GIS BASED STUDY FOR RAIN WATER HARVESTING - A CASE STUDY FOR MUSSORIE

A DISSERTATION

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of

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in

WATER RESOURCES DEVELOPMENT

By

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CANDIDATE'S DECLARATION

I hereby declare that the dissertation entitled **GIS BASED STUDY FOR RAIN WATER HARVESTING – A CASE STUDY FOR MUSSORIE** in partial fulfillment of the requirement for the award of the Degree of Masters of Technology in Water Resources Development, submitted to the Water Resources Development Training Center (WRDTC), Indian Institute of Technology, Roorkee, Uttaranchal, India is a document of my work carried out during the period from 16th July 2002 to 30th November 2002 under the supervision and guidance of **DR. DEEPAK KHARE** and **DR. P.K. GARG**.

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

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ABSTRACT

GIS BASED STUDY FOR RAINWATER HARVESTING (A CASE STUDY FOR MUSSOORIE)

Mussoorie is located in the hilly region of Uttaranchal. Almost all of the spring sources in the vicinity of Mussoorie have been tapped for water supply. Due to the increasing population, water demand is also increasing. The present system is no longer capable of meeting the water requirement. Since 1967, tapping of Aglar River was already considered for alternative source of water supply, however the project has not been realized due to financial and other constraints.

In this dissertation, study has been carried out to focus on the importance of rainwater as an alternative source. GIS is used in carrying out analysis of geographic data and their attributes. Rainwater is the principal source of water, surface and groundwater are the secondary source. Rainfall of considerable amount that reaches the ground surface after some amount percolates below it, becomes runoff and discharges into the sea as wastewater. Rainwater can be harvested in area where it falls before discharging into the sea and utilised it to augment the present water requirement. Rainwater harvesting has been practiced since the ancient time, however it was not properly developed because of reliance in surface and groundwater in this modern era. Rainwater harvesting was neglected for many years but it can be a solution to the present problem in water supply. In this study, it involves harvesting from rooftop of buildings to be used for domestic purposes. Provision of necessary filter and disinfection facilities are required to ensure its potability.

In the present study, attempt has been made to identify priority areas for rainwater harvesting and scope of harvesting has been analysed and proposed for future implementation. Layout of rainwater harvesting system and design of water tank along with economic consideration is also incorporated in this dissertation.

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CHAPTER ONE

INTRODUCTION

1.1 General

Application of computers to environmental and natural resources data handling, and creation of sophisticated information system was developed rapidly in recent years to cater the demand for storage, analysis, and display of the increasing volume of available environmental, geographical and natural resources information. With the existence of an efficient geographic data handling and processing systems, the available large volume of spatial data can be used effectively and transformed into usable information..

Geographic Information System (GIS) is a computer-based system designed to store process and analyze spatial data and their corresponding attributes. Recent technological advances integrated a wide range of information made possible in increasing the input techniques, storage classification, compilation, mapping and retrieval capabilities. GIS have renewed spatial data collection and analytical procedures to assist the decision makers by indicating various alternatives in the development and conservation planning through modelling of potential outcomes of different scenarios.

1.2 Rainwater Harvesting and Its Utility

Rainwater harvesting is the process of collecting, storing and conserving rainwater wherever it falls. There are two classifications of rainwater harvesting namely: 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 ground water reservoir. Rainwater recharge pits in New Delhi help in improving the ground water level and eliminate flooding of streets (Sinha, 2002).

Rainwater harvested from open grounds can be used for irrigation, animal use and recharging groundwater.

1.3 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. Geographic data, such as water bodies, buildings, road networks, dams, drainage, etc., with their corresponding attributes may be obtained from maps, charts, ground information, aerial photographs, and imageries for analysis and modeling in 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 into a digital forms. Integration of large volume of spatial and non-spatial data 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 other related information can be retrieved conveniently and effectively.

1.4 Objectives of the Study

Mussoorie town is selected for this study, where attempt has been made to solve the present water crisis through water harvesting techniques using GIS. The main objectives are:

i) To demonstrate the capabilities of GIS for rainwater harvesting.

ii) To model rainwater harvesting through rooftop using GIS.

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

iv) To identify the priority area for rainwater harvesting as per extent of water shortage.

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

1.5 Scope of the Study

The scope of the study is limited to 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 in Chapter Two. The reports collected from Jal Sansthan and Jal Nigam, Dehradun, topographic and guide maps 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.

1.6 Organization of the Thesis

Chapter 2 deals with the basic principles of Geographic Information System. Chapter 3 deals with Literature Review that highlights the discussion of different water harvesting techniques. Chapter 4 describes briefly the study area. Chapter 5 deals with the GIS study of rainwater harvesting, methodology, software used and data analysis. Chapter 6 deals with analysis and design criteria of rooftop rainwater harvesting structures. Chapter 7 covers the discussion, conclusion, recommendations and scope of future work.

BASIC PRINCIPLES OF A GEOGRAPHIC INFORMATION SYSTEM

2.1 Introduction

Geographic Information System (GIS) is a computer based system capable of accepting large volumes of spatial data derived from various sources to efficiently store, retrieve, manipulate, analyze and display these data according to specific use. Geographical objects include natural phenomena, such as lakes, rivers, forests, etc; manmade structures like dams, highways, buildings, etc; and other convenient objects. These may be define the location and extent of geographical phenomena such as particular soil type, etc. Geographical data describe objects from the real world in terms of their position with respect to a known coordinate system, their attributes that are unrelated to the position and their spatial interrelations with each other, which describe how they are linked together or how one can travel between them.

In GIS, data captured in the form of existing maps, field observations and satellite sensors are called the coverages which form data input subsystem. Data storage and data management provide the storage, organization and maintenance of both spatial data and related attribute data. Data information involves large array of analytical functions, such as classification, overlay and neighborhood analysis, etc. Data output presentation is concerned with the way the data are displayed and the results of analysis are reported to the user (Fig. 2.1).

Geographic data have traditionally been presented in the form of maps. Conventional maps have limitations to meet the modern needs of spatial data management. Some of these limitations are the laborious and time- consuming nature of traditional cartographic methods of map compilation. Conventional maps are primary instruments of presentation rather than analysis.

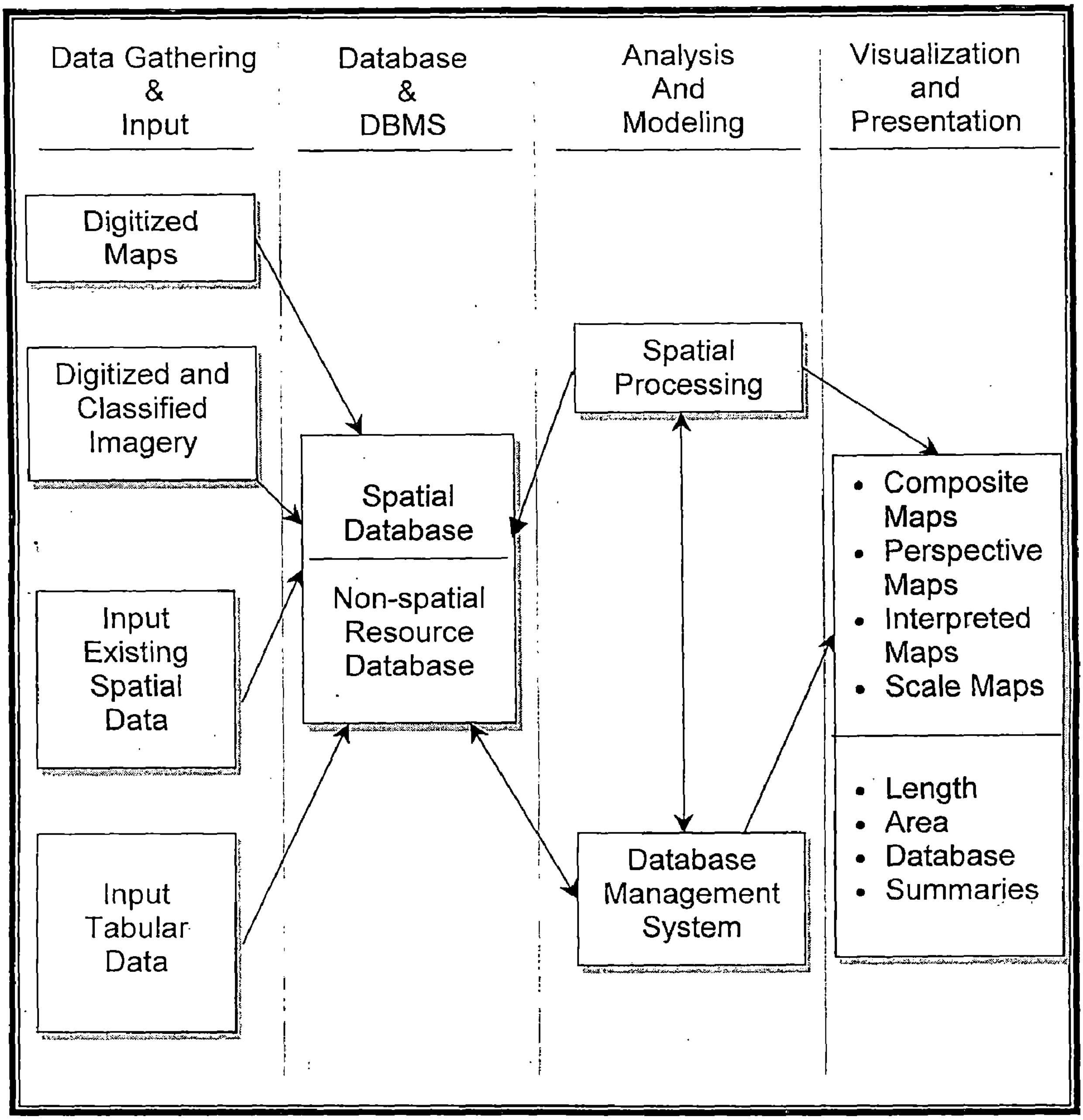


Fig. 2.1 A GIS Schematic Presentation (Marble et al, 1990)

The geographic information systems are developed to provide the power to analyze a large volume of geographic data. Handling and analyzing data that are referenced to a geographic location are key capabilities of computer-based GIS.

2.2 COMPONENTS OF GIS

GIS consists of four basic components:

- Data gathering and input,
- Geographic databases,
- Data analysis and modeling and
- Data visualization and presentation.

Fig 2.1 conceptually presents these basic components of GIS.

In the development, operation and generation of information some, of the following combinations are required in GIS hardware: computer CPU (central processing unit), operating system, storage media (hard disk), color graphics terminal(s), tape drives, digitizer table (or digital scanner), line printer, color printer/pen plotter (Fig. 2.2).

Digitizing table, Digital scanner and tape drive are used in the acquisition of data into the system. This may also be done manually digitizing existing maps or by reading data already in digital format, such as Digital Elevation Model (DEM). The computer CPU, operating system and the system software manage, manipulate and analyze the data. The GIS software (working within the computer's operating systems) often works with other software, such as relevant database, statistical packages and image processing packages for manipulation and analysis work. Line printers, Color printers, pen plotters and digital film recorders produce hard copy data or output either in the form of maps or as tabular information. Tape systems, Modems and Local Area Networks (LAN) allow the transfer of data between several users.

The basic components of GIS are described briefly under the subsequent sections.

2.2.1 GIS Data Input

It is necessary to feed the requisite data, before any spatial analysis or modelling operations can be carried out in a GIS. Data input is the procedure of encoding data into a computer-readable form of writing the data to a GIS database. A good data usually should have good data quality information, such as date of collection, accuracy, completeness, and the method used to collect and encode the data.

(i) GIS Data Sources

Two types of data to be entered in a GIS are: spatial data (georeferenced data) and associated non-spatial attribute data. The spatial data represents the geographic location of the features (i.e., location within geographic space where the features reside). Points, lines and area are used to represent geographic features, like stream, lake, or forest. The non-spatial (attribute) data provide descriptive information, like the name of stream, the salinity of a lake, or the composition of forest stand. Georeferenced data will normally be obtained from one or more of the following (Fig 2.3):

- Existing maps
- Aerial photographs
- Satellite imagery
- Data from airborne scanners
- Field measurements
- Other GIS database
- GPS observations
- From existing digital data

Non-spatial (attribute) data, which are associated with the spatial data, are obtained from field observations, point sampling, census figures, etc.

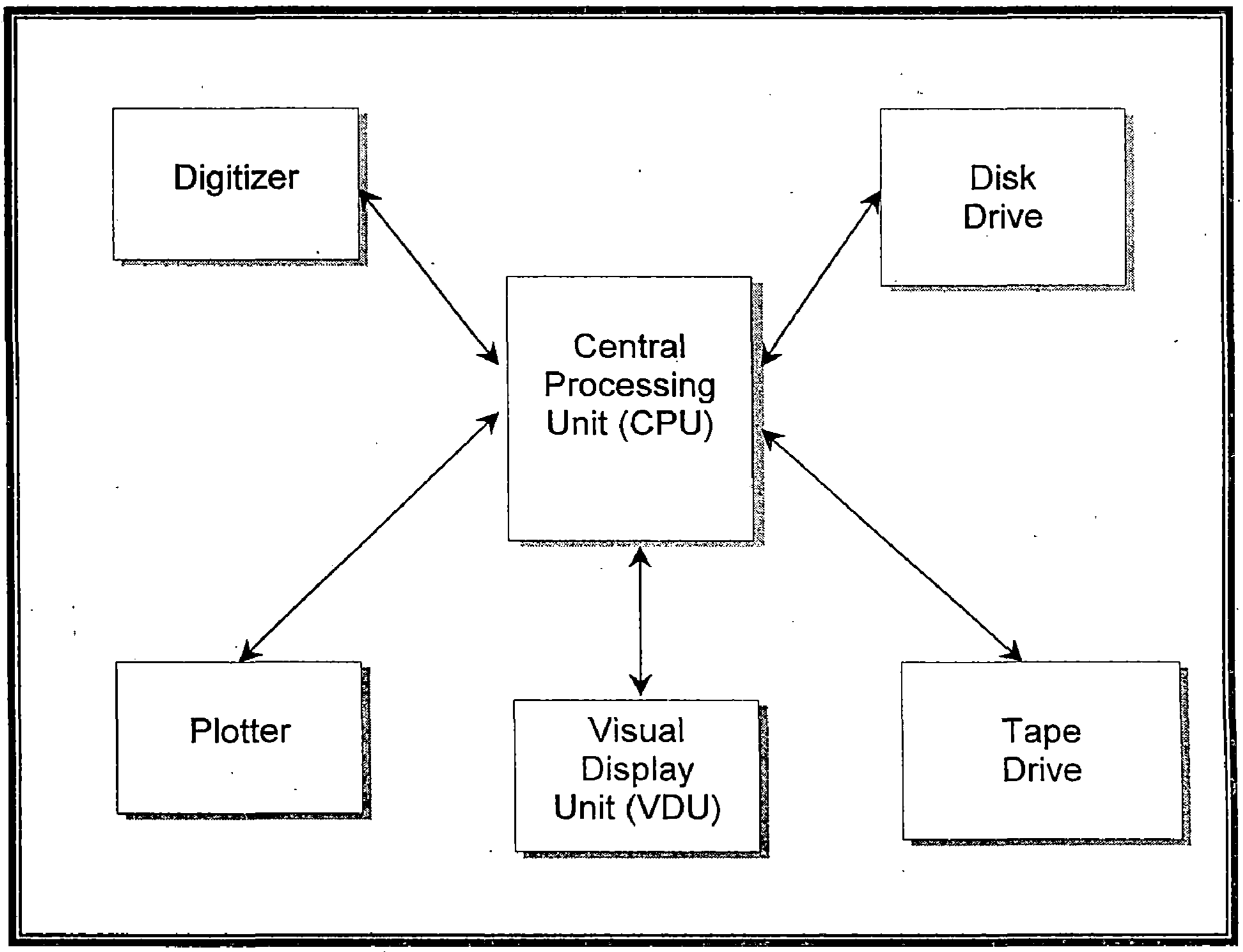


Fig.2.2 Major Hardware Components of GIS (Burrough,1986)

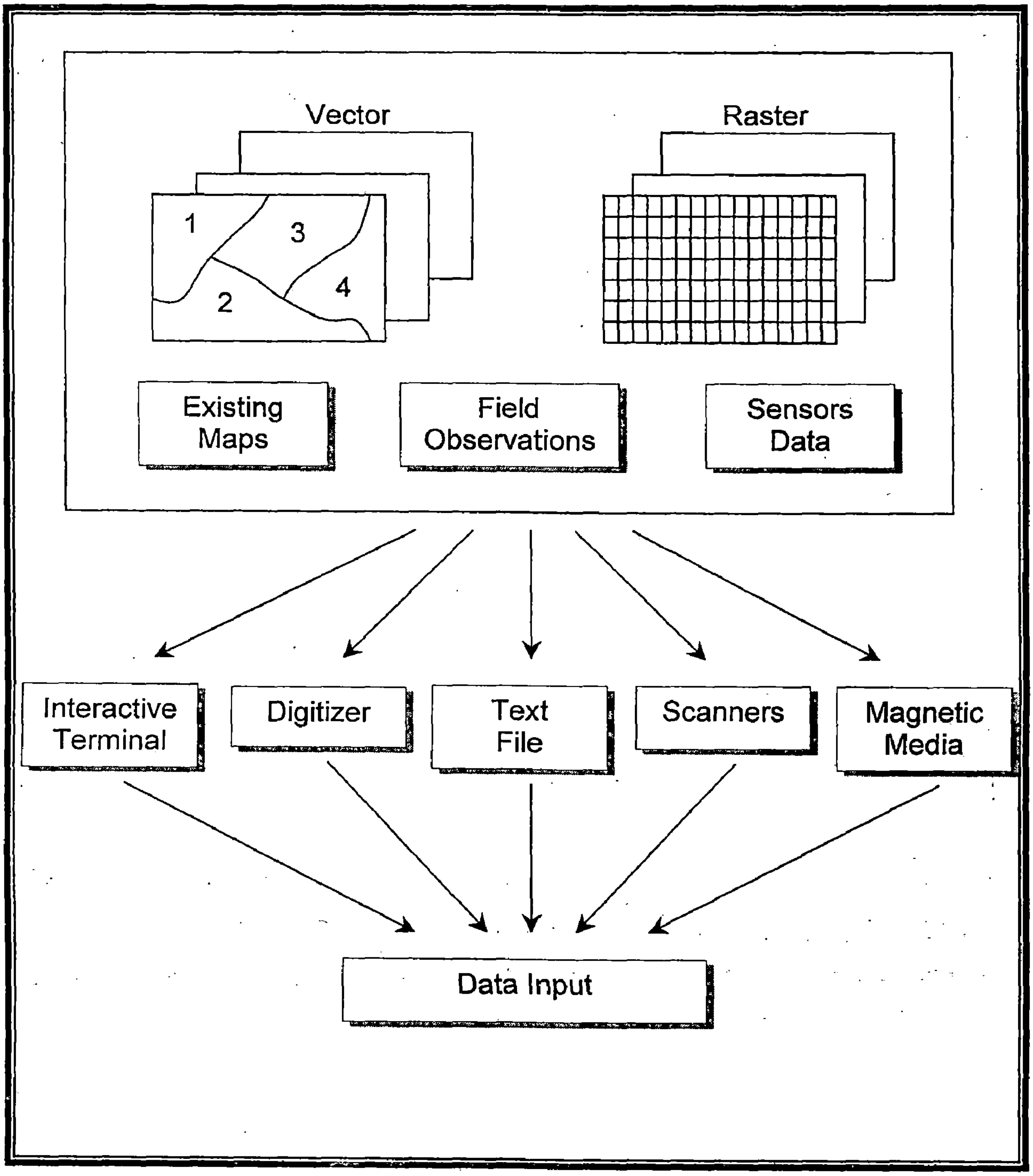


Fig. 2.3 GIS Data Input (Burrough, 1986)

(ii) Data Entry System

The method of spatial data input depends primarily on the source of the data. The actual method of data input is also dependent on the structure of the database of the geographical system. There are five data entry methods commonly used in GIS: Key board entry, coordinate geometry, manual digitizing, scanning, and the input of existing digital files.

2.2.2 GIS Database and Database Management System

Geographic database is the collection of spatially referenced data that acts as a model or reality (Valenzuela, 1990). The stored information has certain characteristics by which it can be identified and handled. The information for geographic features has four major components: geographic position, attributes, spatial relationships and time (Aronoff, 1989). More simply they are: where it is, what it is, its relationship to other spatial features and when did the condition or feature exists (Fig. 2.4)

(Geographic Position (Location): Geographic data input is fundamentally a form of spatial (geogreferenced) data. Each feature has a location that must be specified in a unique way. Locations are recorded in terms of coordinate system like the longitude /latitude, eastings and northings, UTM (Universal Transverse Mercantor) or state plane coordinates.

Attributes: Attributes are often termed non-spatial data. An attribute is a characteristic of an entity. Its value is the actual measurement that is stored in the database.

Spatial Relationship: This refers to the spatial relationships among the geographic features. These relationships are generally very numerous and may be complex. In practical terms, it is not possible to store information about all the possible spatial relationships. Instead, only some of the spatial relationships are explicitly defined in the GIS and the remainder is either calculated as needed or is not made available.

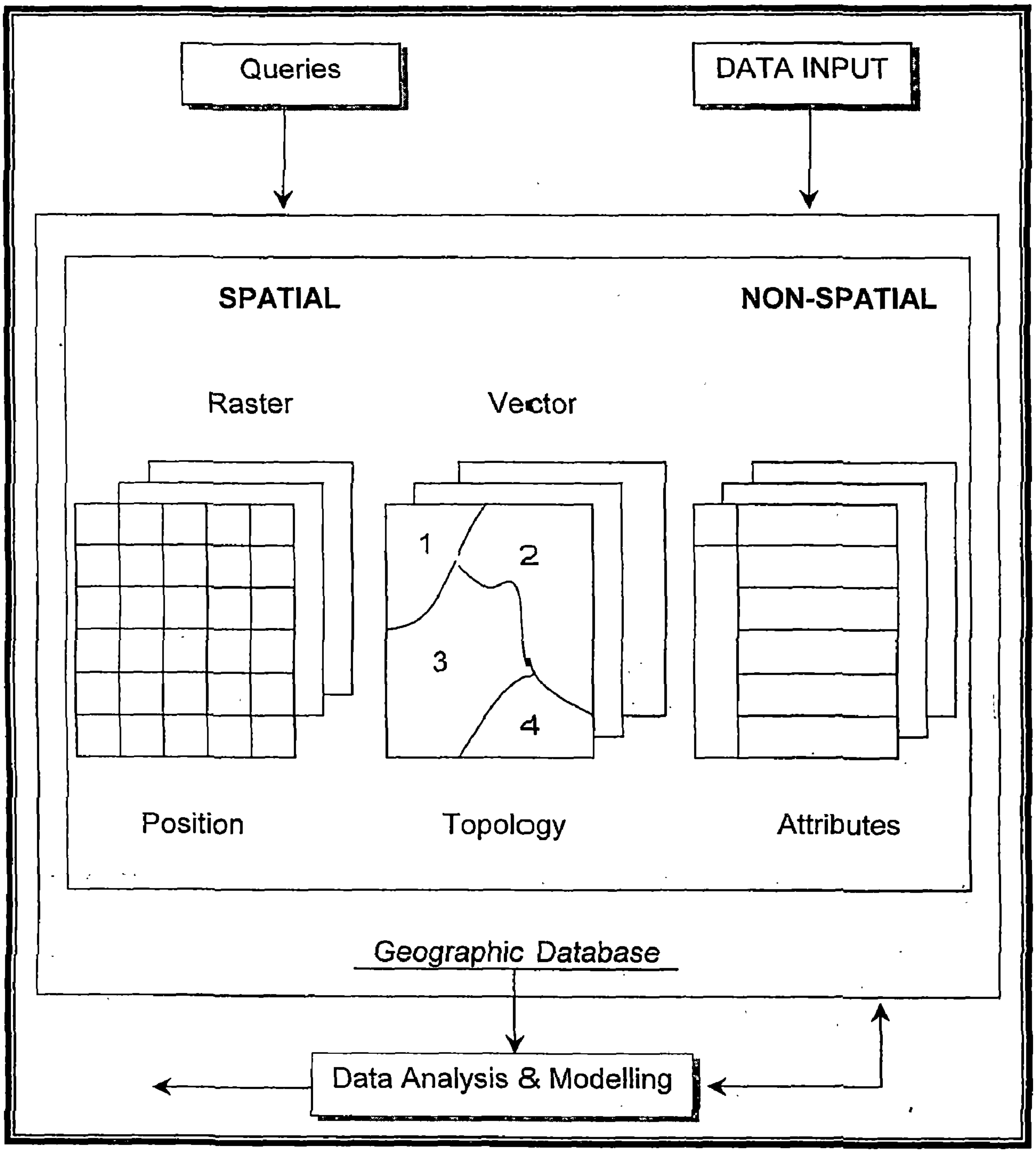


Fig. 2.4 Geographic Database (Valenzuela, 1990)

Time: Geographic information is referred to a point in time or a period of time. The appropriate use of a given data depends upon its time (period) of collection. For instance, the land use system may get changed with time. Therefore, historical information may form a valuable component of GIS database.

