SITE SUITABILITY ANALYSIS FOR SURFACE RAINWATER HARVESTING USING REMOTE SENSING AND GIS

a dissertation submitted for the partial fulfillment of the requirements

for the degree of

MASTERS OF TECHNOLOGY

IN

HYDRAULICS & WATER RESOURCES ENGINEERING

BY

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(2K14/HFE/19)

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CANDIDATE'S DECLARATION

I do hereby certify that the work presented is the report entitled "**Site suitability analysis for surface rain water harvesting using remote sensing and GIS**" in the partial fulfillment of the requirements for the award of the degree of "Master of Technology" in Hydraulics & Flood engineering submitted in the Department of Civil Engineering, Delhi Technological University, is an authentic record of my own work carried out from January 2016 to July 2016 under the supervision of Dr.K.C Tiwari (Professor), Department of Civil Engineering.

I have not submitted the matter embodied in the report for the award of any other degree or diploma.

AVINASH KUMAR

Date: / /16 (2K14/HFE/19)

CERTIFICATE

This is to certify that above statement made by the candidate is correct to best of my knowledge.

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ABSTRACT

Delhi region is facing the problem of scarcity of water throughout the year. To check this problem, various efforts have been made. Rainwater harvesting is such an effort which can be used to address the problem of shortage of water effectively. This can be done by constructing check Dams, Percolation Tank, Bore well, Dug well, Dug cum bore well, Farm Pond, etc. In the present dissertation, Selection of suitable rainwater harvesting site are carried out with the help of GIS and remote sensing in Delhi region. In this study suitability of rainwater harvesting sites is carried out by GPS, Survey of India toposheets on scale of 1:250,000, SRTM data for creation of DEM and satellite imagery of LANDSAT ETM+ (30mt. spatial resolution). This study therefore focused on the development of suitability level for most important factor and parameters for identification of such sites. These factors include rainfall, soil texture, drainage, topography and land use / land cover and integration of these factors using weighted overlay analysis with the help of ArcGIS software provide suitable sites for rainwater harvesting. These sites are then classified into various suitability levels, namely, 1, 2, 3, 4 and 5, 5 suitability level is the most suitable region and 1 suitability level is the least suitable region for rainwater harvesting. By applying above process, the results shows that in Delhi region there are several suitable sites with highest suitability level which can be used for Rainwater harvesting. Hence, the conclusion of the study is that site suitability analysis for surface rainwater harvesting using GIS and remote sensing is the better technique for finding rainwater harvesting suitable site with quite appreciable accuracy.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1 General

Water is an essential requirement for economic and social development of any locality. The population and economy of India is growing thereby resulting in the growth of water demand for domestic, agricultural and industrial use. Reduction of surface runoff can be achieved by construction of suitable structures. These structures also helps to manage the other natural resources like soil, slope, and Land use/Land cover as the watershed condition affect these recourses. Water is important for all life and used in many different ways. It also is a part of the larger ecosystem on which reproduction of the biodiversity depends. Fresh water scarcity is not limited to the arid climate regions only, but in many areas with good supply the access to safe water has become critical problem. Deficiency of water is caused by minimized water storage capability, low infiltration, larger inter annual and annual fluctuations in precipitation due to monsoon rains and high evaporation losses.

The concept of Rainwater harvesting (RWH) is both simple and ancient. Rain water harvesting primarily consists of the collection and storage of rainwater for subsequent use as source of water. The harvested water can be used for Both potable and non-potable applications. There are many examples of rainwater harvesting systems which provide water for domestic, commercial, institutional and industrial purposes as well as agriculture, livestock, groundwater recharge, flood control, process water and as an emergency supply for firefighting (Gould & Nissen-Peterson, 1999). RWH systems can be small and basic, such as attachment of a tank to rainwater downspout, as well as large and complex, such as those that collect water from many hectares and serve large numbers of people. Before the latter half of the twentieth century, RWH systems were used predominantly in areas lacking additional forms of water supply, such as Kutch region of India. Some ancient rain water harvesting system can also be seen in Tamil Nadu, Maharashtra, Madhya Pradesh, Chhattisgarh and Rajasthan states of India.

The flowchart below demonstrates the fundamental process of rainwater harvesting.

Figure 1.1 Flowchart illustrating the fundamental rainwater harvesting processes

1.1.1 Classes of rainwater harvesting –

The system of rainwater harvesting depends on the catchment area in which the runoff is generated, and receiving area, which is the area where the runoff is used (Mzirai 2010). Rainwater Harvesting can be divided into two classes:

A. **Micro catchment** which means that the rainfall is conserved where it falls, and can use water stored directly in the field or utilization area. The properties of this system consist of small semi-circle pits, strip catchment tillage, semi-circle bunds, and contour bunds (Girma 2007). The area of a micro catchment is less than 1000 sq. m. (Zakaria et al 2012).
B. **Macro catchment** involves harvesting of water from a basin area ranging from 0.1 hectare to several thousands of hectares. Macro catchment may be located near or far from the Utilization area (Girma 2007). This system is implemented with intermediate water storage outside the utilization area. The slope of a macro catchment area is ranging from 5 to 50%. This system needs storage structure and transfer infrastructure such as channels, natural streams and gullies to convert the water storage in the utilization area (Zakaria et al 2012).

Gathering rainwater could be significantly improved by applying a specific technique such as macro rainwater harvesting. Applying a system of macro catchment will augment the agricultural production, water productivity and water quality, especially when it is integrated with an irrigation system such as supplementary irrigation. This method indicates that during critical stages of crop growth a limited amount of irrigation for the rain-fed agriculture, which leads to improve the crop productivity and management of water resources, can be added (Zakaria et al 2012). The macro catchment runoff harvesting with supplemental irrigation will increase the agricultural production twice even if supplementary irrigation is not used during dry spells (Adekalu et al 2009).

The depth of ground water table has lowered in recent years in the Delhi region. Therefore, It is necessary to search for systems storing the water from the rainfall and permanent streams runoff to be used as supplementary resources in the dry spells or to provide systems for recharge of ground water.

All above-mentioned reasons lead us to use macro catchment for rainwater harvesting and ground water recharging by constructions of dams and reservoirs to save runoff water for a long time.

1.1.2 Effects of urbanization on ground water Hydrology

- **A.** High water demand**.**
- B. Over exploitation of ground water.
- C. Increase in runoff.
- D. More dependency on ground water use.
- E. Decrease in subsoil infiltration.
- F. Decline in well yields.
- G. Reduction in open soil surface area.

1.2 Requirement of Rainwater Harvesting

Out of the total water source 91% is ocean water and only 2.5% is potable fresh water and balance 6.5% is in other forms. The ground water table has depleted abruptly due to urbanization causing scarcity of water. Rains provide a large amount of fresh water which can be easily harvested by surface or subsurface storage. So rainwater harvesting is the need of the coming years.

1.2.1 Why more suitable for metro city

Over exploitation and heavy withdrawal of ground water in metros has led to declination of water level at an alarming rate making Rainwater harvesting for metro cities a necessity. Rain water can be collected and stored in lakes or tanks. Storing the rainwater in sub surface aquifer is another solution to solve the water supply problems. The process of artificial recharge to ground is fast and it is possible to recharge more than 90% of rainwater to ground system.

1.3 Rainwater Harvesting Practices in India

Today, only 2.5 per cent of the entire world's water is fresh, which is fit for human consumption, agriculture and industry. In several parts of the world, water is being used at a much faster rate than can be refilled by rainfall. In 2025, the per capita water availability in India will be reduced to 1500 cubic meters from 5000 in 1950. The United Nations warns that this shortage of freshwater could be the most serious obstacle to producing enough food for a growing world population, reducing poverty and protecting the environment. Hence the water scarcity is going to be a critical problem if it is not treated now in its peanut stage. Some of the major cities where rainwater harvesting has already been implemented is Delhi. Centre for Science and Environment's (CSE) has designed sixteen model projects in Delhi to setup rainwater harvesting structures in different colonies and institutions. In Bangalore Rainwater harvesting at Escorts-Mahle-Goetze, Designed by S. Vishwanath Rainwater club, http://www.rainwaterharvesting.org /People/innovators-urban.htm. In Indore, Indore Municipal Corporation (IMC) has announced a rebate of 6 percent on property tax for those who have implemented the rainwater harvesting work in their house/bungalow/building. The commonly practiced methods of rain water harvesting in India are

A. **Lakes/Tanks -** Most of the old city, which were not on river banks, had huge lakes or tank to store water. Either these have been lost or their capacity greatly reduced due to silting.
B. **Tanka -**Small underground tanks in house, temples, and Dharamshalas**,** Popular in Bikaner, Dwarka**.**
C. **Baoli/Bavadi -**Traditional step wells in Rajasthan and other state of northern India.
D. **Khadirs -**Long earthen embankment built across the lower hill slope laying below upland, Popular in Jaisalmer, Western Rajasthan.
E. **Bhandaras -** Check dam or diversion weir used to impound water and Raise water levels in rivers, Popular in Maharashtra.
F. **Johad -**Small earthen check dam which capture and conserve water.
G. **Kere -**Tank s fed by channels branching off from check dams, out flow of one tank supplied water to another tank, Popular in central Karnataka.

1.4 Remote Sensing and GIS, and Its Applications in RWH

1.4.1 Remote sensing –

Remote Sensing is the science and art of acquiring information (spectral, spatial, and temporal) about material, objects, area, or phenomenon, without coming into physical contact with the objects, or area, or phenomenon under investigation. Without direct contact, some means of transferring information through space must be utilized. In practice, remote sensing is the stand-off collection through the use of a variety of devices for gathering information on a given object or area.

Application of Remote Sensing - The major applications of Remote Sensing in water resources management are

1. **Resource Exploration:** Geologists use remote sensing to study the formation of sedimentary rocks and identify deposits of various minerals, detect oil fields and identify underground storage of water. Remote sensing is used for identifying potential fishing zone, coral reef mapping and to find other wealth from ocean.
2. **Land Use/Land cover:** By remote sensing, mapping of larger areas is possible in short time. Forest area, agricultural area, residential and industrial area can be measured regularly and monitored. It is possible to find out areas of different crops.
3. **Environmental Study:** Remote sensing is used to study cloud motion and predict rains. With satellite data it is possible to study water discharge from various industries to find out dispersion and harmful effects, if any, on living animals. Oil spillage and oil slicks can be studied using remote sensing.

1.4.2 GIS

A Geographic Information System (GIS) integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information. GIS also allows the integration of these data sets for deriving meaningful information and outputting the information derivatives in map format or tabular format.

Applications of GIS

1. Drainage systems
2. Streams and river basins management
3. Lakes
4. Canals
5. Land records
6. Land use of different crops etc.

1.4.3 Application of GIS and Remote Sensing in Rainwater Harvesting

Remote sensing and GIS can be used to identify potential suitable areas for Rain water harvesting techniques. GIS based models can be developed to generate a suitability map for Rainwater Harvesting (RWH) by using multi criteria evaluation.

1.5 Objective

1. To analyze DEM Model and to generate Slope Map and Aspect Map from DEM model for locating rainwater harvesting site.
2. To Identify and map out the potential rainwater harvesting sites for Delhi region along with recommendation for suitable hydrological structure.

1.6 Outline of Thesis

The first chapter gives the introduction. Chapter 2 presents literature review on Rainwater harvesting potential site identification studies. In Chapter 3 study area and data used are given. Chapter 4 is all about methodology and implementation. And Chapter 5 presents result and discussion. The conclusion of the study is given in chapter 7.

CHAPTER 2
LITERATURE REVIEW

2.1 MOTIVATION

F.O Mkiramwinyi et al., [2014] used Remote Sensing in their study, limited field survey to identify potential sites for RWH technologies. The input into the Decision Support System (DSS) included maps of rainfall, slope, soil texture, soil depth, drainage and land use/cover and the outputs are maps showing potential sites of water storage systems, stone terraces, bench terraces and borders and the Model Builder in the Arc View was used as a platform for the DSS. The results from two sites in the Makanya watershed, in Kilimanjaro Region, Tanzania, were used for testing and validation of the DSS showed areas suitable for RHW in these regions. **Murugesa Bagyaraj et al., (2012)** carried out groundwater study in the Dindigul district of kodaikanal hill, a mountainous terrain in the Western Ghats of Tamilnadu. Ground water potential zones were located with the help of remote sensing and Geographical information (GIS) techniques. All thematic maps are generated using the resource sat (IRS P6 LISS IV MX) data and Inverse distance weight (IDW) model was used in GIS data to identify the groundwater potential of the study area. For the various geomorphic units, weight factors were assigned based on their capability to store groundwater.

