DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR INTEGRATED URBAN WATER MANAGEMENT

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SHAILZA VERMA

DEPARTMENT OF WATER RESOURCES DEVELOPMENT & MANAGEMENT
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE - 247 667 (INDIA)

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INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR INTEGRATED URBAN WATER MANAGEMENT** in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy and submitted in the Department of Water Resources Development & Management of the Indian Institute of Technology Roorkee, Roorkee, is an authentic record of my own work carried out during the period from July 2003 to August 2009 under the supervision of Dr. Deepak Khare, Professor, and Dr. S. K. Jain, NEEPCO Chair Professor, Department of Water Resources Development & Management, Indian Institute of Technology Roorkee, Roorkee.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other Institute.

Shailza Verma

(SHAILZA VERMA)

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

(S. K. JAIN)
Supervisor

(DEEPAK KHARE)
Supervisor

Date: August 17, 2009

The Ph.D. Viva-Voce Examination of **Ms. Shailza Verma,** Research Scholar, has been held on ______________

Signature of Supervisors

Signature of External Examiner

ABSTRACT

Urbanization refers to the migration of the people from rural areas to cities due to many reasons, most common being better quality of life and safety, diversity in socio-cultural life, better facilities of education and employment opportunities, medical services, etc. The process of urbanization comprise of individual development of site, replacement of trees and natural cover by buildings and impervious cover. Rapid and unplanned growth of urbanization has many adverse effects on existing water supply sources, hydrology and the micro-environment. High population density results in high water consumption and change in lifestyle of people's increases per capita water demand. Both the factors have created pressure on the existing water supply sources. Besides, deforestation, construction of buildings, roads, parks, and industrialization have significantly affected hydrology and microclimate of the environment. Imperviousness results in a loss of interception and depression storage, a decrease in the potential infiltration, and redirection of flow paths due to change in local slope. This leads high volume of runoff results in flood problems. Therefore urbanization can be characterized by high population density and change in land use dynamics.

The main objective of any water supply scheme is reduction in water shortage that can be achieved by increasing water supply by some additional sources; rooftop rainwater harvesting, runoff harvesting, recycling waste water and imported water from other sources. Since many water supply sources will not be able to fulfill ever increasing water demands in the long run, it is essential to check water demands. Some water demand reduction measures include increasing price, metering, public awareness about water savings, and toilet retrofitting. These measures can reduce the water demand by upto 50%. Therefore, water shortage reduction, water demand management, increasing groundwater recharge and runoff reductions must be the part of any water supply strategy for urban area. Traditional water management strategies for different subsystems are being practiced in a fragmented way but inefficient management of one subsystem may have severe impact on other subsystems as all the subsystems of water supply system are interlinked. Therefore, the strategies required for urban water management must be carried out in an integrated way.

It is necessary to develop proper and planned infrastructure to overcome the problems of future water demand as well as the sustainability of natural water resources system. This can be done by Integrated Water Resources Management (IWRM) i.e. by

integrated management of all existing water sources, water conservation techniques, recycling waste water and demand management. IWRM is a complex method that includes different analytical processes that require management of large volume of spatial as well as non-spatial data. The IWRM can be implemented by demonstrating and developing an interactive interface so that, it is readily adopted by the decision makers. This requires a computer aided tool called Decision Support System (DSS).

In accordance to the research objective, the essential characteristics of a DSS, as appropriate from water resources study are firstly identified. A comprehensive search on the models and methods of various components of integrated water management was done keeping in view their data need and type of output generated. From the wide literature and other resources available on the Decision Support Systems (DSSs), it is found that most of the DSSs developed are either area specific or problem specific. Many DSSs have been reported on river basin and reservoir planning and management, waste load allocation, irrigation water management and for rural water supply. Very few DSSs have been developed for urban water management considered urban water supply through lake or river, or flood control. There is a need of a DSS for urban area for integrated water management that integrates water supply from different sources as well as demand management, runoff reduction and groundwater recharge. Keeping this in view, a DSS was developed in the present study for Integrated Urban Water Management (IUWM). The prototype DSS developed for water resources planning has been demonstrated for Municipal area of a rapidly growing city "Dehradun" of Uttarakhand state, India.

Development of a DSS requires the following processes; preparation of a framework of the DSS, selection of conceptual methods for analytical modules, computer programming for software development, database creation, testing the various components of the DSS, and demonstration of the utility of the developed DSS. Integrated water management needs much spatial and non-spatial information, so the database module has been provided essential features to manage both the data. The conceptual methods for the analytical modules of the DSS have been selected on the basis of data availability, their popularity, functions provided in software language.

A user friendly DSS was developed using the object oriented programming language Visual Basic 6.0 and an ActiveX control, MapObjects 2.4 was used to make DSS input and access spatial data in the interface of the DSS. The analytical modules developed for the DSS for integrated urban water management are water supply, water demand, water shortage, runoff estimation, groundwater recharge, rooftop rainwater harvesting and

Analytical Hierarchal Process (AHP) module. User interfaces were then developed for each method, called module in the DSS. The developed software platform is a prototype of the **D**ecision **S**upport **S**ystem for **I**ntegrated **U**rban **W**ater **M**anagement, which has been abbreviated and called as **DSS-IUWM.**

The study fulfills its objective for the development of a DSS for IUWM. The spatial and non-spatial database was created for the study area. The DSS developed in the study is user friendly, and has capability to handle both the spatial and non-spatial data as input. The main components of the developed DSS-IUWM are data management module, analytical modules and graphical user interface (GUI). The present status of water supply scenario can be studied by the developed modules of water supply, water demand and water shortage. Population forecast module provides options for three methods of population forecasting Arithmetic Increase Method (AIM), Geometric Increase Method (GIM), and Incremental In crease Method (IIM). Therefore shortfalls of water can be forecasted, so that corrective action can be taken at an appropriate time, which is very essential for sustainable development of available water resources. All the information can be retrieved ward-wise.

Runoff module has been developed to estimates the weighted annual runoff by SCS-CN method and weighted-CN method. Groundwater recharge module has been developed to compute groundwater recharge as per the norms provided by Groundwater Estimation Committee (GEC, 1997) for rainfall infiltration method. The graphical user interface for Rooftop rainwater harvesting module provides the flexibility of computing the total rooftop rainwater harvesting potential under different efficiencies of buildings to collect rainwater.

All the information can be seen in an integrated way. The GUI developed for each module are simple, easy to understand and provide sufficient flexibility to users to increase the adoptability of the DSS-IUWM. Scenario analysis is an important aid in decision-making when IWRM is to be implemented. AHP module contains user interface for calculations of weights by pair-wise comparison methods and comparing the scenarios by AHP method. The user can analyze the scenarios using from 3rd to 15th criteria.

Database for spatial data have been generated in ArcGIS 9.0, whereas tables of non-spatial database have been created in MS Access software. The utility of the DSS have been demonstrated considering different water supply scenarios in the existing and future conditions. In the existing condition, groundwater and surface water are the main water supply sources whereas in future condition integration of rooftop rainwater

harvesting potential, recycling of water, runoff harvesting and water demand reductions assuming different water demand measures have been considered in a water supply scheme.

In the short-term planning, rooftop rainwater harvesting can be a solution to meet the shortfall of water, but to achieve the aim of sustainability a long term planning is required. For long term planning, integration of water demands measures with additional water supply sources may be required. Recycling of waste water is essential to achieve the aim of sustainability. The DSS-IUWM has been developed by integrating different modules, so it can be easily upgraded by adding new modified modules, as per the need of any study area.

In general, study has successfully demonstrated the development of the DSS for integrated urban water management, which may be useful to water resources planners and decision-makers.

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ABBREVIATIONS USED

.shp	Shape File
AHP	Analytical Hierarchy Process
AMC	Antecedent Moisture Condition
API	Application Programming Interface
CI	Consistency Index
CN	Curve Number
CR	Consistency Ratio
DBMS	Database Management System
DEM	Digital Elevation Model
DSS	Decision Support System
DSSs	Decision Support Systems
ERDAS	Earth Resources Data Analysis System
ESRI	Environmental Systems Research Institute
GEC	Groundwater Estimation Committee
GIS	Geographical Information System
GUI	Graphical User Interface
ha	hectare
ha-m	hectare Meter
hr	hour
IDRISI	Raster Geographic Information System and Image Processing
ILWIS	Integrated Land and Water Information System
IRS	Indian Remote Sensing Satellite
IUWM	Integrated Urban Water Management
IWRM	Integrated Water Resource Management
km	kilo meter
km^2	kilo meter square
LANDSAT	Land Satellite
LD	Lambda
LISS	Linear Imaging Self Scanner Sensor
lpm	liter per minute
lpcd	liter per capita per day
m	meter
m^2	meter square

Max	Maximum
MCA	Multi Criteria Analysis
MCDM	Multi Criteria Decision Making
mDSS	Mulino DSS
MIS	Management Information System
MADM	Multi Attribute Decision Making
MODM	Multi Objective Decision Making
MS	Microsoft
MSFlexGrid	Microsoft Flexible Grid
NBSSLUP	National Bureau of Soil Survey and Planning
NIC	National Informatics Centre
NRSA	National Remote Sensing Agency
OLE	Object linking and Embedding
OOP	Object Oriented Programming
PAN	Panchromatic Camera
RDBMS	Rational Database Management System
RI	Random Index
RIF	Rainfall Infiltration Factor
RWH	Rain Water Harvesting
SCS	Soil Conservation Service
SDSS	Spatial Decision Support System
SRTM	Shuttle Radar Topography Mission
USA	United States of America
VB	Visual Basic
VBA	Visual Basic for Applications
VC^{++}	Visual C++
AIM	Arithmetic Increase Method
GIM	Geometric Increase Method
IIM	Incremental Increase Method

Chapter 1
INTRODUCTION

1.1 General

Urbanization refers to the migration of the people from rural areas to cities. The process of urbanization comprises of growth of a city in terms of population and spatial extent. People move from rural to urban areas due to many reasons, viz better quality of life, safety, diversity in socio-cultural life, better facilities of education, employment opportunities, medical services, etc. Urbanization is a very important outcome of population growth and economic development. The global proportion of urban population rose dramatically from 13% (220 million) in the year of 1900, to 29% (732 million) in 1950, to 49% (3.2 billion) in 2005 and the figure is likely to rise to 60% (4.9 billion) in the year of 2030 (UNFPA, 2004).

Urbanization takes place mainly due to human activities to fulfill their social and economic needs. In earlier times, people used to settle in agriculturally fertile regions due to their food need, productivity of surrounding land and capabilities of the transportation media. As technology improved, cities began to develop around the industries and people started to move towards them. These days more people live in cities in most of the countries than in rural area. The processes of industrialization have affected the city building process and rural cultivation process. In the early twentieth century, the invention of automobiles resulted in development of sub-urban area (Lazaro, 1990).

During the first stage of urbanization, the main concern of the city planners was to construct housing, services and industries. In the fifties and sixties, water related problems did not arise and were not considered to be serious but later on high population density and change in lifestyle lead to high percapita water consumption. In general, existing water supply sources are unable to fulfill the increasing water demand in many cities. Besides, effluents from industries and waste began to result in water quality degradation, further limiting water available for the sustainable utilization. It can be stated that urbanization is one of the most significant demographic, social, economic and environmental transformations that affects the availability of water resources and may lead to acute water shortage in future. There is a need to follow an appropriate strategy for urban water management with a view to provide a good quality of services over a long future horizon.

1.2 Present Status of Urban Water Management

These days world's freshwater resources are under increasing pressure partly due to rapid and unplanned growth of urbanization. Urbanization increases the water consumption due to change in lifestyle and high population density. High population implies high water consumption whereas changing life style (use of washing machines, showers, air coolers, maintaining lawns and gardens, swimming pools etc.) has increased the per capita water demand. These two factors frequently imply that the urban areas have a large water requirement which commonly exceeds natural availability.

Water management involves identification and evaluation of various management alternatives, which may satisfy certain desired objectives. Presently, urban water supplies are mainly made through ground water and surface water to fulfill the need of growing population. This includes increasing quantity of supply from the existing resources; lake, ponds, large projects on rivers (dam, reservoir, import water from distance etc.), and augmentation of groundwater. Groundwater resources have an important role in water supply in many urban areas which are far from big dam projects, lakes, etc (Biswas et al., 2008). Rapid and unplanned growth of urbanization leads to over exploitation of groundwater and at the same time its recharge from natural rainfall is also decreasing in the absence of open space. So, there is an urgent need to manage the available groundwater resources to meet the future water demand. It can be said that traditional urban water management is being done to fulfill water demand through available water resources which leads to the stresses on the source from where water is abstracted.

Many activities pertaining to urbanization affect the physical properties of land use. Forest and agricultural areas are replaced by built-up areas which result in high runoff, causing flood problem. However surface water generally runs to waste. Storm water sewer changes the natural drainage of water. Conventional water management systems are designed to collect, convey and discharge runoff as efficiently as possible but this approach only controls the rate of runoff from the pre development conditions and may have reached to its effective capacity (Parkinson and Mark, 2005).

High consumption of water produces more quantity of wastewater, resulting in overloading of sewers and other drainage facilities. Leakage of sewer systems may pollute the ground water and it ultimately leads to loss of water for potential use. There should be leakage control, water conservation, necessary pollution control mechanism and maximum recycling and reuse techniques. After suitable treatment, water can be used for irrigation, gardening and even for drinking also. Presently, recycling and reuse of water is not so common in India, only some industries are using recycled water.

Rapid and unplanned growth of urban areas has created pressure on existing water supply sources. Without improvement in water management strategies, water supplies will diminish and the population pressure will decay infrastructures. This brings the concept of sustainable development as a principal goal of water management. The Bruntland Commission defines sustainable development as a development that meets the needs of the present generations without compromising the ability of future generations to meet their own needs. Sustainable development represents a balance between environmental protection and human economic development and between the present and future needs (Cruz et al., 2007).

Traditionally all the water management strategies were in a fragmented way, but all the components of water management are interlinked and interdependent. So, improper management of any one component may severely affect the other components. Water shortage of the world has motivated the development of the innovative management measures. In this context, recently, there has been a shift in thinking towards the concept of integrated water resources management (IWRM) which includes integration of all the water supply sources and water demand management to achieve sustainability.

1.3 Integrated Water Resources Management (IWRM)

IWRM is the key to sustainable management and calls for integrated planning so that water, land and other resources are utilized in a sustainable manner. According to Murphy et al. (2009), rapid urbanization, rapid growth of population, climate change and wide spread of diseases are affecting the techniques of water management and the solution must be found in an integrated way by combining technology and users' participation. IWRM includes consideration of all existing water sources, water conservation techniques, water demand management with the ultimate aim of management for sustainable development.

Many policies have been launched for integrated water resources management worldwide. In the 1970's a policy called best management practice (BMP) was launched in USA by an economically optimal mix of all available control methods on the catchments and in the sewer system including onsite detention of runoff. According to Carman et al. (1997), conventional land development process requires rapid removal of runoff, but Water Sensitive Urban Planning (WSUP) uses runoff as a potential source.

After reviewing various urban runoff simulator models, Delleur (2003) stated that all urban water problems, whether runoff quantity and quality or water supply or waste water treatment, can no longer be evaluated in isolation and will have to be considered in an integrated manner. White and Fane (2002) described experience with Integrated Resources Planning (IRP) and Least Cost Planning (LCP) for the evaluation of demand management.

In India, there is a gap between planning and implementation as water resources are distributed in time and space, and their availability may vary greatly from time to time and place to place. IWRM consists of integrating many conceptual methods that needs to handle large amount of data and different criteria and objectives, which makes decision-making problematic. The analysis of large volume of data, information, analytical processes and the complexity of the decision-making process in IWRM demands the development of tools or techniques, which should be user friendly. Besides, to keep the aim of sustainability there is need of timely updating the data. So, IWRM can be best performed by developing a computer aided tool called Decision Support System (DSS).

1.4 Decision Support System

DSS is defined by Sprague and Carlson (1982) as "An interactive computer based system that helps decision makers utilizing data and models to solve structured, semi-structured or unspecified problems". According to Loucks (1995), "Computer based models together with their interactive interfaces are typically called DSS". DSSs are user-friendly computer based technical tools that integrate information from various sources, help in analyzing data and aid in understanding the outcome of different management options. They provide a custom, flexible and dedicated management system, to assist managers, decision makers and policy makers.

As a process, a DSS is a systematic method which considers all objectives and evaluates options to identify a specific solution that best solves a problem while satisfying as many objectives as possible (Densham and Goodchild, 1989). The DSS traditionally consists of three essential components: database, analytical models and Graphical User Interfaces (GUI). Database system is the core component of a DSS as it contains tools to manage large amount of data. Analytical modules include the programs on conceptual processes which are required for solving the problems. The user interface is an interactive interface, so that user can access the DSS.

Depending on the particular issue at hand, a DSS in the broadest sense can range from minimal if any computer model is used i.e., where the decision makers provide all data and analyses make the decision and implement those decisions - to fully automated DSSs where no human involvement is present which are rare but do exists (Loucks, 2005). Various phases and levels of the DSS are outlined in Fig. 1.1.

Different phases of a DSS are collection and management of data, analysis of data, option generation, selection of proper option to take the decision and its implementation. In the first level of a DSS, approach of the decision-making is completely unsupported in all the phases. The second level DSS is information supported as data is managed systematically. Third level includes management and analysis of data with the help of the model. Fourth level is further upgraded to generate the options by the model itself and the Fifth level is supported by the model to select the decision. The last level of DSS is fully automated, where models are used in every phase of the DSS.

Various Phase of Decision Support Systems

	Data provided by	Data analyzed by	Options generated by	Decision selection by	Decision implemented by	Approach to decision-making
1.	Decision-maker					Completely unsupported
2.	GIS/DB	Decision-maker				Information supported
3.	GIS/DB	MODEL	Decision-maker			Systematic analysis
4.	GIS/DB	MODEL		Decision-maker		Sys. Analysis alternatives
5.	GIS/DB	MODEL			Decision-maker	System with over-ride
6.	GIS/DB	MODEL				automated

Fig. 1.1 Various types of computer aided decision support systems (based on O'Callaghan, 1996)

The main challenge in the development of a DSS is selection of conceptual method which depends on data limitations and availability of tools in software. Development of a user interface is also a big challenge as a user friendly DSS has more chances of its application rather than those include only good data and analytical methods.

To insure a successful implementation, the DSSs should have flexibility to integrate with new modules, new data and new computer technology to respond quickly and efficiently with the ever increasing technologies (Loucks, 1991).

Remote Sensing & Geographic Information System (GIS) play an important role in providing water related information as well as carrying out modelling and analysis for sustainable development. Therefore most of the water resources management problems are now being solved by using GIS and hydrologic models. GIS-based decision support systems are known as spatial decision support systems (SDSS). A spatial decision support system is needed to integrate various subsystems of water management process (Sample et al., 2001).

The use of integrated decision support tools is a pre-requisite in proper IWRM. Decision making in integrated water resources management is a complex task, where problem formulation and result interpretation requires large amount of data and advanced computer based tools and technologies. There have been several efforts during 90's on the development of DSS from flood operations (Todini et al., 1999) to integrated water management at catchment level (Holms et al., 2005). Earlier, most of the DSSs have been developed for IWRM: AQUATOOL (Andreu et al., 1996; Andreu et al., 1991), Water Ware (Jamieson and Fedra, 1996), HANDSS (Hwanko et al., 1998), GDSS (McKinney et al., 1997) and CTIWM (Ito et al., 2001) for river basin management; MULINO (Jeunesse et al., 2002; Mysiak et al., 2002), WATERSHEDS (Osmand, 1999) for watershed management, DSIRR for assessment of agricultural activity (Bazzani, 2005), DFM (Froukh et al., 2001) for water demand forecasting; COMBESICK (Herb and Graeber, 2002) for seepage prognosis etc. This clearly indicates the extent of application of DSS in water resources planning, development and management.

Very few DSSs have been developed for cities: LLDA for water supply from a Lake (Nauta et al., 2003); urban flood management (Abebe and Price, 2005; Sample et al., 2001); Urban Carrying Capacity Assessment System (Oha et al., 2005). All these DSS for urban area have been developed for the specific objectives and considered single sources of water supply for urban water management or urban capacity assessment. In view of the available DSS it is strongly felt that there is a need for development of a DSS for IWRM for urban area that contains integrated management of surface water, ground water and alternate water sources with water demand measures to obtain the aim of sustainable development. The capabilities of the DSS, for accepting user judgment inputs can enhance the planning process. Decision makers can ask "What if?" questions, obtain answers, and provide a discussion and learning.

1.5 Background of the Study

Rapid and unplanned growth of urbanization leads to the acute water crisis in present condition. Cities are one of the main problem areas of catchments, where water management can be best done by IWRM. The IWRM is a complex process which consists of integration of large amount of data from different sources and various analytical processes. Thus IWRM can be best practiced by a computer based user-friendly tool. DSS provides a framework for integrating analytical modelling capabilities, database management system, and a user friendly interface to support a decision-making.

As already discussed that many DSSs have been developed for watershed management, waste water management, river basin management, agricultural water management and very few DSSs are available for urban water management. Thus, there is a need of developing a DSS for urban water management considering IWRM. The DSS should be able to give answer to various water related problem of a city such as the water supply and demand, water shortage, potential of rooftop rainwater harvesting, runoff and a decision making tool to support the decision maker to select best alternative for sustainable water supply scenario. Most of the DSSs are either area specific or problem specific. Keeping these aspects in view, there is a need to develop a DSS for integrated urban water management.

1.6 Objectives

In the proposed research an attempt has been made to develop a DSS for integrated urban water management. IWRM includes integration of the all the water supply sources and water demand to achieve the goal of sustainability. The specific objectives of the present research work can be outlined as:

- To develop a DSS for integrated urban water management consisting of the following:
  - A database of spatial as well as non-spatial data linked with the DSS to provide the required information.
  - A module for water demand analysis.
  - Modules for assessment of runoff and ground water recharge in an urban area.
  - A module to estimate rooftop rainwater harvesting potential.
  - A module for scenario creation, analysis and intercomparison.
  - Interface of the DSS and linkages among all the modules.
- To demonstrate the capability of the developed DSS for an urban area, and
- To demonstrate the utility of DSS through scenario analysis.

1.7 Scope of the Study

This thesis concerns the development of a DSS for integrated water management for an urban area. IWRM for urban area comprises of water supply analysis, water demand forecasting, runoff estimation, ground water recharge estimation and assessment of rain water harvesting potential. All these tasks are to be performed in an integrated way. Utilization of water resources needs to be planned keeping in view the principal of the sustainable development. The developed DSS consists of different analytical modules as well as user interface to view the results and to handle the data efficiently. User interface consists of options for query, bar charts, tables, line diagrams and integrates some of the GIS functionalities to display the required results. A good user interface increases the adoptability of the DSS. Key aspects of a good DSS are the abilities to create, analyze, and inter-compare various likely future scenarios. "What if" analysis is frequently the major application of a DSS by the decision-makers. In the present DSS, the user has been given flexibility to generate scenarios as per the requirements and compare them. The developed scenarios can be saved and in AHP module the best ranked scenario can be selected by integrated consideration of the factors of water supply, water demand, ground water recharge, rainfall-runoff and population growth.

1.8 Organization of the Thesis

The present thesis has been divided according to the structure of the DSS i.e. model base, database, and user interface development. The contents of the each chapter are briefly described below:

Chapter two presents literatures review that begins with the problems due to rapid growth of urbanization, followed by a brief discussion on the concept of integrated urban water management. Finally, review of applications of DSSs in integrated water management has been given and future research and developments needs of DSS are highlighted.

Chapter three discusses the design and development of DSS. It includes conceptual framework of proposed DSS followed by the development of its various components, viz., database subsystem, model base subsystem that contains various modules and finally GUI.

Chapter four presents general description of study area (Dehradun City). This chapter also discusses the water related problems of the city.

Chapter five presents the details of data collection of the study area and methodology of preparing spatial and non spatial database as per the requirement of the developed DSS.

Chapter six presents the analytical capability of the various modules by using prepared database of the study area.

Chapter seven illustrates the applicability of the proposed DSS by scenario analysis approach; four cases have been presented in the demonstration part of the developed DSS. At the end, conclusions drawn and recommendations made are presented in the **chapter eight**.

Extensive programming has been done to develop the DSS for Integrated urban water management using Visual Basic 6.0 with MapObjects. The programming source codes have been given in appendices of the thesis on a Compact Disc.

Chapter 2

LITERATURE REVIEW

2.1 Prelude

This chapter critically reviews the available literature on application of DSS for integrated water resources management in an urban area. In this context, it is important to identify water related problems due to urbanization, strategies of urban water management, concept of integrated urban water management and need of the DSS. Many DSSs have been reported for water management using remote sensing and GIS. Future research and developments needs of DSS are highlighted on the basis of sustainable and holistic development for urban area.

2.2 Urbanization

Urbanization is due to the economic growth and development of an area because it provides better employment, diversity in socio-cultural life, better facilities of education, medical, safety etc. It is one of the most significant demographic, social, economic and environmental transformations, affecting the world's population and environment (Cocklin and Keen, 2000). Rapid industrialization is one of the prime factors of urbanization in developing countries. From the demographic point of view, it leads to migration of people from rural to urban area and results in high density of settlements in urban area. Further, various human activities pertaining to urbanization are affecting the natural landuse; natural cover and trees are replaced by buildings and impervious cover, and natural streams are replaced by urban drainage system. Therefore, urban centers are characterized by high population density, change in land use and rapid settlement dynamics as well as high water demand for various requirements (Niemczynowicz, 1991), which is a very significant phenomenon in the developing countries.

The urban population is increasingly globally; it is estimated that the number of urban dwellers will rise from 3.2 billion i.e. about 49% of the world's population in the year of 2005 to 5 billion (60%) in the year of 2030. Today worldwide, there are 20 cities having a population of more than 10 million people and by 2015 there will be 22 such mega-cities (UNFPA, 2004).

2.3 Problem of Water Management in Urban Area

Rapid and unplanned growth of urbanization results in an uneven distribution of population and industries, high water demand, and hence creates pressure on water supply and management strategies. Urban area covers only about 2% of the earth land surface but consumes 60% of fresh water. By 2030 some 3 billion people will be living in water-stressed areas of the world. At least 30 percent of the population in China, India, Mexico, and US are expected to face severe water stress (Garnett, 1996; Rosemarin, 2005).

Effects of urbanization on the water resources, hydrology and environment are shown in Fig. 2.1. As it is already discussed that population density and imperviousness are the main parameters of urbanization affecting the natural resources. High population density and changed human life style have increased water consumption significantly and therefore created pressure on the sustainability of natural resources. Besides, satisfactory pressure in the distribution system and size, characteristics and topography of the town also influence the per capita water consumption rate (Neto et al., 2005; Soni, 2005).

The increased water use from various water demand sectors results in high local emissions of wastewater and harmful substances (pathogens, nutrients, salts, persistent organic pollutants), which increases pollution and affects the water quality. Larger quantities of untreated waste discharge into local stream increases pollution and affect the aquatic life (Anderson, 1970; Lazaro, 1990; ASCE, 1996; Ferguson, 1998).