Taken together the four characteristics (geographic position, attributes, spatial relationships and time) make geographic data uniquely difficult to handle. Moreover, location data and attribute data often change independent of one another with respect to time that is an added level of complexity that is difficult to handle. Solving such data complexities are key capabilities of computer-based GIS through its Database Management System (DBMS).

(i) Database Concepts

GIS are increasingly being built around existing Database Management System (DBMS) (Aronoff, 1989). DBMS constitutes computer programs which are used to organize database (Burrough, 1986). These programs are designed to facilitate storage and retrieval of large data collections. They include facilities to protect and secure data, enforce consistency of the data stored and make data available to multiple users at a given time.

The approach of building DBMS facilitates the management of both location data and non-location data. DBMS may handle both spatial and non-spatial data in which the non-spatial data are accessed through DBMS, while spatial data are handled directly through the GIS. The concept of database increases benefit being obtained from GIS. Some of the advantages that can be gained from database are:

- Reduction in data redundancy i.e., instead of independent, databases multiple users can use common data from database for different needs;
- Maintenance of data integrity and quality (i.e., controlling and updating procedures can be implemented more efficiently using database);

- Security restriction (database includes security tools to access to the data).

(ii) Types of Geographic Data

There are four types of notations used for representing or encoding geographic data: points, lines, polygons, (area) and continuous surface.

Point Data: It consist of observations that occur only at points, or occupy very small areas in relation to the scale of database. Features, such as wells, rainfall stations, buildings, etc. may be represented as point data.

Line Data: Features, such as highways, rivers, elevation contours, pipelines and power lines exemplify line data. Vector-based GIS system can show line in fine detail, whereas raster-based system depicts a linear feature only as chain of grid cells.

Polygon (area) Data: Polygon constitutes the most common data type used in GIS. They are bounded regions. The boundaries may be defined by natural phenomena, such as land forms or by man made, such as forest stand or land use unit.

Continuous Surface: Examples of continuous surfaces are elevation (as part of geographic data), rainfall, temperature, etc. Most of GIS products cannot handle 3-dimensional data although they can handle topographic data, usually Digital Elevation Model (DEM).

2.2.3 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, mathematical equations or a set of spatial relationships displayed on a map. The general problem in data analysis is:

User's query → database link output → output

The user has particular specification, constraints and 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 in 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.

(i) 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 into four categories: retrieval, reclassification and measurement; overlay; distance and connectivity; and neighborhood.

a) Retrieval, Reclassification and Measurement Operations

In these functions retrieval of both spatial and attribute data are made and only attribute data are modified. New spatial elements are not created.

Retrieval Operations: This involves the selective search, manipulation and output of the data.

Retrieval operation includes the retrieval of data using:

- Geometric classification,
- Symbolic specifications,
- Name of code of an attribute,
- Conditional and logical statement

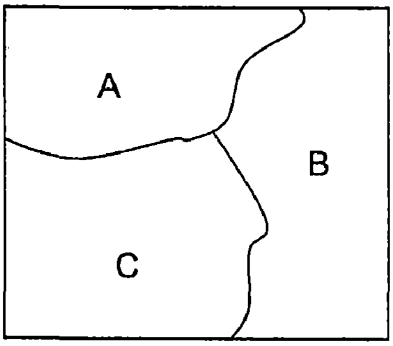
Reclassification procedures: This procedure involves the operation that reassigns thematic values to the categories of an existing map as a function of the initial value, the position size or shape of the spatial configuration associated with each category (for instance a soil map reclassified into erodibility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

Measurement Operations: Spatial data measurement includes: calculation of distance, length of lines, area and perimeter of polygons and volumes. Measurement 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 polygon.

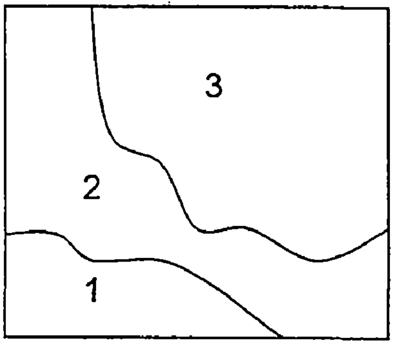
b) Overlay Operation

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 operations, 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 condition is satisfied. Fig 2.5 presents the overlay concept in a vector structure (topologic overlay).

Soil Map

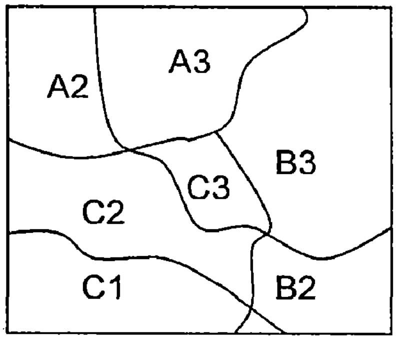


Land Use Map



Soils

Code	Depth
A	150
B	120
C	90



Soil/Land Use Map

Land Use

Code	Name
A	Forest
B	Agrl.
C	Pasture

Land Use / Soils

Soil Use	Use Name	Soil Depth
A2	Agrl.	150
A2	Pasture	150
B2	Pasture	120
B3	Agrl.	120
C1	Forest	90
C2	Agrl.	90
C3	Pasture	90

Fig. 2.5 Overlay Procedure in a Vector System (Valenzuela, 1990)

c) Neighborhood Operation

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

d) Connectivity Functions

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

(ii) Modelling

A model is the simplest representation of reality in which it represents 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.

2.2.4 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 to transfer to another computer system. The basic output formats from GIS are hard copy, soft copy and electronic outputs (Fig. 2.6).

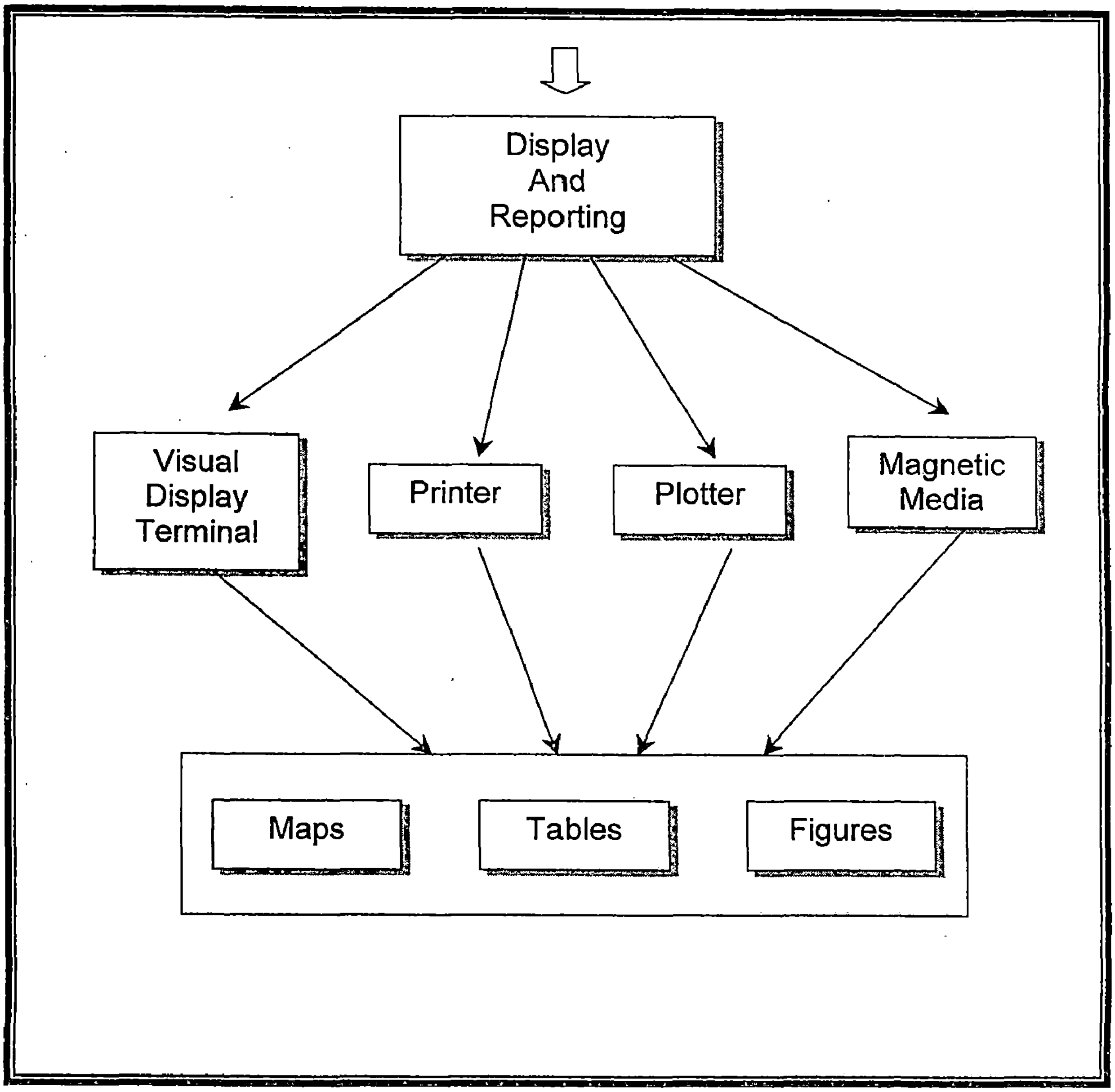


Fig. 2.6. GIS Data Output (Burrough, 1986)

Maps and historical tabulations are output in the hard copy format hard copy output devices, such as dot matrix printers, 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 colour. 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 formats consists of computer compatible files. They are used to transfer data to another computer system either for additional analysis or to produce hard copy output at a remote location.

2.3 GIS and Decision Support System

The successful operational applications of GIS require institutional setting and must support the management of resources (Fig. 2.7) 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. DSS are interactive programs, which integrate resource model with other systems, which assist in decision-making process (Michael et al, 1993). Out of the combination of DSS and GIS emerges an entirely new system called spatial decision support system (SDSS). SDSS are new classes of computer systems that combine the technologies of GIS and DSS to aid decision makers with problems that have spatial dimension. Fig. 2.8 presents the melding of GIS and DSS into SDSS.

SDSS 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 GIS and DSS to assist decision makers.

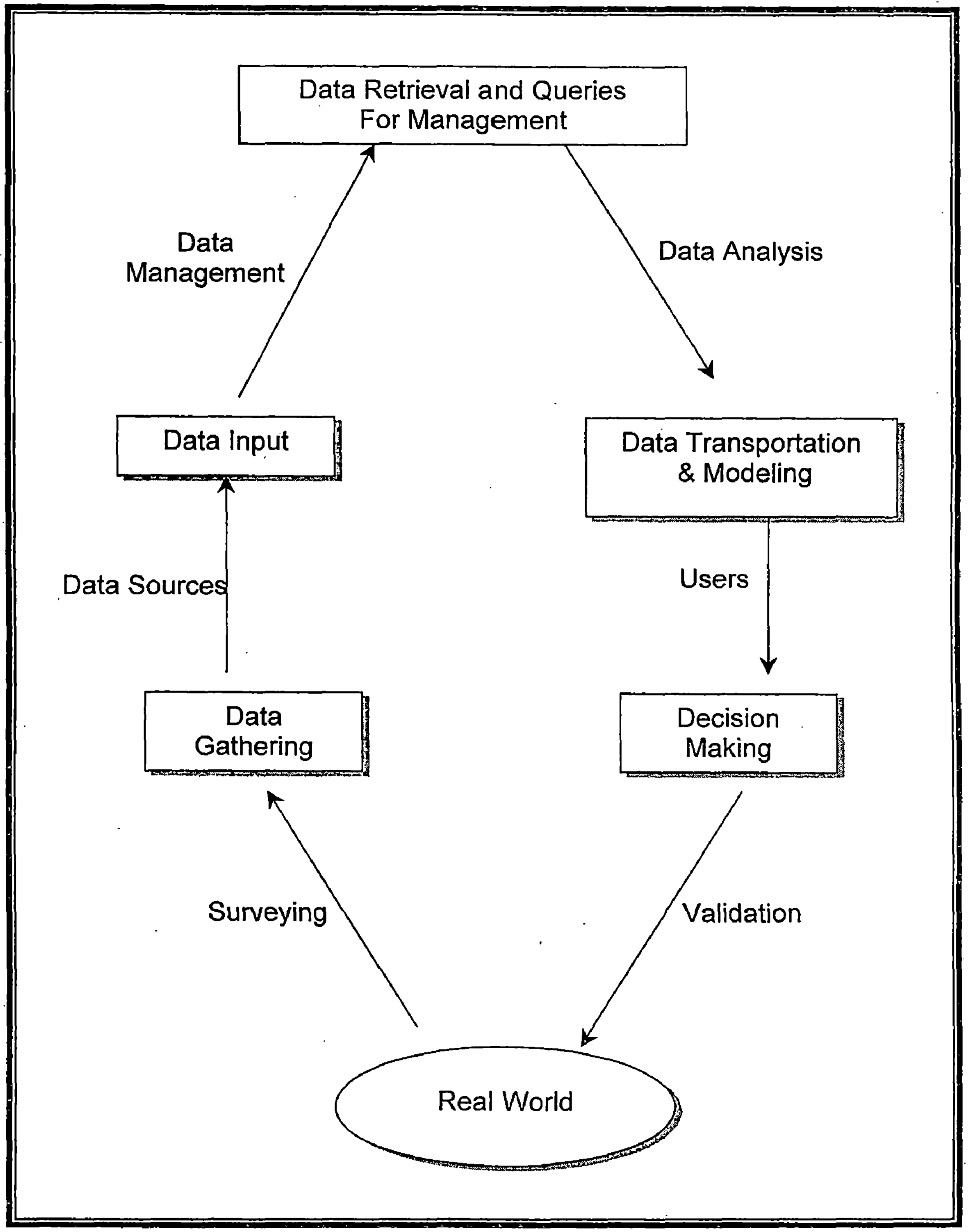


Fig. 2.7 Geographic Information Systems as a Management Tool
(Valenzuela, 1990)

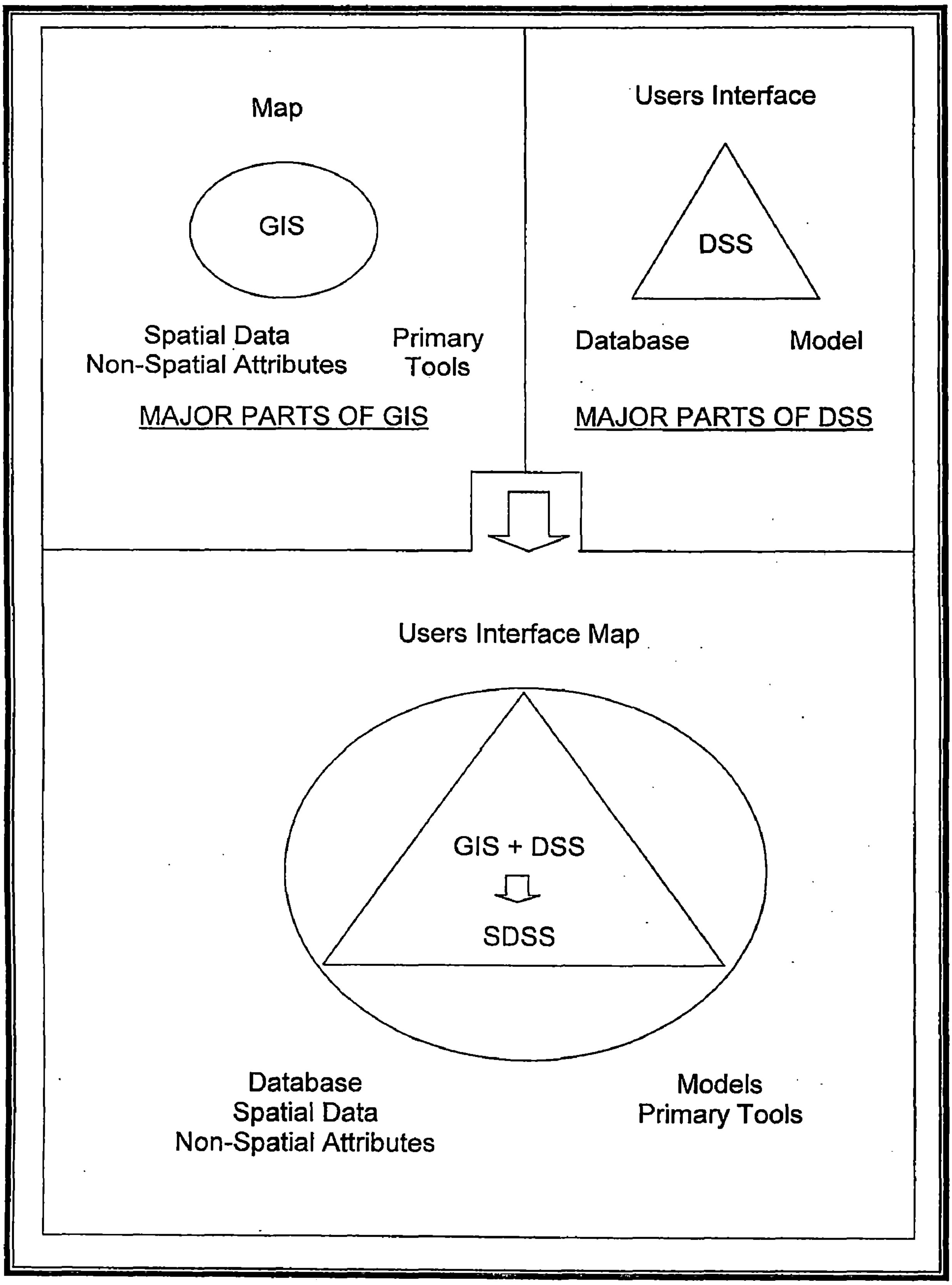


Fig. 2.8 Presentation of SDSS as combination of GIS and DSS
(Michael et al, 1993)

CHAPTER THREE

LITERATURE REVIEW

3.1 General

Water is the 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 organization 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.

3.2 Classification of Rainwater Harvesting

The rainwater harvesting can be classified into two ways:

(i) Rooftop Rainwater Harvesting

(ii) Rainwater Harvesting from Open Areas

3.2.1 Rooftop Rainwater Harvesting

Rooftop rainwater harvesting can be used for (a) domestic needs (Fig.3.1) and (b) recharging groundwater (Figs.3.2 and 3.3).

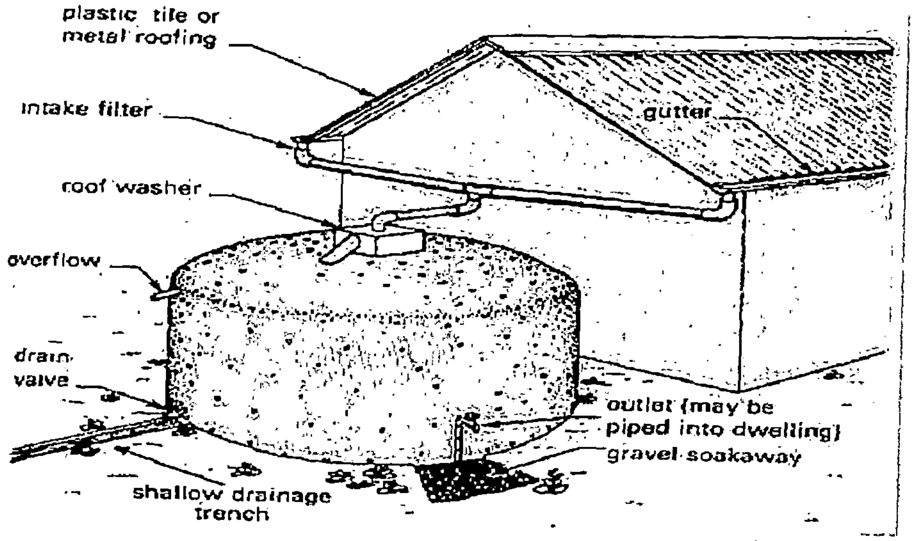


Fig.3.1: Rooftop Rainwater Harvesting for Domestic Needs

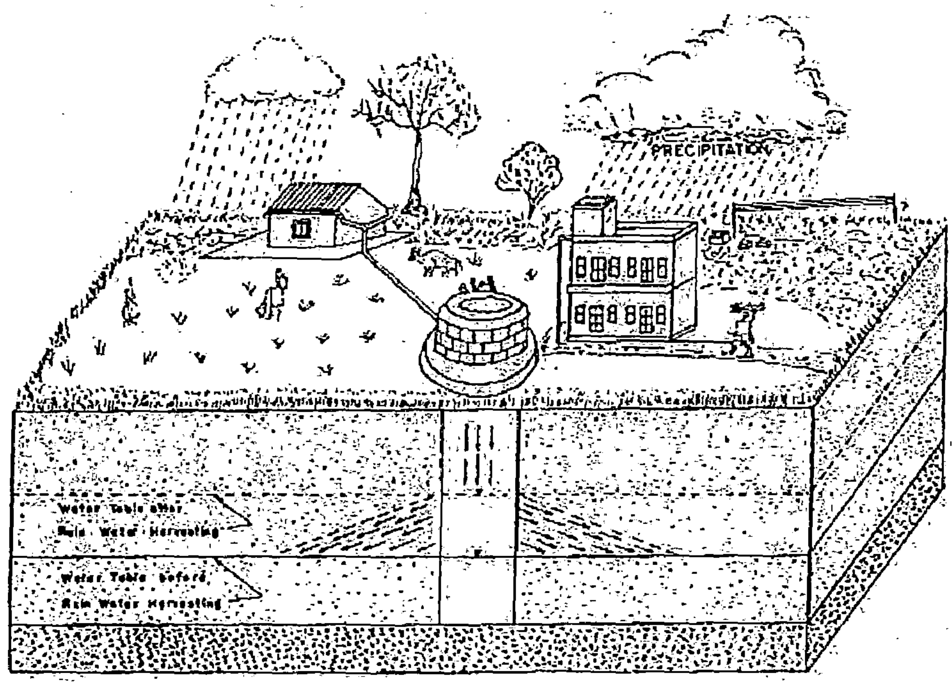


Fig.3.2: Rooftop Rainwater Harvesting for Groundwater Recharge

(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, the size of the catchment area and the 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 Vissher, 1992). Choice of 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 volume of rain and its distribution over the year, the size of catchment area and the expected runoff water supply ultimately determine the size of the tank. The design of rainwater cistern for domestic purpose considers the following:

i) Matching the capacity of the tank to the area of the roof.

ii) Matching the capacity of the tank to the quantities of water required by its users

iii) Choosing a tank appropriate in terms of cost, resources and construction methods

The capacity of the tank is calculated as:

Capacity (Q) = (n x q x t) + e

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 3.1 gives the values for different roofing material. Availability of rainwater from different roof top area for a range of rainfall is given in Table 3.2, assuming runoff coefficient as 0.80. The required roof catchment area can be determined by dividing the tank volume (Q) with runoff volume per square meter.

