USE OF GIS & REMOTE SENSING TECHNIQUES FOR ASSESSING RAINWATER HARVESTING POTENTIAL

A DISSERTATION
Submitted in partial fulfilment of the
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of
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in
HYDROLOGY

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in dissertation entitled "USE OF GIS & REMOTE SENSING TECHNIQUES FOR ASSESSING RAINWATER HARVESTING POTENTIAL" in partial fulfillment of the requirement for the award of the Degree of Masters of Technology in Hydrology, submitted to the Department of Hydrology (DOH), Indian Institute of Technology, Roorkee, Uttaranchal, is an authentic record of my work carried out during the period from July 2005 to June 2006 under the supervision and guidance of Dr. RANVIR SINGH and Dr. P.K. GARG.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

Date: June 30, 2006

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This is to certify that the above declaration given by the candidate is correct to the best of our knowledge.

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ABSTRACT

Assessing, managing and planning of water resources for sustainable use has become a crucial issue in recent times. There is an obvious need for proper understanding of the hydrological processes in the watershed. Rainfall-runoff relationship plays an important role in understanding the dynamic aspects of the hydrological processes that take place in any region. Harvesting of available runoff at a micro-level for storage and recycling is necessary for better utilization of rainfall, control of erosion and providing life saving irrigation to crops during dry spells in the monsoon season and also for growing a second crop in the Rabi season.

In areas under rain fed agriculture, a small additional increment of harvesting water can dramatically increase crop yields and lower the risk of crop failure. Sometimes, it can make a difference between crop and no crop in drought prone areas. The objective and technologies of rain water harvesting are highly location specific and an appropriate technology developed for a particular region cannot be used as such for other areas due to physiographic, environmental, technical and socio-economic reasons. As far as water harvesting is concerned, technologies are not based on annual rainfall only, but terrain, soil permeability, landuse and its variation in space and time also play an important role in determining the sites. Integration of Remote Sensing and Geographical Information System (GIS) Techniques provides reliable, accurate and up-to-date database on land and water resources, which is a pre-requisite for an integrated approach in identifying potential runoff zones and suitable sites for water harvesting structures such as check dams, farm ponds, percolation tanks and bundies etc

Hydrologic information is needed for watershed management planning, analysis and design of water resource projects and for making landuse impact assessment. Sometimes adequate hydrologic, meteorological and biophysical data are not available at locations of interest and even when data are available, deciding the most appropriate method to use can be difficult. Selecting the appropriate hydrological method requires careful consideration of following:

1. The type and accuracy of information and data available
2. The physical and bio-geological characteristics of watershed.
3. The technical capabilities of the individual performing the study

4. The time and economic constraints

The watershed selected for present study is Dehradun watershed in Dehradun district, the interim capital of the new-born state of Uttaranchal, where the burgeoning population pressure is posing ever-increasing water demands. The results indicate that Rajpur and MDDA park are amongst the areas with potential recharge capabilities. Details of roof top water harvesting plan are also indicated.

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CHAPTER ONE

INTRODUCTION

1.0 General

Inspite of astonishing achievements in the field of science and technology, nature remains to be a mystery for human beings. Though water is being obtained through desalination, artificial rain by cloud seeding etc. the shortage of water even for drinking purpose is a perpetual phenomenon throughout the world, especially in developing and underdeveloped countries.

In most of the cities, the water supply sector is facing a number of problems and constraints. The pace of watershed (urban & rural) development and the increase in population in the watershed have resulted in exploitation of water resources to the extremes. Fresh water sources are being heavily exploited to meet the demands of watershed populace. Failure of monsoon makes the situation even worse. As surface water sources fail to meet the ever increasing demands, ground water reserves are tapped, often to unsustainable levels. Also fast rate of urbanization reduces the availability of open spaces for natural re-charge of rain water. Some city (like Chennai) and its suburban areas often get affected with water scarcity during the periods of low rainfall. As the dependence of ground water increases during such periods the ground water table depletes faster than normal rate resulting in dry wells. In addition to quantity, we also face problems of water quality is also faced due to over extraction of ground water. Unplanned and uncontrolled extraction of ground water would disturbs the hydrological balance along the coastal areas which results in possible sea water intrusion. Hence, it is necessary to take up measures to conserve and augment the renewable water resources in all possible ways. Ground water recharge by rain water harvesting (RWH) is the simple and cost effective way.

Rainwater harvesting can not only provide a source of water to increase water supplies but also involves the public in water management, making water management everybody's business. It will reduce the demand of the institutions to meet water needs of the people. It would also help everyone to internalize the full costs of their water requirements, thus encouraging people to be more conscious of their water demands and thus using water more sensibly. Rainwater harvesting is useful in areas, like Dehradun where water moves downstream as soon as it falls on the ground. The upstream areas have comparative less storage of water than the downstream portions. So, rainwater harvesting may be an effective tool for storing the water for individual uses.

1.1 Rainwater Harvesting and its Utility

Rainwater harvesting is the process of collecting, storing and conserving rainwater wherever it falls. There are two classification of rainwater harvesting from rooftops and rainwater harvesting from open areas. Rainwater harvesting although it is an old practice, can be a solution to water supply problem in rural and urban areas. Collected rainwater from roofs of the building can be used directly for domestic purposes or it can be used to recharge groundwater reservoir. Rainwater recharge pits in New Delhi help in improving the groundwater level and eliminate flooding of streets (Sinha, 2002). Rainwater harvested from open grounds can be used for irrigation, animal use and recharging groundwater.

1.2 Need of GIS in Rainwater Harvesting

Rainwater harvesting is an integral part of watershed management. Whereas, watershed management deals with coordinated use of land and water resources, management of these resources requires reliable information concerning variety of details. Geographical data, such as water bodies, buildings, road networks, dams, drainage, etc., with their corresponding attributes may be obtained from maps, ground information, aerial photographs, and satellite imageries for analysis and modelling of rainwater harvesting and watershed management. The management of such large volumes of spatial data requires a computer-based system called GIS which can be used for solving complex geographical and hydrological problems (Garg, 1991). In general practice, GIS is an automatic mapping tool which converts maps and other kinds of spatial data quickly which otherwise is time consuming and expensive if manual techniques are used. The major advantage of GIS is that it is an information system, therefore, the digital database which has been developed at any stage can also be used in future and any related information can be retrieved conveniently and effectively.

1.3 Scope of the Study

The scope of the study is limited to assess rainwater harvesting potential through rooftop for domestic use. For conceptual understanding, some of the basic principles of GIS are reviewed and the basic principles are discussed. A highlight of present trend of GIS as management tool and the possibilities of integrating resources models with GIS through Decision Support System (DSS) are also discussed. The reports collected from Jal Sansthan and Jal Nigam, Dehradun, topographic maps and guide map obtained from Survey of India served as the main data input for the present study.

Considering the existing water system of the study area, water sources, population, water demand, rainfall data and water deficit are assessed. The final results of the analysis are presented in the form of images and tables along with concluding remarks. Detailed design of water harvesting structures based on various classification and criteria being developed along with economical consideration is also incorporated in this dissertation.

1.4 Objectives of the Study

The emergent GIS technology has been gaining popularity in its wide range of application and capability of organizing, storing, editing, analyzing and displaying large volume of information which is referenced to geographic location and its attributes. The recent effort trying to integrate GIS and resource models into tight-coupled system in a way where both can interact directly, laid a ground for better resource planning and management decision-making. To attain the desired benefits from this new technology, it requires the conceptual understanding of the system.

The objectives of this study are:

(i) To show the potential capabilities of GIS in general, for rainwater harvesting.

(ii) To show how predictive runoff can be modelled in GIS.

(iii) To assess the runoff producing potential and accumulation of runoff for different land use/land cover.

(iv) To augment the water requirement through rooftop rainwater harvesting techniques.

(v) To identify the priority area for rainwater harvesting as per extent of water shortage

(vi) To obtain the appropriate techniques of engineering measures for catchments protection on prevailing condition in the target area through GIS modeling.

(vii) To develop a criteria for design of water harvesting structures in a most economical way.

1.5 Methodology used in this Study

The following steps have been undertaken to identify the site suitability for watershed and Rooftop harvesting for Dehradun city. The broad methodology has been given in Fig. 1.1

1. Data collection
2. Creation of different thematic layers in GIS
3. Data integration GIS
4. Preparation of landuse /landcover map from remote sensing
5. Assessment of rooftop rainwater quantity for harvesting
6. Remote sensing and GIS based estimation of runoff at watershed level
7. Identification of suitable rooftop harvesting
8. Remote sensing and GIS based selection of sites for rainwater harvesting at watershed level

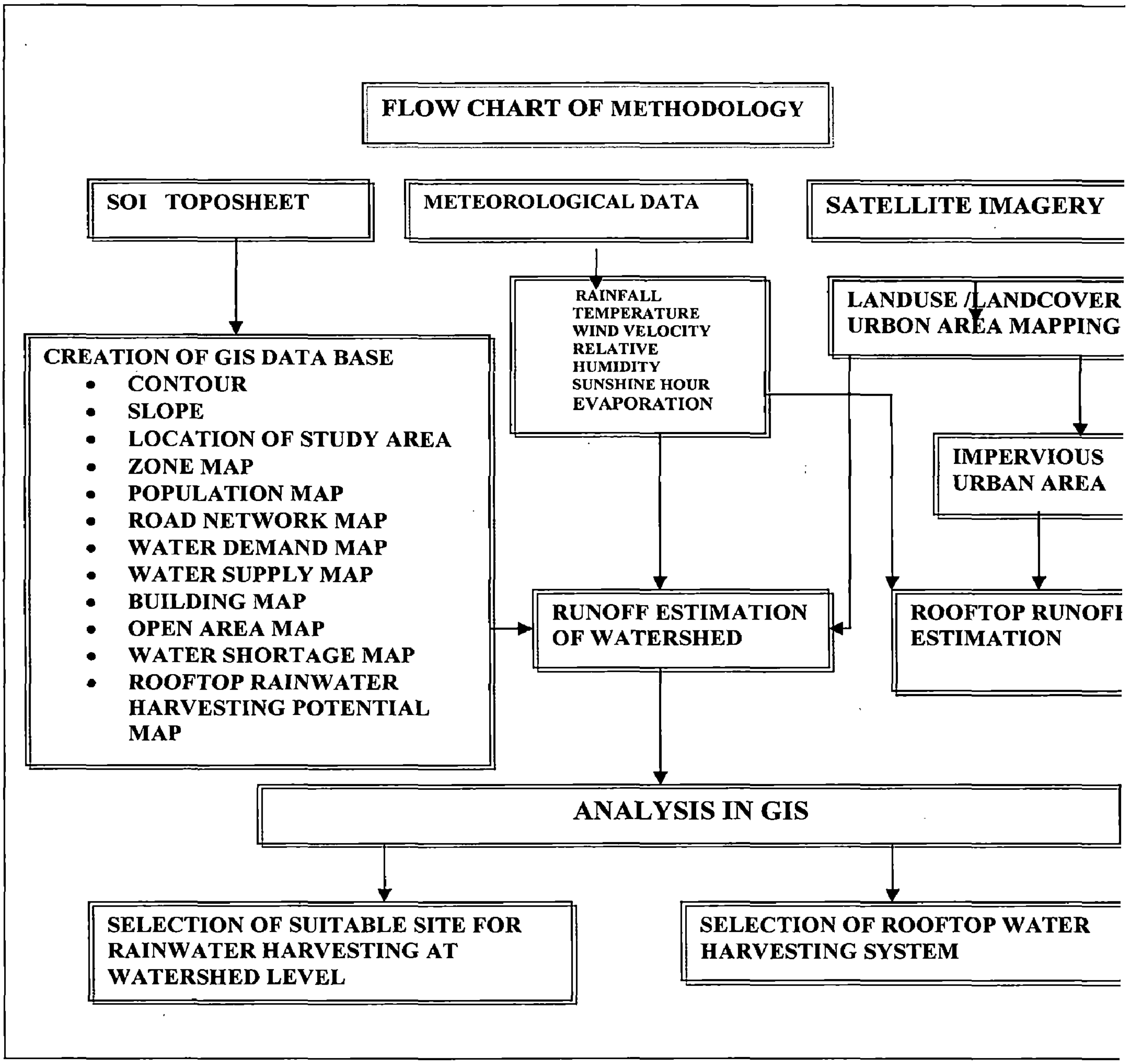

Fig.1 Broad Methodology for Rainwater Harvesting Site Suitability

1.7 Organization of the thesis

Chapter 2 deals with the literature review; it highlights the discussion of different water harvesting techniques and various methods of rainwater harvesting techniques.

Chapter 3 deals with the details of study area of the Dehradun watershed. It covers historical background, physiographic, climate, temperature, urbanization and socio economic growth etc.

Chapter 4 describes briefly the salient features of GIS study area.

Chapter 5 Deal with the water availability senior of Dehradun

Chapter 6 Deals with GIS study of rainwater harvesting, methodology, software used and data analysis.

Chapter 7 Deals with the site suitability analysis

Chapter 8 deals with analysis and design criteria of rooftop rainwater harvesting structures.

Chapter 9 covers the discussion, conclusions and scope of future work.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

Water is most precious natural and universal asset. Water provides life support system for human being, vegetation and animals. It is also a vital part of socio-economic system. Rainwater harvesting, though an old age practice, is an emerging paradigm in water resource development and management. Both government and non-government organizations have recently stepped up their efforts in water harvesting and watershed management activities following participatory approach. Rainwater harvesting systems are relatively more equitable and environmentally sound. Water resources generated locally provide benefits to the local community and minimize social conflicts. Participatory management of harvested water resources ensures effective utilization of the system.

2.2 Classification of Rainwater Harvesting

The rainwater harvesting can be classified into two ways:

2.2.1 Rooftop Rainwater Harvesting

Rooftop rainwater harvesting can be used for (a) domestic needs (Fig.2.1) and (b) recharging groundwater (Figs.2.2 and 2.3).

(I) Rooftop Rainwater Harvesting for Domestic Needs (Rainwater Cistern System)

Rainwater cistern is the system of collecting and storing rainwater from rooftop in small tanks or vessels underground or above the ground. Though the system is recommended in areas of high rainfall well distributed over the years, it is commonly practiced in many arid and semi-arid regions as well. This is ideal in regions where ground water supply is inadequate and surface sources are either lacking or insufficient. Rainwater is bacteriologically pure, free from organic matter and soft in nature. The actual design of the system depends on system cost, amount of rain to be collected, expectations and needs of the owners and level of external support (Gould 1991). The volume of rain and its distribution over the year depends upon the size of the catchment area and the

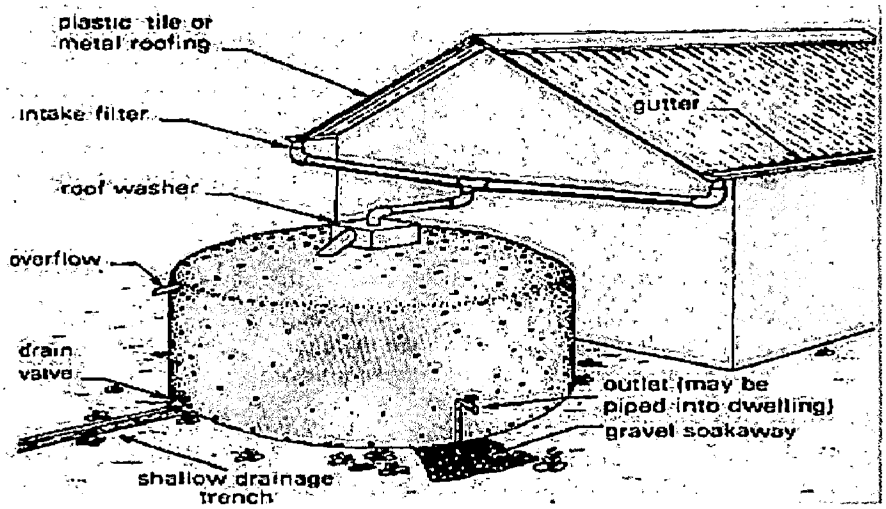

Fig.2.1: Rooftop Rainwater Harvesting for Domestic Needs

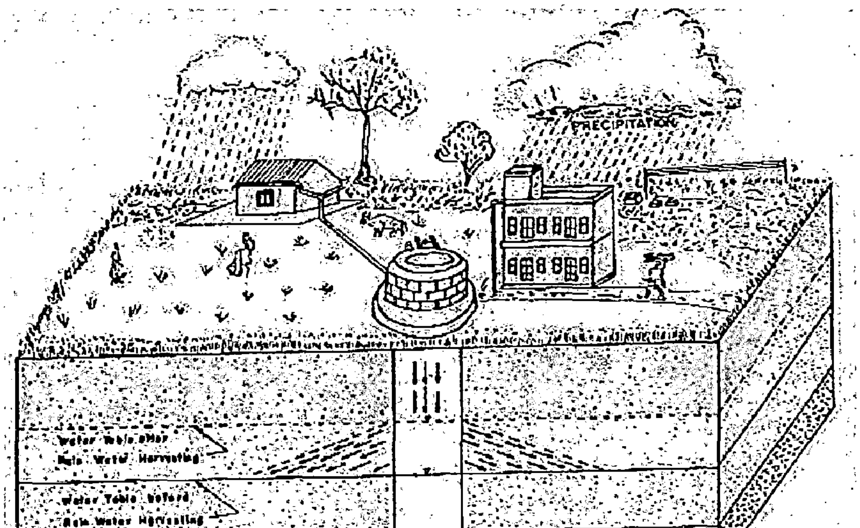

Fig.2.2: Rooftop Rainwater Harvesting for Groundwater Recharge

projected supply ultimately determine the size of the tank (Rathore, 1988). The capacity of the tank is calculated as:

Capacity = (Number of days x number of people x consumption level per capita per day) + evaporation losses

The necessary catchment area can be determined by dividing the tank volume with the accumulated average rainfall volume per m^2 over the preceding wet months, multiplied with runoff coefficient. The runoff coefficient for galvanized iron or tiled roofs can be taken as 0.80 (Michaelides et al., 1986). The roof should be smooth, made of non-toxic substances and sufficiently large to fill the tank with the available rainfall. The gutter should have a uniform slope of 0.5% and sufficient capacity to collect the runoff from intense storms. The runoff from the few showers should be diverted away from the tank to prevent its pollution due to washing out of dust and bird droppings from the rooftop. The shape of the tank may be cylindrical, square or hemi-spherical and may be constructed from galvanized iron, brick, stone, masonry, reinforced concrete and ferrocement (Lee and Visshe r, 1992). Choice of a tank depends upon the availability of materials and spaces, and may be constructed underground or above the ground. When constructed underground, at least 30 cm of the tank should remain above ground. The quality and availability of water in the rooftop harvesting system depends on its periodic maintenance and disinfection.

(a) Design of Cistern System

The actual design of the system depends on system cost, amount of rain to be collected, expectations and needs of the owners, and level of external support. The design of rainwater cistern for domestic purpose considers the following:

- Matching the capacity of the tank to the area of the roof.
- Matching the capacity of the tank to the quantities of water required by its users
- Choosing a tank appropriate in terms of cost, resources and construction methods

The capacity of the tank is calculated as:

$$\text{Capacity } (Q) = (n \times q \times t) + e \qquad (2.1)$$

Where, n = number of persons

q = consumption level per capita per day, (lpcd)

t = number of days of dry period

e = evaporation losses from storage, (liters)

Runoff per unit roof area can be computed by multiplying total average rainfall over the preceding wet months or monsoon with the runoff coefficient (f) (0.80-0.90). The runoff coefficient for a hard roof is taken as 0.80. Table 2.1 gives the values for different roofing material. Availability of rainwater from different roof top area for a range of rainfall is given in Table 2.2, assuming runoff coefficient as 0.80. The required roof catchment area can be determined by dividing the tank volume (Q) with runoff volume per m^2.

Required roof catchment area (m^2) $A = Q/(f \times P)$ (2.2)

Where, P is rainfall in metrer

Types of Catchment	Coefficients
Roof Catchment	
Tiles	
- Corrugated metal sheet	0.80 - 0.90
	0.70 – 0.90
Ground Surface Coverings	
Concrete	
Plastic sheeting (gravel covered)	0.60 – 0.80
Butyl rubber	0.70 – 0.80
- Brick pavement	0.80 – 0.90
	0.50 – 0.60
Treated Ground Catchment	
Compacted and smoothed soil	
Clay/cow-dung threshing floors	0.30 – 0.50
Silicone-treated soil	0.50 – 0.60
Soil treated with sodium salts	0.50 – 0.80
Soil treated with paraffin wax	0.40 – 0.70
	0.60 – 0.90
Untreated Ground Catchment	
Soil on slopes less than 10 percent	
Rocky natural catchment	– 0.30
	0.20 – 0.50

Table 2.1: Runoff Coefficients for Different Roof Surface Conditions (Pacey and Cullis, 1986)

(b) Components of Rooftop Rainwater Harvesting System

Gutter: Gutter collects the rainwater runoff from the roof and conveys the water to the down pipe. Gutter may be constructed from plain galvanized iron sheets or of local material, such as bamboo, wood, etc. All gutters should have a mild slope (say around 0.50%) to avoid the formation of stagnant pools of water. Gutters with semi-circular cross-section of 60 mm radius are sufficiently large enough to carry away most of the inter-monsoon rainfall.

Table 2.2: Availability of Rainwater through Rooftop Rainwater Harvesting

Rainfall (mm)	100	200	300	400	600	800	1000	1200	1400	1600	1800	2000
Rooftop Area (m^2)	Harvested Water from Rooftop (m^3)											
20	1.6	3.2	4.8	6.4	9.6	12.8	16	19.2	22.4	25.6	28.8	32
30	2.4	4.8	7.2	9.6	14.4	19.2	24	28.8	33.6	38.4	43.2	48
40	3.2	6.4	9.6	12.8	19.2	25.6	32	38.4	44.8	51.2	57.6	64
50	4	8	12	16	24	32	40	48	56	64	72	80
60	4.8	9.6	14.4	19.2	28.8	38.4	48	57.6	67.2	76.8	86.4	96
70	5.6	11.2	16.8	22.4	33.6	44.8	56	67.2	78.4	89.6	101	112
80	6.4	12.8	19.2	25.6	38.4	51.2	64	76.8	89.6	102	115	128
90	7.2	14.4	21.6	28.8	43.2	57.6	72	86.4	101	115	130	144
100	8	16	24	32	48	64	80	96	112	128	144	160
150	12	24	36	48	72	96	120	144	168	192	216	240
200	16	32	48	64	96	128	160	192	224	256	288	320
250	20	40	60	80	120	160	200	240	280	320	360	400
300	24	48	72	96	144	192	240	288	336	384	432	480
400	32	64	96	128	192	256	320	384	448	512	576	640
500	40	80	120	160	240	320	400	480	560	640	720	800
1000	80	160	240	320	480	640	800	960	1120	1280	1440	1600
2000	160	320	480	640	960	1280	1600	1920	2240	2560	2880	3200
3000	240	480	720	960	1440	1920	2400	2880	3360	3840	4320	4800

Down pipe: A vertical down pipe of 100 to 150mm diameter may be required to convey the harvested rainwater to the storage tank. An inlet screen (wire mesh) to prevent entry of dry leaves and other debris into down pipe should be fitted.

Foul flush diversion: The first flush of water from the roof is likely to contain dust, dropping and debris collected on roof. This contaminated water should be diverted from the storage tank to avoid polluting the stored rainwater. Such a diversion can be achieved manually by including a 90° elbow on the down pipe so that the pipe can be turned away from the storage to divert flow for the first 5 to 10 minutes of a storm.

Tank: The shape of the tank may be cylindrical, square or hemi-spherical and constructed from galvanized iron, brick, stone masonry, reinforced concrete and ferrocement. Choice of tanks depends upon the availability of materials, cost and space and may be constructed underground or over ground. When constructed underground, at least 30 cm of the tank should remain above the ground. The tank is covered and provided with a filter in the tank to keep water clean. Chlorination may also be needed from time to time. The quality and availability of water in the rooftop harvesting system depends on its periodic maintenance and disinfection.

Filter: Layers of sand and gravel are commonly used as the filter media for water purification. At the top of it, mesh may be provided and in between sand gravel, a thin layer of charcoal may also be used which would absorb odor. This system can also be used for community water supply by conveying rooftop runoff of cluster of houses and buildings at a centralized tank and having a water distribution network from there to houses.

(c) Water Quality

Rainwater harvested from rooftop catchment can provide clean water for drinking purposes. The quality of water is largely dependent on the type of roofing materials used and frequency of cleaning of the surface. A study carried out by Wirojanagud et al (1989, as cited by Gould, 1992) on 189 rainwater tanks and jars in Thailand showed that only 2 of 89 tanks sampled and none of the 97 jars sampled contains pathogens. Based on the result of bacterial analyses, 40% of the 189 tanks and jars sampled met the WHO drinking water standards. All of the tanks and jars sampled met the WHO standards for heavy metals, including the standards for cadmium, chromium, lead, copper and iron.

(II) Rooftop Rainwater Harvesting for Recharging Groundwater

Rooftop rainwater recharge of ground water can be achieved by conveying harvested rainwater through following methods:

- Abandoned dug well
- Abandoned/running hand pump
- Recharge pit
- Recharge trench
- Gravity head recharge well
- Recharge shaft

Abandoned Dug Well: The recharge water is conveyed through a pipe to the bottom of well or below a water level to avoid scouring of the bottom and entrapment of air bubbles in the aquifer. It is suitable for large buildings having roof area more than 1000 m^2.

Abandoned / Running Hand Pump: The water is diverted from rooftop to the hand pump through pipe of 50 to 100 mm diameter. The structure is suitable for small building having roof area up to 150 m^2.

Recharge Pit: These are constructed generally by excavating 1 to 2 m wide and 2 to 3 m deep, circular, square or rectangular shape, and refilled with pebbles and boulders. It is suitable for small building having roof area up to 100 m^2.

Recharge Trench: It is constructed in permeable strata of adequate thickness and the trench is shallow depth filled with pebbles and boulders. The trench may be 0.5 to 1 m wide, 1 to 1.5 m deep and 10 to 20 m long depending the availability of land and rooftop area. These are constructed across the land slope. It is suitable for buildings having roof area of 200 to 300 m^2.

Gravity Head Recharge Well: The rooftop rainwater harvesting is channelised into the well and recharges under gravity flow condition and suitable for roof area about 500-1500 m^2 suitable for areas where ground water levels are deep.

Recharge Shaft: It is constructed where the shallow aquifer is located below surface. The diameter of shaft varies from 0.5 to 3m and the depth varies from 10 to 15 m. The shaft is backfilled with boulders, gravels and coarse sand.

2.2.2 Rainwater Harvesting from Open Areas

The major water harvesting systems prevalent in arid and semi-arid regions of India are as follows:

(a) Nadis, Tanka, Khadin and percolation tanks in Rajastan
(b) Bandharas in Maharashtra
(c) Bundhis in Madya Pradesh and Uttar Pradesh, and
(d) Ahars in Bihar

Tanka: Tanka is the most common rainwater harvesting system in the Indian arid zone, and is local name given to a covered underground tank, generally constructed for storage of surface runoff. The first known construction of Tanka in the Indian arid and semi-arid region can be traced back during the year 1607 in village Vadi Ka Melan near Jodhpur. The Tanka is constructed by digging a circular hole 3.00 to 4.25 m in diameter and plastering the base and sides with 6 mm thick lime mortar or 3 mm thick cement mortar (Vangani et al, 1988). An Improved Tanka of 21 m^3 capacities has been designed by Vangani et al, (1988) to provide adequate drinking water for a family of six persons through out the year.

Nadis: Nadis are excavated or embanked village pond for harvesting meager precipitation to mitigate the scarcity of drinking water in desert regions. This is the most important ancient practice of water harvesting in arid and semi arid region, and the first recorded masonry Nadi was constructed in 1520 near Jodhpur. A Nadi is generally located in areas with lowest elevation to have the benefit of natural drainage and minimum excavation of earth. It consists of two components; catchment area and water storage. The Nadis range from 1.5 to 12 m in depth, 400 to 700,000 m^3 in capacity, and have various shapes and sizes (8 to 2,000 ha).

Khadin: Khadin is a system of growing crops on harvested and stored water by constructing an earthen bund across the gentle slope of the farm in the valley bottom (Kolarkar et al, 1980). It was innovated during 15th century for runoff farming by Paliwal Brahmin Community in Jaisalmer area. They are generally practiced in areas receiving less than 100 mm average annual rainfall.

Anicut, Check Dam and Percolation Tank: These are constructed across the ephemeral streams to intercept runoff from local catchments and store it for optimum utilization (Khan, 1992). The stored water from behind is used for drinking, irrigation and recharging the downstream wells. These structures are suitable in hilly and uneven topography, where ephemeral streams are available in catchments with runoff characteristics, and are widely adopted in hard rock and basaltic terrain of south-east Rajasthan, Gujarat, Maharashtra, Madya Pradesh and in Deccan Plateau (Anon, 1988). The design of two major components i.e. earthen embankments and masonry spillway is based upon 50 years return period. A thorough and detailed knowledge of geological, hydrological and morphological features of the area is necessary while selecting the site.

An anicut constructed on an ephemeral stream in western Rajasthan has been found to enhance the ground water recharge by 35% over a period of three years (Sharma and Kalla, 1980). An anicut is a structure or masonry wall, built across a river, by means of which the water level on the upstream side is raised up to the crest level before it can pass down the river

A percolation tank in basaltic formation influences about 1.5 to 2.0 km^2 area and recharge about (0.15 x 106 m^3) of runoff during the normal rainfall years. The enhanced recharge is variable, ranging from 0.032 x 106 m^3 to 0.0182 x 106 m^3 which is about 50% of the storage capacity (Anon, 1988).

Ahars and Bundies: These are similar to Khadins, and are widely practiced in Bihar and U.P. The basic principle is to allow runoff water to collect behind an earthen bund usually 3 metres in height and running along contour over sizeable distance and hooked up at appropriate points. The length of bunds varies from 100 m to 10 kms or more, depending upon rainfall, watershed area and requirement of communities and individuals. The submergence area may vary from 1 to 500 ha or more with stored water varying from 0.50 to 100 ha-m.

The Ahars are constructed in on a very gentle gradient to facilitate large inundation. The bund is of uniform soil without clay core or cut-off trench and usually has 1:2 upstream and downstream slopes. Spillway is provided to release excess water. The crest of spillway is 1 m lower than the top of the bund. Sluice gates are provided in masonry structures to empty out Ahars quickly at time of sowing. Concrete or cast iron pipes 150-300 mm in diameter are embedded in the bund at intervals of 50-100 m to release water for irrigation.

Bandharas: Bandhara is a Marathi term for weir with vents. The vents have removable shutters held in grooves in pipes. The vents are kept open during floods to carry away heavy silt. The Bandharas catch the flow of streams and utilize it to provide irrigation to crops. In many cases the water is pumped out of the bandharas and conveyed to higher grounds.

Dams/ Reservoir: Earth dams can be built in those regions where the flow is perennial. They consist of earthen embankments, 2 to 5 m in height, mostly with clay core and downstream stone apron. Spillway is provided to drain of excess runoff. The storage capacity generally ranges from 1000 to 50,000 m^3. In arid zone, Luni basin forms the major drainage system, in which, there are 865 minor to major medium reservoirs constructed with a total storage capacity of 1096.63 x 106 m^3 (Anon,1990). The storage water caters to the domestic and livestock requirements in addition to irrigation demand.

2.2 Case Studies

(1.) Gupta and Tamhane (2004) applied GIS as tool for watershed analysis. The work has been carried out are in the following manner:

1. District level resource mapping creation was done using 1: 50,000 Survey of India Toposheets keeping in view the project objectives.

2. IRS–1D, LISS-III digital satellite data of 23.5 metres resolution were procured from NRSA, Hyderabad for two seasons (i.e. Rabi and Kharif cropping seasons) for land cover mapping and updating the information/data gathered from the base maps generated from 1:50,000 Survey of India Toposheets.
3. Digital Image processing of satellite data using standard software packages was done for data merging, enhancement of relevant features, digital classification and conversion to thematic maps bringing the processed data into GIS environment for water resource mapping from satellite imagery.
4. By combining the remote sensing information with adequate field data, based on the status of water resources development and irrigated areas (through remote sensing), artificial recharge structures such as check dams, nala bunds etc were recommended upstream of irrigated areas to recharge downstream areas so as to augment groundwater resources.

(2.) Sarangi et, al (2004) developed user interface in ArcGIS for watershed management, the developed interface is a useful tool for integrated watershed management. This also endorse the use of advanced computer assisted technology applied to the management of natural resources on a watershed basis. The interface provides the inexperienced or new user with an entry point to a powerful GIS without any detailed training in hydrological modelling. The interface command buttons perform a series of inherent GIS instructions and displays the results in a user-friendly format. The link of the developed interface with Watershed and Stream Delineation Tool (WSDT) for watershed delineation and stream network generation assists the user to start watershed management activities from a DEM, without looking for digitization of topological information. The intent of this study was to link the geospatial database with the interpretive routines for estimation of morphological parameterson watersheds.

The Visual Basics for Applications (VBA) programming language and the ArcObjects technology used in this interface are an emerging fields in GIS based applications. The flexibility of the interface for further modification and updation is an added advantage with the interface. This technique will further assist the linkage of hydrologic simulation models for prediction of real time sediment and runoff estimations on watersheds. This interface on watershed morphology estimation within ArcGIS environment is first of its kind and is a useful tool for watershed prioritization and prediction of hydrologic responses.

(3.) Adhikari (2003) developed GIS - Remote Sensing compatible rainfall-surface runoff model for regional level planning. In the broad sense, the term hydrological modelling implies rainfall-runoff modeling, which helps in simulating and forecasting the flow from a catchment and in determining the inflow series for the ungauged catchments. Efforts have been made for the spatial distributed nature of the watershed properties by introducing GIS for spatial discretisation of watershed into interlinked systems of triangles and development of a physically based rainfall-surface runoff model for simulating flood hydrographs in a user-friendly interface (GUI). The model is compatible with both the GIS database and remote sensing data, although interactive option is provided to the user for modifying the database, if necessary. GIS has also been used to describe the various thematic layers such as physiography, landuse, soil etc. in the study. Terrain modelling is a pre-requisite to hydrologic simulation of the rainfall-runoff process. Algorithms have been used in the present study to extract watershed features, such as overland flow cascades, channel network, confluence points, ridges etc., for a given digital elevation data using Triangulated Irregular Network (TIN). The overland flow is modelled as one-dimensional sheet flow over cascades of overland "flow planes" contributing as lateral inflow to the channels flowing in the valley. Both the overland and channel flows are simulated using the kinematic wave approximation of fluid flow and solved through explicit finite difference routines. The main input to the watershed is taken as the rainfall. The usage of the model for regional level planners is demonstrated for tasks such as determination of waterways for small bridges and culverts, design of spillways of small dams, construction of flood protection levees, agriculture, site planning for micro hydels etc

(4.) Hadi and Hamid (2003) worked for the sediment yield potential estimation of Kashmar urban watershed using MPSIAC model in the GIS framework, with due attention to the relatively suitable compatibility of MPSIAC model with the arid and semi-arid conditions of Iran and lack of hydrometric station in region, in order to estimating of sediment yield and providing sediment yield and erosion intensity map in this watershed, we used modified PSIAC model. At first to enter the available raw data into the GIS framework, they digitized topography, geology, geomorphology, land capability, soil hydrologic groups and plant cover maps using on-screen method. In the second stage, digitized maps were encoded based on the values of geology, soil erodibility, climate, land cover, land use, present status of erosion and channel erosion and sediment transport factors. Using the DEM layer, slope and rain (using the rain gradient equation) maps were provided and consequently topographic and runoff (using the logical method) factors maps were prepared. Then these maps were summed together and finally sedimentation score map was provided.

(5.) Pandey and Sahu (2002), worked for generation of curve number using remote sensing and GIS. For ungauged watersheds, accurate prediction of the quantity of runoff from land surface into rivers and streams requires much effort and time. But this information is essential in dealing with watershed development and management problems. Conventional methods of runoff measurements are not easy for inaccessible terrain of Arunachal Pradesh. Remote sensing technology can augment the conventional method to a great extent in rainfall-runoff studies. Many researchers (Ragan and Jackson, 1980; Slack and Welch, 1980, Tiwari et al., 1991) have been utilized the satellite data to estimate the USDA soil conservation Services (SCS) Runoff Curve Number (CN). In this study SCS Curve Number (CN) technique modified for Indian condition has been used for generation of CN for Remi watershed, which is located in the East Siang district of Arunachal Pradesh under Pasighat circle. The area of watershed is 210.00 Km^2. The watershed area lies in the Survey of India (SOI) topo-sheet No. 82 P/4, 82P/8, 83M/1 and 83M/5 .It is located between 27° 50'to 28° 05' N latitude and 95° 05' to 95° 25' E longitude.

(6.) Sharma et. al. (1999) developed micro-watershed plans using remote sensing and GIS for a part of Shetrunji river basin, Bhavnagar district, Gujarat. Micro-watershed level planning requires a host of inter-related information to be generated and studied in relation to each other. Remotely sensed data provides valuable and up-to-date spatial information on natural resources and physical terrain parameters. GIS with its capability of integration and analysis of spatial, aspatial, multi-layered information obtained in a wide variety of formats both from remote sensing and other conventional sources has proved to be an effective tool in planning for micro-watershed development. In this study, an approach using remote sensing and GIS has been applied to identify the natural resources problems and to generate locale specific micro-watershed development plans for a part of Shetrunji river basin in Bhavnagar district, Gujarat. Study of multi-date satellite data has reveled that the main land use /land cover in the area is rainfed agriculture, wasteland with/without scrubs in the plains and undulating land and scrub forests with forest blanks on the hills. Due to paucity of ground water for irrigation, the rain fed agriculture area lacks sufficient soil and moisture to support good agriculture.

(7.) Baruah,(2002) used GIS as tool in watershed hydrology and irrigation water management, this powerful tool holds a very large potential in the field of regional and micro-level spatial planning, particularly in micro-watershed planning and management. A GIS can helpful together various types of disparate data such as remote sensing data, census data, records from different administrative bodies, topographical data and field observations to assist researchers, planners, project officers and decision-makers in resource management. Creation of a spatial database is the first step in micro-level planning. This is followed by spatial analysis to help identify problem areas and, finally, the steps towards planning to mitigate problems are taken by marking out action areas. Taking a watershed as the spatial unit of study, appropriate physiographic and morphometric parameters can be taken into account to enable proper micro-watershed management.

(8.) Sarangi et.al (2004) used GIS tool in watershed hydrology and irrigation water management. Watershed hydrology plays a significant role in generation and quantification of runoff and sediment loss from watersheds. With an aim to asses runoff and soil loss, GIS tool was used to assist in data base development which acted as input to a developed conceptual model (Small Watershed Runoff Generation Model, SWARGEM). The input to the model was in the form of data tables and digitized maps comprising of soil parameters, topological information and land use features of Banha watershed under Damodar Valley Corporation, Bihar, India. The topological information indicated the elevations of corners of square grid array. The model used 4-point pour-point technique to route surface flow from one grid to the other in an overlaid grid array of the Banha watershed. The digitised watershed topology and square grid array was created using ARC/INFO GIS tool . Manning's formulae was used to route water over the entire watershed coupled with water budgeting technique corresponding to rainfall events. The output of the model generated event based Direct Runoff Hydrographs (DRH) for the watershed. The non-parametric statistical analysis (Wilcoxon's matched pair signed rank test) performed on the predicted value and observed runoff rate at the outlet of the watershed revealed that there is no significant difference between the observed and predicted values at 0.05 probability level. The topological information extracted using GIS was also used to obtain the geomorphological parameters of the watershed. The hypsometric analysis which is under geologic geomorphological component was performed using GIS tool. The analysis showed the erosion status of watershed, which is moderately prone to erosion and is at equlibrium stage.

(9.) Sah et.al. (1997) worked for subwatershed prioritization for watershed management using remote sensing and GIS. Delineating the wathershed area into subwatershed for priority based conservation work is essential and appropriate for the developing countries like Nepal. Considering its drainage system can do such delineation. The delineated subwatersheds were used for prioritization. Prioritization can be done by considering their forest loss, soil loss and land sensitivity, which is defined as the locational relationship between forest loss and soil loss. These factors were used to extract the DSI, SI and PC, which were considered as the condition indicator of the subwatershed. Using these condition indicators, a new method of prioritization for conservation work was proposed by the qualitative matrix analysis. Based on prioritization, subwatershed conservation management activities were proposed. Finally, it can be said that remote sensing and GIS in combination with USLE model can be used as appropriate tools for sub wathershed prioritization.

(10.) Greenfield et. al (2004) developed watershed erosion and sediment load estimation tool, The watershed erosion and sediment load estimation tool is an ArcView-based system that can be used to estimate soil erosion and sediment loads from watersheds. The potential erosion from each source (grid) cell in the watershed is calculated using the Universal Soil Loss Equation (USLE) in which the USLE factors, such as K, LS, C and P are automatically calculated based on spatial data layers such as soil, Digital Elevation Map (DEM), land use, road network, and management practices. The potential sediment load to user-specified assessment points in the watershed is estimated by using one of three alternative methods for computing sediment delivery ratio. The user is provided with the capability to easily and quickly prepare alternative scenarios to determine the effects of land use changes, best management practices (BMPs), and road management practices on the erosion and sediment estimates. BMPs that affect the source of the erosion (e.g., tillage practices) and the sediment pathways (e.g., ponds, buffer strips) are considered separately. Other features, such as grouping the estimates by source, automatic report generation, and scenario tracking are also provided.

(11.) Samad et.al (1997) applied GIS and remote sensing for soil erosion and hydrological study of the Bakun Dam catchment area, Sarawak. The USLE was applied to predict annual soil loss in the study area, using the integration of satellite remote sensing GIS technologies. Parameters of the USLE used to generate the relevant raster layers for soil erosion spatial modelling in the GIS are - (i) rainfall erosivity, (ii) slope length/gradient, (iii) cover- conservation method and (iv) soil erodibility. The analysis was done in MICSIS (Micro-computer Spatial Information System), an image processing and GIS software package developed specifically for erosion modeling under the Malaysian-China cooperation.

(12.) A case study of a rooftop water harvesting system in village Satengal, district Tehri Garhwal under "SWAJAL" project carried out by District Project Management Unit, Dehradun with local NGO-Rural Litigation and Entitlement Kendra as a support organization, is presented to illustrate an example that followed a participatory approach (Dobhal, 2000). After detailed deliberation with the community, the community finally selected the ferrocement type storage tank. Following design parameters were taken into account:

Average number of persons per household	n = 5
Average water consumption for drinking purpose	q = 5 lpcd
Average annual rainfall	p = 2000 mm
Dry period	t = 270 days

Runoff coefficient, f

For corrugated galvanized iron sheets (CGI)	= 0.80
For RCC roofs	= 0.70
For slate roofs	= 0.60

Water demand per household during dry period was calculated as:

$$Q = n \times q \times t = 5 \times 5 \times 270 = 6750 \text{ liters}$$

Considering water storage tank of 7kl capacity per household.

Roof catchment area

Required area	A	=	Q/(f x p)
For GI sheet roof	A	=	7/(0.80 x 2) = 4,375, say $5m^2$
For RCC roofs	A	=	7/(0.70 x 2) = 5 m^2
For slate roofs	A	=	7/ (0.60 x 2) = 6 m^2

These requisite roof areas were easily available with the village houses. After this initial feasibility of rooftop rainwater harvesting system, the various technical proposals were discussed with the community. The water storage tanks proposed were of RCC, brick/stone masonry, galvanized iron sheets, synthetic polymer and ferrocement. After detailed deliberation with the community, the community finally selected the ferrocement type storage tank due to the following reasons:

- Low cost
- Ease of construction
- Ease of maintenance
- Lesser area required than brick/stone masonry tank

- Temperature control

13. Rathore, (1988), carried out a study related to rooftop rainwater harvesting in village Jaislan in Nagaur district, western Rajastan. The study area is located in the saline ground water track. The village has geographical area of 868 ha with 879 inhabitants living in 133 households. Drinking water is always a problem in the region since the settlement of the village 250 years ago. The villagers used to transport the drinking water from the nearby village 3 km away. During 1906, a villager tried to rooftop water harvesting in his house. An underground water storage tank was linked through drain pipes with the roof. This was a successful experiment and became an important non-saline potable water source in the village. Inspired by this, more rooftop rainwater harvesting systems were constructed between 1923 and 1926. The water was supplied to entire village during summer when acute scarcity of water was felt. The number increased to about 100 and the structures have been working successfully in the village. The entire village has become self-sufficient in meeting out
the drinking water needs on sustainable basis.

