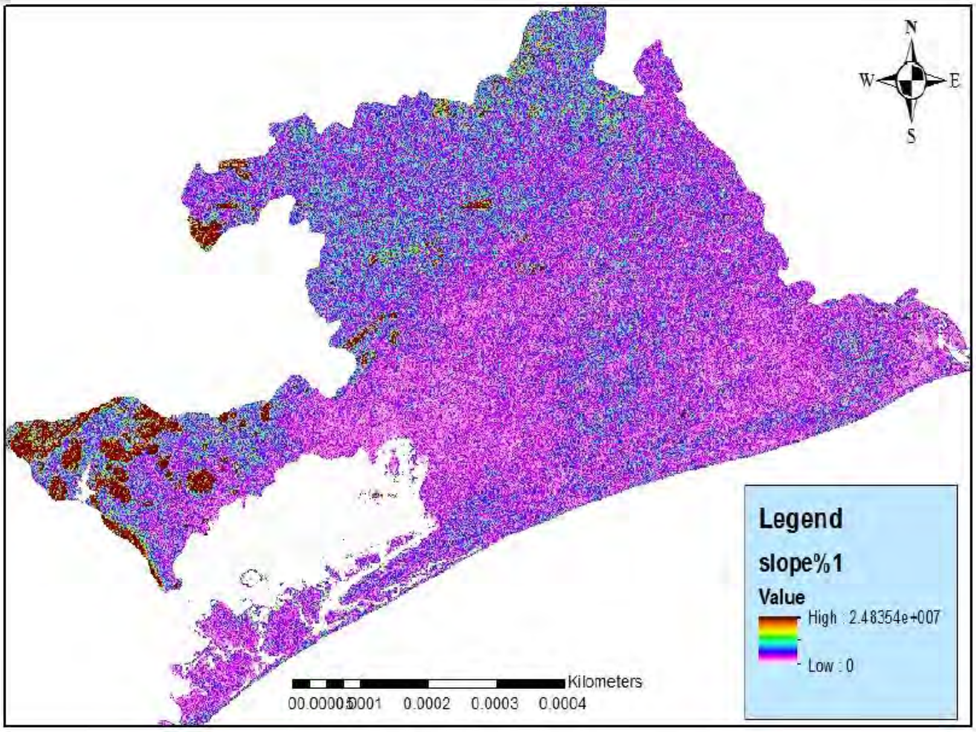


Figure 4.19: Slope Map of the study area

The slope map of the study area shows how the slope is varying through the area. The slope tends to be sloping around the coastal regions and thus the water flow on the sub-surface will result towards the coastal sea.