2.2 Literature Review for Present Study

Many researchers have studied the rainwater harvesting using different techniques. In this dissertation, the study for site suitability analysis is done for rainwater harvesting using GIS and remote sensing, for which previous research and studies referred are given as follows,

Deepesh Machiwal et al., (2010) proposed a standard methodology to delineate groundwater potential zones using integrated RS, GIS and multi-criteria decision making (MCDM) techniques. The methodology was demonstrated by a case study in Udaipur district of Rajasthan, western India. Initially, ten thematic layers were considered. Weights of the thematic layers and their features then normalized by using AHP (analytic hierarchy process) MCDM technique and eigenvector method. Finally, the selected thematic maps were integrated by weighted linear combination method in a GIS environment to generate a groundwater potential map. **Cheng-Haw Lee et al., (2008)** proposed that assessing the potential zone of groundwater recharge is extremely important for the protection of water quality and the management of groundwater systems. Further groundwater potential study was carried out in Taiwan with the help of remote sensing and the geographical information system (GIS) by integrating the five contributing factors: lithology, land cover/land use, lineaments, drainage, and slope. The weights of factors contributing to the groundwater recharge are derived using aerial photos, geology maps, a land use database, and field verification. **Jobin Thomas et al., (2011)** determined groundwater potential zone in tropical river basin (Kerala, India) using remote sensing and GIS techniques. The information on geology, geomorphology, lineaments, slope and land use/land cover was gathered from Landsat ETM + data and Survey of India (SOI) toposheets of scale 1:50,000 in addition, GIS platform was used for the integration of various themes. The composite map generated was further classified according to the spatial variation of the groundwater potential. The spatial variation of the potential indicates that groundwater occurrence is controlled by geology, structures, slope and landforms. **Hasan Mohammed Hameed(2013)** demonstrated the capability of remote sensing techniques and GIS in demarcation of groundwater potential zones in a disuse geological set up. Thematic layers such as lithology, lineaments and surface water bodies were prepared by using remotely sensed data, soils texture, rainfall data, drainage density and slope category layers prepared from conventional data sources were integrated and analyzed using the model developed by applying logical condition in GIS. Assigning appropriate weights for each subunits of an individual layer and the weights are summed up by integration. **Krishnamurthy et al (1996**) developed a GIS based model for delineating groundwater potential zones of Marudaiyar basin, Tamil Nadu, India by integrating different thematic layers such as lithology, landforms, lineaments and surface water body on 1:50,000 scale were used in their work, besides drainage density and slope classes from survey of India toposheets. In addition a soil map of 1:50,000 scale covering the study area was generated from soil map prepared by soil survey and land used organization by regrouping the soil types based on their hydrological characteristics. All the thematic layers were integrated and analyzed using GIS model to achieve groundwater potential map. Further, the results collected from field were validated by the use of field data. Finally, the authors assert that the approach outline as merits and can be successfully used in other similar catchments with appropriate modifications. **Hsin-**

Fu Yeh et al (2008) assessed the groundwater recharge potential zone in Chih-Pen-Creek basin in eastern Taiwan using lithology, land use/land cover, lineaments, drainage and slope. The weights of the factors contributing to groundwater recharge was derived using aerial photos, geology maps, a land use database and field verification. The resultant map of the groundwater potential area was located towards the downstream region in the basin because of the high infiltration rates caused by the gravely sand and agricultural land use in these regions. **Shereif H. Mahmoud (2014**) proposed a standard methodology based on a decision support system (DSS) that combines remote sensing, field survey and geographic information system techniques to identify suitable GWR areas. The DSS been implemented to obtain suitability maps and to evaluate the existing GWR in the study area. The DSS inputs comprised maps of rainfall surplus, slope, potential runoff coefficient, Land-cover/Land-use and soil texture. The spatial extents of GWR suitability areas were identified by a hierarchical process analysis that considered five layers. The model generated a GWR map with four categories of suitability: excellent, good, moderate and poor. **J.P. Singh and Darshdeep Singh (2008**) conducted a study to identify suitable sites for rainwater harvesting structures in Soankhad watershed, Punjab using information technologies such as Remote Sensing and Geographical Information System (RS-GIS). The IRS-1C, P6 satellite imagery of the Soankhad watershed was used. The various Thematic maps such as land use map, hydrological soil group map, slope map and DEM map were prepared for selecting suitable site for construction of water harvesting structures. The suitable sites were not found for nala bunding and farm ponds due to steep slope, less soil thickness and high runoff velocity. Fourteen check dams and six percolation tanks were proposed for the construction as per Integrated Mission for Sustainable Development (IMSD) guidelines.

From the above study, it is found the GIS and remote sensing can be used as a tool for analysis of suitable sites for rain water harvesting using LANDSAT ETM+, SRTM data, Soil Texture map and rainfall data.

CHAPTER 3
STUDY AREA AND DATA USED

3.1 Study Area

The region selected for the present study is Delhi region. It is located between $28^0$24’15’’ and $28^0$53’00’’N latitudes and $76^0$50’24’’ and $77^0$20’30”E longitudes occupying an area of 1483.0 sq. km. The total population of NCT Delhi, as per the census 2011 is 167.53 lakhs with a density of 11297 persons/sq.km area. The normal annual rainfall of Delhi region is 611.8mm. The rainfall increases from the South-West to the North-West. About 81% of the annual rainfall is received during the monsoon months July, August and September. The rest of the annual rainfall is received in the form of winter rain. The Gangetic Plain and the Aravalli Ridge converge at Delhi, giving mixed geological character with alluvial plains as well as quartzite bedrock. Delhi region is divided into 9 districts and 27 sub-division. (CGWB, New Delhi).

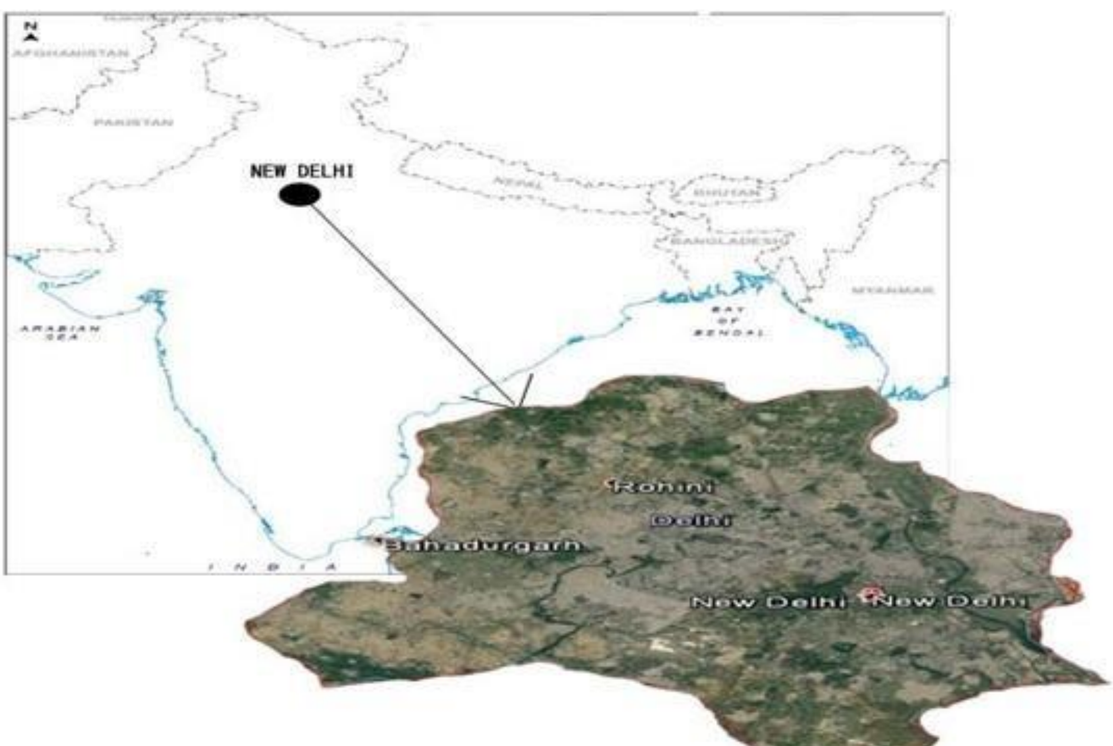

Figure3.1: Location map of the study area (Source: Google earth)

Table 1. Data Used

The following data set were used for the present study:-

Satellite Data	Area	Source	Resolution	Date / Year
SRTM DATA	Delhi region	www.Glcfapp.glcf.umd.edu:8080/esdi/index.jsp **(Global Land Cover Facility)**	90 meter	2000
LAND USE/ LANDCOVER DATA	Delhi region	www.Glcfapp.glcf.umd.edu:8080/esdi/index.jsp **(Global Land Cover Facility)**	30 meter	2000
SOIL TEXTURE MAP	Delhi region	Soil survey of India Delhi.		2012
RAINFALL DATA	Delhi region	www.Indianwaterportal.org		1901-2002

3.2 SOFTWARE USED

ArcGIS 10.2 and ERDAS IMAGINE 9.1 was used for geo-processing and image processing respectively.

1. **SRTM Raw Data Image:**

   SRTM, Degree Tiles 2000 USGS/ GLCF Capture Resolution 3arcsec, And Pixel Resolution 90 meter.

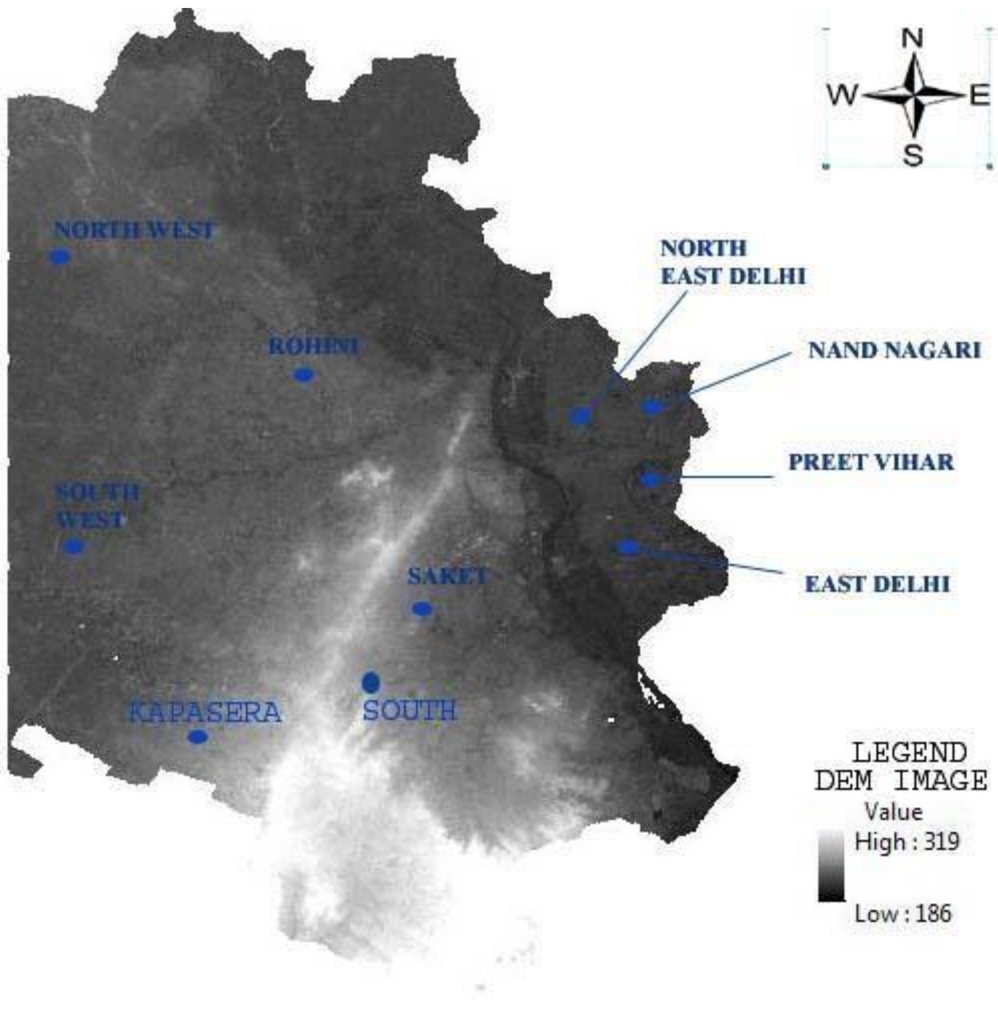

Figure3.2: DEM SRTM Raw data of Delhi region
(Lat : 28°24’15N’- Lon : 77°20’30”E),Source: (Global Land Cover Facility Site)

2. **LAND USE LAND COVER Data:**

Satellite L 7, Sensor ETM+ multi-spectral ,Band 1,2,3,4,5,7, Spectral Range(0.450 - 2.35 μm), Pixel Resolution 30 meter (2000), (path 146-row 040).