14. Study carried out by the Center for Science and Environment (CSE) has found a rise in water table of some areas in New Delhi, where water harvesting structures were installed. Rainwater collected from roof of buildings was conveyed to recharge pit installed in different parts of the city. This water harvesting system is the solution to the depleting water table and water log areas (Sinha, 2002). It was reported to have a significant rise in water table in the following areas: Panchseel Park (92.4 to 87.1 ft), Jamia Hamdard University (148.5 to 132 ft), Janki Devi Memorial College in Ranjinder Nagar (118.14 to 72.93 ft) and Sriram School, Vasant Vihar (119.8 to 115.5 ft).

15. In many states such as Delhi, Maharashtra, Gujarat, Chandigarh (UT), Punjab, Haryana, Rajasthan, Tamil Nadu, Meghalaya, etc., rooftop runoff from housing complexes and institutional buildings is being used to recharge ground water. Chennai Metro Water Board has made rooftop rainwater harvesting mandatory under the city's building regulations. At Shram Shakti Bhawan, New Delhi, artificial recharge structures

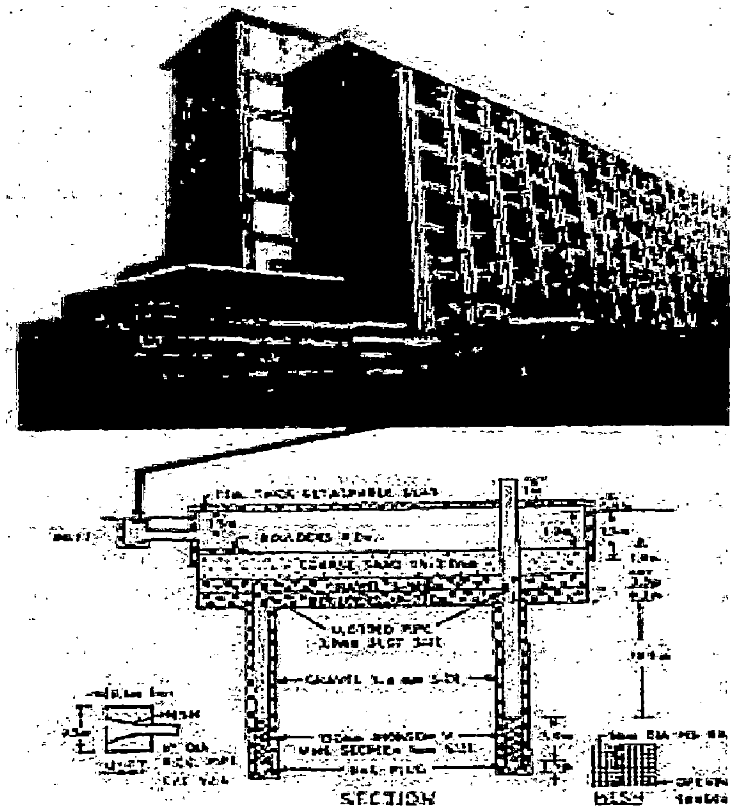

Fig 2.3: Rooftop Rainwater Recharge System at Shram Shakti Bhawan, Delhi

are installed Fig. 2.3. The roof area is 3110 m^2 and receiving the average annual rainfall of 712mm. It is found that there is a rise of water table from 0.62 to 1.37 m.

16. **Raju (1994)** carried out work on sub-surface water harvesting in Kutchh district of Gujarat. Due to over exploitation of ground water in the study area, the water table has gone down drastically in many years. Many open wells have dried up and sea water had intruded into the coastal aquifers. The total area affected by sea water intrusion has been estimated as 15,500 ha in 244 villages. Shree Vivekanand Research and Training Institute constructed water harvesting system since 1987 with the assistance of voluntary organizations and State Government. In all 58 check dams, 48 percolation tanks, two-surface dam, 39 recharge wells and 42 storage tanks were constructed till July 1993. Total capacity of the recharge structures was 1.44 x 106 m^3, which can accommodate two to three floods in normal rainfall year, thus increasing recharge capacity to about 3 x 106 m^3 in a year of good rainfall. The area likely to be benefited is of the order of 3301 ha in 20 villages. The rise in water table over a period of 6 years is of the order of 6 m and maximum decline of salts is of the order of 920 ppm. This water harvesting structure has

given encouraging results and proved the effectiveness of recharge wells and sub-surface dams as recharge structure.

17. A study has been conducted for identification of suitable sites for water harvesting structures in upper Betwa watershed of Betwa basin using "WARIS" package developed over Arc/INFO GIS. The present study uses decision support system "WARIS" for identification of suitable sites for water harvesting structures. It covers an area of 1384.61 km^2 and falls in parts of Bhopal and Raisen districts in Madhya Pradesh. Theme layers viz, landuse / landcover, soil, slope, hydrogeomorphology, etc., which affect the identification of sites were generated in Arc/INFO environment (Bothale, et al, 2002). Following structures were suggested after identification of suitable sites:

- Anicut: For anicut sites buffer of 1 km was constructed around 2nd to 3rd order streams. Medium slope areas between 2 to 8% were taken. Favorable soils were given weights to allow storage of water. A total of 10 sites were marked in the area.
- Nala bund: Nearly plain, (up to 2%), upper reach, catchments greater than 40 ha, permeable soils were the criteria according to which the weights were decided. After the analysis 16 sites were marked which are suitable for nala bund.
- Farm pond: Flat topography, low permeability, absence of faults, joints were the criteria for site suitability.
- Dug cum bore well: Lineament map pertaining to study area was studied and 9 suitable sites were marked on the output.

18. TWAD Board in association with UNICEF launched a pilot project during the year 1994 to study the effectiveness of rainwater harvesting structures constructed in a micro watershed. An evaluation conducted recently indicates that the rainwater harvesting structures contributed considerably to the groundwater regime enhancing both quality and quantity parameters. It has been found out that all the target wells in the project area became sustainable after the intervention of the project.

19. TWAD Board in association with the Anna University undertook an exercise to identify optimum locations for the construction of rainwater harvesting structures throughout the State, using remote sensing technology. The study has identified 13,357 structures that need to be constructed/improved. The details of these structures are: Desilting of tanks (5,266), Check dams (6055), Percolation ponds (1,201), Recharge pits (684), Subsurface dykes (82) and Nala bunds (69).

20. The Government proposes to enlist the participation of the Public and Non Governmental Organization (NGOs) in propagating and installing rainwater harvesting structures. Every household can construct and benefit from rainwater harvesting. Every rooftop and any open space is a potential catchment area for rainwater harvesting (Ramalingam et al, 2002).

2.3 PRESENT SCENARIO

In the present study, critical review of the existing water sources have been made, which are described below:

2.3.1 Critical reviews of the present status and water supply

(a) Drinking water supply and source available (surface and ground water)
(b) Suitability of existing sources for drinking water
(c) Adequacy of these sources
(d) Existing operational systems/policy of drinking water supply
(e) Existence and conditions of springs
(f) Working out demand, availability and deficiency for present & future
(g) Strata charts/stratification- details of formations
(h) Soil and infiltration characteristics

2.3.2 Water Supply

No city can exist without an adequate water supply of safe water that is fit for human consumption. In urban contest besides drinking, water has other purposes, such as washing, industrial uses, fire fighting & air conditioning, irrigating lawns and public parks etc. The most concerned public facilities of all large cities have been with their water supplies.

The larger cities during their expansion found the local sources from wells, springs and brooks that were inadequate to meet the drinking and sanitary demands of growing population. Construction of aqueducts that could bring the water from distance was the solution to fulfill the demand.

Generally, the water supply schemes of this kind are constructed and operated by the municipals corporation. Dehradun city is no longer different than the other cities. In olden days, people met their demands from dug wells, natural springs and canals. Later as the city grew, pipelines were introduced connecting the perennial springs to meet the demand. Subsequently the surface water was brought from river Bandal through gravity main and with_this, a proper water works department with facilities of filtration came in to existence at Dila Ram Bazar. Pipelines were also laid for conveying water to the town's population.

Under the status and the existing set-ups and until few of the Jal Sansthan (Water and Sewage Boards) came up with power to levy water and drainage tax, its realization and also the responsibility of establishing a protected water supply vested with the local bodies representing the community. Obviously the responsibilities of establishing a water supply and promotion of protected water supply in Dehradun, because of the responsibility of the Dehradun Municipality.

2.3.3 Growing Demand of water

With the urbanization and industrial growth the demand started increasing unprecedently. The new areas on all sides of town were inhabited and so the limits of Dehradun across Municipality extended demanding the civic facilities to newly formed settlements. The existing water supply from springs and rivers became inadequate and tapping new sources for augmentation for water needs and also extension of distribution system to the new colonies became essential.

Water supply of Dehradun city is managed by Jal Sansthan. According to data provided, it is known that the total population of Dehradun is 5,78,646 (On year 2003 basis). As per design criteria, the total water demand of the city is 89.69 mld (@155 lpcd) and the institutional demand is 10.00 mld. Thus the total demand is 99.69 mld. But presently supply is being done @ 200 lpcd. Therefore total demand according to 200 lpcd for the present population is 115.73 mld and after including institutional demand it reaches to 125.73 mld. But the total water supplied from various sources is unable to make the demand.

Total water supply for the city is 102.32 mld (On year 2003 basis). Tube wells are the main source of water supply in Dehradun city. Total amount of water supplied from these tube wells is 83.95 mld while rest of the amount i.e. 18.37 mld water is supplied from the natural resources. Table 4.1 shows the present supply and demand statement of the city. Presently there is shortage of about 23.41 mld and the gap is expected to widen in the next decade. Hence corrective measures are necessary to fill this gap. Rainwater if harvested may be used to bridge the gap.

About 82% of total water supply of the city is met from the 52 tubewells that are scattered almost all over in the city. There are 26 overhead tanks of varying capacity in order_to supply the elevated areas. Tables 2.3a, 2.3b & 2.3c show the list of tubewells and overhead tanks. The ground water level varies from 20-90 m.

The present water supply scheme of the capital city is catering the need of 5.79 lakh people (on year 2003 basis). Besides this permanent population it also serves the tourists and the students who are considered to be the floating population.

For the efficient running of a water works system and equal distribution the water supply department works from four zones within the city viz. Upper zone, Rajender Nagar zone, Dharampur zone and Niranjanpur zone. Out of 46,221 connections, there are 36,115 domestic connections, 6,465 non-domestic and 1789 are commercial metered connections. There are 134 bulk connections given for industrial and institutional requirements. To the economically weaker sections of the society, there are 1758 connections given by water works through stand post, which are unmetered. Table 2.4 shows the total no. of registered connection with Water Works Department (W. W. D).

Despite there being a supply of 102.32 mld, the supply situation became grim in every summer. Except the few areas though rest of the city has problem in getting drinking water. The areas facing the shortage of water supply are Clock Tower, Hathi

Barkala, Rest Camp, Tyagi Road, Chander Road, Kaulagarh Road and Genaral Mahadeo Singh Road. The water scarcity in these areas is due to rapid commercialization, construction of new shopping complexes etc., so the demand of water is suddenly increased. The water demand project doesn't include the need of this population. The storage capacity of the overhead tanks and number of tube wells within the city are less in number to meet the demands. Table 2.5 shows the deficiency in storage for the city.

The problem of water pressure in the pipes remains in the areas of higher elevation. This problem clearly indicates the lack of research during the planning for constructing the overhead tanks. Apart from the above reason, the limited economic resources, the cost involved in drilling tube well (approx.18-20 lakhs) and the shortage of man power are also strong reasons for the crippled operational system of water works. Summing up the above issues, it was inferred that a holistic study needs to locate new potential sites, keeping in mind the future requirements of the growing population.

2.3.4 Tariff for Domestic and Non-Domestic Consumers

Water is sold to the domestic consumers @ Rs. 2.50 per thousand liters and non-domestic rate of supplying water is @ Rs.12 per thousand liters. Besides the existing tariff rate of consumption of water, a minimum service charge of Rs.12.50 plus Rs. 2.00 for meter rent is collected monthly. This however holds good for consumers who are drawing water through metered connections, but there is a section of people who do not have either metered or unmetered connection on flat rates, but enjoy and draw water from Municipal Mains. To extend the tax basis to this section of population and also to have a minimum assured income from the water supply system, a water tax @12.5 % of the rental value of the property is levied on all houses and properties except houses belonging to the weaker sections of the society, irrespective of whether that property has a water connection or not and also whether or not water is consumed at such premises. However all those properties which are having metered water connections enjoy a monthly fixed non chargeable quantity of water in lieu of water tax paid, but all consumption over the fixed monthly limits all chargeable. If in any case the monthly consumption fall short of the non-chargeable limit the balance is not carried forward and it lapse. The tariff structure for water consumption is presented in Table 2.6

2.3.5 Springs

There are some springs also in Dehradun and its surroundings and some of them have been in existence till date. Generally they are located in the higher altitudes of the city. These springs are the source of fresh water that can be used for drinking purposes in the locality where they are located. Their discharge may be less with passing time even then they are fulfilling a small amount of demand. Some springs located are like in Guchchupani, Sahastradhara, Robber's Cave and Dhanauld.

Table 2.3: Water Supply Scenario of Dehradun

<table>
<tr><th colspan="5">Source, supply, Demand and Gap of Water Supply</th></tr>
<tr><th>Source</th><th>Withdrawl(mld)</th><th>Current Supply (mld)</th><th>CurrentDemand(mld)</th><th>Gap (mld)</th></tr>
<tr><td>Bandal River</td><td>6.00</td><td rowspan="5">102.32</td><td rowspan="5">89.69mld
@155lpcd+10mld ind.
= 99.69 mld
115.73mld
@200lpcd+10 mld ind.
=125.73 mld</td><td rowspan="5">23.41 mld</td></tr>
<tr><td>Mossy Falls</td><td>12.00</td></tr>
<tr><td>Kolukhet</td><td>0.22</td></tr>
<tr><td>Kaulagarh</td><td>0.15</td></tr>
<tr><td>Tubewells</td><td>83.95</td></tr>
</table>

Table 2.3a: Details of Tube well in Nagar Nigam, Dehradun

Sr. No.	Location of Tube well	Discharge in lpm
1	Vijay Colony	150
2	Dobhalwala	500
3	Badrinath Colony	2000
4	Tagor Villa	1500
5	Nimbuwala	500
6	Kaulagarh-I	2000
7	Kaulagarh-II	1200
8	Rajendar Nagar-I	1800
9	Rajendar Nagar-II	1600
10	Rajendar Nagar-III	800
11	Rajendar Nagar-IV	400

12	Vijay Park	1200
13	Govind Garh	2500
14	Khurbura	1600
15	Panditwadi	1200
16	Basant Vihar-I	2200
17	Basant Vihar-II	1200
18	Indira Nagar-I	1600
19	Indira Nagar-II	2000
20	Maharani Bag	2200
21	Engineer Enclave	2200
22	Patel Nagar	2200
23	Niranjanpur-I	2500
24	Niranjanpur-II	2200
25	Niranjanpur-III	2200
26	Niranjanpur-IV	2500
27	Rest Camp	2500
28	Race Course	2500
29	Nehru Colony-I	2200
30	Nehru Colony-II	2400
31	Nehru Colony-III	1800
32	Nehru Colony-IV	2200
33	Nehru Colony-V	2500
34	Nehru Colony-VI	2200
35	Dharampur	2000
36	Sanjay Colony	2500
37	Curzon Road	1500
38	Survey Chowk	1600
39	Parade Ground	800
40	Tibati Market	1600
41	Gandhi Park	2200

42	Nagar Palika	2200
43	Cement Road, Karanpur	1600
44	Adhoiwala	1000
45	Raffle Home	1200
	Ajabpur Ka Tanda/ Rajiv Nagar	1600
47	Hardwar Road	2200
48	Defense Colony-I	500
49	Defense Colony-II	500
50	Ajabpur Shiv Mandir	1200
51	Mata Mandir	1600
52	Kedar Puram	1400

Total = **87,450 lpm**

Total Daily Average Discharge @ 16 hrs pumping = 83.592 mld

Table 2.3b: Details of Existing Reservoirs in Nagar Nigam, Dehradun

Sl.No.	**Clear Water Reservoirs**	**Capacity (kilo liter)**
1	Shanshai Ashram	480
2	Dhakpatti	260
3	Balyogi	400
4	Kishanpur	120
5	Hathi Burkala	950
6	Water Works Dilaram Bazar-I	730
7	Water Works Dilaram Bazar-II	730
8	Water Works Dilaram Bazar-III	1248
9	Water Works Dilaram Bazar-IV	2250
10	Dharampur-I	200
11	Dharampur-II	60
12	Sahastradhara Road	500

Total=**7928 kilo liter**

Table2.3c: Details of Overhead Tanks in Nagar Nigam, Dehradun

Sr. No.	Overhead Tanks	Capacity(Kilo liter)
1	Water Works Dilaram Bazar-V	1800
2	Parade Ground-I	900
3	Parade Ground-II	2500
4	Nagar Nigam Compound (City Board	900
5	Prem Kunj, Nimbuwala	225
6	Kaulagarh	450
7	Rajendar Nagar	850
8	Dobhalwala	1250
9	Vijay park near ONGC	550
10	Khurbura	1800
11	Jhanda Mohalla	900
12	Basant Vihar	450
13	Indira Nagar	500
14	Engineer Enclave	100
15	Laxman Chowk/Kanvali Road	900
16	Patel Nagar	2500
17	Indira Puram	600
18	Race Course	1250
19	Nehru Colony-I	2500
20	NEHRU COLONY-II	225
21	Ajabpur	300
22	Adhoiwala	450
23	Raffle Home	100
24	Rajiv Nagar	500
25	Defense colony	200
26	Kedar Puram	600

Total = 23,380 kilo liter

CHAPTER THREE

THE STUDY AREA

3.0 Location

The Dehradun city, the capital of newly formed Uttaranchal state, is situated in the south-central part of Dehradun District, and is one of the major urban center of the region. It is located 250 km. north of New Delhi. The study area lies between 77° 57 24' E to 78° 07 44' E and 30 ° 06 27'N to 30 ° 27 40' N latitude (Fig. 3.1).

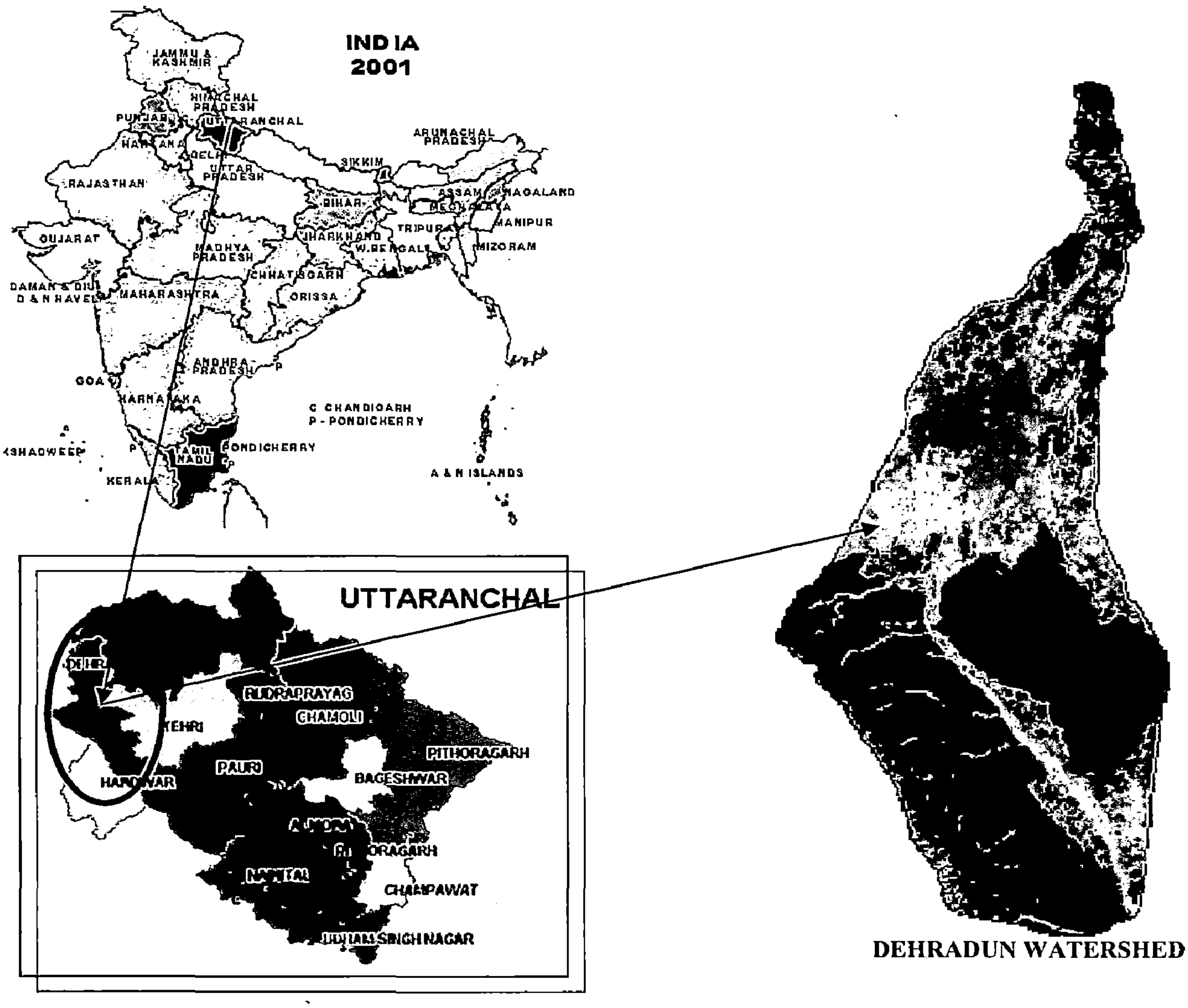

Fig 3.1 *Location of Dehradun watershed, Uttaranchal State*

Surrounded by lush green forests and hills, Dehradun has always been a favorite destination with the tourists. It is endowed with a pleasant, moderate, climate and is well connected with other important places such as Delhi, Haridwar. Dehradun is a gateway and base camp for tourists and pilgrims headed for Gangotri- Jamunotri- Kedarnath-badrinath- valley of flowers and famous hill queen Mussoorie.

Dehradun is one of the beautiful towns in the northern India. It boasts of a number of reputed educational institutions such as the Forest Research Institute, Wildlife Institute of India, Forest Survey of India, Indian Military Academy, The Doon School etc. The entire Dehradun Valley has numerous places of scenic beauty and picnic spots such as Robbers Cave, Rajaji National Park, etc.

Dehradun is strategically located in the foothills of the Himalayas in the north, the Shiwalik hills in the south, the Ganga in the east and Yamuna River in the west. The Doon valley is a longitudinal valley, which extends about 80 km in the length and 20 km in width, lie between the rivers Ganga and Yamuna. The pre-tertiary rocks of the mid Himalayan range rise up to 2200 m. above MSL bounded the north and the Shiwalik range, which rises up to 900 m above MSL, bound Doon valley in the south.

3.1 Historical Background

The name of the city is composed of two words "Dehra" and "Doon". "Dehra" was derived from 'dera' signifying a temporary abode or camp of a religious saint cum preacher. "Doon" or "dun", in Sanskrit and Hindi means an elongated valley, hence the name "Dehradun". The Oxford dictionary defined it as "Valley in Shiwalik Hills". Among the number of large and small valleys between the Lesser Himalaya and Shiwalik Hills, Dehradun is one of the largest and best known of them all.

There are a number of myths related to the naming of "Dehradun" city. According to Skanda Purana, an ancient text, "Dun" formed part of the region called "Kedar Khand". It was included in the kingdom of Lord Ashoka by the end of the 3rd century B.C. History reveals that for centuries the region formed part of Garhwal kingdom with some interruption from Rohillas.

However, most popular myth is that the city derived its name from the local tradition. During the 17th century, the Sikh guru Ram Rai, (a sent in Udasi fakir sect) took up his residence in the Dun. History connects the event with Guru Har Rai, the leader of the famous Sikh sect who died in 1661 leaving behind two sons, Ram Rai and Har Kishan. After the death of Guru Har Rai, emperor Aurangzeb, confirmed the election of guru Har Kishan and direct Ram Rai to retire to the wilderness of the Dun. In obedience to the emperor's command, Ram Rai retired to the Dun at Kandli on the river Tons. Later on he moved from the Dun and settled down in Khurbura, now included in the city of Dehradun. Guru Ram Rai built a temple at the village Dhamanwala, which became the nucleus of the present city and even today his Darbar Saheb is the heart of the city's cultural and spiritual life.

For about two decades till 1815 the city was under the occupation of the Gorkhas. In April 1815, Gorkha rulers were ousted from Garhwal and Garhwal was annexed by the British. In the decades that followed, the British Government felt that the material progress of Dehradun and adjoining hill towns of Mussoorie and Landour was dependent upon colonization and reclamation of the wastelands. This led the government to encourage capitals. The growth of tea industry and the extended operations of forest department, the establishment of two military Cantonments (in 1872 and 1908), increasing popularity of Mussoorie and Landour, as a retreat of well to do pensioners and opening of the railway in 1900 have all contributed towards growth of Dehradun.

Later on, the construction of 1.6 km long Paltan Bazar (from Clock Tower to Gurudwara) led to the trade transaction and thus led to a very rapid growth of the city. This development was further aggravated after the second world war, through the establishment of new Cantonment, Ordinance Factory, Indian Institute of Petroleum, Indian Photo Interpretation Institute (renamed as Indian Institute of Remote Sensing), Oil and Natural Gas Corporation, Survey of India, Doon School and many other institution, offices and the growth of ancillary activities and other infrastructure facilities have contributed considerably to the growth and physical expansion of the city.

Thus, this unprecedented growth of institutions, offices, large and small scale industries, lime based industries at Dehradun have triggered the problems of congestion in the central core of the city and crippled the transportation system have resulted in overall environmental degradation. However, till 1960, there was no effort to channelise the haphazard growth of the city. Under this circumstances the city at present is suffering from a number of problems of uncontrolled and haphazard development, severe traffic congestion, rapid growth of slums on low lands, particularly at the beds of the seasonal streams and encroach of commercial activities.

3.2 Physiography

The general physiography of Dehradun city is located on a gentle undulating intermountain valley at an average altitude of 1350 m above mean sea level. The lowest altitude is 419 m. in the southern part, whereas highest altitude is 2280 m on the northern part. The northern slope (south facing), at the base of Mussorie hills, has gentle gradient of about 8° which mostly comprises of coarse detritus boulders, pebbles, gravels derived mainly from Pre-Tertiary and Siwalik rocks with top soil and silt /sand. The north facing southern slope of Siwalik hill range is steeper in gradient of about 10° formed mainly of reworked Upper Siwalik boulders and gravels with sand and silt. The drainage of the city is borne by two rivers namely: Bindal Rao and Rispana Rao. The direction of flow of these seasonal streams and nalas in the eastern part is north to south and western part it is north to southwest. The whole area is heavily dissected by a number of seasonal streams and nalas, which are locally known as "Khalas". Dense patches of forests exist along the north and in the outer limit of regulated areas.

3.3 Climate

In general, the climatic conditions of the study area are subtropical to temperate. Dehradun experiences four seasons, namely, winter, summer, rainy and post monsoon seasons. The period from November to February is the winter season. The summer season followed continues up to the end of June. The rainy season is from July to about third week of September. The following period, till the middle of November is the post monsoon or transition period.

3.3.1 Temperature

The maximum average temperature is 36± 6 ^{O}C and the minimum is 5 ± 2 ^{O}C. In summers, maximum temperature i.e. 36 ± 6° C and the minimum temperature is 16 ±7° C whereas in winters it varies from 23± 4° C and 5 ± 2° C respectively. In summers, the heat is often so intense and on individual day, the maximum temperature rises to over 42° C. January is generally the coldest month and the maximum temperature sometimes falls down to about a degree below freezing point of water. Inversion of temperature is a conspicuous phenomenon, owing to the location of the city in the valley.

Table 3.1: Rainfall and Temperature Distribution in Dehradun Area (2004-05)

Year / Month	2004			2005		
	Rainfall (mm)	Mean Max Temp ^{0}C	Mean Min Temp ^{0}C	Rainfall (mm)	Mean Max Temp ^{0}C	Mean Min Temp ^{0}C
January	60.6	18.8	5.1	39.3	19.5	4.5
February	107.6	19.0	5.1	3.1	24.8	5.3
March	67.8	26.1	9.4	23.4	28.5	8.9
April	45.2	34.8	13.8	32.2	33.2	14.2
May	108.2	36.5	20.7	49.8	35.9	20.3
June	214.8	31.9	23.0	301.2	31.7	22.8
July	544.2	29.8	24.1	664.0	31.0	24.6
August	215.0	31.1	24.1	307.3	31.3	24.1
September	156.7	31.2	24.4	16.4	32.6	20.5
October	0.0	31.7	15.2	0.9	32.2	16.0
November	1.2	27.0	9.7	2.4	27.4	8.6
December	0.0	22.9	3.6	8.4	22.5	5.0

(Source: Forest Research Institute Annual Report, Dehradun)

3.3.2 Rainfall

The average annual rainfall of Dehradun watershed is 2183.5 mm. About 87% of the rainfall is through monsoon, and is received during the months from June to September, July and August being the rainiest months. The table 3.1 shows the monthly total rainfall (mm) and monthly mean minimum and maximum temperature (°C) during the year 2004 and 2005.

3.3.3 Humidity

The relative humidity is high during the monsoon season normally exceeding 70% on an average in the city of Dehradun. The mornings are generally more humid than the afternoons. The driest part of the year is during the summer season, with the relative humidity becoming less than 45%.

3.4.3 Prevailing Winds

In Doon valley, winds are mostly from direction between south-west and north-west throughout the year except in October and November. The annual wind speed is 3.2 km / hour. Mountain and valley winds are common throughout the year.

3.4 Other Characteristics of City

Cities are attached with intangible values like status, character and function. Activities of the city dwellers, which emerge from the city functions, are manifested in the physical development of the city. A harmonious integration of the function and the activity can lead to a healthy and orderly development of the city. These are the major functions of Dehradun city –

(a) Administrative: Administration is one of its important functions of Dehradun being the interim capital of state. In addition, district headquarters and headquarters of a number of all India organizations are also located in the city.

(b) Educational and Institutional: Dehradun, besides being seat for prestigious educational institutions (e.g. Doon school) and other technical institutes, is famous for national level institutes such as Forest Research Institute, Wadia Institute of Himalayan

Geology, Oil and Natural Gas Corporation, Wild Life Institute, Indian Institute of Remote Sensing and many others.

(c) Commercial: Dehradun is the largest service center in Uttranchal State. It meets the trade and commerce requirements of this region. With the establishment of national level institutes and offices and the expansion of Cantonment area, the commercial activity has gained momentum.

(d) Industrial: Establishment of Industries based mainly on Limestone and Forests have attracted ancillary industrial units and other industries. Development of industries is likely to play a vital role in building a sound economic base of the city.

(e) Tourism: Dehradun is endowed with immense potentialities to be place of tourist attraction besides being gateway to Mussoorie. There are number of tourist places and recreational spots within short distance of the city, which are developed and landscaped for tourist attractions.

(f) Defense: Dehradun is the headquarters of Indian Military Academy. A number of other Defense establishments viz., Doon Cantonment, Clement Town, Ordinance Factory, Indo-Tibet Border Police, President's Body-Guard etc. are located in Dehradun. The defense function has played a vital role in shaping the development of the city and it will continue to influence the future development and economy of the town.

3.5 Environmental Status

Large-scale ecological degradation has taken place in urban Dehradun triggered by human activities. Increase in population pressure, forest clearing, unplanned stone mining, lack of planning and other uncontrolled environmental impacts have lead to mentally stressful life in the city and threaten the very existence of life in Dehradun City.

The air is thick with smoke and pollutants from over 200 lime kilns (Dehradun District). One of the major contributors to air and noise pollution is a cheap public transport, a three-wheeled, diesel operated vehicle, commonly named as 'Vikram'.

The secondary data compiled on the present environmental conditions prevailing in the city is enumerated below –

- Dust concentration (SPM) was found ranging from 266 μg /m^3 to 972 μg /m^3; where as permissible limit of 100 μg /m^3.
- Sulphur Dioxide concentration ranging from 8 μg /m^3 to 60 μg /m^3, against the pernlissible limit of 30 μg /m^3.
- Nitrogen oxide concentration ranging from 4 μg /m^3 to 102 μg /m^3, against the permissible standard of 30 μg /m^3.
- Drinking water data compiled revealed acceptable hardness but fecal coliform contamination varying from 240-9080 /100 ml, against a standard tolerable limit of 10 / 100 ml.
- During summers water supply situation becomes grim with demand increasing as much as 15 gallons/day/capita than the average supply of 30 gallons/ day / capita.
- Some of the disturbing facts are-
- Dust concentration is 3 to 10 times higher than permissible limits.
- SO_2 and NO_2 are two to three times higher than acceptable levels.
- Alarmingly poor quality of water whim hosts 24-900 times high of fecal coliform
- Drastic reduction in water availability during summers often only a third.

The problem of water contamination occurs due to lack of adequate chlorination. The fecal coliform counts found to be higher during the rainy season, as the rainy water brings in all sullage and unwanted things in the surface streams. The growth of algae in the distribution line as well as the tube well walls may also lead to the increase of pathogens in the water.

Dehradun used to be regarded as a green lung but now it is fast converting in to black lung. During the last few decades there is a frightening increase of various stress related disorders, hypertension, coronary artery disease, duodenal ulcer etc. Gastro-intestinal disorders are on rise. There is an ever-increasing incidence of throat irritation, infection, allergy, bronchial asthma and bronchitis with emphysema. The rate of incidence of Enteric fever and jaundice are also recorded to be high.

3.6 Trends of Urbanisation

The past heritage of Dehradun, concentration of national and regional level institutions, economic activities and availability of infrastructure will invite further influx of population from the valley and outside, in addition to its own natural growth. Also the regional linkages by rail and road, the climate and feasibility of spatial expansion of Dehradun will be instrumental in stimulating future growth. The rural growth centers within the valley and close to the vicinity of Dehradun city, which though not fully urbanized but are very much likely to merge. Rural-urban migration due to relatively more employment opportunities will also add to its expansion.

Dehradun is the second most populated district of Uttaranchal after Haridwar and accommodates 15.08% of state population. It is also second highly urbanized district consists 9 cities and towns after Udham Singh Nagar. Increase in population density at district level is also an indication of urbanization. According to Census of India 2001, population density of Dehradun district increased to 414 persons/km^2 in comparison to 332 persons/km^2 in 1991. With successive physical growth, Dehradun has been developed into a group of townships belonging to different periods. The parent township along with its urban out- growths and the cantonment; forms an urban agglomeration (Table 3.2).

Table 3.2- Population of Dehradun Urban Agglomeration

Name of Development	Population
Dehradun Municipal Corporation	4,26,674
Dehradun (C.B.)	53,675
Forest Reserch Institute	5,424
Clement Town (C.B.)	19,569
Rajpur (CT)	24,921
Doiwala (N.P.)	8,043
Total	

(Source: Census of India, 2001)

To conceive and develop a functional and integrated city structure for Dehradun, it is necessary to understand the existing land use pattern or disposition of various activities in all its intent, growth trends and physical limitation etc. Physical expansion or Dehradun has been strictly governed by the physiography of its site. Existence of a number of seasonal streams, dissected topography, hills in the north, east and north-west and other undulations have resulted in a sporadic growth especially in the northern parts. This topography has not only influenced the direction of growth but also conditioned the shape of the city. The main city sand witched between Bindal river and Rispana Rao, spreads around the Gurudwara and the clock tower. Restricted ribbon growth has resulted along Rajpur Road and Sahastradhara road. During the past decade the city has been expanding towards Haridwar road, Saharanpur road and Chakrata road where terrain is relatively plain and accessibility is easier. In general, the development of the city will have to be guided in such a manner that it fits in the topography of the city and enhances the scenic beauty provided by rivers, streams, hillocks and forests.

The quality of urban life and functional efficiency of a city is dependent on proper disposition of activities, the -inter-relationship it establishes between the work centers, living areas, community facilities and recreational areas. The inter-relationship among various land uses suffers from a break-down because of piece-meal and unrelated growth of the city. The wholesale and retail trades have mixed up in a haphazard manner causing inter-mixing of goods and passenger traffic. The road widths within the main city do not allow proper functioning of activities in this area. Scattered location of industries, housing of government offices in rented residential buildings, lack of residential accommodation near the industrial sites and office areas, growth of slums on low lands are leading the city to a chaotic situation.

Existing land use survey (Table 3.3) has reflected some uses as incompatible uses on the basis of their performance characteristics, traffic hazards and harmony with the surrounding areas. Dehradun Master Plan for 2001 proposed the land use pattern of about 7046.13 hc land. Out of which, about 4836.35 ha land has been developed as per the proposed use while 2209.78 ha land, which is about 31.36% of total land developed in other uses than the proposed.

Table 3.3: Deviation in Land Use Pattern in 2004-05 in Comparison to Master Plan Proposed for 2001

S.No.	**Land Use**	**Area in hectare**	**Percentage**
1.	Residential	1157.06	52.36
2.	Commercial	139.35	6.31
3.	Industrial	165.09	7.47
4.	Public & Semi-public	77.21	3.49
5.	Parks, Open Spaces and Recreational Areas	11.52	0.52
6.	Agriculture	355.14	16.07
7.	Orchards and Gardens	172.58	7.81
8.	Forest	19.36	0.88
9.	Circulation	21.49	0.97
10.	Unidentified Uses	90.98	4.12

(Source: Dehradun Master Plan, 2005-2025)

Planning and development of facility for water supply, sanitation and transportation are essentially required to cater the need of city. Other important infrastructure facilities, which require careful study and attention for finding proper solution in the present context, are parks, playground, parking space, drainage etc. for aesthetical value of the city.

3.7 Population Characteristics

The population of Dehradun was 2,100 in 1817. During 1981-91, its population has increased from 2,11,838 to 2,70,159. Taking this figure on an average, everyday 17 persons were assumed to be added to Dehradun Municipal Board population during last decade. The growth at this rate, population predicted for Dehradun Municipal Board to 4,20,271 by the year 2011. While population of Dehradun Municipal Corporation reached to 4,26,674 in 2001 census itself. The following table 3.4 shows the absolute figures of population; increase of population and the percentage increase for each decade from 1901-2001 for Dehradun Municipal Area.

Dehradun is the largest and capital city of Uttaranchal State. During the census year 1931, the population figure showed a decrease due to the outbreak of *Plague*. The migration of people from west Punjab after the partition in the late 40's was the main reason for the sudden increase in population (95.52 %). Since early 60's, the establishments of many government agencies, prestigious research and educational institutions and public schools have increased the population.

Table 3.4: Population Decadal Growth in Dehradun Municipal Area (1901- 2001)

Year	Population	Decadal Variation	% age Decadal Growth
1901	30,995	---	---
1911	42,568	+ 11,573	+ 37.34
1921	50,858	+ 8,290	+ 19.47
1931	43,206	- 7,652	- 15.05

1941	59,535	+ 16,329	+ 37.79
1951	1,16,404	+ 56,869	+ 95.52
1961	1,29,764	+ 13,360	+ 11.48
1971	1,69,827	+ 40,063	+ 30.87
1981	2,11,416	+ 41,589	+ 29.86
1991	2,70,159	+ 58,743	+ 27.78
2001	4,26,674	+ 156,515	+ 57.93

(Source: Census of India)

3.8 Socio-Economic Profile

Density Pattern

A study of density enables us to understand various aspects such as intensity of the use of urban land, problem of overcrowding arising out of congestion and high occupancy rate, adequacy and inadequacy of open space etc. Gross density within Dehradun Municipal area is 7,109 persons/km^2 according to 2001 census. Presently the average population density of Dehradun Municipal area 133 persons per hectare.

Housing

Housing areas, which cover large portion of an urban settlement, influence the quality of urban life, which in turn attacks, the efficiency of the settlements. The main housing areas are Govindpur, Rest Camp, Dharampur, Dalanwala, Karanpur, Rajpur, and relatively new colonies like Satya Bihar, Rajendra Nagar etc. Though in the localities like Jhanda Mohalla, Dandipur, Dhamawala, Balliwala, Kishanpur etc., most of the housing areas especially in the central core of the city have zigzag narrow roads, which are difficult to be widened, and there is a general lack of parks and open spaces. The relatively new housing areas are in the form of developed colonies which are located along Haridwar Road, Mussoorie Road and Chakrata Road. The areas beyond Bindal River are relatively better planned like Vasant Vihar.

Housing Shortage

According to 1971 Census figures, the total number of housing shortage within Dehradun area was 10605, which decreases to 7371 persons in 1981 Census and 880 in 1991 Census (Table 3.5). While, housing shortage increases to 3288 in 2001 Census. There are 1.4 households per residential house, i.e. more than one family is living in one house, which implies high occupancy rate. Household size while related to number of habitable rooms gives an idea about occupancy ratio and the degree of congestion. It is helpful in estimating future housing requirements of the city. On an average, there are 5 members/household.

Table 3.5: Housing Shortage and Occupancy Rate in Dehradun Area (1971-2001)

Year	**Household Size**	**Housing Shortage**	**Occupancy rate**
1971	5.34	10605	0.74
1981	5.22	7371	0.87
1991	5.10	880	0.98
2001	5.11	3288	0.97

(Source: Dehradun Master Plan 2005-2025)

<u>Housing and Slums</u>

The slums in Dehradun come under the jurisdiction of Municipal Corporation. Slums and squatter settlement have become inseparable parts of present urban scene in Dehradun. The problem is attaining serious proportion with slums growing at almost double the rate of the city. The increasing poorer community in slums and their housing requirement are not reflected by the government or commercial housing policies, which forms basis on the economic prospective.

Table 3.6: Area Occupied by Dehradun slum settlements

S. No.	Ownership of land under slum settlements	No. of Slums	Present and projected population			Area under encroachment (in hectare)
			1991	2001	2003	
1.	Municipal Corporation	62	86802	132330	144093	237.384
2.	Guru Ram Rai	9	22050	33615	36603	15.234
3.	Waqf Board	4	6378	9723	10587	8.666
4.	Not available	3	4570	6967	7586	9.036
5.	Shri Badrinath Temple	1	1250	1906	2076	7.530
	Total	79	121050	184541	190358	277.850
	Population density		436	664	685	

(Source : Dehradun Master Plan, 2005-2025)

The increasing population of Dehradun and lesser housing activities for the economically weaker section of the society is resulting in the proliferation of slums on public lands (Table 3.6). The area occupied by the slums is 6.05 % of the total area of Urban Dehradun. These slums are interspersed throughout various parts of the city and have grown mostly on the beds of Bindal river and other small seasonal streams, low lying areas and vacant parts of the city. Insanitary conditions, lack of drainage, water supply, paved streets and poor lighting facilities are the major problems prevailing in the slums

CHAPTER FOUR

BASIC GIS CONCEPT

4.0 GIS and Decision Making

GIS can be defined as a computerized system that deals with spatial data in terms of their collection, storage, management, retrieval, conversion, analysis, modeling, and display/output. It evolved as means of assembling and analyzing diverse spatial data. The development of GIS is the result linking parallel developments of several other spatial data processing disciplines, such as cartography, computer aided design, remote sensing technology, surveying and photogrammetry. Due to increasing complexity of the real world situations, more challenges emerge in knowing about the precious earth, and also in planning and decision making processes. Today, GIS is considered as an important tool in planning and decision-making. It has been found applied in many fields, such as cadastral mapping, land use planning, forestry, wildlife management, infrastructure planning, zoning, military, environmental monitoring, network planning, facility selecting, including socio-economic applications (taxation, census, marketing, health planning).