Urbanization creates a new hydrological environment due to various human activities. Imperviousness leads to loss of interception and depression storage, a decrease in the potential infiltration, and redirection of flow paths, which results in reduction of base flow and recharge. On the other hand, volume of surface runoff increases. Storm-water sewer changes the natural drainage of water. Therefore velocity of runoff increases and so the time of concentration and time to peak of its runoff hydrograph decreases. Flood peaks of shorter recurrence are increased, return periods are reduced and frequency of out-of-bank or local flood magnitudes increases significantly. This may result in higher flood damage, erosion and destruction of channel. Conventional water management systems are designed to collect, convey and discharge runoff as efficiently as possible but this approach only controls the rate of runoff from the predevelopment conditions and may have reached to its effective capacity (NIH, 1999; Delleur, 2003; Parkinson and Mark, 2005). Further pressure on these systems may lead to frequent overloading and leakage of sewers that affects groundwater quality, erosion of channels etc. (Vlachos and Braga, 2001). Therefore, it can be said that urban imperviousness is one of the most critical indicators for considering storm water related environmental problems.

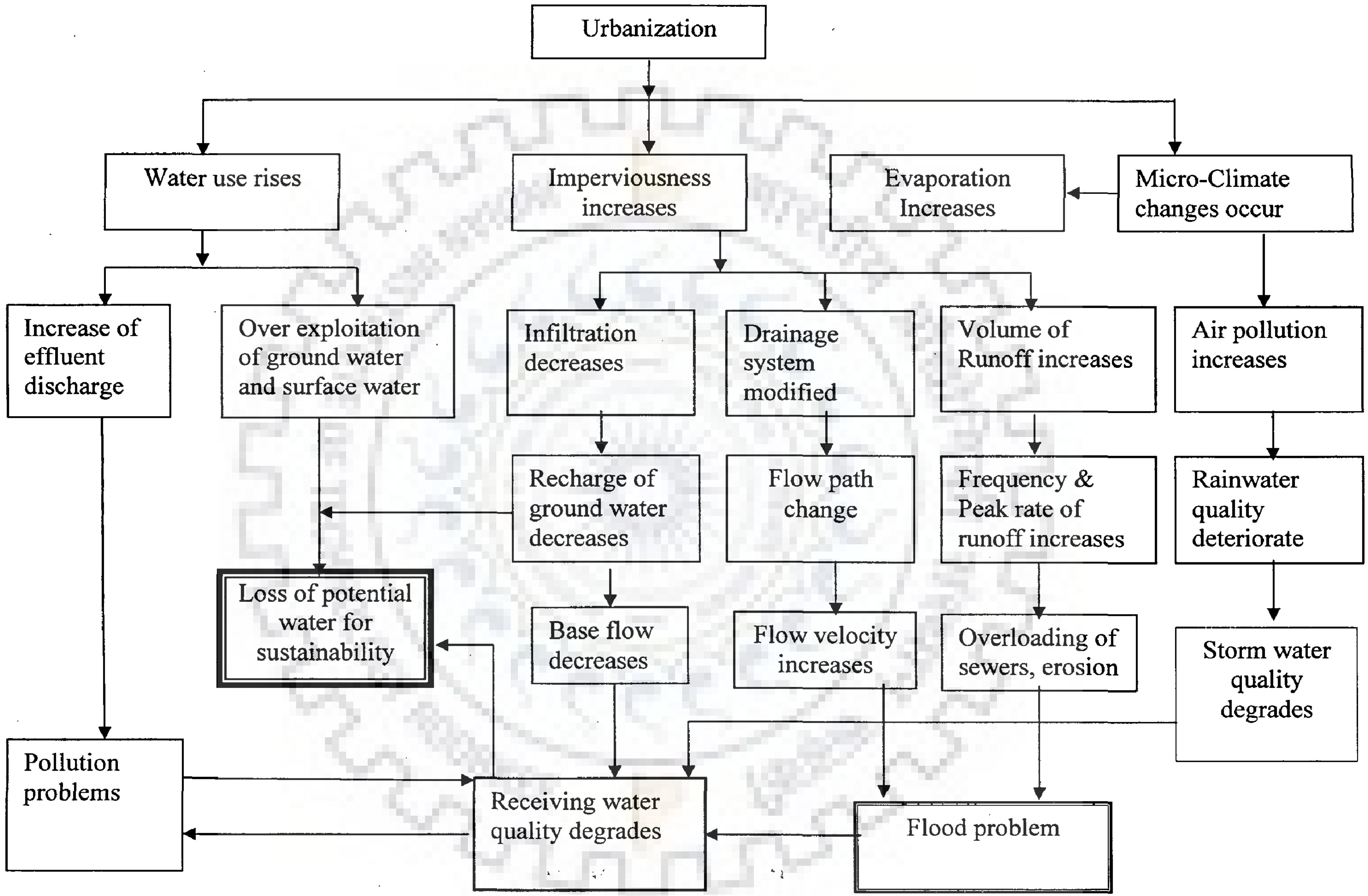


Fig. 2.1 Effects of urbanization on water and the environment

Urbanization affects the local micro-climate in terms of rise in temperature, reduced wind speed, change in rainfall pattern etc. (Hall, 1984; Mansell, 2003; Parkinson and Mark, 2005). The expansion of urbanization often degrades the environment by land, air and water pollution. Polluted rainwater (due to industrial smokes), further transports the surface wastes from lawns, gardens, roads, etc. Frequently, this runoff goes directly into streams without any treatment and degrades the quality of receiving water (Garg, 1986; Sharma et al., 1994; Pouraghniaei, 2002). Further, water is transported through pipe or open sewerage and is finally disposed into receiving surface water. Somewhere it goes to ground water due to leakage and degrades ground water quality. Many cities have combined sewers, and their overflows often contribute to river pollution.

The exploitation of surface and ground water focusing only on economics, without considering holistic consequences, has placed existing natural resources in a critical condition and has lead to adverse environmental degradation and unsustainable use of urban water resources. If an appropriate management strategy for natural resources is not considered, it is likely that natural resources in the near future will no longer be able to meet the demand. To improve existing water supply, it is needed to improve management practices, use full-cost pricing, water demand management etc.

Thus for urban water managers, the main challenges are safe and sufficient water supply, effective demand management for various uses, drainage and disposal of waste water, flood protection, control of environmental pollution, and creation of a pleasant urban living environment in light of global climatic and socio-economic changes. The major requirement is to reduce the water shortage on priority in an urban area. This thesis deals with the quantity aspects of water for sustainable development.

2.4 Strategies for Urban Water Management

A holistic development of urban water management requires implementation of various strategies such as sustainable water supply, ground water management, storm water management, pollution control, and recycle and reuse of waste water etc. Here, the main features of these strategies are explained in brief.

According to Biswas et al. (2008), water management in the urban area has two components: water supply and demand management. The supply side includes increasing the supply from existing sources, tapping additional sources or alternative sources and the demand management deals with reduction of misuse, pricing policies, installation of water meter, water conservation, recycling and reuse, water harvesting, and technological innovations. Prices should be fixed in such a way that the cost of provided services is recovered, there is an incentive to save water and there is no undue burden on the weaker section of the society (Basu and Main, 2001).

Ground water management requires artificial recharge to raise the water table depth and control the leakage and seepage of wastewater to protect the groundwater quality. Rainwater harvesting has been done in various countries resulting increased ground water level, reducing inundation, and availability of good quality of water for domestic use in urban area (Mayo and Mashauri, 1991; Barkhard et al., 2000; Schmidt, 2000; Wolf, 2007). Besides this, social awareness is required, so that participatory management and community based water resources management can be implemented. Besides this, some policy should be made such as use of good quality (deeper) ground water only for drinking purpose and use of shallow water for other purpose.

Urban drainage and flood problems can be solved by reducing the storm-water in drainage system. This can be done by various approaches of infiltration or storage of storm-water such as detention basin, infiltration pit, rooftop rainwater harvesting, parking storage and porous pavement (Whipple et al., 1983; Zhang, 1999; Davis and McCuen, 2005).

Motiee et al. (2006) have demonstrated the utility of *qanats,* a long distance sustainable system facilitating the harvesting of water for centuries in Iran. Recently, more attention is being devoted to Sustainable Urban Drainage System (SUDS), which enhance the water quality, and encourages natural groundwater recharge by providing some natural bio-purification, storage and infiltration (Mansell, 2003). Further, urban hydrologists should work to make available storm water useful for various water uses or after purification, even for drinking purposes (Gray and Becker, 2002; Lin et al., 2004). Rainwater harvesting is widely adopted in Tanjania and efforts are still being made to promote the use of potential of rain water harvesting (Gowing et al., 1999).

In the case of pollution, the primary remedy is to reduce the generation of pollutants at the source as well as mitigate their environmental effects. In this context, concept of water recycling and reusing has been implemented in various countries. Water recycling is reusing treated wastewater for beneficial purposes such as agricultural and landscape irrigation, industrial processes, toilet flushing, and replenishing a ground water basin (Anderson, 2003; Angelakis et al., 2003; Ganoulis, 2003; Khare et al., 2006). Different legislation, criteria and guidelines about it can be a part of the system: zero-waste discharge systems in industries (Durham and Mierzejewski, 2003) and recycling of urban storm water for non-potable use such as toilet flushing, gardening etc (Lazarova et al., 2003). According to Salgot et al. (2003), risk assessment should be done in waste water recycling and reuse.

Forecasting water use (or water demand) at regular interval is needed so that corrective action to meet the future shortfalls can be taken in time (Baumann et al., 1997; Kameenui, 2003; Vicente et al., 2003; EPA, 2004; Koo et al., 2005). Urban water supply system should be made more efficient by reducing contamination and losses from the distribution system; and equitable distribution of safe drinking water to the whole population. Hernandez et al. (2002) have forecasted water quality and quantity hazards using spatially distributed watershed models and biophysical data by AGWA tool. According to Ismail et al. (2004), desalination and high investment is needed for quality control and maintenance of the tap water in Qatar, Arabian Gulf, where one liter of oil is cheaper then one liter of water.

Water demand management involves making existing conveyance of water systems more efficient to reduce the leakage and seepage of wastewater. It prevents the pollution and therefore reduces the degradation of receiving water quality. Waste water should be disposed after the consideration of its impact on groundwater and some protection zones should be defined for control of surface contaminant load (Morris et al., 1997).

Traditionally, urban water systems are managed in a disintegrated manner but it can be seen that all the strategies of urban water management are interlinked, and so one inefficient operating sub-system might have severe negative impacts on the other subsystems. For example, leaking water supply systems that strain freshwater resources, leaking sewers pollute groundwater; large impervious urban areas overload sewer systems, etc. Finally, it adversely affects the environment, and sustainability of the water resources. Urban water management systems should satisfy the environmental regulations, both in terms of quality and quantity to reduce the negative impact of urban development (Renathnam et al., 2004, Kaledhonkar et al., 2006). Therefore, there is a need of integration and linking of these strategies the minimize their adverse impact on the environment. The concept of integrated water management has been described in the following section.

2.5 Integrated Urban Water Management

Recently there has been a shift in thinking towards thinking an integrated management of water resources for sustainable development. According to Loucks (1996), "Integrated water resources system planning and management focuses not only on the performance of individual components but on the performance of the entire system of components." According to Georgakakos (2003), Integrated Water Resources Management (IWRM) is the process of developing and implementing shared vision planning and management strategy for sustainable water resources utilization with due consideration of all spatial and temporal independencies among natural processes and human water use. A key challenge is to understand complex relations between equity, productivity, required efficiency of urban water system and incorporate them into a decision-making framework. This needs a lot of time and cost, involvement and coordination among the expertise of various disciplines (Ejeta, 2000; Citynet, 2003).

According to Maddaus et al. (1996), a carefully planned long-term water conservation program through improvements in efficiency and diminishing wastewater can reduce water consumption up to 10 to 20 percent over a period of 10 to 20 years. Mathur and Gupta (1997) have used the concept of carrying capacity for sustainable development of water resources and have stated that population density should be restricted with respect to available water.

According to Loucks (2000), the major challenge of sustainability can be achieved by getting more from resources and produce less waste along with the involvement of public and professionals from various disciplines. Many approaches for sustainable development of water resources throughout the world have been developed in the recent past. These ideas and approaches are of considerable interest for the development of a framework of integrated water management for urban area.

Rijsberman et al. (2000) have reviewed basic approaches of ecology, socio-economic and carrying capacity for the sustainable development of urban water management in three Dutch cities and concluded that an urban water management system should have case specific approach incorporating all the basic approaches. Review by various researchers and scientist provides some innovative concept and constraints for the sustainable use of water resources management such as integration of environment regulations in the final decision making of water resources management (Whipple, 1996); public awareness for water conservation (Asano, 2005); community based water management for getting affordable structure (Kyessi, 2005); integration of social, political and environmental factors with urban hydrology and integrated water management (Niemczynowicz, 1999); principle of total management of water cycle and sanitation (Niemczynowicz, 2000); integration of agricultural water management and other water use with overall management (Bouwer, 2000; Bouwer, 2002) etc., but these criteria and constraints of integrating various components and policies can be area specific on the basis of its physical land-use, hydrology and availability of water etc.

Lee and Heaney (2003) have evaluated long-term impact on runoff from an apartment area in Miami and showed that the directly connected impervious area (DCIA), which covers 44% of the catchment, contributes 72% of the total runoff volume during 52 years. Further, integrated water management at Sydney Olympic Park saves approximately 850 million liters of drinking water each year by reducing drinking water consumption at Sydney Olympic Park and Newington by around 50%. It is a leading demonstration of sustainable urban water management which treats and re-uses of almost 100% sewage contributing nearly 100% reduction in the discharge of sewage effluent to waterways and the ocean from the area.

According to Biswas et al. (2008), 36% of domestic water supply can be saved using gray water recycling for group housing in Dwarka, Delhi. According to Murphy et al. (2009), the rapid urbanization, rapid population increase, climate change and wide spread disease are affecting the techniques of water and sanitation and the work must be in an integrated way of technology, user's participation and multidisciplinary approach. Wolf (2007) states that holistic and applicable approaches are urgently needed for sustainable urban water management systems.

Effective management also requires collaboration between researchers, policy makers and the community. A brief summary of different water management policies and strategies of various countries are presented in Table 2.1. It can be seen that integrated water management has been done in many countries integrating various water conservation techniques, water demand management, cost effectiveness and environmental aspects. Keeping the above aspects in view, the framework of basic concept of integrated water management has been developed and shown in Fig. 2.2. Concept of integrated urban water management is the key to sustainability which involves integration of rainwater harvesting, runoff harvesting, recycle and reuse of water as additional supply sources.

It can be stated that integrated urban water management is the integration of all the basic water resources system, and their optimal utilization incorporating sustainability for the environment, socioeconomic, cost effective, public health etc. This is accomplished by the integration of different models and management of large volume of database from different sources, involvement of policy makers and users. Computer based hydro-information technologies are very important tools for fast computation, easy demand management and drawing conclusions about certain water policies.

Traditionally, various computer models and tools are being used to implement the strategies of water management. Delleur (2003) has reviewed the urban runoff simulator model and states that all urban water problems, whether runoff quantity and quality or water supply or waste water treatment, can no longer be evaluated in isolation but will

Table 2.1 Urban water management strategy of various countries

Strategy	Year/ Country	Description
Best Management Practice (BMP)	1970 USA	The urban water problem is solved by economically optimal mix of all available control methods on the catchments and in the sewer system including onsite detention of runoff (EPA, 2002).
Integrated Resources Planning (IRP)	1993 USA	It is a least cast planning method designed to incorporate supply enhancement and demand management with the consideration of all the environmental and economic aspects (Maddaus and Maddaus, 2001; Baumann, 1997).
WSUP	1997 Israel	Conventional land development process requires rapid removal of runoff, but Water –Sensitive Urban Planning (WSUP) uses runoff as potential sources (Carmon et al, 1997).
Low impact development (LID)	2000 Maryland	LID measures are more cost effective and lower in maintenance to achieve desired stormwater management or ecosystem control. Main LID Practices are bioretention facilities or rain gardens, grass swales and channels, vegetated rooftops, rain barrels, cisterns, vegetated filter strips and permeable pavements etc. (EPA, 2000; Coffman, 2002).
Integrated Urban Water Management (IUWM)	2002 South Africa	Focuses on technical aspects of the management of water supply and distribution system, management of urban runoff and water conservation and demand management (Bhagwan, 2002).
Integrated water cycle planning (IWCP)	2003 Australia	Dept. of Land and Water Conservation, New South Wales has developed IWCP initially for rural area includes catchments need and issues, environmentally sustainability, Govt. policies and community objectives. Further for urban area water demand management also included (Schneider, 2003).

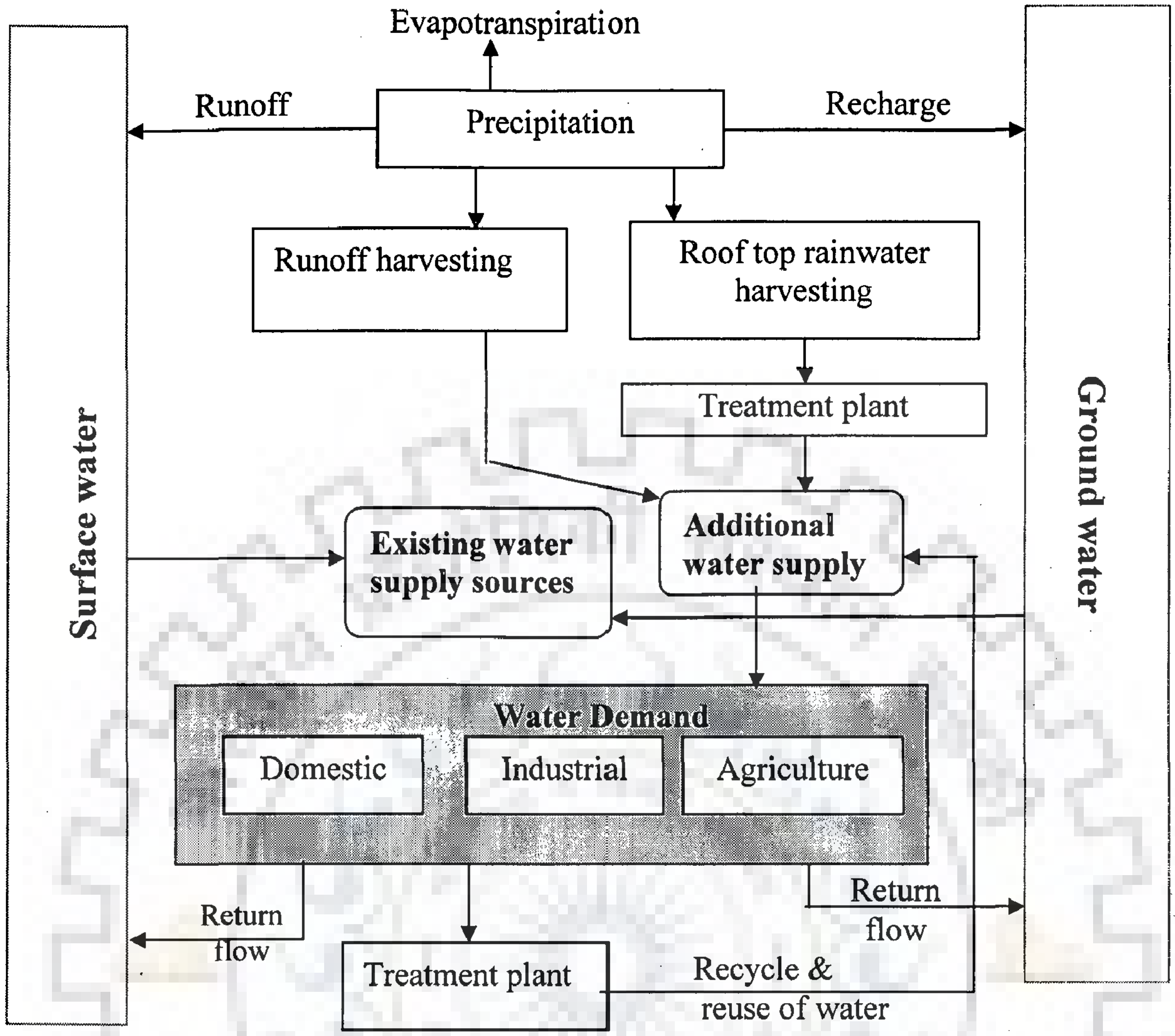


Fig. 2.2 Concept of integrated water resource management

have to be practiced in an integrated way. Schroder and Rosbjerg (2004) have done integrated modeling to estimate ground water recharge and capillary rise in clayey catchments of Denmark. Ngo et al. (2007) optimized the control strategies for the Hoa Binh reservoir operation by applying a combination of MIKE 11 simulation model and optimization tool, the shuffled complex evolution (SCE) algorithm. The results show that both the tools are efficient to optimize a complex system. Rosbjerg and Madsen (1996) have done partial duration series (PDS) modelling to obtain the rainfall at non-monitored site. According to Jayakumar and Dandigi (2004), using constructed wetland for treating municipal wastewater and stormwater has been gaining importance, especially in the past decade. Storm water sewer system often blocked by solid waste and so, solid wastes management must be integrated to water/wastewater management. PROTOCOL is software for estimating the number of waste sorts required to characterize waste percentages in individual categories (Sharma and Mcbean, 2007). Jean-luc et al.(2000)

have discussed various problems related with models and decision-making and stated that the sustainable management of urban water system needs a multidisciplinary and integrated approach at various time and scales.

Extensive modelling works have been done in the area of water management. Wilchfort and Lund (1997) have developed a model by using the concept of Integrated Resources Planning (IRP) for East Bay, Municipal Utility District System. Mitchell et al. (2001) have developed a model "Aquacycle" for Canberra, Australia, for simulating water cycle for that specific catchment. Stephens and Debo (2003) have developed the water balance model for British Colombia. These models have proved to be very useful in diagnostic studies and developing solution to urban water problems. But models have limitations and they do not provide exact duplication of the system. In current use, they do not "make decisions" but provide information to decision makers to serve as one input to decision-making process (Walesh, 1989).

The main problems in integrated urban water management are lack of adequate and reliable data; lack of interaction between users, planners and technical skills and policy makers; lack of awareness of community for optimal water use and management; lack of funding for maintenance and replacement of old and inadequate distribution system, expansion of new system for proper supply and sanitation etc. GIS database is also not available in general and creation of this is time consuming. Lack of skills to implement the latest technologies in the field is felt in many cases. Although models are very useful for such planning and management work, they are still not widely available and used. Integrated urban water management work involves different models because modelling objectives vary widely; each objective requires a different approach to modelling. More research is needed towards interlinking and interfacing of these models (ASCE, 1996; NIH, 2001).

Various criteria such as environmental, economic, social, health, technical etc. should be used to evaluate the best alternative for sustainable water management. Stakeholder and citizens may become the main participants of a management system and therefore there is a need of more flexible system to adopt such criteria (Abrishamchi et al., 2005; Claudia, 2005).

There is a gap between the concept of integrated water management and its formulation and execution as implementation of such a framework requires involvement of a multidisciplinary expertise and a technically sound process of decision-making. Now-a- days DSS are used to provide a framework, which requires both the model and user interaction for decision-making.

Computer based technologies are efficient tools for fast computation, easy to store, manage and analyze large volume of data and decision-making process. Decision Support Systems (DSSs) are computer aided tools, helpful in supporting decision-making and there use for water resources planning and management is growing.

2.6 Decision Support Systems

Many water resources management works have been done by using GIS and other hydrology models, but the real world is not always as the model developers see it. They are much bigger, complex and less structured, which require human input and judgment. So, models provide only information for the decision-making. Information system researchers and technologists have built and investigated Decision Support Systems (DSSs). DSS is defined by Sprague and Carlson (1982) as "An interactive computer based system that helps decision makers utilizing data and models to solve unstructured and unspecified problems". Adelman (1992) defined decision support systems (DSSs) as "interactive computer programs that utilize analytical methods, such as decision analysis, optimization algorithms, program scheduling routines, and so on, for developing models to help decision makers formulate alternatives, analyze their impacts, and interpret and select appropriate options for implementation." According to Loucks (1995) "Computer based models together with their interactive interfaces are typically called DSS". Poch et al. (2004) define a DSS as "an intelligent information system that reduces the time in which decisions are made, and improves the consistency and quality of those decisions." A Decision Support System (DSS) is an integrated, interactive computer system, consisting of analytical tools and information management capabilities, designed to aid decision makers in solving relatively large, unstructured water resource management problems (McKinney, 2004).

The history of DSS begins around 1965 as management DSS or information support system for decision making. DSS evolved as a field of research, development, and practice during the 1970s and 1980s and IBM's Geodata Analysis and Display System (GADS) - developed in the 1970s was one of the earliest large DSS (Sprague and Watson, 1996). In 1980's Group DSS (GDSS) and Executive Information systems (EIS) were developed as a management DSS. In late 1980's there was a technological shift towards water resources planning and management (Power, 2004). Decision makers can ask "What if?" questions obtain answers and provide a discussion and learning. This interactive planning process provides a better means for incorporating subjective and value oriented information in the planning process (Johnson, 1986). In the last twenty years there has been considerable development in the water management using computer based decision support systems. The Spatial Decision Support System (SDSS) concept has evolved in parallel with DSS (Densham and Godchild, 1989). There has been considerable growth in research, development, and applications of SDSS in the last 10 years or so (NCGIA 1990; 1996).

Watkins and McKinney (1995) have reviewed the developments of DSS in water resources and concluded that the trend will bring more focus on the formulation of DSS, which is needed by decision makers rather than modelers and developers. According to Sample et al. (2001), traditional models can and should be a part of DSS. The DSS helps all the stockholders concerned with particular water resources issue and reach to a real 'shared' vision model. It is a user-friendly technical tool that integrates information from various sources, analyze data, and predict the outcome of different management options, which neither man nor computer alone can address efficiently and effectively and therefore enhances the management efficiency.

Decision-making in complex water management processes consists of multiple criteria and alternatives to estimate or identify, compare and evaluate the multiple impacts resulting from different design and management decisions and helps in choosing the 'best decision' to achieve an objective (Andreu et al., 2001; Loucks, 2002; Ngo et at., 2007). Multiattribute/multi-objective decision making process provide efficient tool for various aspects of water resources planning and management. The method can be integrated within a computer based decision-support system. Alkan and Shamir (1980) employed multiobjective optimization method to plan the development and seasonal operation of a regional water resources system in an arid region in the south of Israel. Datta and Peralta (1986) presented a multiobjective optimization procedure for developing a regional conjunctive water management strategy for an important rice production area in Arkansas, U.S.A. and Multiobjective management of a contaminated aquifer for agricultural use have been done by Keshri and Dulta (1995). Hipel (1992) has described the use of multi objective decision making technique in various water resources problems.