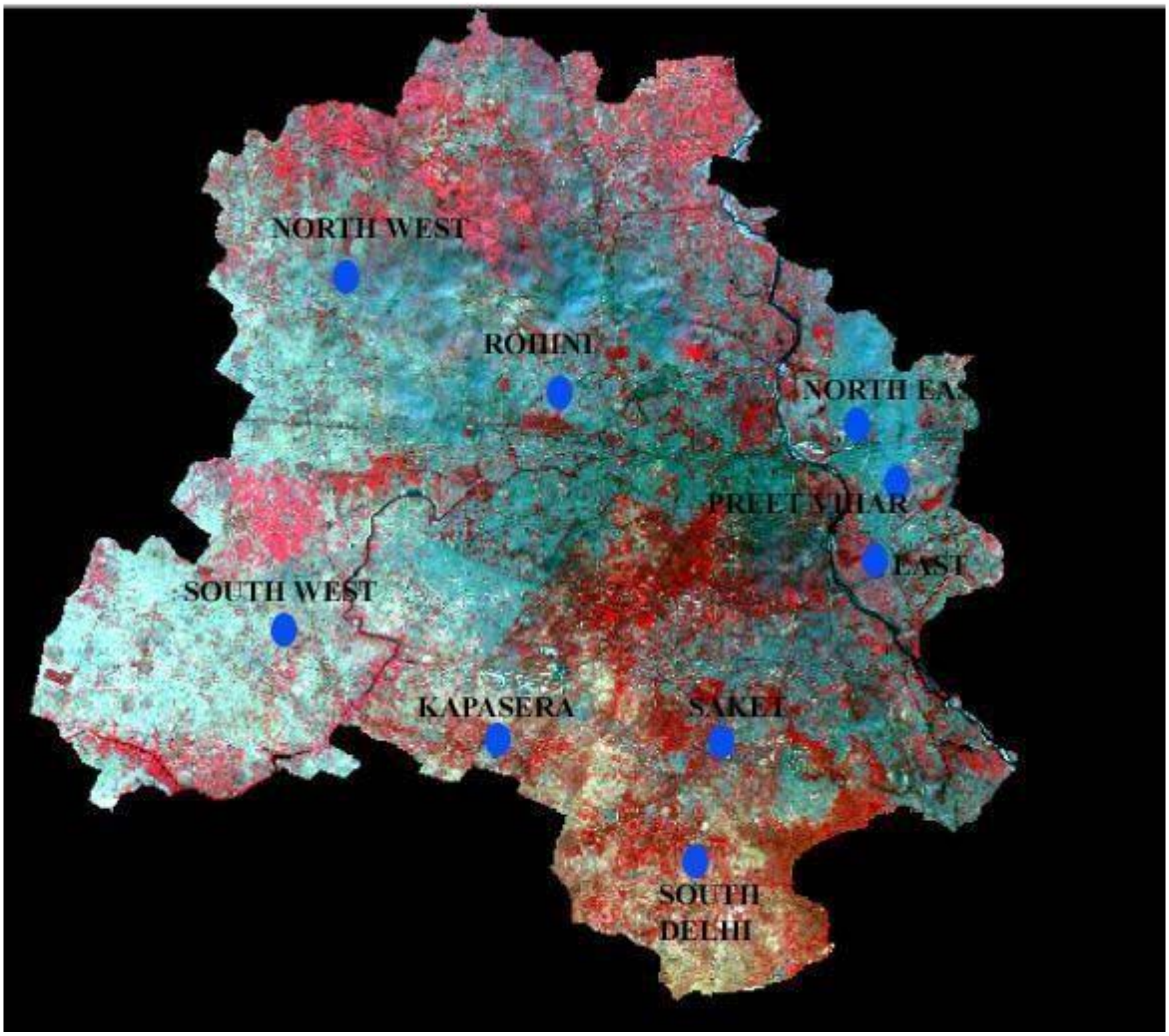

Figure 3.3: Land use/ Land Cover Raw Data of Delhi region. (Lat : 28°24’15N’-Lon77°20’30”E)

Source: (Global Land Cover Facility Site)

3. **SOIL TEXTURE MAP of Delhi**: Soil texture map taken by Soil survey of India Delhi (2012).

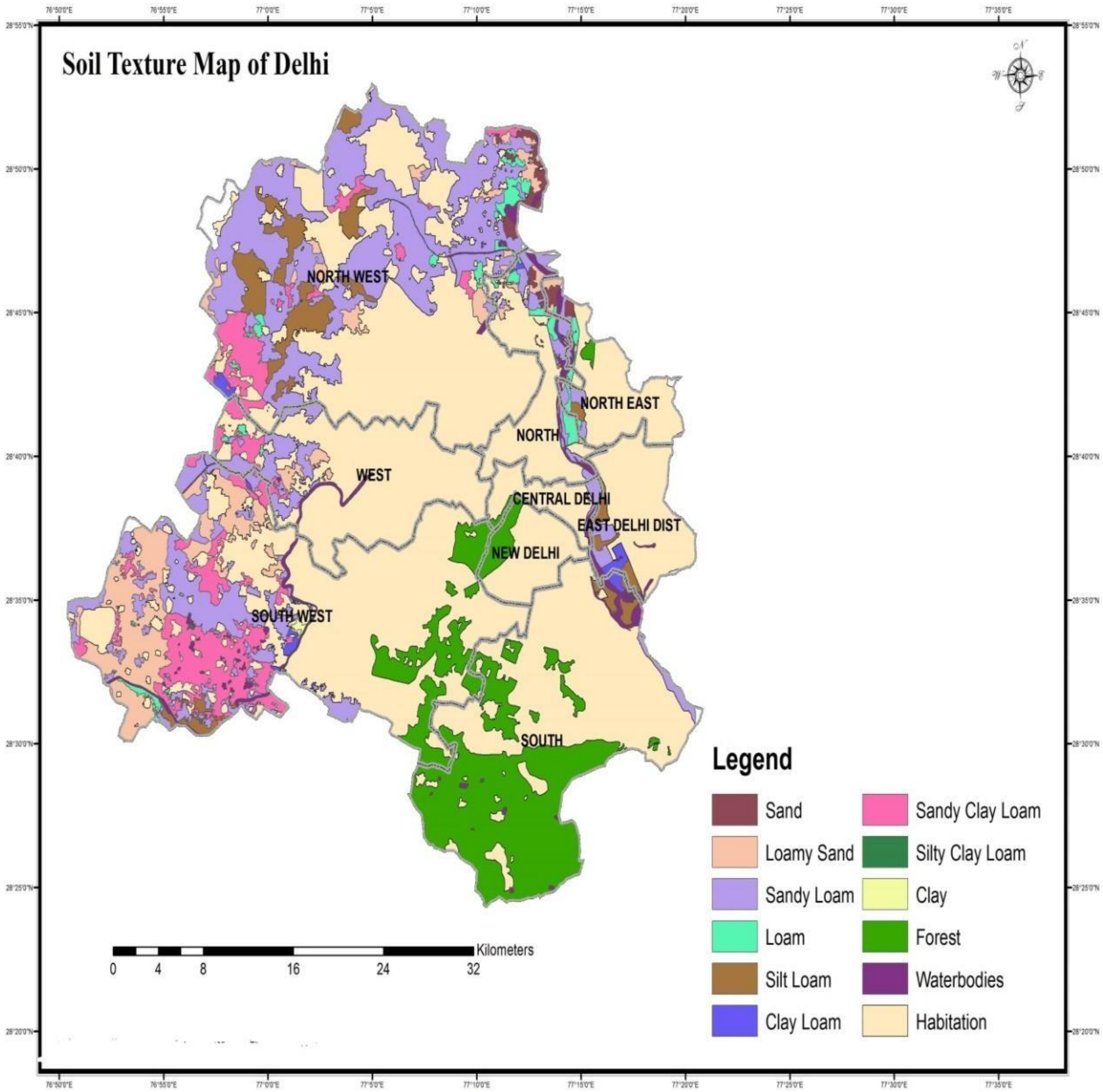

Figure3.4: Soil texture map Delhi.

Source: Soil survey of India Noida

CHAPTER 4
METHODOLOGY and IMPLEMENTATION

4.1 Methodology for present study –

In this dissertation, the study has been conducted for the site suitability analysis for surface rainwater harvesting using GIS and remote sensing. The methodology divided in two parts is discussed separately.

4.1.1 To analyze DEM Model and to generate Slope Map and Aspect Map from DEM model for locating rainwater harvesting site.

A digital elevation model (DEM) is a digital model representation of a terrain's surface commonly for a planet including Earth, moon, created from terrain elevation data. In the present study, analysis of DEM Model is done. DEM Model is generated from SRTM data and slope map and aspect map are generated using ERDAS Imaging software. For this, with the help of preprocessing of DEM model, projection is changed according to the unit of the coordinates of the study area.

1. **Slope Map Preparation**
   The DEM obtained is used for the generation of slope which classifies the entire study area in different categories of slope ranges. The ranges so classified will help in calculating the space of the water flow in that particular region. This information is useful in the categorization of the type of structure to be built in that particular zone.

2. **Aspect Map**
   The compass direction that a topographic slope faces, usually measured in degrees from north. Aspect can be generated from continuous elevation surfaces Find all north-facing slopes on a mountain as part of a search for the best slopes for ski runs. Identify areas of flat land to find an area for a plane to land in an emergency.

3. **Stream order map**
   Stream order is a measure of the relative size of streams. This is also the outcome of the DEM generation using SRTM data. The smallest tributaries are referred to as

first-order streams, while rivers are higher order waterway. Drainage/stream ordering represent the number of streams presents in each order defined i.e. 1, 2, 3, 4, 5 and 6 stream orders. 2nd, 3rd or 4th order streams are suitable for Storage Tank and Percolation Tank. 4th, 5th or 6th order streams are suitable for Check Dams. 3rd or 4th order streams are suitable for Stop Dams. In mathematics, the Strahler number or Horton–Strahler number of a mathematical tree is a numerical measure of its branching complexity. This can be obtained by Spatial Analyst of ArcGIS software Tools which is done by setting the input surface raster as DEM and output surface raster as Stream order.

4.1.2 To identify and map out the potential rain water harvesting sites for Delhi region.

The process of identifying and mapping of potential rain water harvesting sites is based on weighted overlay analysis. In this analysis, the integration of the Land use/Land cover map, Slope map and Stream order map is done for carrying out site suitability analysis for rain water harvesting sites. The flow chart for this objective is given in Figure 4.1 and discussed below –

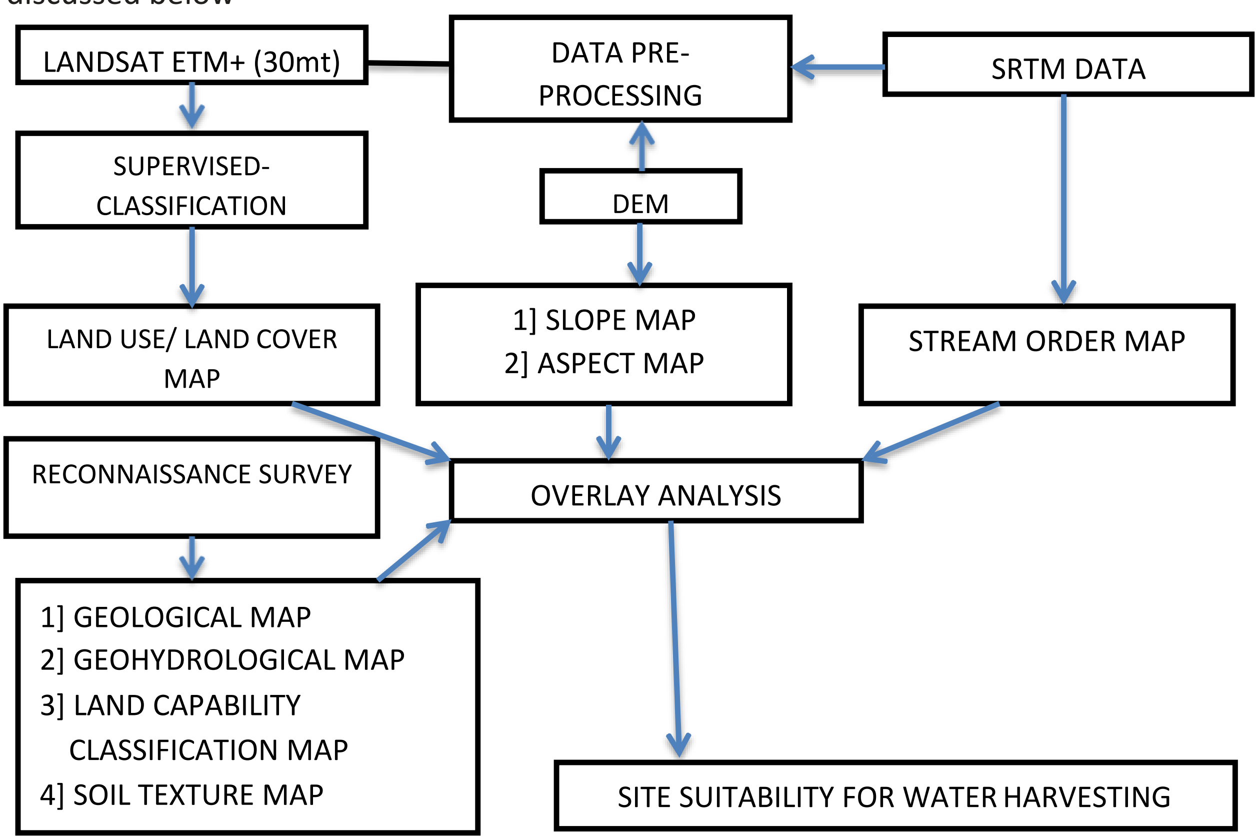

Figure 4.1: Methodology for preparing site suitability map for RWH structures.