The success with which a GIS can be used is determined by several factors that can be grouped as follows:

The Dataset – We cannot use the data if we do not have. Getting the relevant data is important for an efficient GIS and the most cost effective data collection would be to collect only the data we need. The optimum data quality is the minimum level of quality that can be satisfactorily used for intended purpose.

Data Organization – Data is of no value unless the right data can be in the right place at the right time.

The Model – A good model is the simplest model that correctly and consistently predicts the behavior of the real world for the phenomena of interest.

The Criteria – The criteria used should be such that is understandable to a same level by all involved, such as analyst, decision-makers, other stakeholders, etc.

4.1 GIS Components

A GIS is comprised of hardware, software, data, humans, and a set of organizational protocols. These components must be well integrated for effective use of GIS, and the development and integration of these components is an iterative, ongoing process. The selection and purchase of hardware and software is often the easiest and quickest step in the development of a GIS. Data collection and organization, personnel development, and the establishment of protocols for GIS use are often more difficult and time-consuming endeavors.

4.1.1 The Hardware

A fast computer, large data storage capacities, and a high-quality, large display form the hardware foundation of most GIS (Fig. 4.1). A fast computer is required because spatial analyses are often applied over large areas and/or at high spatial resolutions. Calculations often have to be repeated over tens of millions of times, corresponding to each space we are analyzing in our geographical analysis. Even simple operations may take substantial time if sufficient computing capabilities are not present, and complex operations can be unbearably long-running. While advances in computing technology during the 1990s have substantially reduced the time required for most spatial analyses, computation times are still unacceptably long for a few applications.

While most computers and other hardware used in GIS are general purpose and adaptable for a wide range of tasks, there are also specialized hardware components that are specifically designed for use with spatial data. Many non-GIS endeavors require the entry of large data volumes, including inventory control in large markets, parcel delivery, and bank transactions. However, GIS is unique in the volume of coordinate data that must be entered.

4.1.2 The Software

GIS software provides the tools to manage, analyze, and effectively display and disseminate spatial data and spatial information. GIS by necessity involves the collection and manipulation of the coordinates we use to specify location. We must collect qualitative or quantitative information on the non-spatial attributes of our geographic features of interest. We need tools to view and edit these data, manipulate

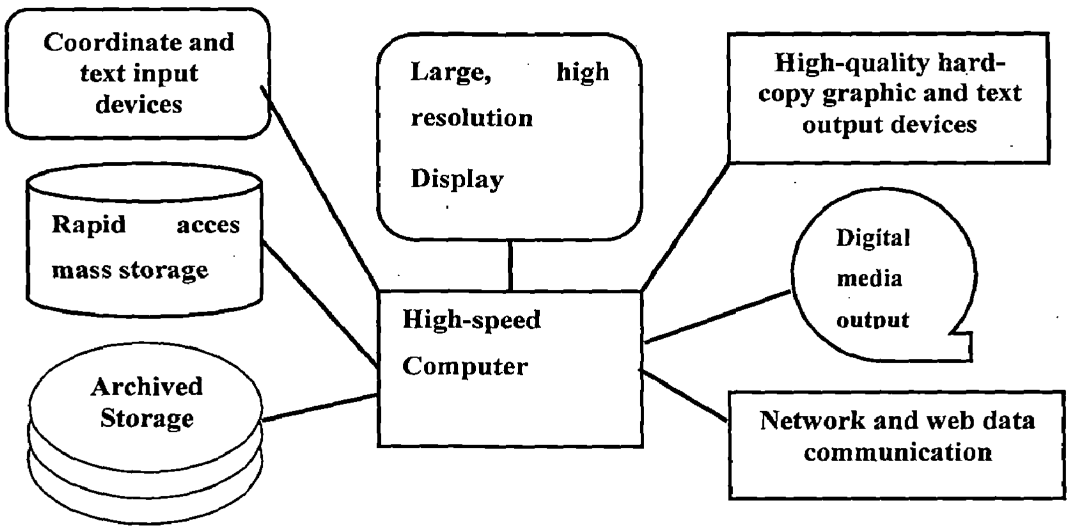

Figure 4.1 GIS are typically used with a number of general purpose and specialized hardware component.

them to generate and extract the information we require, and produce the materials to communicate the information we have developed. GIS software provides the specific tools for some or all of these tasks.

There are many public domain and commercially available GIS software packages, and many of the commercial packages originated at academic or government-funded research laboratories. The Environmental Systems Research Institute (ESRI) line of products, including Arc/Info, is a good example. Much of the foundation for Arc/Info was developed during the 1960s and 1970s at Harvard University in the Laboratory of Computer Graphics and Spatial Analysis. Alumni from Harvard carried these concepts with them to Redlands, California when forming ESRI, and included them in their commercial products.

The function commonly provided by GIS software are :

Data entry	Analysis
manual coordinate capture	spatial query
attribute capture	attribute query
digital coordinate capture	interpolation
data import	connectivity
Editing	proximity

manual point, line and area feature editing manual attribute editing automated error detection and editing Data management copy subset, merge data versioning data registration and projection summarization, data reduction documentation	proximity and adjacency buffering terrain analysis boundary dissolve spatial data overlay moving window analysis map algebra Out put map design and layout hardcopy map printing digital graphic production export format generation metadata output digital map serving

4.1.3 Data, Dataset and Database

Data is information represented in the format of digit, letter and symbol used to describe status, behavior and their consequence of geographical object. There are some inner relations and different between data and information, as defined above, data indicates those value recorded and stored in computer, the meaning of the value represented is information.

Dataset is the minimum body of data used for data transform, storage, manipulation, copying, and other activities. Usually, there is one type of spatial data feature as point, line or polygon employed to represent one kind of geographical object such as river or topography or building. In most cases, data layer have the same meaning with dataset, but a few data layer can be organized into one dataset in some special occasions.

Database, as the word per se means data and base, is the combination of dataset according to the defined logical principles. Usually, the dataset in one database share the same data structure, data storage method, data format and similar data management interface. Except the dataset contained, database itself has some functions as data updating, data manipulation (extracting, clipping, overlaying, statistics), and user propriety definition.

4.1.3.1 Primary data and secondary data

Data and information representing the real world can be stored in simplified forms and processed to facilitate decision-making (Fig. 4.2) or it can also be presented later in simplified forms to suit specific needs. Geographical data come in many different forms. A basic distinction can be made between primary and secondary data.

Primary data refers to the sorts of information that can be collected first hand by fieldwork and questionnaire survey. The primary geo-spatial data can be collected from the sources, such as Geodetic Surveying and Geodetic Control Networks; Surveying; Photogrammetry; and Remote Sensing.

Secondary data are those found in published sources, such as official statistics, maps and aerial photographs, or are gathered by some agency other than you. Secondary data acquisition refers to the process of converting existing maps or other documents into a suitable digital form. There exists lot of secondary data but sometimes not all of them are available for use. Sometimes no convenient secondary data source exists and one has collect the necessary data conducting field survey which can be time consuming and expensive.

There are number of important points relating to why we collect data in the first instance and this should be considered on the ground of sound scientific approach of the problem before the real data collection process start. Depending upon the objectives, there may be two approaches. The *Inductive* approach, also called as classical method, involves observation and collection of data in the first stage followed by statement of theory and verification, where as the *Deductive* approach, also called as critical rational method, involves setting up the problem at the first stage followed by collection of necessary data and statement or theory at later stages.

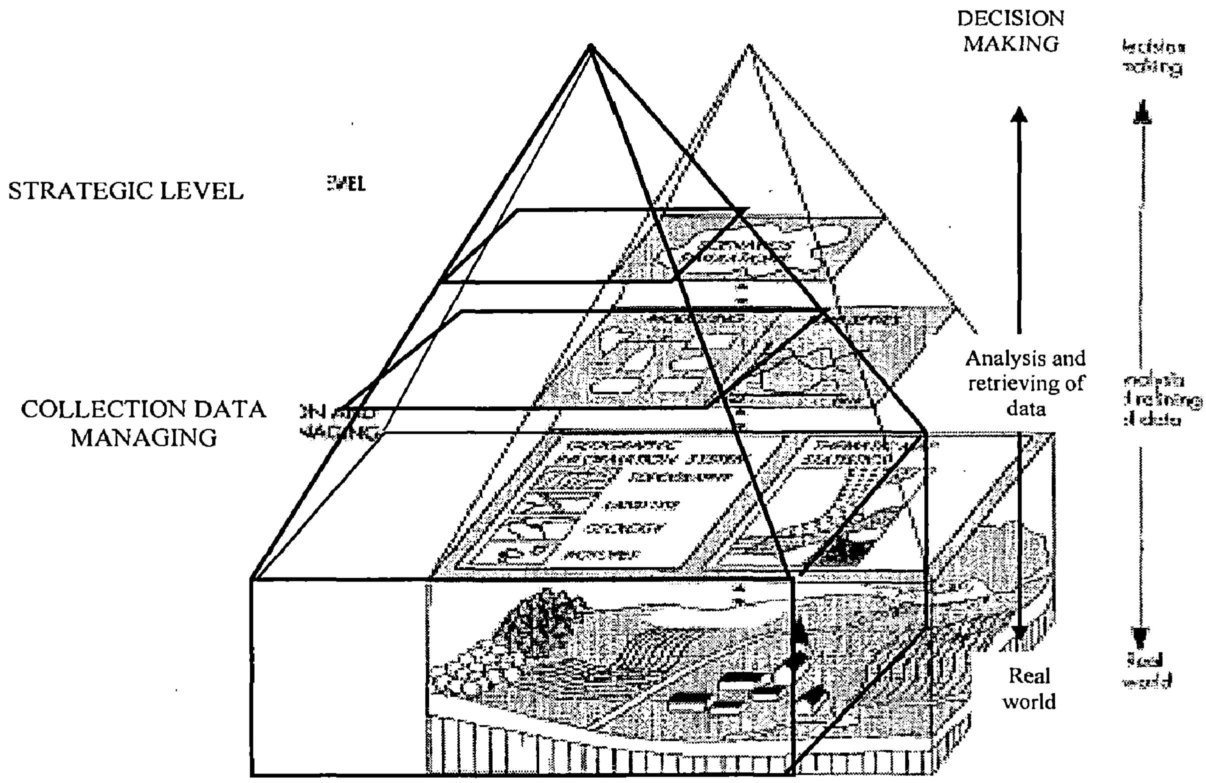

Figure 4.2. A Decision Making Pyramid. (Bernhardsen, 1992 after Grossman, 1983)

4.1.3.2 Geospatial Data

Geo-spatial data are also called as Geographical data, Geographic data, Geographic *Information, GIS data, Earth-sciences data or Geo-scientific data,* and *spatial data.* Geographical data are information that identifies the geographic location and characteristics of natural or constructed features and boundaries on the earth. The main difference between geographical data and other data is that the later helps answer question like, what? or where? as the former answers both what? and where? It is because that it contains *Geometric* or *Spatial* data for spatial elements and *Attribute* data (Figure

Spatial data is used to describe the location of geographical object, and attribute data describe the fundamental characteristics of the phenomena involved. For instance, the objects classified as buildings may have a number stores attributes with legitimate values of 1 to 10, etc. *Attribute data* can in turn be sub-divided into *Qualitative* and *Quantitative* data.

Historically, several terms have been used to describe the data in a GIS database, among them *features, objects, or entities*. The term *feature* derives from cartography and is commonly used to identify "*features shown on a map*," while *entity* and *object* are terms from computer science used to identify the elements in a database. The normal dictionary definitions of these terms are:

Object: a thing that can be seen or touched; material thing that occupies space characterized by type, attribute, geometry, relation and quality.

Entity: a thing that has definite, individual existence in reality (e.g. house number)

Feature: the make, shape, form or appearance of a person or thing (e.g. circle, linear)

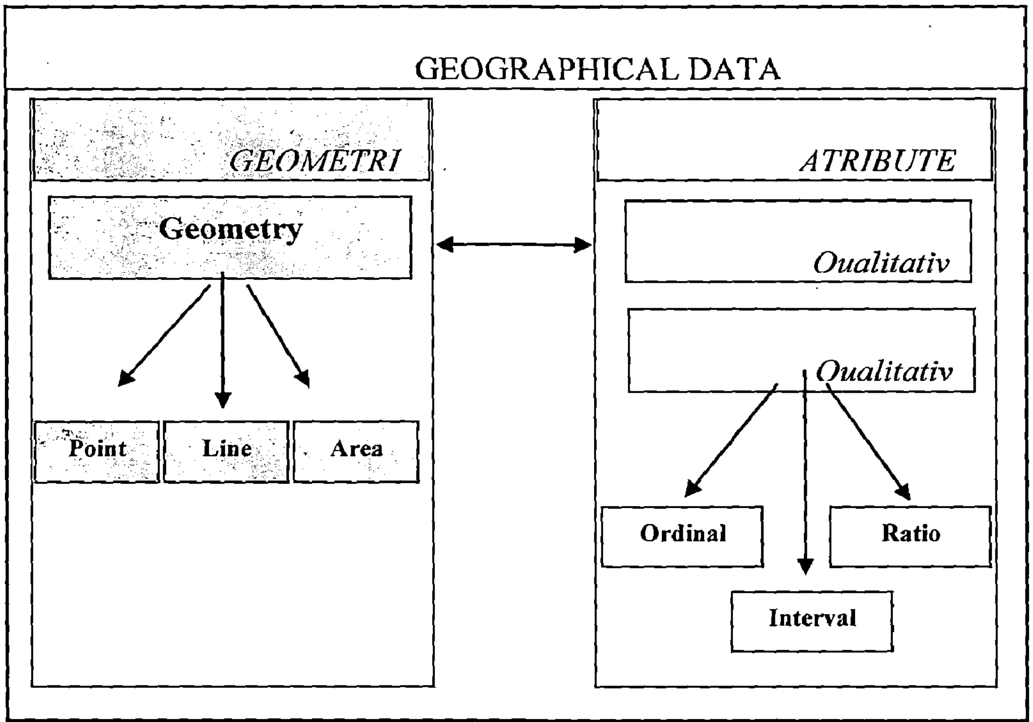

Fig. 4.3. Geographical Data divided into Geometric and AttributeData (Bernhardsen, 1992)

4.1.3.3 Data output:

Data output is the operation of presenting the results of data manipulation in a form that is understandable to a user or in a form that allows data transfer to another computer system. The basic output formats from a GIS are hard copy, soft copy, am) electronic outputs (Fig. 3.6). Maps and historical tabulations are output in the hard copy format by the help of hard copy output devices such as dot matrix pi-inters, ink jet plotters, pen plotters, matrix camera, color laser printer, etc.

Soft copy output is the format as viewed on a computer monitor. It may be text or graphics in monochrome or color. Soft copy displays are used only for temporary display. The soft copy device most often used in GIS is computer monitor", cathode ray tube.

Output In electronic format consist of computer compatible files. They are used to transfer data to another computer system either for additional analysis or to produce a hard copy output at a remote location.

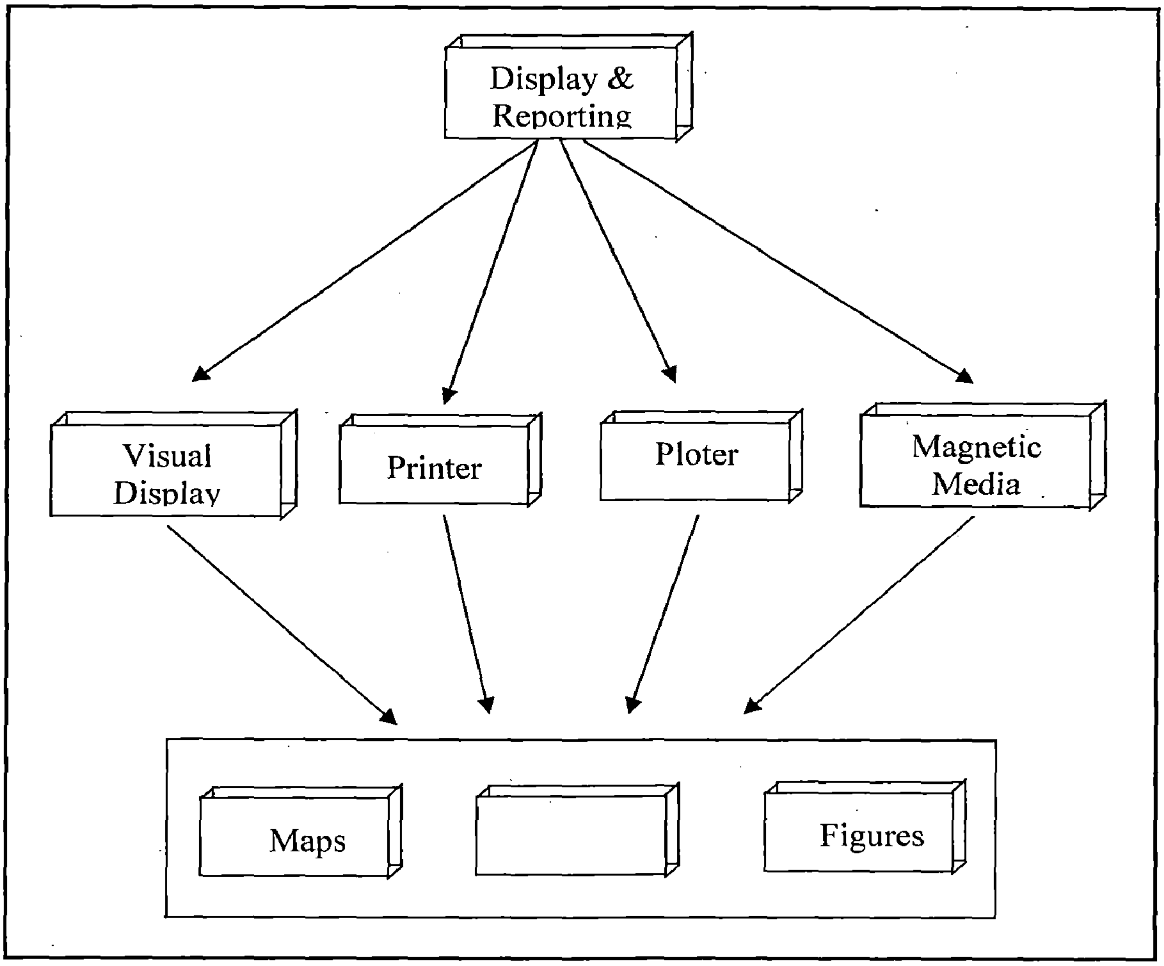

Figure 4.6. GIS Data output (Burrough, 1986)

4.1.3.4 Modeling

A model is the simplest representation of reality in which it presents significant features or relationships in a generalized form, i.e., it is the selective approximation of reality (Valenzuela, 1990). A model can be descriptive (describes the real world, e.g. map), predictive (predicts what might occur under certain conditions, e.g. USLE, soil erosion model) or decisive model. A characteristic of modeling is the use of the attribute data, i.e., each map has one or several tables that include a specific single datum (attribute) of the pertinent map.

4.1.3.5 Spatial Elements

Spatial objects in the real world can be thought of as occurring as four easily identifiable types: *Points, Lines, Areas,* and *Surfaces* (Figure 4.4). Collectively, they can represent most of the tangible natural and human phenomena that we encounter on an everyday basis. In general, points, lines, and areas are used to explicitly represent real-world objects, where as surfaces are mostly used for volumetric representation, such as to represent hills, valleys. Thus, all data can be considered to be explicitly spatial.

Point features are spatial phenomena each of which occurs at one location in space. Each feature is said to be discrete in that it can occupy only a given point in space at any time and considered to have *no spatial dimension* – no width or length. Example of such feature would be a house or a village. But a village can be represented by point feature or area feature as well depending upon the resolution of data.

Line features are conceptualized as occupying only a *single dimension* in coordinate space. They are represented as the series of single coordinates connected to each other. Roads, rivers, are the examples of linear features. The resolution or scale of given dataset once again places a fundamental limitation to conceive them as having any width. Linear features, unlike point features, allow us to measure their spatial extent/length.

Area features have *two dimensions* both length and width dimensions. Area is composed of series of lines that begin and end at the same location. We can describe their shapes and orientations, and the amount of territory occupied as well. In database, the term polygon is often used instead of area. Again, physical size in relation to the scale determines whether an object is represented by an area or by a point.

It is often that area is divided into regular squares or rectangles so that all objects are described in terms of areas. This entire data structure is called a *grid*. Each square or rectangular is known as a cell and represents a uniform value. Adding the dimension of height to area features allows us to observe and record the existence of *Surfaces*. Surfaces have *three dimensions* – length, width, and height. For instance, hills, valleys, and ridges can be described by citing their locations, amount of area they occupy, how they are oriented, and by noting their heights.

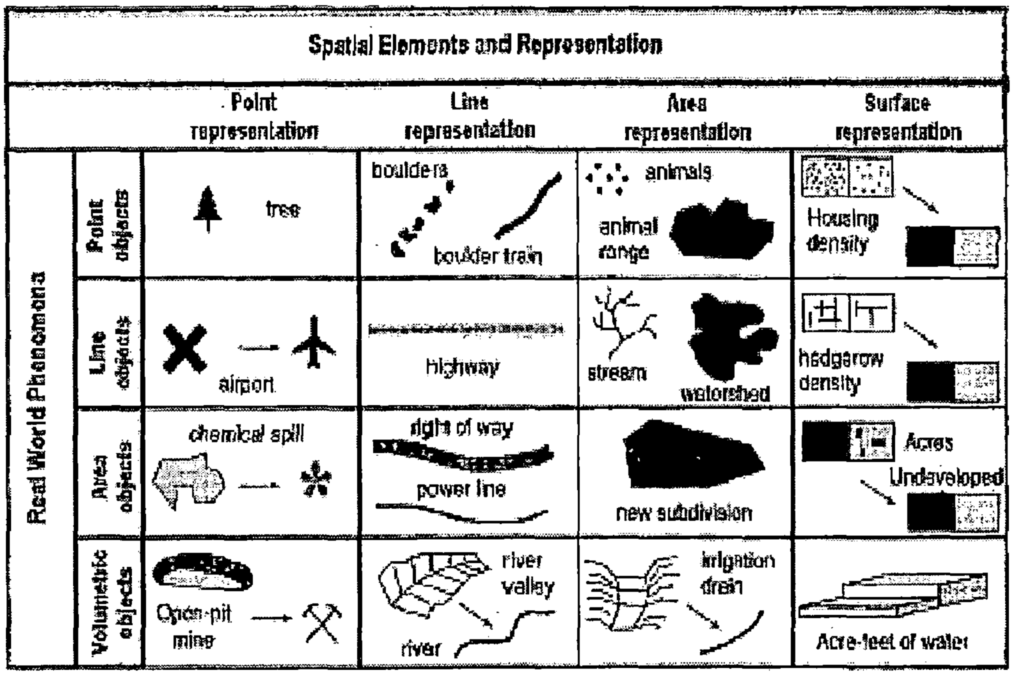

Fig 4.4 Spatial Elements and Representation (DeMers, 2000)

4.2 Basic data Models

Spatial elements can be represented in two models: *Vector* and *Raster/Grid* (Figure 4.5). In the vector model, the spatial locations of features are defined on the basis of coordinate pairs. These can be discrete, taking the form of points (POINT or NODE data); linked together to form discrete sections of line (ARC or LINE data); linked together to form closed boundaries encompassing an area (AREA or POLYGON data). Attribute data pertaining to the individual spatial features is maintained in an external database. The data model used by the software, like Arc/Info, ArcView is Vector model.

In raster model, one or group of cell/grid/pixel depending upon the grid resolution represents spatial elements. Most of raster models adhere strictly to a single attribute per cell structure although some raster models support the assignment of values to multiple attributes per discrete cell.

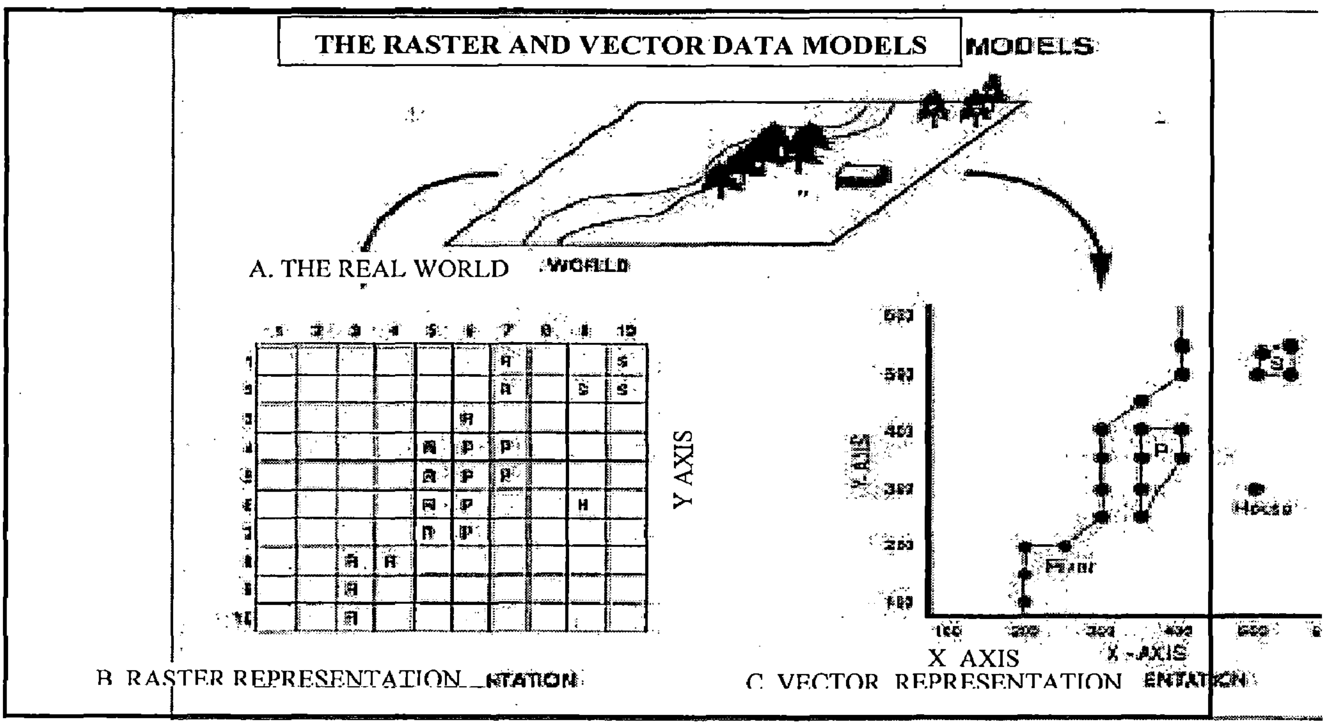

Fig4.5. Comparison of Raster and Vector Models (Aronoff, 1991)

Table 4.1 presents the advantages and disadvantages of vector and raster model. Vector data sets can have topology, i.e. in addition to the position of every feature; the spatial relationships of adjacency and connectivity between features are also maintained. Topological relationships are stored in a series of relational databases. Each database stores information about a feature. For example, a database would store the information about each individual arc, such as number of the arc, beginning node number, ending node number, polygon to its left, and polygon to its right.

Within this model spatial data is not continuous but is divided into discrete units. In terms of recording where individual cells are located in space, each is referenced according to its row and column position within the overall grid. To fix the relative spatial position of the overall grid, i.e. to *geo-reference* it, the four corners are assigned planar co-ordinates. An important concept concerns the size of the component grid cells and is referred to as grid resolution. The finer the resolution the more detailed and potentially closer to ground truth a raster representation becomes. Unlike the vector model there are no implicit topological relationships in the data. The following information should always be recorded when assembling, compiling and utilizing raster data:

. Grid size (number of rows and columns)

. Grid resolution

. Geo-referencing information, e.g. corner co-ordinate, source projection

Table 4.1. Vector vs Raster Data Model

Vector	Raster
Advantages	
Compact data structure (less data volume) Efficient topology encoding, good for operations, such as network analysis Better graphics for precise expression	Simple data structure Easier and efficient overlay operation High spatial variability is efficiently represented Efficient in manipulation and enhancement of digital images
Disadvantages	
Complex data structure Implementation of overlay operations is difficult Inefficient representation of high spatial variability Not effective for manipulation and enhancement of digital images	Large data volume (data compression technique can overcome this problem) Difficult to represent topological relationships Less aesthetic graphic output Not good for some operations, such as network analysis

4.3 Data Analysis and Modelling

The most significant characteristics of GIS are the provision of the capabilities for data analysis and spatial modeling. These functions use the spatial and non-spatial attribute data of the GIS database to answer questions about the real world. The database in GIS is the model of the real world that can be used to simulate certain aspects of reality. A model may be represented in words, m mathematical equations or as a set of spatial relationships displayed on a map. The general problem in data analysis is: users query -* database link -*• output.

The user has particular specification, constraints or query. The database contains information in the form of maps that can be used to answer the users query. All that is necessary is to establish a link between database and output that will provide the answer the form of a map, table, or figure. The link is any function that can be used to convert data from one or more input maps, into an output.

4.3.1 Analysis; Functions:

The power of GIS lies in its ability to analyze spatial and attribute data together. A large range of analysis procedure/ functions have been divided in to four categories: retrieval, red classification and measurement overlay; Distance and connectivity; and neighborhood.

4.3.2 Retrieval, Reclassification and Measurement Operations

In these functions retrieval of both spatial and attribute data are made and only attribute data are modified. Creation of new spatial elements is not made.

Retrieval operations: This involves the selective search and manipulation and output of data. Retrieval operation includes the retrieval of data using:

- Geometric classification,
- Symbolic specifications,
- A name of code of an attribute,
- Conditional and logical statement.

Reclassification procedures: This procedure involves the operation that reassign thematic values to the categories of a existing map as a function of the initial value, the position size or shape of the spatial configuration associated with each category (for instance a soil map reclassified into erodibility map). In raster based GIS, numerical values are often used for indicate classes. A cell might be assigned the value to indicate classes. Classification is done using simple data layers as well as with multiple data layers as part of an overlay operation.

Measurement operations: Spatial data measurement includes: calculation of distance, length of lines, areas and perimeter of polygons, and volumes. Measurements involving points are: distance from a point to a point, a line, a polygon, enumeration of the total number as well as the enumeration of points falling within the po lygon.

4.3.3 Overlay Operation

Overlay operation creates a new data set containing new polygons formed from intersection of the boundaries of the two or more sets of separate polygonal layers. There are two common overlay operations: arithmetic and logical. Arithmetic overlay includes operation such as addition, subtraction, division and multiplication of each value in a data layer by the value in the corresponding location in the second data layer. Logical overlay involves the selection of an area where a set of conditions are satisfied. The logical overlay operation is done using the rules of Boolean logic. Boolean algebra uses the operations of AND, OR, XOR, NOT to see whether a particular condition is true or false .

4.3.4 Neighborhood Operation

This involves the creation of new data based on the consideration of roving window of neighboring points about selected target locations. They evaluate characteristics of an area surrounding spatial location. In all neighborhood operations, it is necessary to indicate one or more target locations, the neighborhood considering each target and the type of function to be executed The typical neighborhood operation in most GIS's are; search topographic functions and interpolation.

Search functions:

This constitutes one of the most commonly use neighborhood function. Value assignment to each target feature is made on the basis of some characteristics of its neighborhood. The basic parameters required to be defined in a neighbor search are targets, the neighborhood, and the functions to be applied to the neighborhood to generate neighborhood value. The search area is usually square, rectangular or circular whose size is determine by the analyst.

Topographic functions:

Topography refers to surface characteristics such as the slope, relief and form of the area. The topography of a surface can be presented in a digital elevation model (DEM). DEM represents a topographic surface terms of a set of elevation values measured at a finite number, o points, and contains terrain features of geo morphological importance such as valleys and ridges, peaks and pits (Valenzuela 1990). Topographic functions are used to calculate values that describe the topography of an area. The most common transformations working with elevation data are the slope and aspect - slope face direction.

Interpolation:

This procedure predicts unknown values at any sampled sites using the known values of existing observations neighboring locations. Point and aerial interpolation involve variety of methods such as polynomial regression, kriging , splines , trend surface analysis, Fourier- series and moving averages (Burrough, 1986; Valenzuela, 1990). The quality of interpolation results is a function of the precision, accuracy, number and distribution of the known points used in the. calculation and the manner in which the mathematical function models reality. The unknown values are the n calculated according to this function.

4.3.5 Connectivity Functions

Connectivity operation is those that estimate values (quantitative or qualitative) by accumulating them over the area that is being traversed. These operations require the specification of the manner in which the spatial elements arc interconnected, specification of the rules that control the movements allowed along the spatial elements and the unit of measurements. Connectivity functions are grouped in to contiguity, proximity, and network and spread operation.

Contiguity:

Contiguity measures characterized spatial units that are connected. A contiguous area is formed by a group of spatial units that have one or more common characteristics and constitute a unit. Common measures of contiguity are the size of the contiguous area and the shortest and the longest straight line distance across the area.

Proximity:

This involves the measurement of the distance between features, the measurement unit can be distance in length, travel distance in time or other units. The necessary parameters, which must be specified to measure proximity, are the features or objects (roads, houses, etc.), the units of measure (meter, length, etc.), a function to calculate proximity (Euclidean distance), and area to be analyzed. A buffer zone may be the result of a proximity analysis.

Network:

Network functions are commonly used in analysis that requires moving resources from one location to another. GIS is used to perform network analysis such as prediction of network loading, |or instance, transport of water and sediment in fluvial system, route optimization such as air line scheduling, urban transportation, services or municipal garbage collection, and resources allocation, eg. subdivision of municipal districts into zones that can be efficiently serviced by hospitals and schools. In network analysis four components are usually considered: a set of resources (eg. sediment transport by water), one or more locations where the resources are located (eg. a fluvial system), destination (eg. outlet of the watershed), and a set of constraints (eg. only permanent streams of higher order).

4.4 Coordinate System and Map Projection

To analyze, manipulate, measure and store reasonably, geospatial data must be put into one certain spatial coordinate system. There are two kinds of coordinate system for geo-spatial data, *Spherical* and *Cartesian* coordinate system (Fig.4.7). In *spherical coordinate* system, each point feature can be described uniquely with a pair of latitude and longitude value although latitude and longitude are not uniform across the Earth's surface.

In *Cartesian* or *Planar* coordinate system, each point feature on the Earth will be projected onto a flat surface by a pair of x and y coordinates on a grid. Using this system, the coordinates at the origin are x = 0 and y = 0. On a girded network and equal spacing, the horizontal line in the center of the grid is call the x-axis, and the central vertical is call y-axis. Therefore, coordinate value; measures of length, angle and area are uniform in this coordinate system.

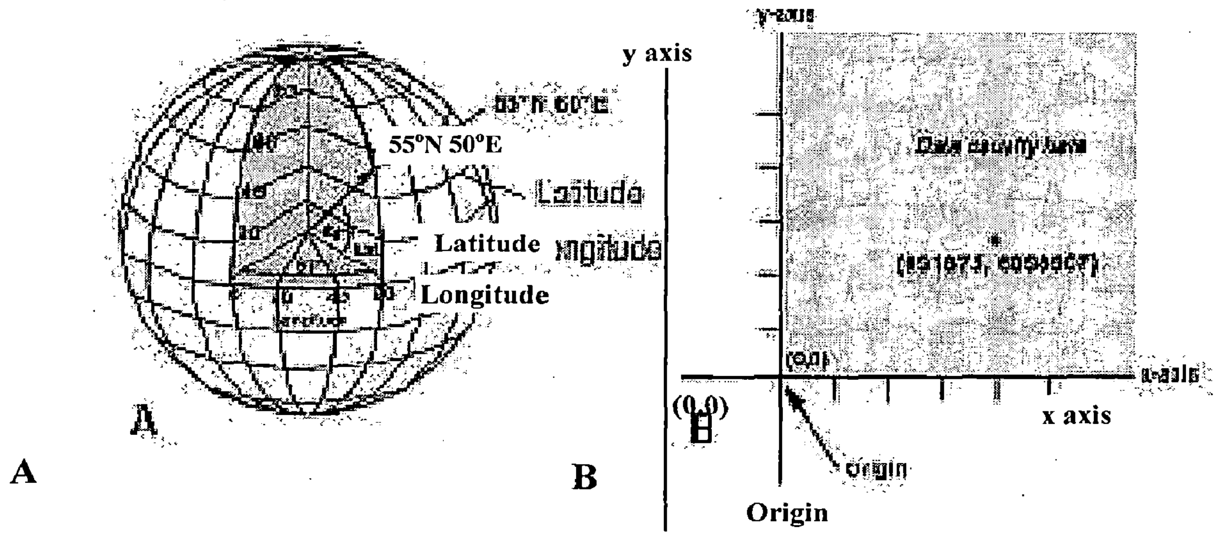

Fig. 4.7 Spherical and Cartesian Coordinate System

The main co-ordinate reference systems for describing a geographic position mathematically are geodetic reference systems and map projections. *Geodetic reference systems* are used for describing the figure of the Earth and positions on it: *ellipsoids* (and the *sphere*) are used for describing the horizontal position. The shape of an ellipsoid is defined by a Semi-major and Semi-minor axis, and there are several spheroids available for use in different parts of the world. Each of them assume different semi-major and semi-minor axis. *Geoids* are the gravity related model for referencing the elevation. Geodetic reference systems have a *datum*, which defines the position of the spheroid relative to center of the earth. It defines the origin and orientation of latitude and longitude lines. There are two types of datum. *The latitude and longitude of a point, the azimuth of a line from that point, and the two radii needed to define the geometric reference surface that best approximates the surface of the earth in the region of the survey define horizontal datum. Vertical datum* ensures that elevation and depth measurements are held to a common vertical standard.

When we try to transform the location information on three-dimensional earth surface onto a two-dimensional map, *projection* is needed. In other words, *Map projections* are used to map the curved surface of an ellipsoid to a plane. This achieved by transforming the values with mathematical expressions. There are three major projection types, namely Planar (also know as Azimuthal), Conic, and Cylindrical projections depending on the shape of the developable surface (Fig. 3.8).

Azimuthal projections, points are projected from the surface of the Earth to the plane. A commonly used projection of this type is the stereographic conformal projection. This type of projection includes Gnomonic, Stereographic, Orthographic, Azimuthal Equal Area, Azimuthal Equidistant, and Globular projection. Planar or Azimuthal Projections are used most often to map Polar Regions.

Conic projections result from conceptually transferring the earth's coordinates onto a cone. This family of projection includes Simple Conic, Two-Standard Parallel Conic, Lambert's Conformal, Albert's Equal Area, Conic Equidistant, Polyconic, and Bonne Projection.

Cylindrical projections are a family of projections resulting from conceptually transferring the earth's coordinates onto a cylinder. Cassini or Cassini-Soldner, Gall's Cylindrical, Mercator, Lambert's Cylindrical Equal-Area, and Transverse Mercator projection. *Universal Transverse Mercator (UTM)* projection system is one of the commonly used projection systems.

The two most commonly used projection system are polyconic and world geodetic system 1984 (WGS 84). These coordinate systems can successfully be used in the context of GMS countries.

4.5 GIS and Decision Support System

The successful operational applications of GIS require institutional setting and must support the management of resources or some problem solving processes. Furthermore, it must exist within an organizational setting that is capable of providing it with proper support.

The recent development of decision support system (DSS) brought a new concept of integrating GIS and resource models into a tightly-coupled system in that the systems more likely to be used to aid decision making. Out of the combination of DSS and GIS emerges an entirely new system called spatial decision support system (SDSS). SDSSs are new classes of computer systems that combine the technologies of GISs and DSSs to aid decision makers with problems that have spatial dimension. Fig. 4.8 presents the melding of GIS and DSS into SDSS.

SDSSs are oriented towards the decision makers and offers one unifying framework for integrating GIS and DSS including the models within the DSS, i.e, the SDSS framework offers a means to increase the utility of both GISs and DSSs to assist decision makers.

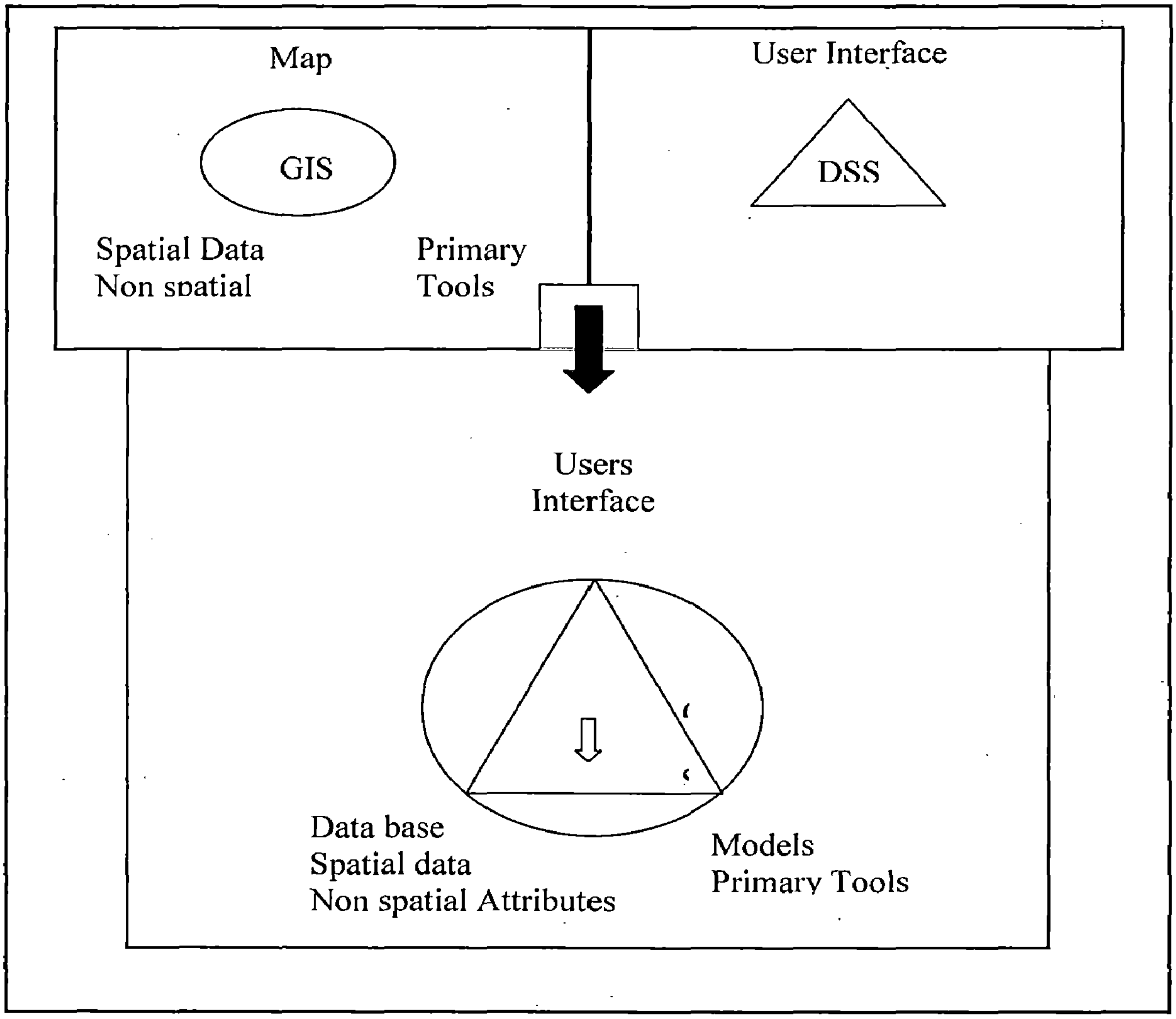

Figure 4.8 SDSS as Combination of GIS & DSS (Michael et al,1993)

4.6 Remote Sensing Concept

Remote sensing is a technology for sampling electromagnetic radiation to acquire and interpret non-immediate geospatial data to extract information about features, objects, and classes on the Earth's land surface, oceans, and atmosphere. Generally, remote sensing refers to the activities of recording/observing/perceiving (sensing) objects or events at far away (remote) places (Fig. 4.9). In remote sensing, the sensors are not in direct contact with the objects or events being observed. The information needs a physical carrier to travel from the objects/events to the sensors through an intervening medium. The electromagnetic radiation is normally used as an information carrier in remote sensing. So remote sensing is the term used to describe (i) acquiring of images, (ii) processing of images, and (iii) the interpretation of images. This is done by studying the interaction between the objects of interest and the electromagnetic spectrum. Remote sensing in which the object of study is subjected to electromagnetic radiation emitted from the data collection device is active remote sensing. Radar is an example of active remote sensing. Passive remote sensing is done by recording the naturally occurring interaction between the object of study and the source of electromagnetic radiation, such as photography.