Jayyousi and Shatanawi (1995) have used a DSS for the analysis of future water policies in Jordan and concluded that only multiple water policies can serve a solution to water shortage. There are many concepts and methods for multicriteria decision making:

GOAL programming, compromise programming, AHP, ELECTRE III and ELECTRE II, Expert Choice etc. Analytic Hierarchy Process (AHP) is a decision-making algorithm developed by Dr. Saaty in 1970. The method can be used in complex, unstructured, and multiple attributes decision-making for the water resources planning and management. AHP method provides a systematic approach for comparison and weighting of these multiple criteria and alternatives (Raju et at., 2000; Raju and Kumar, 2006). The application of AHP method has been involved in many fields: resources allocation (Karagalein, 1982), Aquifer vulnerability assessment (Thirumalaivasan and Karmegam, 2001), water policy and management (Mei et al, 1989) in China, irrigation water allocation in a Tampo river basin in west Sumatra, Indonesia (Febriamansyah, 2001).

Malczewski (1999) has developed collaborative planning support system consists a module for multi-criteria decision making by GIS, Expert system and fuzzy technic in Monitoba. Sharifi (2002) has developed an integrated planning system consisting a water balance model, a planning model and a multiple criteria evaluation model, and in order to study and assess the possible impacts of different government policies in La Mancha Province, Spain for sustainable watershed development. Rao (2005) has used multi-criteria decision-making for forecasting urban water demand in Dehradun city of India. Abrishamchi et al. (2005) have used Multi Criteria Decision-Making (MCDM) theories to urban water management in Iran and found the approach to be realistic and promising.

2.6.1 Components of a DSS

Building of a DSS involves identification of a problem by taking users and experts view, selection of conceptual analytical methods to solve the problems and computer programming, testing and validation of the DSS and modifications as per the requirements. Challenges arise in developing DSS due to the complexities of integrating separate technologies, which emphasizes the importance of cross-discipline collaboration. The database component, always considered a central part of a DSS. Development of a DSS is very complex and difficult task having integration of its components: data management module, model subsystem and user interface.

A database management system allows the user to store data in an organized form and retrieve it on the basis of specified selection criteria, to serve as input to the model subsystem and to display the output in required formats. Characteristics of a database are its ability to integrate data from several files and various sources. Data sources are various organizations, satellite data, master plan etc. Various GIS software; ArcView, ArcGIS, ERDAS, and MS Access, Excel, Oracle, Structured Query Language (SQL), Visual FoxPro, text files etc., may be used for developing efficient database management subsystem. Loucks (1991) stated that future research must be in the area of hardware and software to access any database at any location.

Model subsystem contains the models and/or software routines to analyze the data and it should have the ability to create new models quickly and easily, to maintain a wide range of models, ability to interrelate these models and linkage with database (Sprague and Watson, 1993; Rossouw, 2000). Integration of various models and modules are needed for integrated water management. Output information of one model can be input for another model used for the analysis. Interlinking of models with the user interface and database subsystem is very essential. Models or modules can be developed by using computer languages such as C++, VC++, Visual Basics, VB.NET, Python, Java, Arc Macro Language (AML), Fortran Power station etc.

One of the crucial elements of a DSS is the user interface. It is the vehicle of interaction between the user and the computer and is generally in the form of menu-based interactions with the user to display model output or summarize data. It enables the user to address the different components of the DSS such as tools, data, and models (Loucks, 1991). User interface should be easy and understand for the user and appropriate for the problem being addressed. Computer software such as Visual Basic (VB) or VB.net, multimedia (video and sound links) may be used for the development of user interface (Watkins and McKinney, 1995).

2.6.2 Application of GIS in DSS

With the emergence of GIS in the late 1980's, water resource DSSs shifted to integrate a spatial component into the decision-making process (Walsh, 1993). Many organizations are using GIS in water resources modelling due to its spatial nature and analytical ability. Water management requires spatial information, which is obtained from maps and remote sensing images, and so integration of GIS with the models and DSS is being common (Singh, 1996; George et at., 2004; Goyal and Arora, 2004; Semmense and Kepner, 2004; Tripathi et al., 2004; Miller et al., 2007). Most of the available data about urban imperviousness are based on land use or zoning, using image-processing techniques with satellite or airborne imagery. Densham and Goodchild (1989) presented an approach to develop spatial decision support systems (SDSS) to integrate spatial data and modeling capacity into an operational framework by linking a DSS and a GIS. According to Xiang and Stratton (1993), GIS can be used not only for information management but also for spatial analysis and the visualization of model output. Meyer et al. (1993) linked a physically based urban stormwater runoff model to a raster based GIS package and compared the results with a previous non-GIS study and shows that GIS provides an improved assessment of the reliability of estimated parameter. DeVentier and Feldman (1993) have reviewed GIS application in hydrologic modelling and highlighted its utility in database management and modelling.

Further, Tsihrintzis et al. (1996) have reviewed the use of GIS in water resources and stated that the one difficult task of incorporating GIS with water resources modelling is the interfacing of water resources model with GIS and another one is that the data availability and compatibility, which are major constraints in running and implementation of GIS. Fedra (1993) stated that although the integration of water resources models, GIS, expert system and graphics is a challenging and promising development in the field of environmental research and applied informatics, there is a need of better tool to handle even more critical problems.

Spatial DSS (SDSS) is a new term given to the merging of GIS, DSS and water resources models to assist decision makers with decisions regarding water resources, which offers a new paradigm for the management of water resources (Bhasker et al., 1992; Leipnik et al., 1993; Walsh, 1993). One of the benefits of SDSS is that highly visual and interactive modelling and more considered analysis can be done on problem-solving capabilities by improved processes of human interaction and processes. The need of operational DSS that operate effectively in a spatial–temporal context is growing rapidly (Batty and Densham, 1996; Marble, 1999). Sewilam and Nacken (2004) have suggested a participatory DSS concept of a water resources management not only due to multiple objective and multiple participant decision making situations but also due to the complexity of participating different expertise in a modelling process.

To sum up the reviews of literatures shows that more research and implementation in particular of GIS and remote sensing technologies is needed in the area of water resources planning and management.

2.7 Applications of DSS in IUWM

Several efforts have been made to develop water resources decision support systems. Implementation of DSS for water resources management-related decision making can be found in the literature with number of case studies. Many DSSs have been developed for irrigation water management: estimating Reference Evapotranspiration (Biju et al., 2002); agriculture land and water management (Raman et at., 1992); GPFARM for agriculture water and land management (Ascough et al., 2001); COMBESICK fo r seepage prognosis (Herb and Graeber, 2002); SIMIS for irrigation management information system (Mateos et al., 2002).

Raman et al. (1992) have developed a DSS for crop planning during drought using an expert system for suggesting the optimal cropping pattern to be followed during drought was demonstrated with particular reference to an existing irrigation reservoir system. Arumugam and Mohan (1997) have developed the DSS for the operation of tank irrigation systems in the state of Tamil Nadu in India. The DSS is used by operators for assessing real time allocation of water from the reservoir to different channels for irrigation purposes. Bazzani (2005) developed a DSS for the economic-environmental assessment of agricultural activity focusing on irrigation, designed to answer both public and private needs. It is a useful tool for more sustainable agriculture and the definition of a sound water policy.

Rural Water Supply (RWS) DSS was developed by the Institute for Water Research at Rhodes University in South Africa. It is a planning and design tool for sustainable rural water supply which covers technical, social, environmental, and economic factors (Carmichael et al., 2001). Olsen (2005) has developed a prototype DSS called NRWS (Nilgiris Rural Water Supply) containing six modules for water sources yields, capital cost, operational and maintenance cost, impact of legal policy, rooftop rainwater harvesting, and water quality. NRWS uses similar concepts as RWS DSS, but focuses on evaluating the suitability of potential water sources based on a pre-defined set of criteria, as opposed to creating a computer program that organizes the logistics for developing rural water supply systems.

Kaur (2008) has developed a DSS for long term conjunctive use planning and management IMPASSE (IMPact Assessment and management of Saline Environments) which is a user-friendly field scale DSS designed for managing saline soils and waters in freely draining irrigated and rainfed agricultural lands. This DSS leads to the selection of most appropriate and sustainable agricultural practice.

Earlier, DSSs have been developed for integrated water management of river basin, watershed, agriculture, water demand forecasting, waste management etc. Some of the DSSs developed for integrated water management are listed along with their applications in Table 2.2.

The DSSs developed for integrated water management for agricultural area are THANNI, NELUP and Parched Thrust DSS (Table 2.2). THANNI have been developed for optimal water allocation between different water demand area The DSS has a database that holds basic hydrologic, agricultural, and urban data for use in an optimization model and management. NELUP DSS consist of models of ecology, economy and hydrology and environmental parameters and provides quantitative description of the economic and environmental impacts arising out of rural land use changes. Parched thrust DSS contains module for rainwater harvesting for irrigation. To identify the impact of change in agriculture land use on the basin, some water demand management strategies could also be included in it to make it more efficient.

Some of the DSSs have been applied for integrated water management of river basin i.e. AQUATOOL, Waterware, River ware, HANDSS, MODSIM, CDSS, and CTIWM (Table 2.2). River basin management is a highly integrated task. AQUATOOL consists of optimization and simulation models along with modelling capabilities for basin simulation, aquifer flow, and risk assessment although it does not have water quality components. Waterware DSS is sufficient to address the normal range of issues of river basin management, still some component could be added such as rainwater harvesting. Riverware solves policy problem through opyimization model. HANDSS can be used for some water budget and cost effective analysis. MODSIM DSS integrates other applications such as GIS and the groundwater model MODRSP. Colorado DSS (CDSS) has been developed for planning of future water related projects and has been implemented successfully in the two river basins of Colorado although it could have some environmental modules also. CTIWM consists of various hydrologic models for the river basin management.

Some DSSs have been developed for watershed management such as MULINO and WATERSHEDS (Table 2.2). MULINO-DSS, contains a common structure for integrating hydrologic, socioeconomic and environmental models in a multicriteria analysis tool, in the case no dynamic modelling has been done. Watershed management requires integration of water quality, rainfall-runoff, ecological and economical analysis. WATERSHEDS evaluate the non point sources pollution. LOWFLOW 2000 is a DSS, which integrates different modules of water and environment management. WEAP is an integrated approach for water policy management. Other applications of DSS in water resources planning and management are for domestic water demand forecasting (DFMS), wastewater management (MOSTWATER), DSS for rainwater harvesting (Mbiliny et al., 2007), IWADSS for water quality and eco-system. DFM is a part of WaterWare DSS, having multi objective decision analysis.

Haagsma (1996) states that the main problems arise in the procedure of model integration in DSSs for integrated water management are the exchange of data between different models having different ways of storing and retrieving data and setting in time steps. It can be seen that all the DSSs have different models and different parameters. NELUP and CDSS have been applied for two study areas, whereas most of the DSS are area specific. Future research can be done to make DSSs more flexible of selecting models or modules as per the area and it should be independent of specific area. Very few DSSs have been reported for urban area. Sample et al. (2001) developed a DSS for urban storm-water management that carries out hydrologic and economic analysis on small-scale neighborhoods. UCCAS is a GIS-based assessment system for planning in South Koria. McIntyre and Parfitt (1998) developed a DSS to select appropriate residential land development locations based on a hierarchal structure of factors weighted on a predetermined scale of relative importance.

Thus, it can be seen that various DSS have been applied successfully for integrated water resources planning and management although they have some limitations. As per the problem of urban area, some DSSs have been developed for storm water management and integrated water management without considering the concept of rooftop rainwater harvesting so for. Consideration of rainwater harvesting can help in reduction of inundation and can also be used to supplement water supply after applying some treatment method. Although, in urban areas people have significantly altered the natural environment, which needs to be addressed. Cities change the hydrological cycle and degrades the quality of water and cause harm to environment (Gomez, 2004; Rotmans et al., 2005). Therefore, urban area needs more attention of people and administration for the sustainable management of water resources. An ideal DSS should provide the desired information and understanding in a timely and cost-effective manner. Then it should provide a clear understanding of various issues associated with any particular problem and a basis for identifying and evaluating alternative ways to solve the problems.

Table 2.2. Application of DSS for integrated water management

DSS	Application
AQUALTOOL	Design for the planning stage of decision making for complex basin, including multiple reservoirs, aquifers and demand centers (Andreu et al., 1991; Andrue et al., 1996).
Water Ware	Water Ware is an integrated, model-based information and DSS a river basin planning tool. Its purpose is to assist government agencies of Europe for making better water resource management decisions (Jamieson and Fedra, 1996).
RiverWare	Eschenbach et al. (2001) developed a general river basin DSS called RiverWare that solves complex optimization problems by specifying a physical and economic model of the system, listing prioritized policy goals, and indicating linearization parameters.
HANDSS	This DSS is developed for integrated and sustainable management of Han river basin, Korean Peninsula. It contains three models to simulate the quantity and quality of water and optimal waste load allocation model for maximizing the utilization of water and minimizing adverse environmental impacts and conflicts (Hwanko et.al., 1998).
NELUP	The DSS has been developed to provide quantitative description of the main economic and environmental impacts arising out of rural landaus change around river basin (Dunn et al., 1995).
CDSS	It is a water management system and provides a key component to the planning process associated with future water construction project in Colorado (Annual report, 2005). (http://cdss.state.co.us)
WATERSHEDS	The main objective is to transfer water quality and land treatment information to watershed manager for land management / treatment decisions to access and evaluate NPS Pollution in a watershed based on user-supplied information and decisions (Osmand, 1999).
THANNI	The World Bank and Institute for Water Studies, Chennai has developed the DSS THANNI (Tools for the Holistic Analysis of Natural Network Information) as a tool for IWRM for irrigation i.e. optimal water allocations among users, cropping patterns, water pricing, water trades, optimal canal lining to reduce losses, etc. (IWRM, 1999).
MULINO	Multi-sectoral, Integrated and Operational DSS has developed for sustainable use of water resources at the catchments scale for Vela catchment, in the watershed of Venice Lagoon (North-Eastern Italy) (Jeunesse et al., 2002).
DFM	DFMS ((Decision Support System for Domestic Water Demand Forecasting and management) provides water resources planners with the facilities for estimating future water demand for domestic use and any demand and time period (Froukh, 2002).

WEAP	WEAP (Water Evaluation And Planning) system takes an integrated approach to water resources planning; developed by the Stockholm Environment Institute to provide a framework for policy analysis. It include a water demand and conservation analysis, water rights and allocation priorities, groundwater and stream flow simulations, reservoir operations, hydropower generation, pollution tracking, ecosystem requirements, and project cost-benefit analyses (Levite et al., 2003; Alfarra, 2004).
CTIWM	CTIWM, developed for to support the testing and evaluation of water management policies and at facilitating integration of user-selected scenarios into planning strategies of the water resource system in the Chikugo River basin, a multipurpose multi-reservoir system (Ito et al., 2001).
IWADSS	Integrated Water Assessment Decision Support System (IWADSS) has been developed by Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management; to aid government decision makers who deal with activities that potentially affect the water quality and aquatic ecosystem health of coastal waters (Harris et al., 2005).
Low Flows 2000	Low Flows 2000 is a fully integrated water-environment decision support system, which combines various hydrological models to address real-world water resource issues in U.K. (Holmes et al., 2005).
UCCAS	Urban Carrying Capacity Assessment System, is a GIS-based carrying capacity assessment system, integrates seven factors energy, green areas, roads, subway systems, water supply, sewage treatment, and waste treatment, for the planning and management of urban development in Seoul, South Korea (Oha et al., 2005).
MODSIM	MODSIM is a generalized river basin Decision Support System and network flow model developed at Colorado State University designed specifically to meet the growing demands and pressures on river basin managers today (Fredericks et al., 1998).
DSS for Rainwater harvesting	Mbiliny et al. (2007) have developed a (GIS)-based decision support system (DSS) that uses remotely sensed data, limited field survey and GIS to identify potential sites for RWH technologies. The GIS-based DSS will facilitate planning, implementation and promotion of RWH activities, as well as monitoring and evaluation of land resources in the targeted areas.
Parched thrust Rain water harvesting	The DSS has been developed to simulate the important processes in micro-catchment rainwater harvesting system (Young et al., 2002).

2.8 Summary and Research Needs

An exhaustive literature review has been done to identify the problems and strategies of water management in an urban area. Integrated water management for urban area should contain sustainable water supply with the aim of reduction of water shortage, water demand measures, ground water recharge and reduced runoff. As water quality is also an essential component but in the present study the major problem is to reduce the severe water shortage problem on priority with the aim of sustainable development has been considered.

DSS are becoming popular for supporting a complex decision making in water resources planning and management. From the wide literature review on DSS and IWRM, Integrated urban water resources are found to be emerging area for the sustainable development of the existing water supply resources. Earlier, the DSSs have been developed in many fields of water resources: irrigation water management, water policy, water allocation, river basin management, watershed management waste load allocation etc. There is a need of developing a DSS for integrated water management for a city, as cities are the area of catchments having high population density and high water demand.

Only a limited number of DSSs have been developed and used in the past for water management of urban area; DSS LLDA for water supply from a Lake (Nauta et al., 2003) and urban flood management (Sample et al., 2001; Abebe and Price, 2005). Qinhuangdao Hydro Engineering Management Information and Decision Support System (QHEMIDSS), has been developed for management of water supply from Qinglonghe River to a city Qinhuangdao, North China. The DSS contains the model for water supply, allocation and flood control are the key issues (Zhang, 1993).

The scenario based approach should be done to achieve the aim of sustainability. Within urban areas there is a need for developing a DSS that determine suitable scenario to deal with the water demand and water supply problem within integrated framework to achieve the goal of sustainability. Multiattribute/mutiobjective decision-making in complex water management processes consists of multiple attributes to estimate or identify, compare and evaluation of different scenario and helps in choosing the 'best decision' to achieve an objective. The DSS for integrated urban water management should be able to give answer to various water related problems of a city: water supply and demand, potential of rainwater harvesting, groundwater recharge, runoff harvesting, and best ranked alternative for sustainable water supply.

Chapter 3

DESIGN AND DEVELOPMENT OF THE DSS

3.1 General

Design and development of a Decision Support System (DSS) requires many processes such as integration of models/modules, development of main interface, database management, testing and validation of different interfaces. Each subsystem is connected with another subsystem and so, development of a DSS is very complex and difficult process, which requires a systematic approach. Problems and challenges in developing the computer based DSS are selection of software, integration of software, analysis, and developing an easy user-interface. To gain wider acceptance, computer based DSS should have a user-friendly graphical interface, state-of the-art analytical capacity and needs to be integrated with various spatial and non-spatial databases. The following section will highlight the procedure for the development of the DSS.

3.2 Processes Involved in Development of the DSS

Development of a DSS for integrated urban water management (IUWM) is a very complex and difficult task having integration of three main components, viz. database subsystem, model subsystem and user-interface. The three subsystems constitute the logical framework of the DSS. Figure 3.1 shows the general diagram of a DSS, where primary consideration is user's needs and wants. The step-by-step process for building a DSS is shown in Fig. 3.2. The first step is the identification of problem, which involves finding/listing the questions which should be answered by the DSS. The second step is to make a conceptual diagram of the problem i.e. what processes are required for solving the user's problem. On the basis of the conceptual diagram, the analytical process to be included in DSS can be finalized. The third step is to make a framework of the DSS which involves the details of the components of the DSS such as the analysis, utility modules, flow of data among the modules etc. After the preparation of framework of a DSS, programming part starts. This involves writing the computer program in the chosen language for different subsystems of the DSS. Sometimes, to make the modules more efficient and user-friendly, procurement and customization of commercial software may be essential. Software development is an iterative work. As the development of various modules progresses, an already developed module may require modifications since the modules may be interdependent. Further, the output file of a module may be the input file for another module or two different modules may share the same data files. Thus the modification is a time consuming task, which requires patience. Testing and validation of a DSS is done by the input of actual field data and checking and cross verifying the result.

This chapter includes the framework of the DSS and development of software for building and design of the DSS by developing utility modules, flow of data among the modules. This is done by taking the actual data of Dehradun city. Large amount of raw database from different sources in different format were collected and converted into suitable formats as per the requirement of components of the DSS. Database preparations have been discussed in Chapter 5. Further, testing and validation of the DSS have been demonstrated in Chapter 8.

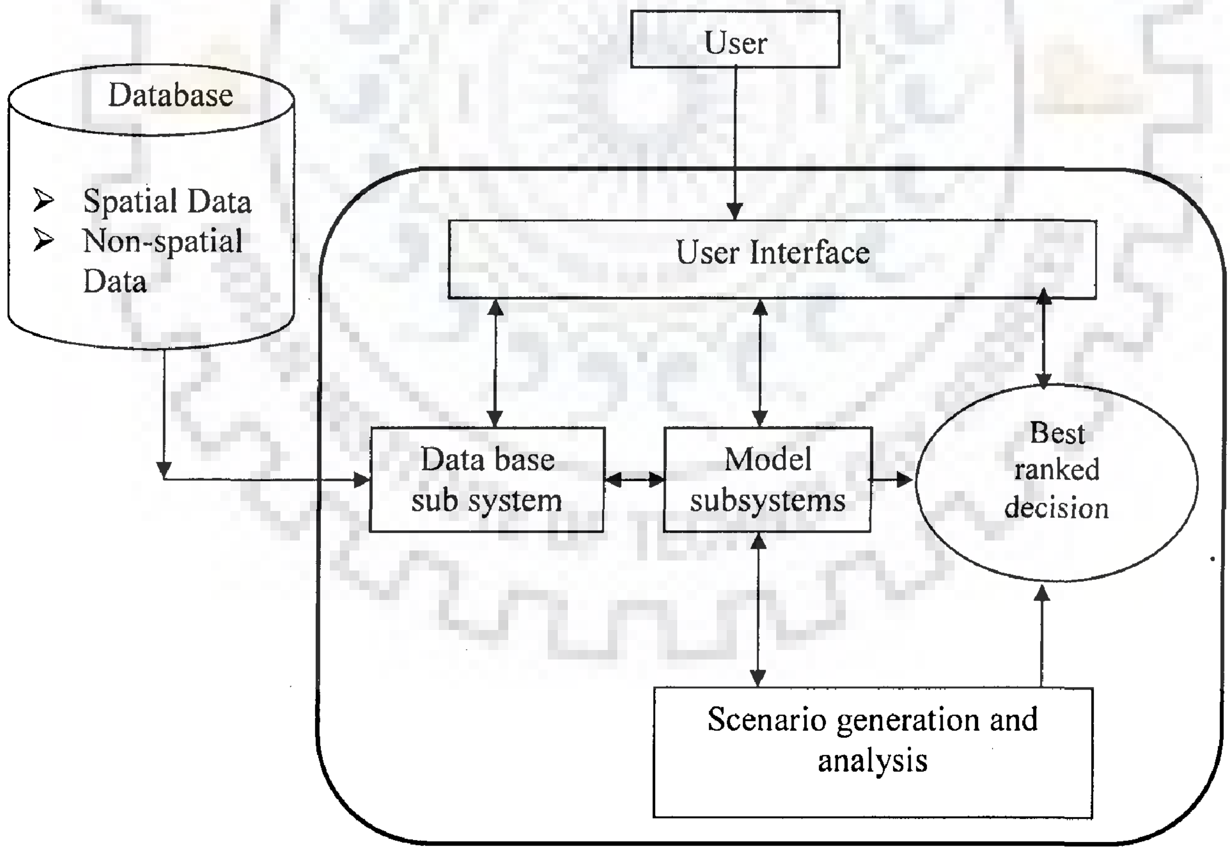


Fig. 3.1 Conceptual diagram of a DSS

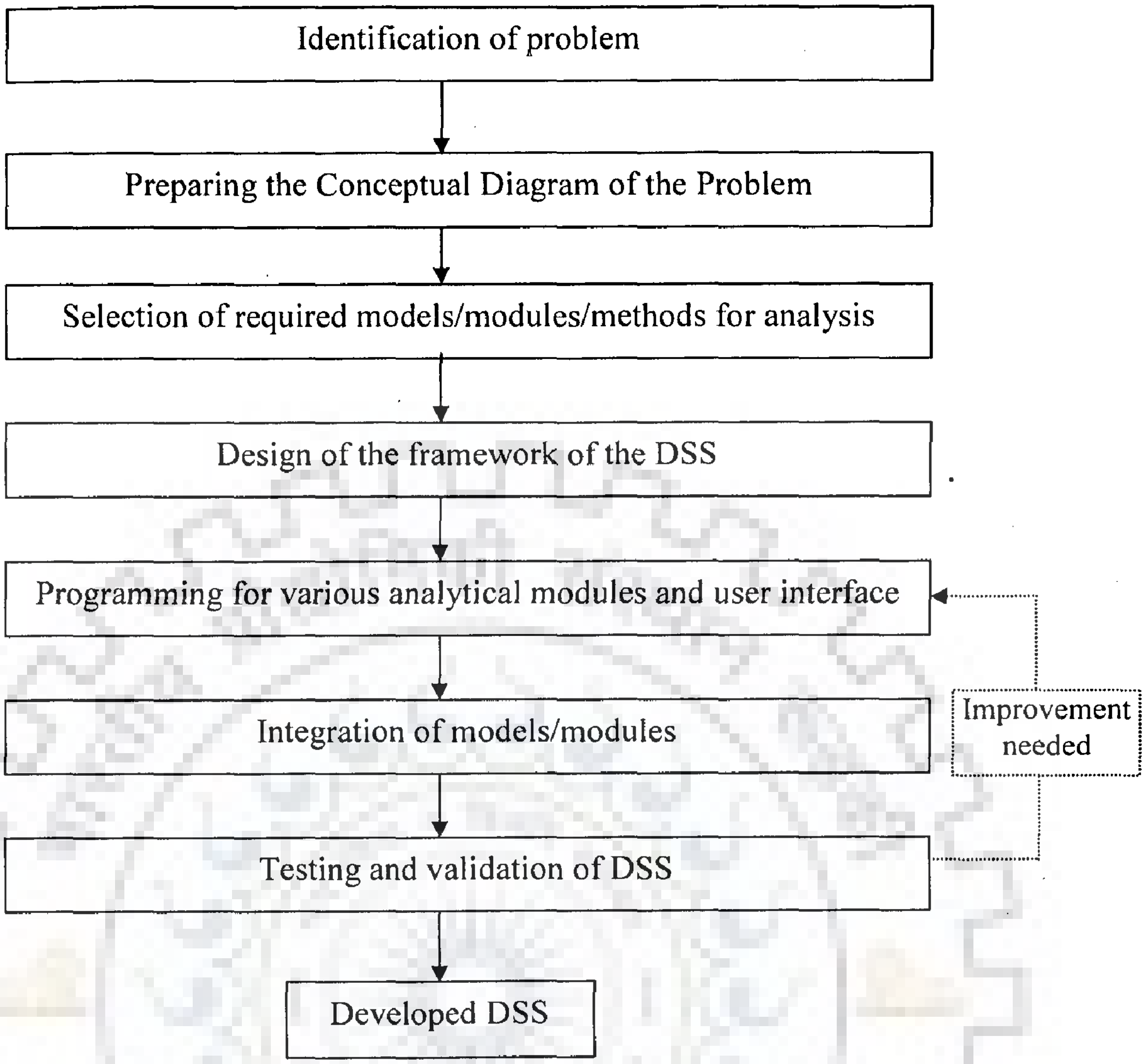


Fig. 3.2 Steps for developing a computer based DSS

3.3 Framework for the DSS

Integrated water resources management is the set of technical, institutional, managerial, legal and operational activities required to plan, develop, operate and manage water resources. It requires management of large amount of spatial and temporal data. Many organizations are using GIS in water resources modelling due to its spatial features and analytical ability. The user can retrieve the information from the data using the spatial and logical query with the associated attribute table of the data.