Required roof catchment area (m^2) A = Q/(f x P)

Where, P is rainfall in meter

Table 3.1: Runoff Coefficients for Different Roof Surface Conditions (Pacey and Cullis, 1986)

Types of Catchment	Coefficients
Roof Catchment	
- Tiles	0.80 - 0.90
- Corrugated metal sheet	0.70 – 0.90
Ground Surface Coverings	
- Concrete	0.60 – 0.80
- Plastic sheeting (gravel covered)	0.70 – 0.80
- Butyl rubber	0.80 – 0.90
- Brick pavement	0.50 – 0.60
Treated Ground Catchment	
- Compacted and smoothed soil	0.30 – 0.50
- Clay/cow-dung threshing floors	0.50 – 0.60
- Silicone-treated soil	0.50 – 0.80
- Soil treated with sodium salts	0.40 – 0.70
- Soil treated with paraffin wax	0.60 – 0.90
Untreated Ground Catchment	
- Soil on slopes less than 10 percent	0.0 – 0.30
- Rocky natural catchment	0.20 – 0.50

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.

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.

Table 3.2: 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 (cu.m.)											
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

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^{o} 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:

a) Abandoned dug well
b) Abandoned/running hand pump
c) Recharge pit

d) Recharge trench
e) Gravity head recharge well
f) 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 is channelised into the well and recharges under gravity flow condition. Suitable for roof area about 500-1500 m^2 and 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 3 m and the depth varies from 10 to 15 m. The shaft is backfilled with boulders, gravels and coarse sand.

3.2.2 Rainwater Harvesting from Open Areas

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

(i) Nadi, Tanka, Khadin and percolation tanks in Rajastan

(ii) Bandharas in Maharashtra

(iii) Bundhies in Madya Pradesh and Uttar Pradesh, and

(iv) 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 capacity has been designed by Vangani et al, (1988) to provide adequate drinking water for a family of six persons through out the year.

Nadi: Nadis are excavated or embanked village ponds, 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 drainage basins of 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 15^{th} 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 (0.15×10^6 m^3) of runoff during the normal rainfall years. The enhanced recharge is variable, ranging from 0.032×10^6 m^3 to 0.0182×10^6 m^3 which is about 50% of the storage capacity (Anon., 1988).

Ahars and Bundhies: 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 meters 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, 2-5 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 10^6 m^3 (Anon.,1990). The storage water caters to the domestic and livestock requirements in addition to irrigation demand.

3.3 Case Studies

(a) A case study of a roof top 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).

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:

i) Low cost

ii) Ease of construction

iv) Ease of maintenance

v) Lesser area required than brick/stone masonry tank

vi) Temperature control

(b) 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.

(c) In many states such as Delhi, Maharastra, Gujarat, Chandigar (UT), Punjab, Haryana, Rajastan, 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 are installed (Fig.3.3). The roof area is 3110 m^2 and receiving the average annual rainfall of 712 mm. It is found that there is a rise of water table from 0.62 to 1.37 m.

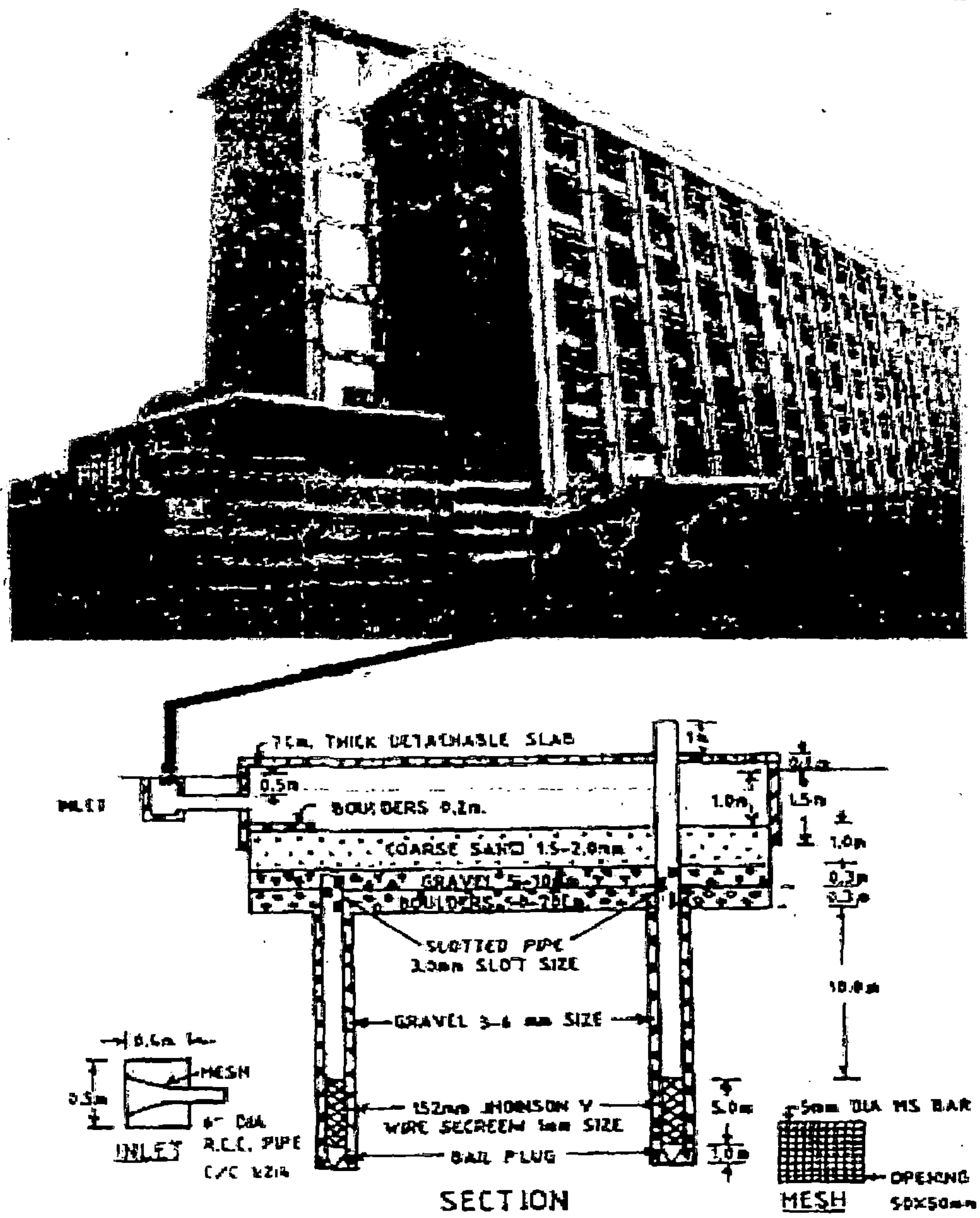


Fig. 3.3 : Rooftop Rainwater Recharge System at Shram Shakti Bhawan, Delhi

(d) A 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).

(e) 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 10^6 m^3, which can accommodate two to three floods in normal rainfall year, thus increasing recharge capacity to about 3 x 10^6 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.

(f) 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 (R.V. Bothale, et al, 2002). Following structures were suggested after identification of suitable sites:

i) **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.

ii) **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.

iii) **Farm pond**: Flat topography, low permeability, absence of faults, joints were the criteria for site suitability.

iv) **Dug cum bore well**: Lineament map pertaining to study area was studied and 9 suitable sites were marked on the output.

(g) A Study has been carried out for Groundwater Recharge and Rainwater Harvesting for Tamil Nadu Water Supply System Using Remote Sensing and GIS.

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.

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).

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 (M. Ramalingam et al, 2002).

DESCRIPTION OF THE STUDY AREA

4.1 General

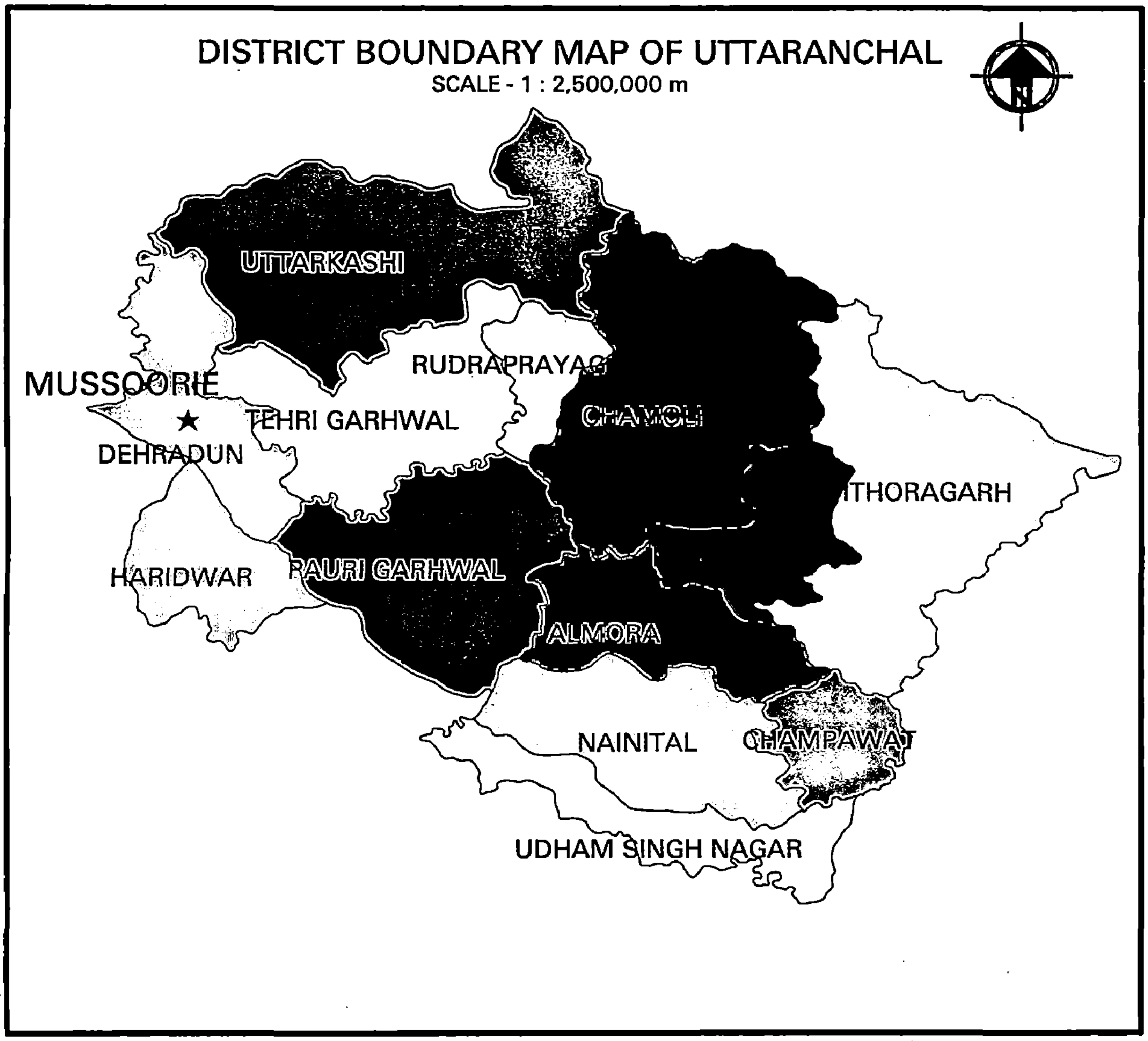
Mussoorie is a fascinating hill resort. Its green hills and varied flora and fauna make it a colourful and picturesque hill station, commanding a wonderful view of Himalayan snow ranges to the Northeast and glittering views of the Doon Valley, Roorkee, Hardwar and Saharanpur to the south.

4.2 Topography

Mussoorie town is about 35 km from Dehradun (Fig 4.1), which is the nearest railhead station, connected to Mumbai, Calcutta, Delhi, Lucknow and Varanasi by direct trains. Mussoorie is also accessible from Delhi by road traversing agricultural land and densely forested Shiwalik hills leading to the railroad junction of Dehradun in Doon Valley. Mussoorie is also conveniently connected to Tehri, Uttarchasi, Chakrata, and Simla by motor road and is the gateway to the Yamunotri and Gangotri shrines of Northern India.

Geographically, Mussoorie lies between 78° 00' to 78° 07' north latitudes and 30° 25' to 30° 30' east longitudes. The town is spread over a hill range about 15 km long, having an area of about 64 km^2. The topography of the town is very much undulating, and altitude varies from 1800 to 2277 m. above mean sea level. It covers three peaks; the highest of which is called Lal Tibba about 2277 m above mean sea level, 5 km north of town proper. In the western part of the town is another peak at about 2191 m above mean sea level, known as the Vincent Hill. The Central peak is the Gunhill with an altitude of 2142 m above mean sea level. The main municipal road is the Mall, which passes through the heart of the town in east-west direction from Kulri Bazar terminating at the Library Bazar in which the main market is confined to both sides of this road.

Fig. 4.1: Location Map of the Study Area



4.3 Climate

In summers, maximum temperatures vary from 25.6°C to 31.7°C in the day time and the minimum temperature varies from 7.2°C to 17.8°C in the night time. While in winters the maximum day temperature varies from 2.2°C to 7.2°C and minimum night temperature varies from 1°C to 4.4°C. Total annual rainfall in the town is 2215 mm.

4.4 Socio-Economic Condition

The socio-economic conditions of the people of Mussoorie are above normal. There is no noticeable industry of any kind in the town. The main occupation of the inhabitants is business. The hotels and restaurants, hosiery and handicrafts are the households industry. The town has more than a hundred of hotels and restaurants. During the tourist season, a number of village folks from the adjoining villages join the permanent establishment of the town and earn their livelihood by way of pulling the rickshaws and providing horses and ponies to the tourists coming to Mussoorie.

4.5 Tourist Resorts

Surrounded by hills and overlooking the Doon Valley, the gay summer resort, Mussoorie, presents a fairly land atmosphere to the tourists. Two ropeway trolley buses ply from the Jhulaghar, on the Mall to Gun-Hill covering a distance of 400 meters in four and a half minutes.

From Library, a metalled road leads to the blooming Municipal Gardens, four kilometres away a glow with gay flowers, velvety lawns, deodar and pine trees, set off by an artificial lake. Thirteen kilometres away, on the Mussoorie Chakrata road, is the most beautiful spot in Mussoorie, known as Kempty Falls, attracting scores of people every day.

Lal Tibba, the highest peak in Mussoorie is also worth seeing. Television transmitter tower is installed here, which relays programs from Delhi. Here, with the aid of electric, coin-operated binocular, one can get a bird's eye view of the Gangotri, Kedar Nath, Chaukhaurba, Nanda Devi and Srikanta peaks.

Camels Back Road is an ideal place for horse riding, the road starts from Kulri Bazar behind the Skating Hall ending at the Library Bazar.

Mussoorie with its inherent beauteous scenery, good roads and conveniently placed rest houses and bungalows is trekker's paradise. There are trekking routes from Mussoorie to Dhanolti, Nag Tibba, Harkidoon, Yatmori, Gangotri, Dodital, Lakhamandal and many other tourist spots.

4.6 Water Supply

The total water, which could be made available from different water sources, tapped at present is 8.67 million litres per day, as detailed in Table 4.1

Table 4.1 Main Water Sources of Mussoorie

S. No.	Name of Sources	Discharge (mld)
1	Murray Springs including Kandighat, Basi and Khanati Springs	2.015
2	Mackinnon Springs	0.34
3	Jinsy Springs	2.99
4	Bhilaru Springs	2.45
5	Kolti Springs	0.87
TOTAL		**8.67**

The water of these springs/Khalas is pumped into five zones through five pumping stations. The details are given below:

4.6.1 Murray Pumping Station

The water from the following sources is collected at Murray Pumping Station in a common sump of 325 kiloliters capacity constructed near the pumping station.

a) Murray Springs: Five intake chambers are constructed to tap number of springs. Water collected from these springs is conveyed to a common chamber from where it is carried to 325 kl sump by gravity through 80 mm diameter G.I. pipe.

b) Kandighat Springs: The water from Kandighat Springs is pumped to the 325 kl common sump at Murray Pumping Station. There are two pumping station at Kandighat named lower Kandighat.and upper Kandighat.

c) Basi Springs: There are five springs, which have been tapped. The water of these springs is collected into 325 kl common sump at Murray Pumping Station by gravity through 100 mm diameter G.I. pipe.

d) Khanati Springs: Twenty eight small springs have been tapped. The water of these springs is collected in a common chamber which is carried to 325 kl sump at Murray Pumping Station by gravity through 125 mm diameter G.I. pipe.

The total discharge available from the above water sources is about 2.015 mld. Water from the 325 kl common sump (R.L. 1670 m.) is pumped into Vincent Hill Reservoir at an elevation of 2190 m through three number rising mains, having 150 mm & 125 mm diameter pipes. It is a single stage pumping. The capacity of Vincent Hill reservoir is 1,040 kl.

4.6.2 Mackinnon Pumping Station

There are five springs, named Mackinnon springs, which have been tapped by constructing intake chambers, and water is conveyed by gravity up to a sump of 135 kl capacity located at an elevation of 1830 m near Mackinnon Pumping Station. The discharge available from these springs is 0.34 mld. Water from sump is pumped into a reservoir of 382 kl capacity near Library at an elevation of 2010 m through 125 mm dia rising main in single stage.

4.6.3 Jinsy Pumping Station

The discharge of Jinsy and Gadhera springs is about 3 mld. The water from Jinsy water source is conveyed to a sump of 22.50 kl capacity through 150 mm dia gravity main and then pumped into the reservoir of 900 kl capacity located at Mount Rose at an elevation of 2050 m. The water from Jinsy pumping station is pumped to Mount Rose into two stages through 200 mm dia rising main. The intermediate pumping station is at Bhilaru at an elevation of 1750 m.

4.6.4 Bhilaru Pumping Station

There are seven springs at Bhilaru. The water from Bhilaru springs is collected in a common collecting chamber from where it is taken to a sump of 325 kl capacity (R.L. 1747 m) through gravity main of 125 mm dia. The total discharge of these springs is 2.45 mld . The water from the sump is pumped to Gun Hill reservoirs at an elevation of 2142 through 100 mm diameter rising main in single stage. The capacity of Gun hill reservoir is 16,380 kl.

4.6.5 Kolti Khala Pumping Station

A cross wall is constructed across the Khala. The water from collecting chamber is being pumped into the Lal Tibba reservoir with a capacity of 800 kl. The pumping is done in three stages through a rising main of 100 mm diameter pipe. The discharge of this source is 0.87 mld. The Lal Tibba reservoir is located at an elevation of 2,277 m.

4.6.6 Other Spring Water Sources

Aside from the water sources that are being pumped, there are five small springs located at higher elevation than the service area. The water from these springs are collected and delivered by gravity 24 hours daily in Barlowganj, Jharipani, Bhatta, Kolhukhet and Bala Hisssar (Table 4.2). These areas are part of Mount Rose Zone.

Table 4.2 Other Spring Sources

S. No.	Name of Source	Discharge (mld)
1	Company Khud	0.058
2	Brook Land	0.13
3	Nalapani	0.04
4	Pargakala	0.158
5	Duglusdail	0.13
	Total	**0.52**

4.6.7 Total Available Water Sources

The total water sources of 8.67 mld presently tapped is presented in Table 4.1. If the power supply is made available for 16 hours a day, the effective total available water is calculated at 5.78 mld. Therefore, the combined total available water sources (i.e. by pumping and by gravity flow) is 6.30 mld. Table 4.3 & 4.4 represent the Zonewise water potential and water availability.

Table 4.3: Total Potential Source of Water

TYPE	ZONES				
	Library	Vincent Hill	Mt. Rose	Gun Hill	Lal Tibba
By Pumping (mld)	0.34	2.015	2.99	2.45	0.87
By Gravity (mld)	0	0	0.52	0	0
Total water available (mld)	0.34	2.015	3.51	2.45	0.87

Sample calculation for Vincent Hill:

Water available for 16 hours pumping per day = (2.015*16)/24

= 1.34 mld

Table 4.4 : Total Available Water Source

TYPE	ZONES				
	Library	Vincent Hill	Mt. Rose	Gun Hill	Lal Tibba
By Pumping (mld)	0.23	1.34	1.99	1.63	0.58
By Gravity (mld)	0	0	0.52	0	0
Total Water Available (mld)	0.23	1.34	2.51	1.63	0.58

Total available water for Mussoorie at 16 hours pumping per day =6.3 mld

4.6.8 Water Distribution

The topography of the town is undulating, the altitude varying from 1800 m to 2277 m above mean sea level. The existing water sources are situated on all four sides and the water is being pumped to different parts of the town. The town has been divided into the following five zones on the basis of topography, existing storage reservoirs and pumping arrangement. These are:

1. Library Zone
2. Vincent Hill Zone
3. Mount Rose Zone
4. Gun Hill Zone
5. Lal Tibba Zone

All these five zones have their separate sources of water and storage reservoir. Laying of feeder mains or rising mains to balance the water demand of different zones interconnecting all reservoirs. Here, water supply is rationed daily at 2 hours in the morning and evening. During summers supply is sometimes increased to 2.5 hours in the morning depending on availability. Water supply using pump depends directly on electricity supply. Power cuts of 3-4 hours result in a drop in supply by 1-2 mld. During summer months when demand is highest, electricity supply is erratic. Water stored in balancing reservoir at Gun Hill is used to meet shortfalls in water supply during summer months. At times when there is surplus, excess water is pumped into these tanks to be used during days of peak demand.

4.7 Population

Mussoorie, being one of the important tourist centers of Northern India, owing to its proximity and easy access from plains, is frequented by a large number of tourists every year. It has a permanent population as well as a large number of floating populations. Due to colder climate and lack of business in winters, a large number of permanent residents who are mostly dependent on tourists shifted to plains during winter. The projected population is presented monthwise to correlate the monthly tourist arrival.