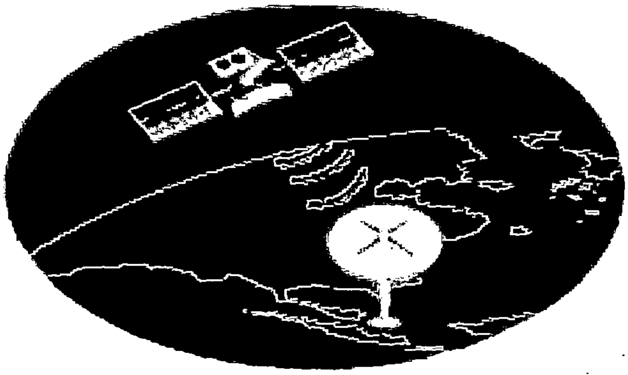

Fig. 4.9 Acquisition of Remote Sensing Images

Remote sensing is a technology to observe objects' size, shape and character without direct contact with them. The reason why they can be observed without contact because of the characteristics of electromagnetic waves, such as light reflected or radiated from the objects. These reflected or radiated electromagnetic waves are received by sensors aboard earth observation satellites. Different objects reflect different amounts of light in different parts of the electromagnetic spectrum (EMS). For example, vegetation strongly reflects light in the green wavelengths of the visible part of the EMS which is why plants appear green. However, plants reflect even more infra-red light than they do in green light.

The spectral signature of an object differs in reflectance in the different wavelengths of EMS. Knowing about the spectral signatures of different types of features helps us to interpret remotely sensed data (which is a record of the reflectance values of the ground for different wavelengths, or 'bands'). The EMS is a continuum of all electromagnetic waves arranged according to frequency and wavelength (Fig. 4(a).2).

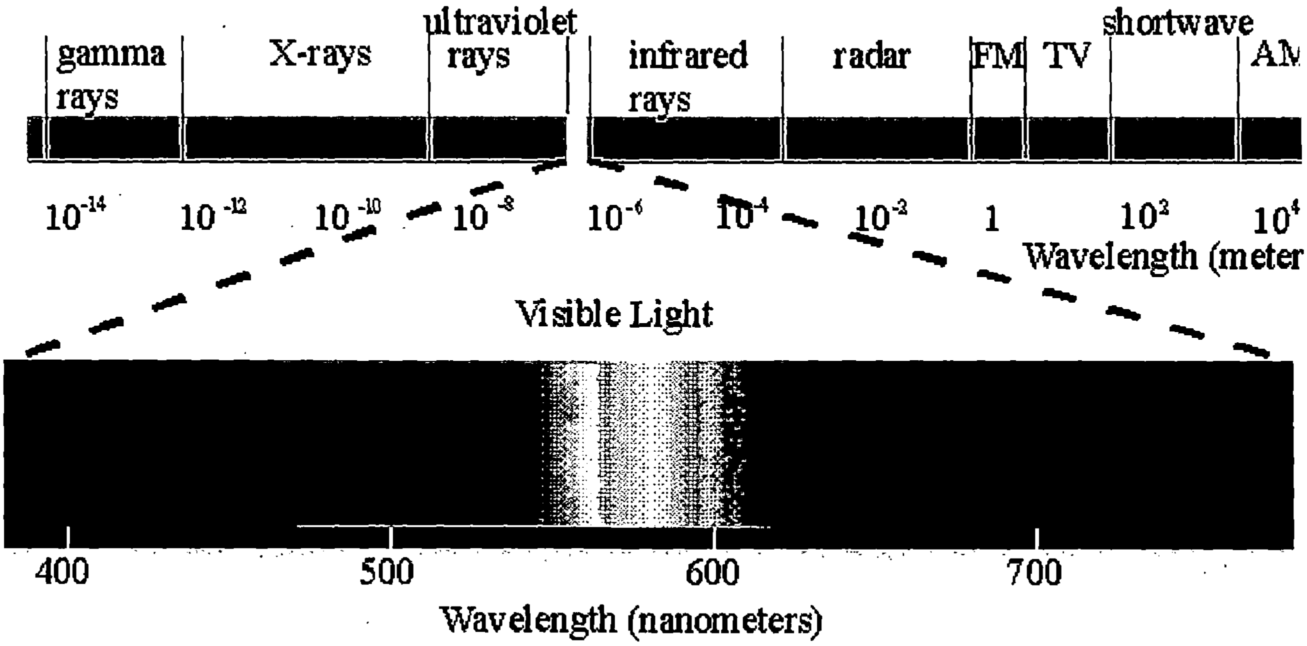

Fig. 4.10: Electro-magnetic Spectrum (EMS)

The sun, earth, and other bodies radiate electromagnetic energy of varying wavelengths. Electromagnetic energy passes through space at the speed of light in the form of sinusoidal waves. The wavelength is the distance from one wavecrest to another wavecrest. In general, the characteristics of reflected or radiated electromagnetic waves depend on the type or condition of the objects (Fig. 4.10). Therefore by understanding the characteristics of electromagnetic waves and by comparing to the observed information, we can know the size, shape and character of the objects.

4.6.1 Spectral Reflectance Curves

Figure 4(a).4 shows typical spectral reflectance curves for three basic types of earth features; healthy green vegetation, dry bare soil, and clear lake water. These curves

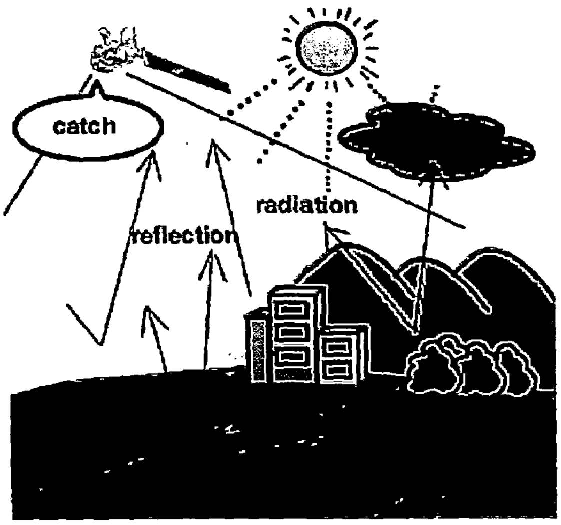

Fig 4(a).3: Reflected Radiation from Various Objects

indicate how much incident energy would be reflected from the surface, and subsequently recorded by a remote sensing instrument. At a given wavelength, the higher the reflectance, the brighter the object appears in an image.

It is clear from this Figure that the vegetation reflects much more energy in the near-infrared (0.8 to 1.4 μm) than it does in visible light (0.4 to 0.7 μm). The amount of energy that vegetation reflects is related to the internal structure of the plant, and the amount of moisture in the plant. A green surface, like vegetation will appear dark in the near infrared, because it doesn't have the internal structure of living vegetation. Another feature to notice is that clear water reflects visible light only, so it will appear dark in infrared images.

4.6.2 Digital Remote Sensing Image Analysis

A digital image is a two-dimensional array of pixels. Each pixel has an intensity value (represented by a digital number) and a location address (referenced by its row and column numbers) (Fig. 4.6.2). Analysis of remote sensing imagery involves the identification of various targets in an image, and those targets may be environmental or artificial features which consist of points, lines, or areas. Targets may be defined in terms of the way they reflect or emit

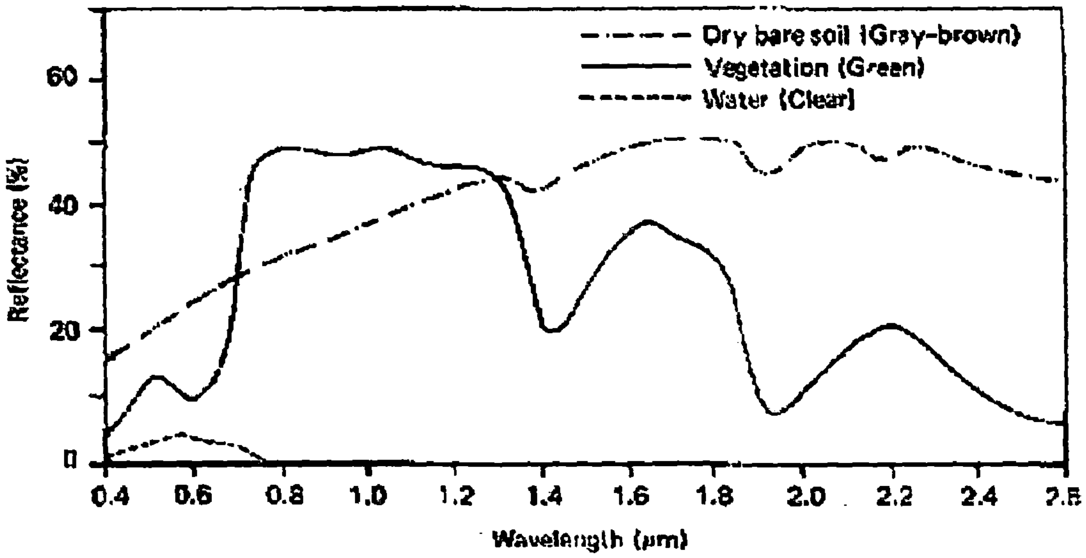

Fig. 4.11: A Typical Spectral Reflectance Curves for Three Types of Features

radiation. This radiation is measured and recorded by a sensor, and ultimately is depicted as an image product such as an air photo or a satellite image.

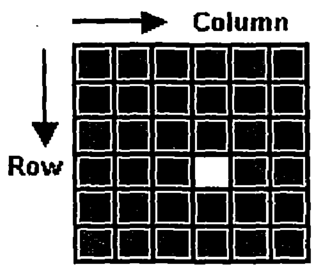

Fig 4.12: Representation of Digital Satellite Image

Recognizing targets is the key to interpretation and information extraction. Observing the differences between targets and their backgrounds involves comparing different targets based on any, or all, of the visual elements of tone, shape, size, pattern, texture, shadow, and association. Examining satellite images on the weather report, or following high-speed chases by views from a helicopter are all familiar examples of visual image interpretation. Identifying targets in remotely sensed images based on these visual elements allows us to further interpret and analyze.

WATER AVAILABILITY

5.0 General:

In this chapter, a water balance will be set up. The purpose of the water balance is to quantify the water availability in the watershed, $Q_{available}$, today. The water availability is the amount of water supplied from natural processes, such as rainfall. Not all the rainfall will become available since losses occur in the form of evapotranspiration. The chosen watershed is the area that at present supplies the city with the majority of its water supply. The amount of water coming from neighboring watersheds which adds to Dehradun's water supply is also included in $Q_{available}$, only small amounts of water are at present taken from neighboring watersheds.

The estimated water availability will be compared to the total water production for domestic and industrial use in Dehradun in chapter seven to see how large proportion of the available water that is used at present. This will also indicate to what extent the supplies can be increased to satisfy the demand by using water available within the watershed as effectively as possible.

5.1 The Water Balance Equation

The watershed can be viewed as a three dimensional piece of land, see Figure 5.1. Based on geological and hydrological information of the area, the water inputs and outputs can be defined and the water balance can be set up as the following:

Water balance: Inputs = Outputs ± changes in storage

$$P = AET + Q_{surface} + Q_{ground} \pm \Delta ST \qquad (5.1)$$

5.1.1 Definition of Parameters in the Water Balance

Precipitation (P) is the amount of rain that falls over the watershed. The rainfall is assumed to be evenly distributed over the watershed. It is also assumed to be equal to that measured at the New Forest Meteorological Observatory, which is located just outside the watershed

Infiltration (I) affects the water balance on a monthly basis, since some of the infiltrated rainfall will add to the **soil moisture storage** (ΔST) and some will add to the **groundwater flow** (Q_{ground}) after deep percolation. ΔST is positive in the water balance equation when it adds to the actual evapotranspiration due to withdrawal from the soil moisture storage during soil moisture utilization and negative when it adds to the soil moisture storage due to soil moisture recharge. The amount of water stored as soil moisture varies in a cyclic way over a year. Per definition it can van" between the wilting point of the plants and field capacity' of the soil (Devi 1992). The differences in stored amount are generally cancelled out over a year, so that the annual difference becomes approximately zero, $\Delta ST = 0$.

Surface water ($Q_{surface}$) within the watershed consists of the two seasonal rivers, the Rispana and the Bindal river mentioned in chapter three. These are supplied by water mainly from springs in the north of the watershed. Only the northern pan of Rispana and the southern pan of Bindal river have a flow all year round. The main pans of the rivers are *dry* and there is only a great amount of flow during a few days of the monsoon season each year, following days of heavy rainfall (Chopra 2003a).

Groundwater (Q_{ground}) flow within the watershed follows the topography and is in north-south direction The size of the aquifers is not estimated in the water balance. It is assumed for the water balance study that the water divide is the same for both surface water and groundwater.

Actual evapotranspiration of the watershed (ΔET) is water that evaporates back to the atmosphere either through direct evaporation or transpiration from plants. When the soil is not at field capacity, the actual evapotranspiration will be less than the potential evapotranspiration. The soil moisture content changes over the year depending on rainfall, vegetation growth as well as on other factors.

5.1.2 Equation for Water Availability

The purpose of the water balance is to estimate the water available in the watershed due to rainfall. The water balance equation is as previously mentioned:

$$Q_{ground} + Q_{surface} = P - AET \pm \Delta ST \qquad (5.2)$$

The total water availability includes the water coming from neighboring watersheds. The surface water supply from the Bindal River is such a source as well as groundwater from 8 tube-wells. Hence the total water availability can be written:

$$Q_{available} = Q_{ground} + Q_{surface} + Q_{neighbor} = P - AET \pm \Delta ST + Q_{neighbor} \qquad (5.3)$$

monsoon season each year, following days of heavy rainfall (Chopra 2003a).

Groundwater (Q_{ground}) flow within the watershed follows the topography and is in north-south direction according to the map in appendix 12.4. The size of the aquifers is not estimated in the water balance. It is assumed for the water balance study that the water divide is the same for both surface water and groundwater.

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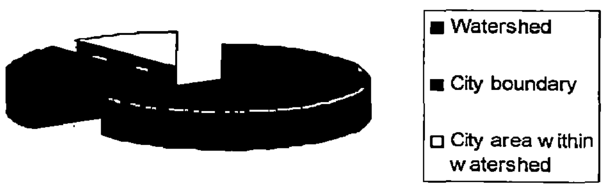
5.2 Areal Extent of Watershed

The areal extent of the watershed, the city and the part of the city that is within the watershed were estimated from the map

Table 5.1 Showing Areal Extent

Area Estimated	Area [km^2]
Watershed	327
City boundary	114
City area within watershed	60



5.4 Evapotranspiration

Evapotranspiration is the process where water evaporates back to the atmosphere as vapor either through direct land evaporation or through the plants metabolic process called transpiration. The potential evapotranspiration (PET) is defined as "the amount of water that will be lost from a surface completely covered with vegetation if there is sufficient water in the soil at all times for the use of the vegetation" (Thorntwaite 1955). Hence, potential evapotranspiration assumes an infinite supply of water.

According to the water balance ($Q_{ground} + Q_{surface} = P - AET \pm \Delta ST$), the actual evapotranspiration (AET) needs to be estimated. Actual evapotranspiration is dependent on the soil moisture and is less than or equal to the potential evapotranspiration. When the soil is saturated with water, evapotranspiration proceeds at the potential rate so the actual evapotranspiration equals the potential evapotranspiration. As the soil moisture content decreases it becomes increasingly difficult for water to be lost by evaporation or transpiration, since the suction pressure of the soil increases (FAO, 2004). Therefore, the rate of actual evapotranspiration will decrease as the soil moisture content decreases.

5.4.1 Estimation of Potential Evapotranspiration

Potential evapotranspiration needs to be estimated as a first step in the estimation of actual evapotranspiration, which can be achieved using data of meteorological variables. The variables affecting evaporation losses include (Garg 2000);

- Vapor pressure
- Wind speed
- Temperature
- Solar radiation

The Penman Formula for Calculating Potential Evapotranspiration

In 1948, Penman developed a formula to calculate the evaporation from a free water surface. It was a combination of the energy budget and the mass transfer method. In 1963 it was modified in a new publication by Penman to apply for the potential evapotranspiration (PET) from vegetated areas (Shaw 1994). The equations used for the calculations are based on those given in Shaw (1994), which are the standard equations used by the hydro-meteorological branch of the United Kingdom

Meteorological Office with an amendment of the original Penman for the blackbody radiation of vegetation (Grindley 1970).

The Penman equation for potential evapotranspiration from a vegetated surface is given by:

$$\text{PET (Penman)} = \frac{(\Delta/\gamma)H + E_{at}}{(\Delta/\gamma)+1} \qquad (5.4)$$

PET (Penman) Potential evapotranspiration [mm]

Δ Slope of the curve of saturated vapor pressure plotted against temperature [mm Hg °C-i]

γ The hygrometric constant, depending on the atmospheric pressure [mm Hg°C^{-1}}

H Net radiation [mm of evaporable water day-^{1}]

E_{at} Mass transfer [nun of evaporable water day-^{1}]

Equation for net radiation (H):

The net radiation is the net incoming solar (shortwave) radiation minus the net outgoing (long wave) radiation:

$$H = R_i - R_O \qquad (5.5)$$

R_i Net incoming (shortwave) radiation [mm of evaporable water day-1)

R_O Net outgoing (long wave) radiation [mm of evaporable water day-]

The net incoming radiation (R_i):

The solar radiation has been calculated using the Angstrom formula, which relates solar radiation to extraterrestrial radiation and relative sunshine duration:

$$R_S = (a + b\frac{n}{N})\ R_a \qquad (5.6)$$

R_S Solar or shortwave radiation [mm of evaporable water day']

n Actual duration of sunshine [hours] N

N Maximum possible duration of sunshine or daylight hours [hours]

$\frac{n}{N}$ Relative sunshine duration

R_a Extraterrestrial radiation [mm of evaporable water day^{-1}]

a Regression constant expressing the fraction of extraterrestrial radiation reaching the earth on overcast days (when n=0)

$a+b$ Fraction of extraterrestrial radiation reaching the earth on clear day (when n=N). The Angstrom values a and b vary with atmospheric condition (Humidity, dust) and declination (latitude and time of the year).

Accounting for the albedo (the reflection coefficient) of the area, with an assumed albedo of 0.25 for grass-covered land taken from Garg (2000), the net incoming radiation can be expressed:

$$R_i = (1\text{-}r)\ R_S \tag{5.7}$$

R_i Net incoming (shortwave) radiation [mm of evaporable watet day-1]

r the albedo [-]

The net outgoing (long wave) radiation (R_O):

The Stefan-Boltzman law expresses the quantitative long wave energy emission from the earth as the absolute temperature of the earth surface raised to the fourth power. The net energy flux leaving the earth's surface is less due to absorption and downward radiation from the atmosphere. Green house gases, water vapor and dust are responsible for the absorption and emission of long wave radiation. These factors have been corrected for in the equation for outgoing (long wave) radiation, where the second term expresses a correction for air humidity and the third the effect of cloudiness. A correction factor of 0.95 has been multiplied to the equation to account for the fact that vegetation does not radiate as a perfect black body:

$$R_O = 0.95\sigma\ T_a^4\ (0.56 - 0.092\sqrt{e_a})\,(0.10 + 0.90\frac{n}{N}) \tag{5.8}$$

R_O Net outgoing (long wave) radiation [mm of evaporable water day

σ Stefan-Bolzman constant [2.01*10-^{9} mm day-^{1}]

T_a Mean air temperature [K]

e_a Actual vapor pressure [mm Hg] $\frac{n}{N}$

relative sunshine duration [-]

The final equation for the net radiation (H):

Putting together the values of R_i and R_O gives the equation:

$$H = R_s\,(1-r) - 0.95\sigma T_a^4\,0.56 - 0.092 e_a^{0.5})(0.10 + 0.90\frac{n}{N} \quad (5.9)$$

Mass transfer equation (E_{at}) **:**

The empirical mass transfer equation derived by Penman and later modified to apply for evapotranspiration over a vegetated land surface is related to wind speed and the saturation deficit and is given by:

$$E_{at} = 0.35(1 + \frac{u_2}{160})(e_a - e_S) \quad (5.10)$$

u_2 Wind speed measured at 2 m above the ground surface [km day^{-1}]

$e_a - e_S$ The vapor pressure deficit which is the difference between the saturated vapor pressure at the temperature of the evaporative land surface and the actual vapor pressure of the air above [mm Hg]

Correlation with Thomtwaite for Longer Time Series

For the time period 1960—1967, only temperature data were available and other necessary parameters for using the Penman formula were missing. In order to get a complete time series of PET data between 1960 and 2002 using Penman, a linear relationship between Thorntwaite's empirical formula and Penman was found by plotting the PET values calculated bv Thomthwatie and Penman against each other. Thorntwaite's formula is simpler than the Penman formula, only taking into account the mean temperature and an adjustment factor for the number of daylight hours. The Throntwaite formula was taken from Shaw (1994).

The first step was to calculate PET values with Thornthwatie's empirical formula between the years 1967—2002. Thorntwaite's empirical formula is expressed as:

$$PET(Thornthwaite) = 16 N_m (\frac{10 T_m}{I})^a \quad (5.11)$$

$PET(Thornwaite)$ Potential evapotranspiration [mm]

N_m Monthly adjustment factor related to hours of daylight calculated from N/12, where N is the mean monthly value of possible sunshine hours/day for each month for 30 degrees north latitude. For N values

T_m Monthly mean temperature [°C]

I Heat index for the year for m = Jan... .Dec [-]

a A third grade polynom

Heat index equation (I):

$$I = \sum i_m = \sum \left(\frac{T_m}{5} \right)^{1.5}$$

Third grade polynom (a):

$$a = 6.7*10^{-7} I^3 - 7.7*10^{-5} I^2 + 1.8*10^{-2} I + 0.49 \qquad (5.12)$$

In the second step the monthly average PET values from the Penman calculations for the years 1967-2005 was plotted against monthly average PET values from the Thorntwaite calculations for the same time period. A linear relationship, see Figure 5.2, was found with determination coefficient of $R^2 = 0.85$.

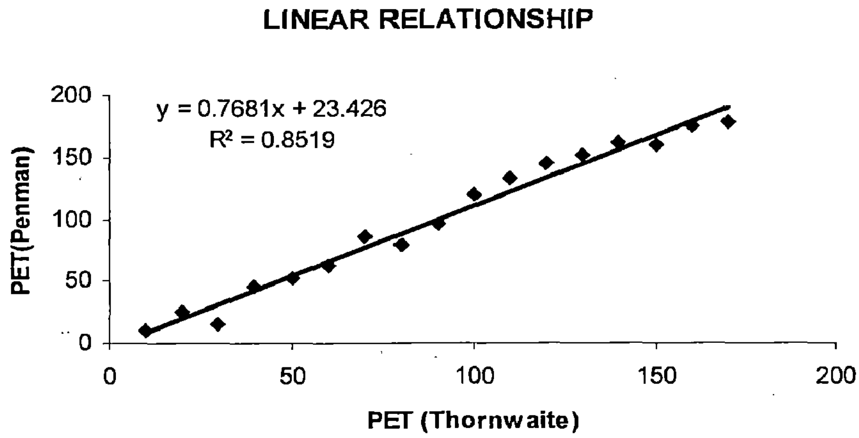


Fig. 5.2 Linear Relationships between Average Monthly Potential Evapotranspiration Values Calculated by Penman and Thorntwaite between 1967 and 2005.

The relationship can be expressed as:

$$PET(Penman) = 0.77 * PET(Thornwaite) + 23.43 \qquad ($$

From this relationship PET (Penman) was extrapolated and calculated for the time period 1960—1967 using the linear relationship.

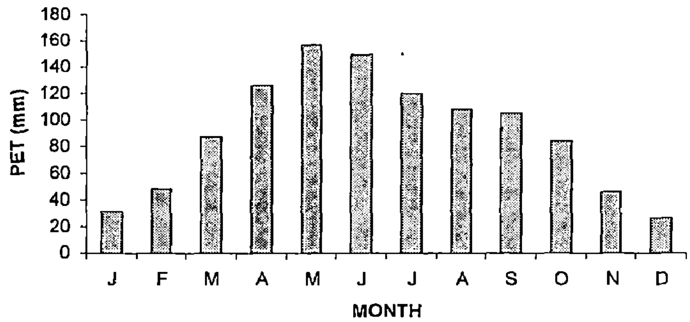
Equations and Variables for the PET Calculations

Tables and constants for the Penman equations come from Garg (2000) and are presented in Appendix 12.2. The equations used were based on Shaw (1994). Also, for the PET calculations using Thorntwaite's empirical formula, Shaw (1994) was used.

5.4. 2 Results

The monthly potential evapotranspiration is based on an average for the years 1960-2002. As previously mentioned, the potential evapotranspiration is mostly dependent on temperature, wind speed, actual vapor pressure, and solar radiation (sunshine hours). It is evident from Figure 5.3 that the potential evapotranspiration is highest during the warmest months when sunshine hours are many and the wind speed is quite high. The potential evapotranspiration decreases with the onset of the south-west monsoon when the solar radiation decreases because of the formation of clouds and the high vapor content of the air. During the winter the potential evapotranspiration is low mostly because of low temperatures.

Fig5.3 Monthly Average Potential Evapotranspiration in Dehradun based on Data between 1960 and 2005.



5.4.2 Estimation of Actual Evapotranspiration

The estimation of actual evapotranspiration takes into account not only the meteorological parameters as those used for estimating the potential evapotranspiration, but also takes into account the fact that the soil moisture storage is different during different times of the year. The soil moisture influences the actual evapotranspiration since the rate of evapotranspiration becomes less when the soil is not at field capacity

Estimation of AET using Thomtwaite's Method

In order to compute the monthly actual evapotranspiration as well as the soil moisture deficit and surplus according to Thomtwaite's method it is necessary to have:

- Mean monthly air temperatures
- Mean monthly rainfall
- Necessary conversion and computational tables
- Information on the water holding capacity of the depth of soil for which the balance is to be computed

Mean monthly air temperature and mean monthly rainfall from FRI for the years 1960-2002 has been used. The water holding capacity of the soil is assumed to be 50 mm, which is equivalent to brown hill soils and a vegetation of temperate forest tvpe that is typical for the Doon valley (Anandeshwari 1995). The conversion and computational tables are published in Thorntwaite and Mather (1957). The computational approach involves a step to estimate the PET. Instead of this step, the calculated values of PET from the previous section have been used.

5.4.2.1 Results

Following the steps in Thorntwaite and Mather (1957) produces the results presented in Table 5.2 below.

Table 5.2 Results from Thorntwaite Method Computing AET, Moisture Surplus and Deficit.

Parameter	J	F'	M	A	M	J	J	A	S	0	N	D	YEAR
PET [mm]	32	48	86	126	15"	148	120	109	105	84	45	29	1089
P [mm]	45	57	51	26	49	223	568	620	258	36	8	24	1965
P-PET [mm]	13	9	-35	-	-108	75	448	511	153	-48	-37	-5	876
AWL[mm]			-35	-	-243					-48	-85	-90	
ST [mm]	20	29	24	3	1	50	50	50	50	18	8	7	
AST [mm]	+13	+9	-5	-21	-)	+49	0	0	0	-32	-10	-1	0
AET [mm]	32	48	56	47	51	148	120	109	105	68	18	25	827
D [mm]	0	0	30	79	106	0	0	0	0	16	27	4	262
S [mm]	0	0	0	0	(1	26	448	511	153	0	0	0	1138

PET the potential evapotranspiration as estimated in the previous section

P the monthly average rainfall

P-PET the potential water surplus or deficit

AWL the accumulated potential water loss, which is the accumulated sum of the negative P-PET.

ST for positive AWL values, ST is the moisture storage compared to previous month (P-PET+ST $_{\text{previous month}}$), 50 mm being the soil moisture holding capacity and hence the highest possible storage. Values for negative AWL are found in Appendix 12.3.

ΔST the change in soil moisture storage as compared with the previous month

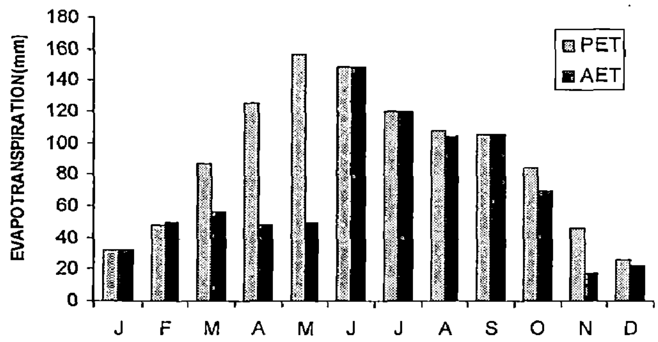
AET the actual evapotranspiration (P-AST when AST has a negative value otherwise AET = PET)

D the soil moisture deficit (PET-AET)

S the soil moisture surplus (P-AET-AST)

In Figure 5.4 the monthly AET calculated using Thorntwaite and Mather (1957) is plotted together with the PET calculated in chapter 5.4.1. The actual evapotranspiration is equal to the potential evapotranspiration during the south-west monsoon season (June-September) when the excess of rainfall is high and the soil moisture content is equal to the moisture holding capacity.

Figure5.4 Monthly AET and PET in Dehradun based on Monthly Average Data between 1960 and 2005.



5.5 Available Water

5.5.1 Annual and Monthly Surplus

The soil moisture surplus from the AET calculations is defined as the water which could become runoff in the form of either surface or groundwater flow (Thornwaite and Mather 1957). On an annual basis, the change in soil moisture storage is assumed to be zero and surplus water is equal to:

$$S_{annual} = Q_{ground} + Q_{surface} = P - AET \qquad (5.14)$$

The rainfall greatly exceeds the actual evapotranspiration on an annual basis and therefore the watershed has an annual water surplus.

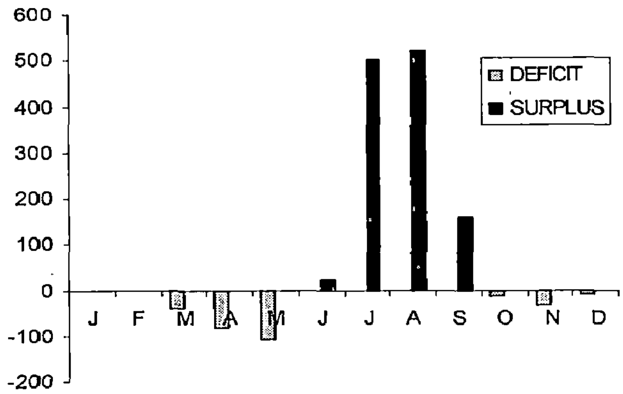
For monthly values of available water it is necessary to consider the change in soil moisture storage for each month. Following months of prolonged drought, a water deficit may occur due to vegetation utilization of soil moisture (which becomes AET) and when rain falls again, recharge will take place before there will be an actual surplus. The monthly surplus is therefore equal to:

$$S_{monthly} = Q_{ground} + Q_{surface} = P - AET \pm \Delta ST \qquad (5.15)$$

5.5.2.1 Results

The monthly deficit is equal to PET-AET, which is the amount of water needed to put the soil back to field capacity. The dry months are represented by a soil moisture deficit and occur in March-May (hot season) and October—December (post-monsoon season and beginning of old season). The wet months represents the south-west monsoon season, which is June—September. The monthly water availability due to rainfall is shown in Figure 5.5.

Figure 5.5 Monthly Water Availability in Dehradun based on Monthly Average Data between 1960 and 2005.



S_{annual} = 1138 mm for a comparable value, based on the area of the watershed which is 270 km^2, this equals 349 million liters daily (MLD). Values on $S_{monthly}$ are found in Table 5.2.

5.5.2 Water Received from Neighboring Watersheds

Water coming from the Bandal river is an external water source, coming from a neighboring watershed, which supply Dehradun with water. The supply is 6 MLD excluding distribution losses (Uttaranchal Jal Sansthan 2003). The Bandal river is located east of Dehradun as a tributary to Song river and should not be mixed up with Bindal River located within the studied watershed. There are also 8 tube-wells located just outside the watershed which contribute to Dehradun's water supply, Since the discharge is not known, the water from these tube-wells is assumed to be equal to an average of the amount of discharge from one tube-well multiplied by eight which is 13 MLD.

5.5.3 Total Water Availability

The total water availability includes soil moisture surplus from rainfall and the water coming from neighboring watersheds. The water availability in million liters daily is:

Q available = 349 + 6 + 13 MLD = 368 MLD

CHAPTER SIX

RAINFALL RUNOFF MODELLING IN GIS ENVIRONMENT

6.0 Introduction:

The Soil Conservation Service (SCS) runoff equation which came into use in the mid-50's is the product of more than 20 years of studies of rainfall-runoff relationships from small rural agricultural watershed areas. The procedure which is basically empirical was developed to provide a rational basis for estimating the effects of land treatment and land use changes upon runoff resulting from storm rainfall. It was initially used by SCS in project planning for the small watershed program. Because of its simplicity, however, its use has spectrum of hydrologic application by the hydrologists. The procedure is reliable when used in situation for which it was designed but it is not adequate for solving all types of hydrologic problems.

6.1 Soil Conservation Service (SCS) Model

The Soil Conservation Services procedure, which came into common use in the year 1954, is the product of more than 20 years of studies of rainfall runoff relationships for small rural watershed areas. Thousands of infiltrometer tests were carried out by SCS in the late 1930s and early 1940s. The intent was to develop basic data to evaluate the effects of watershed treatment and soil conservation measures on the rainfall-runoff process. The procedure which is basically empirical was developed to provide a rational basis for estimating the effects of land treatment and land use changes upon runoff resulting from storm rainfall. Because of its simplicity, its use has spread through the spectrum of hydrologic application of Agriculturists, Hydrologists and Soil Conservation Engineers.

The SCS developed an index, which is called the runoff curve number (CN) to represent the combined hydrologic effect of Soil, Land use, agricultural land treatment class, hydrologic condition and antecedent soil moisture. The SCS has also developed a soil classification system that consists of four hydrologic groups according to their minimum infiltration rate, which is obtained for a bare soil after prolonged wetting. The soil groups are identified by the letters A, B, C and D.

The SCS has also used an antecedent moisture to estimate three conditions (AMC I – dry, AMC II – normal and AMC III – wet). The relationship between rainfall and runoff for these three conditions is expressed as curve number. Each storm in a rainfall series is assigned one of the three curve numbers according to antecedent moisture condition.

6.1.1. Runoff Curve Number Equation

The fundamental hypotheses of the SCS - CN method are

(i) Runoff starts after an initial abstraction I_a has been satisfied. This abstraction consists principally of interception, surface storage, and infiltration.

(ii) The ratio of actual retention of rainfall to the potential maximum retention S is equal to rainfall minus initial abstraction.

Mathematically,

$$\frac{F}{S} = \frac{Q}{P - I_a} \qquad (6.1)$$

Where, F = actual retention = P - Q

S = potential maximum retention.

Q = runoff volume uniformly distributed over the drainage basin.

P = mean rainfall over the drainage basin.

I_a = initial abstraction.

The value of P, Q and S are given in depth dimensions. While the original method was developed in U.S. customary units (inches), an appropriate conversion to SI units (cm) is possible. Rainfall P is the total depth of storm rainfall. Runoff Q is the total depth of direct runoff resulting from storm rainfall P. Potential retention S is the maximum depth of storm rainfall that could potentially be abstracted by a given site.

In a typical case, a certain amount of rainfall, referred to as "initial abstraction", is abstracted as interception, infiltration, and surface storage before runoff begins. In the CN method the initial abstraction I_a is subtracted from rainfall P in (1) to yield

$$\frac{P - I_a - Q}{S} = \frac{Q}{P - I_a} \quad (6.2)$$

Solving for Q in (6.2) yields,

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \quad (6.3)$$

Which is valid for $P > I_a$, that is, after runoff begins; and Q = 0 otherwise. Eq. (6.3) has two parameters: S and I_a. To remove the necessity for an independent estimation of initial abstraction, a linear relationship between I_a and S was suggested by SCS (1985).

$$I_a = \lambda.S \quad (6.4)$$

Where λ = initial abstraction ratio. Eq. (6.4) was justified on the basis of measurements in watersheds less than 10 acres in size (SCS 1985). According to NEH-4 50% of the data points lay within the limits $0.095 \leq \lambda \leq 0.38$ [SCS (1985)]. This led SCS to adopt a standard value of the initial abstraction ratio $\lambda = 0.2$. With $\lambda = 0.2$ in (6.4), Eq. (6.3) becomes

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad (6.5)$$

Which is the rainfall-runoff relation used in the SCS method of estimating direct runoff from storm rainfall.

Now,

Equation (6.5) can be re arranged as

$$Q = P - S\,(1.2 - \frac{S}{(P + 0.8S)}) \quad (6.6)$$

Clearly, this is a one-parameter model containing S as the parameter.

Equation (6.6) is a form of the hydrologic budget, (an elementary expression of conservation of mass).

i.e. $Q = P - L$

in which L accounts for losses expressed as

$$L = S\,[1.2 - \frac{S}{(P + 0.8S)}]$$

These losses fall into five categories:

1. Interception storage in a rural setting, by vegetation foliage, stems, by cultural features of the landscape.
2. Surface storage in ponds, puddles and other usually small temporary storage locations.
3. Infiltration to the subsurface to feed and replenish soil moisture, interflow, and ground-water flow.
4. Evaporation from water bodies such as lake, reservoirs, streams, and rivers as well as from moisture on bare ground.
5. Evapotranspiration from all types of vegetation.

Of these five types of hydrologic abstractions, infiltration is the most important for storm analysis (short term). Evaporation and evapotranspiration are the most important for seasonal or annual yield evaluations (long term). The remaining two losses (interception and surface storage) are usually of secondary importance.

It is important to note that if $P \geq 0.2S$ than only runoff will occur, otherwise runoff be assumed as Zero. So the above formula (6.5) is valid only when $P \geq 0.2S$.

6.1.2. Estimation of S

The parameter S depends upon characteristics of the soil- vegetation-land use (SVL) complex and antecedent soil-moisture conditions in a watershed. For each SVL complex, there is a lower limit and an upper limit of S. The soil conservation service expressed S as a function of curve number (CN) as

$$CN = \frac{1000}{S+10}$$

$$\text{or,} \quad S = \frac{1000}{CN} - 10; \qquad (6.7)$$

S is in inches.

Where CN is the curve number, it is a relative measure of retention of water by a given SVL complex and takes on values from 0 to 100. A CN= 100 represents a condition of zero potential retention (S=0), that is, an impermeable watershed. Conversely, a CN=0 represents a theoretical upper bound to the potential retention ($S = \infty$), that is, an infinitely abstracting watershed.

Substituting (6.7) into (6.5), yields

$$Q = \frac{(P - \frac{200}{CN} + 2)^2}{(P + \frac{800}{CN} - 8)}$$

or, $$Q = \frac{[CN(P+2) - 200]^2}{CN[CN(P-8)+800]} \qquad (6.8)$$

In this equation, CN is the only parameter to be determined.

6.1.3. Determination of Curve Number

The CN value is determined from (a) Soil type and (b) Antecedent moisture conditions.

6.2.3.1. Soil Group Classification

The soils are classified on the basis of intake of water at the end of long duration storms occurring after prior wetting and opportunity for swelling without the protective effects of vegetation.

The hydrologic soil groups as defined by SCS are classified into four groups.

Group A → Soil in this group have a low runoff potential (high-infiltration rates) even when thoroughly wetted. e.g. - Deep sand or Gravels, deep loess.

Group B → Soils in this group have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep well drained to moderately well drained soils. e.g.- sandy loam soil with shallow loess.

Group C → Soils have slow infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes the downward movement of water. These soils have a slow rate of water transmission. e.g. - clay loam.

Group D → Soils have a high-runoff potential (very slow infiltration rates) when thoroughly wetted. These soils consist chiefly of clay soils with high swelling potential.

TABLE 6.1 SOIL GROUP CLASSIFICATIONS

Group	Soil Characteristics	Minimum infiltration rate(in/hr)/cm/hr
A.	Deep sand, deep loess and aggregated silts.	0.3 – 0.45 / 7.6 – 11.4
B.	Shallow loess and sandy loam	0.15 – 0.30 / 3.8 – 7.6
C.	Clay loams, shallow sandy loam, soils in organic content, and soils usually high in clay	0.05 – 0.15 / 1.3 – 3.8
D.	Soils that swell upon wetting, heavy plastic clays, and certain saline soils	0 – 0.05 / 0 – 1.3

6.1.3.2. Hydrologic Soil Cover Complexes

SCS has considered the following parameters to assign curve number in hydrologic soil cover complex.

- Hydrologic soil group
- Land use or land cover
- Treatment class
- Hydrologic condition

The curve number has been assigned for watershed condition with AMC II and $I_a = 0.2S$. The numbers show the relative value of the complexes as direct run off. The higher the CN, the greater the amount of direct runoff to be expected from a storm.Hydrologic condition may be poor, fair or good depending upon percentage of ground cover present.

Poor – heavily grazed land (50% under ground cover)

Fair – moderate cover (50% - 75%)

Good – heavy or dense cover (> 75% under ground cover)

6.1.3.3. Antecedent Moisture Condition

The amount of rainfall in a period of 5 days prior to a particular storm starts, is termed as AMC. Also, it refers to the water content present in the soil at a given time.

The SCS developed three AMC conditions and labeled them as I, II, and III. These AMC's correspond to the following soil conditions.

AMC I - Soils are dry, lowest runoff potential.

AMC II - The average condition.

AMC III - Highest runoff potential. The watershed is practically saturated from antecedent rains (Last 5 day's antecedent rainfall).

Table 6.2 AMC for Determining the Value of CN

AMC Group	Total 5-day Antecedent Rainfall	
	Dormant season	Growing season
I	Less than 0.5 in. (1.27cm.)	Less than 1.4 in. (3.5cm.)
II	Between 0.5 to 1.1 in. (1.27 to 3.25cm.)	Between 1.4 to 2.1 in (3.5 to 5.25cm.)
III	Over 1.1 in. (3.25cm.)	Over 2.1 in. (5.25cm.)

6.1.3.4. Selection of CN

The value of CN for AMC condition II and for a variety of land uses, soil treatment or farming practices can be obtained from the table of runoff curve numbers for hydrologic soil-cover complexes(after soil conservation service 1969). All the areas of a watershed do not fall under AMC II condition. A correction table for CN has been developed by SCS to convert AMC II condition to AMC I and AMC III. The correction table is shown in table 6.2. After knowing the value of CN for required AMC, Q can be determined easily.

6.1.4. Assumptions of SCS-CN method

1. The basin is covered with a soil group that has uniform hydrologic characteristics throughout the basin area.
2. Rainfall is uniform and is distributed uniformly over the basin area.
3. All other hydrologic characteristic are uniform. Most drainage basin do not satisfy these assumptions and, as a result, the SCS-CN method over predicts by a large magnitude.