Figure 3.3 shows the framework of the DSS, which comprises of three main subsystems: database subsystem, analytical modules subsystem and user-interface. Besides, pre-and post-processors are the tools required to convert the data from user- friendly manner to the format required by the analytical modules. DSS requires different information through the input data. Data needed for the present work are various spatial data such as boundary map, ward map, water supply sources, geological map, soil map, land use, contour map.

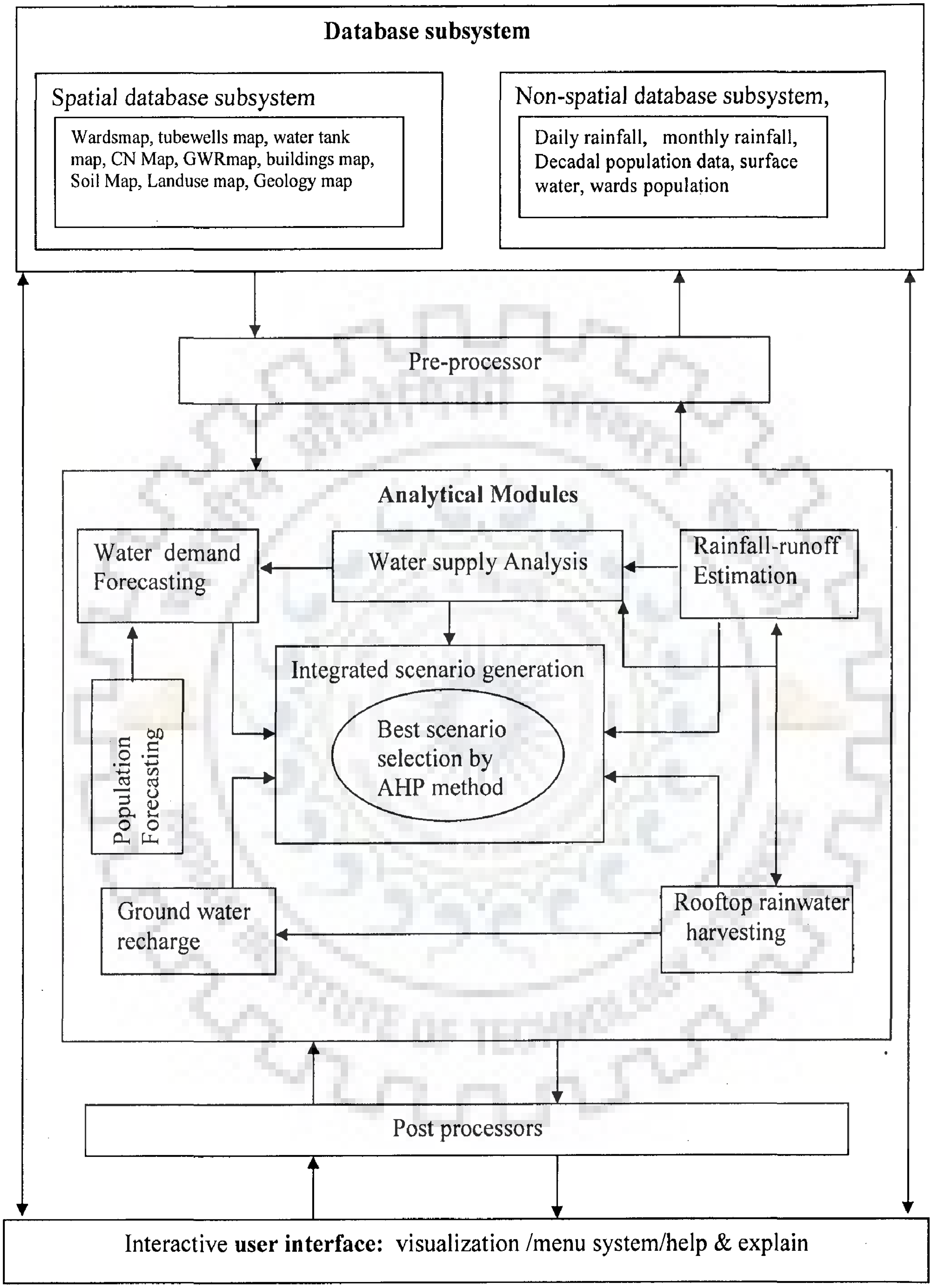


Fig. 3.3. Framework of a DSS for integrated urban water management

Data sources are various organizations, satellite data, master plan etc. Non-spatial data are rainfall data, decadal population and ward-wise population, surface water supply in mld, runoff coefficient etc. Details of the data have been discussed in Chapter 5. Therefore an efficient database subsystem must be a part of the DSS, which allows the users to define, create, and maintain the spatial and non-spatial database, and offers controlled access to this database. It can be seen that database subsystem of the DSS is capable to manage spatial, non-spatial data, temporal data, knowledge based data and text data. Model subsystems of the DSS comprise of various analytical modules such as water supply, water shortage, population forecasting, rainfall–runoff, roof top rainwater harvesting, and Analytical Hierarchal Process (AHP). Details of modules and their sub modules are shown in Fig. 3.4.

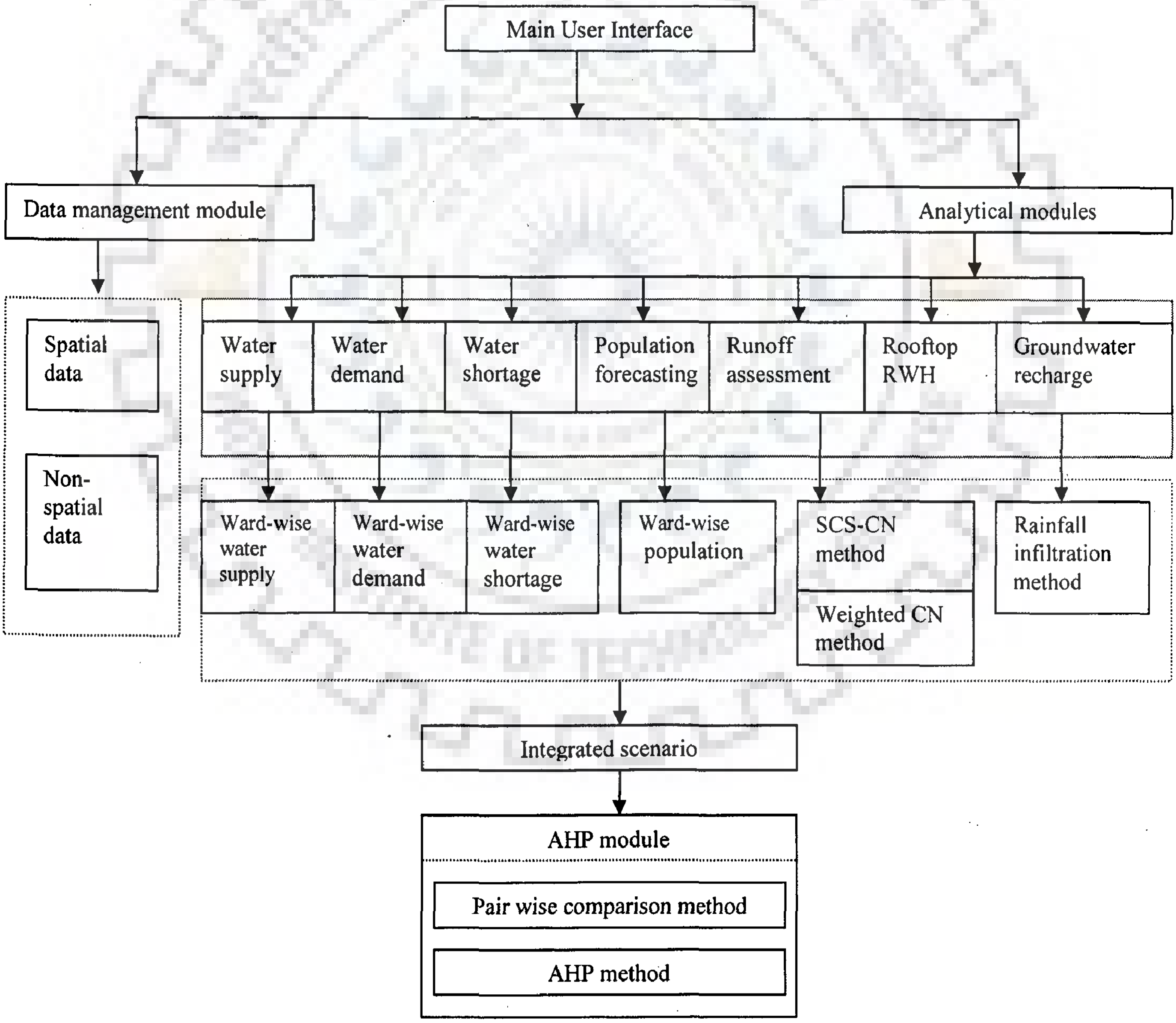


Fig. 3.4 Details of Modules and sub modules in the DSS

The user-interface is the vehicle of interaction between the user and the DSS. The DSS comprises the main interface, from where user can access the required database subsystems or analytical modules. Every module has a menu based user interface, which allows the user to easily understand the required steps. In addition to that, help is also available to understand the process completely. Use and utility of a DSS increases manifolds if it has a real user friendly interface.

3.4 Programming Languages for Software Development

Building of the computer based decision support system requires complete knowledge of a programming language to develop the software after preparing the framework. All components or subsystems in a DSS should be developed preferably using the same operating system. With the recent advances in the information technology, there are many alternatives to develop the software-based DSS. Generally, the design of the DSS depends on the availability of resources. Available programming tools are Visual Basic (VB), Turbo C++, and Visual C++. The Visual basic 6.0 was selected as the main programming language in this case, as it is easy to understand and has good graphical capability. It can be easily connected with the MS Access database, which is used to manage temporal data such as decadal population and rainfall. One of the limitations of 'Visual Basic' was to access the spatial data in the vector format. Since almost every water resources process requires visualization of GIS and satellite data, this limitation of 'Visual Basic' is overcome by its customization with MapObjects ActiveX control. Commonly used GIS softwares are Arc/GIS 9.0, MapInfo, ArcView, MapObjects etc. Here, MapObjects is selected to develop the DSS as its customization with Visual Basic, can develop standalone software. Although spatial database have been prepared in ARC/GIS 9.0 and ERDAS 8.6, in future most of the spatial data will be available as shape files from various agencies and then user would be able to use shape files directly in the developed DSS.

Development of software DSS has been done in MS Visual basic and MapObjects 2.4 at front end and MS Access is used at back end of the software. List of the software used to develop the DSS are presented in Table 3.1 and the software used to develop each components of the DSS are presented in Table 3.2.

Table 3.1 List of the software used to devleop the DSS

S.No.	Software	Version	Developed by
1.	Visual Studio Professional Edition	6.0	Microsoft Inc., USA
2.	MapObjects	2.3	Environmental Systems Research Institute (ESRI), Redlands, California, USA
3.	MS Office Access	2003	Microsoft Inc, USA

Table 3.2 Components of the DSS and software used for their development

S.No.	Component	Module	Software used
1.	User- interface	Non spatial data	Ms access and VB 6.0
		Spatial data	MapObjects 2.4, VB 6.0
2.	Database	Non spatial data	MS Access
		Spatial data	MapObjects 2.4 , VB 6.0
3.	Analytical modules	Water demand Water supply Population forecasting Water shortage Rooftop RWH Rainfall-runoff analysis Groundwater recharge module	Ms access , MapObjects 2.4, VB 6.0
		AHP, Pair-wise comparison method	Ms access and VB 6.0
		Scenario generation	

The following section briefly describes basic principles of VB programming and its functionalities with ActiveX control MapObjects.

3.4.1 MS visual basic

Visual basic is an Integrated Development Environment in which an application program can be developed. It is one of the most powerful programming languages available these days with very good graphical capability. Table 3.3 shows a brief description of main components of Visual basic. It can be seen that VB has two sides of programming: (i) Inserting forms and putting controls over it so as to make a graphics, and (ii) Writing codes to activate the control and perform the desired operation. Items associated with each objects are given in Table 3.4. User-interface is created by drawing controls on a form. The properties can be set for the *form* and *controls* such as caption, colour, size etc. Finally, the code is written to develop the required application.

Table 3.3 Components of Visual Basic and their description

Sr. No.	Objects	Description
1.	Forms	In Visual Basic, a window is called a form. Each form includes a title bar at the top. It may include a menu bar or status bar. All controls can be dragged and dropped in the form.
2.	Controls	The icons with which the user interacts are called controls. Commonly used controls are command buttons, check boxes, labels, lost boxes and menus.
3.	Objects	The forms and controls are collectively referred as objects. Most of the objects are associated with the events. They are also associated with their own properties and methods.

Table 3.4 Description of Items associated with objects

S.No.	Item	Description
1.	Properties	Objects include properties that generally define the appearance of behavior. The choice of properties depends on the type of object.
2.	Methods	Some objects also include special program statement called methods. A method brings about some predefined action affecting the associated object.
3.	Events	Code associated with an object is always assigned to an event procedure. Most commonly used event processes are click event, double click, drags and drops and so on.

When user clicks to 'open a file' from the file menu, one window opens up and the one *form* can be selected. Figure 3.5 shows the screenshot of opening a standard EXE form to the main window of visual basic. After selecting a form, controls can be put over it. Some common controls used in the DSS area *Common Dialog box*, *command button*, *text box*, *calendar control*, *data control*, *colour dialog*, *combo box*, *List box* etc. *Common dialog* control is used to open a file. A *command button* is typically used to start an event that performs an action such as closing a form, moving to a different record, methods for some analysis, and so on. *List box* and *combo box* are used to select a data from a list to the application. *Text box* is used to write a data for further use in programming. *Calendar control* is used to select a date from a calendar for easy understanding and visualization. *Colour dialog* is used to select a colour for visualization of the classified map.

To manage the non-spatial data, database programming can be done in VB by using a *data control* and a *data access objects*. The *data* control gives access to the database by setting its few property. *MSflexgrid* control is an extremely useful tool for displaying data. It has the limitation that user can not edit the cell. Therefore, this control is used in tabular calculations. The *datagrid control* has the ability of to display data in row and column format. Further, this control allows the user to edit and update the data. Therefore this control has been used in database module.

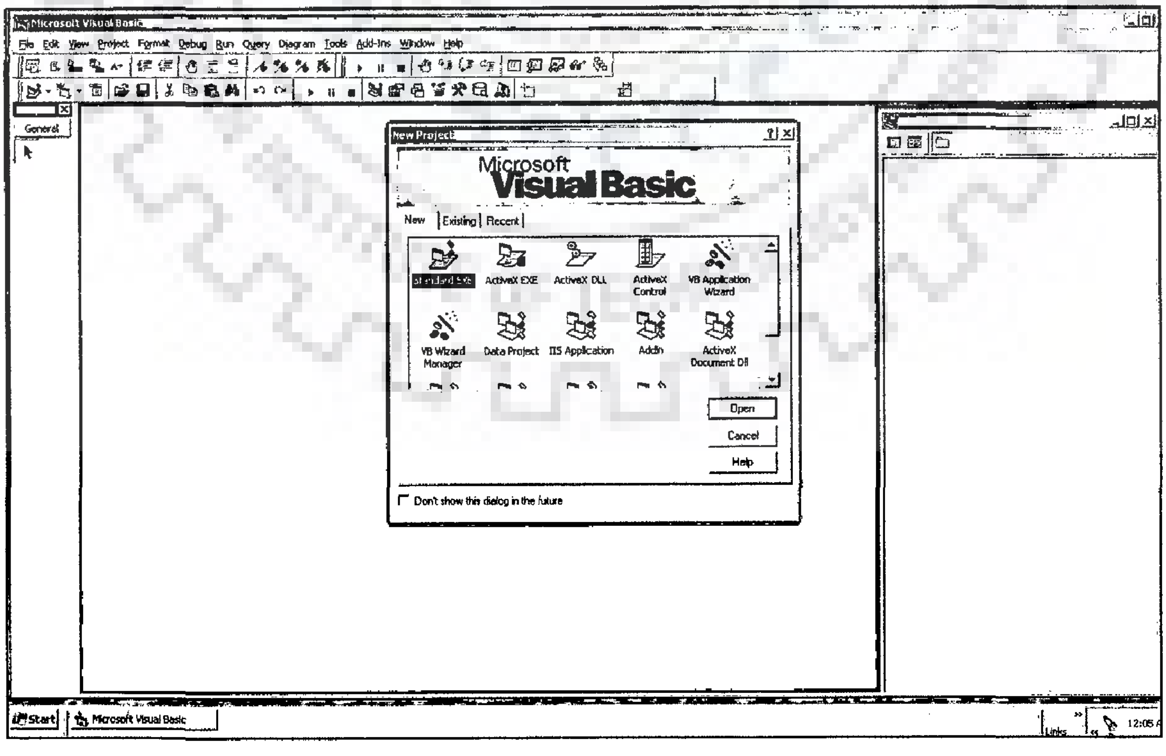


Fig. 3.5 Inserting a Standard EXE form to the window

Data search was developed based on the Structured Query Language or SQL as it is commonly called. The SQL is a particular language that has emerged from the development of the relational model. It is a non-procedural language and is relatively easy to learn. SQL is essentially free-format which means that the statements do not have to be typed at particular locations on the screen.

For making graphical user interface, different menu and radio buttons are required to access various modules and query. Radio button toolbar is a set of two or more options that are mutually exclusive. In order to build the Radio button toolbar, Image List control is added the Visual Basic project as shown in Fig. 3.6. Image List control can be accessed by adding Microsoft Windows Common Controls 6.0 from the components of project menu.

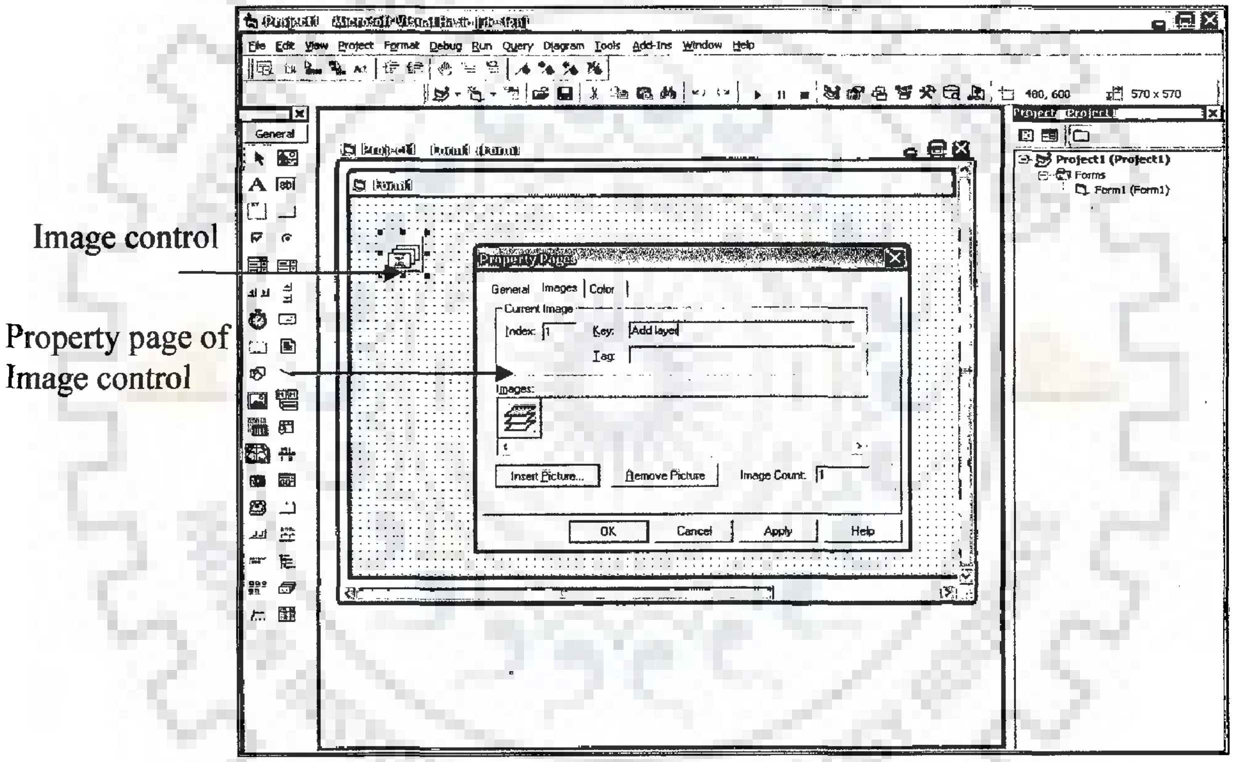


Fig. 3.6 Adding a button toolbar to the form

3.4.2 MapObjects

ActiveX controls were originally called Object Linking and Embedding (OLE) controls. An ActiveX automation control is a software component that lets the user add specific functionality within an application that is an ActiveX container. An ActiveX object is a programmable object accessed through an ActiveX server. Examples of ActiveX containers and ActiveX servers are Visual Basic, Visual C++, PowerBuilder, Delphi, and Microsoft Access. The MapObjects provides the linkage between any object oriented programming language, such as VB, C++, Borland and Java and GIS database. Therefore, it is quite easy to access the GIS component from within the software. MapObjects provides flexibility for creating customized interfaces for maps as it contains a set of mapping software components that help the programmer by adding dynamic mapping and GIS capabilities to existing windows applications or to build custom mapping and GIS solutions. MapObjects comprises an *ActiveX control* called the *Map control* and a set of 46 ActiveX automation objects, each containing the analysis and display capability information of GIS data. *Map control* helps the programmer by adding dynamic mapping and GIS capabilities to existing windows applications or to build custom mapping and GIS solutions. MapObjects provides flexibility for creating customized interfaces for maps.

3.4.3 Customization of software

When a new project is opened in visual basic, toolbox contains some, but not all of the custom controls available with the software. Instead of loading the required controls every time, it is convenient to create a project template of the required controls. The first step is to open a standard EXE form as already shown in earlier Fig. 3.5. Then MapObjects component is loaded from the *components tool* of the Visual Basic as shown in Fig. 3.7. After loading the MapObjects component to the Visual Basic toolbar, *Map control* is dragged to the form (Fig. 3.8), and the project is saved at template directory of VB and type MO.vbp. Now, any time the developer can open the visual basic and choose the MO template that contains the *Map control* in the toolbox as shown in Fig. 3.9.