Garhwal Jal Sansthan, Dehradun, conducted survey and calculated the permanent population growth rate at 2.6% per year. Based on the average tourist arrival, month wise from 1990 to 1996 Jal Sansthan estimated the tourist arrival at 0.6% per year. The total projected population is the sum of permanent and tourist population, as presented in Table 4. 5

Projected Total Population = Permanent Population + Tourist Population

Table4.5: Total Projected Population

Month	1997	2002*	2007*	2012*
January	27,245	30,290	33,721	37,589
February	29,113	32,199	35,673	39,584
March	46,786	51,495	56,799	62,774
April	49,172	53,953	59,330	65,381
May	56,779	61,788	67,400	73,693
June	69,157	74,537	80,532	87,219
July	58,667	63,733	69,403	75,756
August	46,049	50,736	56,017	61,968
September	45,460	50,129	55,392	61,325
October	46,196	50,887	56,173	62,129
November	45,678	50,354	55,623	61,563
December	28,844	31,922	35,388	39,290

*Projected Population

4.7.1 Zonewise Population Projection

Jal Nigam, Dehradun, estimated the population in each zone according to the total population percentage as follows:

1.	Vincent Hill Zone	19.66%
2.	Gun Hill Zone	29.91%
3.	Lal Tibba Hill Zone	10.26%
4.	Mount Rose Zone	29.91%
5.	Library Hill Zone	10.26%
	Total	100 %

Based on above estimate, the projected zone-wise population for the year 2002 and 2012 is presented in Tables 4.6 and 4.7

e.g. Population at Vincent Hill in January = 30,290 *19.66% = 5,955

Table 4.6: Zonewise Total Population Projection for 2002

Month	ZONES				
	Library	Vincent Hill	Mt. Rose	Gun Hill	Lal Tibba
January	3,108	5,955	9,060	9,060	3,108
February	3,304	6,330	9,631	9,631	3,304
March	5,283	10,124	15,402	15,402	5,283
April	5,536	10,607	16,137	16,137	5,536
May	6,339	12,148	18,481	18,481	6,339
June	7,648	14,654	22,294	22,294	7,648
July	6,539	12,530	19,062	19,062	6,539
August	5,206	9,975	15,175	15,175	5,206
September	5,143	9,855	14,994	14,994	5,143
October	5,221	10,004	15,220	15,220	5,221
November	5,166	9,900	15,061	15,061	5,166
December	3,275	6,276	9,548	9,548	3,275

Table 4.7: Zonewise Total Population Projection for 2012

Month	ZONES				
	Library	Vincent Hill	Mt. Rose	Gun Hill	Lal Tibba
January	3,857	7,390	11,243	11,243	3,857
February	4,061	7,782	11,840	11,840	4,061
March	6,441	12,341	18,776	18,776	6,441
April	6,708	12,854	19,555	19,555	6,708
May	7,561	14,488	22,042	22,042	7,561
June	8,949	17,147	26,087	26,087	8,949
July	7,773	14,894	22,659	22,659	7,773
August	6,358	12,183	18,535	18,535	6,358
September	6,292	12,056	18,342	18,342	6,292
October	6,374	12,215	18,583	18,583	6,374
November	6,316	12,103	18,413	18,413	6,316
December	4,031	7,724	11,752	11,752	4,031

4.8 Water Demand

It is proposed that Mussoorie town will be provided with drinking water at the rate of 150 lpcd. The monthly water demand zonewise for 2002 and 2012 is presented in Tables 4.8 and 4.9.

Table 4.8: Zonewise Projected Water Demand (mld) for 2002

Month	ZONES				
	Library	Vincent Hill	Mt. Rose	Gun Hill	Lal Tibba
January	0.47	0.89	1.36	1.36	0.47
February	0.50	0.95	1.44	1.44	0.50
March	0.79	1.52	2.31	2.31	0.79
April	0.83	1.59	2.42	2.42	0.83
May	0.95	1.82	2.77	2.77	0.95
June	1.15	2.20	3.34	3.34	1.15
July	0.98	1.88	2.86	2.86	0.98
August	0.78	1.50	2.28	2.28	0.78
September	0.77	1.48	2.25	2.25	0.77
October	0.78	1.50	2.28	2.28	0.78
November	0.77	1.48	2.26	2.26	0.77
December	0.49	0.94	1.43	1.43	0.49

Table 4.9: Zonewise Projected Water Demand (mld) for 2012

Month	ZONES				
	Library	Vincent Hill	Mt. Rose	Gun Hill	Lal Tibba
January	0.58	1.11	1.69	1.69	0.58
February	0.61	1.17	1.78	1.78	0.61
March	0.97	1.85	2.82	2.82	0.97
April	1.01	1.93	2.93	2.93	1.01
May	1.13	2.17	3.31	3.31	1.13
June	1.34	2.57	3.91	3.91	1.34
July	1.17	2.23	3.40	3.40	1.17
August	0.95	1.83	2.78	2.78	0.95
September	0.94	1.81	2.75	2.75	0.94
October	0.96	1.83	2.79	2.79	0.96
November	0.95	1.82	2.76	2.76	0.95
December	0.60	1.16	1.76	1.76	0.60

4.9 Proposed Project

Almost all of the available water sources in the near vicinity of the town has been tapped for water supply of Mussoorie. Tapping of Aglar River has been proposed since 1967. Aglar River has a reported minimum discharge of 140 mld. The river is proposed to be tapped by constructing a cross wall across the river, infiltration gallery, treatment facilities and four stages pumping system. The scheme is capable of drawing 12 mld of water. This project is a long term solution to the water supply problem of Mussoorie. As per 1989 project report "Mussoorie Water Supply Project Augmentation of Source and Storage" by U.P. Jal Nigam,Dehradun, the estimated cost of the project is Rs.732 lacs.

APPLICATION OF GIS IN RAINWATER HARVESTING (WITH SPECIAL REFERENCE TO MUSSOORIE TOWN)

5.1 Introduction

Water supply system problem of Mussoorie needs a long-term solution to augment the present and future water requirements but a huge sum may be required to meet the water requirements. In this study, an attempt has been made to assess the potential of rainwater harvesting in Mussoorie. Although rainwater harvesting is not the total solution to the present water crises, it may partly help in shortening the gap between the supply and demand of water for Mussoorie. Generally, the success of adopting the concept of the rainwater harvesting relies on people's awareness and participation.

5.2 Software Used

ERDAS IMAGINE 8.5 (Earth Resources Data Analysis System) software developed by ERDAS Inc. Atlanta, Georgia, USA, is designed for image processing and GIS concepts, such as GIS analysis, cartography and map projections, graphic display, statistics and remote sensing-data analysis.

5.3 Methodology

Planning of rainwater harvesting project requires a large quantity of reliable information for creating the database to be used in GIS analysis. These information may be collected from various sources in the form of maps, charts, project reports and ground information through site visits. Satellite images are also a major source of information, however, in this study, these have not been used due to their non-availability.

5.3.1 Data Acquisition

Data for this study are collected from different agencies, such as:

(i). Topographic Map (53J/3), 1:50,000 scale from Survey of India, Dehradun.

(ii). Guide Map, 1:10,000 scale from Survey of India, Dehradun.
(iii). Tourist Map, 1:15,000 scale from Survey of India, Dehradun.
(iv). Project Report " Mussoorie Water Supply Project Augmentation of Source and Storage" from U.P. Jal Nigam, Dehradun.
(v). Project Report " Carrying Capacity of Mussoorie" from Garhwal Jal Sansthan, Dehradun.

5.3.2 Scanning of Maps

Digital scanner was used for scanning the maps by parts and mosaicking was done in Photoshop 6.0.

5.3.3 Map Registration

Map registration was done through polynomial rectification in ERDAS IMAGINE 8.5 software. Rectification is the process of projecting the data onto a plane and making it conform to a map projection system. Assigning map coordinates to the image data is called georeferencing. Since all map projection systems are associated with map coordinates, rectification involves georeferencing. Polynomial equation is used to transform the coordinate from one system to another. In this process, polyconic projection and Everest datum were used.

About 19 ground control points (GCP) are assigned to the image data and checked the units of residuals and RMS errors. The raster data layer in the source file (rectified image) is resampled to create a new image called registered map or imaged map.

5.3.4 Digitization

Digitizing refers to any process that converts non-digital data into numbers. Vector data are created by digitization. Geographic data or features from registered map were digitized, such as buildings, road network, rivers, streams, gullies, contour lines, zone boundary, etc using ERDAS IMAGINE 8.5 software. Vector layers were created for each feature.

5.3.5 Creation of Attributes

Attribute information is displayed in CellArrays. This is the same information that is stored in the INFO database of ARC/INFO. Some attributes are automatically generated when the layer is created. Custom field can be added to each attribute table. Attribute fields can contain numerical or character data. Some column attributes are automatically calculated such, as area and perimeter of polygon. Attributes are briefly discussed as follows:

(i) Contour Attributes: Contour values or elevation was assigned corresponding to each contour line at 100 m interval.

(ii) Building Attributes: Polygon areas were automatically calculated. Statistical calculations were also performed, such as total number of buildings, polygon area (i.e. total area, minimum area, maximum area, and average area). Selection of items is also performed with a given set of criteria in each zone (i.e. $Area > 100 and $Area < 500 and Zone = 3). The selected items in the table of the software are highlighted on the map.

(iii) Zone Attribute: Area of each zone is automatically calculated. Additional columns are created to input external data, such as zone number, water demand, available water, population, etc.

5.3.6 Creation of Different Maps

Different thematic maps were prepared using map composer module and their brief description is presented below:

(i) Zone Map: Zone map (Fig.5.1) composed of five zones namely; Library Zone, Vincent Hill Zone, Mount Rose Zone, Gun Hill Zone and Lal Tibba Zone. The water supply zonation map prepared by U.P. Jal Nigam, Dehradun, was adopted in this study. Code number is assigned for each Zone for easy manipulation. Land area coverage with corresponding weightages is presented in Table 5.1.

Table 5.1: Zonewise Land Area

Zone	Description	Land Area (sq.km.)	%
1	Library Zone	1.20	8
2	Vincent Zone	2.57	18
3	Mount Rose Zone	6.10	42
4	Gun Hill Zone	2.21	15
5	Lal Tibba Zone	2.54	17
	Total	**14.62**	**100**

(ii) Population Map: Population projection used in this study was adopted from the estimates derived by Garhwal Jal Sanstan and U.P. Jal Nigam. Population map for 2002 were presented in Fig. 5.2. Population projection is briefly discussed in Chapter Four.

(iii) Altitude Map: Altitude map (Fig.5.3) is generated out of the contour values after creating the DEM. Table 5.2 shows the average elevation of each zone.

Table 5.2: Zonewise Average Elevation

Zones	Average Elevation (m.)
Library	1900
Vincent Hill	1945
Mount Rose	1613
Gun Hill	1944
Lal Tibba	1987

(iv) Road Network Map : Road network map (Fig. 5.4) indicates the main roads and secondary roads.

(v) Drainage Network Map: Drainage map (Fig.5.5), indicates the location and direction of drainage pattern, such as gullies, streams and rivers. Drainage features were digitized from guide map at 1:10,000 scale.

Fig.5.1 : ZONE MAP

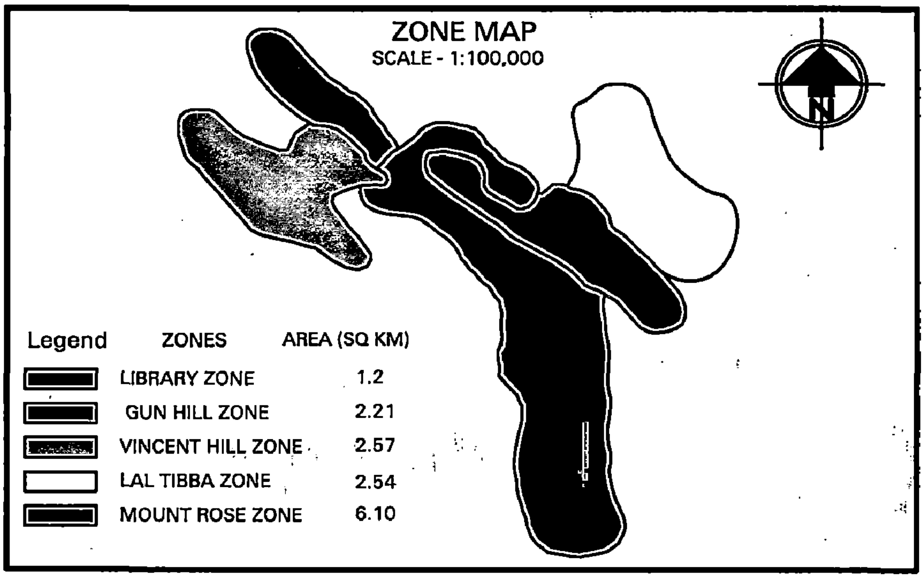


Fig. 5.2 : POPULATION MAP OF 2002

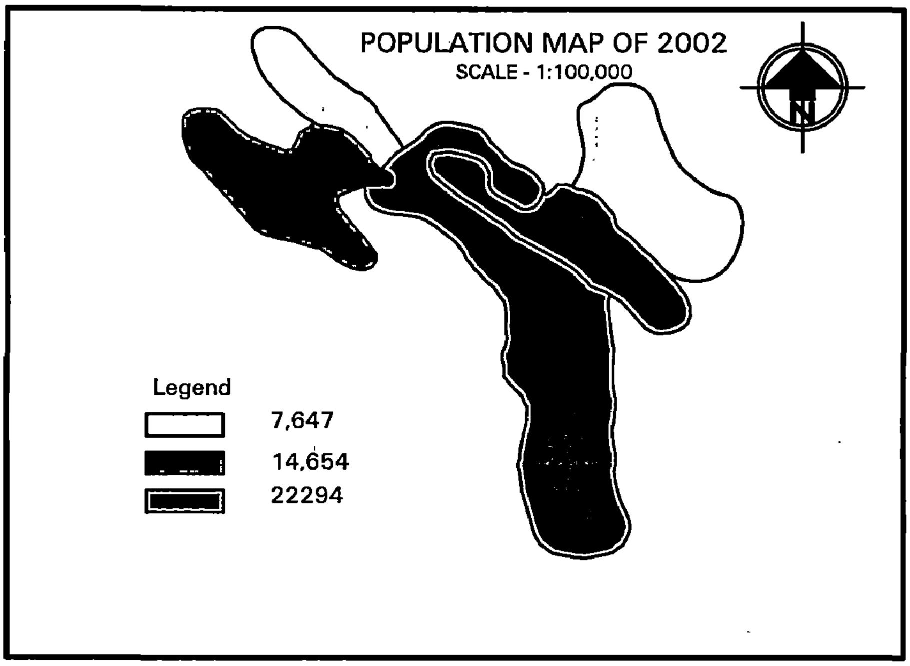
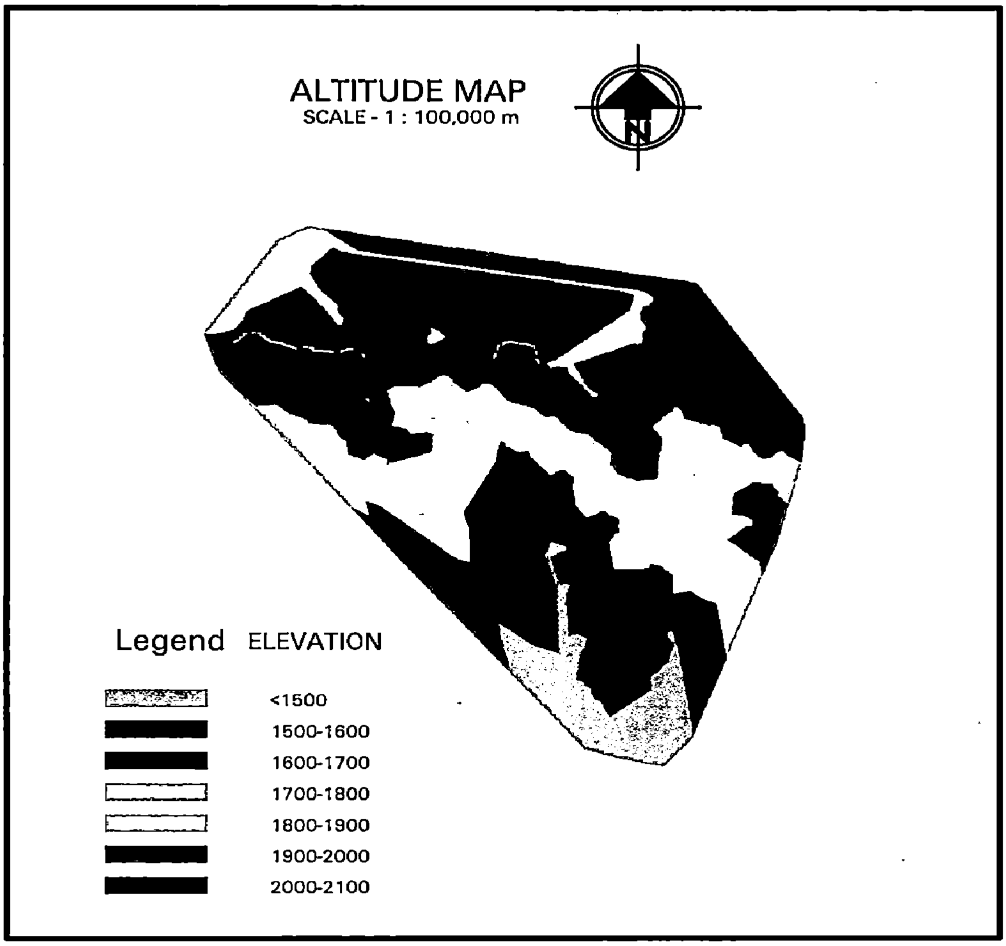


Fig. 5.3 : Altitude Map



(vi) Water Demand Map: Water demand map (Fig.5.6), indicates the water demand in each zone for 2002 based on the water demand rate of 150 lpcd adopted by Garhwal Jal Sansthan, Dehradun (Table. 5.3).

Table 5.3: Zonewise Water Demand for 2002

Zones	Quantity (mld)	(%)
Library	1.15	10
Vincent Hill	2.20	20
Mount Rose	3.34	30
Gun Hill	3.34	30
Lal Tibba	1.15	10
Total	**11.18**	**100**

(vii) Water Supply Map: Water supply map (Fig.5.7), indicates the available water sources in each zone. Garhwal Jal Sansthan, Dehradun, provided the water sources quantities. Percentage of demand is calculated for each zone (Table 5.4), which can be satisfied by available sources. It can be seen from the table that only 56 % of total water demand is met by the available sources.

Table 5.4: Zonewise Water Availability

Zones	Quantity (mld)	%of Total Water Demand
Library	0.23	2
Vincent Hill	1.34	12
Mount Rose	2.51	22
Gun Hill	1.63	15
Lal Tibba	0.58	5
Total	**6.29**	**56**

(viii) Building Map: Building Map (Fig.5.8) indicates the roof area of the buildings generated from guide map surveyed in 1967. The total roof area and number of buildings are projected in 2002 with an increase of 150%. Roof areas were classified as presented in Table 5.5. Zonewise projected roof area is presented in Table 10 (Appendix B).