6.1.5. Limitation of SCS-CN method

i. Equation (6.5) is valid only for $P \geq 0.2S$; otherwise $Q = 0$.

ii. The method does not consider the effect of variations in rainfall intensity and its duration.

iii. The method does not properly predict I_a for shorter, more intense storms because I_a is assumed constant.

iv. The method cannot be extended to properly predict infiltration within a storm.

v. The method assumes depth of infiltration S after which all rainfall becomes runoff.

In the this chapter SCS rainfall - runoff equation was used to assess runoff from Dehradun watershed. Considering the existing land use plan, the runoff capabilities of the watersheds were assessed by applying GIS methodology.

6.2 Rainfall Patterns :

Rainfall received in the watershed during various periods is shown in Table 6.3, 6.4 and 6.5 along with the different AMC conditions and daily rainfall pattern (shown in fig 6.1,6.2.&6.3)

Table 6.3 Daily Rainfalls with AMC Condition, Year 1988

S. no	Day	Month	Year	Rain_88(mm)	Last 5 days Rain	AMC CONDITION
1	14	1	1988	6.4	2.4	I
2	13	2	1988	4	2.2	I
3	23	2	1988	4.6	1	I
4	28	2	1988	14.6	4.6	I
5	29	2	1988	15.4	14.6	II
7	9	3	1988	20	2.5	I
8	11	3	1988	16.4	22.5	II
9	12	3	1988	23.2	38.9	III
10	27	3	1988	20.6	0	I
11	19	4	1988	20.8	0	I
12	7	5	1988	3.2	4.7	I
13	15	5	1988	11.6	0	I
14	18	5	1988	11.7	11.6	I
15	20	5	1988	10	23.3	I
16	1	6	1988	17	0	I
17	2	6	1988	4	17	I
18	5	6	1988	9.3	21	I

19	14	6	1988	8.3	1.3	I
20	15	6	1988	18	9.6	I
21	18	6	1988	9.7	28.6	I
22	22	6	1988	21	10.7	I
23	24	6	1988	46.6	24.6	I
24	25	6	1988	35.9	70.2	III
25	27	6	1988	3.6	106.5	III
26	28	6	1988	15.1	89.1	III
27	29	6	1988	13.6	101.6	III
28	30	6	1988	4.7	68.6	III
29	2	7	1988	23	39.4	II
30	4	7	1988	7.6	45.1	II
31	5	7	1988	21.8	39.1	II
32	6	7	1988	28	56.2	III
34	10	7	1988	4.8	57	III
35	12	7	1988	17.4	12	I
36	13	7	1988	10	22.6	I
37	14	7	1988	23.8	32.2	I
38	15	7	1988	3	56	III
39	17	7	1988	10.7	54.6	III
40	20	7	1988	5.9	17.1	I
41	21	7	1988	11	20	I
42	22	7	1988	13.2	30.6	I
43	23	7	1988	22.5	33.1	I
44	24	7	1988	12.6	55.2	III
45	25	7	1988	7	65.2	III
46	26	7	1988	9.2	66.3	III
47	27	7	1988	45.5	64.5	III
48	31	7	1988	62.4	60.1	III
49	1	8	1988	46	113.3	III
50	2	8	1988	38.7	113.8	III
51	3	8	1988	31	150.7	III
52	6	8	1988	48	117.2	III
53	7	8	1988	15.1	119.2	III
54	8	8	1988	29.6	95.6	III
55	10	8	1988	12.1	97	III
56	12	8	1988	56	59.9	III
57	14	8	1988	22.8	71.2	III
58	15	8	1988	68	91.2	III
59	16	8	1988	20.5	147.1	III
60	17	8	1988	18.4	167.3	III
61	19	8	1988	9.4	130.5	III
62	24	8	1988	62.2	13.1	I
63	27	8	1988	10.8	67.1	III
64	4	9	1988	6.5	0	I
65	6	9	1988	14	6.5	I
66	9	9	1988	4.6	20.9	I
67	16	9	1988	18.6	0	I

68	19	9	1988	24.9	18.6	I
69	22	9	1988	13.9	24.9	I
70	23	9	1988	32.1	38.8	II
71	24	9	1988	17	70.9	III
72	25	9	1988	95.9	63	III
73	27	9	1988	13	158.9	III
74	23	12	1988	18.2	1.8	I
75	24	12	1988	8.8	20	II
76	25	12	1988	4.4	28.8	II
77	26	12	1988	18.5	32	II

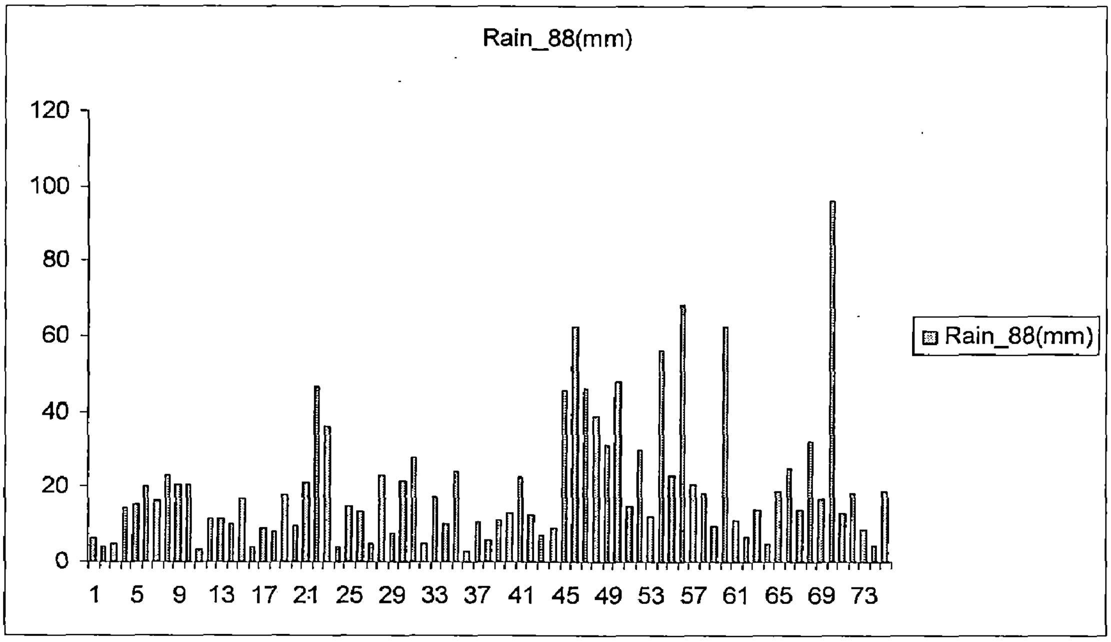


Fig.6.1 Daily rainfall in Dehradun watershed (Year1988)

Table 6.4 Daily Rainfalls with AMC Condition, Year 2001

S.No.	Day	Month	Year	Rain_01	Last 5 days Rain	AMC CONDITION
1	2	1	2001	25.5		I
2	20	1	2001	20.2	0	I
3	21	3	2001	4.6	0	I
4	29	3	2001	16	0	I
5	31	3	2001	17.3	16	I
6	14	4	2001	7	0	I
7	18	4	2001	27.6	11.7	I
8	16	5	2001	33.2	0.9	I
9	17	5	2001	12	34.1	II

10	19	5	2001	36	46.1	II
11	28	5	2001	15	2.5	I
12	2	6	2001	109.8	16.7	I
13	3	6	2001	13.3	111.5	III
14	4	6	2001	11.2	123.1	III
15	7	6	2001	22	134.3	III
16	12	6	2001	4.4	22	I
17	14	6	2001	52.2	4.4	I
18	15	6	2001	11.9	56.6	III
19	19	6	2001	12.4	72.8	III
20	21	6	2001	14.5	21.1	I
21	25	6	2001	6.8	21.1	I
22	26	6	2001	20.5	27.9	I
23	27	6	2001	3.4	33.9	I
24	28	6	2001	27	35.3	II
25	29	6	2001	14.5	59.5	III
26	30	6	2001	20	72.2	III
27	1	7	2001	19.2	85.4	III
28	2	7	2001	45.4	84.1	III
29	5	7	2001	11.6	86.4	III
30	6	7	2001	61.2	78	III
31	11	7	2001	7.5	66.4	III
32	13	7	2001	9.5	11.8	I
33	14	7	2001	15.6	17.5	I
34	15	7	2001	94.4	32.6	I
35	16	7	2001	32	127	III
36	17	7	2001	43.8	151.5	III
37	18	7	2001	4.5	195.3	III
38	20	7	2001	7.5	174.7	III
39	21	7	2001	72	87.8	III
40	22	7	2001	12.2	127.8	III
41	23	7	2001	10.2	96.2	III
42	25	7	2001	13.5	101.9	III
43	26	7	2001	32	107.9	III
44	27	7	2001	32	67.9	III
45	28	7	2001	35.4	87.7	III
46	29	7	2001	22.4	112.9	III
47	31	7	2001	6.7	122.3	III
48	3	8	2001	6.5	29.6	I
49	4	8	2001	12.8	13.7	I
50	6	8	2001	44	19.3	I

51	7	8	2001	8	63.3	III
52	8	8	2001	4.2	71.3	III
53	9	8	2001	11	69	III
54	10	8	2001	4.6	67.2	III
55	12	8	2001	30.6	28.3	I
56	13	8	2001	44.4	50.9	II
57	14	8	2001	74.7	91.1	III
58	18	8	2001	75	121.1	III
59	19	8	2001	93.8	151.7	III
60	21	8	2001	45.2	171.3	III
61	22	8	2001	5.3	216.5	III
62	23	8	2001	2.5	221.8	III
63	29	8	2001	15.5	2.7	I
64	30	8	2001	24.4	18.2	I
65	31	8	2001	52.8	42.6	II
66	1	9	2001	15.5	93.2	III
67	4	9	2001	33.2	92.7	III
68	10	9	2001	19	0	I
69	13	9	2001	14.8	19.5	I
70	15	9	2001	4.8	35.1	II
71	30	9	2001	36.6	0	I

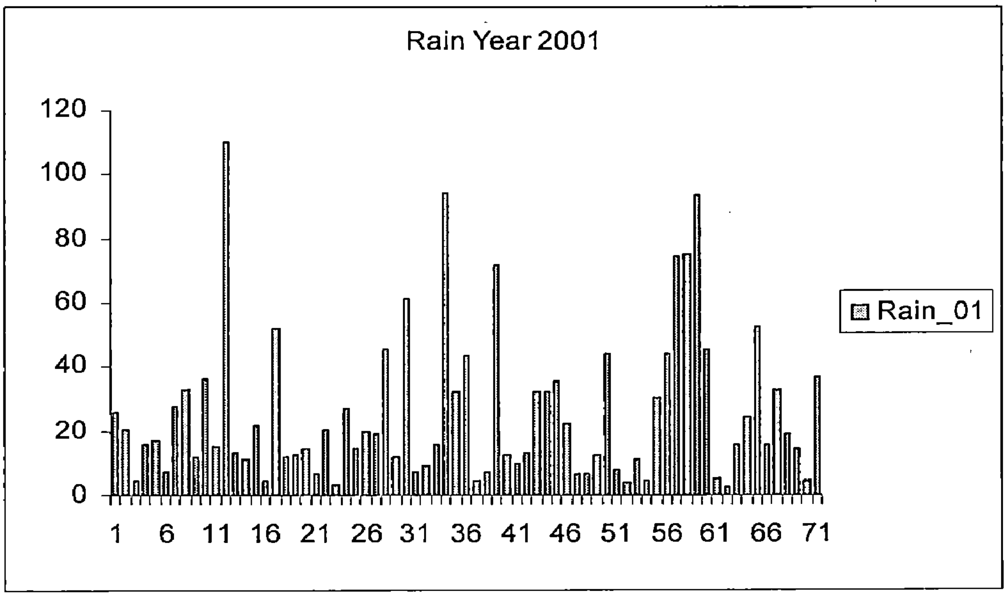


Fig.6.2 Daily rainfall in Dehradun watershed (2001)

Table 6.5 Daily Rainfalls with AMC Condition, Year 2005

S.No.	Day	Month	Year	Rain_05	5 DAY RAIN	AMC condition
1	26	6	2005	22	33.2	I
2	28	6	2005	51	73	I
3	30	6	2005	18.2	91.2	III
4	1	7	2005	8.9	78.1	III
5	2	7	2005	30.8	108.9	III
6	5	7	2005	35	75.7	III
7	6	7	2005	26.4	93.2	III
8	7	7	2005	10	72.4	III
9	11	7	2005	131	143.7	II
10	12	7	2005	68.4	202.1	III
11	13	7	2005	63.4	265.5	III
12	14	7	2005	61.4	326.9	III
13	15	7	2005	26.2	350.4	III
14	16	7	2005	14	233.4	III
15	17	7	2005	5.5	170.5	III
16	18	7	2005	88.5	195.6	III
17	19	7	2005	7.5	141.7	III
18	20	7	2005	34.1	149.6	III
19	21	7	2005	16.8	152.4	III
20	22	7	2005	21.8	168.7	III
21	23	7	2005	84.2	164.4	III
22	25	7	2005	10.2	136	III
23	26	7	2005	25	144.2	III
24	30	7	2005	5.3	31	II
25	31	7	2005	7.6	13.6	I
26	1	8	2005	24.6	37.8	I
27	6	8	2005	56.4	64.6	I
28	8	8	2005	5.9	74.1	III
29	14	8	2005	9.5	9.5	I
30	16	8	2005	37.4	46.9	I
31	17	8	2005	57.8	104.7	II
32	18	8	2005	19.2	123.9	III
33	20	8	2005	36.7	153.7	III
34	24	8	2005	6.8	47.8	II
35	25	8	2005	58.2	69.3	II
36	27	8	2005	34.4	103.7	III
37	28	8	2005	32.8	132.2	III
38	5	9	2005	16.6	20.8	I
39	6	9	2005	8.9	29.7	I
40	9	9	2005	11.6	39.2	I

41	10	9	2005	3.9	26.5	II
42	11	9	2005	14.5	32.1	I
43	13	9	2005	6.5	36.5	I
44	14	9	2005	7.5	32.4	II
45	17	9	2005	20.7	39.6	I
46	18	9	2005	57.4	90.5	II
47	19	9	2005	4.8	87.8	III
48	24	9	2005	52	58.9	I
49	25	9	2005	74	132.9	III
50	26	9	2005	14.5	147.4	III

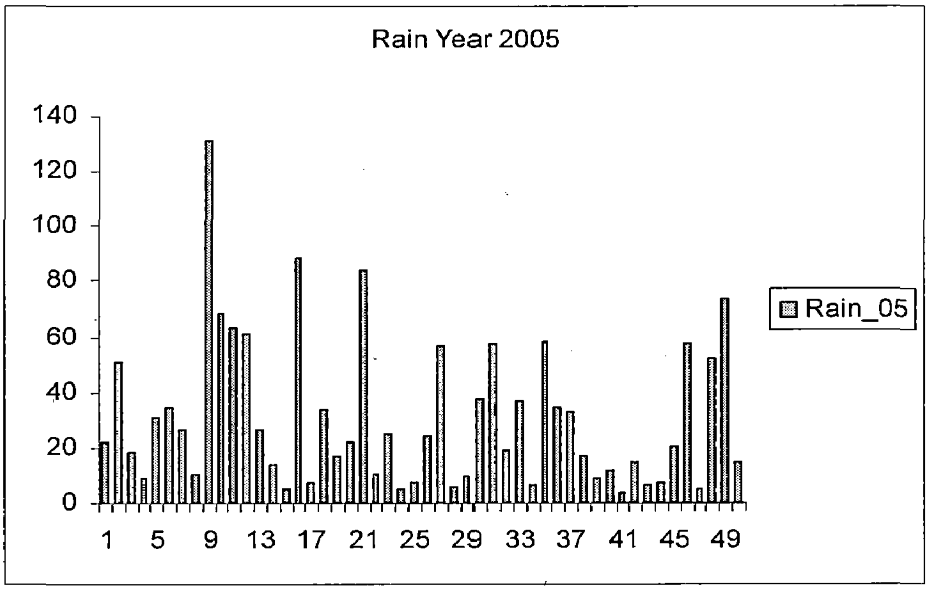


Fig.6.4 Daily rainfall in Dehradun watershed (Year2005)

6.3 Runoff using GIS

In this chapter SCS rainfall - runoff equation was used to assess runoff from Dehradun watershed. Considering the existing land use plan, the runoff capabilities of the watersheds was assessed by implementing NRCS approach in GIS.

Results obtained by GIS are in the form of maps or tabular form (attributes of the map). Runoff maps obtained from the daily rainfall storm received in Dehradun watersheds are given in the above table. The various input maps such as rainfall, curve number, S value etc. map which has been used to get the runoff maps are shown in the Figs. 6.5 to 6.18. The maps are self explanatory and properly classified as per the runoff depth classes in the particular colour coded areas.

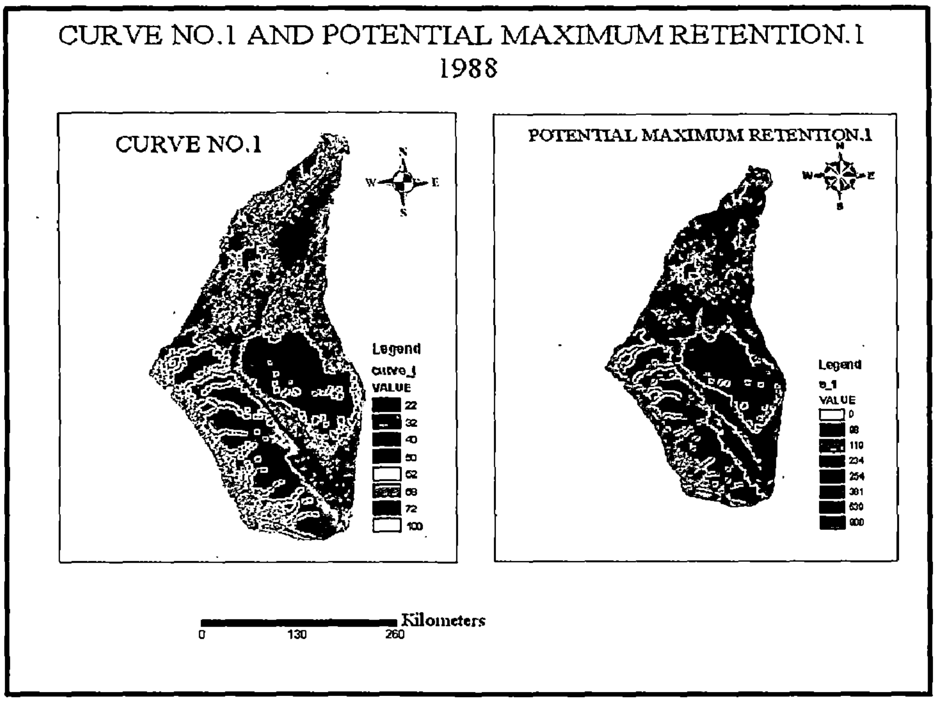


Fig 6.4 Curve No.1 (AMC I) and Potential Maximum Retention I (1988)

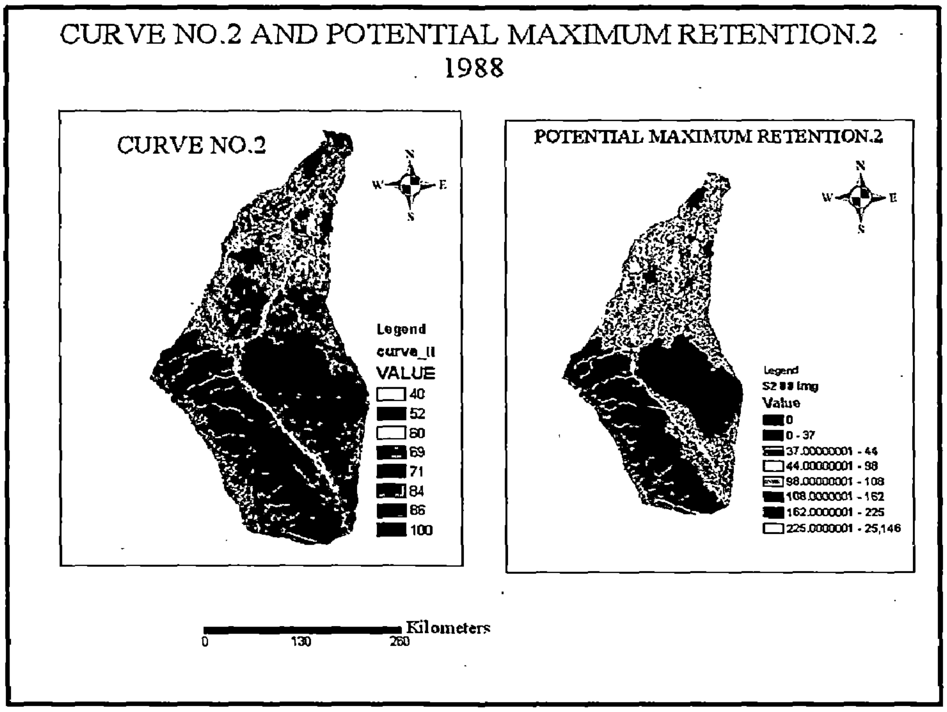


Fig 6.4 Curve No.2 (AMC II) and Potential Maximum Retention II (1988)

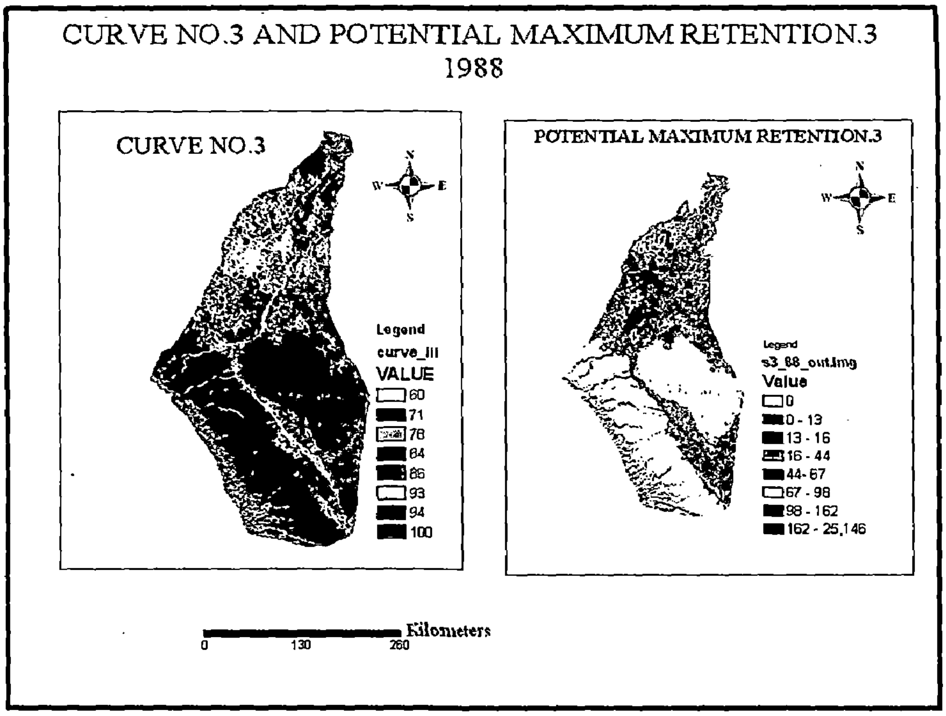


Fig 6.5 Curve No.3 (AMC III) and Potential Maximum Retention III(1988)

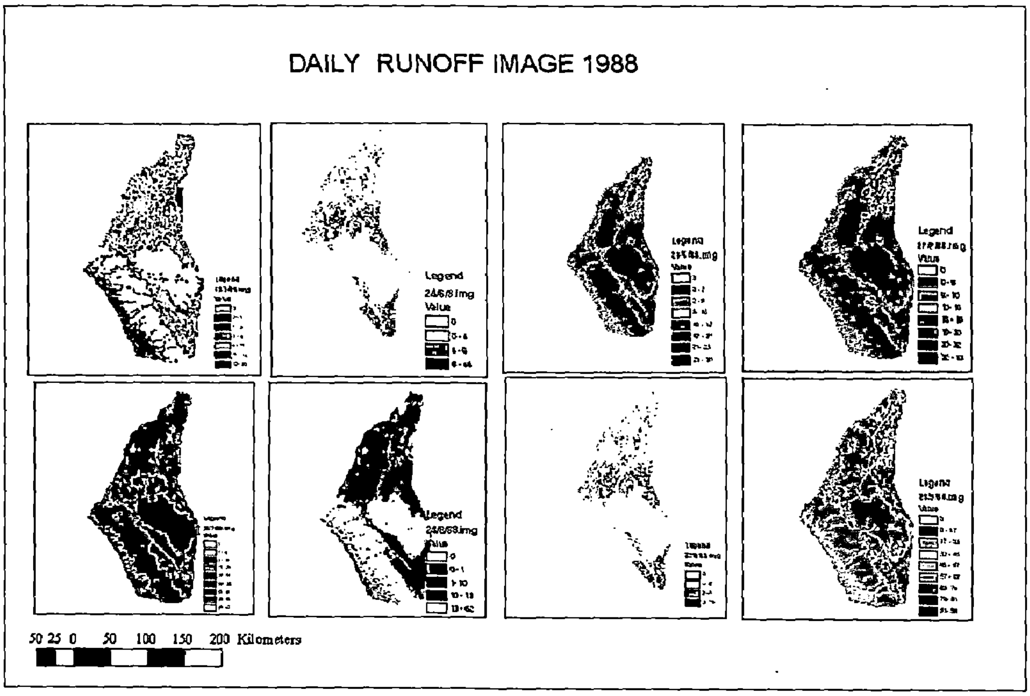


Fig. 6.8 Daily Runoff Image (1988)

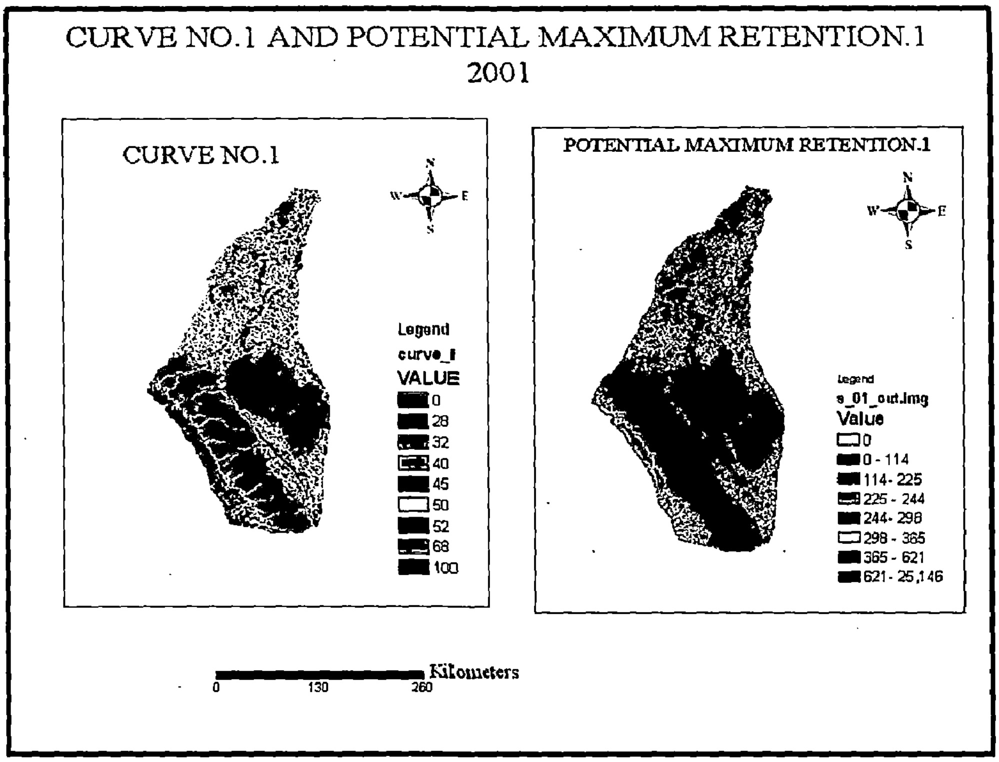


Fig 6.8 Curve No.1 (AMC I) and Potential Maximum Retention I (2001)

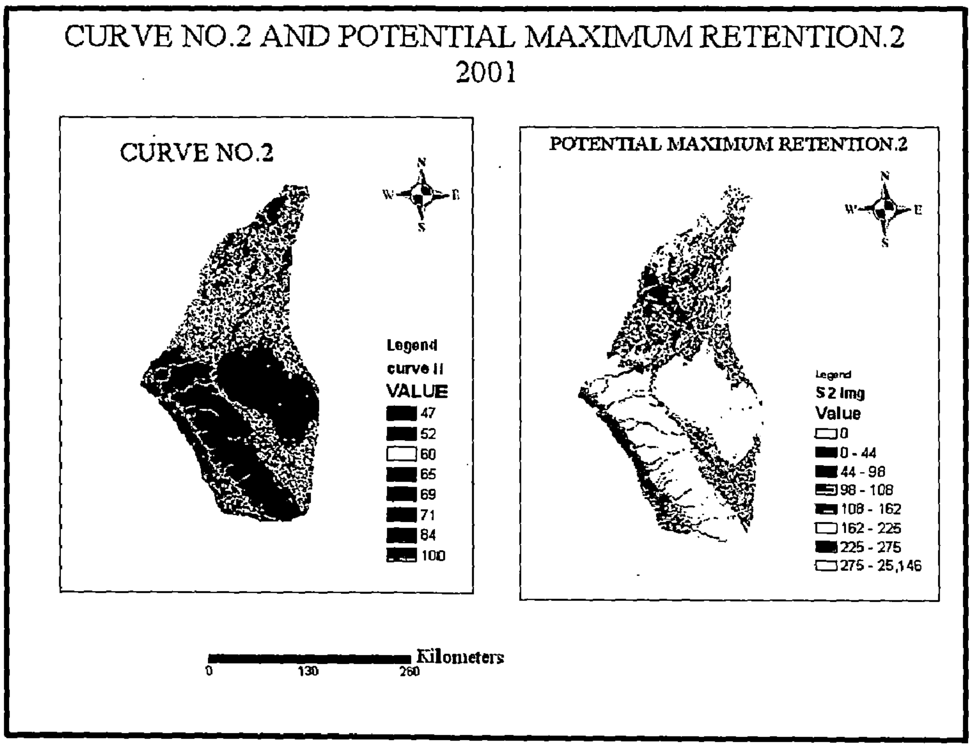


Fig 6.9 Curve No.2 (AMC II) and Potential Maximum Retention II (2001)

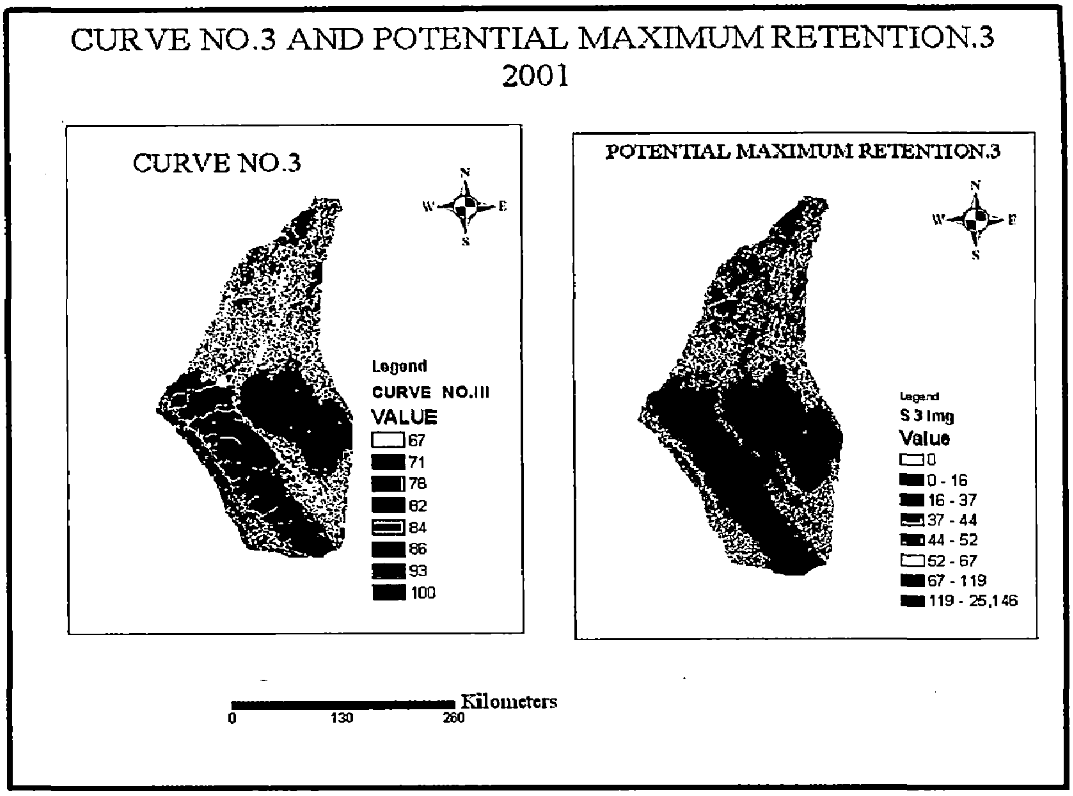


Fig 6.10 Curve No.3 (AMC III) and Potential Maximum Retention III (2001)

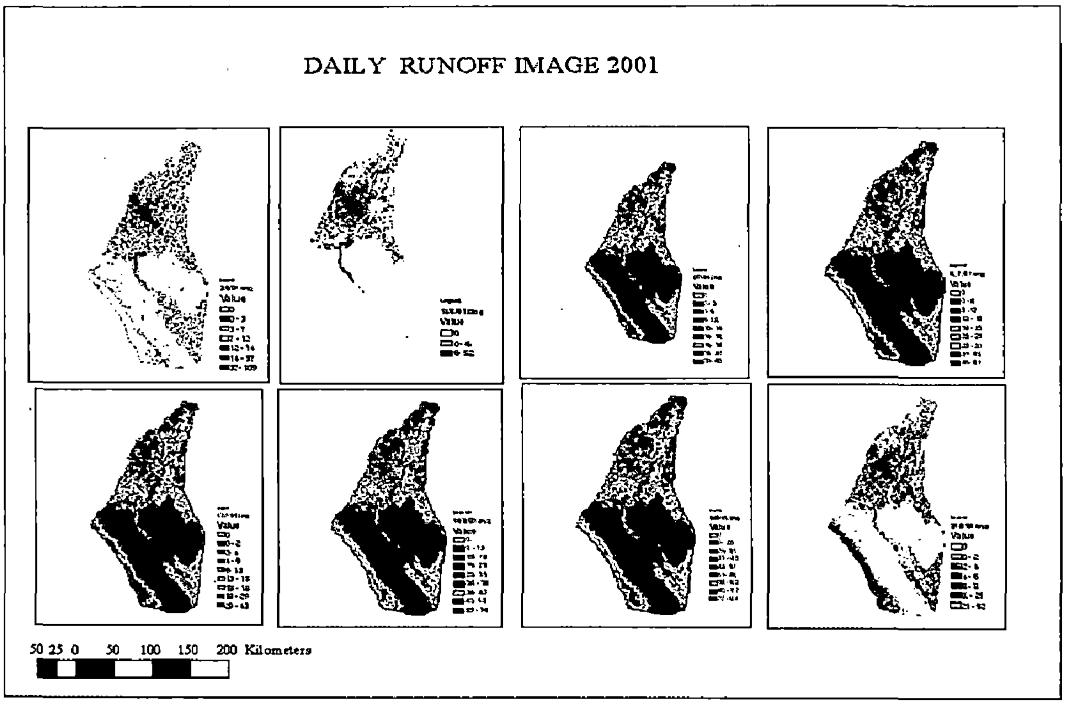


Fig. 6.11 Daily Runoff Image (2001)

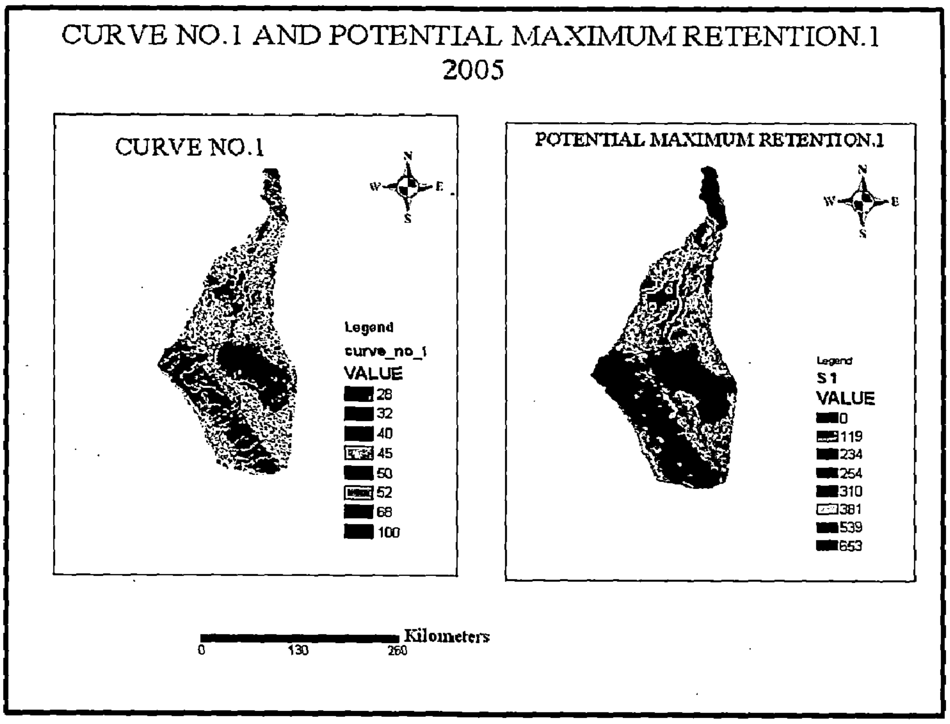


Fig 6.12 Curve No.1 (AMC I) and Potential Maximum Retention I (2005)

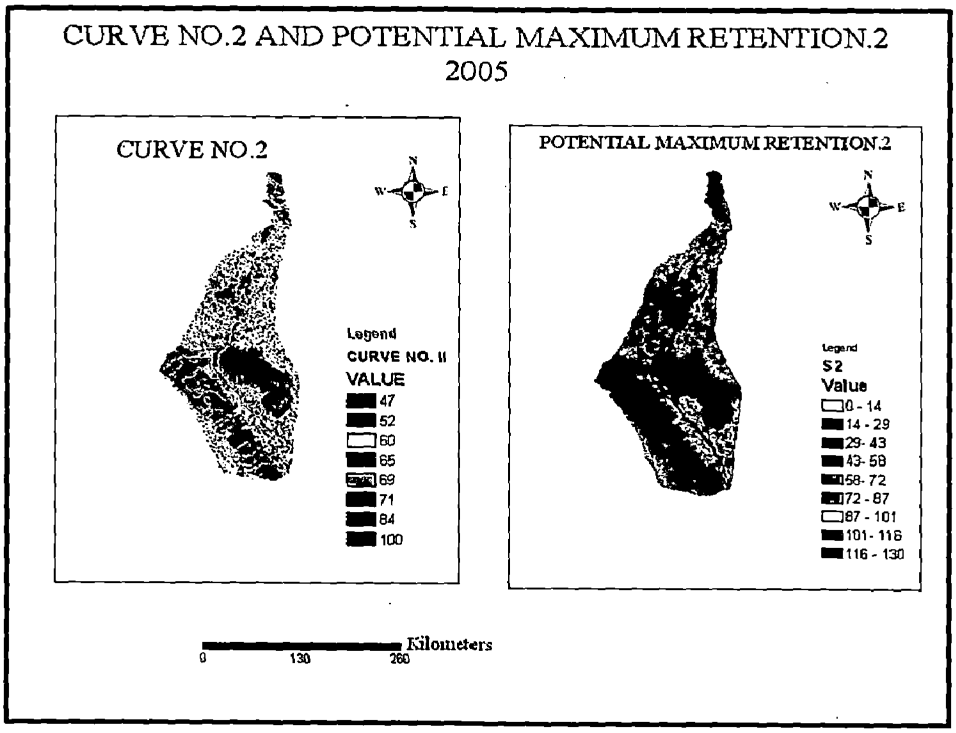


Fig 6.13 Curve No.1 (AMC II) and Potential Maximum Retention II (2005)

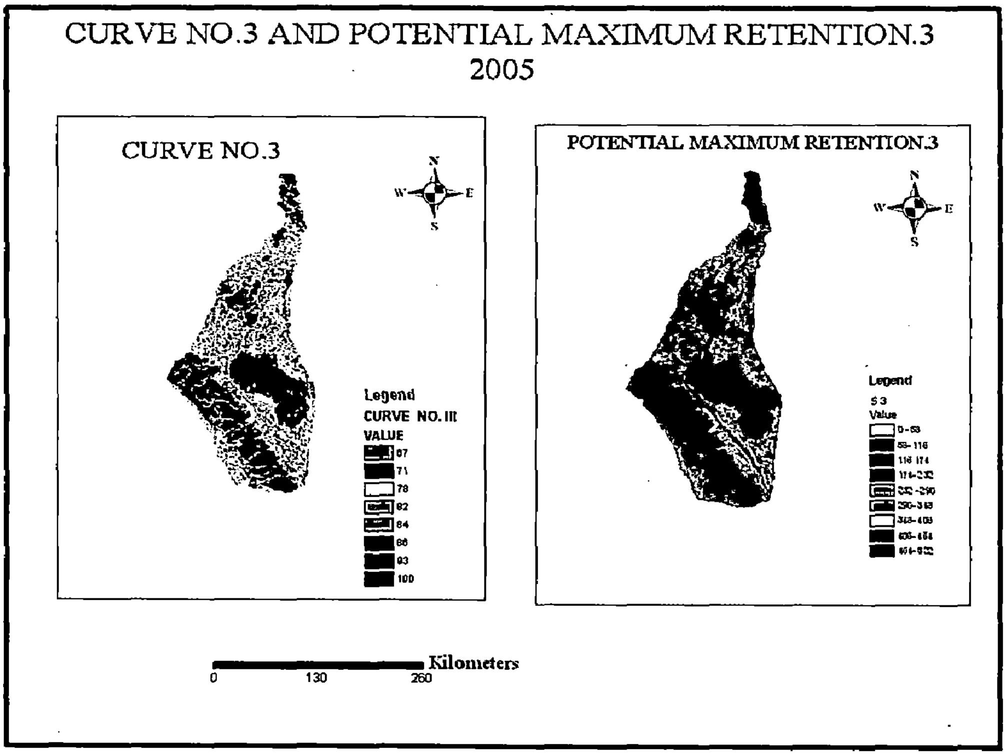


Fig 6.14 Curve No.3 (AMC III) and Potential Maximum Retention III (2005)