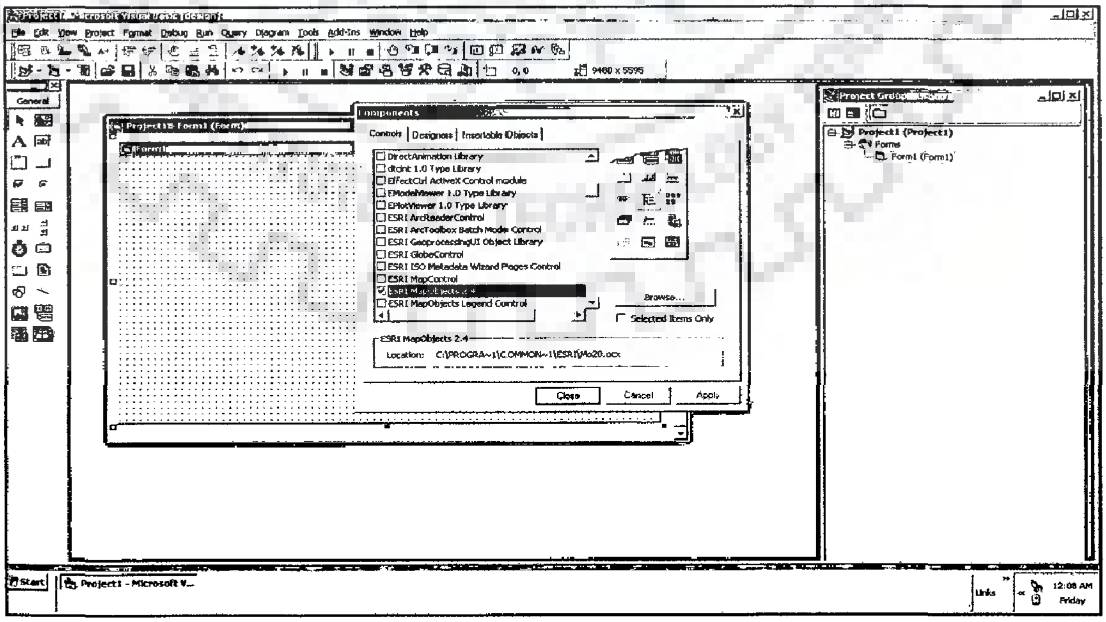


Fig. 3.7 Loading map control from components toolbox in Visual Basic

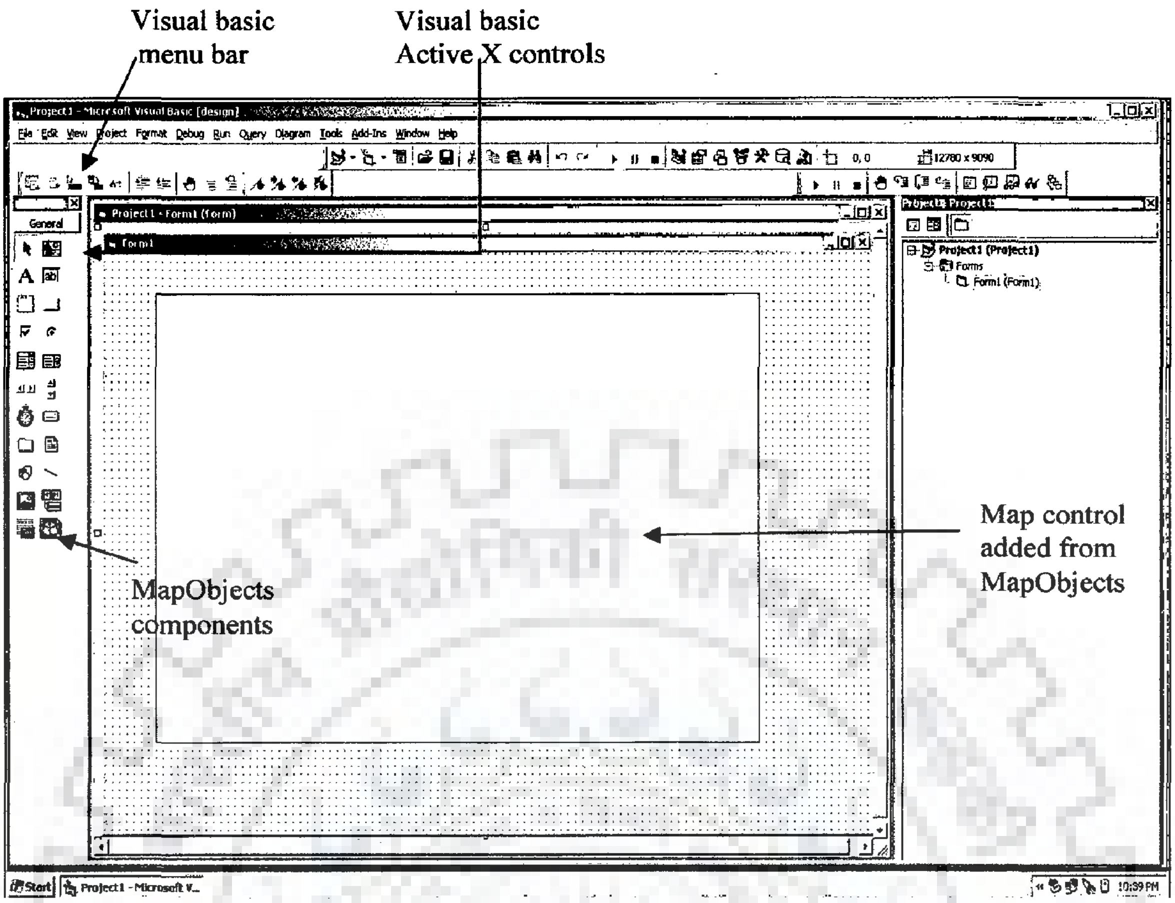


Fig 3.8 Adding Map control from MapObjects components

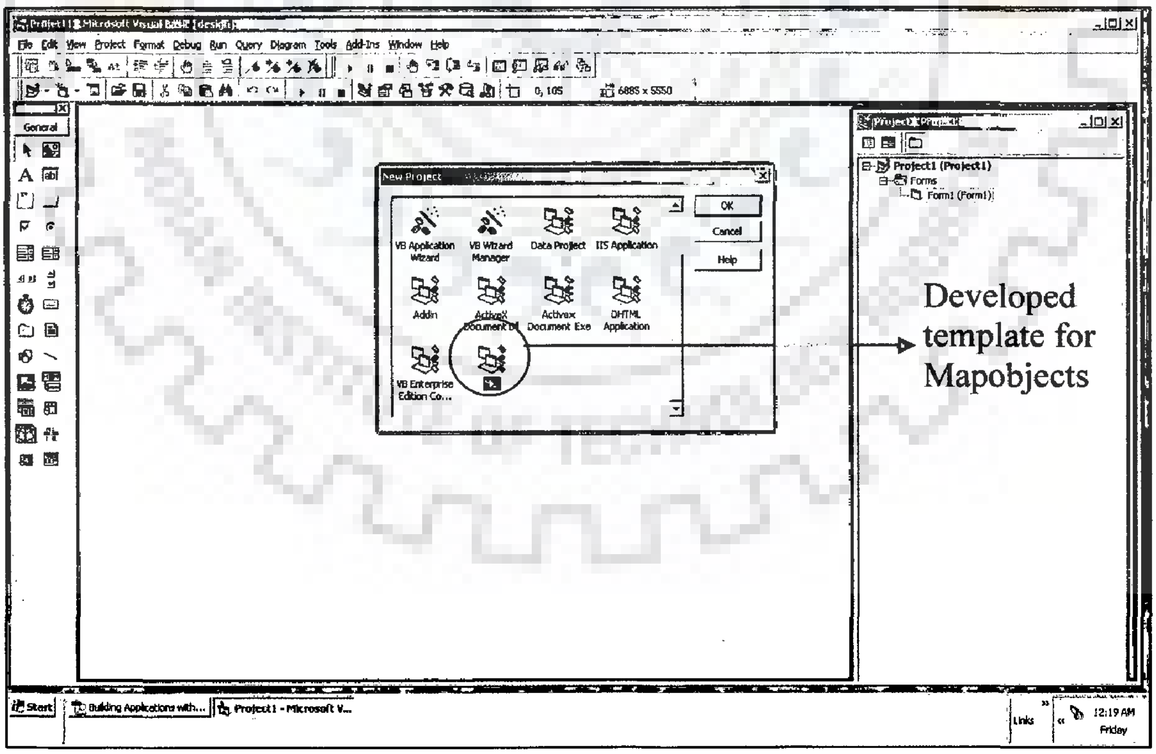


Fig. 3.9 Developed template for MapObjects in Visual Basic

The data sources supported by MapObjects are Shape files, ArcINFO coverages, Spatial Database Engine™ (SDE™) layers, Computer-aided design (CAD) drawings, Vector product format (VPF) files, Attribute tables, Grid data and Image files. Here, shape files (*.shp) are input spatial data for DSS. A shape file is an ESRI data file format for storing geographic features in vector format. The entire spatial databases have been prepared in ArcGIS 9.0 and ERDAS 8.5 would be discussed in Chapter 5. Programs built with MapObjects will run on windows operating systems. MapObjects based applications are built by a developer and can be delivered to an end user.

3.5 Database Management Subsystem

Database subsystem is designed to store data, manipulate the data, to serve as input to the model subsystem, and to display the output in required formats. Therefore, it can be said that database is a core component of any DSS.

A database management system allows the user to store data in an organized form and retrieve it on the basis of specified selected criteria, to serve as input to the model subsystem and to display the output in required formats. Characteristics of a database are its ability to integrate data from several files and various sources. Planning and management of water resources system requires large amount of spatial and temporal data. Decision making requires information and this needs to be collected. Developed database subsystem comprises a graphic user interface for (a) non-spatial data and (b) spatial data. Details of the database modules have been described in the following sections.

3.5.1 Non spatial database management module

Water resources management work requires much information related with rainfall data such as general trend of rainfall, average daily rainfall, hourly rainfall, maximum rainfall etc. This module provides general information related with rainfall of the study area. User can input rainfall data from the database saved in any location. Rainfall database is prepared in a specified format in MS Access (*.mdb) file. The database contains four tables for monthly rainfall, daily rainfall, hourly rainfall and annual rainfall. Different tables are prepared because of availability of the data are different for monthly, daily, hourly and annual rainfall. As per the present study monthly rainfall data is available for 30 years, daily rainfall data is available for 10 years, hourly data is available for 5 years The user has the flexibility to open database located in any directory of the systems through *Common Dialog* control as shown in

Fig. 3.10. After linking the database user can see all the associated tables in a *combo box* and can select any one table. As soon as user selects a table, the table would be displayed in a *datagrid* control of VB as shown in Fig. 3.11. If data table have more rows and columns, then table can be scrolled vertically and horizontally. Description of menu and submenu of the non-spatial database module with their user-interface are presented in Table 3.5.

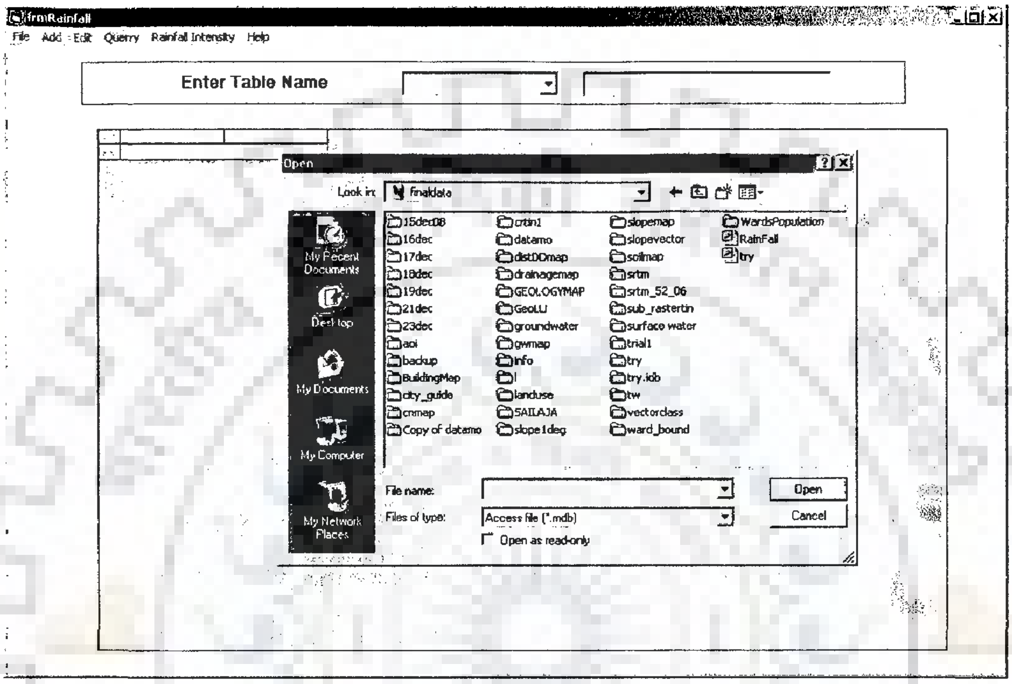


Fig. 3.10 Graphical user interface for non-spatial database management subsystem

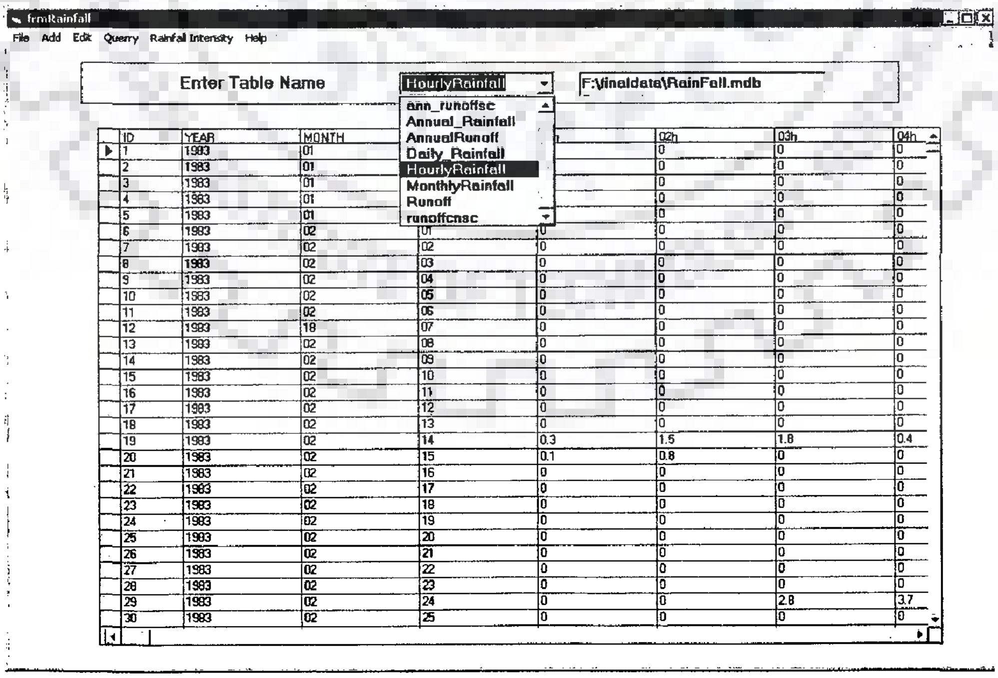
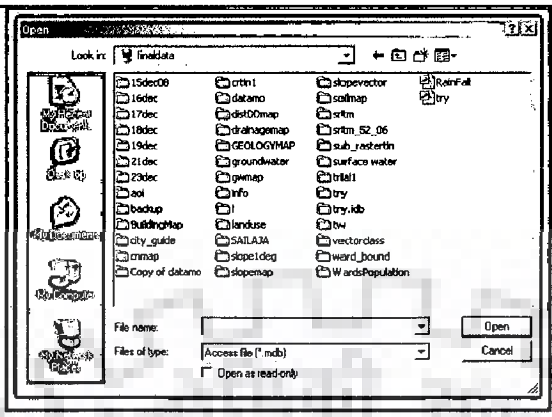
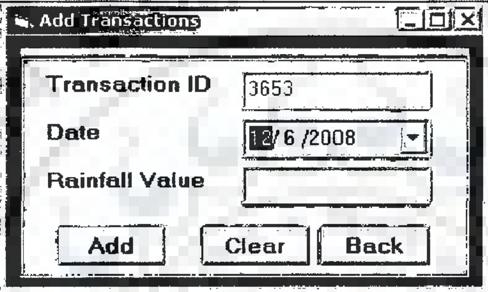
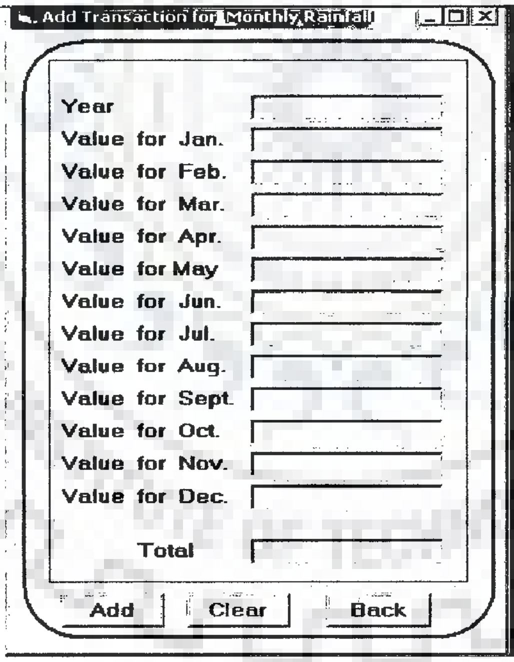
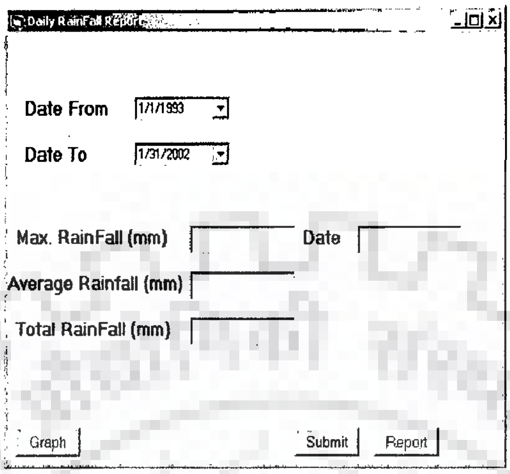
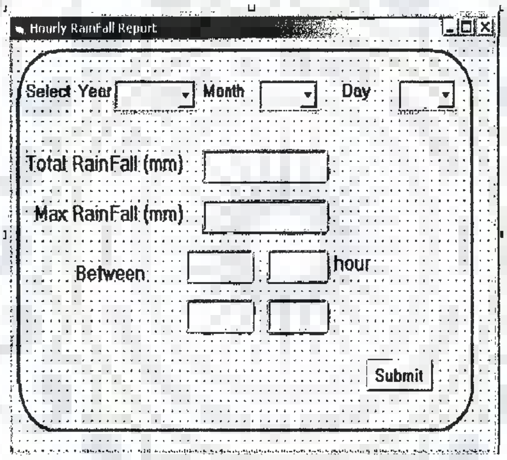
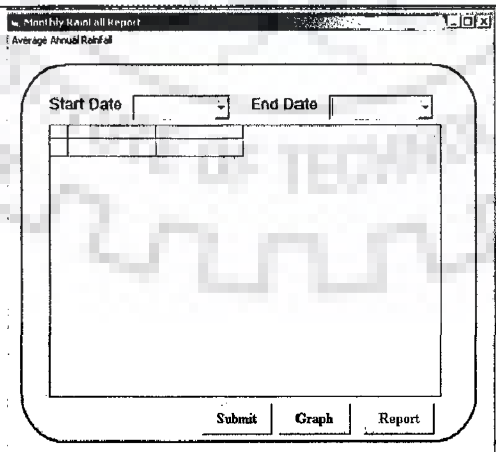


Fig. 3.11 Hourly rainfall data displayed through GUI

Table 3.5 Description of menu, submenu and user-interface for rainfall data

Menu	Options	User-Interface	Description
File	Link the data		Clicking on this menu will open a *Common Dialog box* to browse the database and user can select a table to open.
Add Data	Add Daily		Clicking on this menu will open a different user interface and user can enter the required data. When user clicks to the command button "Add", the values will be added to the corresponding table.
	Add Monthly		
Edit Data	Edit Daily	Same as user interface of "Add Daily" and "Add Monthly" Rainfall	User can edit/update any data from the table.
	Edit Monthly		

	Edit Hourly	To edit hourly data, user can directly edit it on data grid at main user interface.	Data can be edited directly in the hourly rainfall data.
Query	Daily Rainfall		User enters two dates and can get the following information between them: • Average rainfall (mm), • Maximum rainfall (mm) • Date of maximum rainfall • Total rainfall (mm) Graphical view of rainfall vs time
	Hourly Rainfall		• The day and time, when the maximum rainfall occurs • Graphical view of rainfall and time • Rainfall intensity at a particular day
	Monthly Rainfall		User enters two values of years and can get the following information between them: • Maximum monthly rainfall • Average monthly rainfall • Bar chart of maximum and average rainfall

The code for operating this module is given in Appendix A.

3.5.2 Spatial database management module

A number of parameters are required for water resources planning. Large quantities of spatial as well as non-spatial data are required in decision-making process. The collection and proper organization of updated and reliable data, both thematic and attribute is necessary for any study. As already discussed, MapObjects software are a set of mapping software components that allow the programmer to add dynamic mapping and GIS capabilities to the existing windows applications or to build custom mapping and GIS solutions. Here, properties and methods of Map controls are used with other Visual Basic controls to build well efficient spatial database management module. Figure 3.12 shows the Graphical User Interface (GUI) for spatial database management subsystem. It can be seen that the main user interface consists of a main menu, a button toolbar, a list box and two combo boxes to select a layer and to select a field. The brief description of its main menu containing submenu of 'File', 'Query', 'Classification', 'Bar-chart' and Help are given in Table 3.6. Users have been given flexibility to open file from any directory, user defined classification of map, to display attributes, to search a record, and visualization by bar chart. Button toolbar contains the buttons for 'Add layer', 'Zoom-in', 'Zoom-out', 'Pan', and 'Help'. *List box* contains list of all the map layers added to the subsystem. Here, *Checkboxes* have also been provided to display the maps selected by the user from the *list box.*

After adding the required shape files to the spatial database management subsystem, user can do some query analysis on the selected map layer. The combo boxes and list box are used to select a map layer and its fields and records from the list. ActiveX objects of *Map control* such as *Data access objects* and *Map display objects* are used to develop the spatial data management subsystem. *Data access objects* allows the user to establish connections to map data, update shape attribute values, and return shapes and attributes from features on the map. Main data access objects used are *Data Connection Objects*, *Geodatasets, Recordset, Tabledesc, Fields object, Statistics objects* etc. Here, the properties and methods of a *Data Connection object* is used to establish a connection to *GeoDatasets.* A *Recordset object* represents records in a map layer. A *TableDesc object* contains information about the fields in the table associated with a *Recordset.* A *Field object* represents a list of fields of shape files. Further, a '*Statistics' object* represents simple statistical information about a *Recordset.* User can calculate the statistics on the *Recordset.* The submenu 'Save', 'Find', 'Attribute' and buttons of button toolbar 'Add layer' and 'Identify' have been developed using the above data access objects. When map layers are added to the DSS, related *combo boxes* add all the map layers. As soon as the user selects a map layer one *field object* sets its property for the selected map layer and thus all the fields associated with the map layers can be accessed through any *combo box* or *list box*. When the user selects a field from a list, the property of a record set object is set for that field and the user can access all the records of that field. This concept is used for the development of all the menus in the DSS.

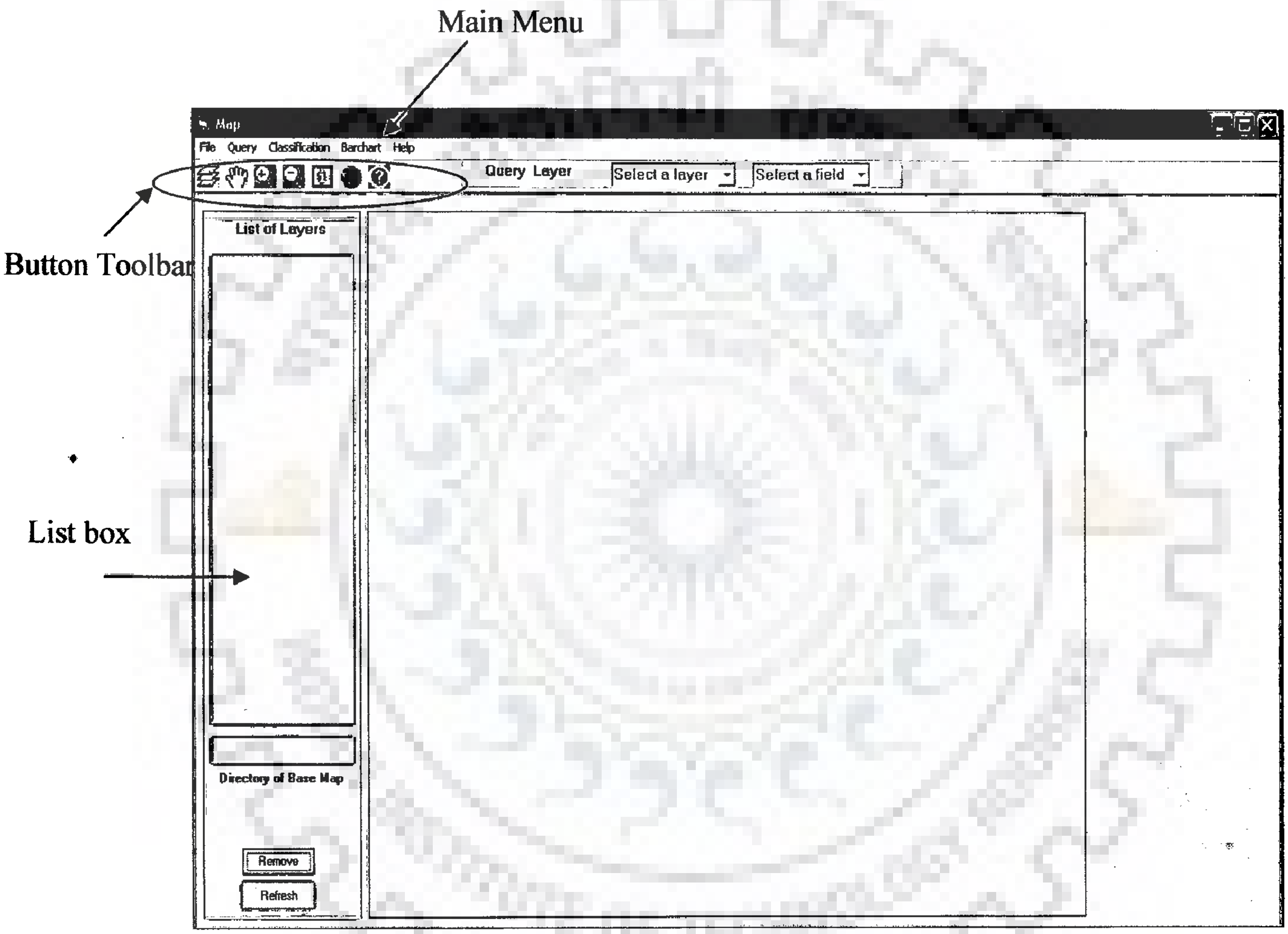


Fig. 3.12 Graphical user interface for spatial database management module

Table 3.6 Main menu of Graphical User Interface (GUI) of spatial data

Menu	Sub-menu	Description
File	Save	Clicking the save allows the user to browse for and save the selected map in query layer.
	Print	Clicking the Print allows the user to print the selected map.
Query	Find	Clicking the find opens a 'Find dialogue' to search any record of any field of any layer opened in map layer spatially (Fig. 3.13).
	Attribute	Clicking the attribute opens an attribute dialogue to allow the user to view records of the selected fields of any layer opened in map layer. The user can select at a time 3, 4 or 5 fields and their records will be displayed (Fig. 3.14).
	Annotation	Clicking the annotation allows the user to display the records of a selected field spatially.
	Weighted Value	Clicking the weighted value allows the user to display weighted value of records of a selected field.
Classification	Base Map	Clicking the base map allows the user to display the map for anyone selected numerical/string field.
	Classes	The numerical field of any map can be classified statistically.
	User-Defined Class	User can classify the map as per the requirement.
Bar-chart	--------------	Clicking the bar-chart allows the user to compare various records of a field of a layer by depicting the attributes as elements of a bar chart.
Help	--------------	Clicking the help button will open the user's manual of DSS.

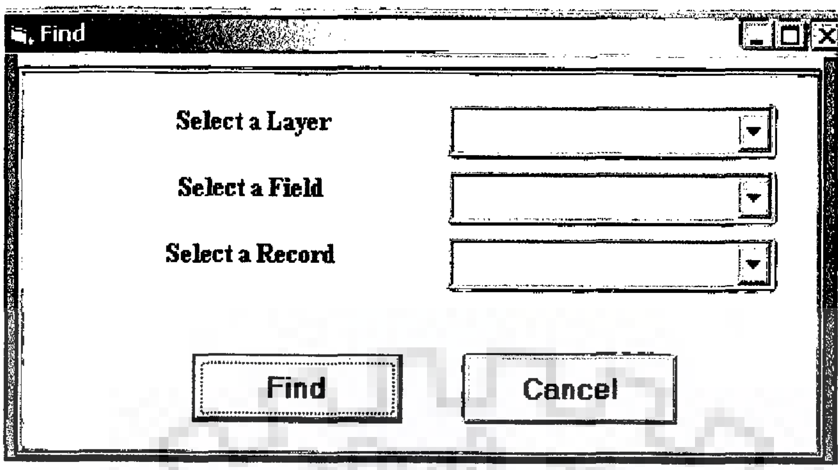


Fig. 3.13 User-Interface for 'Find' submenu.