Fig. 5.4: ROAD NETWORK MAP

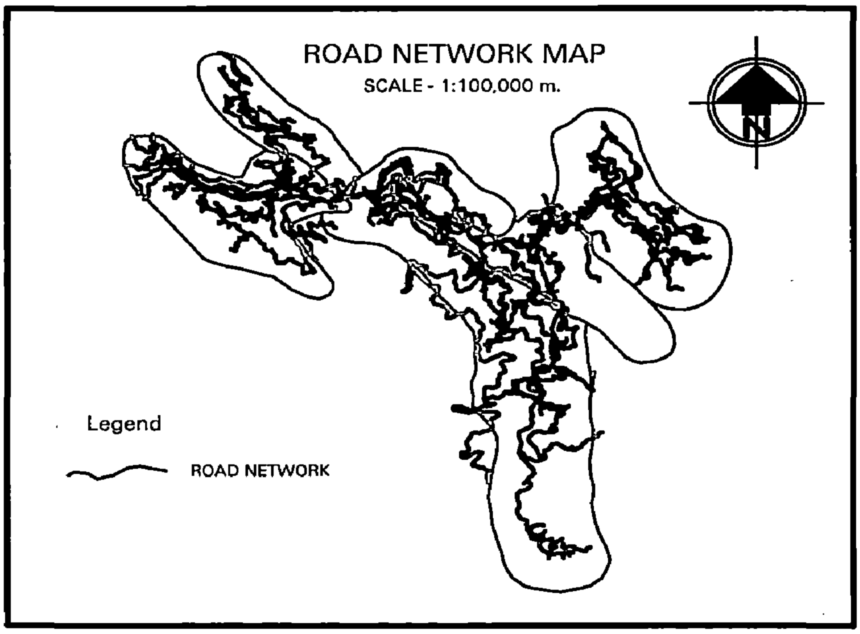


Fig. 5.5 : DRAINAGE NETWORK MAP

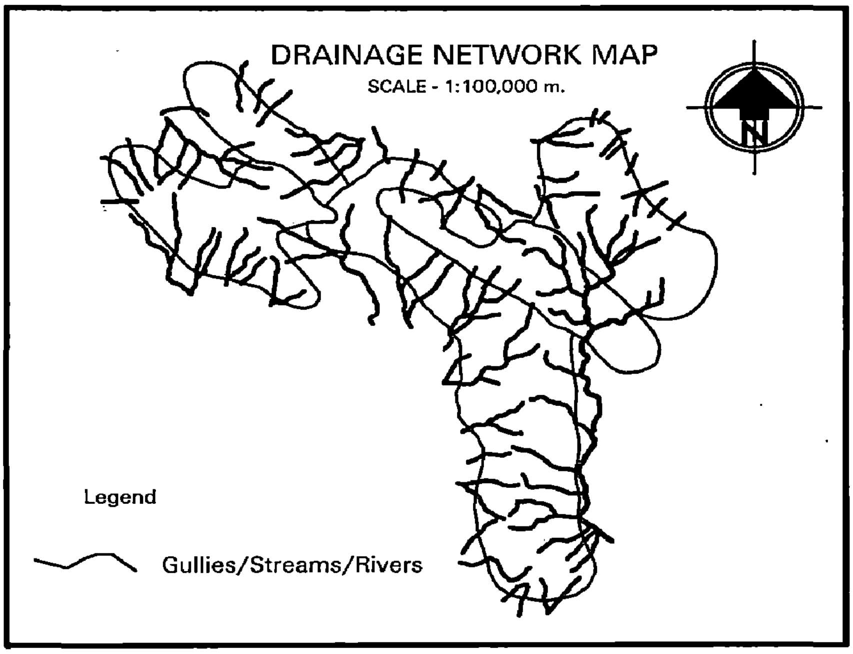


Fig.5.6: WATER DEMAND MAP

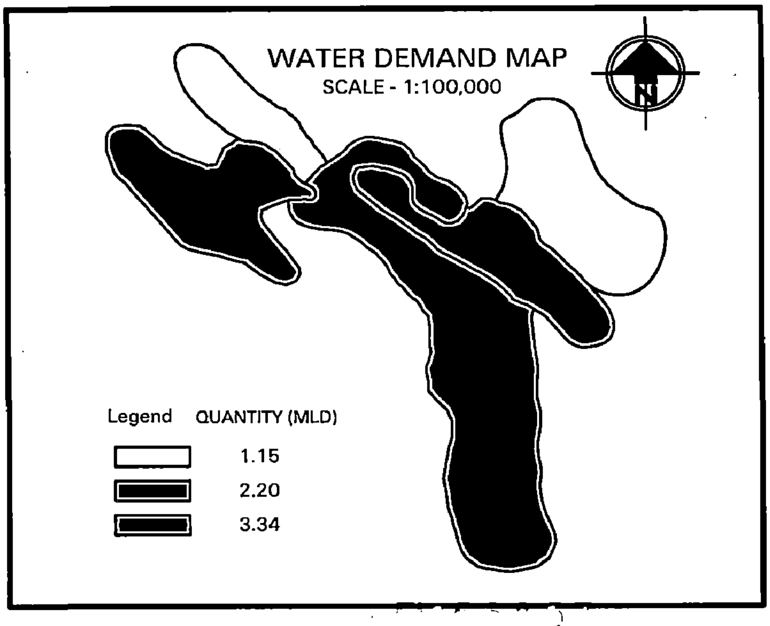


Fig. 5.7 : WATER SUPPLY MAP

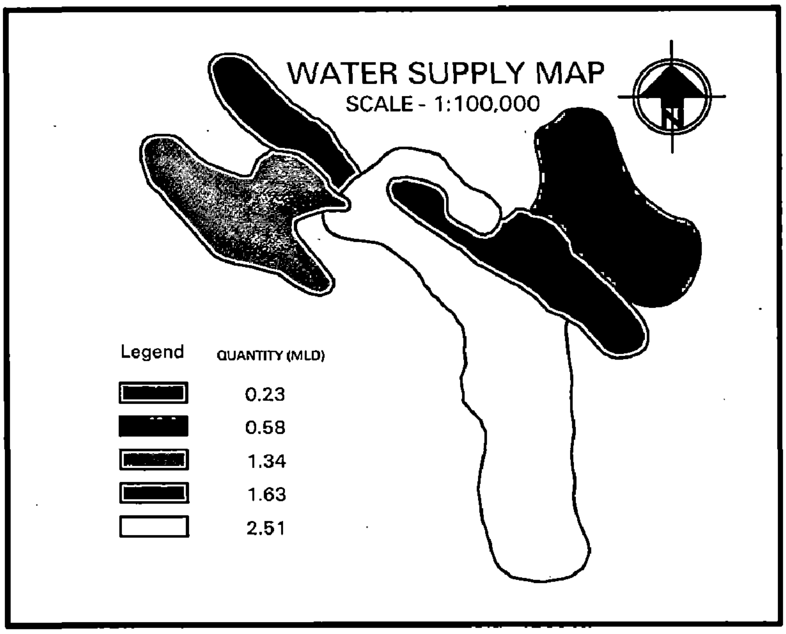


Fig. 5.8 : Building Map

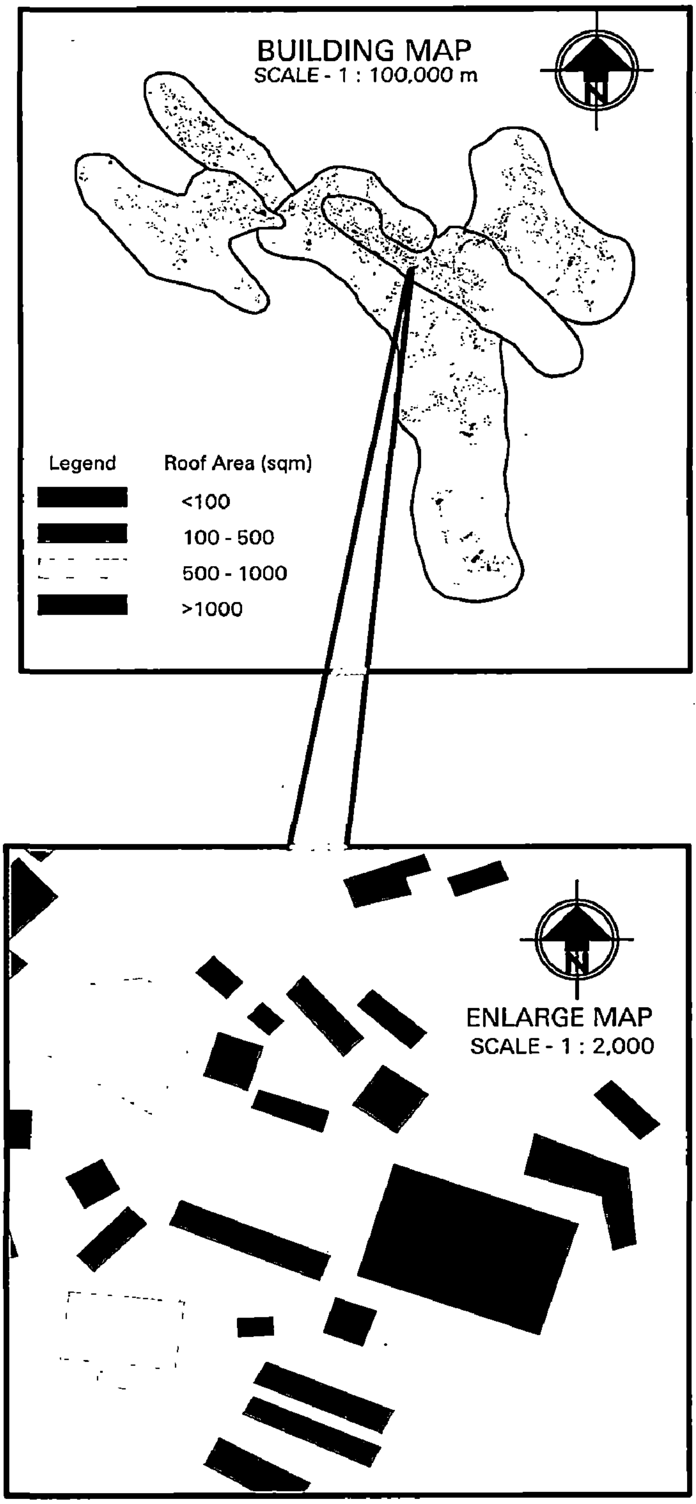


Table 5.5: Projected Roof Area for 2002

Class	Number Of Bldgs.	%	Roof Area (m^2.)			
			Total	Min.	Max.	Mean
<100 m^2	2,488	41.23	187,440	21.66	99.94	75.35
100-500 m^2	3,133	51.93	646,393	100.17	499.57	206.35
500-1000 m^2	283	4.68	192,260	502.10	997.80	680.57
1000-6000 m^2	130	2.15	233,160	1,003.40	6,011.88	1,793.54
Total	**6,033**	**100**	**1,259,254**			**208.74**

(ix) Open Area Map: Zone map is overlaid with the building map. Open area map (Fig.5.9) is the arithmetical difference of the land area and total roof area. Percentage of the total land area is calculated in each zone (Table 5.6).

Table5.6 : Zonewise Open Area

Zones	Land Area (km^2)	Total Roof Area (m^2)	Open Area (km^2)	% of Total Land Area
Library	1.2	143,513	1.06	7
Vincent Hill	2.57	166,437	2.40	16
Mount Rose	6.1	407,602	5.69	39
Gun Hill	2.21	337,654	1.87	13
Lal Tibba	2.54	204,048	2.34	16
Total	**14.62**	**1,259,254**	**13.36**	**91**

5.4 Identification of Water Shortage Zones

Water demand map is integrated with water sources map. Water shortage map (Fig 5.10) is derived when water demand is more than the water sources. Shortage of water is classified into four categories (Table 5.7). Percentage of total water demand is computed for each zone, as shown in Table 5.8.

Table 5.7: Classification of Shortage

Classification	Criteria
Low Shortage	<5% of Total Demand
Medium Shortage	5%-10% of Total Demand
High Shortage	>10% of Total Demand
No Shortage	Supply > Demand

Fig.5.9 : Open Area Map

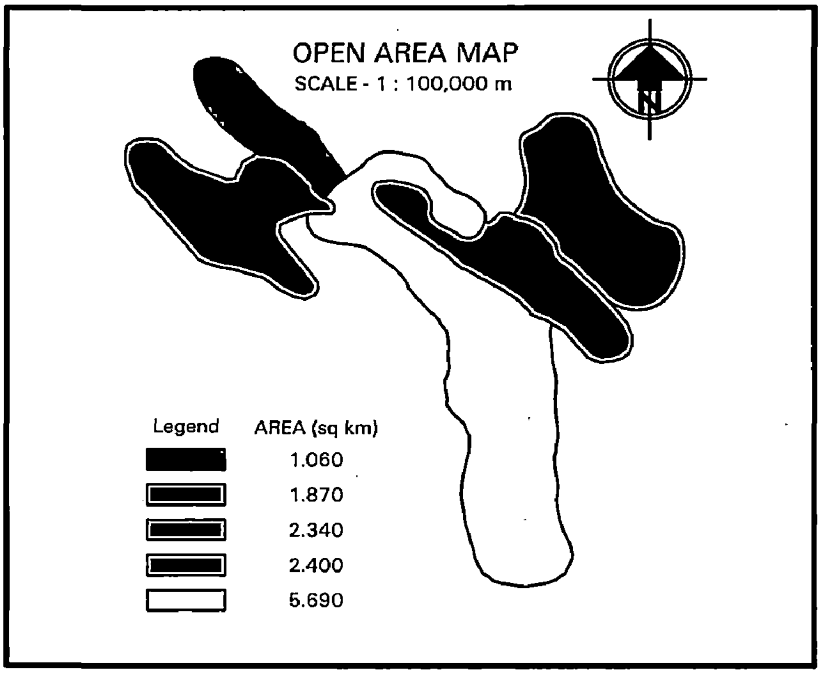


Fig. 5.10 Water Shortage Map

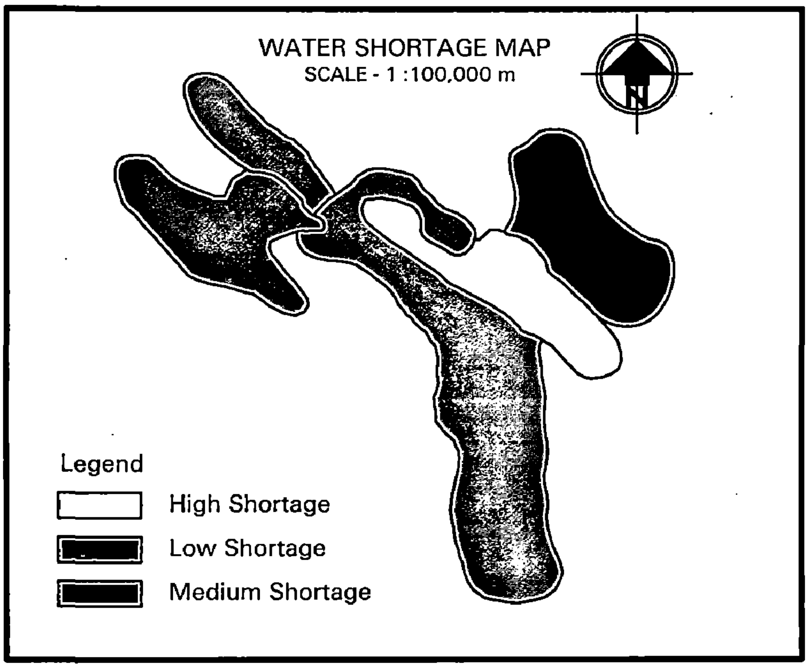


Fig. 5.11 : Rooftop Rainwater Map

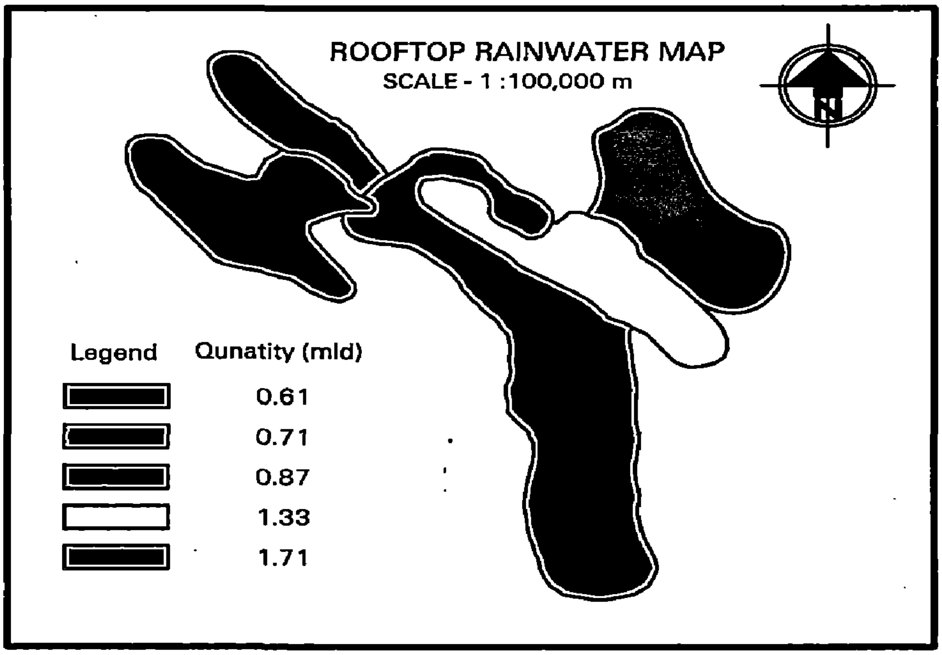


Fig. : 5.12 Rooftop Rainwater Harvesting Potential Map

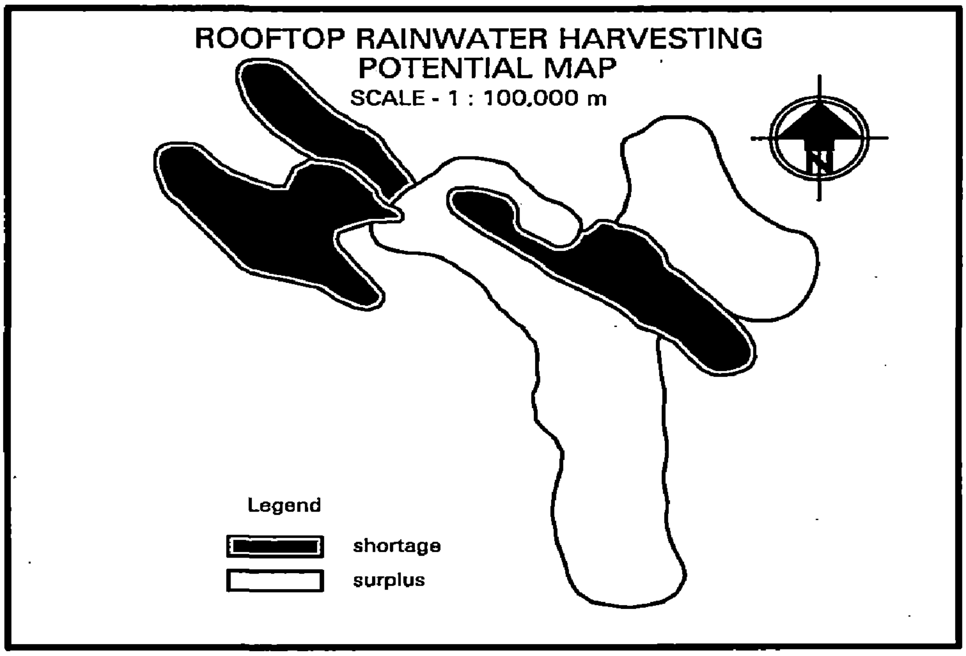


Table 5.8: Zonewise Water Shortage for 2002

Zones	Quantity (mld)	Shortage in % of Total Water Demand	Classification	Rank
Gun Hill	1.71	16	High Shortage	1
Library	0.92	8	Medium Shortage	2
Vincent Hill	0.86	8	Medium Shortage	2
Mount Rose	0.83	7	Medium Shortage	2
Lal Tibba	0.57	5	Low shortage	3
Total	**4.89**	**44**		

It can be observed that all zones have water shortage. Gun Hill zone exhibited the highest shortage of 16% owing to its larger population and insufficient water sources.

5.5 Effect of Rooftop Rainwater Harvesting

Rooftop rainwater map (Fig 5.11) is created indicating the quantity of water harvested from rooftops in each zone. Quantity of rainwater harvested from roof is the product of multiplying the roof area by 2215 mm total annual rainfall and 0.70 efficiency. Efficiency (E) covers the roof coefficient less evaporation losses and wastage during flushing of first rains. Percentage of water demand is calculated in each zone as shown in Table (5.9).

Table 5.9: Zonewise Water Available from Rooftop Rainwater Harvesting

Zones	Annual Rainfall (mm)	E	Roof Area (m^2)	Volume of Water		% of Total Water Demand
				Per Annum (m^3)	Per Day Mld	
Library	2,215	0.7	143,513	222,517	0.61	5
Vincent Hill	2,215	0.7	166,437	258,061	0.71	6
Mount Rose	2,215	0.7	407,602	631,987	1.73	15
Gun Hill	2,215	0.7	337,654	523,533	1.43	13
Lal Tibba	2,215	0.7	204,048	316,376	0.87	8
Total			**1,259,254**	**1,952,473**	**5.35**	**48**

Water shortage map is integrated with the rooftop rainwater map to evaluate the potential of rooftop rainwater harvesting to augment the water supply. Rooftop rainwater harvesting potential map (Fig.5.12) is generated after integrating. Reclassification of water shortage is presented in Table 5.10.

Table 5.10: Reclassification of Water Shortage

Zones	Change in Water Shortage		Class
	Quantity (mld)	% of Total Water Demand	
Library	-0.31	-3	Shortage
Vincent Hill	-0.15	-1	Shortage
Mount Rose	0.90	8	Surplus
Gun Hill	-0.28	-2	Shortage
Lal Tibba	0.30	3	Surplus
Total	**0.46**	**4**	**Surplus**

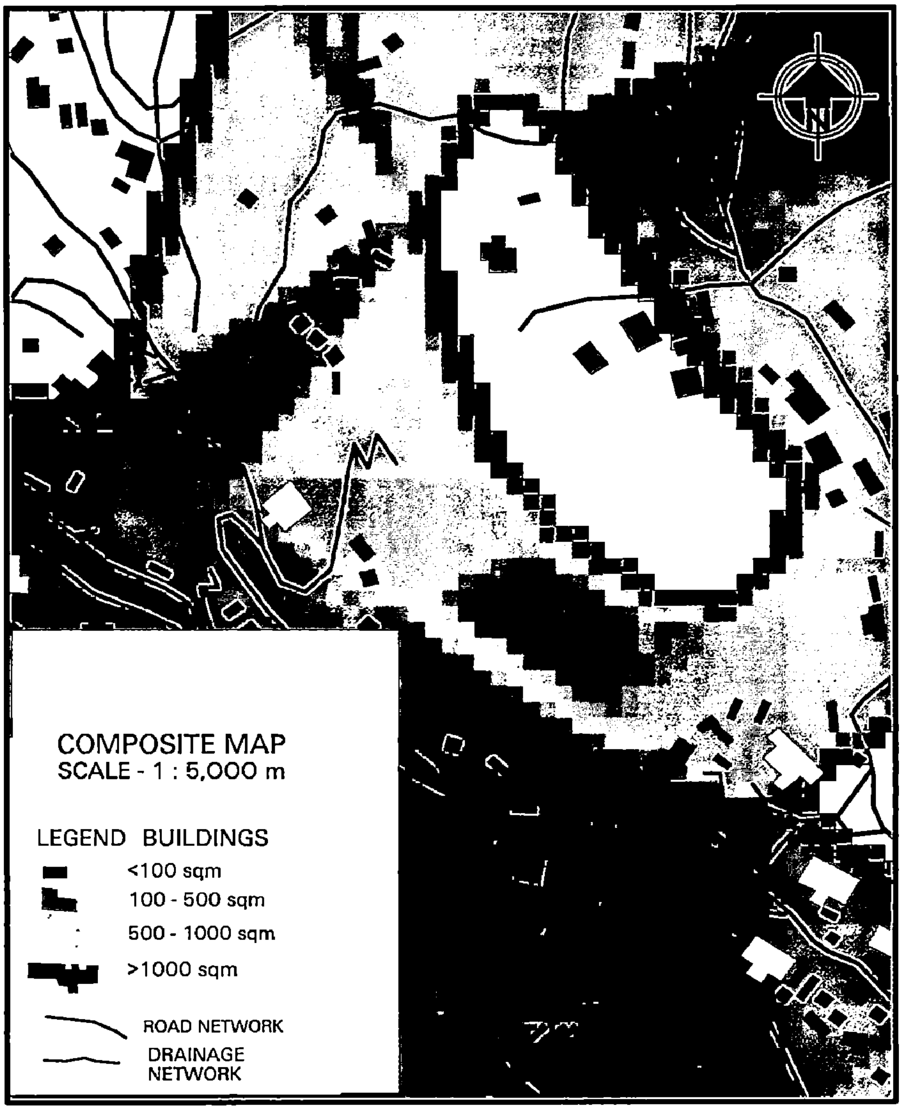
It can be observed that the overall impact of rooftop rainwater harvesting, a surplus of 4% can be made available which is equivalent to 0.46 mld . Mount Rose zone contributes the highest surplus of 8% and followed by Lal Tibba zone for having 3% surplus. Library Zone, Gun Hill Zone and Vincent Hill Zone have still shortages in the order of 3%, 2% and 1% respectively.

Hence, the total water shortage of 44% equivalent to 4.89 mld (Table 5.8) can be met with the available water from rooftop harvesting.

5.5 Identification of Site for Construction of Water Tank

Building map, drainage map and road map are overlaid onto slope map to evaluate the suitable site of water tank (Fig.5.13). Every building should be provided with individual water tank. Required ground area suited for the size of the tank near the premises of the building can be easily determine from the map. Suitable site is free from obstruction, such as road, drainage and adjacent building or any permanent structure.

Fig. 5.13 : Composite Map



ANALYSIS AND DESIGN

6.1 Introduction

The present chapter deals with the development of criteria for the design of tank capacity for a particular roof area based on the inputs available from GIS analysis. Various parameters are considered based on the available data collected from different sources as well as ground information through site visit to Mussoorie conducted on November 8, 2002. With the help of GIS, storing, processing, analyzing, and displaying of spatial data and their attributes become easy.

Simulation study is performed to come up with an approximate capacity of tank considering various parameters, such as roof area, maximum rainfall, population density, runoff coefficient, and water demand. Final result is demonstrated in the form of graph, where the roof area-tank capacity relationship is developed.

6.2 Design Parameters

Various design parameters are considered for approximating the tank capacity which are briefly discussed below:

6.2.1 Roof Area

Roof area of the buildings are digitized from guide map at scale 1:10,000 which was surveyed in 1967and stored in GIS database. The total number of buildings and roof areas are projected in 2002 with an increase of 150%. Maximum and minimum roof area are considered in the design analysis.

6.2.2 Population Density

Population per square meter of roof area is proportionate to the projected total population of 2002 with projected total roof area of 1,259,254 m^2. The area/population ratio is used to approximate the number of person for a certain roof area. Minimum of 5 persons per household is used for roof sizes of 30 -100 m^2.