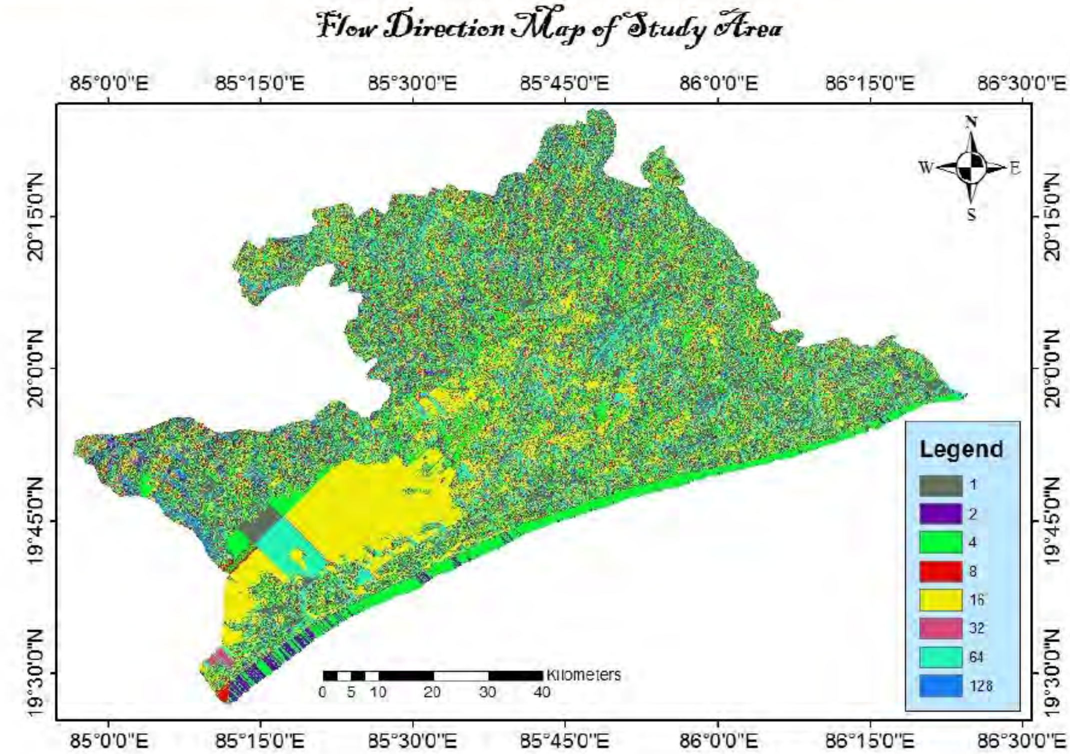
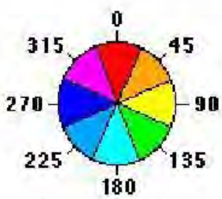


Figure 4.20: Flow Direction Map of the study area

The flow direction map shows the flow of water on the sub-surface through the study area.

Aspect identifies the downslope direction of the maximum rate of change in value from each cell to its neighbors. It can be thought of as the slope direction. The values of each cell in the output raster indicate the compass direction that the surface faces at that location. It is measured clockwise in degrees from 0 (due north) to 360 (again due north), coming full circle. Flat areas having no downslope direction are given a value of -1.



Aspect directions

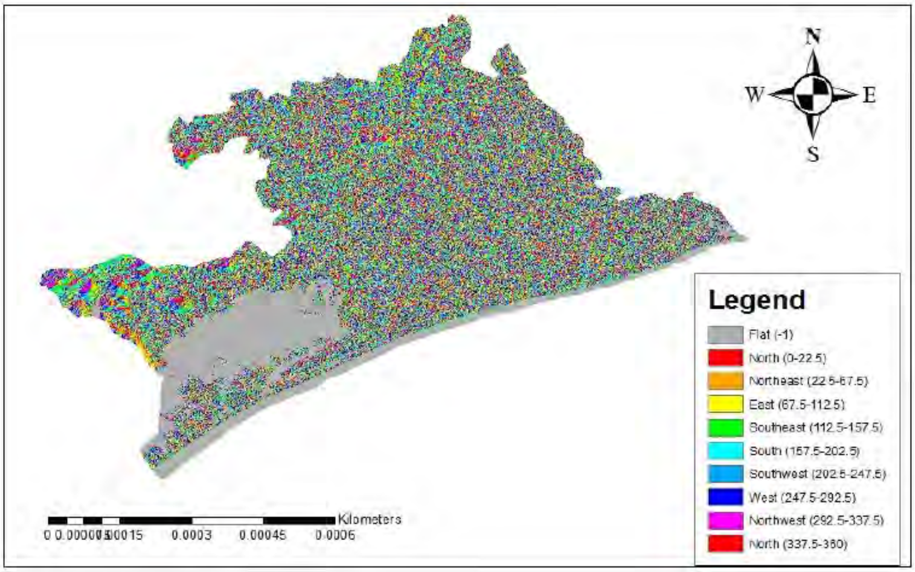


Figure 4.21: Aspect Ratio of the Study Area

The Aspect tool fits a plane to the z-values of a 3 x 3 cell neighborhood around the pro cessing or center cell. The direction the plane faces is the aspect for the processing cell.