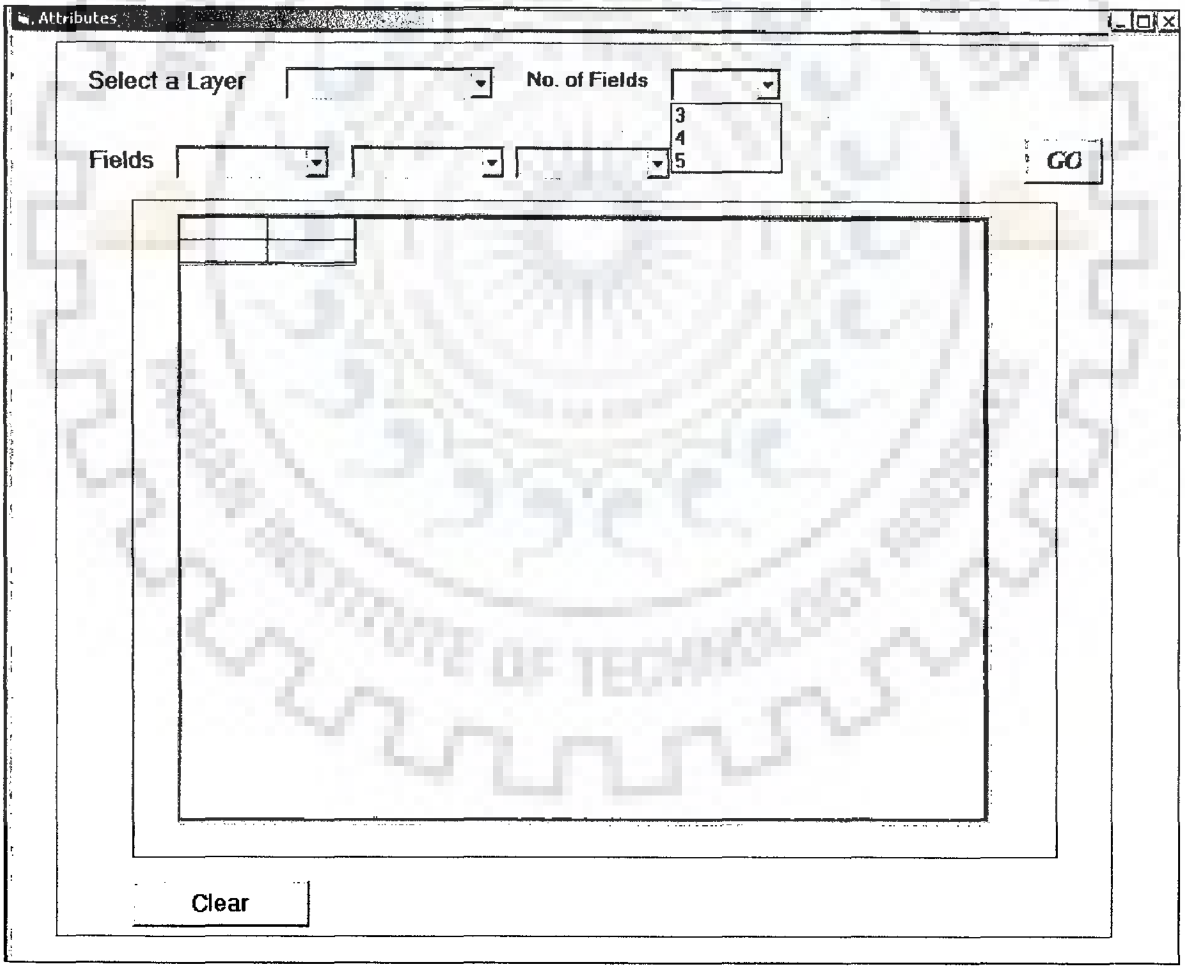


Fig. 3.14 User-Interface for displaying attributes of a shape file.

MapDisplayObjects allow the user to draw maps with *symbols* and thematic *renderers*. *MapDisplayObjects* that are used in the development of the module are *symbol*, *ClassBreak Renderer*, *ValueMapRenderer*, and *LabelRenderer*. A *'Symbol'* object is a frequently used object that affects many aspects of the display of features on the map including symbol color, font, size, and style. This object with other *renderers* is used to display the classified map. The "Classification" menu consists of three submenus of 'Basemap', classification, user defined classification. A *ValueMapRenderer object* displays features in a *MapLayer object* with *symbols* by unique values for a specified field. This *renderer* is used for displaying a "basemap". A *ClassBreaksRenderer* object enables the user to display *symbols* for features in a *Map layer object* by classification of a numeric field. The property of this *renderer* can be used to classify numerical values only. User can also define the classes as per the required/desired range of values. *LabelRenderer* object is used to draw text from the attribute values in a specified field along side the features from a *MapLayer object*. This *renderer* is used for the submenu 'Annotation' of the main menu 'Query'. *'ChartRenderer'* object allows the user to display multiple attributes of a feature by depicting the attributes as elements of either a pie chart or a bar chart. This object is used to develop the menu 'Barchart'.

The menu 'Query' consists of a submenu of 'Weighted Value'. Graphical user interface of this menu is shown in Fig. 3.15. User selects the map layer, area field and the field of any numeric variable whose weighted average area value is to be determined. When the user clicks on the command button 'Compute', calculated weighted value will be displayed.

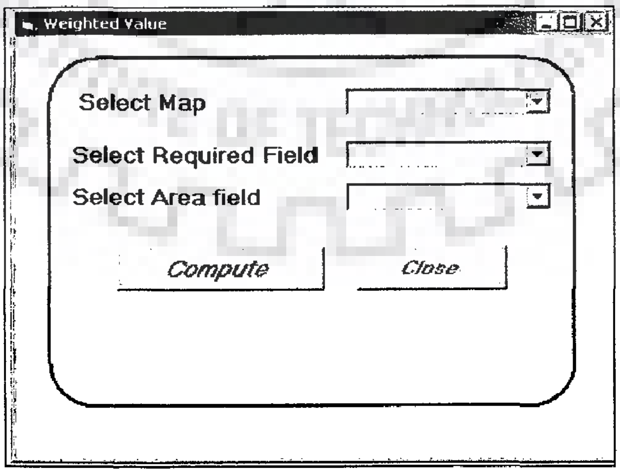


Fig. 3.15 User interface for computing weighted area average value in a shape file

The equation used for calculating weighted area value is as follows

$$X_{weighted} = \sum_{i=1}^{n} \frac{Xi \times Ai}{A_{total}} \tag{3.1}$$

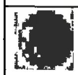
where, A_{total} = Total area

A_i = Area of i^{th} ward,

X_i = Value of a numeric field "X" of the layer for i^{th} polygon.

All the features developed in DSS have been run by input shapefile data of a study area and demonstrated in Chapter 6. Brief description of the 'Button toolbar' having buttons for 'Add- layer', 'Pan', 'Zoom-In', 'Zoom-Out', 'Identify', 'Full-Extent' property and help is presented in Table 3.7.

Table 3.7 Brief description of spatial information button toolbar

Icon	Item	Description
	Add-Layer	Clicking the 'Add Layers' button allows the user to browse for and select any shape files to add to the Main Map.
	Zoom-In	Clicking the 'Zoom- In' buttons will change the main map extent to show half the area than currently displayed.
	Zoom-Out	Clicking the 'Zoom- Out' button will change the main map extent to show two times the area than currently displayed.
	Pan	Clicking the 'Pan' button will put the main map in pan mode. The user can now move the main map extent by holding down the left mouse button and dragging.
	Full Extent	Clicking the 'Full- Extent' button will change the main map extent to the total extent of all the layers currently loaded so that all the layers in the main map are visible.
	Identify	The user can click on a feature in the selected polygon map to display the 'Identify' dialogue. All the records stored in the related fields of the selected features are displayed in a table. The name of the layers on which the feature appears is displayed as they appear in the query layer combo box
	Help	Clicking the 'help' button will open the user's manual of the DSS

The developed GUI for spatial database management module has provision to open, more than one layer. It can be seen that user can easily add shape files to the DSS through Common Dialog box; where-ever it is located. The user can selects a shape file through combo box to perform the button tool bar. User can 'Zoom-In' the selected map for enlarging a specific area of interest. Besides this, with the use of identify button the user can click anywhere in the map and will be able to see the associated attribute information. Since the user interface can open many layers at a time, therefore firstly user have to select a map layer on which query has to be done. The code for operating this module is given in Appendix B.

3.6 Model Subsystems

Development of analytical modules requires the conceptual design and associated algorithms for each module. There are many methods and algorithms available for each module. Here, the methods have been selected on the basis of availability of the data, availability of tools in programming software, etc. After that programming was taken up to develop the graphical user interface and associated algorithms for each method. Development of each module is discussed in detail in the following sections.

3.6.1 Water supply module

The main aim of this module is to compute the quantity of total water supplied to the study area. This quantity is computed from the withdrawal from ground water and surface water. For this module, the required input data include spatial data and non-spatial data. Spatial data are tubewell map having discharge as attribute data, surface water tank map and ward map. Before starting the analysis, all the input map layers should be added to the spatial database management subsystem. Non-spatial data are quantity of surface water supply and number of pumping hours and floating or adjoining population. User can enter these data directly to the text boxes. Table 3.8 shows the topological requirement of input data to run the module. The output will be overall supply of water in mld and LPCD.

Total ground water withdrawal is calculated by adding the discharge data of all the tube wells and so, equation used for developing the function with associated command button is given in Eq. 3.2.

$$GWS_{total} = \sum_{i=1}^{\text{No. of Tubewell}} Qi * Nph * 60 / 10^6 \quad (3.2)$$

where, GWS_{total} = Total ground water withdrawal (mld)

Qi = Ground water discharge of i^{th} tubewell (litre per minute)

Nph = Number of pumping hours

Water tank map provide the information about the capacity of surface tank and overhead tank. Total water storage capacity is the sum of capacity of all the tanks. Therefore the equation used to develop the programme is as follows,

$$Q_{total} = \frac{1}{1000} \sum_{i=1}^{No.ofTank} Ci \quad (3.3)$$

where, Q_{total} = Total capacity of surface water tank (Million Litre)

Ci = Water storage capacity of i^{th} water tank (kilolitre)

Total population of the area, where water is to be supplied is the sum of wards population and population of adjoining area.

$$P_{total} = Pa + \sum_{i=1}^{No.ofWards} Pi \quad (3.4)$$

where, P_{total} = Total Population

Pa = Adjoining/ floating population

Pi = population of i^{th} ward

$$\text{Total water supply (mld)} = GWS_{total} + SWS_{total} \quad (3.5)$$

$$\text{Total water supply (lpcd)} = \frac{\text{Total water supply (mld)} \times 10^6}{\text{Total population}} \quad (3.6)$$

Data access object of Mapobjects such as *recordset* and *field object* with visual basic controls of *text boxes*, *combo boxes* and *command button* have been used for programming. The code for the development of the module is given in Appendix C. The process of water supply module is shown in Fig 3.16 and the user interface for water supply module is presented in Fig. 3.17. User opens all the maps in spatial database management module. After that in water supply module, user has to select the required input maps and respective fields in combo boxes of input data frame. Then user clicks on the main menu of "Total water supply" and get the output framework. This module provides the information about number of tubewells in the study area, total ground water supply, total capacity of water tank, total water supply in mld and lpcd.

After getting the output, user clicks on the command button "Ward-wise water supply", and ward wise water supply will be displayed in tabular form on a different form. Further user can add the field of water supply to the base map and see the classified map in spatial database management module. Here user has been provided flexibility to save all the records of water supply by any desired name.

Table 3.8 Input data for water supply module

Data	Name	Description	Type	Attributes
Spatial Data	Ward map	Boundary of all the wards of the study area	Polygon	Wards Name Population Wards ID
	Tubewell map	Location of all the tubewells	Point	Discharge (lpm) ID
	Water tank	Location of over head tank and surface reservoir	Point	Capacity (Kiloliter) ID
Non Spatial Data	Name	Description	Type	
	Surface water capacity (mld)	Surface water resources can be canal, river, pond , springs etc.	Number	
	Number of pumping hours	....	Number	

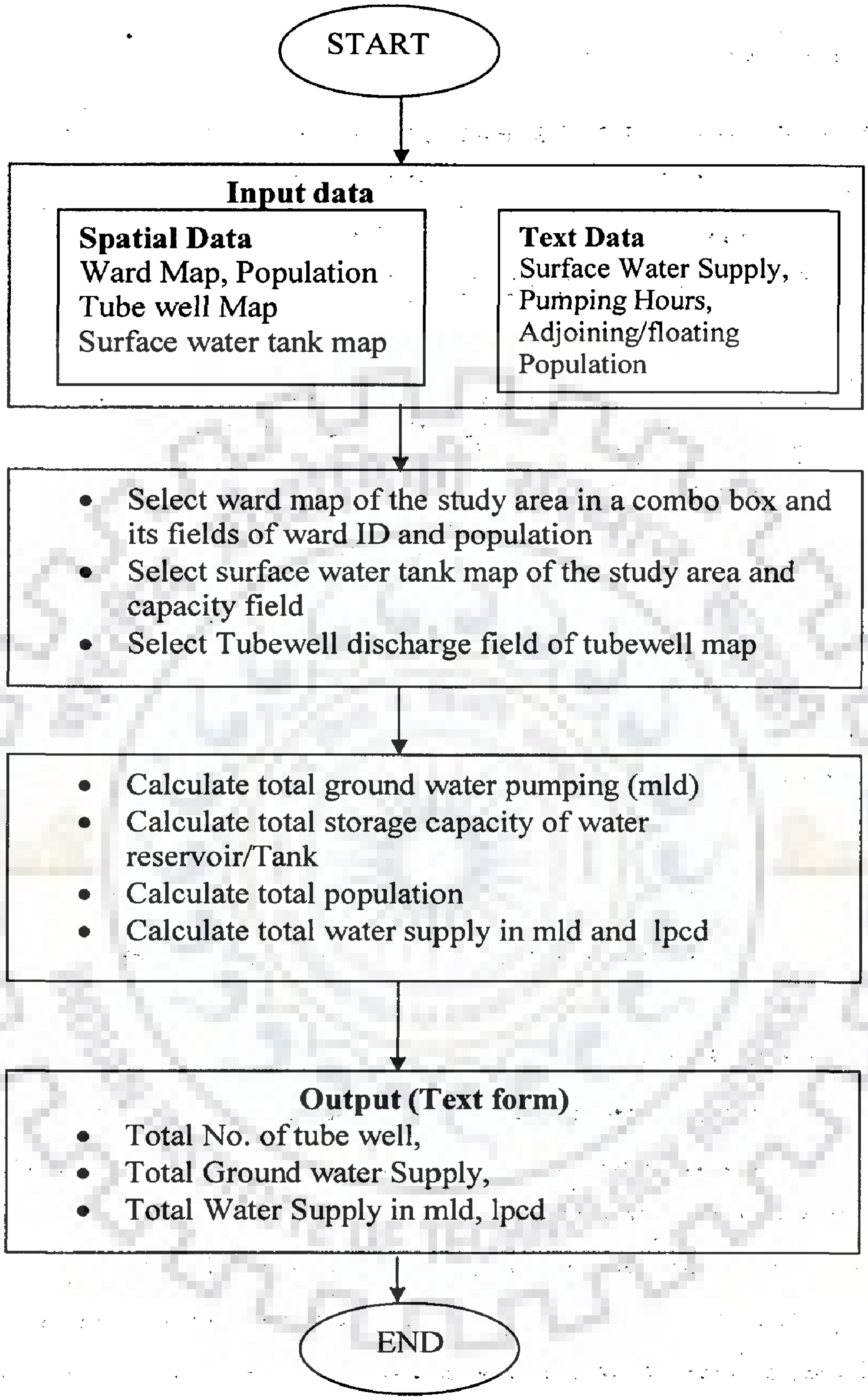


Fig. 3.16 Step by step process involved in water supply module

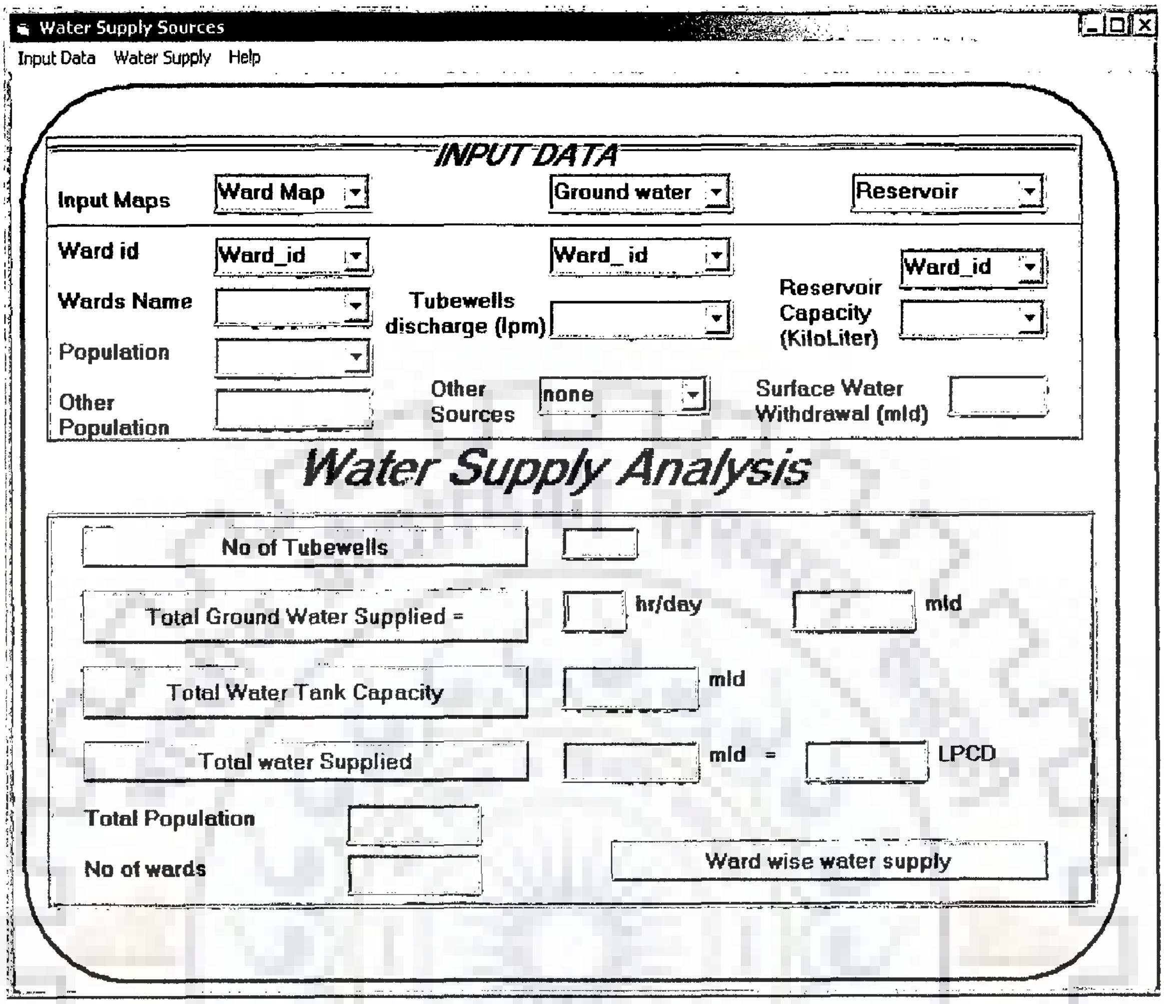


Fig. 3.17 User interface for water supply module

3.6.2 Water Demand Module

In this module, user enters different water demands and will be able to get the total demand of the area in lpcd. This module contains the simple user interface to calculate the total water demand of a city. Input data is non spatial data.

Total domestic water demand includes water demand for drinking, cooking, washing cloths, washing utensils, bathing, washing and cleaning of houses, flushing of toilets etc. Besides the domestic water demand a city requires water for lawn, garden, washing car, air cooling etc. Since all these data depend on the type of a city, so user can input the data in lpcd and can get the total water demand of that area. Table 3.9 gives the brief description of the data for water demand module.

Two frameworks are present in the graphic user interface for water demand management module as shown in Fig. 3.18. Water demands for many uses for a city is shown in framework 1 while details of domestic water demand is displayed in framework 2. The programming code is for sum of all the demands and is given in Appendix D. When user clicks on the menu or command "Ward's Water Demand" another form will be opened and user can see the ward wise water demand in tabular form. Further user can add the field of water demand to the base map and see the classified map in spatial database management module. In this module user has been given the flexibility to save all the records of water supply by any desired field name.

Table 3.9 Brief description of input data for water demand module

S. No.	Data	Description
1.	Domestic water requirement	It contains the water requirement for cooking, bathing, washing cloths, washing and cleaning house, washing utensils, flushing toilets. Besides, water is also requires for lawn ,garden, use of cooler, etc.
2.	Industrial & commercial	In a city water is supplied to offices, shops hotels, stores, factories within the city etc. It is taken as 20-25% of domestic use.
3.	Civic/Public use	In a city water is supplied to schools, hospitals, jail, etc. It is considered as 10% of domestic and industrial use.
4.	Fire demand	Assumed as 5 % of total consumption
5.	Conveyance losses and waste	For a fully metered system, these losses can be assumed as 15%, but the distribution system in Dehradun city is very old, not metered properly at all the places and the diameter of the pipes have reduced due to scaling, losses are assumed as 21% (approx.) of the total consumption (Rao,2005).

3.6.3 Water shortage module

This module has been developed to get the water shortage of an urban area. This module provides overall shortage of water as well as ward-wise water shortage. Figure 3.19 shows the graphical user interface for water shortage module. The user interface consists of two command buttons and text boxes to enter the input data. User can easily understand the process of running the module as the required label is provided for every command. This module calculates total water shortage in mld, further ward wise shortage can be calculated by

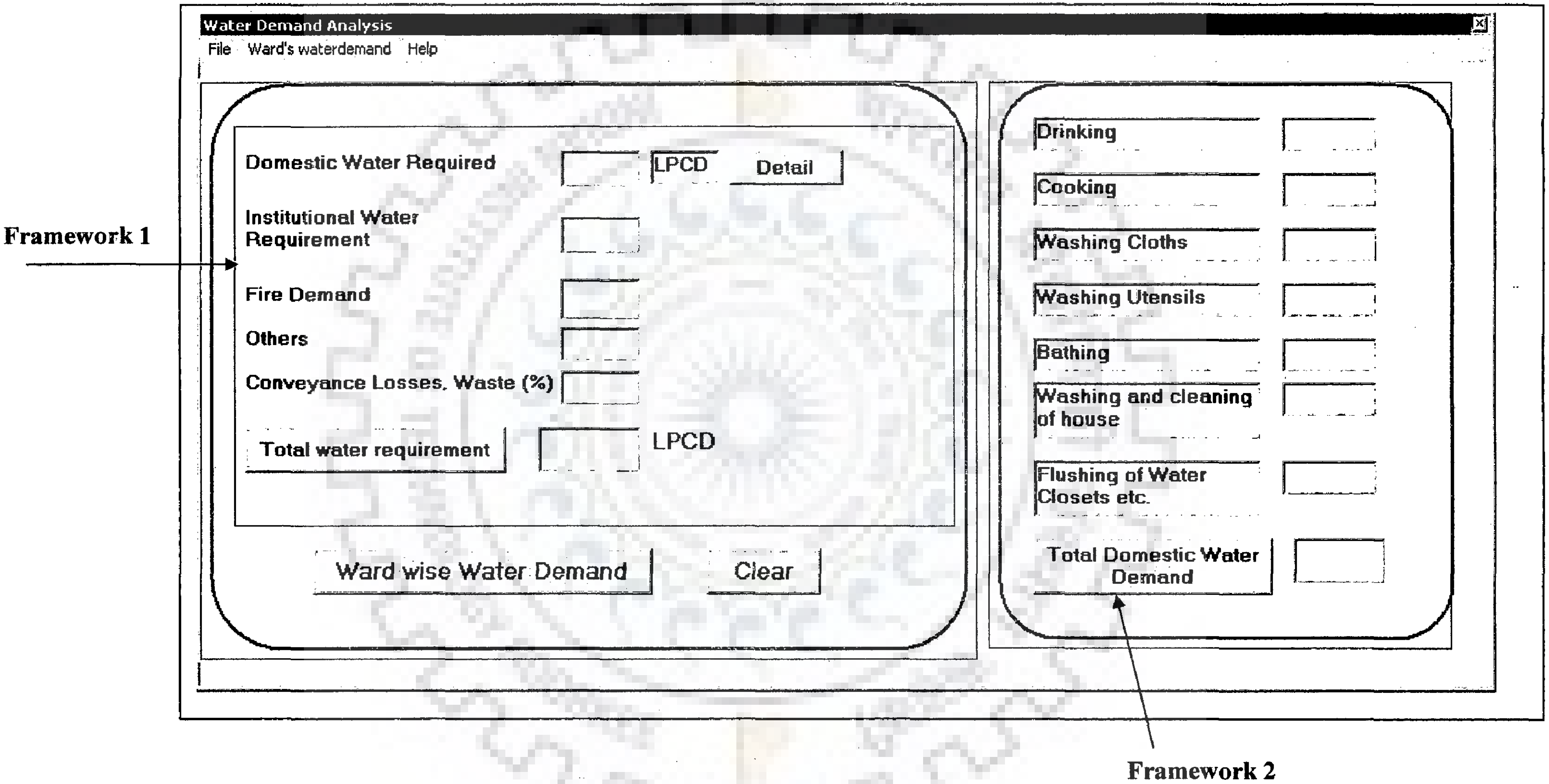


Fig. 3.18 User Interface to estimate total Water demand in LPCD

clicking the command button of ward wise water shortage. User has been given the flexibility to enter any water demand, supply, population. Results can be obtained for forecasted population or for different water demand and supply. This module shows ward wise water shortage on a different *form* as shown in Fig 3.20.The programming code in given in Appendix E. Further, user can save the results and see the classified map in spatial database management module.

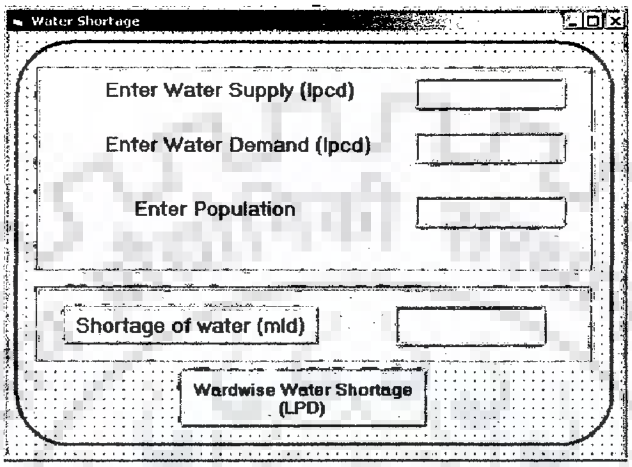


Fig. 3.19 User-interface for water shortage module

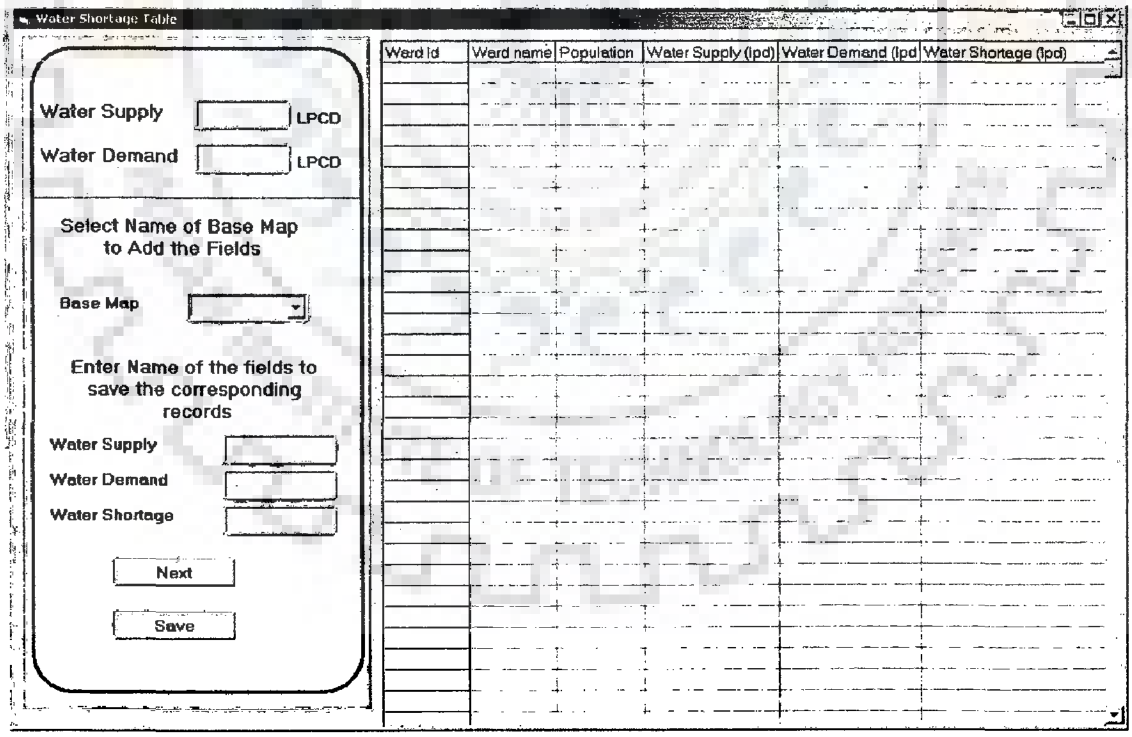


Fig. 3.20 User-interface for ward wise water shortage module

3.6.4 Population forecasting module

The normal methods for population projection of a city are: Arithmetical Increase Methods (AIM), Geometrical Increase Method (GIM), Incremental Increase Method (IIM), Decreasing Rate of Growth Method and logistic curve method etc (Garg and Garg, 1999). In this module three options for first three methods are provided for users to use for population forecasting.