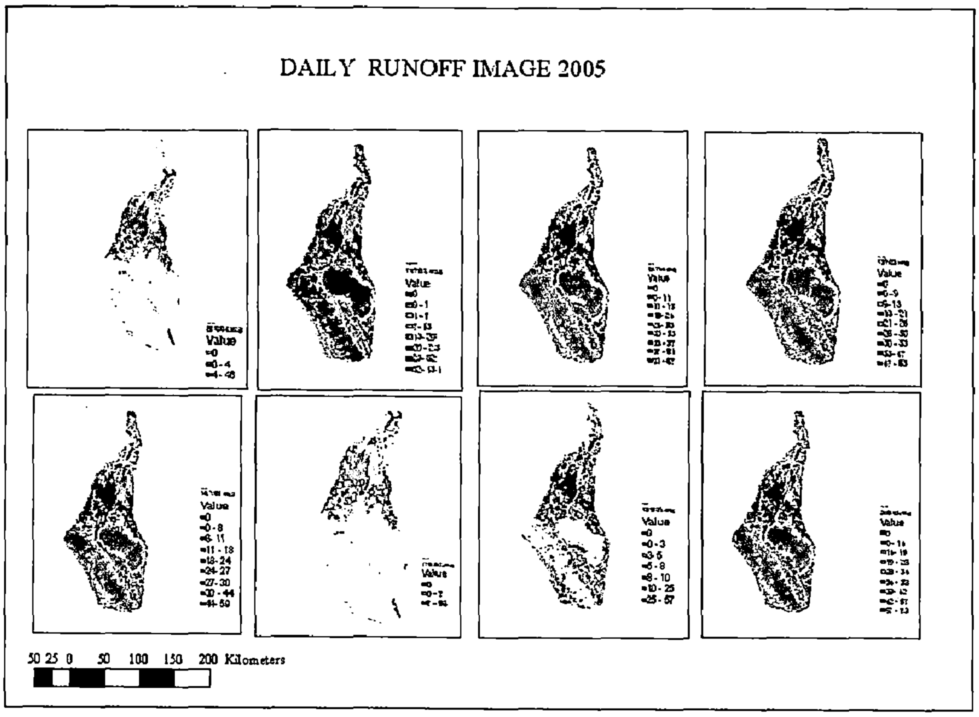


Fig. 6.15 Daily Runoff Image (2001

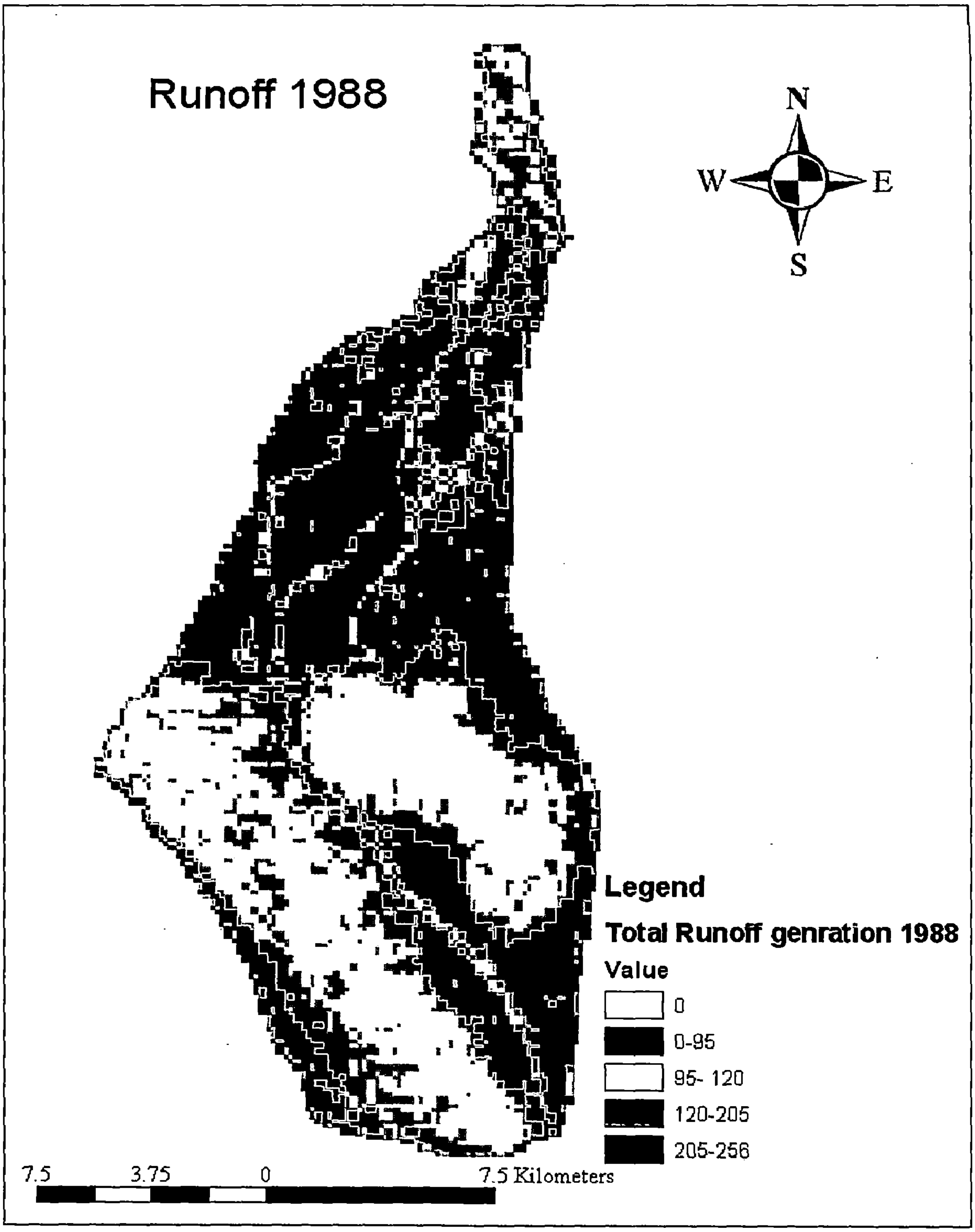


Fig. 6.8 Total Runoff Generation in mm (1988)

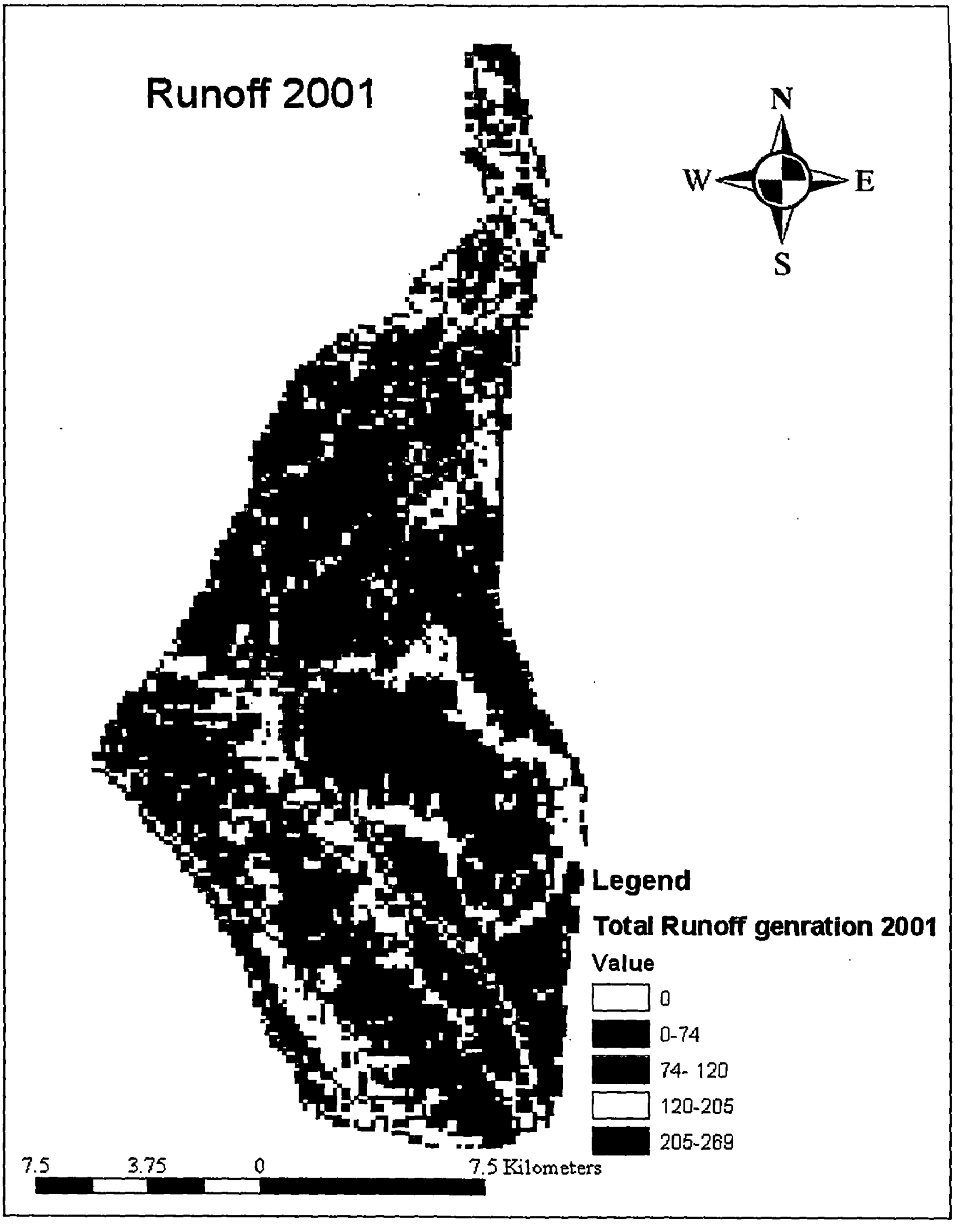


Fig. 6.8 Total Runoff Generation in mm (2001)

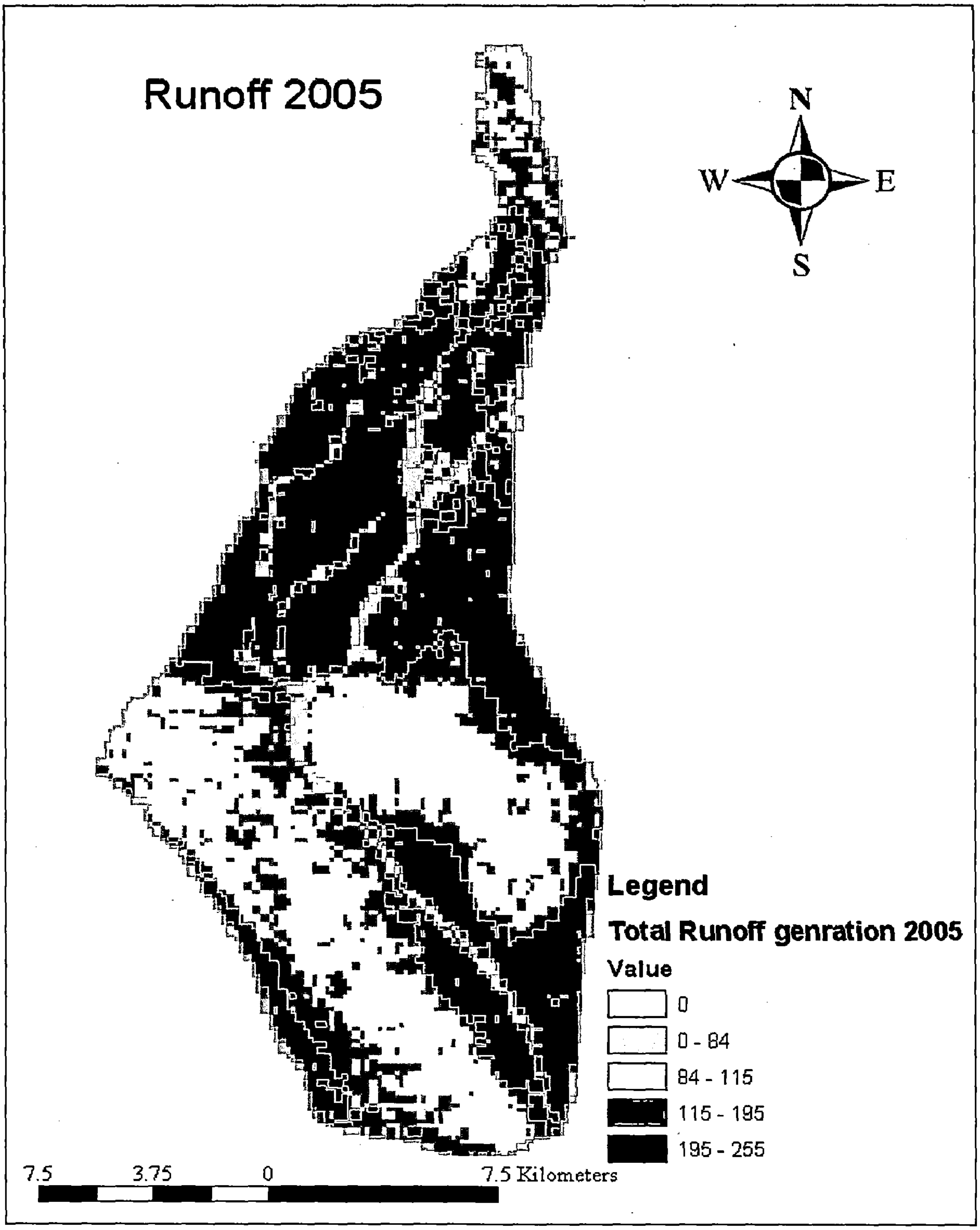


Fig. 6.8 Total Runoff Generation in mm (2005)

Table – 6.6 Runoff generated on year in Dehradun Watershed

Year	Area (in km^2.)	Runoff Depth (in km.)	Runoff (Ha-m.)
1988	317.3	0.58932	18699123.6
2001	315.7	0.66275	20923017.5
2005	327.2	0.582681	19065322.32

6.4 Conclusion

The runoff curve number method gaining its popularity among hydrology practioners to its simplicity, predictability, and stability. The method is a conceptual model of hydrologic abstraction of storm rainfall, supported by empirical data. Its objective is to estimate direct runoff volume from storm rainfall depth, based on a curve number CN. The method does not take into account the spatial and temporal variability of infiltration and other abstractive losses; rather it aggregates these into a calculation of the total depth loss for a given storm event and drainage areas.

The runoff was generated by analysis of three years satellite data. from analysis it was observed that in 1988 the runoff is 18699123.6 Ha-m, in 2001 the runoff is 20923017.5 HA-m and in the year 2005 the runoff is 19065322.32 HA-m.

CHAPTER SEVEN

SITE SUITABILITY ANALYSIS FOR RAIN WATER HARVESTING

7.0 Introduction

Unprecedented and continued urban expansion in developing countries, however inevitable, could be planned optimally through controlled growth of future expansion areas. While the past cannot be erased, proper planning of future expansion becomes undoubtedly the most important function of urban management. Optimal management of cities requires a careful planning of their future expansion. While in the past, the management system suffered due to lack of appropriate data, inadequate resources, fast growth and poor knowledge of the consequences of such expansion, remote sensing information available today have facilitated orderly expansion of cities to ensure a reasonable quality of life in the cities. Evaluation of the suitability of land for different purposes to identify areas for locating Industries, residential complexes and green belts based on soil depth, soil texture, slope, relief, flood and erosion proneness, availability of drinking water, drainage characteristics and wind pattern has resulted in arriving at suitable strategy for optimal land use pattern to cater to the futuristic requirements of the new cities.

Urban land use mapping seems to be a most sought-for activity for dealing with the dynamic cities and their growth areas The rapid urbanization of the Dehradun requires the development of new growth areas that can eventually absorb the greater demands for space and resources from an increasing population. The exponential population growth and the consequent expansion of urban conglomerations being an inevitable reality, the challenge of today lies in understanding the population dynamics and realising the effective utilisation of high technology tools as that of space technology for optimal and sustainable management of urban environments. Identification of suitable land for water harvesting is one of the critical issues of planning. The assessment of suitability conditions of a terrain for developing a new area based on evaluation of terrain parameters like geology, geomorphology, slope, ground water prospects, land use, soil, natural hazards like floods and earthquakes etc. and proximity of roads and railways can be done effectively using geoinformatics. While in the past, time consuming and expensive detailed land and aerial surveys were the inhibiting factors preventing optimal planning of urban expansion, availability of high resolution space imageries combined with parallel technological developments such as GIS and GPS have overcome this problem.

The ability to identity different classes of land use and land cover and providing estimates of the areas under each land use such as agricultural lands, forest cover, built up land etc, together with its capability to provide information on natural resources including underground water, makes remote sensing a unique tool for urban management Major parameters for developing the urban environment should naturally include physiography, land use pattern, geology, water resources, soil and drainage pattern apart from the effects of human usage of land. Geological, soil slope, aspect , and landuse/ landcover information can be extracted from remote sensing data and were used to elaborate maps of land use suitability with respect to ground and surface recharge purpose, areas for urban expansion and areas with risks of natural or human induced hazard. This information, associated with land use/land cover maps and socio-economic diagnosis, allowed the elaboration of maps to provide guidelines for regional land use policies.

7.1 Terrain Parameters used in this Study

The planning of developing a new harvesting site in a geodynamically unstable and environmentally fragile domain of watershed region require assessment of various terrain parameters in order to safeguard the life and property of the inhabitants due to recurrent natural calamities and human induced hazards caused by unplanned development of the city. The key parameters used in this study are geology, landuse/landcover, soil texture, slope, drainage density, and, relief required to be accessed for sustainable development of a new harvesting site are described below:

7.1.1 Geological features

The geological realm in the area is dominated by alluvium in the flat terrain and rocks in the hilly terrain. The lithological formation exposed in the hilly terrain primarily consists of various types of shale, slate, limestone and quartzites. The rocks types, like shale because of their splintery nature and limestone due to high weathering rates are less suitable for infrastructure development as compared to massive slates and hard quartzites. On the contrary, Shiwalik range dominated terrains have ideal conditions for development of harvesting site. The building stone resources of the rocky terrain can be harnessed for the construction material. The natural hazards like landslide and earthquake impact are more prevalent and disastrous in hilly region whereas land hazards caused by flood inundation and water logging can pose serious threat to healthy geoenvironment in plain regions. In this the study the geology map is prepared by using Arc GIS software. The geological map has been given in Fig. 7.1.

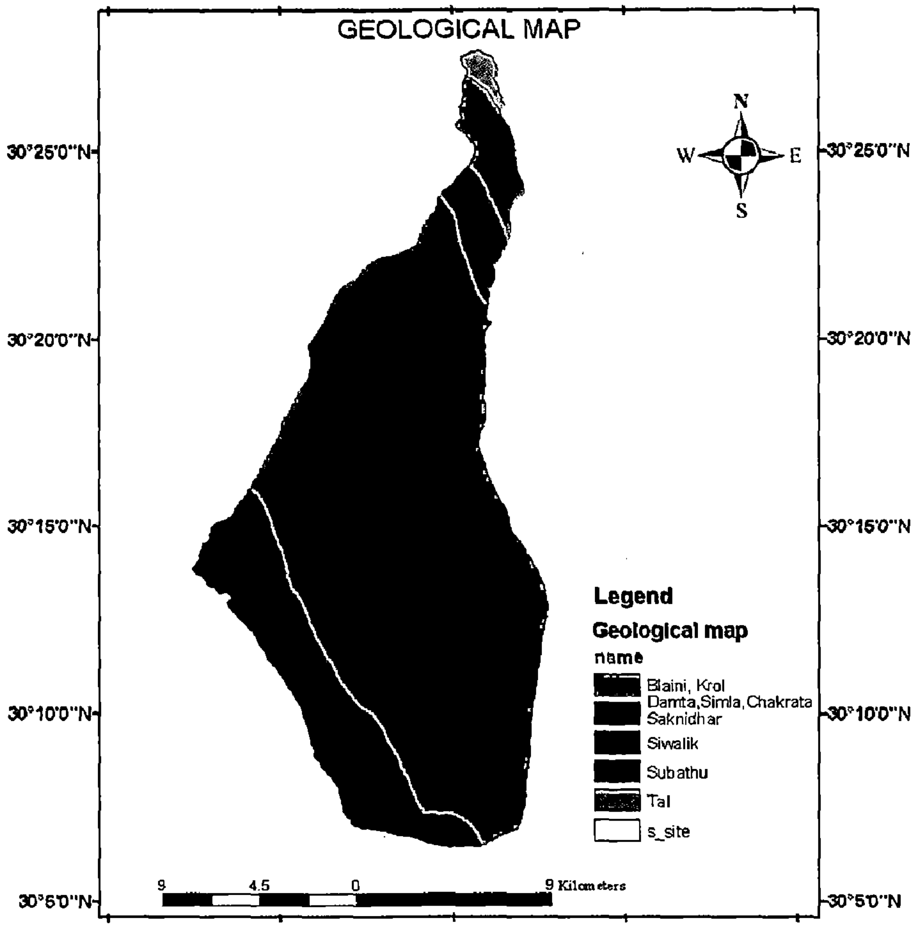


Fig.7.1 Geological map

7.1.2 Landuse / Landcover

Land is becoming a scarce commodity due to the immense agricultural and demographic pressure. The information on land resources and possibilities for their optimal use is essential for the selection, planning and implementation of appropriate land use practices to meet the increasing demands for basic human needs and welfare Satellite remote sensing has played an important role in generating information about the natural resources present in an area and their temporal changes through times, The information being in digital form can be brought under GIS, which will make the data update, retrieval and manipulation easy. The natural resources information in GIS environment can be utilised for its correlation with other resource information. The information under GIS environment helps the planners to take effective decisions in land resource planning on the basis of patterns of land use / land cover dynamics.

The Dehradun watershed and its environs have a distinct variability in physical landscape with a diversity of land use patterns and ground water occurrences. The land use land cover patterns are generally controlled by agro-climatic conditions, ground water potential and hosts of other factors like soil characteristics, socio-economic status and demography. To prepare action plans pertaining to land resources utilization on sustainable basis, a detailed database on landuse/landcover and ground water is a prerequisite. The high spatial resolution satellite images viz., LISS-III (23.5 m) and PAN (5.8 m) provide a plethora of information on terrain features like land use land cover, ground water, geology, structure, geomorphology, drainage, slope aspects and many other spatial information, which are required for building a comprehensive database for analysing land dynamics.

Land use / land cover information is essential for a number of planning and management activities. The existing land use patterns, because of their strong influence on how land could be used in future, become a crucial factor in deciding as to how land development, management and planning activities should be undertaken. Most of the natural resources are directly or indirectly related to the surface cover in a given locality. Therefore, to maintain harmony among resources and socio-economic needs, land use and land cover studies should be dealt with care In the present study attempt has been made to map land use / land cover of Dehradun and its environs (327.2 sq km.) using digital image processing technique. A part of the area around Dehradun has been taken up for change detection study using temporal satellite data to envisage the landuse/landcover dynamics in the fast growing Dehradun.

IRS—IC LISS-III data of 13 november1988, 1 April 2001 and 21 March 2005 (as shown in fig.no.7.2,7.3.and 7.4) along with Survey of India (SOI) topographical maps 53 J/3, 53 J/4 53 F/15& 53 F/16 at 1: 50,000 scale for the year 1965 and SOI guide map of Dehradun area at 1:20,000 scale has been used in the present study Digital image processing techniques have been used for preparation of land use/ land cover maps using Anderson's multilevel classification system (Anderson, et. al., 1976) in ERDAS IMAGINE 8.6 image processing software. The multispectral classification was carried out using supervised classification techniques by applying maximum likelihood classifier. The standard image processing techniques such as, image extraction, rectification, restoration, and classification were applied in the current study. The image obtained from the NRSA, Hyderabad in four bands, viz., band 1 (blue) band 2 (green), band 3 (red) and band 4 (near infrared) have been used to create a false colour composite (FCC) (Fig. 2) using ERDAS imagine software. Satellite images of all the years have been preprocessed further before their classification using image processing techniques like image enhancement, noise removal and de-stripping. Images have been georefenced and rectified using nearest neighborhood algorithm resampling procedure.

Unsupervised classification has been carried out using ISODATA algorithm to ascertain the probable land use classes which can be extracted from the image. Further, supervised classification has been carried out to extract the land use / land cover information. Signatures of the different landuse classes have been selected from the FCC's satisfying statistical criteria's like standard deviation and unimodal plot. The maximum likelihood method (MLC) has been used for the classification of satellite imageries. Accuracy assessment of classified images was carried out using reference data available from toposheets and other maps. Further, urban area (built-up) in all four years (1988, 2001and 2005) have been extracted from the classified images by overlaying the municipal boundary layer of the Dehradun using ArcGIS software.
Different landuse classes obtained from the classified images are (1) urban land, (2) degraded forest, (3) barren land, (4) agriculture land, (5) forest (6) water (7) sandy soil (8) plantation and (9) waste land the classified images for the year 1988,2001and 2005 as shown in fig. no7.5,7.6, and 7.7as shown below.

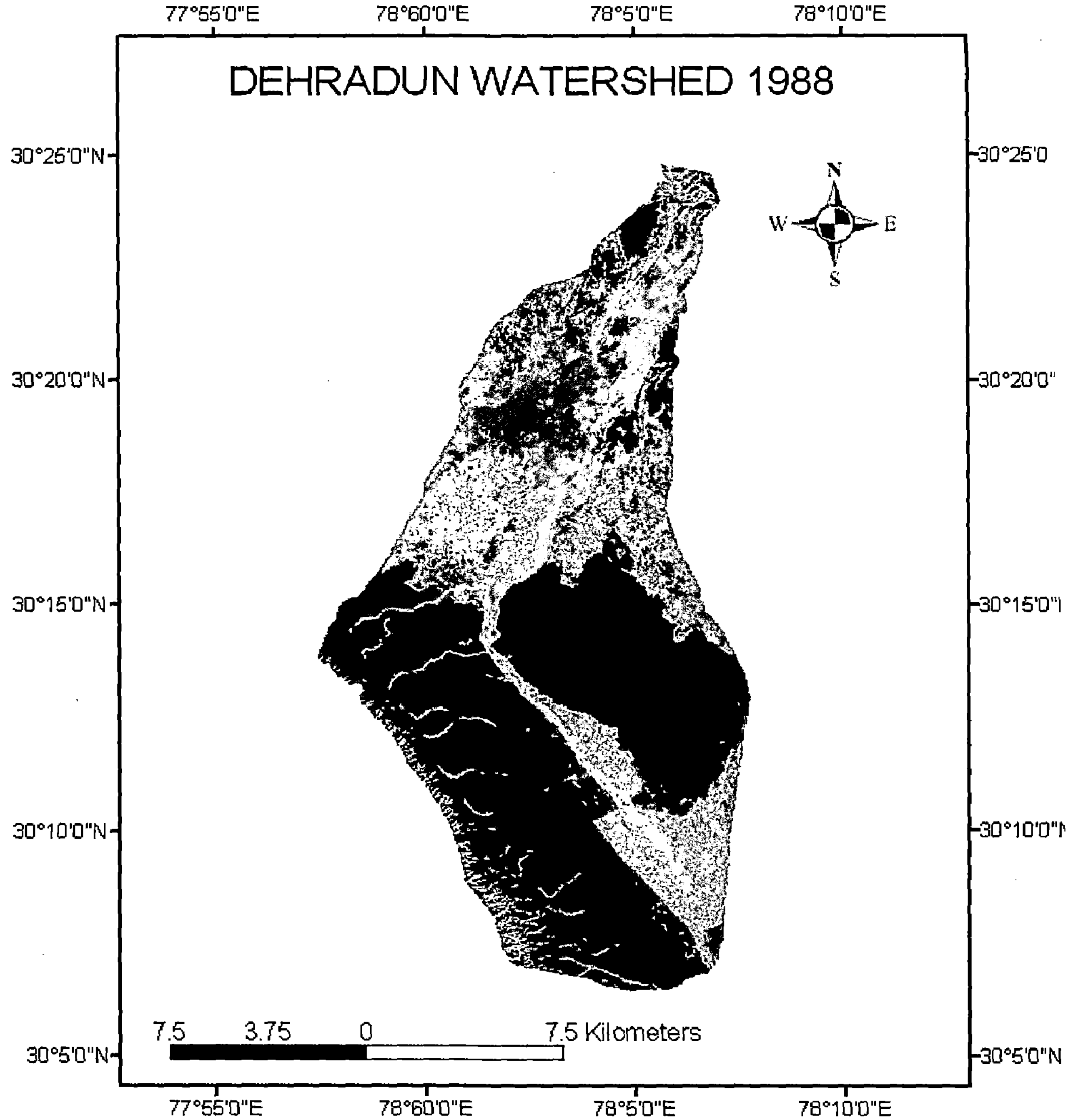


Fig 7.2: LISS III FCC Image 1988.

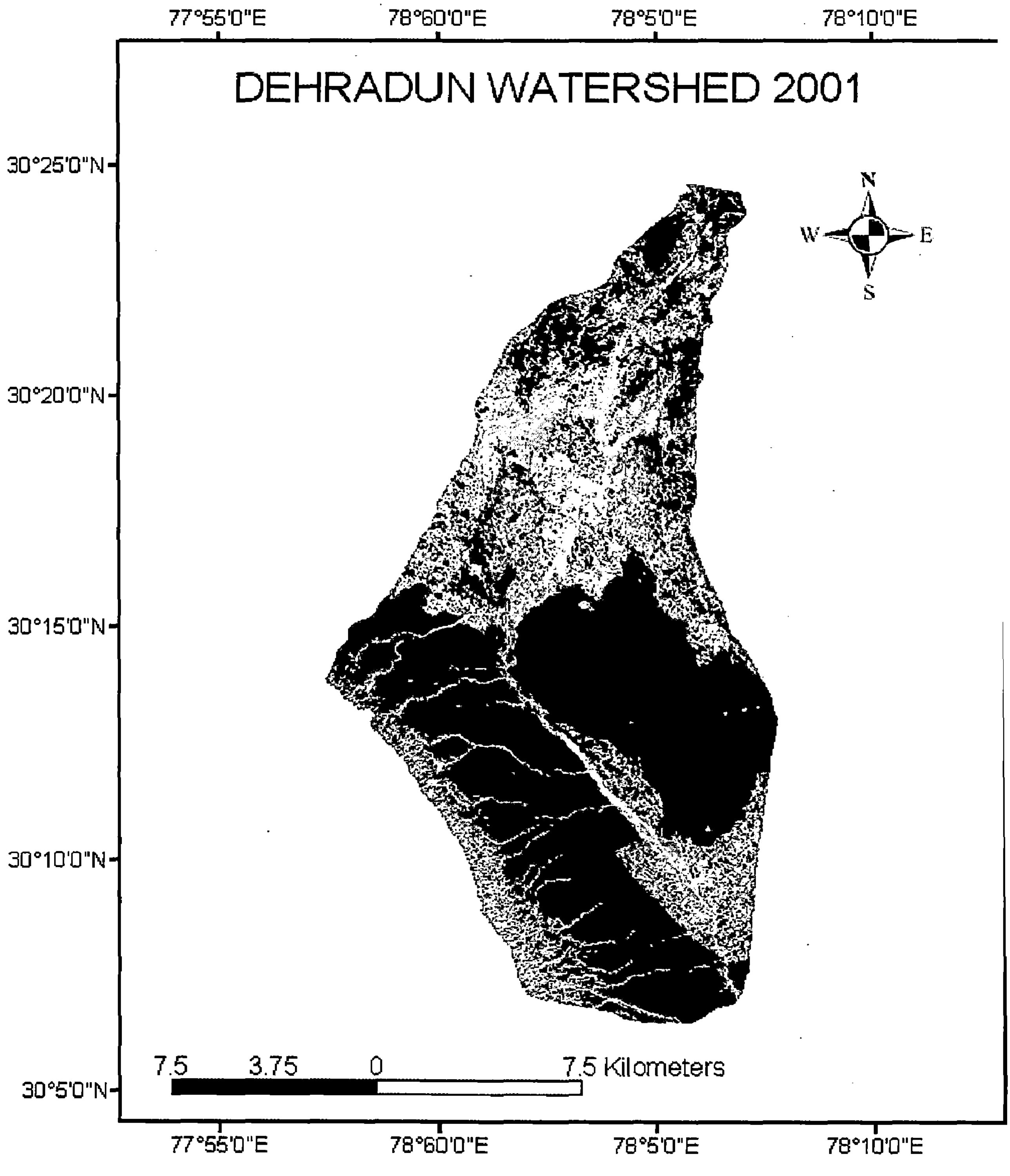


Fig. 7.3: LISS III FCC Image 2001.

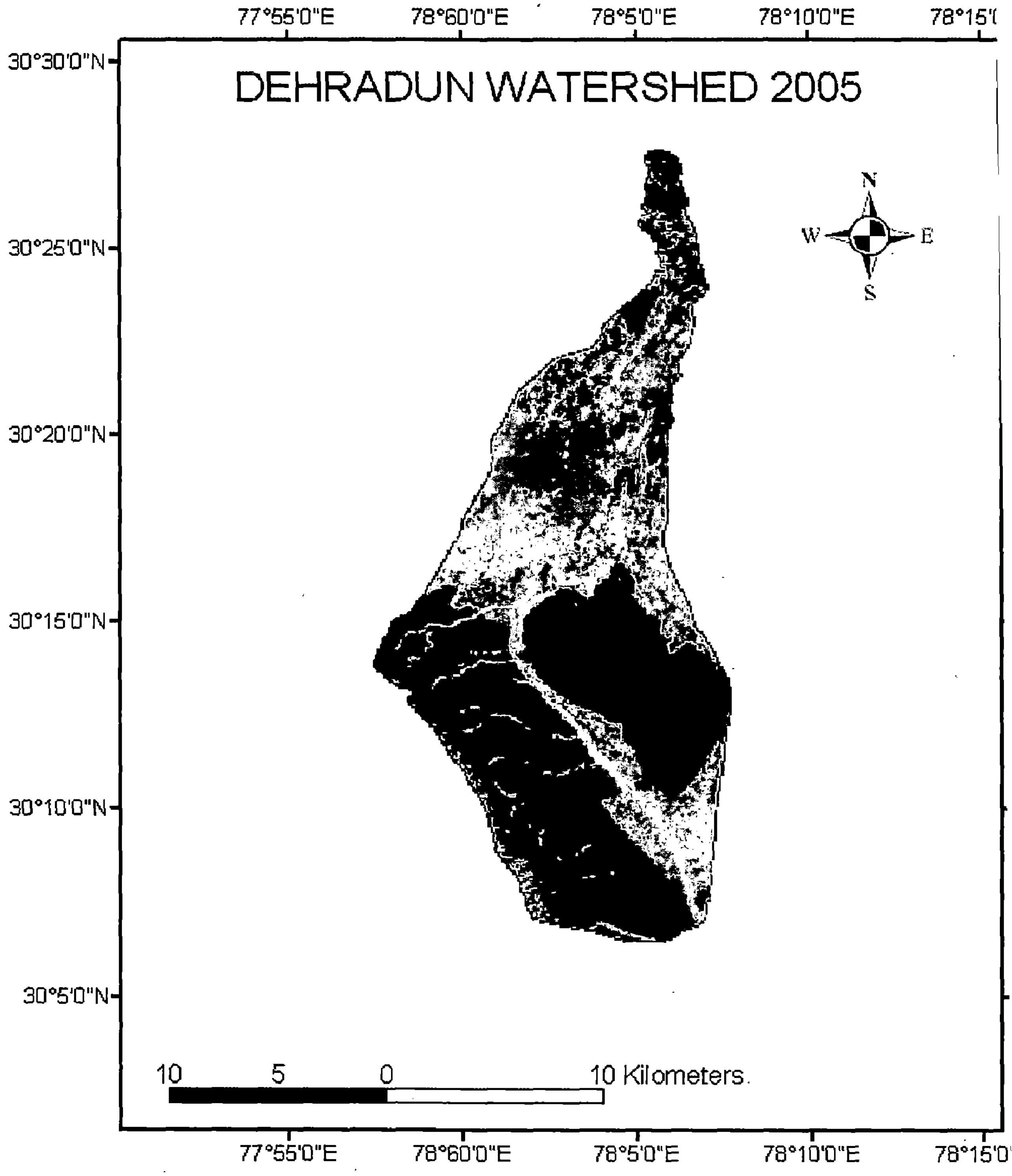


Fig 7.4: LISS III FCC Image 2005.

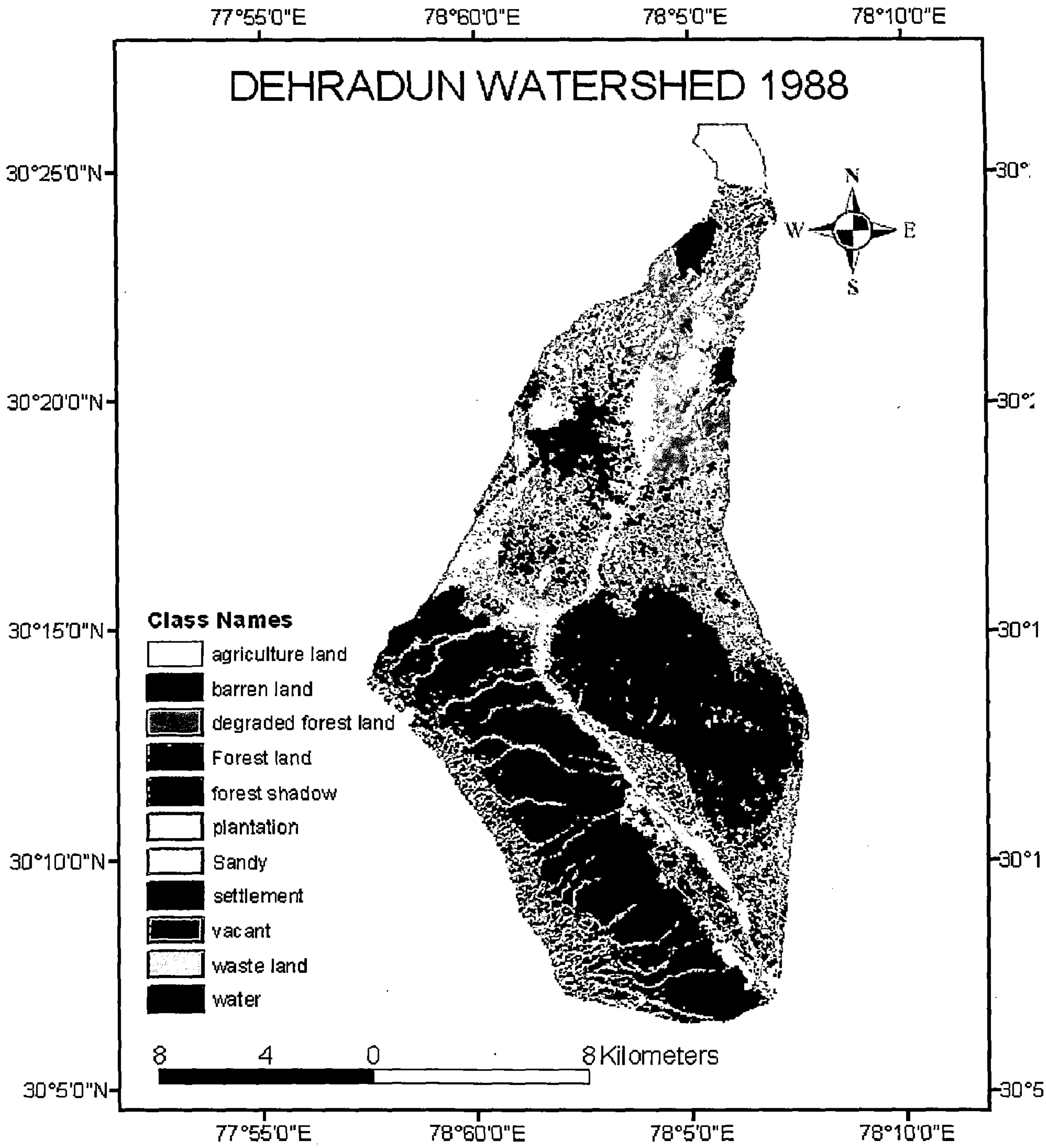


Fig 7.5: Classified Image 1988.

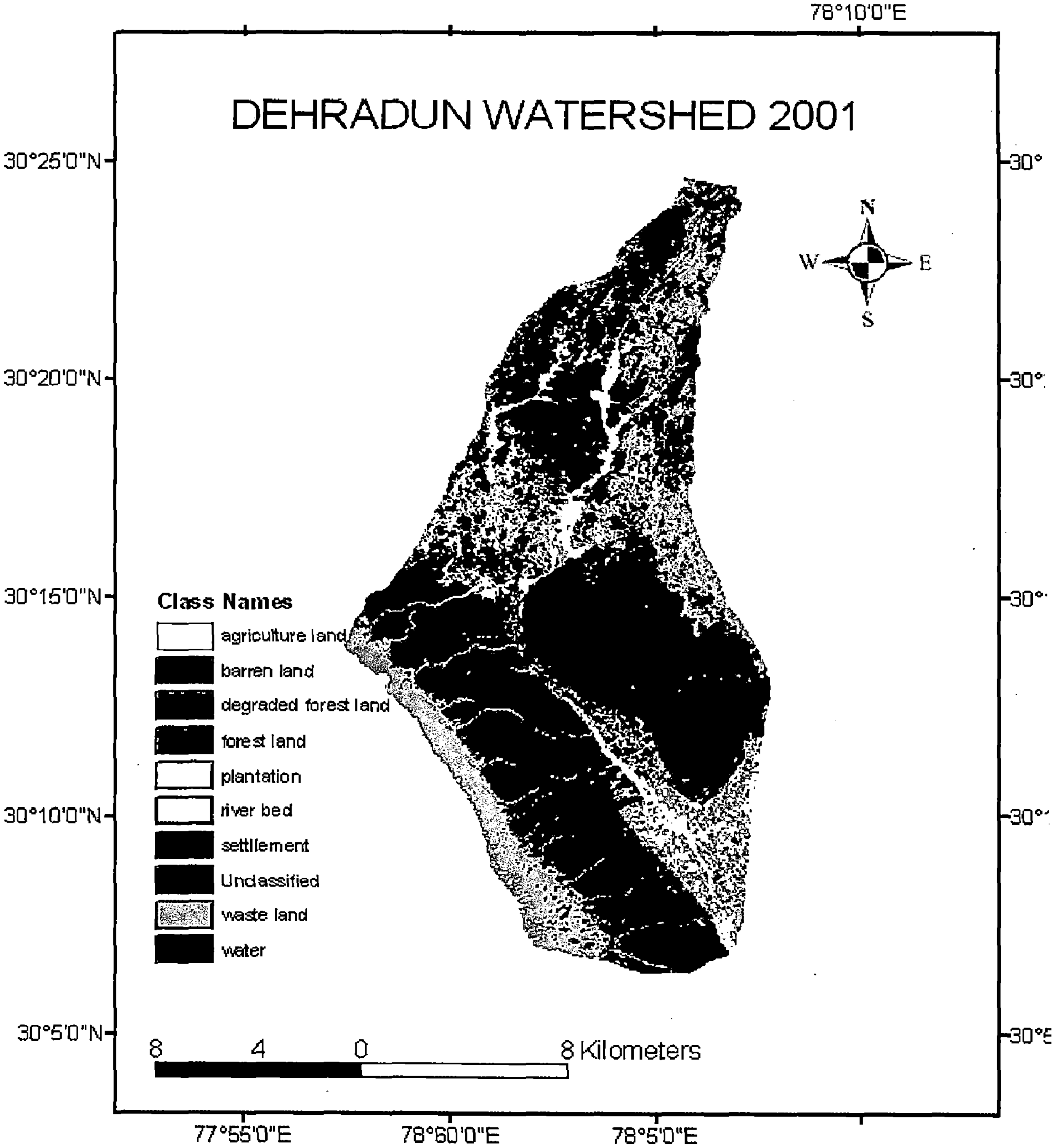


Fig 7.6: Classified Image 2001.