4.5 Buffer Results

The Buffer tool is used to identify or define an area within a specified distance around a feature.

The buffer is created along the National Highway around the study area and the results are shown below:

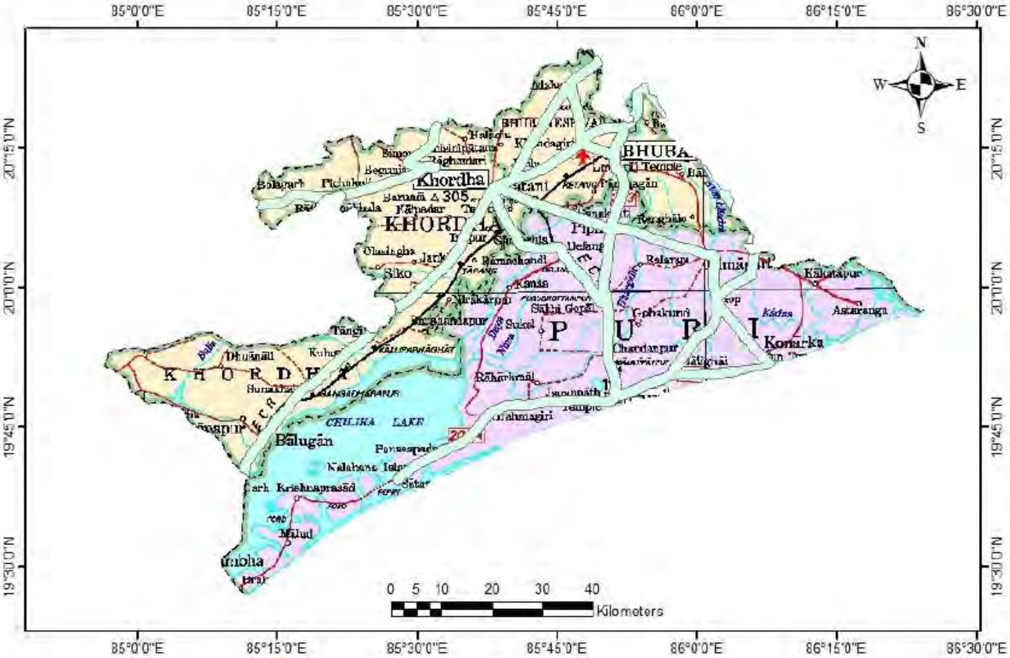


Figure 4.22: Buffer over NH of the Study Area

The linear buffer shows the change of urbanisation along the sides of National Highway in the study area. The more buffer indicates the more settlements in the area like Bhubaneswar and puri.