AIM is based on the assumption that the rate of growth is constant. Therefore, population after *n* decades

$$Pn = Po + n\bar{x} \tag{3.7}$$

Where, Po = Present population.

Pn = Forecasted population after *n* decades.

$\bar{x}$ = Arithmetic mean of population increase in the known decades

n = Number of decades

In GIM, the decade wise percentage increase or percent growth rate is assumed to be constant. In this method the growth rate is geometrical mean of percentage of population increase in the known decades.

Thus, population after *n* decades

$$Pn = Po + \left(1 + \frac{r}{100}\right)^n \tag{3.8}$$

where, Po = Present population.

Pn = Forecasted population after *n* decades.

N = No of decades

r = Percent of increase in population in the known decades and can be calculated by geometric mean of the growth rate

$$r = (r_1 \times r_2 \times r_3 \times \dots\dots\dots r_n)^{1/n} \tag{3.9}$$

where r_1, r_2, r_3......r_n is the percent of increase in population for each decade.

Sometimes, the user wants to forecast population on any desirable percentage growth such as growth rate given by any policy or management, therefore user have been given the flexibility of entering any growth rate. At the time of calculation one input box is displayed and user is asked to enter a desirable growth rate. The user can take results by entering any growth rate.

IIM is based on the assumption that per decade growth rate is not constant, but is progressively increasing or decreasing. Hence, population after *n* decades

$$Pn = Po + n\bar{x} + \frac{n(n+1)}{2}\bar{y} \qquad (3.10)$$

where, Po = Present population.

Pn = Forecasted population after *n* decades.

$\bar{x}$ = Average increase in the known decades.

$\bar{y}$ = Average incremental increase in known decades.

n = Number of decades.

In this module, User has been given the flexibility of

- Selecting any one method
- User can see the results by selecting one by one all the methods and then average forecasted population
- In geometrical increase method, results can be taken for user defined growth rate.

Brief descriptions of input data required for the module are presented in Table 3.10. Ward map should already be added to the spatial database management subsystem and decadal population data table can be entered to the module directly. Besides, list of forecasted year is provided in combo box. User can select any year and any method and get the results in very short time. Figure 3.21 shows the graphical user interface for population forecasting module. Table 3.11 shows a brief description of menu and submenu of the developed module.

Table 3.10 Description of required input data for population forecasting module

Data Type	Name	Description
Non spatial Data	Decadal Population Data of last 100 years	The data table is in *.mdb file.
Spatial Data	Wards Map as base map having population field, ward name field and ward ID field.	Shape file and polygon topology

Table 3.11 Description of menu and submenu of population forecasting module

Menu	Sub-menu	Descriptions
Data	Link The Data	Clicking on "Link the data" will link the population data to this module. Then all tables of the database will be displayed in combo box and user can select the required table.
View	Decadal Population	Clicking the menu will show the population data.
	Graph	Clicking the menu will show the Graphical view of population data, to understand the general trend of its growth.
Forecasting	--------	Clicking the menu will show the framework for entering the "Start Year" and "End Year", and options for selecting any one forecasting method.
Help	-----	Clicking the menu shows the required help

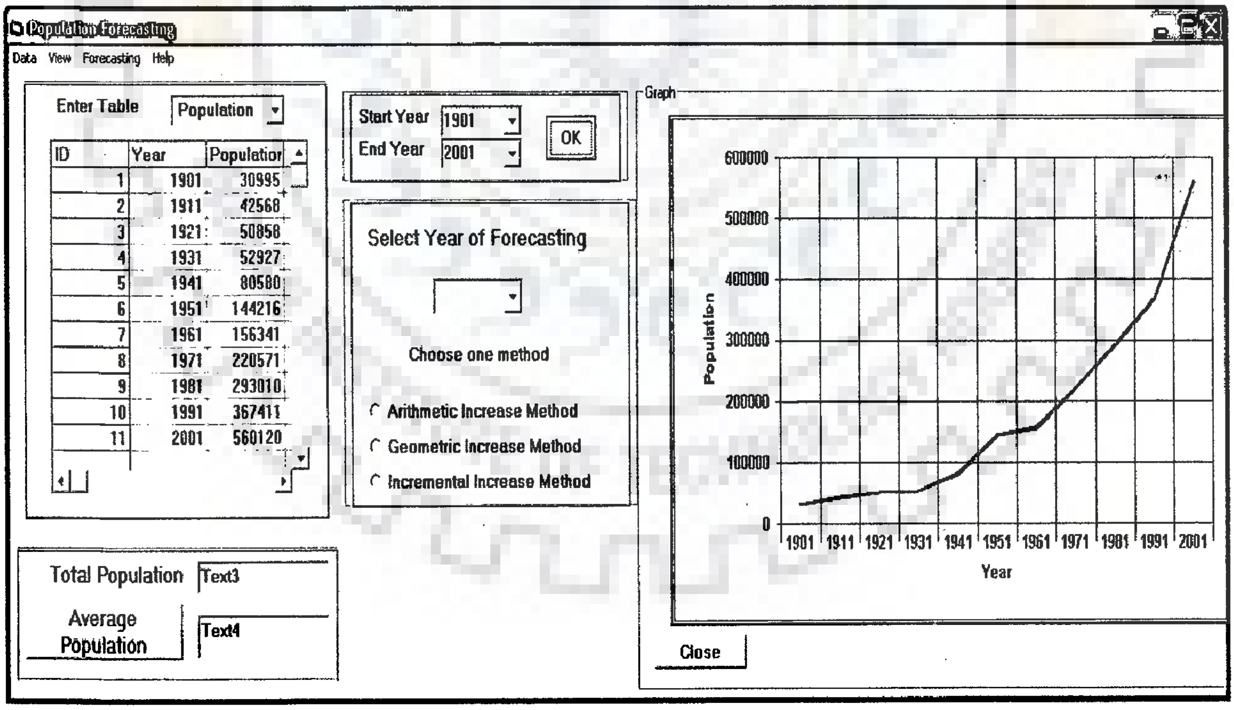


Fig. 3.21 Graphical user interface for population forecasting

3.6.4.1 Ward-wise population

Projected population has been distributed to all the wards. The distribution has been done according to the area of wards. Dehradun Nagar Nigam area comprising of 45 municipal wards is 65 km^2.

The algorithm used to project the population of a ward is as follows:

$$Pp = \sum_{i=1}^{No.ofWards} P_{pi} = \sum_{i=1}^{No.ofWards} \left[Pi + (Pp - P) \times \frac{ai}{A} \right] \qquad (3.11)$$

where, P = Total present population

P_p = Total projected population of wards

P_{pi} = Projected population of ith ward

P_i = Present population of ith ward

a_i = Area of ith *Ward*

A = Total area of the study area

After calculating the projected population of wards, user enters a field name to add the field of projected population to the base map and click on the 'Save' command button. After clicking the user gets a message that 'Field added successfully' and 'Records entered'. Now the projected population map can be prepared by using 'Classification' menu of spatial data management module. Figure 3.22 shows user interface for ward wise population forecasting.

This module provides the answers of questions or information regarding-

- What will be the total population in the years of 2011, 2021, 2031, 2041?
- Graphical view of growing population
- Ward wise distribution of the projected population in Tabular form
- Classified ward wise projected population map through spatial database management module.

The programming codes for the population projections have been developed in Visual Basic for the above equation in Visual Basic is given in Appendix F.

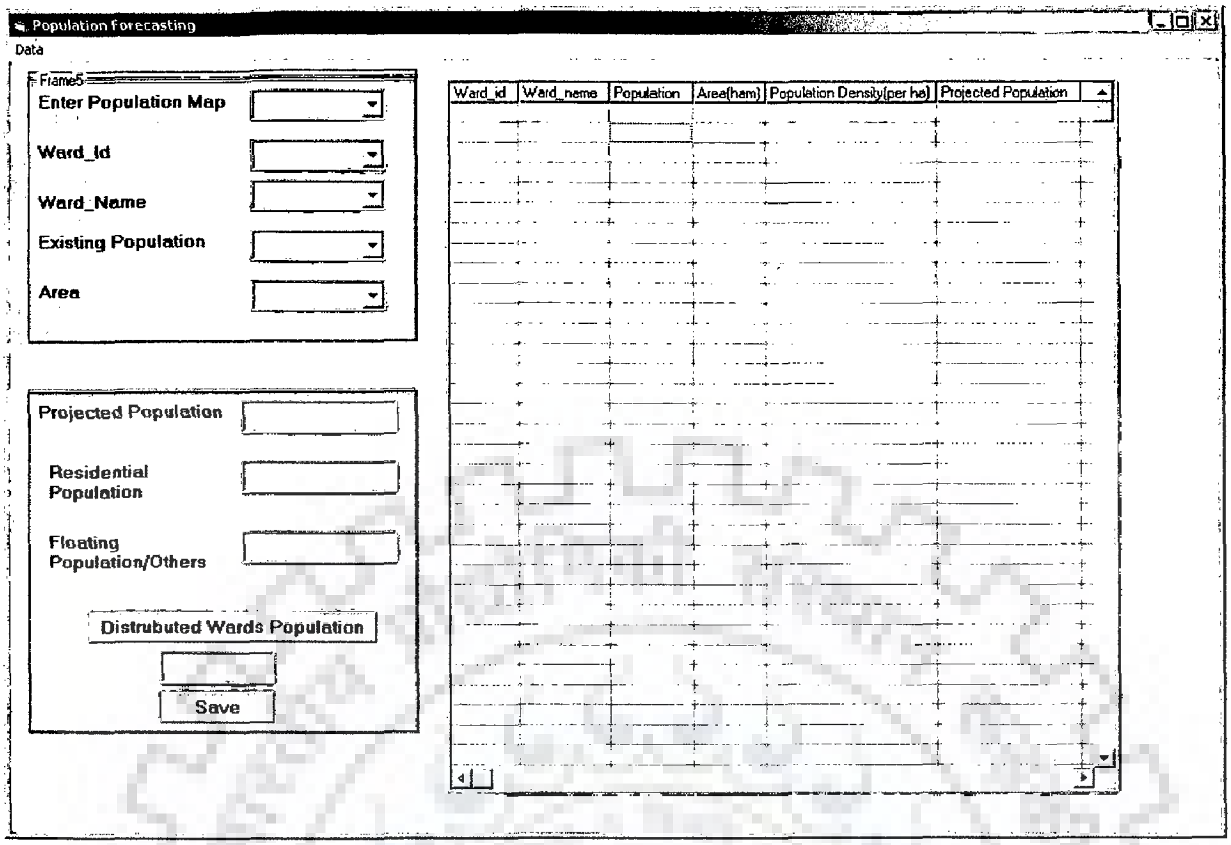


Fig 3.22 Graphical user interface for ward-wise population module

3.6.5 Rainfall-runoff module

This module determines average annual runoff of an area by SCS-CN method. In watershed hydrology, the soil conservation service-curve number (SCS-CN) method (Soil Conservation Service, 1972) is one of the most popular methods for computing the volume of surface runoff for a given rainfall event from small agricultural watersheds (Mishra et al, 2003; Mishra et al., 2005).This method is one of the popular methods for computing surface runoff for a given rainfall for a small watershed. The primary reason for its wide applicability and acceptability lies in the fact that it accounts for most runoff producing watershed characteristics: soil type, land use/treatment, surface condition, and antecedent moisture condition. Many existing modules of rainfall-runoff require rainfall data as well as runoff data. Extensive data normally are not available for micro watersheds. So, it is decided to incorporate analysis of rainfall-runoff by the SCS –CN method as this method is simple, easy to understand and apply, and useful for a watershed. The method requires daily rainfall data and a runoff coefficient called Curve Number (CN). Here, CN map is the major input for estimating runoff depth. This section describes the conceptual process of the method, programming for basic algorithm and graphical user interface of the module.

The SCS-CN method is based on the water balance equation and two fundamental hypotheses. The first hypothesis equates the ratio of the actual amount of direct surface runoff (Q) to the total rainfall (P) (or maximum potential surface runoff) to the ratio of the amount of actual infiltration (F) to the amount of the potential maximum retention (S). The second hypothesis relates the initial abstraction (I_a) to the potential maximum retention. Thus, the SCS-CN method consists of

(a) Water balance equation:

$$P = I_a + F + Q \tag{3.12}$$

(b) Proportional equality hypothesis:

$$\frac{Q}{P - I_a} = \frac{F}{S} \tag{3.13}$$

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \tag{3.14}$$

where, Q = Direct surface runoff over the drainage basin, mm

P = Rainfall depth, mm

F = amount of actual infiltration, mm

S = potential maximum retention, mm

I_a = initial abstraction, mm

The initial abstraction includes all losses before runoff begins i.e. water retained in surface depressions, water taken up by vegetation, evaporation and infiltration. It is calculated as:

I_a = 0.3S for AMC condition I

I_a = 0.2S for AMC condition II

I_a = 0.1S for AMC condition III

where, AMC is the five days antecedent moisture condition of the soil. Later CSWCR&TI (Handbook of Hydrology, 1972) has modified the relationship between 'Ia' and 'S' to suite in Indian condition as,

I_a = 0.3S for AMC condition I in black soils region

I_a = 0.1S for AMC condition II & III in black soil region

I_a = 0.3S for all other regions and all AMC condition

Since, black soil does not exist in the study area, the Eq. 3.14 becomes

$$Q = \frac{(P - 0.3S)^2}{P + 0.7S} \tag{3.15}$$

The Eq. (3.15) is the basic equation for computing the depth of excess runoff by the SCS method. Eq. (3.15) is valid for P ≥ I_a; Q = 0 otherwise. The potential maximum retention, S is related to the Characteristics of the soil cover complex and antecedence moisture condition in the watershed. It is related to the soil and cover conditions of the watershed through the CN. CN has a range of 0 to 100, and S is related to CN as;

$$S = \frac{254000}{CN} - 254 \tag{3.16}$$

Factors affecting the Curve Number (CN) are land cover, hydrologic condition of the soil, hydrologic soil group etc. Soils are extremely important in determining the CN values. CSWCR&TI (Handbook of Hydrology, 1972) has classified soil in four hydrologic soil group A, B, C and D; on the basis of its infiltration rates as given in Table 3.12.

Table 3.12 Soil Group Classification by CSWCR&TI (1972)

Group	Infiltration Rate		Soil Texture
	Class	Value (mm/hr)	
A	High	>25	Sand, loamy sand or sandy loam
B	Moderate	12.5 to 25	Silt loam or loam
C	Low	2.5-12.5	Sandy clay loam
D	Very Low	<2.5	Clay loam, silty clay loam, sandy clay, silty clay or clay

Another factor affecting the CN value is the hydrologic condition of an agricultural watershed, which is defined in terms of the percent area of grass-cover. The larger the area of grass cover in a watershed, the lesser will be the runoff potential of the watershed and more will be infiltration. Such a situation describes the watershed to be in a good hydrologic condition. Brief description of the hydrologic condition of the area is presented in Table 3.13 The AMC is defined as the soil moisture present in the soil before rainfall and affecting runoff which is one of the most influential factors in describing CN. The soil conservation service has developed three conditions to estimate different values of CN such as for AMC I (dry condition), AMC II (normal moisture condition) and AMC III (wet condition) from the five days accumulated rainfall limits as shown in Table 3.14. The U.S. department of Agriculture has prepared simple tables and monograms, by which CN value for AMC II condition can be determined on the basis of ground cover, soil type and antecedent precipitation as given in Appendix N.

Table 3.13 Description of hydrologic conditions as per the vegetation condition

Sr. No.	Vegetation Condition	Hydrologic Condition
1	Heavily grazed or regularly burned. Litter, small trees, and brush are destroyed.	Poor
2	Grazed but not burned. Some litter exists, but these woods not protected.	Fair
3	Protected from grazing and litter and shrubs cover the soil.	Good

Table 3.14 Antecedent soil moisture conditions (AMC)

AMC	Soil Condition	Total 5-day antecedent rainfall (mm)	
		Dormant season	Growing season
I	Soils are dry but not to the wilting point	< 12.7 mm	<35mm
II	Sufficient cultivation has taken place, Average Condition	12.7 to 32.5 mm	35 to 52.5 mm
III	Heavy rainfall or light rainfall and low temperature have occurred within last 5 days, Saturated Soil	> 32.5 mm	> 52.5mm

Further, CN values for AMC I & II can be computed using the following equations respectively.

$$CN_I = \frac{4.2CN_{II}}{10 - 0.058CN_{II}} \quad (3.17)$$

$$CN_{III} = \frac{23CN_{II}}{10 + 0.13CN_{II}} \quad (3.18)$$

Curve numbers given by SCS model are suitable for slope upto 5%. To consider the effect of the slope on the CN_{II} Value, Williams (1991) proposed the following equation, applicable for the slope more then 5%.

$$\mathrm{CN}_{\mathrm{II\,slope}} = \frac{1}{3}(CN_{III} - CN_{II})[1 - 2\exp(-13.86S)] + CN_{II} \quad (3.19)$$

where, $CN_{II\ slope}$ is the corrected CN_{II} value, CN_{III} and CN_{II} are the values from the standard equations, and s is the slope steepness (%).

The developed module for rainfall-runoff estimation requires a weighted CN_{II} Value for calculating the runoff depth of the area. The spatial database module contains the facility of calculating weighted value in query menu. Therefore before running the rainfall-runoff module user add the CN_{II} map in spatial database module and through query analysis, weighted CN_{II} value can be calculated by the 'weighted value' of 'query' menu of the spatial database module. Table 3.15 contains the brief description of main menu of rainfall-runoff module. Figure 3.23 shows the step by step process for calculating the runoff by weighted-CN Method. Main input of the module is CN Map and daily rainfall data. CN map (Fig. 5.11) was generated in ArcGIS 9 and discussed in Chapter 5. The user interface for weighted CN method for calculating runoff is presented in Fig. 3.24..

The user interface for rainfall-runoff assessment consists of command buttons for every step. For computing runoff by weighted CN, user has to enter the required data and clicks the command buttons, the results will be displayed in the table and can be visualized through graph. User can query about maximum runoff.

Table 3.15 Brief description of main menu of rainfall-runoff module

Menu	Description
File	Clicking on this menu will link the database of daily rainfall saved in any directory of the system and tables of the database will be shown in a combo box, from where user can select daily rainfall table.
Analysis	Clicking on this menu will open frame1, which contains the steps of the process.
Query	User can query for maximum runoff.

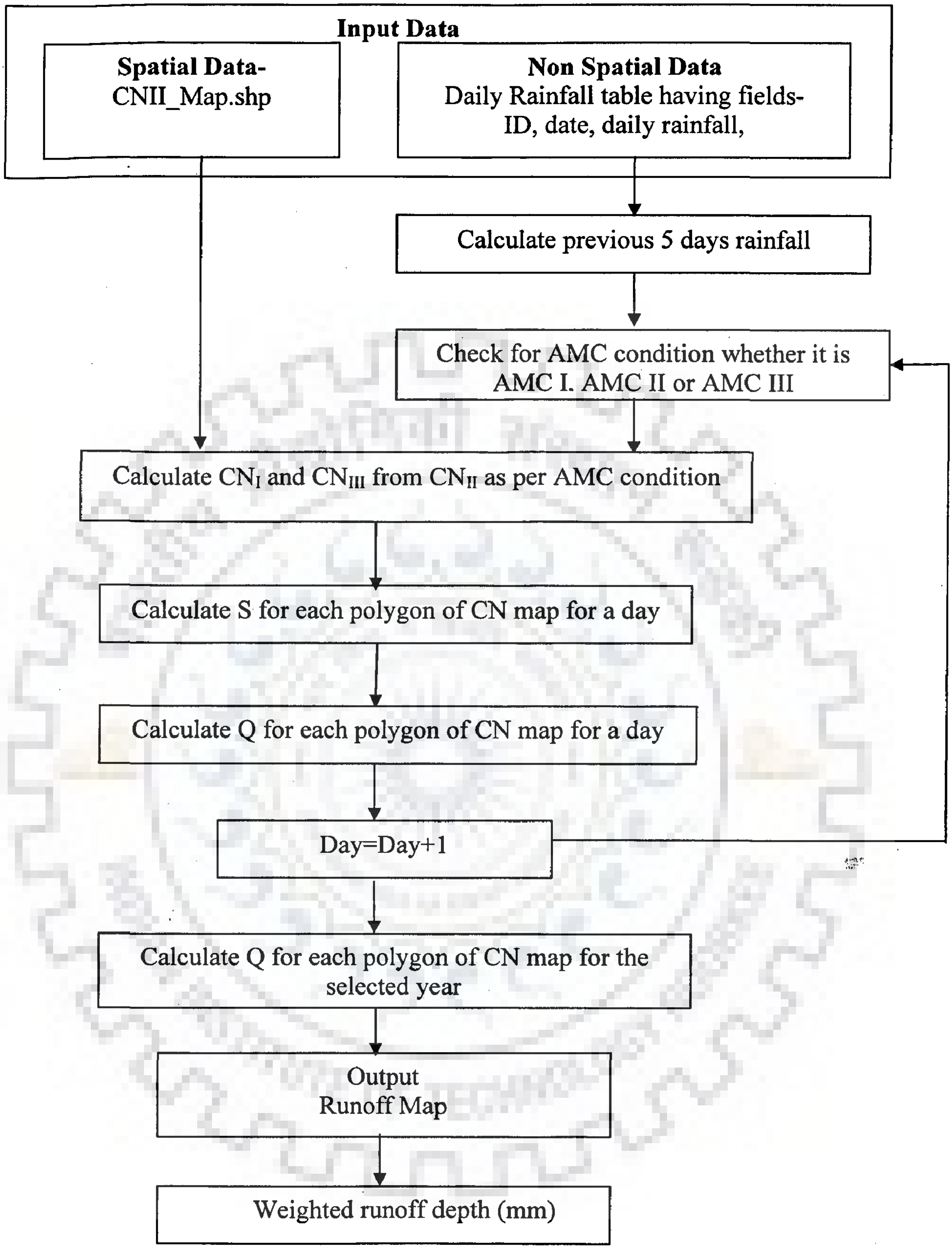


Fig. 3.23 Step-by-step process for calculating Runoff by SCS-CN Method

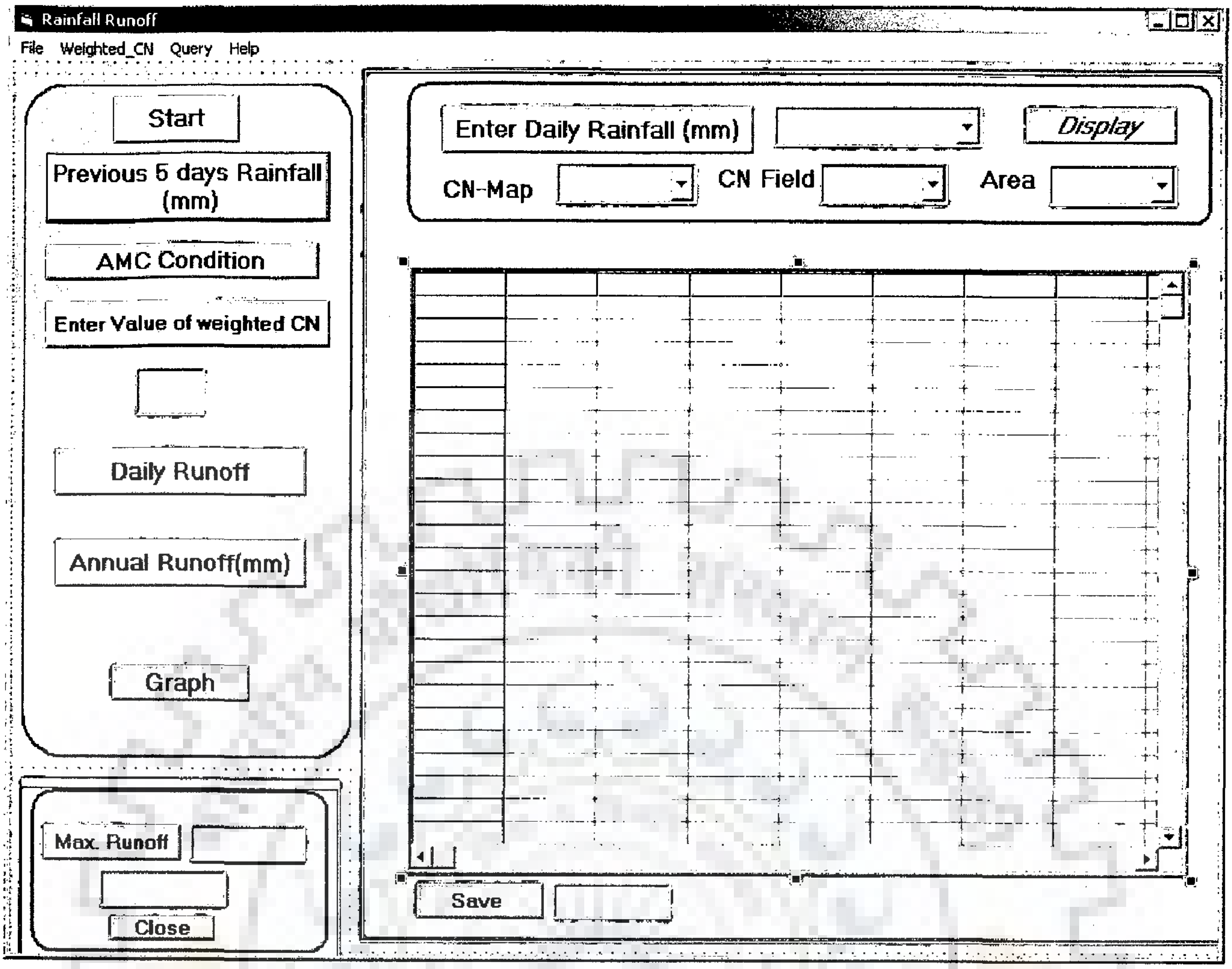


Fig. 3.24 Graphical user-interface for weighted CN method of runoff calculation

Step-by-step process for calculating Runoff by weighted CN by SCS-CN Method is shown in Fig. 3.25. The programming codes for both the methods are given in Appendix G. Many a times, land use map for a particular year were not available. To overcome this problem, weighted CN method has been used to estimate the runoff. A provision was made in the DSS to consider a multiplying coefficient due to linear yearly variation in the weighted CN. To estimate the runoff, user can multiply the weighted CN_{II} value of a year by a coefficient to get the CN value for the next desirable years.

$$\text{Weighted } CN_{II\,(i+1)} = \text{Weighted } CN_{IIi} * Xc \tag{3.20}$$

where Xc=Multiplying coefficient, Weighted CN_{II}i and Weighted $CN_{II\,(i+1)}$, represents weighted CN_{II} for i[th] year and (i+1)[th] year.