6.2.3 Monthwise Population

A variation in water demand is attributed by different population intensity for the whole year. For winter month (December to February) due to absence of tourists and temporary shifting of people to plains, population is minimal, whereas, in the month of June maximum population occurred due to tourist arrivals (Table 4.5). Monthwise yearly population projection from 2003 to 2012 is presented in Table 3 (Appendix A).

6.2.4 Maximum Rainfall

Mussoorie has a minimum rainfall of 10 mm in the month of February and April, and maximum rainfall of 790 mm in the month of July. Monthly rainfall is presented in Table 6.1.

Table 6.1 : Monthly Rainfall Data

Month	Monthly Rainfall (M)
January	0.12
Feb.	0.01
March	0.02
April	0.01
May	0.02
Jun	0.04
July	0.79
Aug.	0.705
Sept.	0.33
October	0.04
November	0.04
December	0.09
Total	**2.215**

6.2.5 Efficiency

The types of material used affect the quantity of rainwater harvested from rooftop. Due to limited time and resources, classification of roof according to type of material has not been done. It has been observed during site visit that most of the roofs used GI sheets. Runoff coefficient for GI sheets 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 0.70 is used considering also the evaporation losses and wastage.

6.2.6 Water demand

Water demand considered in the analysis is 150 lpcd. It has been discussed in Chapter 5 that rooftop rainwater harvesting has a potential of 48% which is sustainable to balance the gap between the water supply and water demand at a rate of 150 lpcd.

6.2.7 Water Available from Water System

It has been discussed in Chapter 5 that the water available from the water system is only 56% of the water demand. This is used in simulation study to determine the change in storage and design capacity of the tank.

6.3 Calculation of Tank Capacity with Storage Simulation

Different roof area from 30 m^2 to 6000 m^2 is analyzed considering all parameters discussed above to determine the required tank capacity in cubic meters. In order to determine the sustainability of tank capacity, simulation is performed for a sequence of 10 years (2002-2011). Table 6.2 represents the calculation procedure in tabular form, from which the tank capacity is determined. Brief description of each column is:

- Column A: Month in a year
- Column B: Projected population from 2002 –2011
- Column C: Rainfall data (m)
- Column D: Area/Population Ratio, Total Roof Area / (Col. B)
- Column E: Roof area considered for analysis

- Column F: Roof Area Population, (Col. E / Col. D), minimum number of person per household is 5.
- Column G: Water Demand = (Col. B)*(150 lpcd) x (No. of days for the month) / 1000 liters per cubic meter.
- Column H: Water Quantity Available from System = 56% x (Col. G)
- Column I: Water Quantity Available from Roof = (Col.E) x (Col. C) x 0.70
- Column J: Percentage of Rainwater Harvested over Water demand = (Col. I / Col. G)
- Column K: Change in Storage = (Col. H) + (Col. I) – (Col. G) + (Col. L of previous month)
- Column L: Storage Volume

  If Col. K is negative, Col. L is equal to zero

  If Col K is > 0, but not more than tank capacity, Col K is equal to Col. L

  If Col. K is > 0, and > tank capacity, Col. L is equal to tank capacity

Example: July Month is considered to have maximum rainfall, to demonstrate the design procedure.

Total Roof Area	:	1,259,254 m^2
Roof Area under consideration	:	1000 m^2
Population for the Month of July (Table 4.5)	:	63,733
Roof Area Population Ratio	:	19
Number of Person for 1000 m^2 roof	:	51 persons
Max Rainfall intensity (Month of July)	:	0.79 m

Water Demand:

51 x 150 lpcd =76,50 liters per day = 235.34 m^3 (for July month)

Water Available from the System is calculated at 56 % of water demand as discussed in Chapter 5.

= 56 % x 235.34 = 131.79 m^3

Water Available from Roof :

$1000\ m^2 \times 0.79\ m \times 0.70 = 553\ m^3$ (for July month)

Tank capacity is decided at 553 m^3 as the maximum water that can be collected from roof.

Change in storage = 131.79 + 553 - 235.4 = 449.4 m^3 which is also equal to storage volume. If change in storage is negative as shown in June, storage volume is equal to zero, If change in storage is more than tank capacity as shown in August, then storage volume is equal to 553 m^3.

Table 6.2 : Simulation Study for Tank Capacity Determination

Year: 2002 **Total roof Area:** 1,259,254 m^2 **Roof Area:** 1000 m^2

Water Demand: 150 lpcd **Capacity (m^3):** 553 Min. No. of person per Household: 5

Month	Population	Monthly Rainfall (M)	Ratio (Area/Pop.)	Roof Area (m^2)	Roof Area Population	Water Demand m^3/month	Water from System (m^3/mo)	Harvested Water Quantity (m^3/mo.)	Harvested Water % of Demand	Change in storage (m^3)	Storage Volume (m^3)
A	B	C	D	E	F	G	H	I	J	K	L
January	30,290	0.12	42	1,000	24	111.85	62.64	84	75.10	34.8	34.8
Feb.	32,199	0.01	39	1,000	26	107.39	60.14	7	6.5	-5.5	0.0
March	51,495	0.02	24	1,000	41	190.15	106.49	14	7.4	-69.7	0.0
April	53,593	0.01	23	1,000	43	191.52	107.25	7	3.7	-77.3	0.0
May	61,788	0.02	20	1,000	49	228.16	127.77	14	6.1	-86.4	0.0
Jun	74,537	0.04	17	1,000	59	266.36	149.16	28	10.5	-89.2	0.0
July	63,733	0.79	20	1,000	51	235.34	131.79	**553**	235.0	449.4	449.4
Aug.	50,736	0.705	25	1,000	40	181.31	101.53	493.5	272.2	863.2	553.0
Sept.	50,129	0.33	25	1,000	40	185.11	103.66	231	124.8	702.6	553.0
October	50,887	0.04	25	1,000	40	187.91	105.23	28	14.9	498.3	498.3
November	50,354	0.04	25	1,000	40	179.94	100.77	28	15.6	447.1	447.1
December	31,922	0.09	39	1,000	25	117.88	66.01	63	53.4	458.3	458.3

Year: 2003

January	30,976	0.12	41	1,000	25	114.39	64.06	84	73.44	492.0	492.0
Feb.	32,894	0.01	38	1,000	26	109.71	61.44	7	6.4	450.7	450.7
March	52,556	0.02	24	1,000	42	194.07	108.68	14	7.2	379.3	379.3
April	55,028	0.01	23	1,000	44	196.65	110.12	7	3.6	299.8	299.8
May	62,910	0.02	20	1,000	50	232.31	130.09	14	6.0	211.5	211.5
Jun	75,736	0.04	17	1,000	60	270.65	151.56	28	10.3	120.5	120.5
July	64,867	0.79	19	1,000	52	239.53	134.14	**553**	230.9	568.1	553.0
Aug.	51,792	0.705	24	1,000	41	185.08	103.65	493.5	266.6	965.1	553.0
Sept.	51,182	0.33	25	1,000	41	189.00	105.84	231	122.2	700.8	553.0
October	51,945	0.04	24	1,000	41	191.81	107.42	28	14.6	496.6	496.6
November	51,408	0.04	24	1,000	41	183.71	102.88	28	15.2	443.8	443.8
December	32,615	0.09	39	1,000	26	120.44	67.45	63	52.3	453.8	453.8

Continuation of Table 6.2

Year: 2004 **Total roof Area:** 1,259,254 m^2 **Roof Area:** 1000 m^2

Water Demand : 150 lpcd **Capacity (m^3) :** 553 Min. No. of person per Household : 5

Month	Population	Monthly Rainfall (M)	Ratio (Area/Pop.)	Roof area (m^2)	Roof area Population	Water Demand m^3/month	Water from System (m^3/mo)	Harvested Water Quantity (m^3/mo.)	Harvested Water % of Demand	Change in storage (m^3)	Storage Volume (m^3)
A	B	C	D	E	F	G	H	I	J	K	L
January	31,663	0.12	40	1,000	25	116.92	65.47	84	71.84	486.3	486.3
Feb.	33,589	0.01	37	1,000	27	112.03	62.74	7	6.2	444.0	444.0
March	53,617	0.02	23	1,000	43	197.99	110.87	14	7.1	370.9	370.9
April	56,104	0.01	22	1,000	45	200.49	112.27	7	3.5	289.7	289.7
May	64,033	0.02	20	1,000	51	236.45	132.41	14	5.9	199.7	199.7
Jun	76,935	0.04	16	1,000	61	274.93	153.96	28	10.2	106.7	106.7
July	66,001	0.79	19	1,000	52	243.72	136.48	**553**	226.9	552.5	552.5
Aug.	52,848	0.705	24	1,000	42	188.86	105.76	493.5	261.3	962.9	553.0
Sept.	52,234	0.33	24	1,000	41	192.88	108.02	231	119.8	699.1	553.0
October	53,002	0.04	24	1,000	42	195.72	109.60	28	14.3	494.9	494.9
November	52,462	0.04	24	1,000	42	187.47	104.99	28	14.9	440.4	440.4
December	33,308	0.09	38	1,000	26	123.00	68.88	63	51.2	449.3	449.3

Year: 2005

January	32,349	0.12	39	1,000	26	119.45	66.89	84	70.32	480.7	480.7
Feb.	34,284	0.01	37	1,000	27	114.35	64.03	7	6.1	437.4	437.4
March	54,677	0.02	23	1,000	43	201.90	113.07	14	6.9	362.6	362.6
April	57,179	0.01	22	1,000	45	204.33	114.43	7	3.4	279.7	279.7
May	65,155	0.02	19	1,000	52	240.60	134.73	14	5.8	187.8	187.8
Jun	78,134	0.04	16	1,000	62	279.22	156.36	**28**	10.0	92.9	92.9
July	67,135	0.79	19	1,000	53	247.91	138.83	**553**	223.1	536.9	536.9
Aug.	53,905	0.705	23	1,000	43	192.63	107.87	493.5	256.2	945.6	553.0
Sept.	53,287	0.33	24	1,000	42	196.77	110.19	231	117.4	697.4	553.0
October	54,059	0.04	23	1,000	43	199.62	111.79	28	14.0	493.2	493.2
November	53,516	0.04	24	1,000	42	191.24	107.09	28	14.6	437.0	437.0
December	34,002	0.09	37	1,000	27	125.56	70.31	63	50.2	444.8	444.8

Continuation of Table 6.2

Year: 2006 **Total roof Area:** 1,259,254 m^2 **Roof Area:** 1000 m^2

Water Demand: 150 lpcd **Capacity (m^3):** 553 Min. No. of person per Household: 5

Month	Population	Monthly Rainfall (M)	Ratio (Area/Pop.)	Roof area (m^2)	Roof area Population	Water Demand m^3/month	Water from System (m^3/mo)	Harvested Water Quantity (m^3/mo.)	Harvested Water % of Demand	Change in storage (m^3)	Storage Volume (m^3)
A	B	C	D	E	F	G	H	I	J	K	L
January	33,035	0.12	38	1,000	26	121.99	68.31	84	68.86	475.1	475.1
Feb.	34,978	0.01	36	1,000	28	116.66	65.33	7	6.0	430.8	430.8
March	55,738	0.02	23	1,000	44	205.82	115.26	14	6.8	354.2	354.2
April	58,255	0.01	22	1,000	46	208.18	116.58	7	3.4	269.6	269.6
May	66,278	0.02	19	1,000	53	244.74	137.06	14	5.7	175.9	175.9
Jun	79,333	0.04	16	1,000	63	283.50	158.76	28	9.9	79.2	79.2
July	68,269	0.79	18	1,000	54	252.10	141.17	**553**	219.4	521.3	521.3
Aug.	54,961	0.705	23	1,000	44	196.40	109.99	493.5	251.3	928.3	553.0
Sept.	54,339	0.33	23	1,000	43	200.66	112.37	231	115.1	695.7	553.0
October	55,116	0.04	23	1,000	44	203.52	113.97	28	13.8	491.4	491.4
November	54,569	0.04	23	1,000	43	195.01	109.20	28	14.4	433.6	433.6
December	34,695	0.09	36	1,000	28	128.12	71.74	63	49.2	440.3	440.3

Year: 2007

Month	Population	Monthly Rainfall (M)	Ratio (Area/Pop.)	Roof area (m^2)	Roof area Population	Water Demand m^3/month	Water from System (m^3/mo)	Harvested Water Quantity (m^3/mo.)	Harvested Water % of Demand	Change in storage (m^3)	Storage Volume (m^3)
January	33,721	0.12	37	1,000	27	124.52	69.73	84	67.46	469.5	469.5
Feb.	35,673	0.01	35	1,000	28	118.98	66.63	7	5.9	424.1	424.1
March	56,799	0.02	22	1,000	45	209.74	117.45	14	6.7	345.8	345.8
April	59,330	0.01	21	1,000	47	212.02	118.73	7	3.3	259.6	259.6
May	67,400	0.02	19	1,000	54	248.89	139.38	14	5.6	164.1	164.1
Jun	80,532	0.04	16	1,000	64	287.79	161.16	28	9.7	65.4	65.4
July	69,403	0.79	18	1,000	55	256.28	143.52	**553**	215.8	505.7	505.7
Aug.	56,017	0.705	22	1,000	44	200.18	112.10	493.5	246.5	911.1	553.0
Sept.	55,392	0.33	23	1,000	44	204.54	114.54	231	112.9	694.0	553.0
October	56,173	0.04	22	1,000	45	207.43	116.16	28	13.5	489.7	489.7
November	55,623	0.04	23	1,000	44	198.77	111.31	28	14.1	430.3	430.3
December	35,388	0.09	36	1,000	28	130.68	73.18	63	48.2	435.8	435.8

Continuation of Table 6.2

Year: 2008 **Total roof Area:** 1,259,254 m^2 **Roof Area:** 1000 m^2

Water Demand: 150 lpcd **capacity:** 553 Min. No. of person per Household: 5

Month	Population	Monthly Rainfall (M)	Ratio (Area/Pop.)	Roof area (m^2)	Roof area Population	Water Demand m^3/month	Water from System (m^3/mo)	Harvested Water Quantity (m^3/mo.)	Harvested Water % of Demand	Change in storage (m^3)	Storage Volume (m^3)
A	B	C	D	E	F	G	H	I	J	K	L
January	34,495	0.12	37	1,000	27	127.38	71.33	84	65.95	463.7	463.7
Feb.	36,455	0.01	35	1,000	29	121.59	68.09	7	5.8	417.2	417.2
March	57,994	0.02	22	1,000	46	214.15	119.92	14	6.5	337.0	337.0
April	60,540	0.01	21	1,000	48	216.34	121.15	7	3.2	248.8	248.8
May	68,659	0.02	18	1,000	55	253.53	141.98	14	5.5	151.3	151.3
Jun	81,870	0.04	15	1,000	65	292.56	163.84	28	9.6	50.5	50.5
July	70,674	0.79	18	1,000	56	260.98	146.15	**553**	211.9	488.7	488.7
Aug.	57,207	0.705	22	1,000	45	204.43	114.48	493.5	241.4	892.2	553.0
Sept.	56,579	0.33	22	1,000	45	208.93	117.00	231	110.6	692.1	553.0
October	57,364	0.04	22	1,000	46	211.83	118.62	28	13.2	487.8	487.8
November	56,811	0.04	22	1,000	45	203.02	113.69	28	13.8	426.5	426.5
December	36,168	0.09	35	1,000	29	133.56	74.79	63	47.2	430.7	430.7

Year: 2009

January	35,268	0.12	36	1,000	28	130.23	72.93	84	64.50	457.4	457.4
Feb.	37,238	0.01	34	1,000	30	124.20	69.55	7	5.6	409.8	409.8
March	59,189	0.02	21	1,000	47	218.56	122.40	14	6.4	327.6	327.6
April	61,750	0.01	20	1,000	49	220.67	123.57	7	3.2	237.5	237.5
May	69,918	0.02	18	1,000	56	258.18	144.58	14	5.4	137.9	137.9
Jun	83,207	0.04	15	1,000	66	297.34	166.51	28	9.4	35.1	35.1
July	71,945	0.79	18	1,000	57	265.67	148.77	**553**	208.2	471.2	471.2
Aug.	58,397	0.705	22	1,000	46	208.69	116.86	493.5	236.5	872.8	553.0
Sept.	57,765	0.33	22	1,000	46	213.31	119.45	231	108.3	690.1	553.0
October	58,555	0.04	22	1,000	47	216.23	121.09	28	12.9	485.9	485.9
November	57,999	0.04	22	1,000	46	207.26	116.07	28	13.5	422.7	422.7
December	36,949	0.09	34	1,000	29	136.44	76.41	63	46.2	425.6	425.6

Continuation of Table 6.2

Year: 2010 **Total roof Area: 1,259,254 m^2** **Roof Area: 1000 m^2**

Water Demand: 150 lpcd **Capacity (m^3): 553** Min. No. of person per Household: **5**

Month	Population	Monthly Rainfall (M)	Ratio (Area/Pop.)	Roof area (m^2)	Roof area Population	Water Demand m^3/month	Water from System (m^3/mo)	Harvested Water Quantity (m^3/mo.)	Harvested Water % of Demand	Change in storage (m^3)	Storage Volume (m^3)
A	B	C	D	E	F	G	H	I	J	K	L
January	36,042	0.12	35	1,000	29	133.09	74.53	84	63.12	451.1	451.1
Feb.	38,020	0.01	33	1,000	30	126.81	71.01	7	5.5	402.3	402.3
March	60,384	0.02	21	1,000	48	222.98	124.87	14	6.3	318.2	318.2
April	62,961	0.01	20	1,000	50	224.99	126.00	7	3.1	226.2	226.2
May	71,176	0.02	18	1,000	57	262.83	147.18	14	5.3	124.5	124.5
Jun	84,544	0.04	15	1,000	67	302.12	169.19	28	9.3	19.6	19.6
July	73,215	0.79	17	1,000	58	270.36	151.40	**553**	204.5	453.6	453.6
Aug.	59,588	0.705	21	1,000	47	212.94	119.25	493.5	231.8	853.4	553.0
Sept.	58,952	0.33	21	1,000	47	217.69	121.91	231	106.1	688.2	553.0
October	59,747	0.04	21	1,000	47	220.62	123.55	28	12.7	483.9	483.9
November	59,187	0.04	21	1,000	47	211.51	118.44	28	13.2	418.9	418.9
December	37,729	0.09	33	1,000	30	139.32	78.02	63	45.2	420.6	420.6

Year: 2011

January	36,815	0.12	34	1,000	29	135.95	76.13	84	61.79	444.7	444.7
Feb.	38,802	0.01	32	1,000	31	129.42	72.47	7	5.4	394.8	394.8
March	61,579	0.02	20	1,000	49	227.39	127.34	14	6.2	308.7	308.7
April	64,171	0.01	20	1,000	51	229.32	128.42	7	3.1	214.8	214.8
May	72,435	0.02	17	1,000	58	267.48	149.79	14	5.2	111.2	111.2
Jun	85,882	0.04	15	1,000	68	306.90	171.87	28	9.1	4.1	4.1
July	74,486	0.79	17	1,000	59	275.05	154.03	**553**	201.1	436.1	436.1
Aug.	60,778	0.705	21	1,000	48	217.19	121.63	493.5	227.2	834.0	553.0
Sept.	60,138	0.33	21	1,000	48	222.07	124.36	231	104.0	686.3	553.0
October	60,938	0.04	21	1,000	48	225.02	126.01	28	12.4	482.0	482.0
November	60,375	0.04	21	1,000	48	215.75	120.82	28	13.0	415.1	415.1
December	38,510	0.09	33	1,000	31	142.20	79.63	63	44.3	415.5	415.5

6.4 **Sustainable Roof Area and Tank Capacity**

Sustainable roof area and tank capacity refers to the minimum roof area and minimum tank capacity required to meet the water requirement. Different roof area class is analyzed along with minimum tank capacity to determine the sustainability after 10 years. Results of simulation are summarized in Tables 6.3, 6.4, 6.5 and 6.6.. Graphical presentation is shown in Figs. 6.1, 6.2, 6.3 and 6. representing the roof area – tank capacity curve.