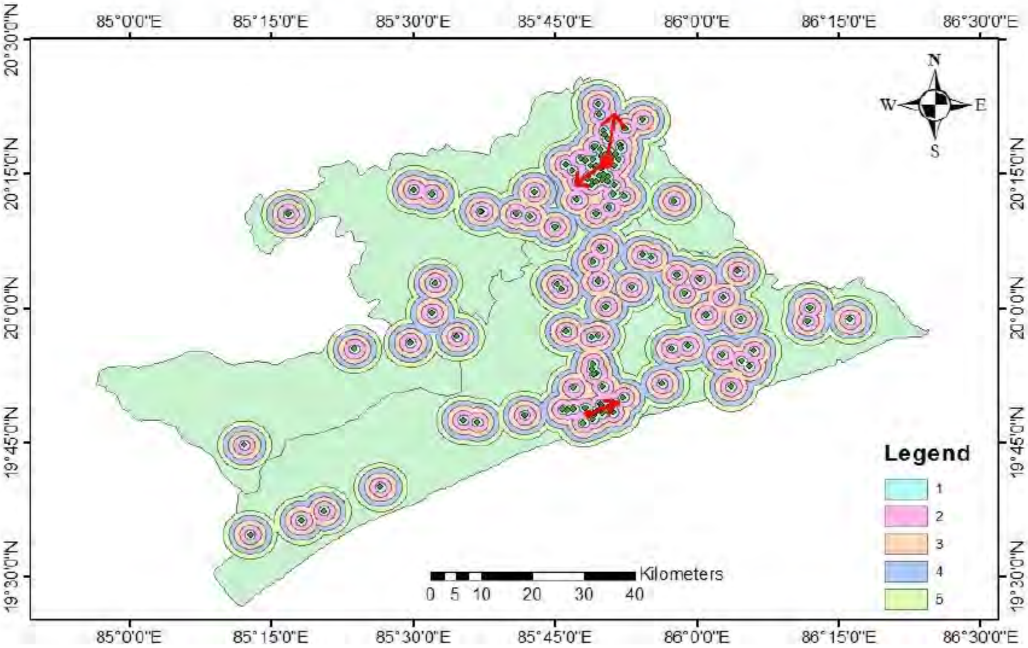


Figure 4.23: Ground Water Buffer of the Study Area

The ground water buffer shows the change in the need of ground water along the direction of need.

In Bhubaneswar region the ground water depletion direction is towards the north-east and south-west of the city and in puri region the direction is around north-east direction.

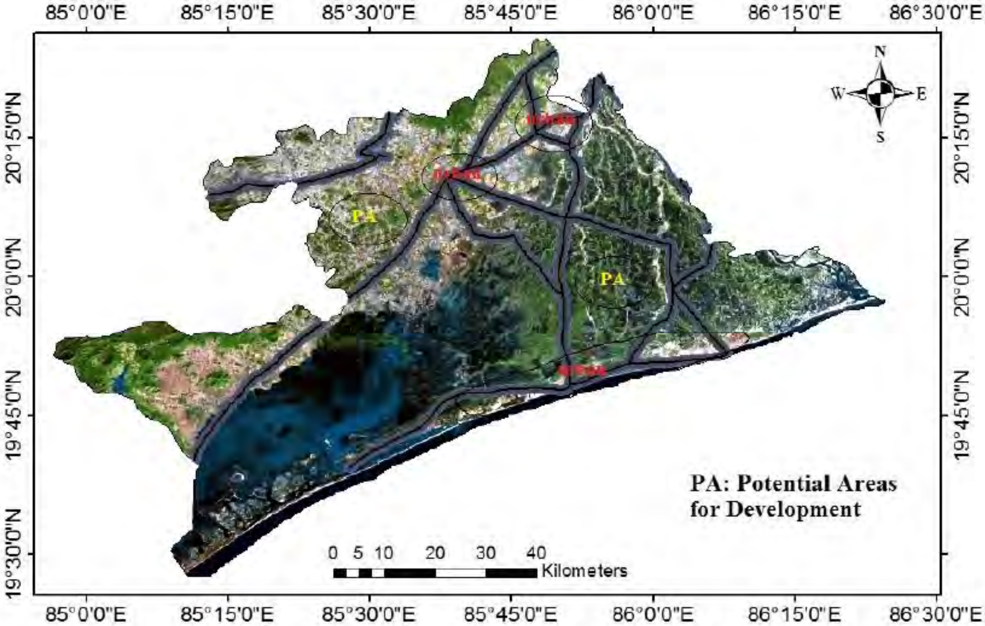


Figure 4.24: Final Buffer Result of the Study Area

The final buffer result shows the urbanised areas under the study area and potential areas that can be developed in future time.

Chapter 5

CONCLUSIONS AND FUTURE SCOPE

5.1 CONCLUSION

In the present investigation, the results of the computational analysis are presented. The Ground water analysis and urban sprawl were computed in the previous chapter from which conclusions are being drawn and presented in this chapter. Also a comparative study between the years and with urban and the ground water is presented. The effect of urban sprawl is presented in detail in this chapter. Based on the above results the following conclusions may be drawn:

- Urban sprawl depletes the ground water.
- Ground water flow depends on the topology
- Urban sprawl is rapidly increasing in the urban areas.
- Undeveloped areas are next for potential development
- Agricultural land cover gradually decreasing with time.