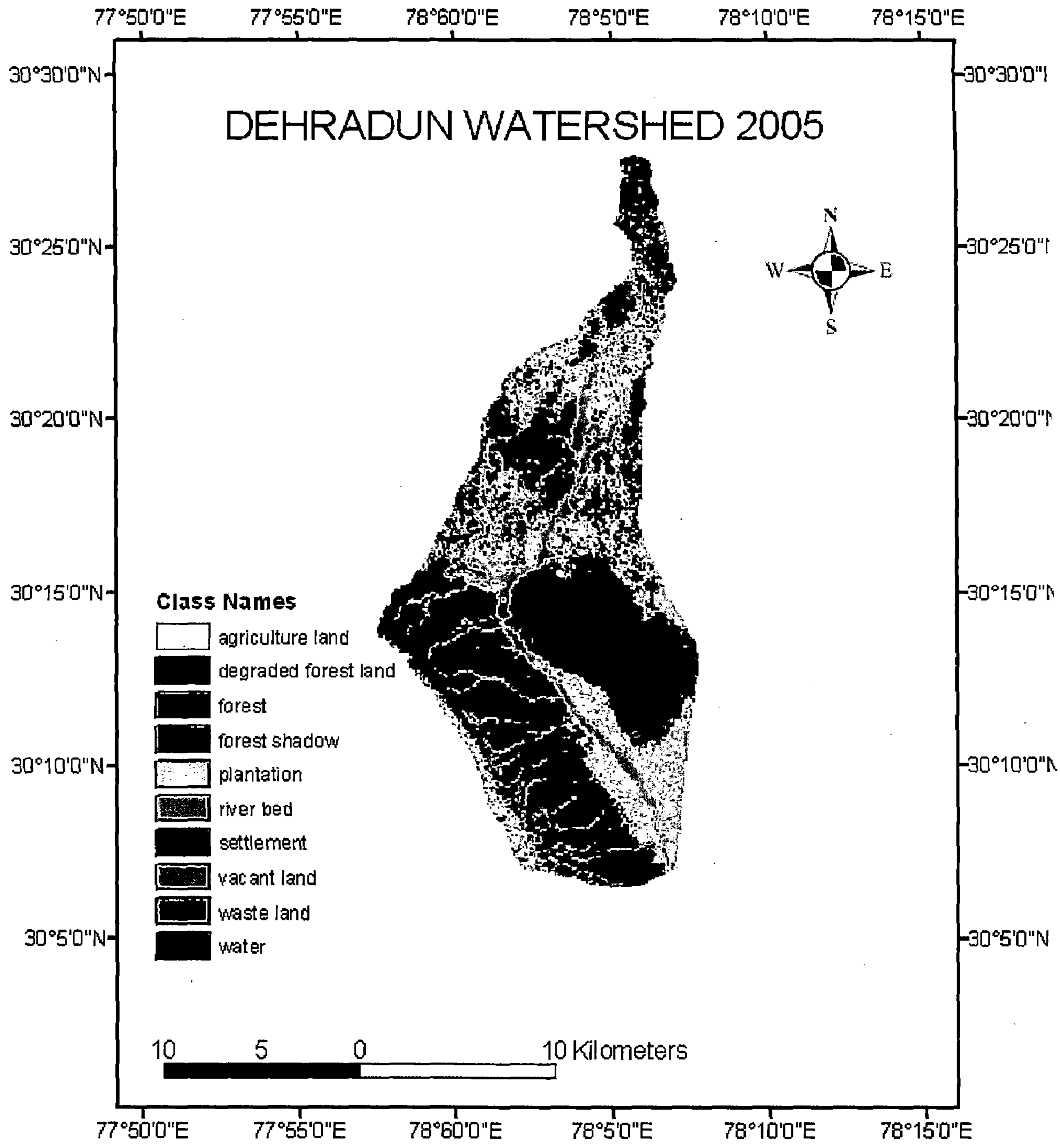


Fig 7.7: Classified Image 2005.

7.1.3 Soil Type

Assessment of soil texture and soil depth constitutes a prerequisite for planning any developmental activity The uneven compaction of soil during post construction period can pose danger to the overlying structure Presence of fine loamy and sandy soils with high bulk densities is better suited for road foundations and building sites as compared to coarse loamy and skeletal soils heavy structures require deeper foundation and therefore require regions with deep soils Shallow soils with rocky basement incur problems during construction and poses heavy risk during earthquakes The deeper soils are met towards the southwestern portion of the area over alluvial planes are best suited for developing new township in view of the location of the area in Zone IV of the earthquake hazards and its vicinity to seismically active Delhi-Hardwar Ridge.The soil map was prepared using arc GIS software (Fig. 7.8)

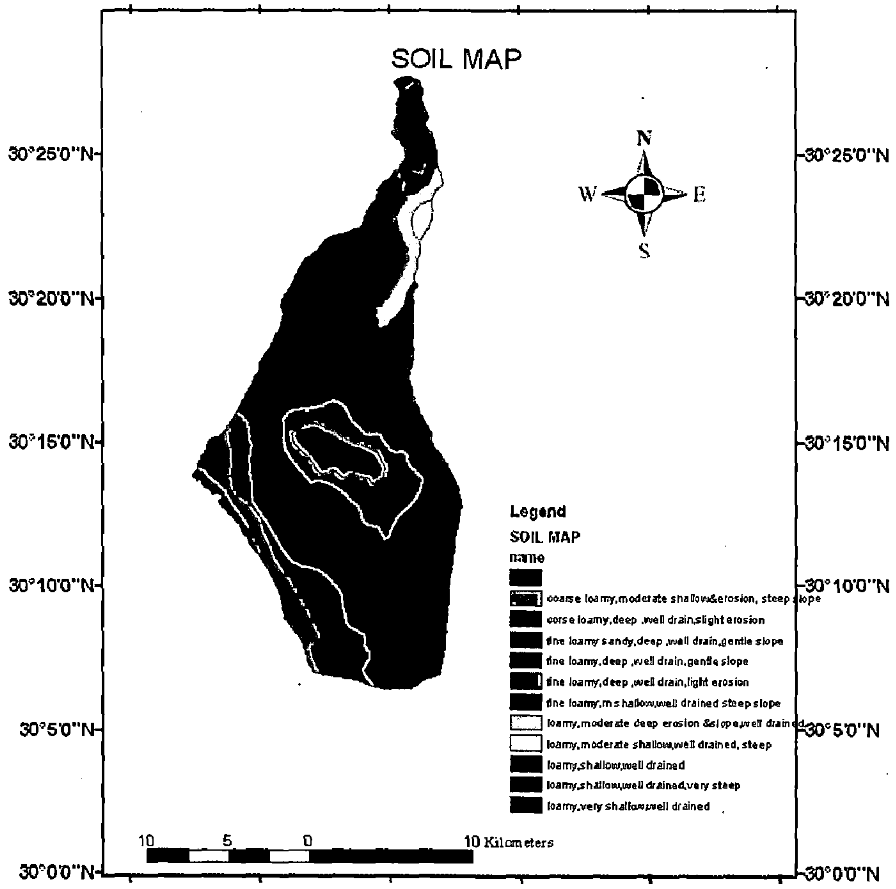
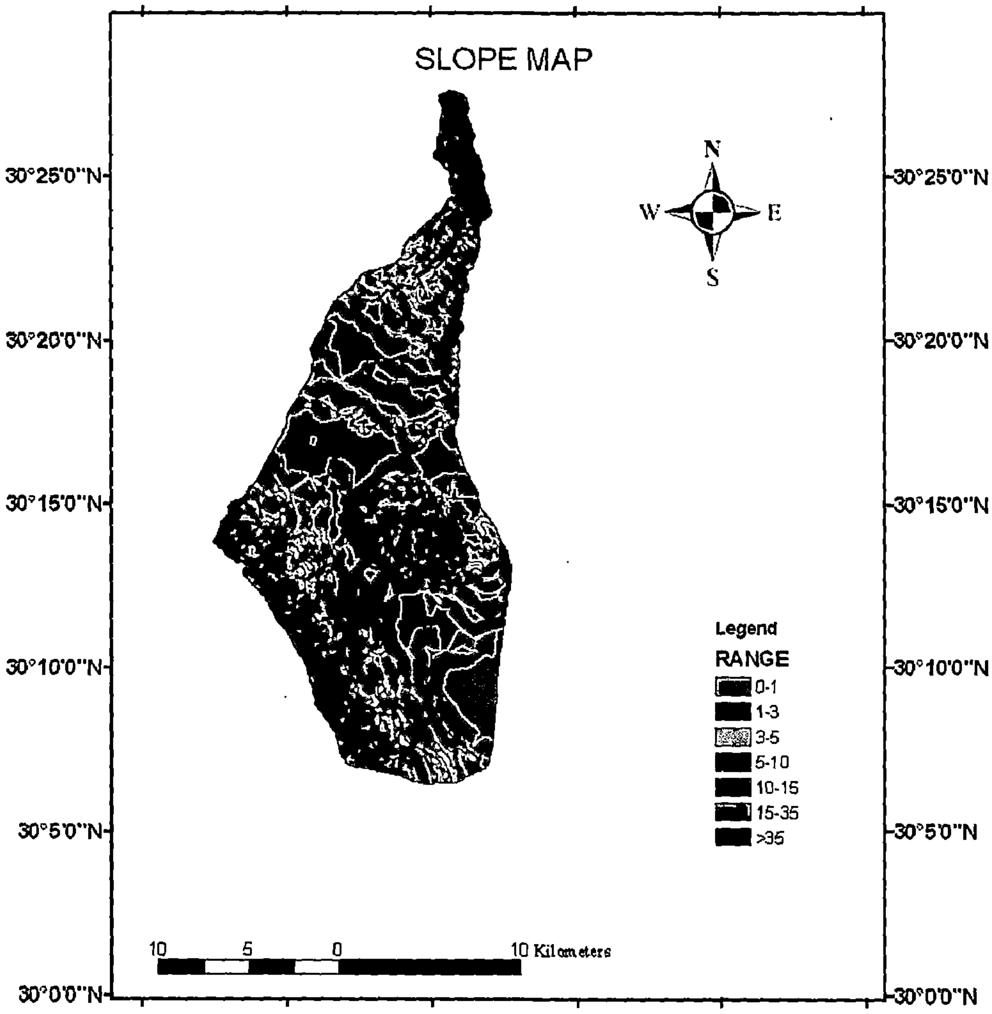


Fig.7.8: Soil Map

7.1.4 Terrain Slope

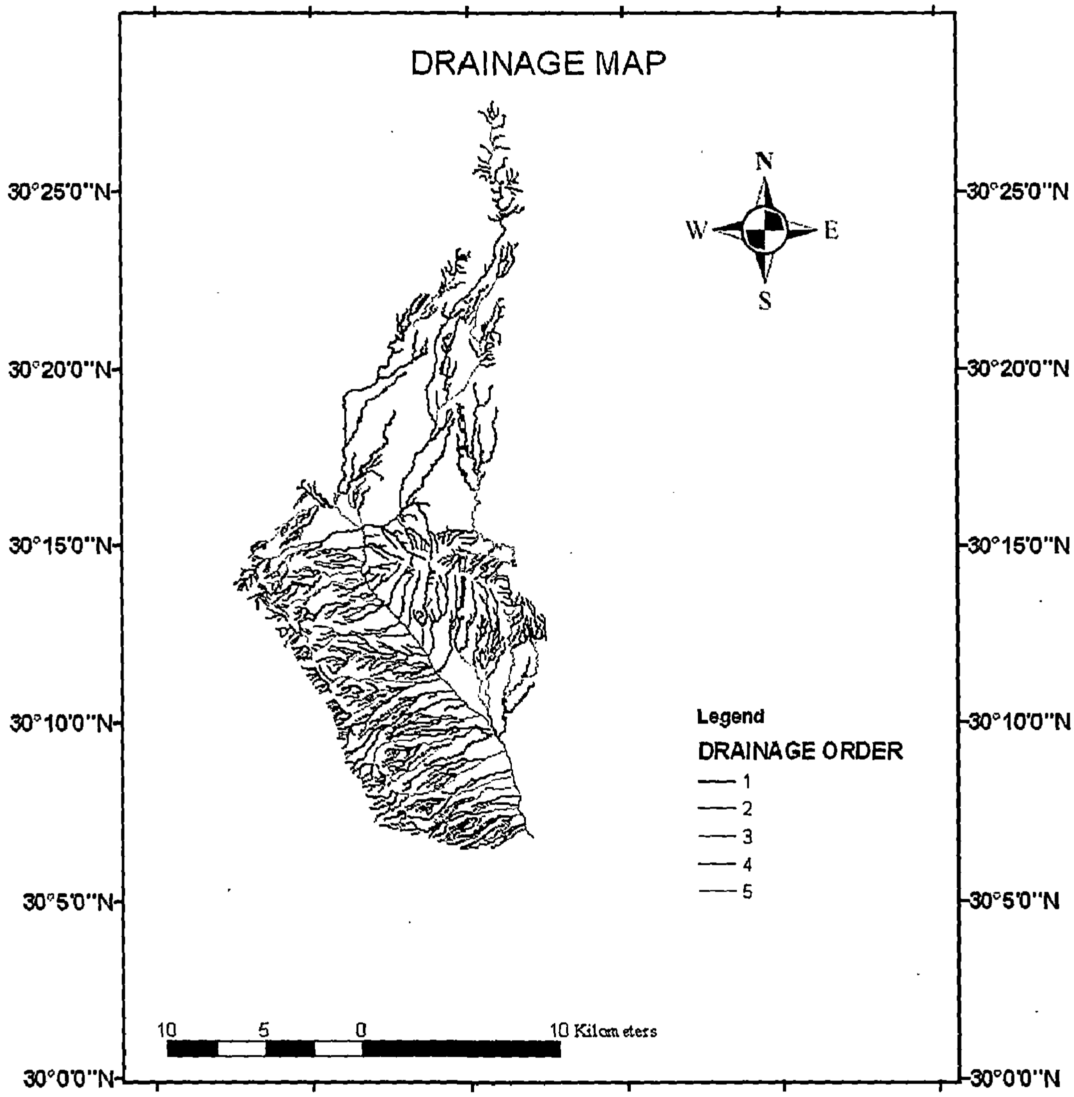
Terrain slope is an important factor for the distribution of utilities-facilities in a planned development site Lower the slope easier would he the activities involved in infrastructure development The cost of development in hilly regions is also very high as compared to flat regions Terrain slopes in hilly tracts of the area are generally were then 25 and have very little flat areas for development of township The plain areas have suitable slopes of less than 5 which is recommended for ideal development of a medium size township in the area The slope map was prepared using arc GIS software the Fig. no.7.9 as shown below



. *Fig.7.9*: Slope Map (in percentage)

7.1.5 Drainage order

Natural drainage provides escape routes for the turbulent surface flow to move down slope, thereby reducing soil erosion and danger to the surrounding infrastructure. They also act as recharge zone for ground water Higher costs are envisaged in developing infrastructure without disturbing the natural drainage of the region Therefore areas with higher drainage density should be avoided while infrastructure development The drainage order map was prepared using arc GIS software the Fig. no.8.10 as shown below



Drainage Map (Order)

7.1.6 SETTLEMENT BUFFER

Settlement buffer was generated using ARCGIS software. The buffer distance around the settlement was taken 500m.in the settlement region all surface is impervious so it most unsuitable water harvesting Fig. no.8.11 as shown below

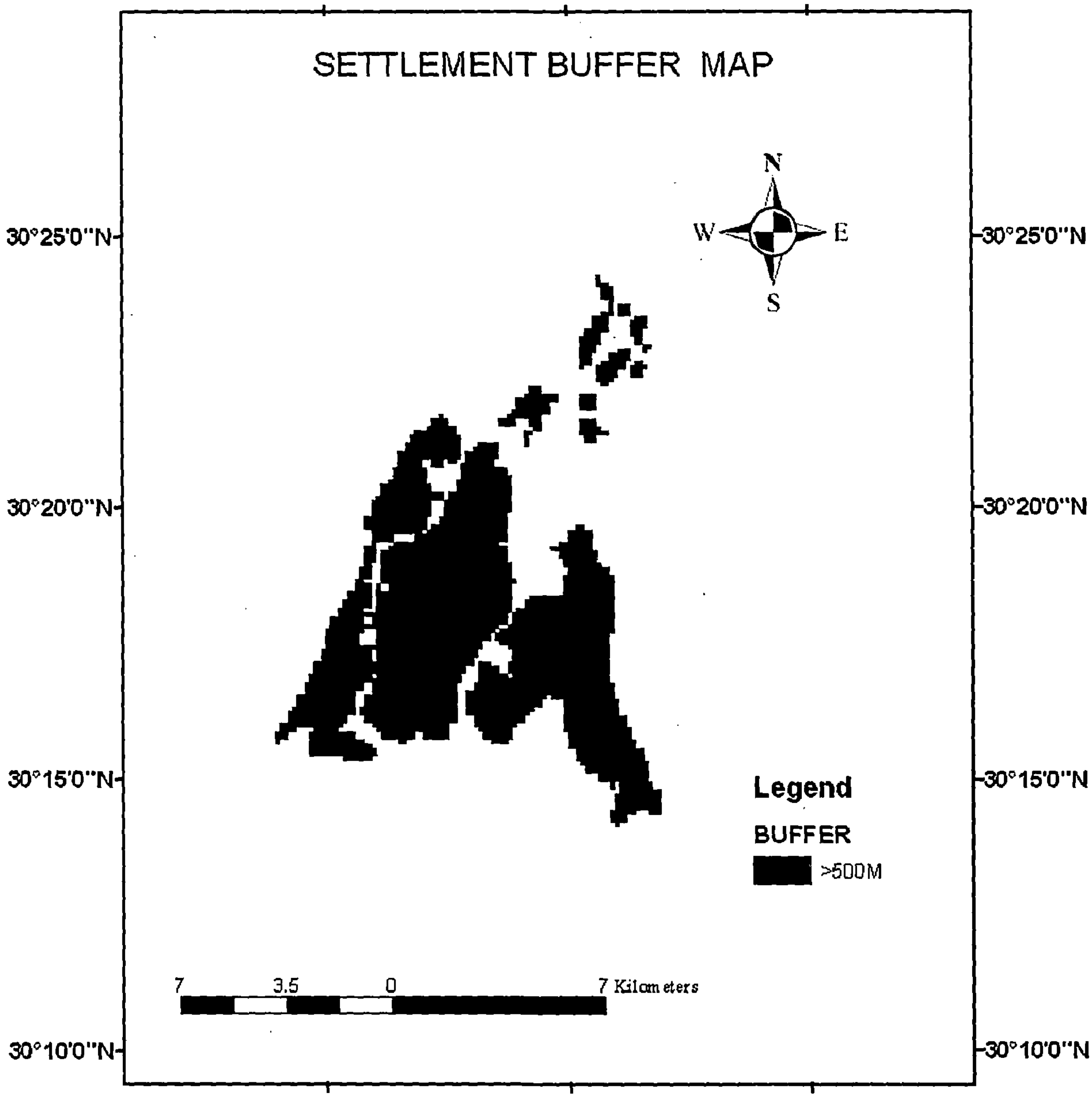


Fig.7.11: Settlement Buffer

7.3. Methodology for Site Suitability Analysis

One of the major problems in decision rule development on multi parameter analysis is the determination of the relative importance of one parameter with respect to the other. A numbers of methods are available to deal with such problems, in this study weighted rating approach was utilised for rain water harvesting site suitability on the scale of 1-5,in this scale 1 indicates more important 5 indicates less important or unsuitable and each parameter reclassified using ERDAS IMAGINE 8.6 spatial modeler and the weight are given to each sub class based on the important of the parameter the analysis was carried out for surface water harvesting and sub surface water recharge using above approach the final out put is obtained multiply all the parameter weights by corresponding rating .the resultant output classified into three classes. The classes are most suitable, suitable, and unsuitable. The field visits are carried out to check the classified result output and it has given 95% accuracy of resultant output.

In the present study for evaluating site suitability for new water harvesting site in the vicinity of Dehradun watershed , terrain parameters viz, geology, slope, land use, soil (depth and texture), drainage order, and settlement buffer zone were used for analysis (see Table.8.1& 8.2)

Table 7.1Rain Water harvesting for Ground Recharge

S.No CLASS		Weight	Rating
1.Slope	0-1	50	1
	1-3	50	1
	3-5	50	1
	5-10	100	2
	10-15	100	3
	15-35	100	4
	>35	100	5
2.Geology	Tal	150	5
	Blaini, Krol	100	4
	Damta,Simla,Chakrata,Saknidhar	100	3

	Subathu	50	2
	Siwalik	50	1
3.Soil	Loamy, shallow, well drained	150	4
	loamy, very shallow, well drained	150	4
	loamy, shallow, well drained, very steep	150	5
	loamy, moderate deep erosion &slope, well drained,	100	3
	Coarse loamy, moderate shallow erosion, steep slope	150	4
	fine Loamy, deep ,well drain, light erosion	100	2
	Coarse loamy, deep ,well drain, slight erosion	50	1
	fine loamy, deep ,well drain, gentle slope	50	1
	Fine Loamy sandy, deep ,well drain, gentle slope	100	2
4.LANDUSE/LANDCOVER	Agriculture	150	4
	Settlement	150	5
	Forest	100	3
	Forest shadow	100	3
	Degraded forest	100	3
	Sandy	50	2
	Plantation	100	3
	Water	50	1
	Vacant land	50	2
	Waste land	50	1
5.DRAINGE	1	150	5

	2	150	4
	3	50	1
	4	50	2
	5	100	3
6. SETTLEMENT BUFFER	0	100	0
	1	150	5

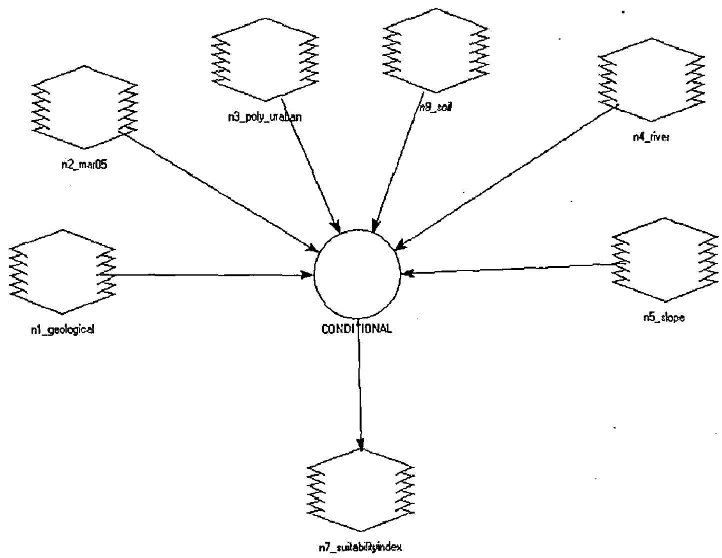


Fig 7.12: Rainwater Harvesting Model for New Site Selection (Ground water)

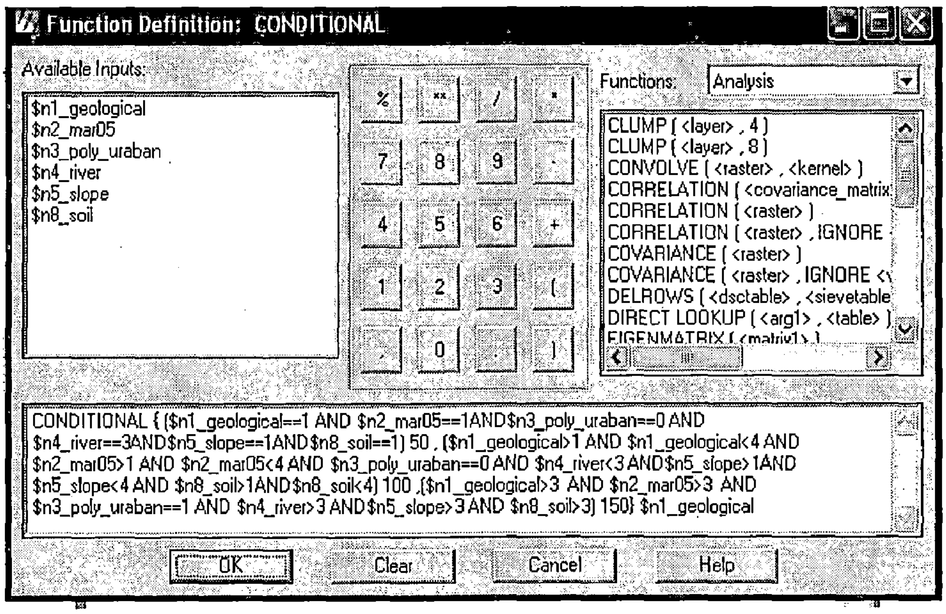


Fig 7.13: Parameter Conditions for rain water harvesting (Ground water)

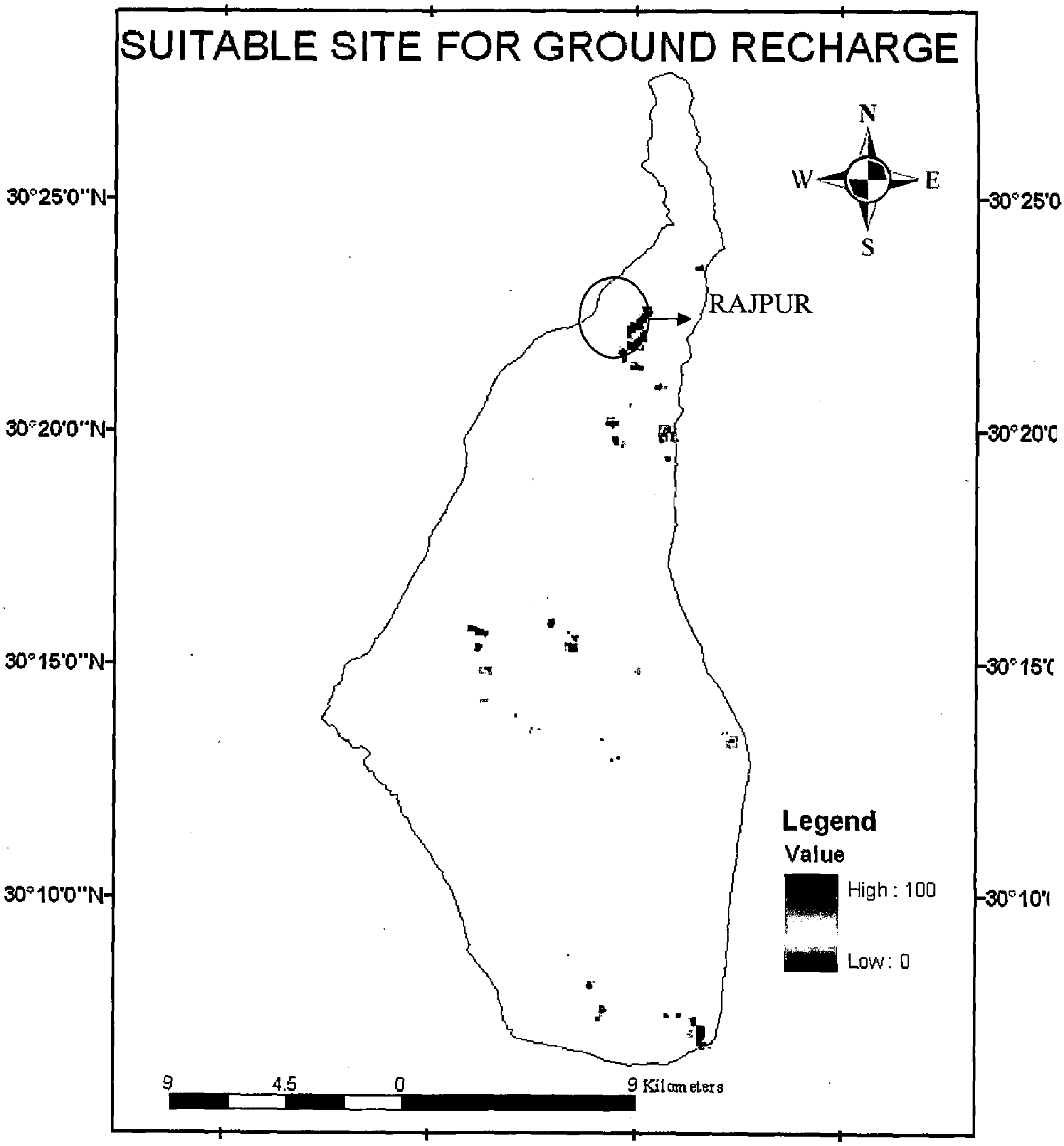


Fig 7.14: Suitable Site for Ground Water Recharge

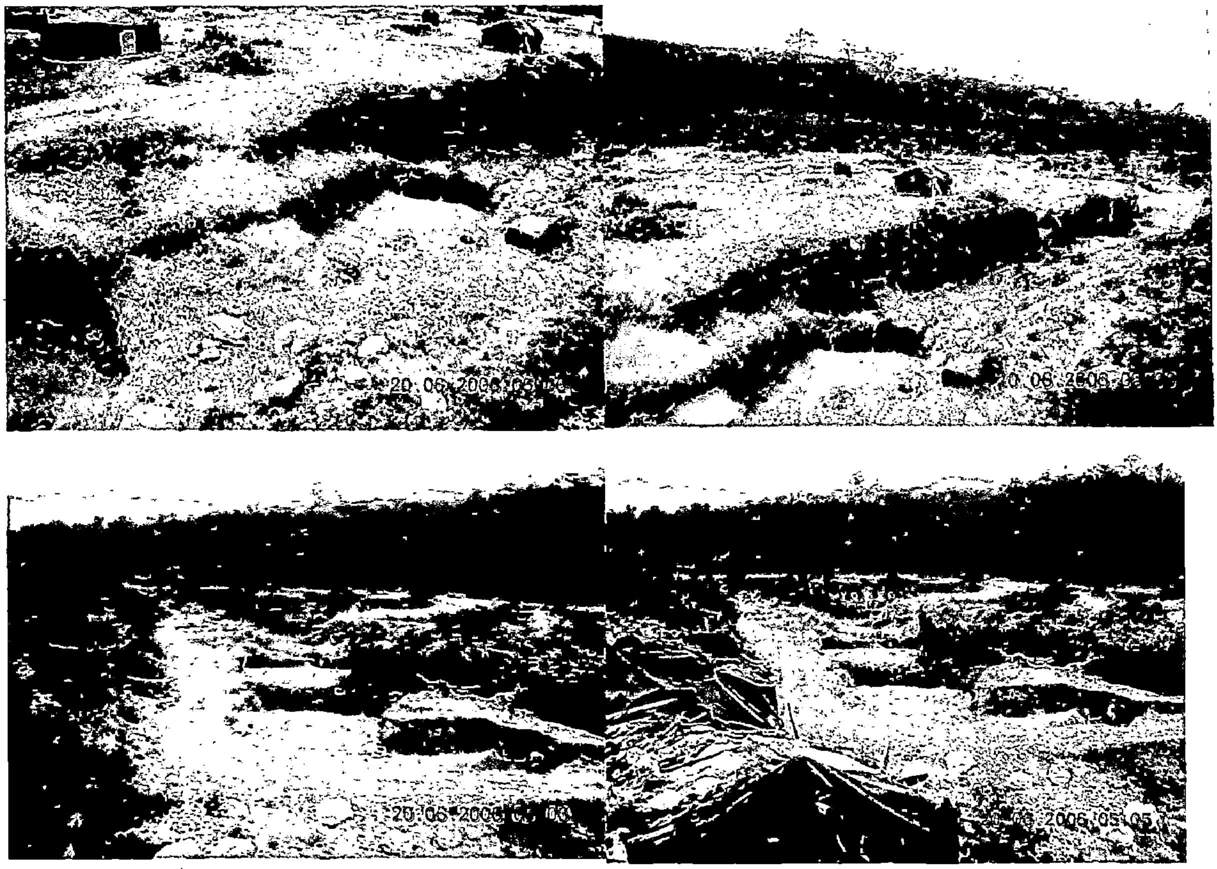


Fig 7.15: Field Photos: Identified Ground Recharge Sites in the Study Area (Rajpur)

Table 8.2: Surface Rainwater harvesting

S.No	Class	Reclassifications	Weight	Rating
1.	Slope	0-1	50	1
		1-3	50	1
		3-5	50	1
		5-10	100	2
		10-15	100	3
		15-35	100	4
		>35	100	5
2.	Geology	Tal	150	1
		Blaini, Krol	100	2
		Damta,Simla,Chakrata,Saknidhar	100	3

	Subathu	50	4
	Siwalik	50	5
3. Soil	Loamy, shallow, well drained		2
	loamy, very shallow, well drained	100	2
	loamy, shallow, well drained, very steep	50	1
	loamy, moderate deep erosion &slope, well drained,	100	2
	Coarse loamy, moderate shallow erosion, steep slope	150	4
	fine Loamy, deep ,well drain, light erosion	100	3
	Coarse loamy, deep ,well drain, slight erosion	150	5
	fine loamy, deep ,well drain, gentle slope	150	5
	Fine Loamy sandy, deep ,well drain, gentle slope	150	4
4. Landuse/Landcover	Agriculture	150	4
	Settlement	150	5
	Forest	100	3
	Forest shadow	100	3
	Degraded forest	100	3
	Sandy	50	2
	Plantation	100	3
	Water	50	1
	Vacant land	50	2
	Waste land	50	1
5. Drainage	1	150	5
	2	150	4
	3	50	1

	4	50	2
	5	100	3
6. Settlement Buffer	0	100	0
	1	150	5

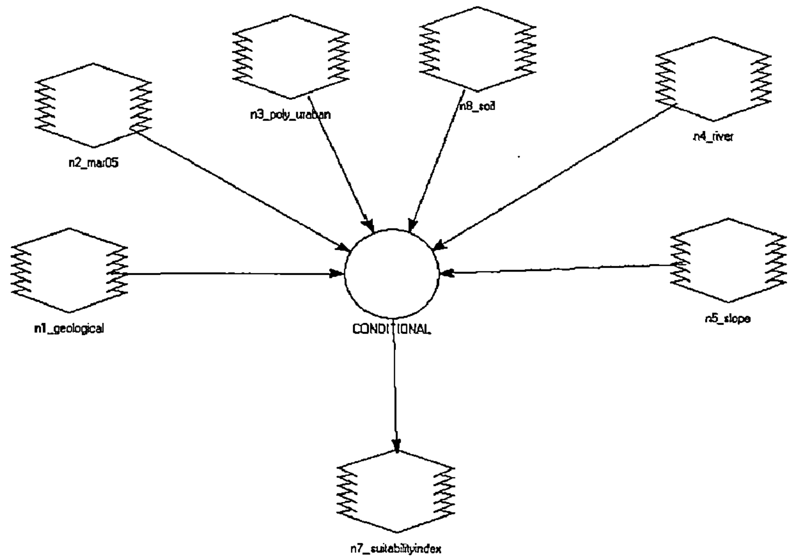


Fig 7.16: Rainwater Harvesting Model for New Site selection (surface water)

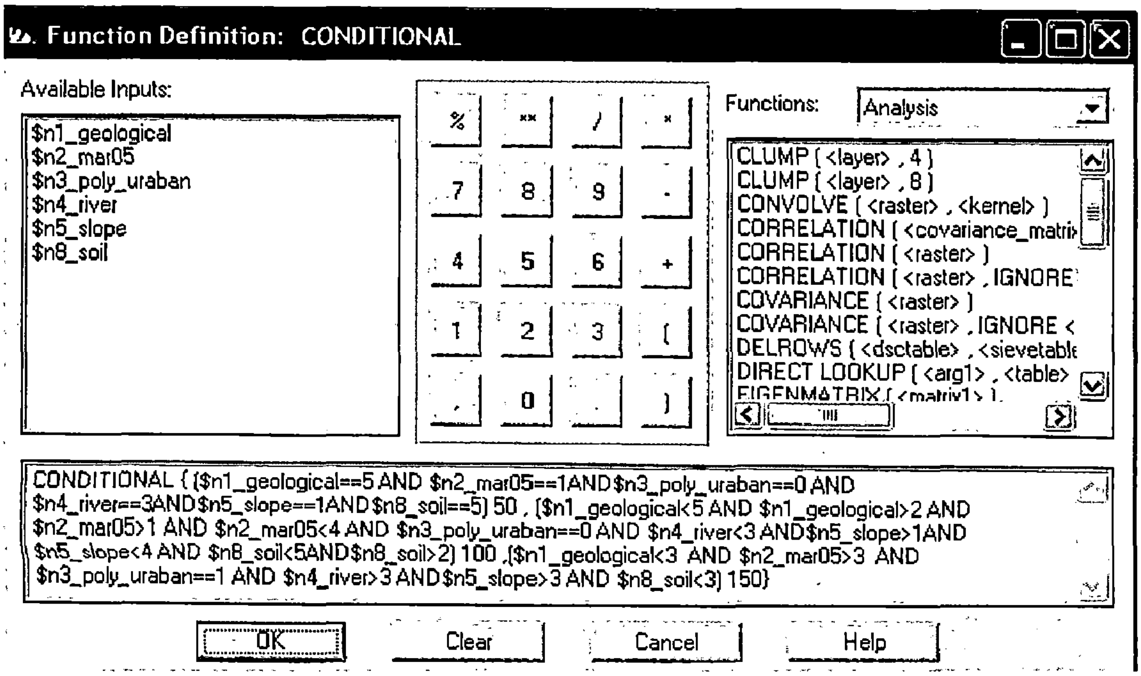


Fig 7.17: Parameter Conditions for Rainwater Harvesting (Surface Water)

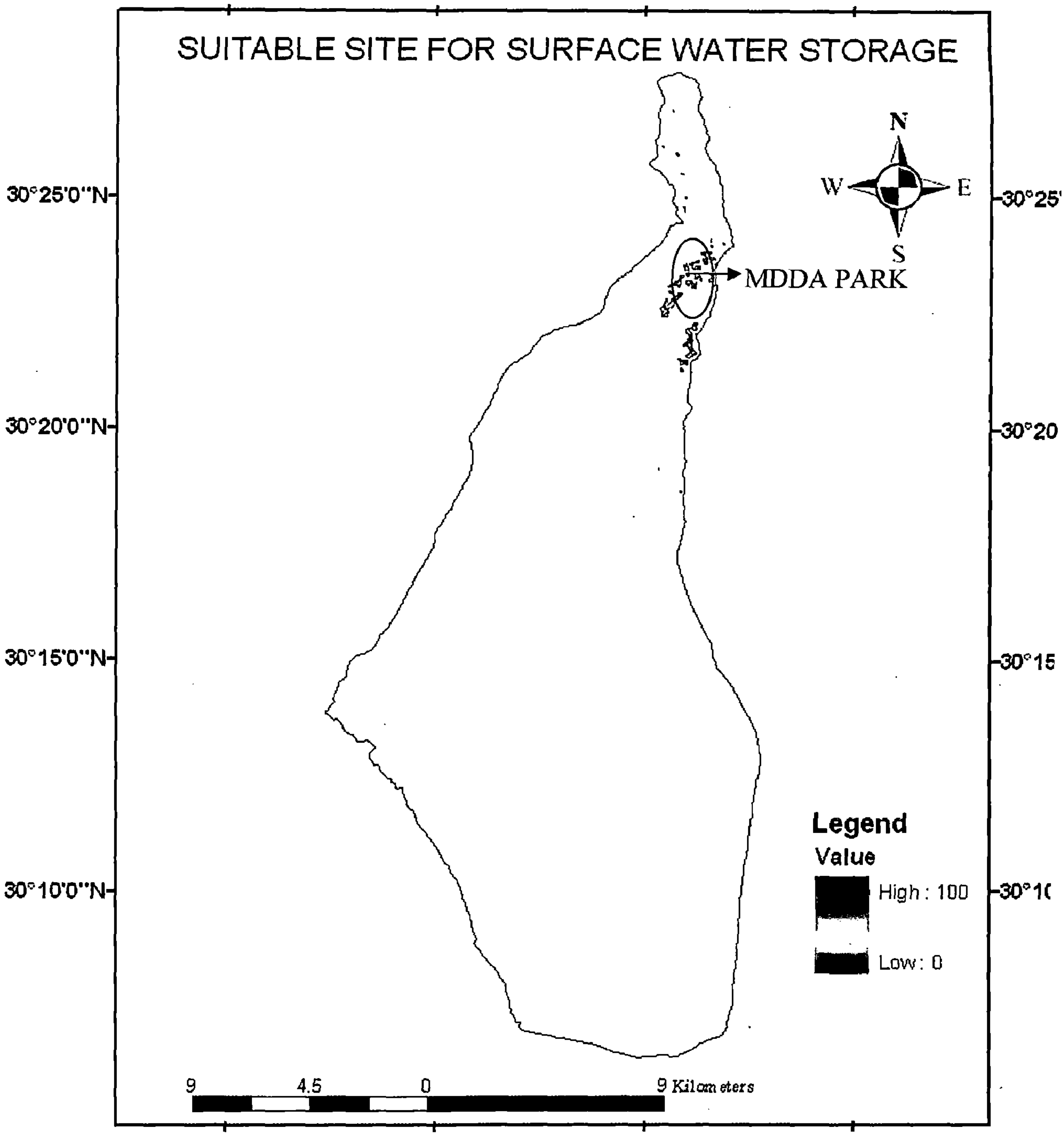


Fig 7.18: Suitable Site for Surface Water Storage (MDDA Park)

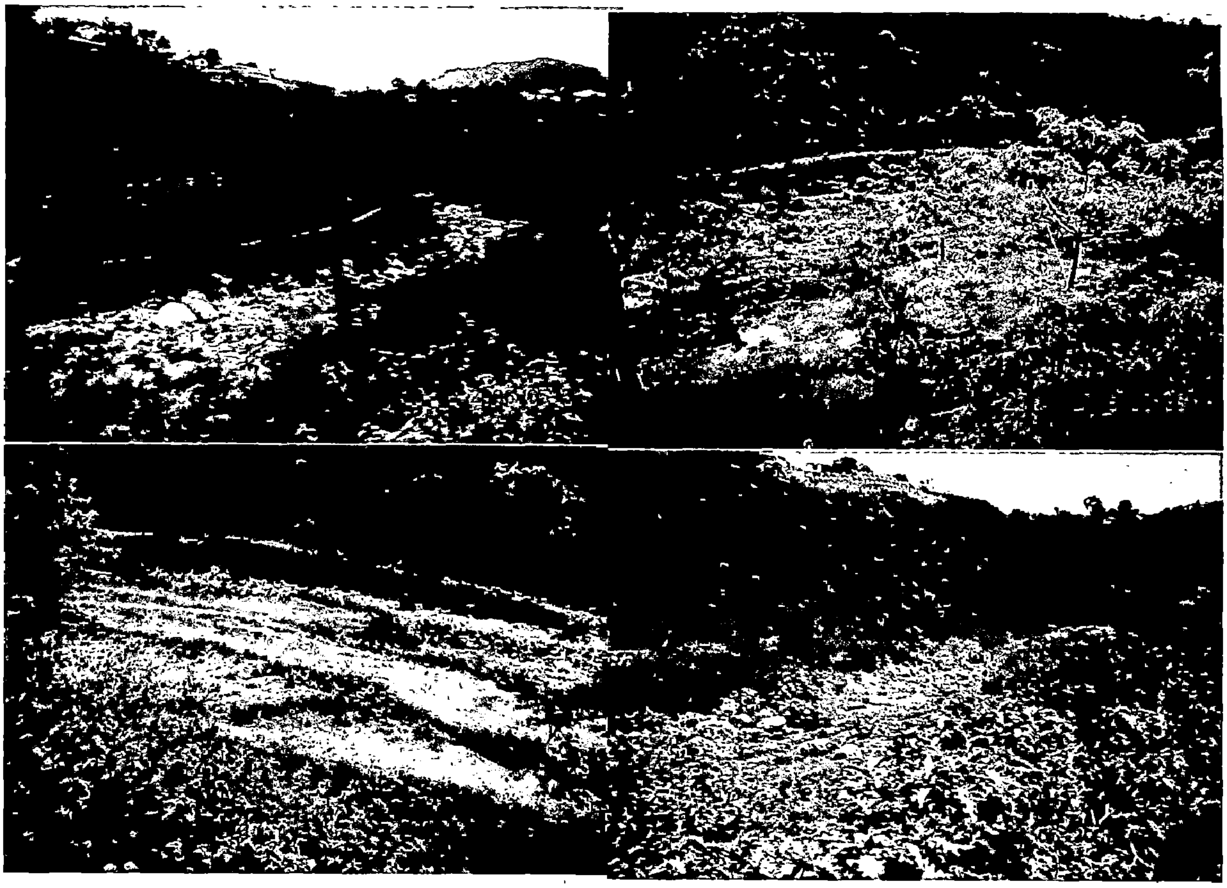


Fig 7.18: Field Photos: Identified Surface Water Storage Sites in the Study Area (MDDA Park)

7.4. Results and Discussion

The first step in evaluating the site suitability for a new ground and surface water harvesting is the selection of parameter required for the development. In the present study six terrain parameters viz; geology, Slope, land use, soil depth-soil texture, drainage order and settlement buffer zone were selected for analysis.