1. **Land use/ Land cover map**

ERDAS IMAGINE 9.1 Software was used to mosaic the collected satellite images. The cluster Supervised classification tool and maximum Likelihood classification function in the ERDAS IMAGINE 9.1 Software were used for the supervised classification of Land use/Land cover data or Landsat ETM+ image for carrying out Land use/Land cover map. Training samples collected were used to create spectral signature for the supervised classification to identify what the cluster represent (i.e. water, bore earth and sand). Land Use/ Land Cover shows six main classes, namely (Built up area, Barren Area, Agriculture, Water, Forest and Sand).

Beside land use/ Land cover map, Slope map and stream order map, soil texture map is also the important factor in deciding the outcome of the site suitability analysis for rain water harvesting. This factor is described as follow,

2. Soil Texture map

In this dissertation, Soil texture map taken by Soil survey of India Delhi (2012). Soil texture is an important soil characteristic that will be taking into consideration of suggesting water harvesting structures .The study area is having different types of soil texture as sand, clay loam, sandy loam, loamy sand, silty loam, loam, silt clay loam, sandy clay loam and clay.

3. Weighted Overlay Analysis

The purpose of the weighted overlay analysis is to apply a common scale of values to diverse and dissimilar data input to create an integrated analysis. ArcGIS is used to implement Weighted Overlay Analysis. The weights calculated for each factor using

$$\text{S=SUMMATION} * X\text{i}$$

Where Zi is the weight of indicator i and Xi is the criteria score of the indicator I.

To implement the rules laid by integrated mission for sustainable development (IMSD) guide lines, number of information layers is prepared by overlaying the Land use, slope, stream order to match the criteria laid. A Multi Criteria based analysis is used for the identification of the site suitability map for various Rainwater Harvesting structures for water storage. The generated layers are in vector format, for Weighted Overlay Analysis the "Rasterization" of each layer is performed. The first step of data conversion is "Rasterization" for converting different lines and polygon coverage into raster data format. After this, reclassification of all the raster files is processed along with providing the scale value of each unit. A scale value in the range 1 to 3 is used in which "1" is for least suitable, "2" is for moderate suitable and "3" is for highly suitable. All the layers are given ranking based on their influence on the study applying equal weightage to all the parameters which means all parameters are of equal importance. Further, in the Spatial Analyst Tool, Weighted Overlay Function has been processed for identification of the suitable area. Based on the Weighted Overlay Function a site suitability map and most suitability map is prepared and is shown in figure.

Weight and Scale Value given to Different layers

A scale value in the range 1 to 3 is used in which "1" is for least suitable, "2" is for moderate suitable and "3" is for highly suitable. All the layers are given ranking based on their influence on the study applying equal weightage to all the parameters which means all parameters are of equal importance. Tabular representation of weight and scale value given to different layers is as follows,

Table 2. Weight and Scale Value given to Different layers

Raster Feature	%Influence(Weight Assigned)	Feature Classes	Feature Weight Scale value
LAND USE/ LAND COVER MAP	60	Built up Area	3
		Barren Area	2
		Agriculture	1
		Water	2
		Forest	1

		Sand	2
SLOPE	15	Nearly Level	1
		Very Gently	3
		Gently Slope	3
		Moderately Slope	2
		Steep Slope	2
STREAM ORDER	25	1st ORDER	1
		2nd ORDER	1
		3rd ORDER	2
		4TH ORDER	2

4. SUITABILITY PROCESS

Suitability process is the process of carrying out suitable sites for rainwater harvesting structures. The Model Builder tool of Arc GIS is used to create suitability model and then applying Weighted Overlay Analysis finally creates most suitable map.

To create a suitability raster for the location of rain water harvesting sites.

$$S = \sum_{i=1}^{n} w_i C_i \prod_{j=1}^{m} r_j$$

Where
S = Suitability for rainwater harvesting site

W_i = Weight for criteria i (C_i)

C_i = Criteria for suitability

r_j = Restriction

Suitability Model

$$S = \sum^{n} w_i\, C_i \prod^{m} r_j$$

$$S = (w_s C_s . w_{lu} C_{lu}) \prod_{j=1}^{m} r_j$$

Where

w_s and C_s = Weight and Criteria for slope

W_{lu} and C_{lu} = Weight and Criteria for land use

Weight and Scale

Weights

$$S = (0.60 C_s\, .\, 0.25 C_{lu}) \prod_{j=1}^{m} r_j$$

Scale

Evaluation scale is taken from 1 to 3 by 1

After, integrating all thematic layers in GIS Environment, Using ArcGIS Model Builder all thematic layers are added in model. Using the arc tool box initially converted all vector layers into rasters. The cell size is maintained constant for all the layers. The thematic layers are Stream order, Land use/Land cover, contour slope, Slope map, converted these thematic layers into rasters using one of attributed column form each layer. DEM layer converted into slope map using 3d analyst in arc toolbox. All thematic raster are reclassified. Using spatial analyst tool the weighted overlay analysis command added in to model builder. All reclassified raster are added to weighted overlay command. According to each layer importance the weightages are given in weighted overlay tool. Finally the tool creates a raster of our required decisions which gives the most suitable sites for rain water harvesting structures.

CHAPTER 5
RESULT AND DISCUSSION

In the present study, DEM is constructed from SRTM raw data and Land use/land cover map is constructed from LANDSAT ETM+ raw data. With the generation of DEM, Slope map and stream order are fabricated using ArcGIS 10.2. Land use/Land cover map is obtained by using ERDAS Imagine 9.1.

5.1 Stream Profile Process (All the Output Maps)

5.1.1 Digital Elevation Model. DEM data start the first step for analysis of stream profile. DEM image show in figure5.1.1, (Zone 43), Delhi region

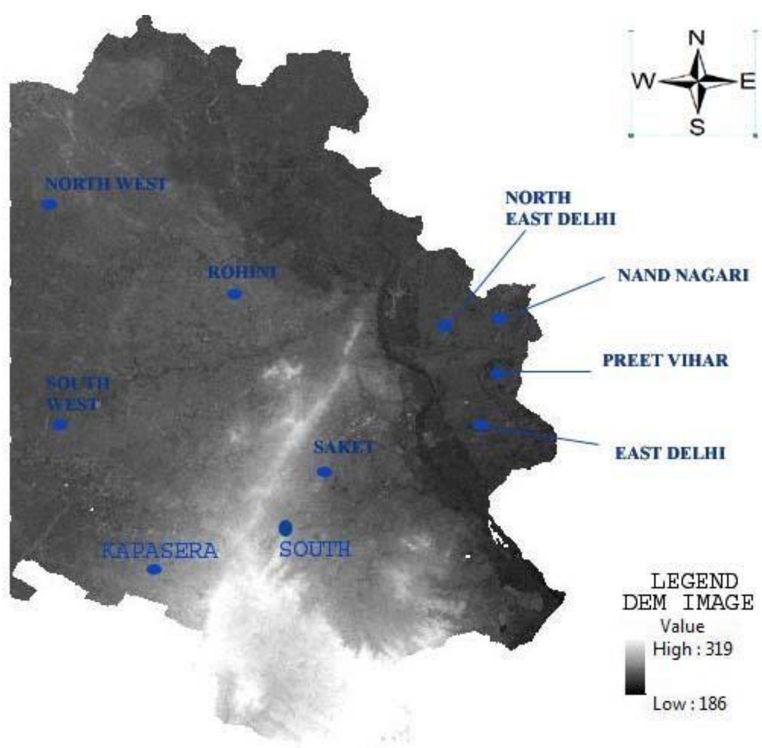

Figure5.1: Delhi Digital Elevation Model (Lat 28^{o}24’15N’- Lon 77^{o}20’30”E)
Source: (Global Land Cover Facility Site)

5.1.2 Flow Direction image:

It is very important to create a flow direction map for study area. Flow direction represents direction of each cell to its steepest down slope neighbor. This helps in obtaining results with minimum error. Flow direction helps to calculate accumulated flow at each cell in the area. Cell is an area which has same direction of flow. The output of the Flow Direction tool is an integer raster whose values range from 1 to 255. Flow direction image are the 2nd step to create stream. First SRTM data is selected, then with the help of hydrological tool, such as 'fill' tool, flow accumulation is calculated then using flow accumulation we get flow direction is calculated. Select **Spatial Analyst Tools → Hydrology → Flow Direction**. Set the input surface raster as fill image and output surface raster as flow direction image.

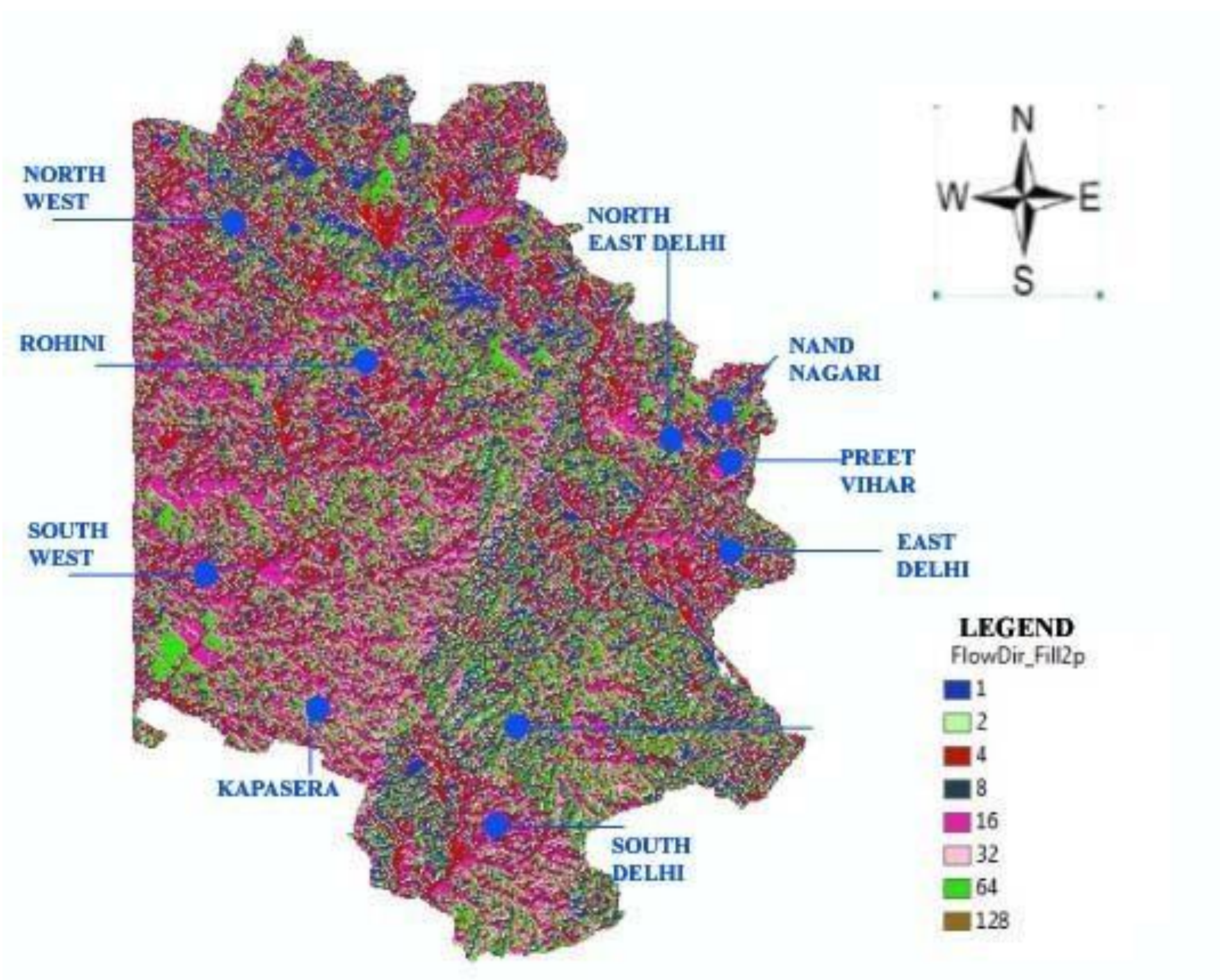

Figure5.2 Flow Direction Map Delhi region, (Lat 28°24'15N'- Lon 77°20'30"E),Source: (Global Land Cover Facility Site)

5.1.3 Fill Image of DEM Data:

Fills sinks in a surface raster to remove small imperfections in the data. Sinks are often errors due to the resolution of the data or rounding of elevations to the nearest integer value. Sinks should be filled to ensure proper delineation of basins and streams. If the sinks in the pixels are not filled, a derived drainage network may be discontinuous. The tool iterates until all sinks within the specified z limit are filled. As sinks are filled, others can be created at the boundaries of the filled areas, which are removed in the next iteration. Process Select **Spatial Analyst Tools → Hydrology → Fill**. Set the input surface raster as DEM map and output surface raster as fill image.