5.2 FUTURE SCOPE OF WORK

The following are some of the areas where further studies may be carried out:

- To study over exploitation of urban areas.
- To study more potential areas for development
- Physiographic characteristics can be further improved.

References

A Pathy and G. K Panda (2012): "Modeling Urban Growth in Indian Situation - A Case Study of Bhubaneswar City", *International Journal of Scientific & Engineering Research Volume 3, Issue 6.*

Alberti, M., Weeks, R., and Coe, S. (2004) Urban land-cover change analysis in Central Puget Sound. *Photogrammetric Engineering and Remote Sensing*, **70**, 1043–1052.

Aguilar, M. and Dymond, R. (2013). "Innovative Technologies for Storm-Water Management Programs in Small Urbanized Areas." J. Water Resour. Plann. Manage, 10.1061/ (ASCE) WR.1943-5452.0000410, 04014029.

Anu, Amiya and Ashwani (2014): "Monitoring Land Cover Changes in Coastal Tract of Odisha Using Landsat ETM+ Imagery", *Department of water Resources*, vol. 9(2), 430-436.

Arthur-Hartranft, S.T., Carlson, T.N., and Clarke, K.C. (2003) Satellite and ground-based microclimate and hydrologic analyses coupled with a regional urban growth model. *Remote Sensing of Environment*, **86**, 385–400.

Batty, M. (2008) The size, scale, and shape of cities. *Science*, **319**, 769–771.

Bartlett, J.G., Mageean, D.M., and O'Connor, R.J. (2000) Residential expansion as a continental threat to US coastal ecosystems. *Population and Environment*, **21**, 429–468.

Bhatta, B. (2010). *Analysis of Urban Growth and Sprawl from Remote Sensing Data*, Springer-Verlag, Berlin, Heidelberg.

Burns, M. J., Fletcher, T. D., Walsh, C. J., Ladson, A. R., and Hatt, B. E. (2012). "Hydrologic shortcomings of conventional urban storm-water management and opportunities for reform." Landscape and Urban Planning, 105(3), 230–240.

C. Sudhakar Reddy & C. S. Jha (2012): "Assessment and monitoring of long-term forest cover changes in Odisha, India using remote sensing and GIS", *Environ Monit Assess* 185:4399–4415.

Central Ground Water Information System.

Colwell, R.N. (1997) History and place of photographic interpretation, in *Manual of Photographic Interpretation* (2nd) (ed W.R. Phillipson), ASPRS, Bethesda, pp. 33–48.

Grimm, N.B., Faeth, S.H., Golubiewski, *et al*. (2008) Global change and ecology of cities. *Science*, **319**, 756–760.

Herold, M., Scepan, J., and Clarke, K.C. (2002) The use of remote sensing and landscape metrics to describe structures and changes in urban land uses. *Environment and Planning A*, **34**, 1443–1458.

Hepinstall, J.A., Alberti,M., andMarzluff, J.M. (2008) Predicting land cover change and avian community responses in rapidly urbanizing environments. *Landscape Ecology*, **23**, 1257–1276.

Javaid Ahmad Tali, Divya S And Asima Nusrath (2014):" A Literature Survey On Rural Urban Fringe", *Journal of International Academic Research For Multidisciplinary* Volume 2, Issue1.

Jha R., Singh V. and Vatsa V. , " Analysis of Urban development of Haridwar, India, using Entropy Approach", KSCE journal of Civil Engineering, Vol No. 12, 282-287, 2008.

Lo, C.P. (2004) Testing urban theories using remote sensing. *GIScience & Remote Sensing*, **41**, 95–115.

Lo, C.P. (2007) The application of geospatial technology to urban morphological research. *Urban Morphology*, **11**, 81–90.

Lo, C.P., Quattrochi, D.A., and Luvall, J.C. (1997) Application of high-resolution thermal infrared remote sensing and GIS to assess the urban heat island effect. *International Journal of Remote Sensing*, **18**, 287–304.