Table 6.3: Tank Capacity for Roof Area < 100 m^2

Roof Area (m^2)	Tank Capacity (m^3)	Sustainability	Duration
30	17	3 months	July-Sept
40	23	5 months	July-Nov
50	28	6 months	July- Dec
60	34	7 months	Jan, July-Dec
70	39	8 months	Jan-Feb, July-Dec
80	45	9 months	Jan-Mar, July-Dec
90	50	10 months	Jan-Apr, July-Dec
100	56	10 months	Jan-Apr, July-Dec

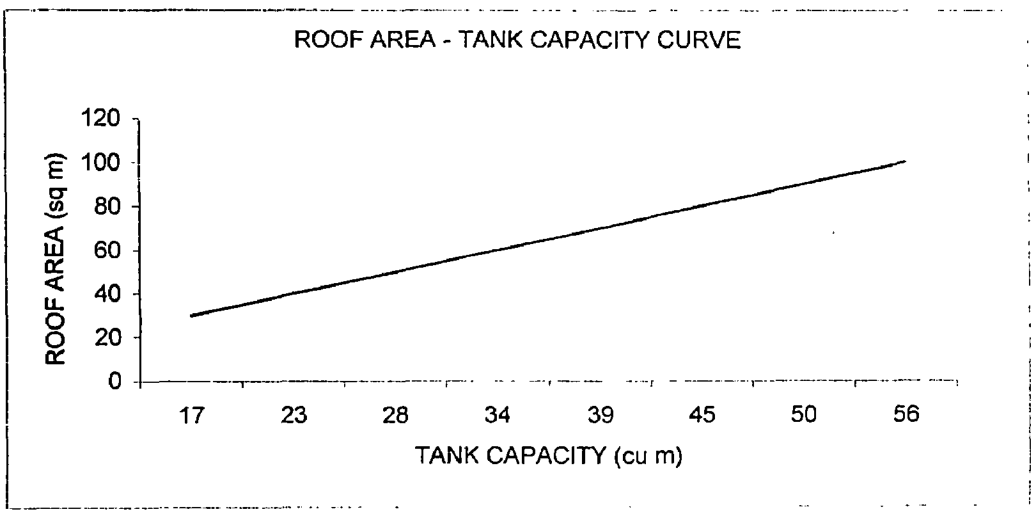


Fig.6.1: Roof Area – Tank Capacity Curve for Roof Area < 100 m^2

Table 6.4: Tank Capacity for Roof Area between 100 to 500 m^2

Roof Area (m^2)	Tank Capacity (m^3)	Sustainability	Duration
100	56	10 months	Jan-Apr, July-Dec
150	86	12 months	Jan-Dec
200	110	12 months	Jan-Dec
250	138	12 months	Jan-Dec
300	165	12 months	Jan-Dec
350	193	12 months	Jan-Dec
400	220	12 months	Jan-Dec
450	247	12 months	Jan-Dec
500	275	12 months	Jan-Dec

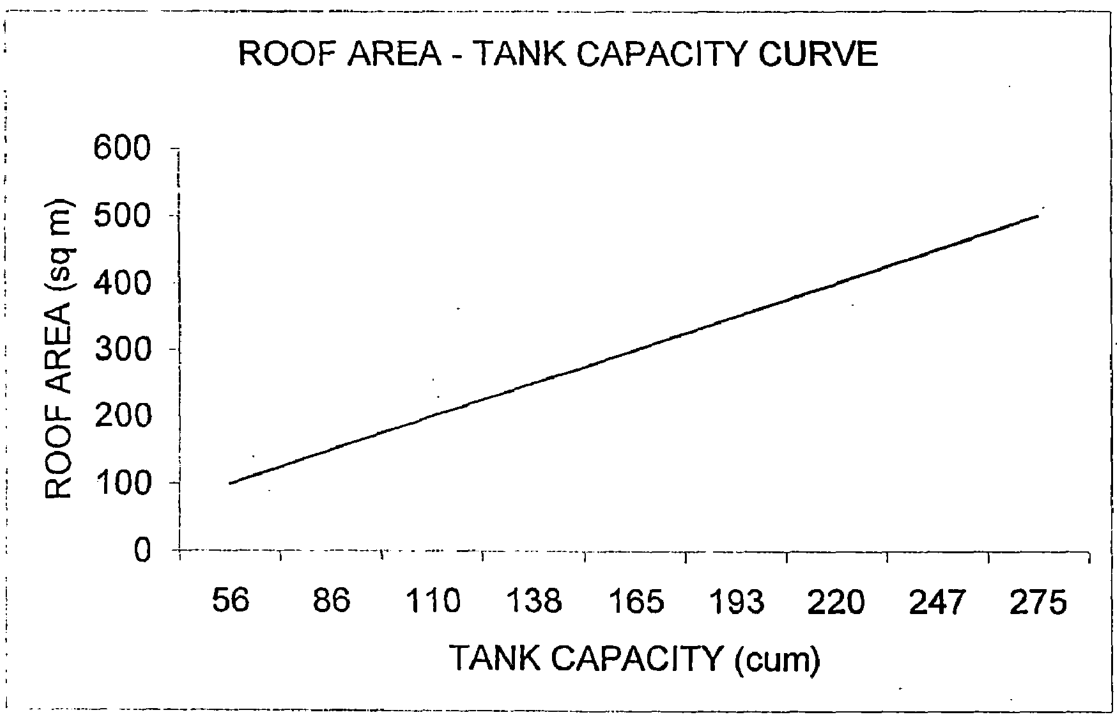


Fig.6.2: Roof Area – Tank Capacity Curve for Roof Area between 100 to 500 m^2

Table 6.5: Tank Capacity for Roof Area between 500 to 1000 m^2

Roof Area (m^2)	Tank Capacity (m^3)	Sustainability	Duration
500	275	12 months	Jan-Dec
550	302	12 months	Jan-Dec
600	330	12 months	Jan-Dec
650	357	12 months	Jan-Dec
700	385	12 months	Jan-Dec
750	412	12 months	Jan-Dec
800	440	12 months	Jan-Dec
850	467	12 months	Jan-Dec
900	494	12 months	Jan-Dec
950	522	12 months	Jan-Dec
1000	549	12 months	Jan-Dec

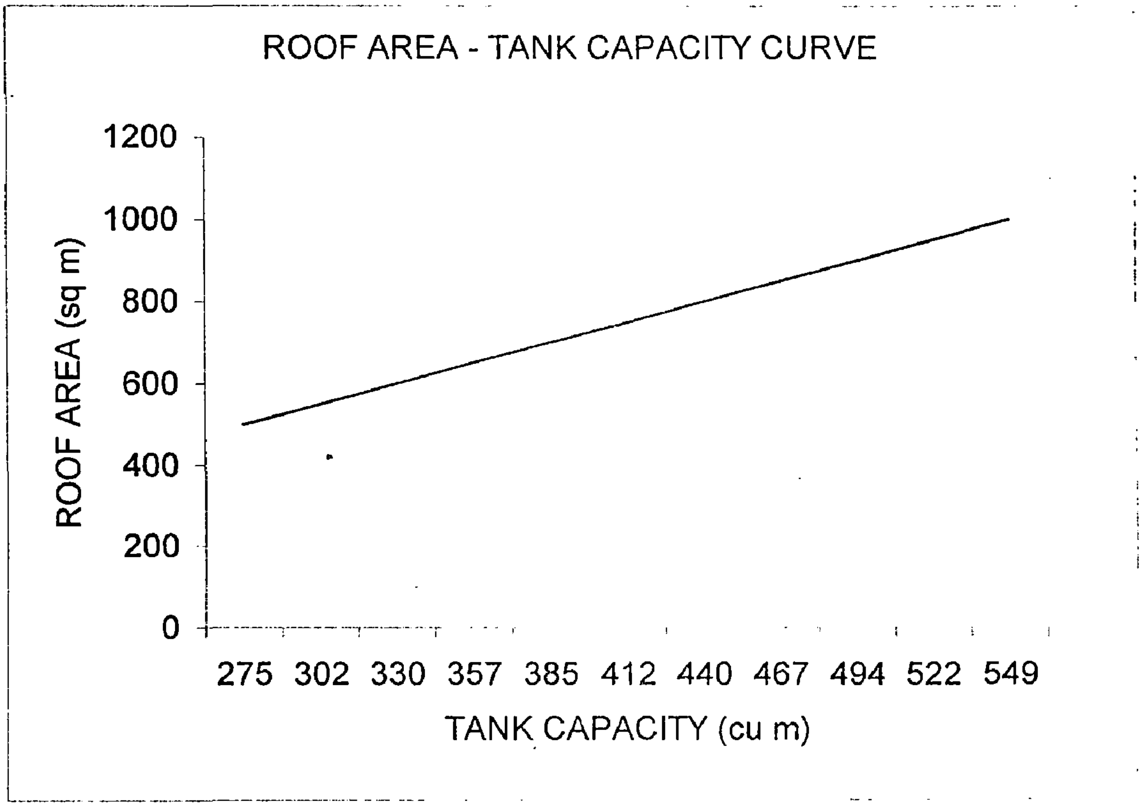


Fig.6.3: Roof Area – Tank Capacity Curve for Roof Area between 500 to 1000 m^2

Table 6.6: Tank Capacity for Roof Area between 1000 to 6000 m^2

Roof Area (sqm)	Tank Capacity (cum)	Sustainability	Duration
1000	549	12 months	Jan-Dec
1500	824	12 months	Jan-Dec
2000	1098	12 months	Jan-Dec
2500	1373	12 months	Jan-Dec
3000	1647	12 months	Jan-Dec
3500	1922	12 months	Jan-Dec
4000	2196	12 months	Jan-Dec
4500	2470	12 months	Jan-Dec
5000	2745	12 months	Jan-Dec
5500	3019	12 months	Jan-Dec
6000	3294	12 months	Jan-Dec

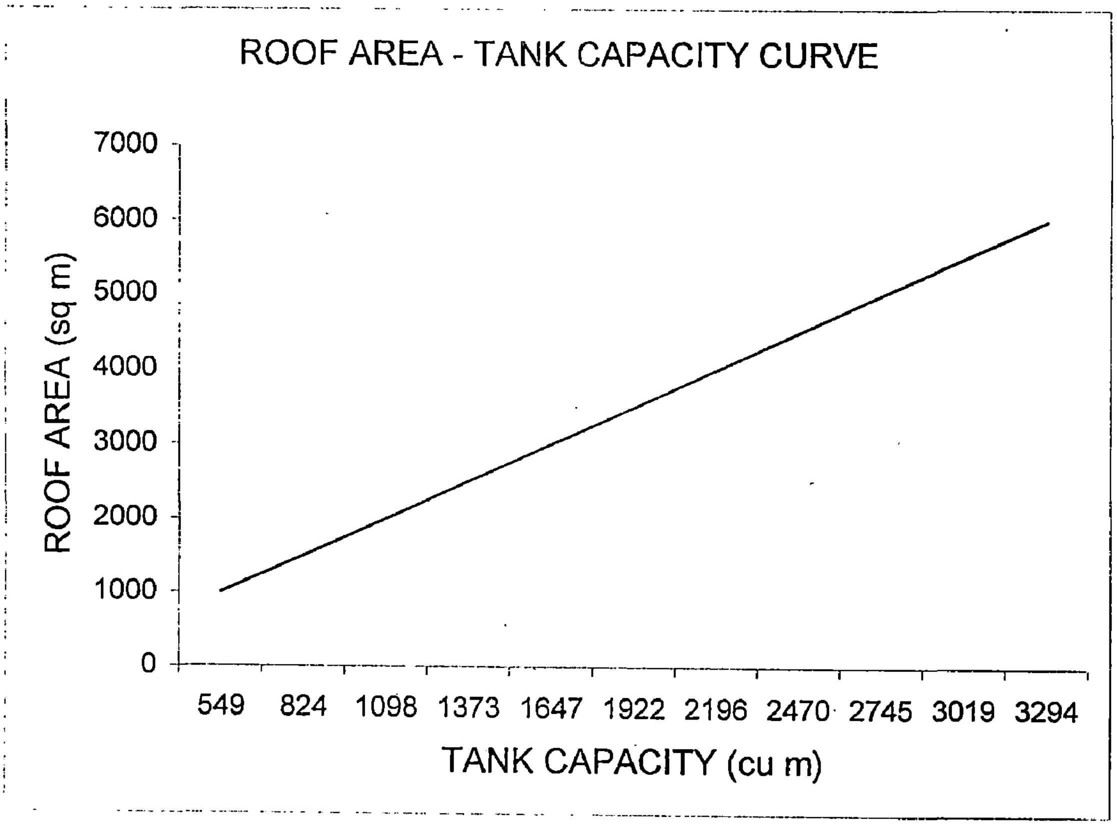


Fig.6.4:Roof Area–Tank Capacity Curve for Roof Area between 1000 to 6000 m^2

It was found out that for roof area less than 100 m^2 is not sustainable in other months, and for area more than 100 m^2 is sustainable up to 2011. In order to determine the sustainability of roof area less than 100 m^2, simulation was repeated considering an increase in tank capacity and roof area. It is assumed that the number of person per household is fixed at 5. Increase in roof area refers to additional roofings, such as covered car park, covered walk or any structure to be constructed aside from the building intended only for harvesting rains. Table 6.7 represents the result of simulation.

Table 6.7. Re-evaluated Tank Capacity for Roof Area<100 m^2

Roof Area (m^2)	Tank Capacity (m^3)
550	17
466	20
348	25
278	30
207	35
164	40
165	45
147	50
128.5	55
110.2	60
92	65

It can be observed that the value of roof area is decreasing while the tank capacity is increasing. To determine the most economical matching of roof area and tank capacity, cost is calculated based on the assumed unit price per cubic meter of tank capacity and square meter of roof area. It is assumed that RCC tank is Rs 5000 per m^3 and GI sheet is Rs 500 per m^2. It was found out that 207 m^2 of roof area and 35 m^3 of tank capacity is the most economical combination to make it sustainable for roof area less than 100 m^2 (Table 6.8).

Table 6.8: Combined Cost of Roof Area and Tank Capacity

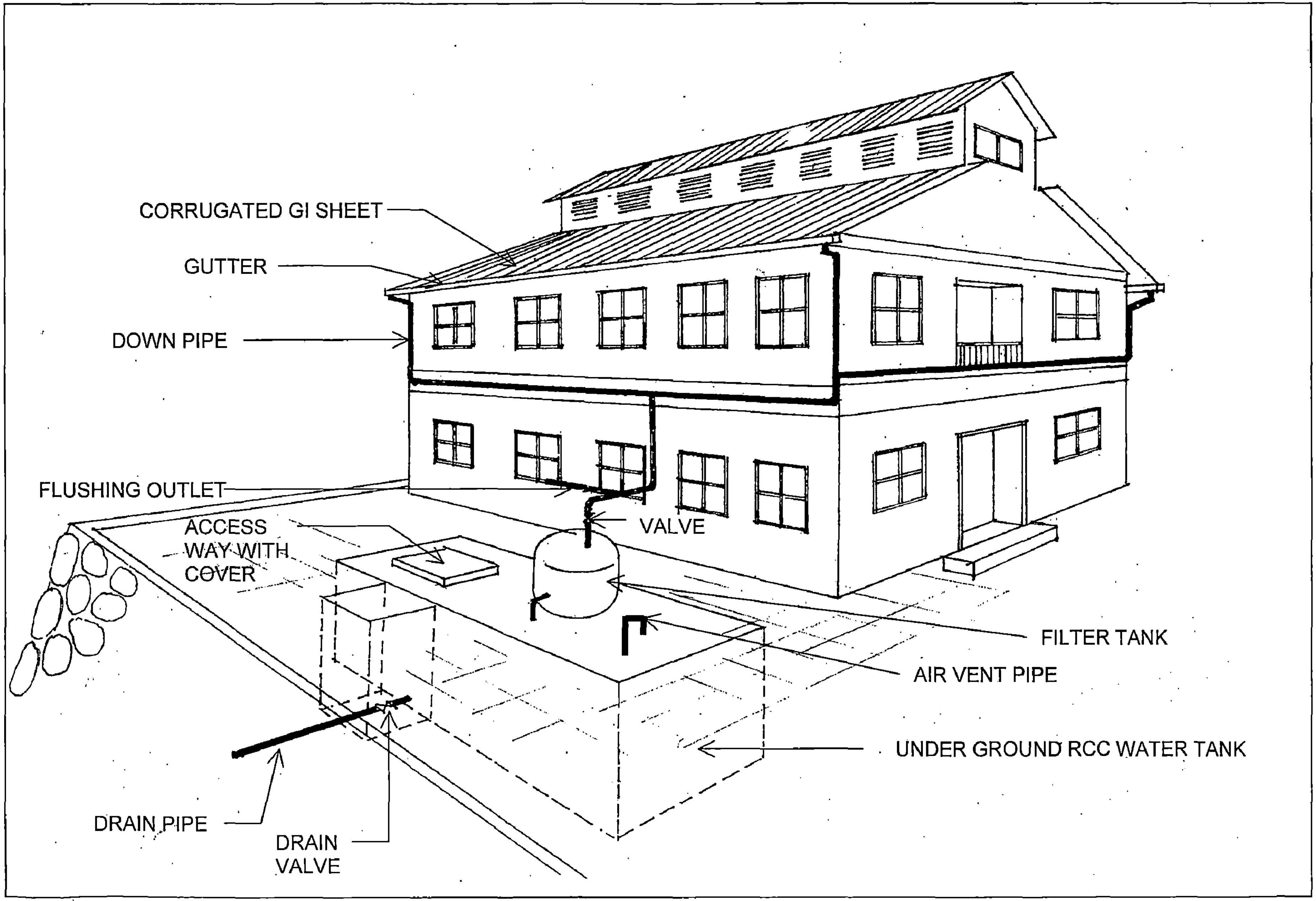
Roof Area (m^2)	Tank Capacity (m^3)	Cost of Roof (Rs)	Cost of Tank (Rs)	Combined Cost (Rs)
550	17	275,000.00	85,000.00	360,000.00
466	20	233,000.00	100,000.00	333,000.00
348	25	174,000.00	125,000.00	299,000.00
278	30	139,000.00	150,000.00	289,000.00
207	**35**	103,500.00	175,000.00	***278,500.00**
164	40	82,000.00	200,000.00	282,000.00
165	45	82,500.00	225,000.00	307,500.00
147	50	73,500.00	250,000.00	323,500.00
129	55	64,250.00	275,000.00	339,250.00
110	60	55,100.00	300,000.00	355,100.00
92	65	46,000.00	325,000.00	371,000.00

*** Minimum Cost**

6.5 Layout Plan of Rooftop Rainwater Harvesting Structure

Typical layout of rooftop rainwater harvesting structure is presented in Fig. 6.5. Most of the buildings in Mussoorie have a sloping roof made of GI sheets. (Figs. 6.6, 6.7, 6.8 and 6.9). Rainwater collected from roof is conveyed through down pipes. At the end of the down pipe, a 1000 liters pvc tank filled with sand and gravel served as filter media is provided. The collected water will pass through the filter before flowing into the tank. Before the filter, a flushing outlet is provided to flush out contaminated water during initial rains. Location of water tank is verified on site considering the availability of open space and ground slope near the building premises.

Fig.6.5: Typical Layout of Rooftop Rainwater Harvesting System



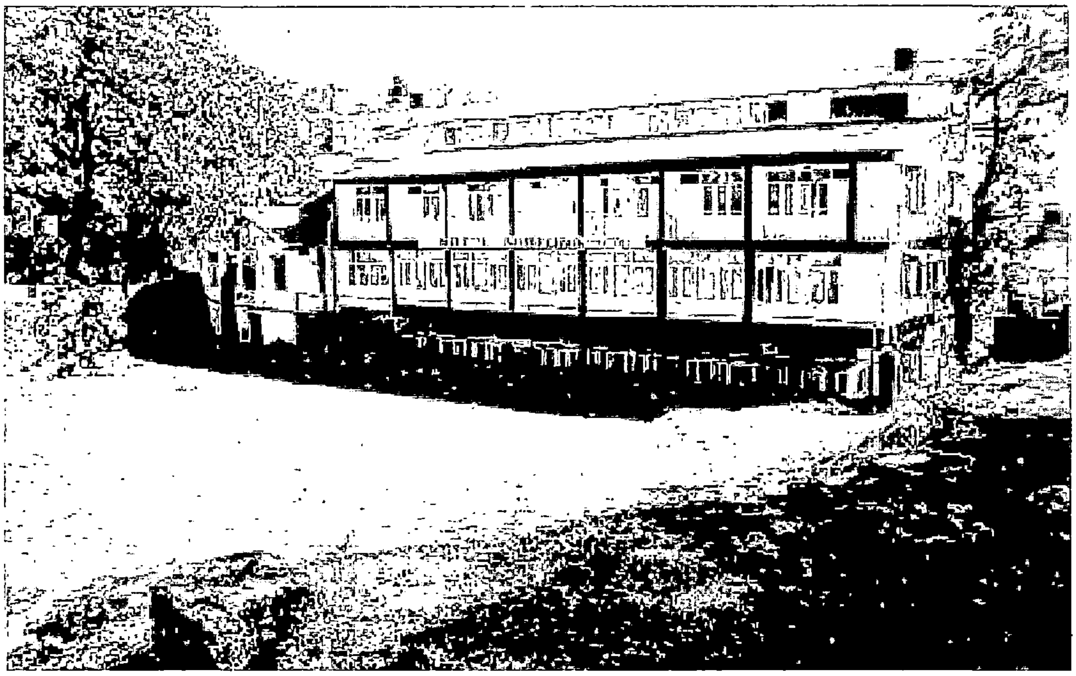


FIG. 6.6 : ELEVATIO N VIEW OF MIDTOWN HOTEL

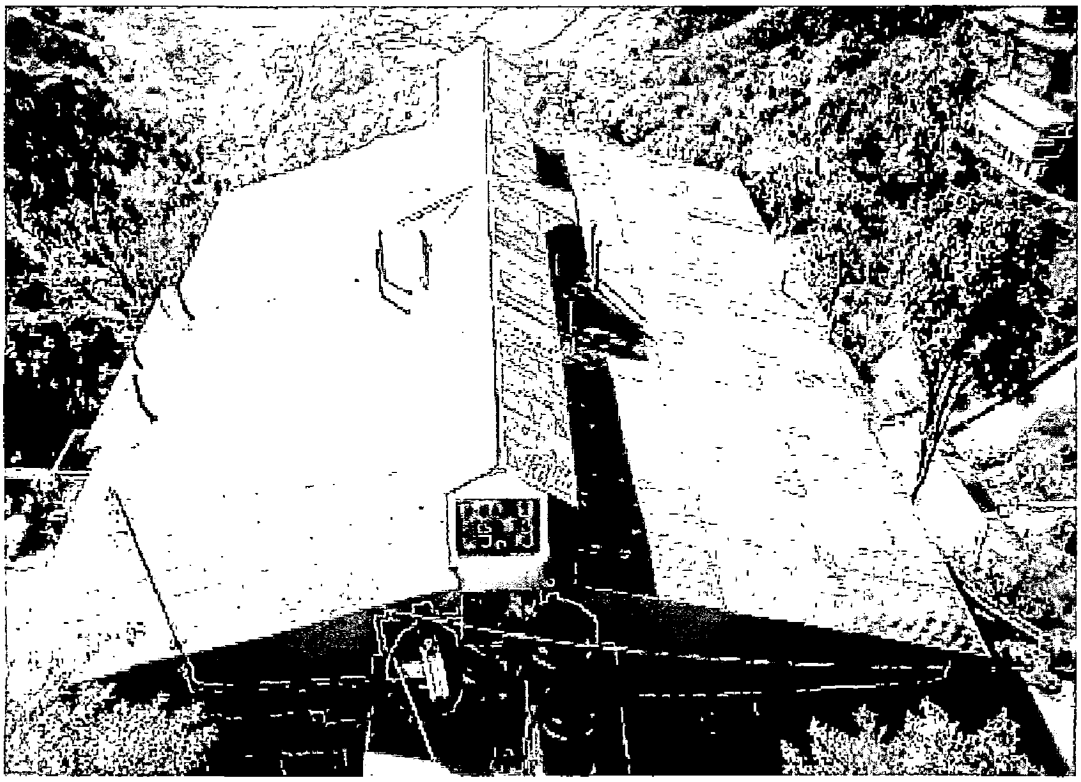


FIG. 6.7 : AERIAL VIEW OF STELLA COTTAGE

FIG. 6.8 : ELEVATION VIEW OF SYLVERTON HOTEL

FIG. 6.9 : ELEVATION VIEW OF YWCA BUILDING

FIG. 6.6 : ELEVATION VIEW OF MIDTOWN HOTEL

FIG. 6.7 : AERIAL VIEW OF STELLA COTTAGE

FIG. 6.8 : ELEVATION VIEW OF SYLVERTON HOTEL

FIG. 6.9 : ELEVATION VIEW OF YWCA BUILDING

DISCUSSION AND CONCLUSIONS

7.1 Shortage of Water

Shortage of water occurs when the water demand is more than the available water supply. Owing to its large population and inadequate water sources; Gun Hill Zone has been identified as the highly shortage zone, while Library Zone, Vincent Hill Zone and Mount Rose Zone as medium shortage zones and Lal Tibba as low shortage zone (Table 5.8).

7.2 Rooftop Rainwater Harvesting Potential

The concept of rooftop rainwater harvesting indicates a promising solution to water crisis problem of Mussoorie. The study shows that it can generate a total of 5.35 mld of rainwater which is 48% of the total water demand (Table 5.9). Mount Rose Zone exhibited the highest quantity of water that can be collected from roofs, which is 15% of the total demand. Likewise, Library Zone has the lowest percentage in the order of 5%. Quantity of rainwater harvested from roof depends mainly on the size of available roofs. Mount Rose Zone is identified for having the highest total roof area which is 32.4%. On the other hand, Library Zone has only 11.4% (Table 11 Appendix B).

7.3 Effect of Rooftop Rainwater Harvesting Concept

Availability of water collected from roofs is evaluated to determine its impact on the water shortages. It has been found that there is a significant change in the water shortage, reclassified as "shortage" and "surplus". It can be observed that the total effect of rooftop rainwater harvesting can generate a surplus water of 4% which is equivalent to 0.46 mld (Table 5.10). Mount Rose Zone and Lal Tibba Zone are reclassified as surplus category, while Library Zone, Vincent Hill Zone and Gun Hill Zone are in shortage category.