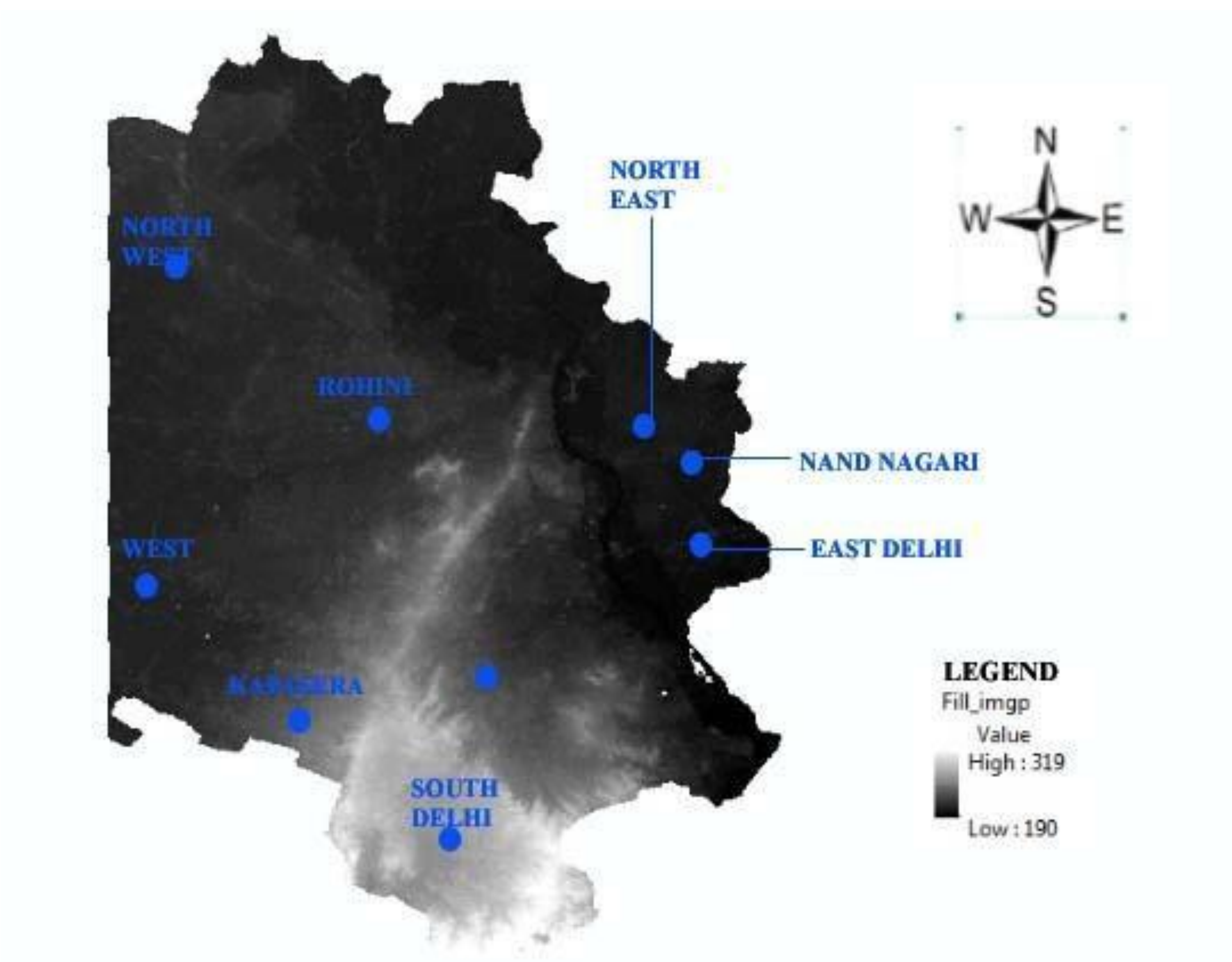

Figure5.3 Fill image of the watershed of Delhi region.

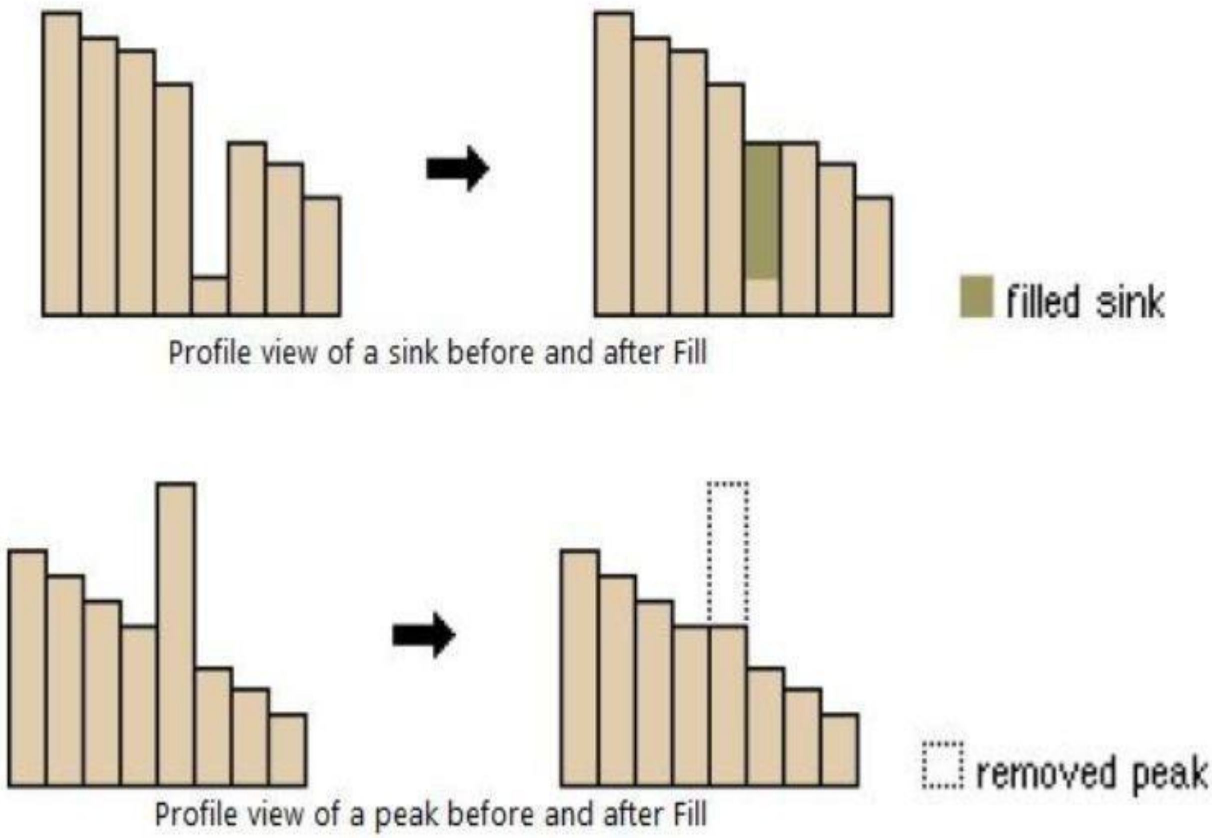

Figure 5.4 Profile view of pixels before and after Fill

5.1.4 Flow Accumulation:

The Flow Accumulation is the accumulated weight of all cells flowing into each down slope cell in the raster. A weight factor can optionally be applied. The result of Flow Accumulation is a raster of accumulated flow to each cell, as determined by accumulating the weight for all cells that flow into each downslope cell. The accumulated flow is based on the number of cells flowing into each cell in the output raster. Output cells with a high flow accumulation are areas of concentrated flow and can be used to identify stream channels. Select **Spatial Analyst Tools → Hydrology → Flow Accumulation** . Set the input surface raster as flow direction and output surface raster as flow accumulation image.

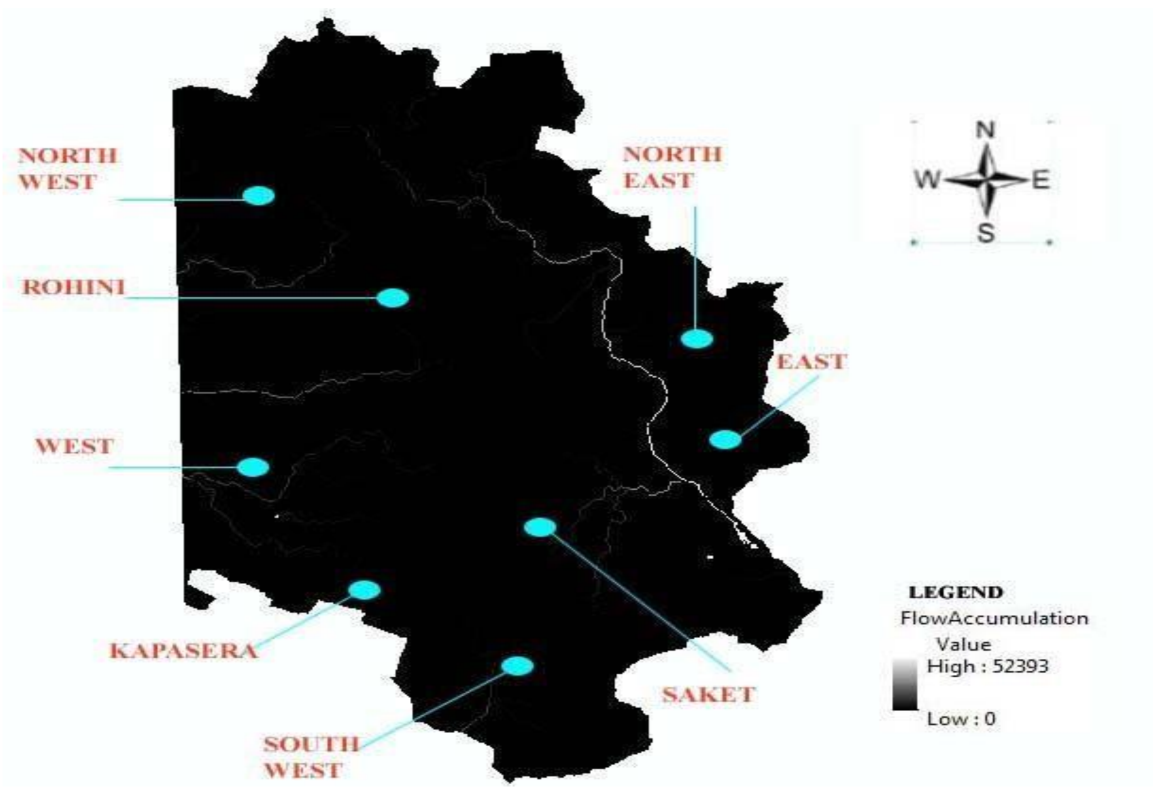

Figure5.5: Flow Accumulation map of Delhi region.

The Flow direction operation determines the natural drainage direction for every pixel in a Digital Elevation Model (DEM). Based on the output Flow direction map, the Flow accumulation operation counts the total number of pixels that will drain into outlets.
For example, the matrices shown below briefs the method of calculation of flow accumulated according to stream order. For this, DEM data is converted into flow direction map, then the calculation for flow accumulated is done.