Lo, C.P. and Quattrochi, D.A. (2003) Land-use and landcover change, urban heat island phenomenon, and health implications: A remote sensing approach. *Photogrammetric Engineering and Remote Sensing*, **69**, 1053–1063.

Longley, P.A. (2002) Geographical information systems: will developments in urban remote sensing and GIS lead to 'better' urban geography? *Progress in Human Geography*, **26**, 231–239.

Mittelbach, F.G. and Schneider, M.I. (2005) Remote sensing: With special reference to urban and regional transportation. *Annals of Regional Science*, **5**, 61–72.

Nagarajan, M., and Basil, G. (2014), "Remote sensing- and GIS-based runoff modelling with the effect of land-use changes (a case study of Cochin Corporation)". *Springer Science+Business Media Dordrecht* **73**, 2023–2039.

Naik, M. and Jha, R. (2013). "Urban Sprawl of Bhubaneswar city using GIS applications and entropy."

Prabhu Prasad Das and Hrushikesh Sahoo (2014):" A Geospatial Evaluation of SRTM DEM for Representative Groundwater Sampling of Rajnagar Block, Odisha, India" *International Journal of Emerging Technology and Advanced Engineering* Volume 4, Issue 11.

Rashed,T., Weeks, J.R., Stow, D. and Fugate, D. (2005) Measuring temporal compositions of urbanmorphology through spectral mixture analysis: toward a soft approach to change analysis in crowded cities. *International Journal of Remote Sensing*, **26**, 699–718.

Santana, L.M. (2007) Landsat ETM+ image applications to extract information for environmental planning in a Colombian city. *International Journal of Remote Sensing*, **28**, 4225–4242.

Schneider, A. and Woodcock, C.E. (2008) Compact, dispersed, fragmented, extensive? A comparison of urban growth in 25 global cities using remotely sensed data, pattern metrics and census information. *Urban Studies*, **45**, 659–692.

Sherbinin, A.D., Balk, D., Jaiteh, M. *et al*. (2002) A CIESIN Thematic Guide to Social Science Applications of Remote Sensing. Available http://sedac.ciesin.columbia.edu/tg/guide_frame.jsp?rd=RS&ds=1 (accessed 10 July 2010).

Small, C. and Nicholls, R.J. (2003) A global analysis of human settlement in coastal zones. *Journal of Coastal Research*, **18**, 584–599.

Srivastava and Bhattacharya (2000): "Delineation of Ground Water Potential Zones in a Hard Rock Terrain of Bargarh District, Orissa Using IRS Data", *Journal of the Indian Society of Remote Sensing, Vol. 28, No. 2&3.*

Stefanov, W.L. and Netzband, M. (2005) Assessment of ASTER land cover and MODIS NDVI data at multiple scales for ecological characterization of an urban center. *Remote Sensing of Environment*, **99**, 31–43.

Sugumaran, R., Zerr, D. and Prato, T. (2002) Improved urban land cover mapping using multi-temporal IKONOS images for local government planning. *Canadian Journal of Remote Sensing*, **28**, 90–95.

Turner, B.L., Lambin, E.F., Reenberg, A. (2007) The emergence of land change science for global environmental change and sustainability. *Proceedings of the National Academy of Sciences*, USA, **104**, 20666–20671.

USGS (U.S. Geological Survey)

UN-HABITAT (2010) *State of the World's Cities 2010/2011 – Cities for All: Bridging the Urban Divide*. Available http://www. unhabitat.org/content.asp?cid=8051&catid=7&typeid=46& subMenuId=0 (accessed 10 July 2010).

Veena Srinivasan, Steven M. Gorelick, and Lawrence Goulder (2010). "A hydrologic-economic modeling approach for analysis of urban water supply dynamics in Chennai, India."

Yang,X. (2002) Satellite monitoring of urban spatial growth in the Atlanta metropolitan region. *Photogrammetrical Engineering and Remote Sensing*, **68**, 725–734.