It is to remark that the proposed water harvesting site which is situated in the vicinity of Dehradun district towards its southern extremities need concern in terms of priority of development selection of residential and industrial areas coupled with risk factors due to predicted natural disasters in the region In order to evaluate the priority of development the present day landuse/landcover, vicinity to major transport network and perennial and non-perennial rivers are considered for spatial analysis.

Adopting this approach, the said parameters were analyzed with respect to the final suitability map for demarcation of areas suitable for surface and ground water harvesting purpose.

CHAPTER 8

ANALYSIS AND DESIGN OF ROOFTOP RAINWATER HARVESTING

8.0 Introduction

The present chapter deals with the development of criteria for the design of storage/recharging structures for a particular roof area based on the inputs available from GIS analysis. Various parameters based on the available data collected from different sources as well as ground reality information through site visits to Dehradun city are considered.

8.1 Design Parameters

Various design parameters are considered for approximating the tank capacity for storage or recharging structures, which are briefly discussed below:

8.1.1 Roof Area

Roof areas of the buildings are digitized from IKONOS IMAGE at 1m resolution, obtained from NRSA Hyderabad and stored in GIS database (Fig.8.1). The total number of buildings and projected roof areas for 2001 are given in Table 8.1. Maximum and minimum roof areas are considered in the design analysis.

Table 8.1: Projected Roof Area for the Year 2001

Classification of Area	Number of Buildings	Percentage	Roof Area (m^2)			
			Total	Min.	Max.	Mean
< 100 m^2	5,034	11.89	1,79,411.76	4.26	93.91	35.64
$100m^2$-200 m^2	21,798	51.50	37,518,71.76	101.03	196.44	172.12
$200m^2$ -500 m^2	11,715	27.68	47,08,844.25	200.63	499.99	401.95
$500m^2$-1000 m^2	2,207	5.21	14,11,795.83	500.00	999.67	639.69
>1000 m^2	1,573	3.72	34,33,481.48	1000.64	47463.16	2182.76
Total	42,327	100	1,34,85,405.08			

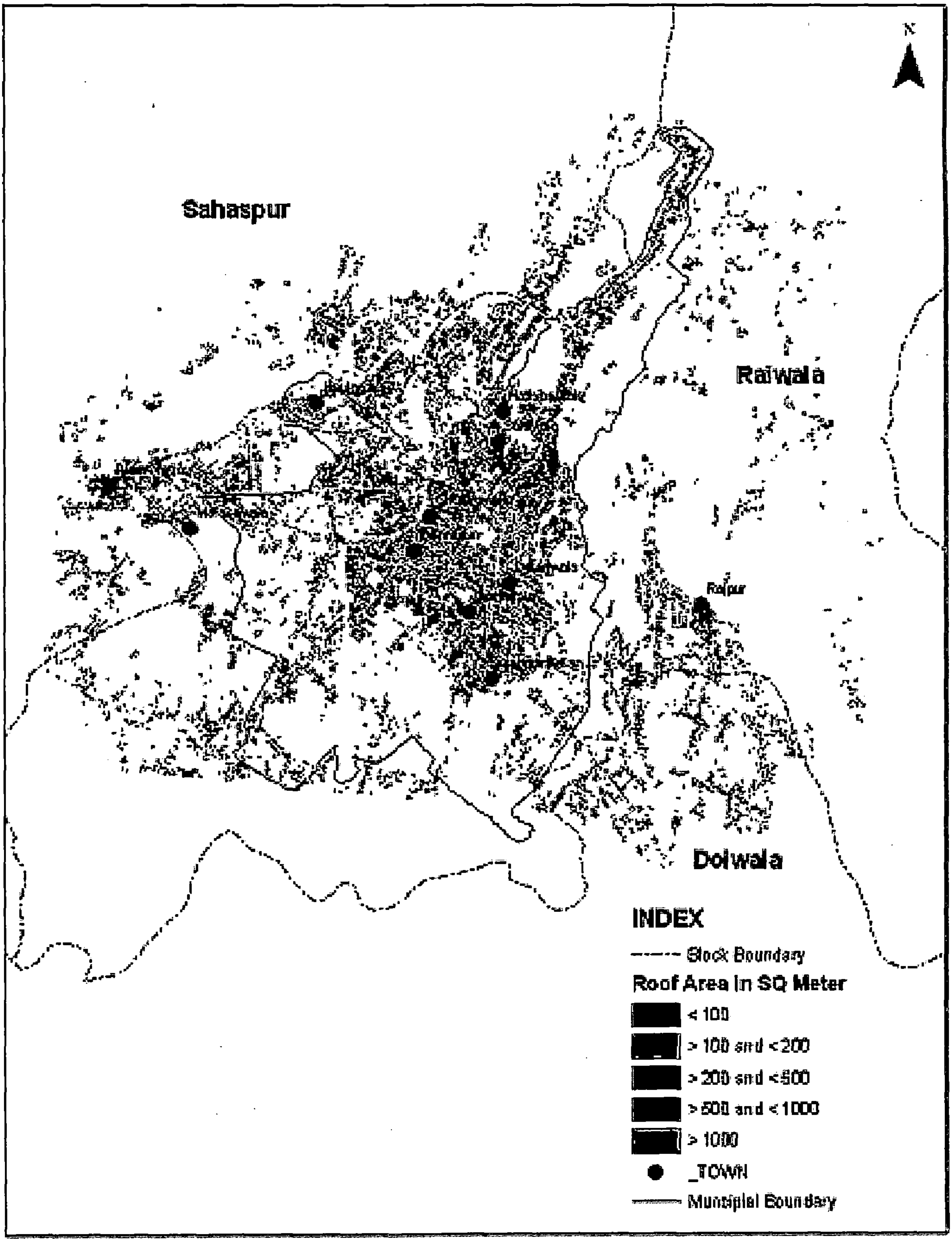


Fig. 8.1 Building Map of Dehradun City

8.1.2Maximum Rainfall

Dehradun experiences a minimum rainfall of 9.4 mm in the month of November and maximum rainfall of 688.3 mm in the month of August. Monthly rainfall is given in Table 8.2. Variation of rainfall year to year is shown below (see Fig 8.2).

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	A4G	SEPT	OCT	NOV	DEC
1973	104.0	27.9	40.0	Tr	34.0	310.0	1256.5	645.7	363.0	125.1	0.0	9.9
1974	26.5	18.4	6.2	14.8	21.2	139.4	735.5	553.1	92.3	26.0	0.0	57.9
1975	79.7	69.7	113.5	0.0	29.4	324.7	554.4	477.1	520.1	54.8	0.0	0.0
1976	20.7	72.4	22.0	6.7	38.3	156.3	819.6	653	167.9	1.3	0.0	0.5
1977	51.7	2.0	6.6	29.3	61.8	228.1	849.8	750.4	438.7	18.0	0.0	52.2
1978	6.0	59.2	164.5	44.8	9.1	293.7	630.7	816.2	574.1	2.4	64.6	8.4
1979	58.7	115.9	13.8	24.2	39.8	245.7	521.0	588.4	33.9	0.0	0.8	26.3
1980	16.0	18.3	52.4	8.3	6.2	261.5	615.8	904.6	223.7	7.0	21.7	12.4
1981	77.9	8.7	82.2	13.6	109.6	285.4	758	505.8	97.8	0.0	76.8	8.5
1982	78.1	62.4	197.0	52.8	57.4	71.4	540.4	642.7	55.7	16.6	1.3	50.3
1983	82.1	25.1	73.1	125.9	121.2	155.3	353.2	871.9	341.8	44.8	0.0	5.2
1984	12.2	148.6	6.6	5.6	Tr	394.2	879.6	403.4	328.8	0.4	0.0	10.5
1985	69.4	5.2	4.5	27.0	49.4	75.2	653.4	622.0	336.5	195.3	0.0	58.5
1986	10.9	97.6	55.3	33.8	74.6	304.2	805.8	730.5	198.7	164.5	7.5	48.5
1987	28.7	53.2	67.3	40.2	127.6	95.2	297.9	637.2	388.5	19.1	0.0	12.5
1988	22.7	40.0	108.7	37.8	44.3	328.2	526.6	607.4	244.2	0.0	0.0	60.5
1989	111.0	8.8	15.4	4.8	20.7	202.2	714.1	674.5	265.0	21.7	24.1	62.1
1990	1.2	121.2	98.2	35.1	114.4	183.8	903.4	887.1	460.7	33.6	7.2	121.9
1991	11.6	56.0	50.6	54.1	21.2	265.2	306.3	481.5	288.1	0.0	11.7	43.9
1992	81.6	40.5	13.5	1.8	26.3	156.1	571.8	980.1	191.0	7.7	6.8	0.0
1993	77.1	63.1	112.2	11.2	40.0	269.3	534.4	744.7	458.9	0.0	1.4	0.0
1994	57.2	56.9	1.9	78.2	9.4	217.7	724.2	776.9	65.0	0.0	0.0	2.2
1995	53.3	73.9	39.2	14.6	0.8	83.5	494.5	630.1	310.3	2.2	0.5	9.3
1996	40.3	106.2	45.5	13.4	10.0	355.8	604.0	962.1	282.3	57.7	0.0	0.0
1997	34.0	21.9	65.6	111.1	130.0	397.4	785.6	558.5	385.8	94.5	44.8	90.8
1998	5.4	72.4	117.7	78.6	86.3	110.4	855.8	1114.2	270.2	248	0.9	0.0
1999	57.3	4.2	4.9	Tr	6.9	398.4	795.3	536.3	671.0	75.8	0.0	9.9
2000	71.5	110.9	44.4	12.4	141.1	308.4	767.3	724.7	381.2	0.2	Tr	0.0
2001	42.0	2.2	31.8	51.1	131.5	505.4	803.4	613.2	134.2	2.9	1.4	9.4
2002	47.1	139.1	65.7	62.6	24.1	126.4	164.8	643.7	273.5	17.9	0.0	0.2
2003	38.6	98.9	49.6	13.8	31.2	138.5	424.7	601.3	436.1	61	12	27.5
2004	38.1	76	61.9	29.3	45.5	398.5	597.8	786.8	458.2	41..7	6.8	12.8
2005	57.1	40	52.2	41.4	61.4	167.2	454.5	456.8	395.5	19.6	7.5	30.5
Average	47.6	58.0	57.1	34.7	53.9	238.3	653.2	688.3	299.3	41.2	9.4	25.7

Table 8.2: Monthly Rainfall Data (mm)

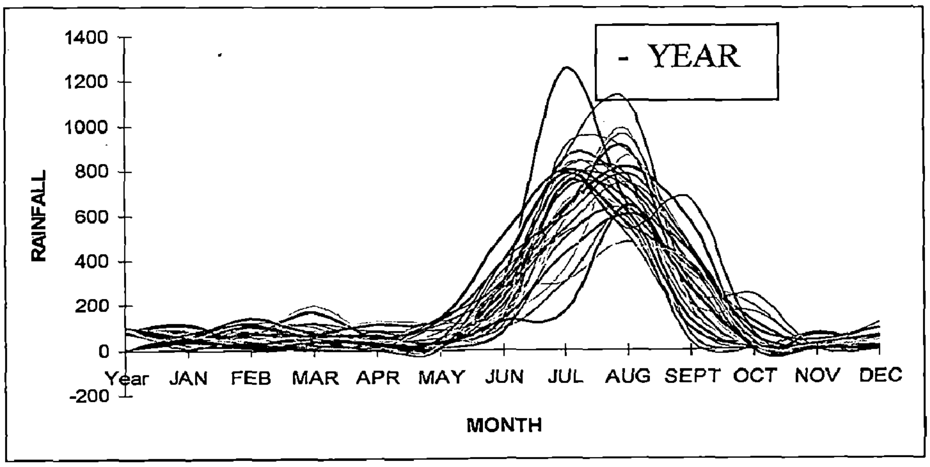


Fig 8.2 Rainfall Variations

8.1.3 Efficiency

Efficiency is one of the important factors in computing the runoff generated from rooftops. The type of roof would affect the quantity of rainwater harvesting. It has been observed during site visits that most of the roofs are flat and made of re-inforced concrete. Runoff coefficient for re-inforced concrete is about 0.70–0.90 (Pacey and Cullis, 1986). Another factor that affects the quantity of water harvested from roofs are evaporation and wastage due to flushing during initial rains. In this analysis, efficiency of 0.80 is used considering the evaporation losses and wastage.

8.1.4 Potential of Rooftop Rainwater Harvesting:

The total roof area of the buildings in Dehradun is 13.48 Mm^2, which is 13.48 km^2. The planning for the above area has to be done under different categories of buildings. To understand the potential of Rooftop Rainwater Harvesting, let us consider the normal rainfall of Dehradun, which is 2183 mm.

Total Roof Area	= 13.48 Mm^2
Normal rainfall	= 2.18 m
Volume of water available at rooftop	= 29.44 Mm^3
Runoff Coefficient	= 0.80
Volume of water that can be used for storage/recharge	=23550 M liters
	= 5233.33 M Gallons
	=14.33 MLD

8.2 Estimate of Rainwater Harvesting

For rainwater harvesting at the first stage Rooftop Rainwater Harvesting would be appropriate. The total roof area of the buildings is 1,23,85,405 m^2. The average cost of installation of Rooftop Rainwater Harvesting system is about Rs 125/- per m^2. The estimated cost is the average of the cost for installation including cost of pipe assembly, filters and tanks, whenever necessary. The estimated cost for the Rooftop Rainwater Harvesting is given in Table-8.3.

Table 8.3: Classification of Roof Area

Classification of Area	Average Roof Area (m)	Number of Buildings	Total (m^2)	Rate (Rs/ sq m)	Amount (Rs. in lacs)
ROOF TOP RAIN WATER HARVESTING (Direct Method)					
< 100 m^2		5,034	1,79,411.76	125	224.265
100 m^2-200 m^2	150	21,798	37,518,71.76	125	4689.840
200 m^2-500 m^2	350	11,715	47,08,844.25	125	5886.055
500 m^2-1000 m^2	750	2,207	14,11,795.83	125	1764.745
>1000 m^2		1,573	34,33,481.48	125	4291.852
Total			1,34,85,405.08		16856.757

8.3 Roof top Rainwater Harvesting

Rooftop catchment tanks are storage containers installed to receive runoff water from the roof of a house, a shed or a public building via a gutter and a down pipe. The most suitable roofs for the purpose are those covered with iron sheet, tiles and fiberglass-sheet. Existing asbestos sheets can also be used (because the health hazards from inhaling and ingesting asbestos fibre is only related to the production and construction process). Thatched roofs too have been used, particularly for the traditional systems but they give a much lower yield and often produce coloured water (Handbook on Rainwater Harvesting-Rajiv Gandhi Drinking Water Mission).

8.3.1 Site Assessment

Assessing the site conditions together with future tank owners is the first step towards a sound system design. The five main site conditions to be assessed are:

- Availability of suitable roof catchment
- Foundation characteristics of soil near the house
- Location of trees
- Estimated runoff to be captured per unit area of the roof;
- Availability and location of construction.

8.3.2 Estimating Size of the Required Systems

The actual size of the system will depend on various factors. Primarily, the size will be influenced by the cost of the system, the amount of rainwater to be collected, expectations and needs of tank owners and the level of external support.

The key to the solution here lies in matching the supply and demand to the satisfaction of the user(s) at the lowest cost possible. The amount of rain and its distribution over the year, the size of the tank. Usually the worst scenario will present itself during the longest dry spell. The size of the catchment area and tank should be enough to supply sufficient water for the users during this period. Assuming a full tank at the beginning of the dry season (and knowing the average length of the dry season and the average water use), the volume of the tank can be calculated by the following formula:

$$V = (t \times n \times q) + et \tag{8.1}$$

Where

V	=	volume of the tank (litres)
t	=	length of the dry season (days)
n	=	Number of people using the tank
q	=	consumption per capita per day (litres)
et	=	evaporation loss during the dry period

8.3.3 General Design Features

- Rooftop water harvesting systems can provide good quality potable water if the design features outlined below are followed:
- The substances that go into the making of the roof should be non-toxic in nature.
- Roof surfaces should be smooth, hard and dense since they are easier to clean and are less likely to be damaged and release materials/ fibres into the water.
- Roof painting is not advisable since most paints contain toxic substances and may peel off.
- No overhanging trees should be left near the roof.
- The nesting of birds on the roof should be prevented.

- All gutters ends should be fitted with a wire mesh screen to keep out leaves, etc.
- A first-flush rainfall capacity, such as a detachable downpipe section, should be installed.
- A hygienic soakaway channel should be built at water outlets and a screened overflow pipe should be provided.
- The storage tank should have a tight fitting roof that excludes light, a manhole cover and a flushing pipe at the base of the tank (for standing tanks).
- There should be a reliable sanitary extraction device such as a gravity tap or a hand pump to avoid contamination of the water in the tank.
- There should be no possibility of contaminated wastewater flowing into the tank (especially for tanks installed at ground level).
- Water from other sources, unless it is a reliable source, should not be emptied into the tank through pipe containers or the manhole cover.

8.3.3.1 Main System Components

A rooftop catchment system has the three main components, *viz,* a roof, a guttering and first flush device and a storage tank.

(a) Roof: The roof should be smooth, made of non-toxic substances and sufficiently large to fill the tank with the available rainfall conditions. Existing roofs of houses and public buildings can be used for a rooftop catchment system. In some cases enlarged or additional roofed structures can be built.

(b) Guttering and first-flush device: Guttering is intended to protect the building by collecting the water running off the roof and direct it, *via* a down pipe, to the storage tank. Gutters should have a uniform slope of 0.5 % large enough to collect the heavy runoff from high-intensity rain.

(C)Tank: Water tanks using Ferro cement technology come in different designs with volumes ranging between two and 200 m^3. For example, a freestanding cylindrical tank can be built in sizes between 10 and 30 m^3, while a capacity of upto 200 m^3 is possible with sub-surface covered tanks. The latter is most economical when the capacity exceeds 50 m^3. Even PVC tanks can be used for this purpose.

8.3.4 Design of Storage Tanks

Storage tanks in accordance with the volume of water expected to be collected at 2.5 and 5.0 cm/hr have been proposed. The volume of the proposed storage tanks range from 2500 liter to 50,000 liter. The cost of the rainwater harvesting arrangements in the buildings of Dehradun has been worked out (Table 9.3) at the rate of Rs. 50/- per square meter.

8.3.5 Design of Filters

The purpose of filters is to purify the water. In case of rooftop rainwater harvesting filters are being provided as a purification device in the way of rainwater collected from rooftop to the recharging structures in vicinity. Filters of different capacities are in use-1000, 500 and the 200 liters.

(a) Details of 1000 litre Capacity Tank

This normally comprises of a Syntax tank of capacity 1000 litre. Having an internal diameter 110 cm and height 115 cm, the over flow is provided at 10 cm above the top layer.

Arrangement of filter media: (Top to Bottom)

- Sand
- Charcoal
- Pebbles and gravel

One nylon mesh is also provided between the aggregate and charcoal for protection of clogging. On the top of sand layer one piece of sand stone is placed for protection of sand layer due to the high pressure of rainwater on it. But it reduce the total surface area and the position of sand stone is not proper and due to it the effective depth of sand is reduce at that point, which ultimately effect the rate of filtration and turbidity removal efficiency of filter. (Fig 9.1) shows its cross section. This filter can be used for roof areas greater than 500 m^2.

(b) Details of 500 Liter Filter

Here the internal diameter is of 92 cm and the height 98 cm. The overflow is provided 10cm. above the top layer (Fig 9.2), which can be used for medium size roof i.e. 200-500 m^2.

Arrangement of filter media is (top to bottom)

- Sand
- Charcoal
- Pebbles and gravel

(c) Details of 200 litre Filter

The tank is Syntax tank of capacity 200 liter with internal diameter of 64 cm and height 70 cm (Fig 9.3). The overflow is provided at 10 cm above the top layer. The arrangement of the different layers is the same as the other filters cited above. This can be used for roof area upto 200 m^2.

The details of the filters and the schematic diagrams are given through figures.

8.4 Concluding Remark

As discussed in the previous sections, there is enough potential of rainwater harvesting in Dehradun. Since more than 80% of water supply is met by groundwater alone, it is the necessary to augment the groundwater storage through rainwater harvesting and artificial recharging. The rooftop rainwater harvesting can be taken up with the different kind of recharging schemes as given in this chapter. It is recommended that the filters be installed with utmost care so that there is no possibility of pollution from the recharged water. The drains flowing within the city should not be used for recharge purpose as their conditions are very poor.

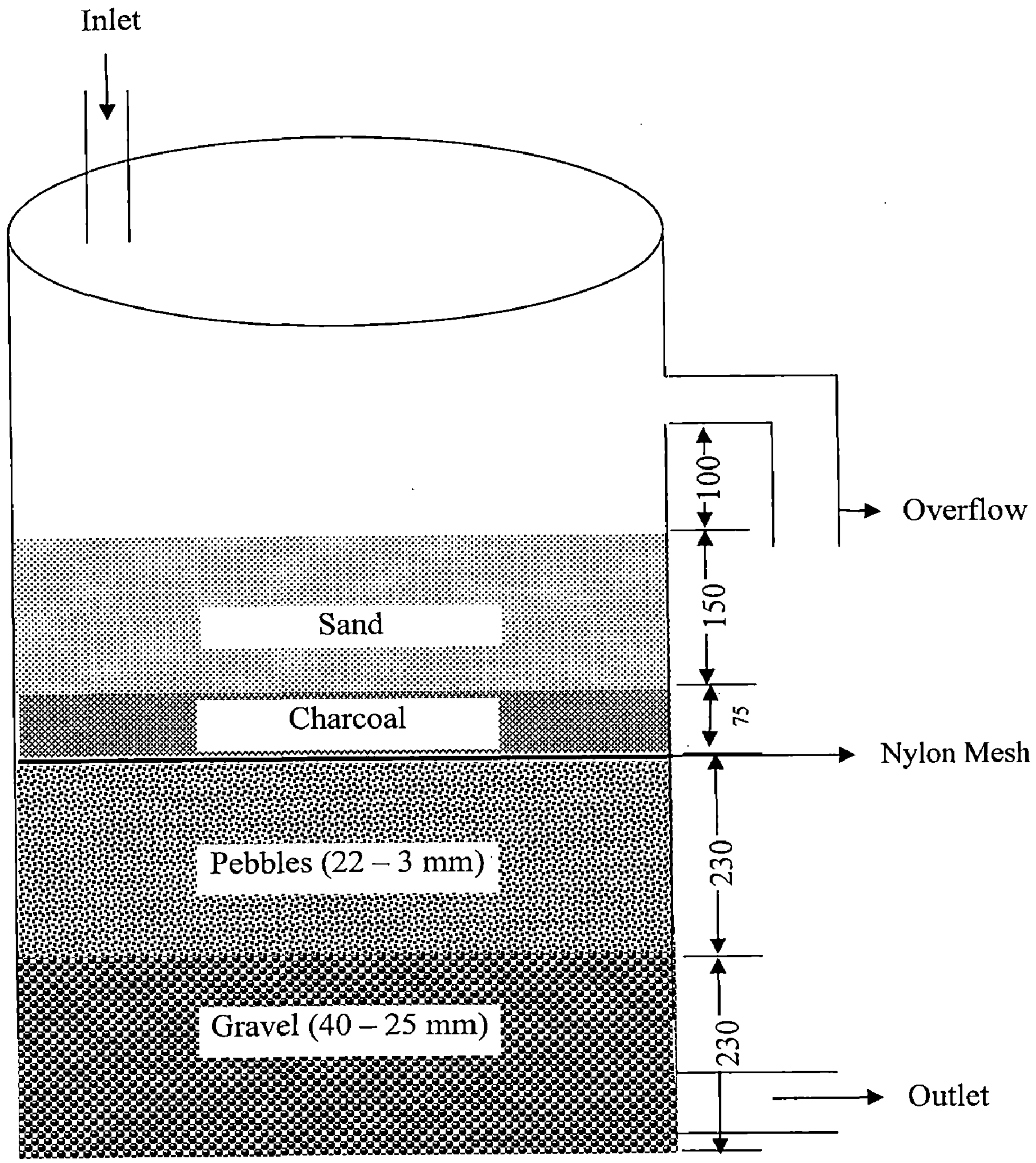


Fig 8.3: Cross Section of 1000 litre Traditional Filter

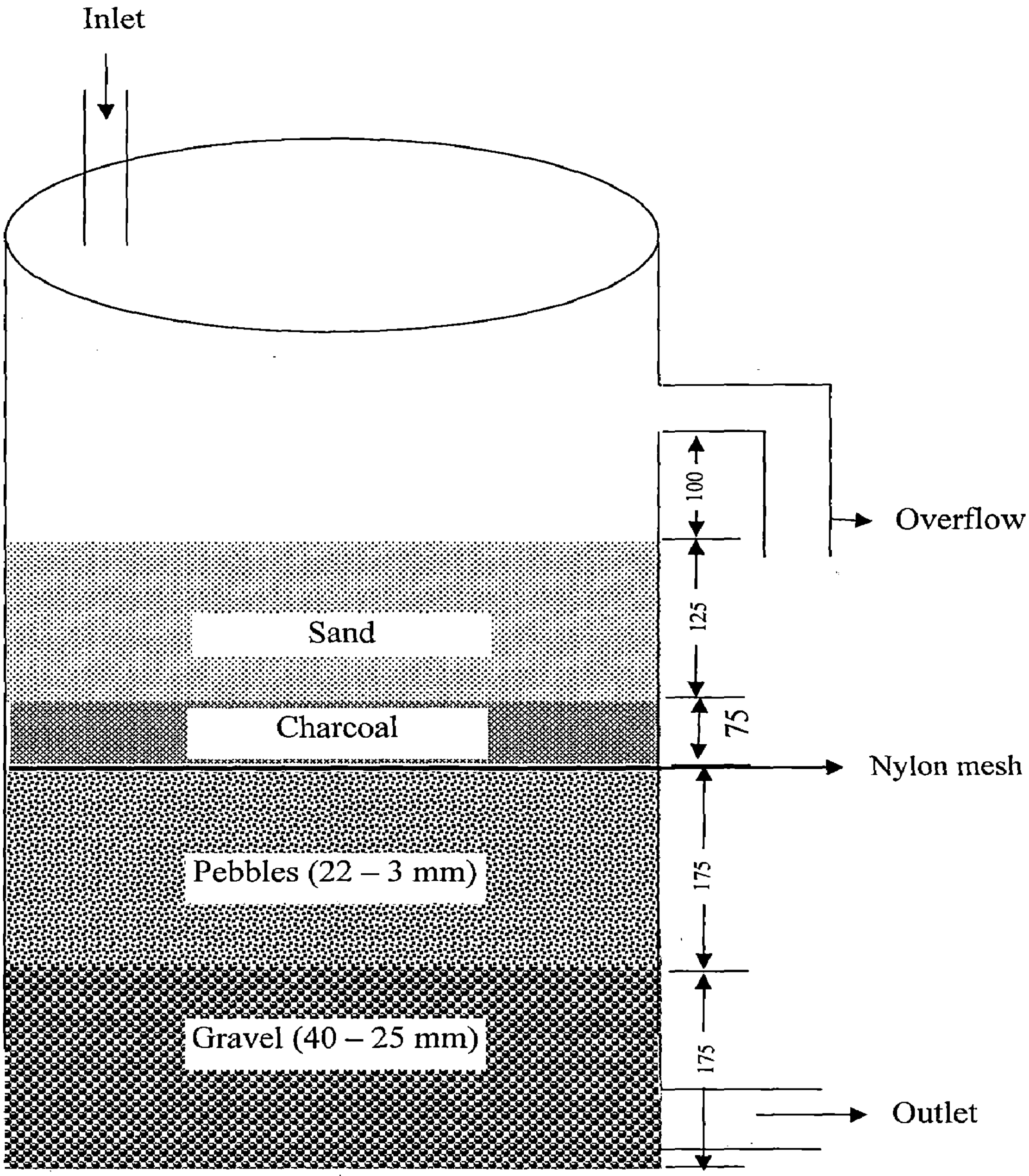


Fig 8.4: Cross Section of 500 litre Traditional Filter

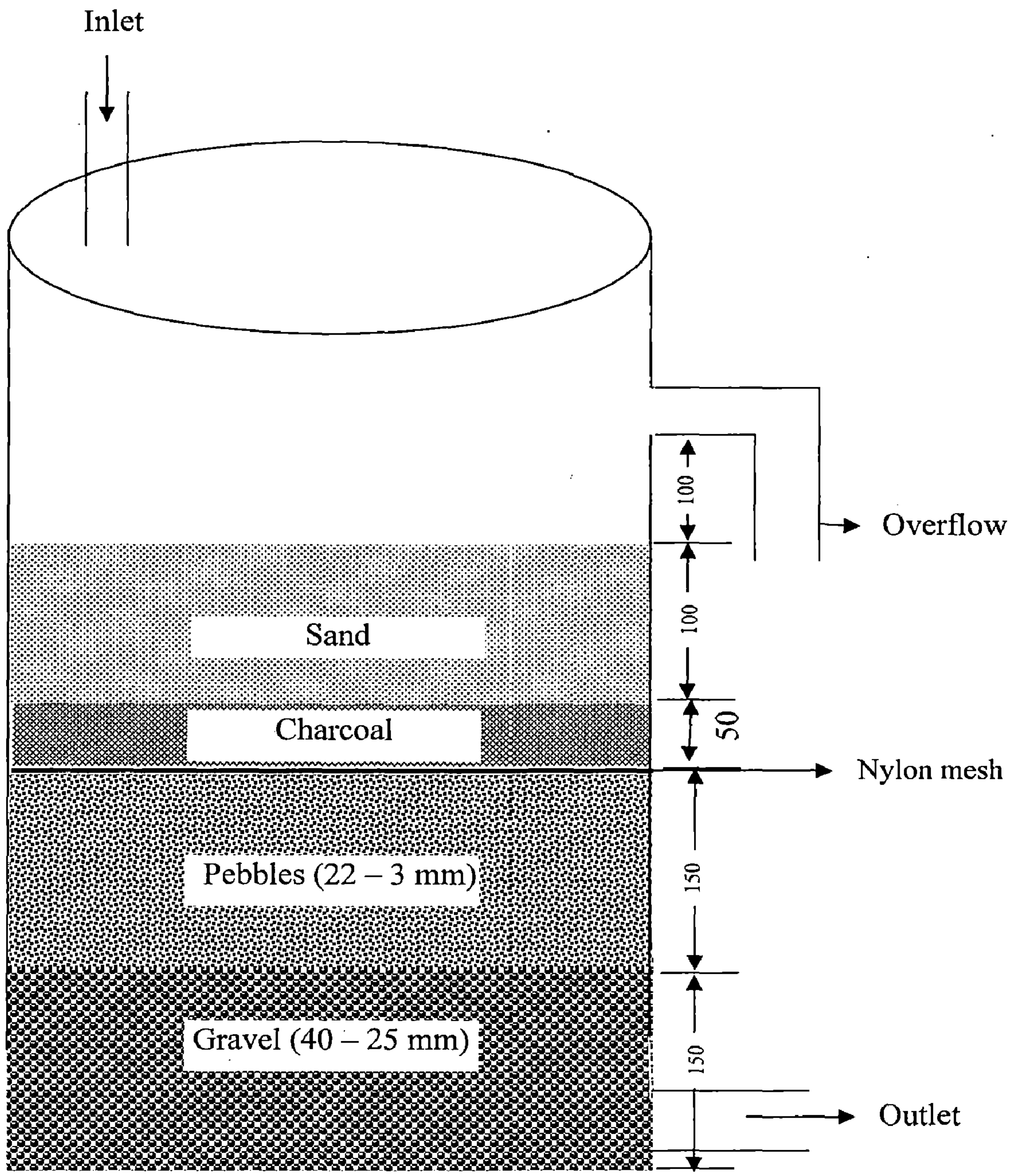


Fig 8.5: Cross Section of 200 litre Traditional Filter

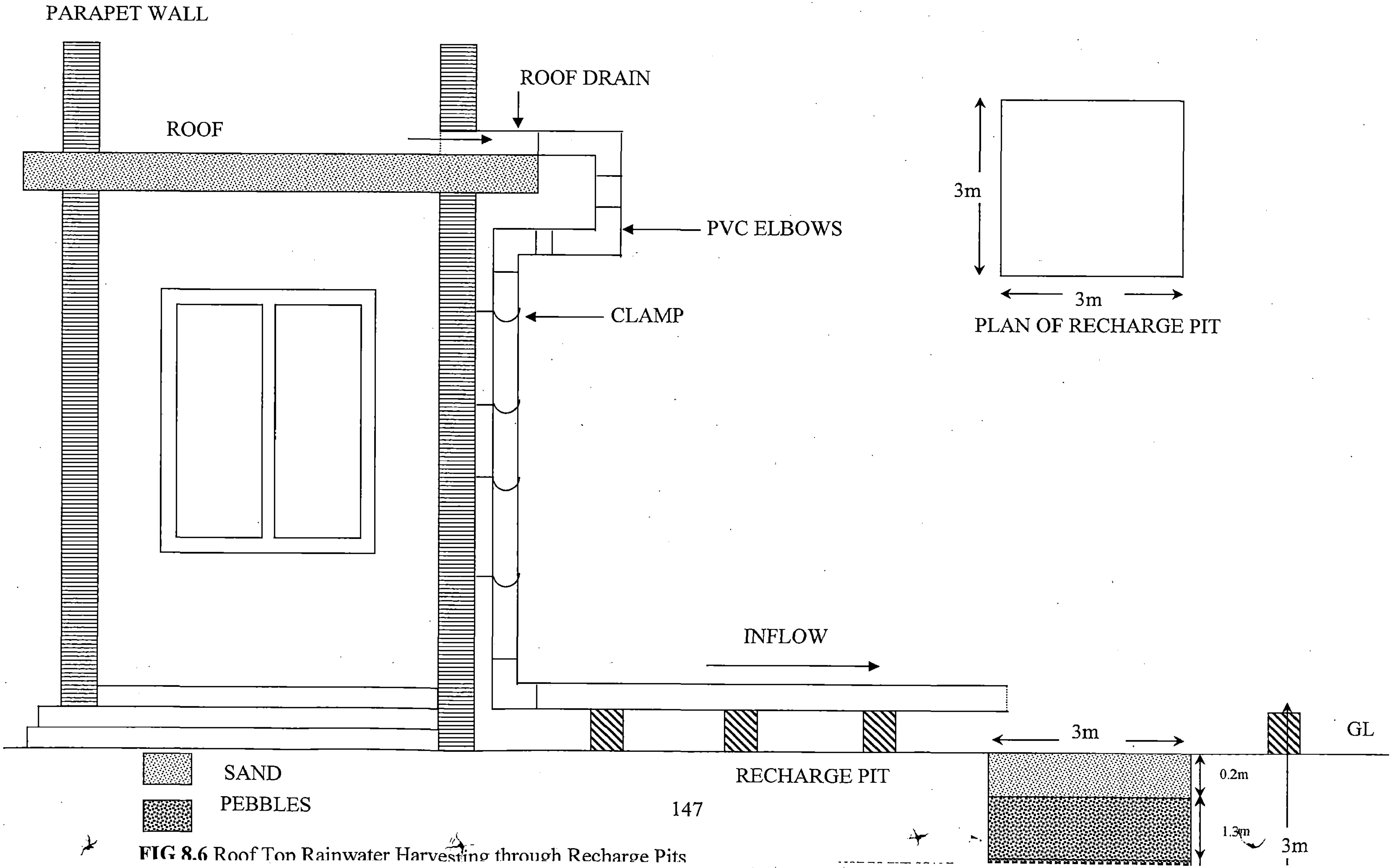
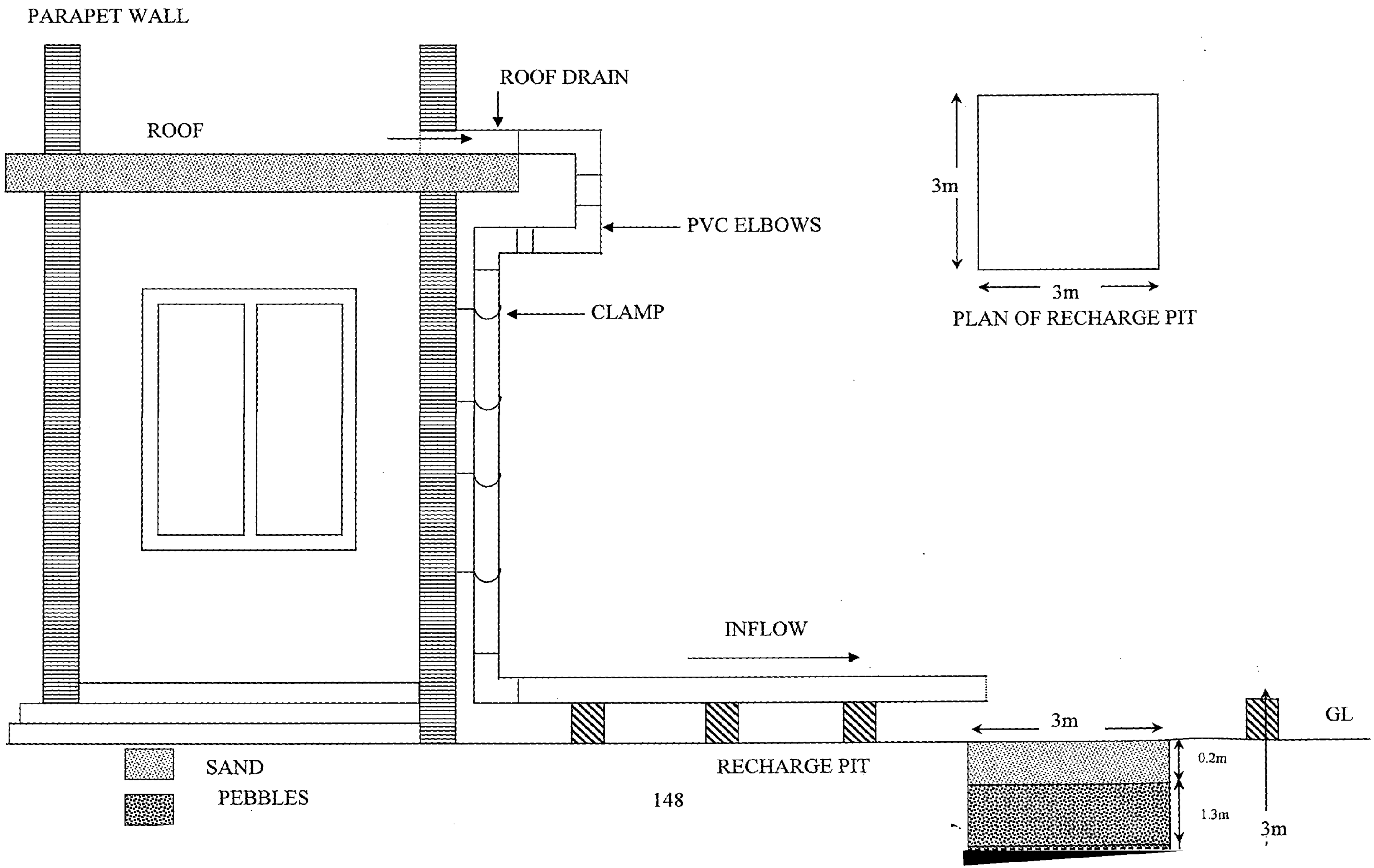


FIG 8.6 Roof Top Rainwater Harvesting through Recharge Pits


PARAPET WALL
ROOF
ROOF DRAIN
PVC ELBOWS
CLAMP
3m
3m
PLAN OF RECHARGE PIT
INFLOW
3m
GL
0.2m
1.3m
3m
RECHARGE PIT
SAND
PEBBLES

CHAPTER NINE

CONCLUSIONS AND RECOMMENDATIONS

9.0 Conclusions

Development plans relevant to small and medium water harvesting require acquisition of basic information regarding geoenvironment of the area, location of existing utilities-facilities, and their accessibility and development trends in relation to socio-economic structure of the Watershed.

Geoinformatics with its powerful tools of Remote Sensing, and GIS has emerged as a State of art technology for the policy maker, planners, urban administrators and related professional concerned with the development and regulation of urban / regional activities for better planning and judicious management. Various spatial database layers related to meteorological and geological parameters have been created and analyzed in GIS environment.

Using this spatial database, the SCS rainfall-runoff was evaluated and then runoff estimation was created.

The silent features of the study are:

i) Calculation of runoff is done by SCS modified model using remote sensing and GIS

ii) Identification of rainwater harvesting suitable site

The total water availability includes soil moisture surplus from rainfall and the water coming from neighboring watersheds. The water availability in million liters daily was found to be 368 MLD

The runoff curve number method gaining its popularity among hydrology practioners to its simplicity, predictability, and stability. The method is a conceptual model of hydrologic abstraction of storm rainfall, supported by empirical data. Its objective is to estimate direct runoff volume from storm rainfall depth, based on a curve number CN. The method does not take into account the spatial and temporal variability of infiltration and other abstractive losses; rather it aggregates these into a calculation of the total depth loss for a given storm event and drainage areas

The runoff was generated by analysis of three years.satellite data. It has been observed that during 1988, 2001, and 2005, the runoff was 18699123.6 Ha-m, 20923017.5 Ha-m and 19065322.32 Ha-m respectively.

The identified water harvesting site which is situated in the vicinity of Dehradun district towards its southern extremities need concern in terms of priority of development of residential and industrial areas coupled with risk factors due to predicted natural disasters in the region. There is enough potential of rainwater harvesting in Dehradun. Since more than 80% of water supply is met by groundwater alone, it is the necessary to augment the groundwater storage through rainwater harvesting and artificial recharging. The rooftop rainwater harvesting can be taken up with the different kind of recharging schemes as given in this chapter. It is recommended that the filters be installed with utmost care so that there is no possibility of pollution from the recharged water. The drains flowing within the city should not be used for recharge purpose as their conditions are very poor.

9.1 Recommendations

- The present gap between the demand and supply in Dehradun city is about 20% in spite of the large number of tubewells constructed by the government departments.
- The demand for drinking water of the city is met more than 80% by groundwater through tubewells. This has resulted in lowering of groundwater table in general.
- The existing tubewells and/or abandoned wells may also be used for recharge, for this purpose.
- Existing springs especially Sahastradhara, Gucchu-Pani, Nala Pani etc., needs immediate attention, as they are still the main source in some rural areas. Their recharge areas to be increased by soil and water conservation practices.

- Soil and water conservation techniques in grassland in the catchment of springs are required in the form of controlled grazing or fencing to avoid degradation of existing vegetation with the catchments of springs.

- Depending upon the suitability/availability of space, contour trenches can be constructed to check the runoff and increase the recharge of the springs.
- Gully control structures i.e. check dams, brushwood check dam, loose boulder/rock dam, gabions etc., in the catchment of springs need to be constructed to check the runoff and soil erosion at the same time will recharge the springs.
- It is recommended that for the drains passing through the city, government should consider for an alternate system of waste disposal. In addition to that cleaning of these drains would be required to check the pollution.
- Rooftop rainwater harvesting should be made mandatory for all the new construction with the municipal limit of Dehradun.

9.3 Scope of Future Work

- Efforts should be made for identification of potential rainwater harvesting sites in open areas, particularly for those zones having a shortage of water.
- Extension of the study area and methods to cover recharging capacity of spring sources.
- High resolution satellite image (e.g. IKONOS) may be used to get the accurate surface feature information and identifications of potential rain harvesting site at large scale.

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