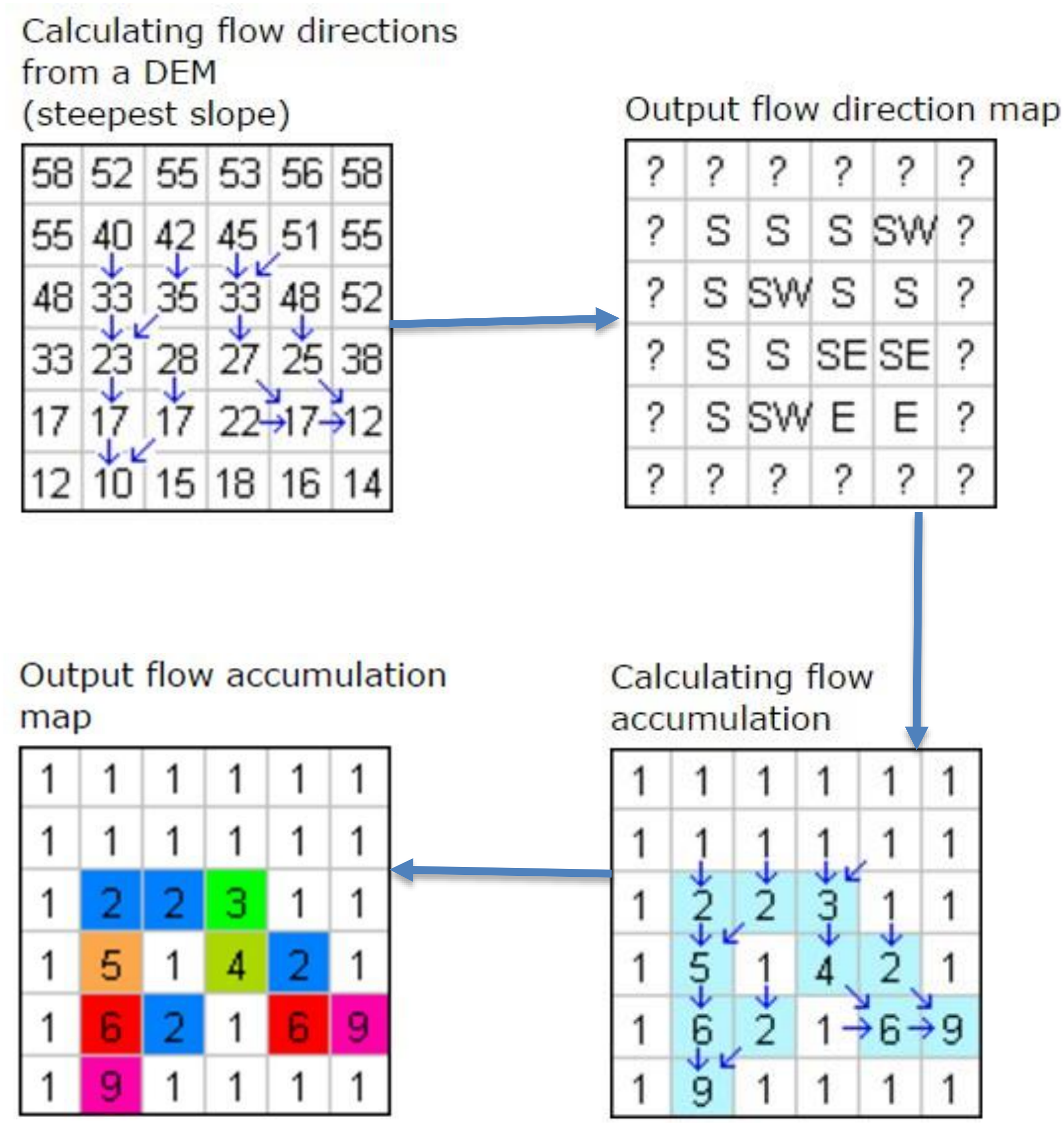

Figure5.6: flow diagram of calculation of accumulation flow

5.1.5 Stream Link:

Assigns unique values to sections of a raster linear network between intersections. Links are the sections of a stream channel connecting two successive junctions, a junction and the outlet, or a junction and the drainage divide. The input stream raster can be created by thresholding the results of the Flow Accumulation tool. Select **Spatial Analyst Tools → Hydrology → Stream Link.** . Set the input surface raster as flow direction and output surface raster as stream link image.

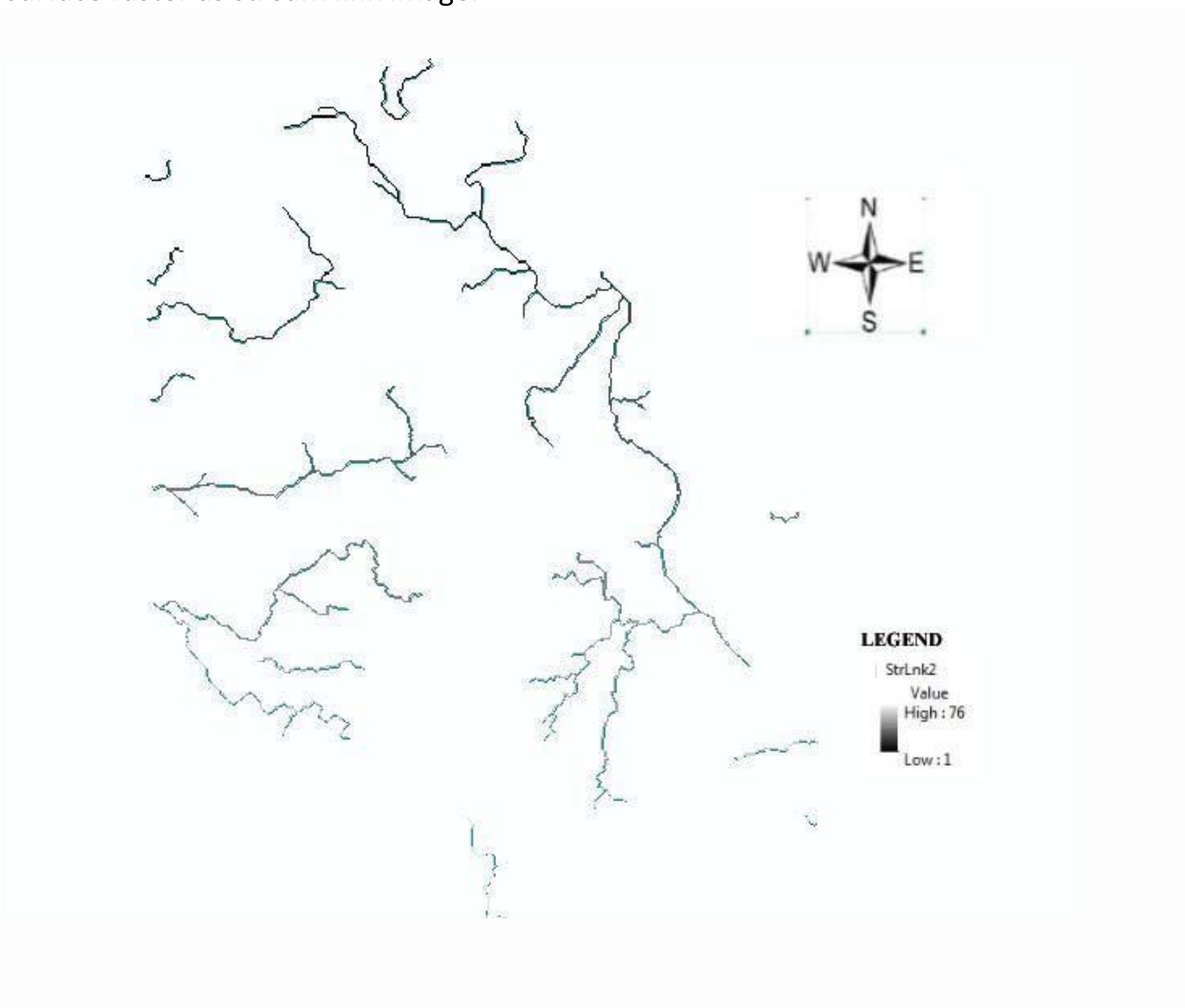

Figure5.7: Stream link Flow map of Delhi region.

5.1.6 Stream Order:

Assigns a numeric order to segments of a raster representing branches of a linear network. The output of Stream Order will be of higher quality if the input stream raster and input flow direction raster are derived from the same surface. If the stream raster is derived from a rasterized streams dataset, the output may not be usable because, on a cell-by-cell basis, the direction will not correspond with the location of stream cells.

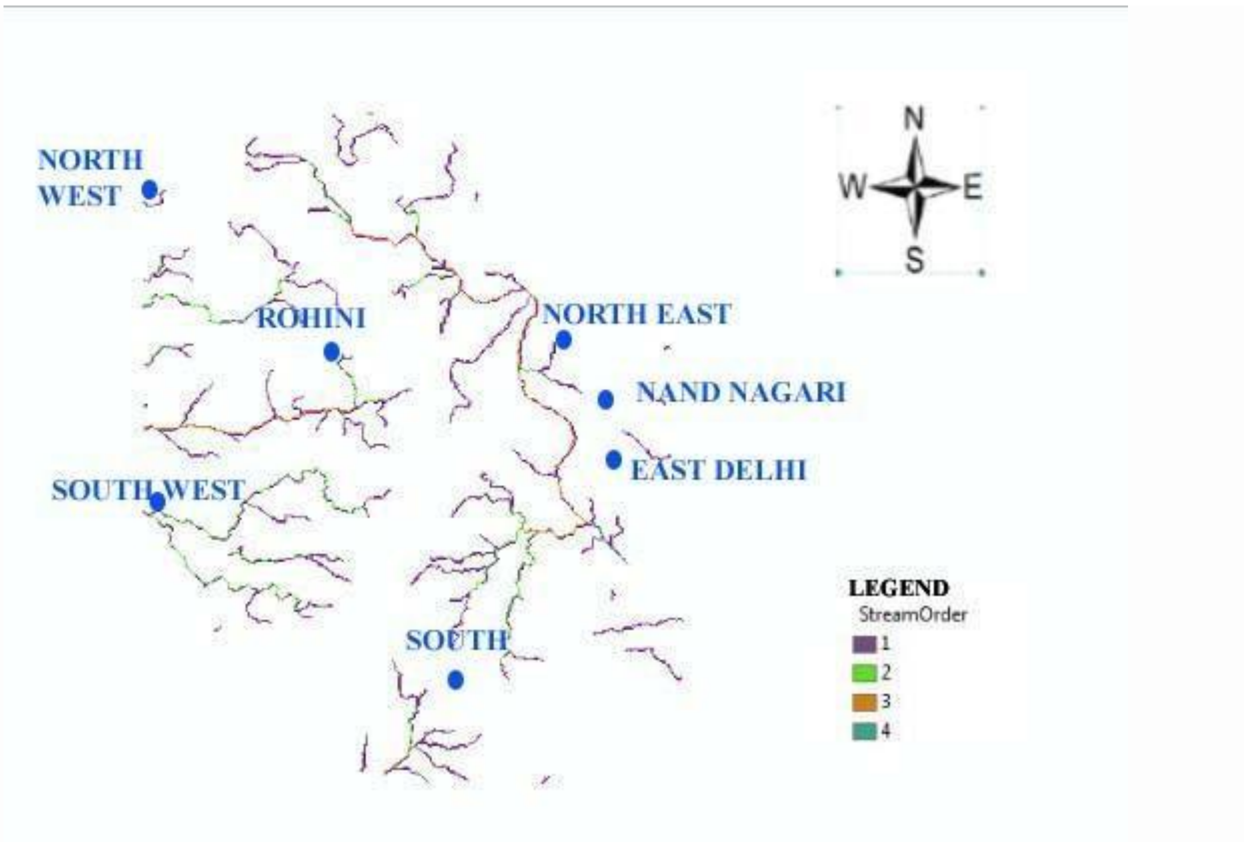

Figure5.8: Stream order map of Delhi region.

Stream order map was prepared with the help of DEM analysis in ArcGIS. Spatial analyst tool is being applied for extracting the stream lines and stream order tool is utilized to derive the order of the stream lines. As per the GIS analysis stream order ranges from 1st order to 7th order. Drainage ordering represent the number of streams presents in each order defined i.e. 1, 2,3,4,5 and 6 stream orders. 2nd , 3rd or 4th order streams are suitable for Storage Tank and Percolation Tank. 4th, 5th or 6th order streams are suitable for Check Dams. 3rd or 4th order streams are suitable for Stop Dams.

Table 3. Stream order

Sl No	**Stream Order**
1	1st Order
2	2nd Order
3	3rd Order
4	4th Order

5.1.7 Watershed:

A watershed is the upslope area that contributes flow generally water to a common outlet as concentrated drainage. It can be part of a larger watershed and can also contain smaller watersheds, called sub basins. The boundaries between watersheds are termed drainage divides. The outlet, or pour point, is the point on the surface at which water flows out of an area. It is the lowest point along the boundary of a watershed. Select **Spatial Analyst Tools → Hydrology → Watershed** . Set the input surface raster as flow direction image and output surface raster as watershed image.