7.4 Design Capacity of Water Tank

Each building should be installed with individual water tank. Minimum tank capacity required to store the collected water from roof is designed to satisfy the water requirement for the particular building. Roof area as a function of water quantity that can be collected from roof is evaluated to come up a relationship between roof area and tank capacity. Simulation study reveals that roof area more than 100 m^2 with a minimum tank capacity is sustainable until 2011 (Tables 6.4, 6.5, and 6.6)

Roof area of less than 100 m^2 with a minimum tank capacity shows that it satisfies the requirements only for a few months. Further analysis is done to determine its sustainability with respect to roof area. It was found that the roof area should be increased as well as the tank capacity to meet the water requirement for a fixed number of persons per household which is being kept at 5. Increase the roof area can be done in different ways, such as construction of covered car park, covered walk or any roof structure aside from the building intended primarily for water harvesting. It can be observed that the value of roof area is kept on decreasing while the value of tank capacity increases (Table 6.7). To determine the most economical matching of roof area with tank capacity, cost is evaluated based on the assumed unit prices in the order of Rs 5,000 per m^3 of tank capacity and Rs 500 per m^2 of roof area. The optimum roof area comes out to be 207 m^2 and tank capacity is 35 m^3 (Table 6.8), however, availability of space and its cost should be taken into consideration.

7.5 Conclusions

(i) Through GIS technology, water harvesting can be modelled and analysis can be done easily by overlaying different thematic maps. Updating and reclassification of data are also done conveniently and effectively. Information can be accessed readily for the planners for making decisions logically and scientifically to achieve desirable results. Basically, the results depend upon the reliability and accuracy of information and input data.

(ii). All zones are suffering from water shortages. Gun Hill is identified as the most affected by water shortage problem (Table 5.8). All the spring sources within the vicinity of Mussoorie are already tapped for water supply. It is worth to note that the combined capacity of all spring sources is 6.29 mld (Table 5.4) while the water demand is 11.18 mld (Table 5.3), so therefore, water shortage of 4.89 mld (Table 5.8) is realized. Through rooftop rainwater harvesting concept, water requirement can be augmented. Generally, if all the rains that fall on the rooftops are collected, 5.35 mld (Table 5.9) of water can be made available, which is more than enough to balance the gap between the water supply and water demand.

(iii) With the concept of rooftop rainwater harvesting, shortages in three zones are partly reduced in the order of 16%-2% in Gun Hill Zone, 8%-3% in Library Zone and 8%-1% in Vincent Hill Zone. Likewise, shortages in two zones are totally overcome with surplus water in the order of 8% in Mount Rose Zone and 3% in Lal Tibba Zone (Tables 5.8 and 5.10).

(iv) Water tank is designed for minimum capacity in relation with the roof area. For roof area more than 100 m^2, tank capacity obtained from simulation study is the minimum capacity to meet the water requirement. Roof area-tank capacity relationship indicates that the scheme is sustainable up to 2011, otherwise water shortages can be felt onwards. Tank capacity for a specified roof area (>100 m^2) can be selected through linear interpolation using the graph in Figs. 6.4, 6.5, and 6.6.

(v) For roof area less than 100 m^2, optimum area required is 207 m^2 and tank capacity is 35 m^3 to make it sustainable up to year 2011.

7.6 Recommendations

(i) The success of rooftop rainwater harvesting concept depends on people's awareness and participation. Everybody should know the importance of rainwater and how to harvest it. During rains, wherever it falls and before it flows as runoff into any water bodies, harvesting and storing the rainwater either on tanks or ponds can be done for domestic or irrigation purposes particularly during dry periods. Awareness on rooftop rainwater harvesting concept should be initiated by concerned agencies from Government and supported by individual person or private organizations. The Municipal Corporation and Town Planning Department of Mussoorie should act on this by making it mandatory to have water-harvesting structure in all existing buildings as well as those soon-to-rise ones.

(ii) If rooftop rainwater harvesting is to be implemented in Mussoorie, it should be done on priority basis. Gun Hill zone classified as highly shortage zone may be taken on top priority, followed by the medium shortage zones (Library Zone, Vincent Hill Zone and Mount Rose Zone) and lastly the low shortage zone (Lal Tibba zone).

(iii) For all buildings having roof area of less than 100 m^2, construction of additional roofs is necessary such as, covered car park, covered walk or any roof structure intended primarily for rainwater harvesting, to make the system sustainable.

(iv) As much as possible, water tank should be made of concrete and constructed below the ground if open space is limited, otherwise it can be in the basement. Stability analysis is required to ensure safety of the structure.

(v) Water quality from roofs depends upon the frequency of cleaning the roofs and gutters before monsoon comes. Disinfection of tank after construction is required before putting it into use.

Chlorination of water should be maintained if it is use for domestic purposes. Since water stored in tanks should be used during dry periods, water quality test should be conducted to ensure its potability before utilizing it for drinking, however, there is no such document regarding quality of water stored in tanks for almost a year or more.

7.7 Scope of Future Work

This work has been carried out with limited time and resources. Updating of information with GIS technology can be made effectively and efficiently. Updating of information requires recent survey of urbanization, classification of buildings, census data of 2002, rainfall pattern, geological data and groundwater survey, which is time consuming to collect. Future work may include:

(i) Evaluation of runoff to be made to assess the potential of rainwater harvesting in open areas, particularly for those zones having a shortage of water namely; Gun Hill Zone, Library Zone and Vincent Hill zone.

(ii) Identification of suitable sites for construction of rainwater harvesting structure in open areas.

(iii) Extend the study area to cover recharging of spring sources.

(iv) High resolution satellite image (e.g. IKONOS) may be used to get the updated information about each building and open space.

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Population Projection

I. Permanent Population

Table 1: Projected Resident Population of Mussoorie

1997	2002	2007	2012	2017
34,864	39,396	44,518	50,305	56,845

Population growth rate estimated by Jal Sansthan at 2.6% per year

Population of 1997 = 34,864

Survey of 1983 = 25,456

Growth rate for 14 years = 36.95 % per year

Annual growth rate = 2.6%

Population of2002: = 34,864 + 2.6% x 34,864 x 5 years

= 39,396

Winter Population for December and February of 1997:

Resident Population = 65% of Permanent population + Boarders in Tibetan School

= (65% x 34,684) + 1,761

= 24,423

Winter Population for January of 1997:

Resident Population = (65% x 34,684) + 1,268

= 23,930

In season Population of 1997:

Total Residents = 34,864

Boarders in Public School = 4,267

Boarders in Tibetan School= 1,761

Total = 40,892

Similarly, Population Projection of January 2002

= 65% x 39,396 + 1268

= 26,876

Monthwise projected permanent population for 1997 up to 2017 at 5 years interval is presented in Table 2.

Table 2: MONTH-WISE VARIATION IN PROJECTED PERMANENT POPULATION

Month	1997	2002	2007	2012	2017
JANUARY	23,930	26,876	30,205	33,966	38,217
FEBRUARY	24,423	27,369	30,698	34,459	38,710
MARCH	40,892	45,424	50,546	56,333	62,873
APRIL	40,892	45,424	50,546	56,333	62,873
MAY	40,892	45,424	50,546	56,333	62,873
JUNE	40,892	45,424	50,546	56,333	62,873
JULY	40,892	45,424	50,546	56,333	62,873
AUGUST	40,892	45,424	50,546	56,333	62,873
MAY	40,892	45,424	50,546	56,333	62,873
JUNE	40,892	45,424	50,546	56,333	62,873
JULY	40,892	45,424	50,546	56,333	62,873
AUGUST	40,892	45,424	50,546	56,333	62,873
SEPTEMBER	40,892	45,424	50,546	56,333	62,873
OCTOBER	40,892	45,424	50,546	56,333	62,873
NOVEMBER	40,892	45,424	50,546	56,333	62,873
DECEMBER	24,423	27,369	30,698	34,459	38,710

Table 3: Monthwise Yearly Projected Permanent Population

Month	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
JANUARY	27,541	28,207	28,873	29,539	30,205	30,957	31,709	32,462	33,214	33,966
FEBRUARY	28,034	28,700	29,366	30,032	30,698	31,450	32,202	32,955	33,707	34,459
MARCH	46,449	47,473	48,497	49,522	50,546	51,703	52,861	54,018	55,176	56,333
APRIL	46,449	47,473	48,497	49,522	50,546	51,703	52,861	54,018	55,176	56,333
MAY	46,449	47,473	48,497	49,522	50,546	51,703	52,861	54,018	55,176	56,333
JUNE	46,449	47,473	48,497	49,522	50,546	51,703	52,861	54,018	55,176	56,333
JULY	46,449	47,473	48,497	49,522	50,546	51,703	52,861	54,018	55,176	56,333
AUGUST	46,449	47,473	48,497	49,522	50,546	51,703	52,861	54,018	55,176	56,333
MAY	46,449	47,473	48,497	49,522	50,546	51,703	52,861	54,018	55,176	56,333
JUNE	46,449	47,473	48,497	49,522	50,546	51,703	52,861	54,018	55,176	56,333
JULY	46,449	47,473	48,497	49,522	50,546	51,703	52,861	54,018	55,176	56,333
AUGUST	46,449	47,473	48,497	49,522	50,546	51,703	52,861	54,018	55,176	56,333
SEPTEMBER	46,449	47,473	48,497	49,522	50,546	51,703	52,861	54,018	55,176	56,333
OCTOBER	46,449	47,473	48,497	49,522	50,546	51,703	52,861	54,018	55,176	56,333
NOVEMBER	46,449	47,473	48,497	49,522	50,546	51,703	52,861	54,018	55,176	56,333
DECEMBER	28,034	28,700	29,366	30,032	30,698	31,450	32,202	32,955	33,707	34,459

II. Tourist Population

Tourist population of 1997 = 51,390

Population Growth rate = 0.6% per year

Population of 2002 = 51,390 + (51,390 x 0.6%) x 5 years

= 52,932

Table 4: Monthwise Projected Tourist Population at 5 years interval

Month	1997	2002	2007	2012	2017
JANUARY	51,390	52,932	54,520	56,155	57,840
FEBRUARY	65,666	67,636	69,665	71,755	73,908
MARCH	91,361	94,102	96,925	99,833	102,828
APRIL	124,194	127,920	131,757	135,710	139,781
MAY	164,164	169,089	174,162	179,386	184,768
JUNE	282,648	291,127	299,861	308,857	318,123
JULY	275,570	283,837	292,352	301,123	310,156
AUGUST	79,941	82,339	84,809	87,354	89,974
SEPTEMBER	68,521	70,577	72,694	74,875	77,121
OCTOBER	82,223	84,690	87,230	89,847	92,543
NOVEMBER	71,803	73,957	76,176	78,461	80,815
DECEMBER	68,521	70,577	72,694	74,875	77,121

Table 5: Monthwise Yearly Projected Tourist Population

Month	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
JANUARY	53,249	53,567	53,884	54,202	54,520	54,847	55,174	55,501	55,828	56,155
FEBRUARY	68,042	68,448	68,853	69,259	69,665	70,083	70,501	70,919	71,337	71,755
MARCH	94,666	95,231	95,796	96,360	96,925	97,506	98,088	98,670	99,251	99,833
APRIL	128,687	129,455	130,222	130,990	131,757	132,548	133,339	134,129	134,920	135,710
MAY	170,103	171,118	172,133	173,147	174,162	175,207	176,252	177,296	178,341	179,386
JUNE	292,874	294,621	296,368	298,114	299,861	301,660	303,460	305,259	307,058	308,857
JULY	285,540	287,243	288,946	290,649	292,352	294,106	295,860	297,615	299,369	301,123
AUGUST	82,833	83,327	83,821	84,315	84,809	85,318	85,827	86,336	86,845	87,354
SEPTEMBER	71,000	71,424	71,847	72,270	72,694	73,130	73,566	74,002	74,439	74,875
OCTOBER	85,198	85,706	86,214	86,722	87,230	87,754	88,277	88,801	89,324	89,847
NOVEMBER	74,401	74,845	75,288	75,732	76,176	76,633	77,090	77,547	78,004	78,461
DECEMBER	71,000	71,424	71,847	72,270	72,694	73,130	73,566	74,002	74,439	74,875

Projected Tourist Population Pressure per day:

Tourist day @ 3 for May and June and @ 2 in other Month

Tourist Day @ 3 for May = 3 x 164,164 = 492,492

Number of Tourist per day = 492,492 / 31 days = 15,887

Tourist Day @ 2 for January = 2 x 51,390 = 102,780

Number of Tourist per day = 102,780 / 31 days = 3,315

Table 6: Monthwise Variation in Tourist Population

Month	1997	2002	2007	2012	2017
JANUARY	3,315	3,414	3,517	3,622	3,731
FEBRUARY	4,690	4,831	4,976	5,125	5,279
MARCH	5,894	6,071	6,253	6,441	6,634
APRIL	8,280	8,528	8,784	9,048	9,319
MAY	15,887	16,364	16,855	17,360	17,881
JUNE	28,265	29,113	29,986	30,886	31,813
JULY	17,775	18,308	18,857	19,423	20,006
AUGUST	5,157	5,312	5,471	5,635	5,804
SEPTEMBER	4,568	4,705	4,846	4,992	5,141
OCTOBER	5,304	5,463	5,627	5,796	5,970
NOVEMBER	4,786	4,930	5,077	5,230	5,387
DECEMBER	4,421	4,554	4,690	4,831	4,976

Table 7 : Monthwise Yearly Projected Tourist Population

Month	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
JANUARY	3,435	3,455	3,476	3,496	3,517	3,538	3,559	3,580	3,601	3,622
FEBRUARY	4,860	4,889	4,918	4,947	4,976	5,005	5,035	5,065	5,095	5,125
MARCH	6,107	6,144	6,180	6,217	6,253	6,290	6,328	6,365	6,403	6,441
APRIL	8,580	8,631	8,682	8,733	8,784	8,837	8,890	8,942	8,995	9,048
MAY	16,462	16,560	16,658	16,756	16,855	16,956	17,057	17,158	17,259	17,360
JUNE	29,288	29,462	29,637	29,812	29,986	30,166	30,346	30,526	30,706	30,886
JULY	18,418	18,528	18,638	18,748	18,857	18,971	19,084	19,197	19,310	19,423
AUGUST	5,344	5,375	5,407	5,439	5,471	5,504	5,537	5,570	5,602	5,635
SEPTEMBER	4,733	4,762	4,790	4,818	4,846	4,875	4,904	4,933	4,962	4,992
OCTOBER	5,496	5,529	5,561	5,594	5,627	5,661	5,695	5,728	5,762	5,796
NOVEMBER	4,959	4,989	5,018	5,048	5,077	5,108	5,138	5,169	5,199	5,230
DECEMBER	4,581	4,608	4,636	4,663	4,690	4,718	4,747	4,775	4,803	4,831

III. Total Population

Total Population = Permanent Population + Tourist Population

Tbale 8: Monthwise Yearly Projected total Population

Month	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
JANUARY	30,976	31,663	32,349	33,035	33,721	34,495	35,268	36,042	36,815	37,589
FEBRUARY	32,894	33,589	34,284	34,978	35,673	36,455	37,238	38,020	38,802	39,584
MARCH	52,556	53,617	54,677	55,738	56,799	57,994	59,189	60,384	61,579	62,774
APRIL	55,028	56,104	57,179	58,255	59,330	60,540	61,750	62,961	64,171	65,381
MAY	62,910	64,033	65,155	66,278	67,400	68,659	69,918	71,176	72,435	73,693
JUNE	75,736	76,935	78,134	79,333	80,532	81,870	83,207	84,544	85,882	87,219
JULY	64,867	66,001	67,135	68,269	69,403	70,674	71,945	73,215	74,486	75,756
AUGUST	51,792	52,848	53,905	54,961	56,017	57,207	58,397	59,588	60,778	61,968
SEPTEMBER	51,182	52,234	53,287	54,339	55,392	56,579	57,765	58,952	60,138	61,325
OCTOBER	51,945	53,002	54,059	55,116	56,173	57,364	58,555	59,747	60,938	62,129
NOVEMBER	51,408	52,462	53,516	54,569	55,623	56,811	57,999	59,187	60,375	61,563
DECEMBER	32,615	33,308	34,002	34,695	35,388	36,168	36,949	37,729	38,510	39,290

I. Zonewise Roof Area as of 1967

Table 9 : Zonewise Roof Area as of 1967

1. Library Zone

Criteria	Number of Bldgs.	%	Roof Area (sq.m.) Total	Min.	Max.	Mean
<100 sqm	68	25.19	5,671	31.88	99.84	83.39
100-500 sqm	183	67.78	33,692	100.76	497.82	184.11
500-1000 sqm	15	5.56	10,709	521.37	921.44	713.96
1000-2000 sqm	3	1.11	3,765	1,148.33	1,333.34	1,255.14
2000-3000 sqm						
3000-4000 sqm	1	0.37	3,568	3,567.73	3,567.73	3,567.73
Total	270	100	57,405			212.61

2.Vincent Zone

Criteria	Number of Bldgs.	%	Total	Min.	Max.	Mean
<100 sqm	150	45.87	11,496.89	28.14	99.88	76.65
100-500 sqm	159	48.62	31,895.37	101.08	493.88	200.60
500-1000 sqm	12	3.67	7,963.82	503.71	924.22	663.65
1000-2000 sqm	4	1.22	5,745.97	1,254.72	1,623.65	1,436.49
2000-3000 sqm						
3000-4000sqm	1	0.31	3460.78	3460.78	3460.78	3,460.78
4000-5000 sqm						
>5000 sq.m	1	0.31	6011.88	6011.88	6011.88	6,011.88
Total	327	100.0	66,574.71			203.59

3. Mount Rose

Criteria	Number of Bldgs.	%	Total	Min.	Max.	Mean
<100 sqm	249	33.29	19,603.71	35.77	99.94	78.73
100-500 sqm	452	60.43	90,731.80	100.17	492.17	200.73
500-1000 sqm	31	4.14	20,105.84	502.10	898.43	648.58
1000-2000 sqm	10	1.34	14,507.32	1,066.48	1,992.91	1,450.73
2000-3000 sqm						
3000-4000sqm	4	0.53	9839.58	3460.78	3460.78	2,459.90
4000-5000 sqm	2	0.27	8,252.46	4,010.27	4,242.19	4,126.23
>5000 sq.m						
Total	748	100	163,040.71			217.97

4. Gun Hill Zone

Criteria	Number of Bldgs.	%	Total	Min.	Max.	Mean
<100 sqm	258	43.80	19,533.72	21.66	99.79	75.71
100-500 sqm	272	46.18	60,880.69	100.39	499.57	223.83
500-1000 sqm	40	6.79	28,245.19	505.86	997.80	706.13
1000-2000 sqm	18	3.06	24,064.47	1,003.40	1,786.20	1,336.92
2000-3000 sqm	1	0.13	2337.61	2337.61	2337.61	2,337.61
Total	589	100	135,061.68			229.31

5. Lal Tibba Zone

Criteria	Number of Bldgs.	%	Total	Min.	Max.	Mean
<100 sqm	270	56.37	18,671.00	34.90	99.78	69.15
100-500 sqm	187	39.04	41,357.79	100.35	491.71	221.16
500-1000 sqm	15	3.13	9,879.53	512.08	889.47	658.64
1000-2000 sqm	5	1.04	6,531.42	1,023.33	1,973.48	1,306.28
2000-3000 sqm	2	0.42	5179.44	2228.64	2950.8	2,589.72
Total	479	100	81,619.18			170.39
Grand Total	2413		503,701.50			

II. Projected Roof Area for 2002

Projected roof area for 2002 @ 150% increase

Table 10: Zonewise Roof Area for 2002

1. Library Zone

Criteria	Number of Bldgs.	%	Roof Area (sq.m.) Total	Min.	Max.	Mean
<100 sqm	170	25.2	14,177	31.88	99.84	83.39
100-500 sqm	457.5	67.8	84,229	100.76	497.82	184.11
500-1000 sqm	37.5	5.6	26,774	521.37	921.44	713.96
1000-2000 sqm	7.5	1.1	9,414	1,148.33	1,333.34	1,255.14
2000-3000 sqm						
3000-4000sqm	2.5	0.4	8,919	3,567.73	3,567.73	3,567.73
Total	675	100	143,513			212.61
	2488					

2. Vincent Zone

Criteria	Number of Bldgs.	%	Total	Min.	Max.	Mean
<100 sqm	375	45.87	28,742	28.14	99.88	76.65
100-500 sqm	398	48.62	79,738	101.08	493.88	200.60
500-1000 sqm	30	3.67	19,910	503.71	924.22	663.65
1000-2000 sqm	10	1.22	14,365	1,254.72	1,623.65	1,436.49
2000-3000 sqm						
3000-4000sqm	3	0.31	8,652	3460.78	3460.78	3,460.78
4000-5000 sqm						
>5000 sq.m	3	0.31	15,030	6011.88	6011.88	6,011.88
Total	818	100	166,437			203.59

3. Mount Rose

Criteria	Number of Bldgs.	%	Total	Min.	Max.	Mean
<100 sqm	623	33.29	49,009	35.77	99.94	78.73
100-500 sqm	1130	60.43	226,830	100.17	492.17	200.73
500-1000 sqm	78	4.14	50,265	502.10	898.43	648.58
1000-2000 sqm	25	1.34	36,268	1,066.48	1,992.91	1,450.73
2000-3000 sqm						
3000-4000sqm	10	0.53	24,599	3460.78	3460.78	2,459.90
4000-5000 sqm	5	0.27	20,631	4,010.27	4,242.19	4,126.23
>5000 sq.m						
Total	1870	100	407,602			217.97

4. Gun Hill Zone

Criteria	Number of Bldgs.	%	Total	Min.	Max.	Mean
<100 sqm	645	43.80	48,834	21.66	99.79	75.71
100-500 sqm	680	46.18	152,202	100.39	499.57	223.83
500-1000 sqm	100	6.79	70,613	505.86	997.80	706.13
1000-2000 sqm	45	3.06	60,161	1,003.40	1,786.20	1,336.92
2000-3000 sqm	3	0.17	5,844	2337.61	2337.61	2,337.61
Total	1,473	100	337,654			229.31

5. Lal Tibba Zone

Criteria	Number of Bldgs.	%	Total	Min.	Max.	Mean
<100 sqm	675	56.37	46,678	34.90	99.78	69.15
100-500 sqm	468	39.04	103,394	100.35	491.71	221.16
500-1000 sqm	38	3.13	24,699	512.08	889.47	658.64
1000-2000 sqm	13	1.04	16,329	1,023.33	1,973.48	1,306.28
2000-3000 sqm	5	0.42	12,949	2228.64	2950.8	2,589.72
Total	1198	100	204,048	204,048		170.39
Grand Total	6,033		1,259,254			

Table 11: Summary of Projected roof Area for 2002

ZONES	Roof Area (m²)					Mean
	No. of Bldgs.	Total Area	%	Min.	Max.	
Library Zone	675	143,513	11.4	31.88	3567.73	212.61
Vincent Zone	818	166,437	13.2	28.14	6011.88	203.59
Mount Rose Zone	1,870	407,602	32.4	35.77	4242.19	217.97
Gun Hill Zone	1,473	337,654	26.8	27.66	2337.61	229.31
Lal Tibba Zone	1,198	204,048	16.2	34.9	2950.8	170.39
TOTAL	**6,033**	**1,259,254**	**100**			**208.74**