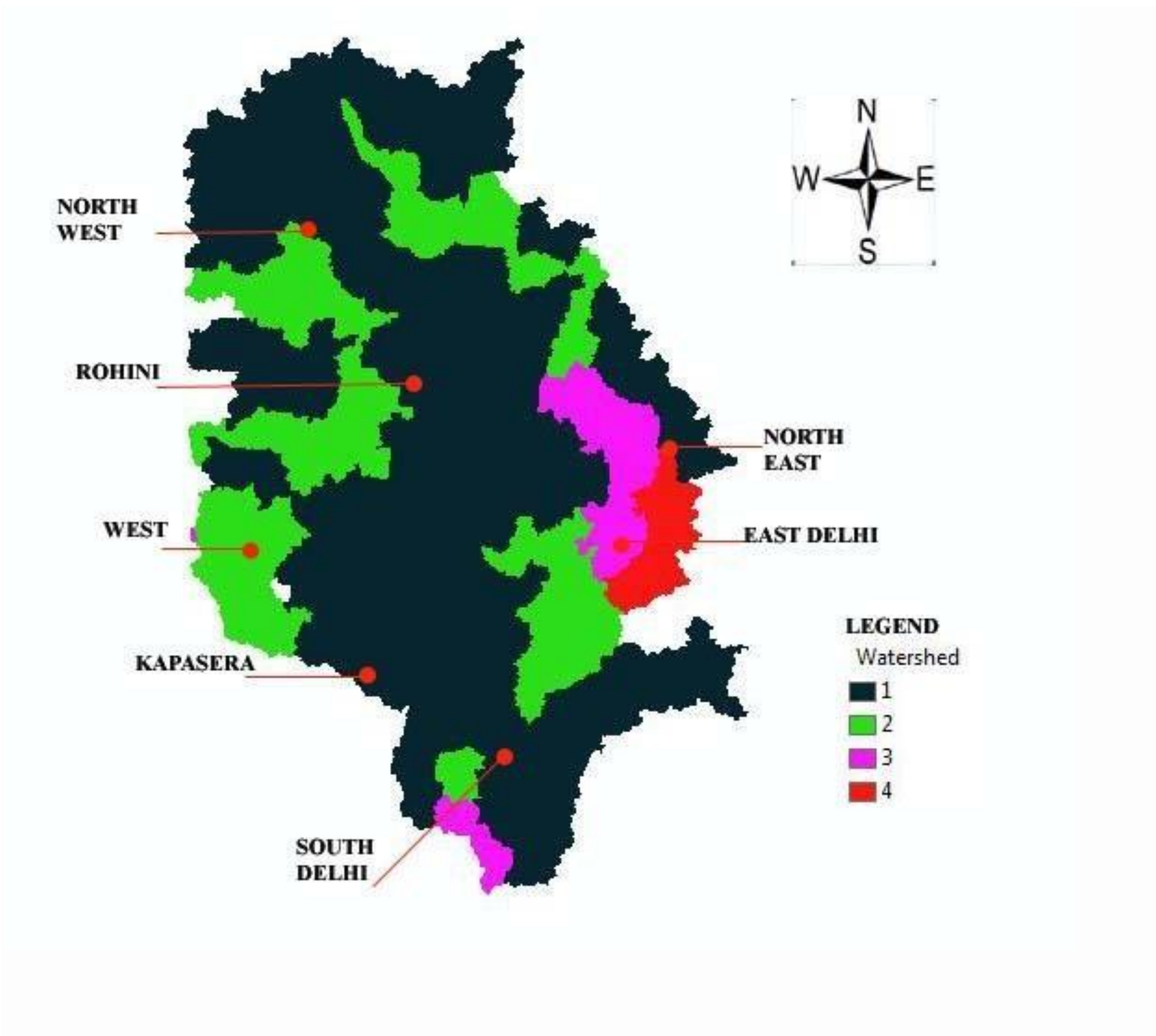

Figure5.9: watershed map of Delhi region.

5.1.8 Slope map:

For each cell, the Slope tool calculates the maximum rate of change in value from that cell to its neighbors. Basically, the maximum change in elevation over the distance between the cell and its eight neighbors identifies the steepest downhill descent from the cell. The output slope raster can be calculated in two types of units, degrees or percent (percent rise). The percent rise can be better understood to slope area. In the figure the slope calculated is percentage.

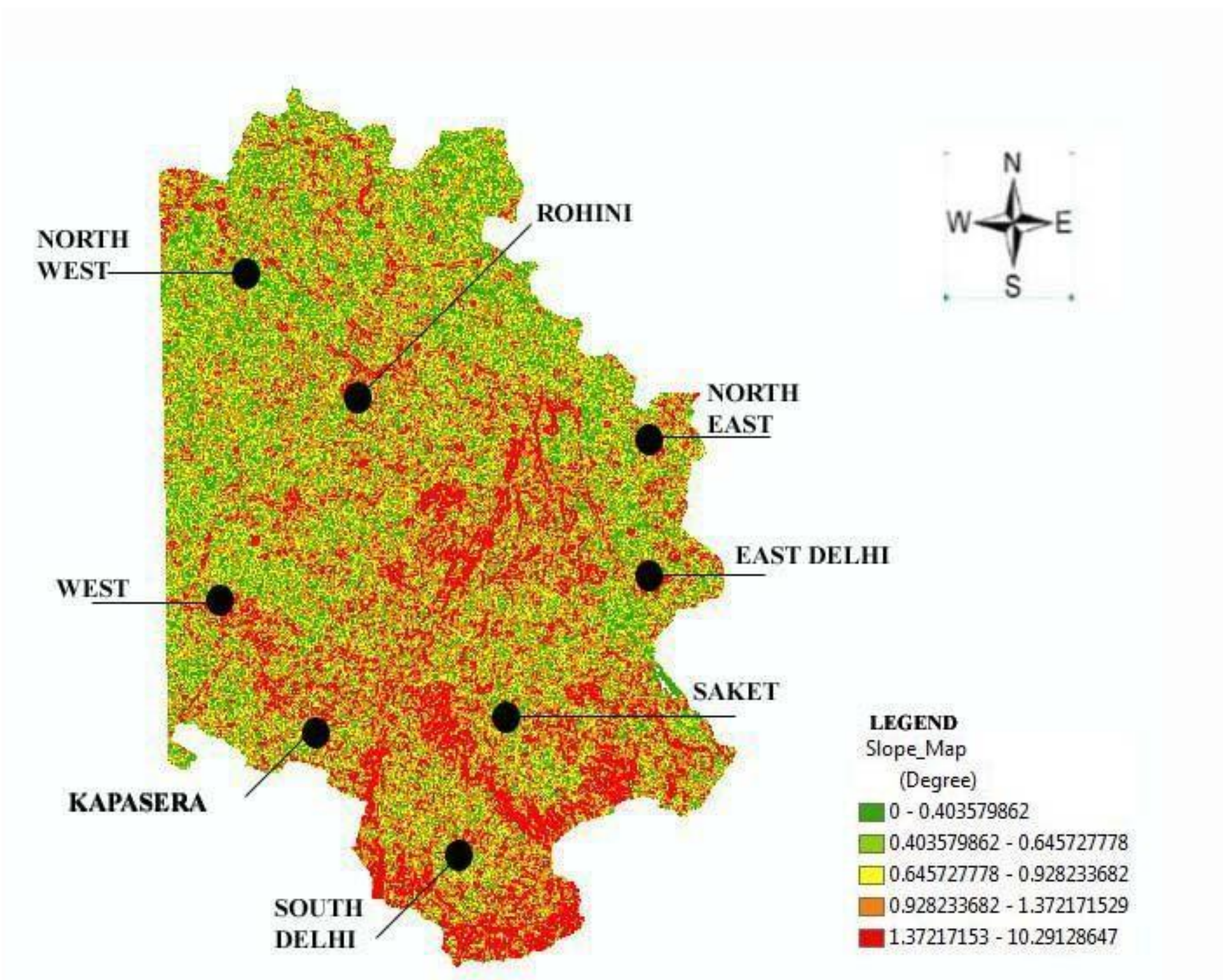

Figure5.10: Slope map of study area Delhi.

The slope map will be derived from the DEM into following categories

Table 4. Slope Category

Sl No	**Slope Category**	**Slope %**
1	Nearly Level	0-0.1
2	Very Gently Sloping	0.1-2
3	Gently Sloping	2-10
4	Moderately Sloping	10-13
5	Steep Sloping	13-21
6	Very Steep sloping	21-27
7	Extremely steep	27-28

5.1.9. Land use/Land Cover output map:

Land use/Land Cover map presents multiple levels of land cover classifications for the continental Delhi States based on Landsat TM 2000 satellite imagery.

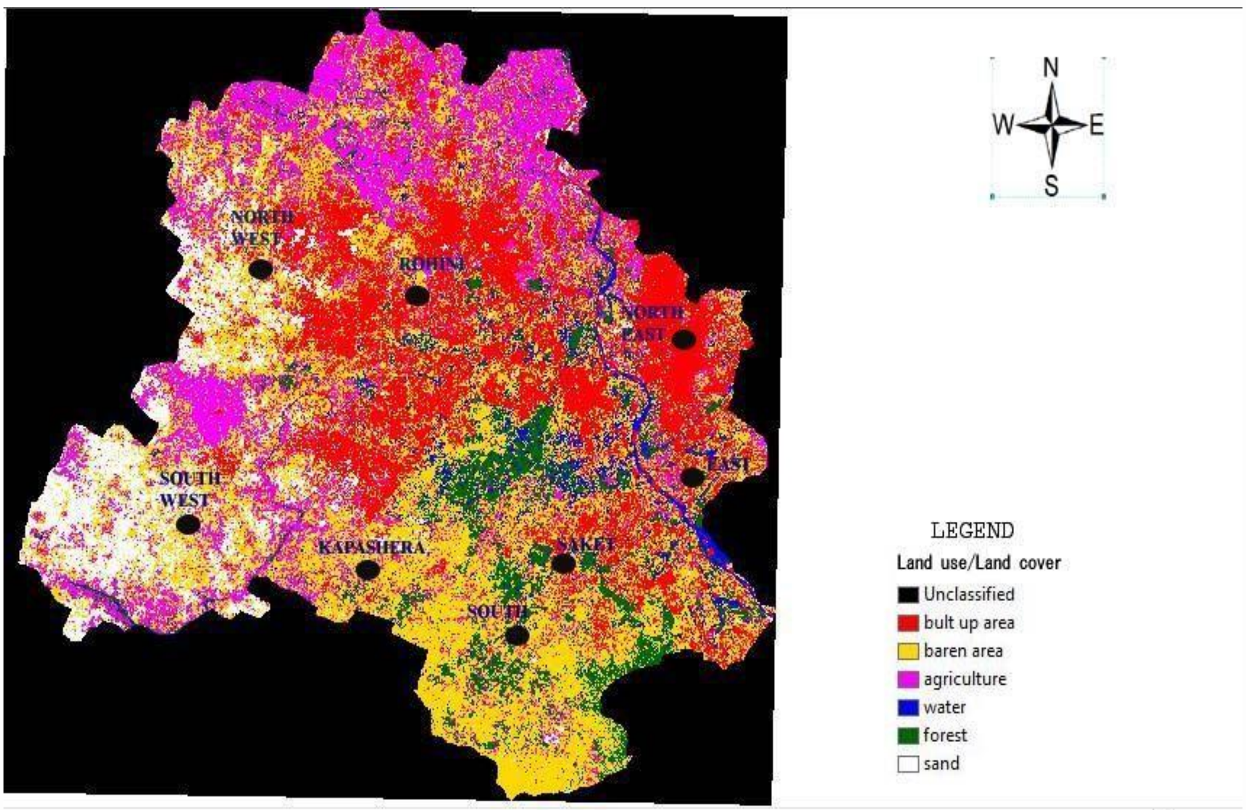

Figure5.11: Land use/Land Cover Map of Delhi region. Source: (Global Land Cover-Facility Site)

5.1.10 .Land use/Land cover Classes in study area

These classes are obtained after supervised classification of LANDSAT ETM+ data using ERDAS Imagine 9.1 from attribute table of the output of the classification process.

Table 5

Sl No	Land use Type Land cover Type	Area(sq.m) 2000
1	BUILTUP AREA	38548
2	WATER	24757
3	FOREST	18539
4	AGRICULTURE	52765
5	BARREN AREA	84335
6	SAND	17513
	TOTAL	236457

5.1.11 Suitability Map:

The suitability map shows two classes of Delhi region such as 1 less suitable and 2 more suitable.

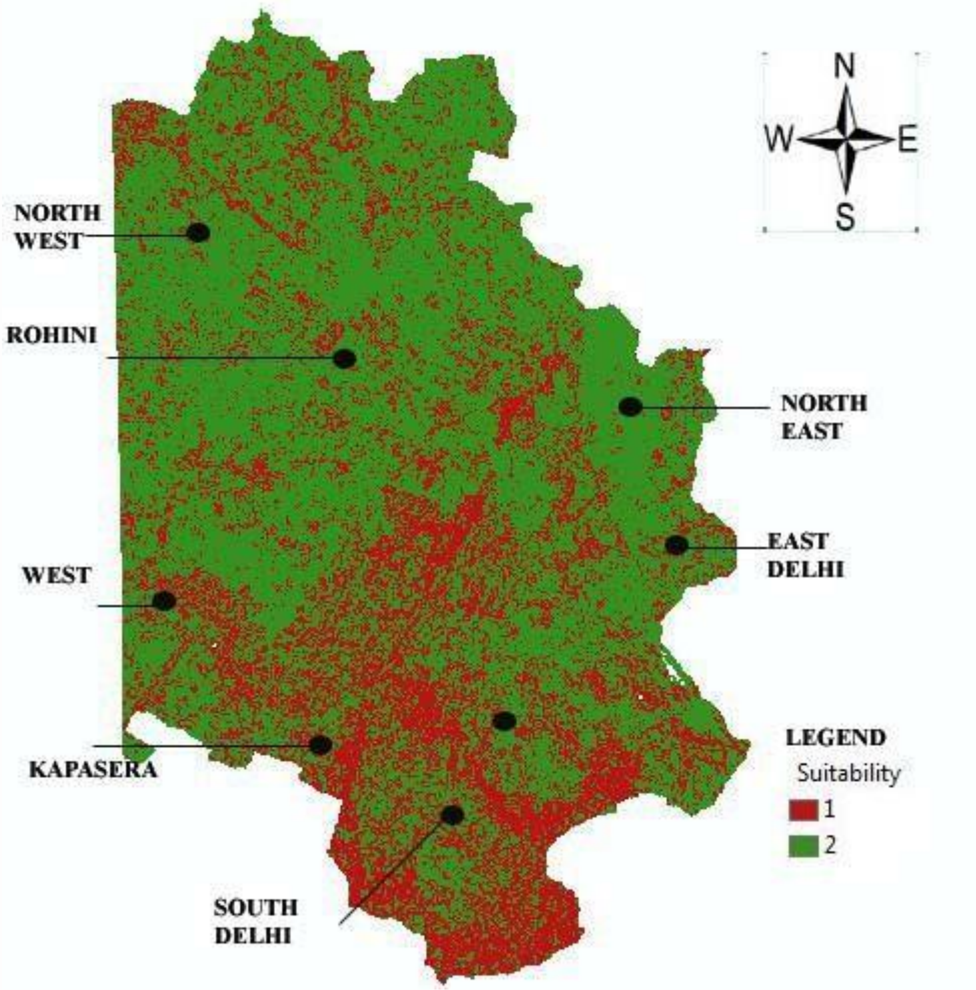

Figure5.12: Suitability map of Delhi region

From the above suitability index, level 1 is less suitable for suitability analysis, whereas, level 2 is more suitable for rain water harvesting site.

5.1.12 Most Suitable Site:

Finally most suitable area shown in figure below. In this study, five most suitable area and two suitable areas are found. All suitable and most suitable area shown in figure.

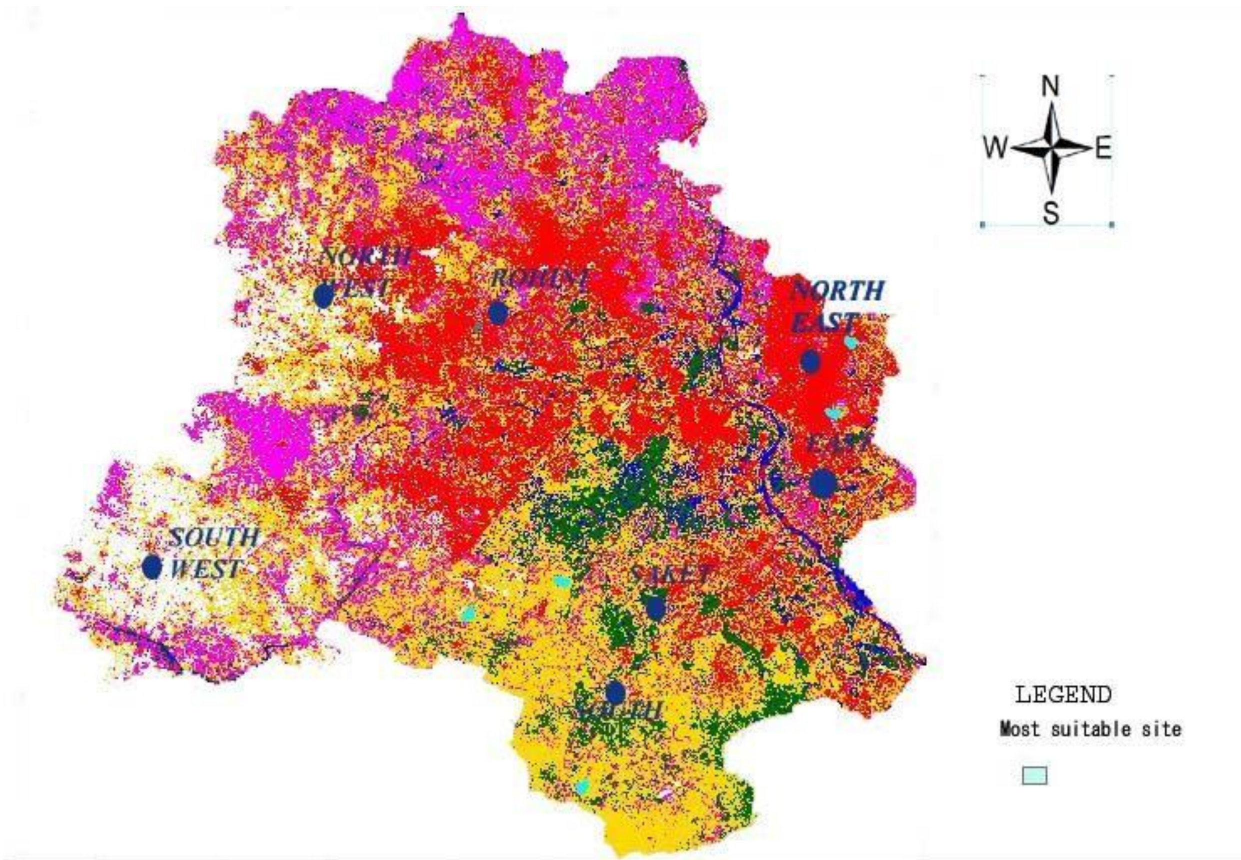

Figure5.13: Most Suitable Map of Delhi region.

5.2 Result Comparison with Delhi Jal Board study for rainwater harvesting in Delhi region

Delhi Jal Board conducted study to setup rain centers to promote rainwater harvesting to fulfill the requirement of water in Delhi region and replenish the falling water table. DJB published an article in Hindustan Times on July 29, 2016 as stated there are three rain centers in Delhi – R K Puram, Dwarka and Lajpat Nagar. The plan is to open many more in the coming six months. The Delhi Jal Board has made it mandatory for owners of properties built on an area of more than 500 metre squares to install a water harvesting system. Delhi gets an average of 611 mm of rain in a year. The Delhi Jal board conducted a study for suitable site for rain water harvesting. My result match with the study with suitable site no. 1, 11, 15 and 17 which are Preet Vihar, Seemapuri, Hauz Khas and Vasant Kunj.

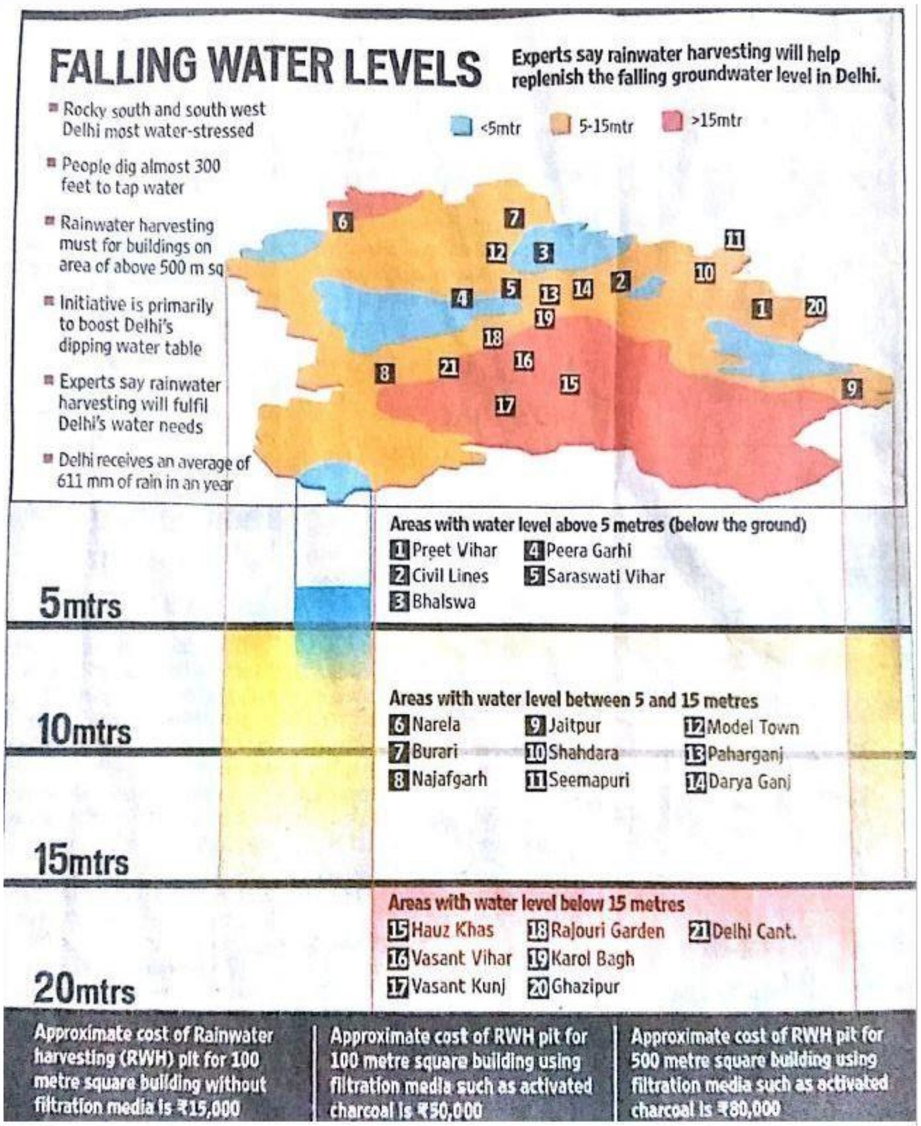

Figure5.14: Result of Delhi Jal Board study

CHAPTER 7
CONCLUSION

The multi-layer integration through Land use /Land cover, slope, stream order, gave the suitability of sites for identifying the rainwater harvesting sites. These layers were combined in ArcGIS using weighted overlay tool. A final map was generated which provide us the suitable and most suitable location for rainwater harvesting sites, as per the criteria laid by IMSD. Figure5.12 & Figure5.13 show the suitability and most suitable map for location of rainwater harvesting sites. There are about 2 suitable and 5 most suitable numbers of sites identified, which are highly suitable for creating water storage structures. Suitable and most suitable areas identified in Delhi region are located at south Delhi, North east Delhi, East Delhi and South west Delhi.

As per the slope and soil texture map following suggestions are made for rain water harvesting structures at the suitable sites of Delhi region.

1. **North East Delhi-** Loni is the most suitable site in this region. It is suggested to construct Farm ponds, bore wells and dug wells at this location. The soil here is sandy loam and due to low slope it is more suitable for construction of farm ponds/percolation tank.

2. **South Delhi-**Aya Nagar extension is the most suitable site in this region. Due to presence of sandy clay loam soil, low slope of <10% and high ground water depth. As the area is barren land it is suggested to construct check dams and dug wells in this area.

3. **South West Delhi-**Samalkha and Jindal Colony, Kapasera is the most suitable site in this region. Construction of dug wells is suggested in this area. Due to low slope and presence of sandy loam soil it is found suitable for dug wells.

4. **East Delhi-**Kiran Vihar and Karkardooma is the most suitable site in this region. It is suggested to construct dug/bore wells in this area. The presence of sandy loam soil and gentle slope (<10%) this area is found suitable for dug/bore wells.

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