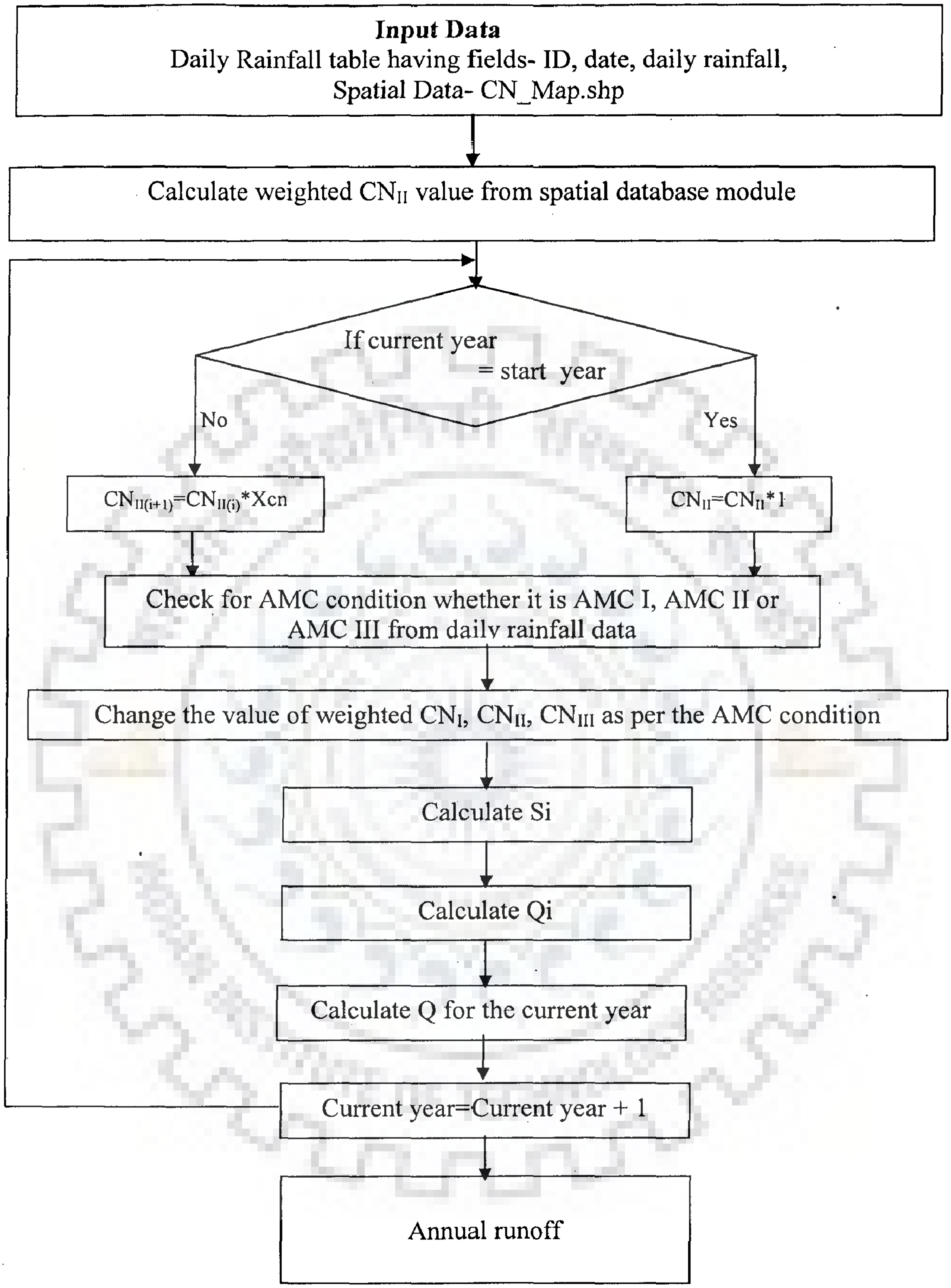


Fig. 3.25 Step-by-step process for calculating Runoff by weighted CN Method

3.6.6 Rooftop rainwater harvesting module

This module provides the information of total rooftop rain water harvesting (RWH) potential of an urban area. Building map of the study area is the main input of this module. Further a classification of buildings can be done on the basis of the size of roof area, number of buildings and RWH potential for each category of the roof can be calculated. The output of the module can be seen in the form of map. Efficiency is one of the important factors in computing the runoff generated from rooftops. The type of roof would affect the quantity of rainwater harvesting. It has been observed during site visits that most of the roofs are flat and made of reinforced concrete. Runoff coefficient for reinforced concrete is about 0.70–0.90 (Pacey and Cullis, 1986). Another factor that affects the quantity of water harvested from roofs is evaporation and wastage due to flushing during initial rains. In this analysis, efficiency of 0.80 is used considering the evaporation losses and wastage.

Rain water harvesting potential is calculated by taking average annual rainfall from the last 30 years annual rainfall.

$$RWHP_i = \sum_{i=1}^{no.of\,building} \frac{A_i * C_i * P}{365000} \qquad (3.21)$$

where, P = Average annual rainfall (m)

C_i = coefficient of Runoff

A_i = Area of i^{th} building (m^2)

$RWHP_i$ = Total rainwater harvesting potential (mld)

i =1, 2, 3..........no. of building in the building map

The user interface for calculating the rooftop rain water harvesting potential is presented in Fig. 3.26. User can enter the building map and the required fields of roof area, type of roof, and runoff coefficient and can get the total rainwater harvesting potential. As it is not possible to implement roof top rainwater harvesting for 100% buildings, an option is given in this module for efficiency of RWH. User can enter the efficiency of rainwater harvesting and can get the corresponding RWH potential.

Further some information regarding total roof area, maximum area, minimum area, RWH potential and percentage of RWH potential can be calculate to obtain the classified rooftop RWH potential map. User-interface for above output is presented in Fig. 3.27. The programming code for the module is given in Appendix H.

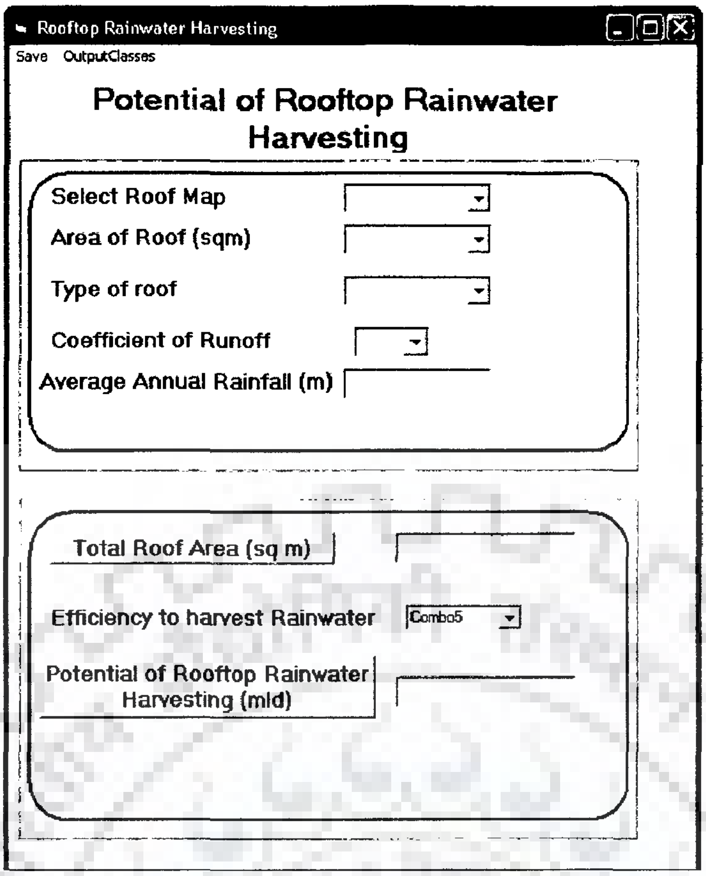


Fig. 3.26 User-interface for rooftop rainwater harvesting module

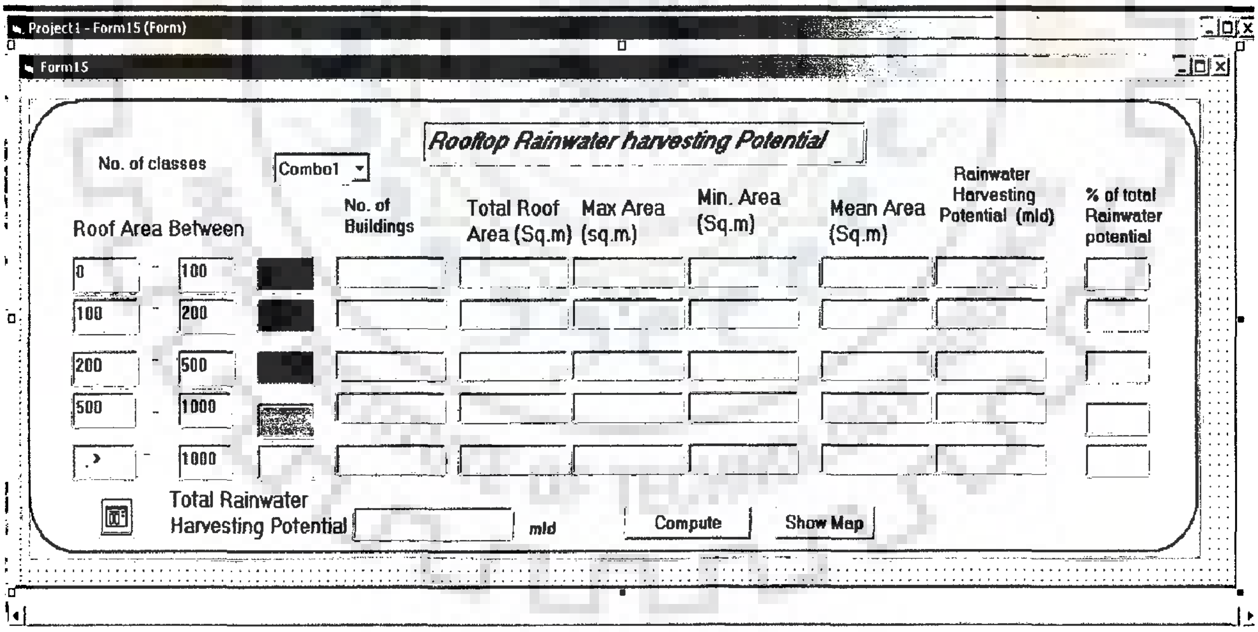


Fig. 3.27 User-interface for output from rooftop rainwater harvesting module

3.6.7 Ground water recharge module

Various models and methods are available for the assessment of ground water recharge such as MODFLOW, DRASTIC, SPRING. But these are too complicated in terms of processes involved and extensive data requirement. Implementation of these models in DSS becomes difficult with limited information available for micro watersheds.

Government of India constituted a Groundwater Resource Estimation Committee (GEC) in 1997 to prepare the norms for estimation of groundwater potential. The norms for rainfall infiltration method to estimate ground water recharge, are evolved based on the studies undertaken in various water balance projects in India. It has been reported that the ground water resource estimation methodology recommended by the Committee is being used by most of the organizations in India. As a guideline, norms are given in Table 3.16. The same norms may be adopted for non monsoon season also provided the rainfall in the non-monsoon season is greater than 10% of the annual rainfall. If rainfall is less then this threshold value, the recharge due to rainfall in the non-monsoon season may be taken as zero. Based upon the knowledge of the study area or land use, a value of rainfall infiltration factor can be chosen between the given ranges.

Simplicity, popularity and acceptability make it convenient to implement this method in the DSS. As per the guidelines, areas having slopes higher then 5% should not be considered in the recharge estimation.

Table 3.16 Portion of rainfall contributing to the recharge

S.No	Geological Formation	Rainfall infiltration factor
1	In Sandy areas	20 to 25
2	In Areas with higher clay content	10 to 20
3	Friable and highly porous (Semi-consolidated sandstones)	10 to 15
4	Weathered and fractured Granite	10 to 15
5	Unweathered Granite	5 to 10
6	Vesicular and jointed basalt	10 to 15
7	Weathered basalt	4 to 10
8	Phyllites, limestones, sandstones, quartzites, shales etc	3 to 10

The same recharge factor may be used for both monsoon and non-monsoon rainfall with the condition that the recharge due to non-monsoon rainfall may be taken as zero, if the normal rainfall during the non-monsoon season is less than 10% of normal annual rainfall (GEC,1997). Ground water recharge can be determined using the equation 3.22 and 3.23.

$$\text{Annual GW}R = Wi \times \text{P} \quad (3.22)$$

$$Wi = \frac{1}{A_{Total}} \sum_{i=1}^{no.ofpolygon} p_i \times Ai \qquad (3.23)$$

where, p_i = Rainfall infiltration factor for i^{th} class of landuse and soil

P = Average annual rainfall (mm)

A_i = Area of i^{th} Polygon (m^2)

GWR = Total ground water recharge(mm)

W_i = Weighted percentage of rainfall going to be recharge

In urban area, land use has significant impact on the recharge due to high imperviousness. Therefore, land use map must be overlaid to the geology map of the area. The weighted rainfall infiltration factor can be calculated by using equation 3.22. For a growing city imperviousness increases with time, so percentage of rainfall contributing to recharge is decreasing with time. If land use map is not available, user can enter the value of weighted rainfall infiltration factor and a reduction constant to get the recharge for the next desirable year. The weighted percentage of rainfall, contributing to recharge can be calculated by using the reduction constant by the equation 3.24. Table 3.17 shows the input data required for estimating the ground water recharge.

$$W_{j+1} = W_j - x \qquad (3.24)$$

X = Reduction constant

Wj = Weighted rainfall infiltration factor for j^{th} year

Table 3.17 Input data required for ground water recharge module

Data type	Data	Attribute
Spatial Data (*.shp)	Groundwater recharge map	• Rainfall infiltration factor • Shape Area
Non-spatial data (*.mdb)	Monthly rainfall data	Monthly Rainfall for all the years in mm
	Knowledge based data	• Weighted Rainfall infiltration factor • Reduction constant

The user interface for ground water recharge module has been presented in Fig. 3.28. User can open the geology map in spatial database subsystem and select the layer through corresponding *combo box* of this module and select the area fields and the field of rainfall infiltration factor. Now monthly rainfall data will be open in non-spatial database management subsystem. Here, start year, end year, and the value of reduction constant will be entered. Now user can get the rainfall and recharge for pre-monsoon and post-monsoon between the start year and end year in tabular form and barchart. The programming code for the module is given in Appendix I.

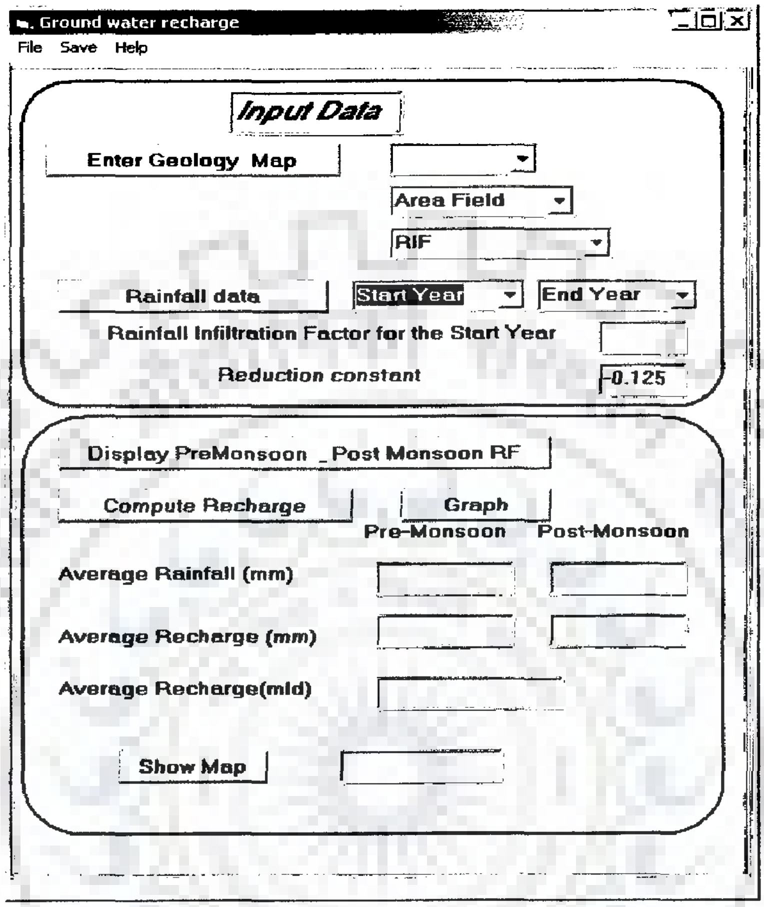


Fig. 3.28 Graphical user interface for ground water recharge module

3.6.8 Integrated scenarios analysis

User can integrate all the information in the relative text box of the user interface of "integrated scenario analysis" as shown in Fig. 3.29. Every module has been provided the option in menu "Save to scenario"; by which user can display the values in the related text box provided in this module. When user clicks the "Save the Project" command button, another window will be opened. Here, user enters the name of table to save the scenario of water sources, and scenario-criteria tables for any desire period will be created in MS Access database. In the preset study, different tables will be created for the year 2011, 2021 and 2031. Now "Ok" button will be highlighted and user clicks to this command button, the values of the criteria will be revised and rewritten to their corresponding text boxes. The values will be revised as follows;

(1) Water supply (mld) = Ground water supply (mld) + Surface water supply (mld) + Rainwater harvesting for storage (mld) +Runoff harvesting (mld) + Others (mld) + Recycled water (mld)

(2) Net water demand (mld) = Water demand (lpcd) * Population *(1/1000000)

(3) Net ground water recharge (mld) = Groundwater recharge in the corresponding year (mld) + Recharge from rainwater harvesting (mld)

(4) Net runoff (mld) = Runoff in the corresponding year (mld)-Rainwater harvesting for storage (mld) - Rainwater harvesting for recharge-runoff harvesting (mld)

(5) Water shortage (mld) = Water demand (mld) - Water supply (mld)

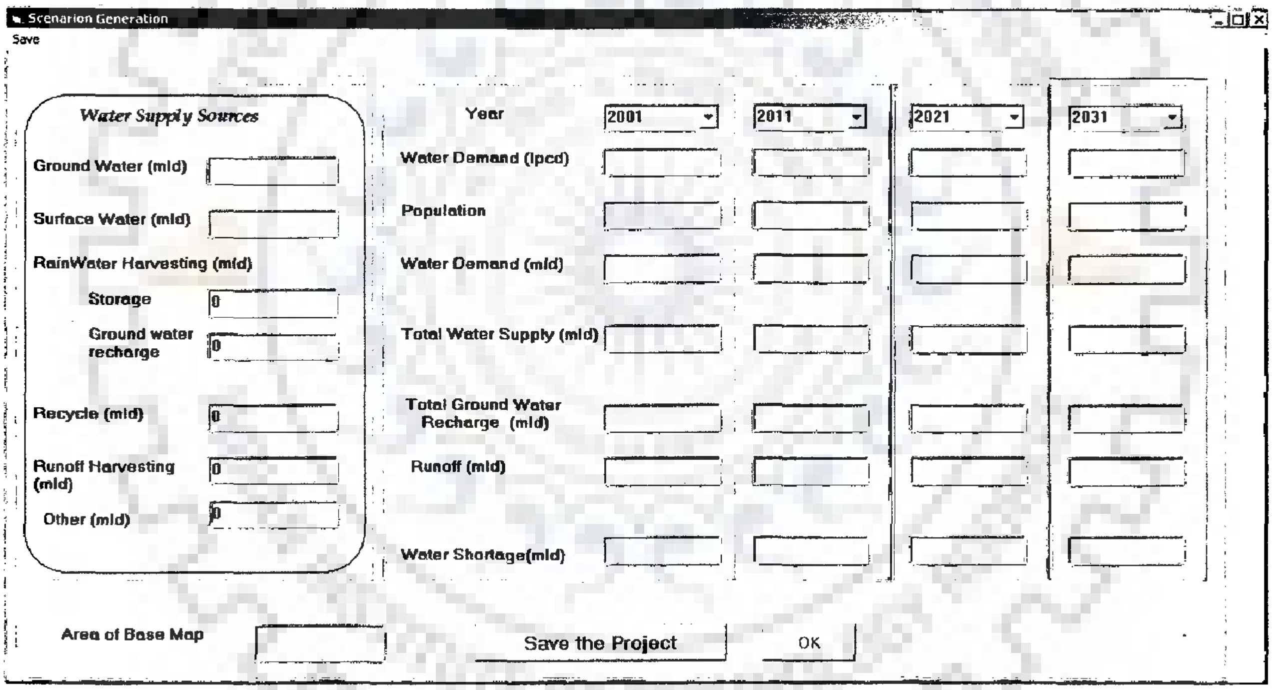


Fig. 3.29 User-interface for integrated scenario analysis

To generate the optimum sustainable water supply scheme, a scenarios based approach has been considered, in which the main parameters are net water shortage, net water demand, net ground water recharge, and net runoff reduction. Different scenarios have been generated using different population growth rate. Therefore population growth rate have also been taken as one parameter to get the sustainable water supply scenario

Further user can get the best ranked scenario by Analytical Hierarchal Process (AHP) method which is discussed in subsequent section. In spite of saving the scenario or if user found it difficult to take results in continuation, user can directly create the table in

MS Access and use as input to the AHP module. The programming code for the module is given in Appendix J.

3.6.9 Analytical Hierarchal Process (AHP)

Multicriteria decision-making analysis is a methodology that provides a systematic framework for the comparison of various alternatives based on various quantitative and qualitative criteria. Each criteria needs to be given by a weight according to their relative importance in decision-making process. The aggregate decision is expressed as a numerical score; the higher score indicates aggregate positive impact of the decision. This method consists of simple formulation based on real life problem and understanding, which makes it possible to be applied to the real world.

AHP is a decision analysis technique to evaluate complex multi attributed alternatives with conflicting objectives among multiple players (Weiss and Rao, 1987). The AHP employs a systematic procedure for representing the elements of a problem hierarchically, enabling the sub problems to be easily comprehended and evaluated. This process begins with the development of a decision hierarchy with an objective, alternative and criteria. The 9 point scale (Table 3.18) has been the standard rating system used for the AHP. The basic component of AHP method is pair wise comparison method, which compares all the criteria with one another. Development of a module for pair wise comparison matrix has been done to compute the weights. The AHP model involved in the DSS, estimate, compare and evaluate the multiple impacts resulting from different design and management scenarios and help is choosing the "best decision" (Loucks, 2002; Andreu et al., 2001).

3.6. 9.1 Pair-wise comparison method

The method involves pair wise comparisons to create a ratio matrix. It takes pair wise comparisons as input and produces relative weights as output. The pair wise comparison method involves three steps. The first step is development of a pair wise comparison matrix that employs an underlying scale with values from 1 to 9 point scale to rate the relative preferences for two criteria (Table 3.18). A pair wise comparison on n criteria (i.e. n_1, n_2,....$n_{n)}$ involves constructing n X n matrix showing the dominance of the criteria to left hand side. Weights are assigned only for the upper half matrix as shown in Table 3.19. Here. C_{1j}, $C_{2j.....;}$ represents original weights given by the user to the relevant criteria (A, B, C,...E). Then pair wise comparison matrix is prepared by taking transpose of the reciprocal of the upper half matrix to fill the lower half matrixes.

Figure 3.30 shows the step-by-step process of calculating the weights by pair wise comparison method. First step is the summation of the values in each column of the matrix. Then, each element in the matrix should be divided by its column total (the resulting matrix is referred to as the normalized pair-wise comparison matrix). The second step involves the computation of weights which is the average of elements in each row of the normalized matrix.

Third step is to determine the Consistency Ratio (CR) which is the degree of consistency and shows that the comparisons are consistent or not. To calculate the value of CR firstly lambda (λ) and Consistency Index (CI) needs to be computed. The value of λ is simply the average value of the consistency vector. CI and λ provides a measure of departure from consistency.

$$CI = \frac{\lambda - n}{n-1} \tag{3.25}$$

$$CR = \frac{CI}{RI} \tag{3.26}$$

where RI is the random index which depends on the number of elements being compared. The values of RI are given in Table 3.20. If CR<0.10, the ratio indicates a reasonable level of consistency in the pair wise comparison, however, if CR ≥ 0.10, the values of the ratio indicates inconsistent judgments.

Table 3.18 Scale of relative importance

Intensity of importance	Definition	Description
1	Equal importance	Both the factors are equally important to achieve the objective
2	Equal to moderate importance	One factor is slightly in favour over other
3	Moderate importance	One factor is moderately in favour over other
4	Moderate to strong importance	One factor is moderately to strongly in favor over other
5	Strongly importance	One activity is strongly favoured over another.
6	Strong to very strong importance	One activity may be strong or may be very strongly favored over another.
7	Very strong importance	One activity is very strongly favoured over another and its dominance is proved in practice
8	Very to extremely importance	When one factor is very to extremely important over another factor.
9	Extremely important	The importance of one activity is of highest priority

Table 3.19 Pair-wise comparison of evaluation criteria

Criteria	A	B	C	---	E
A	1	C_{12}	C_{13}	------	C_{1j}
B	$1/C_{12}$	1	C_{23}	-----	C_{2j}
C	$1/C_{13}$	$1/C_{23}$	1	-- --	C3i
----	------	------	-----	1	C_{4j}
E	$1/C_{1j}$	$1/C_{2j}$	$1/C_{3j}$	$1/C_{4j}$	1

Table 3.20 Random consistency indices (RI) for n=1, 2,......,15 (Saaty, 1980)

N	RI	N	RI	N	RI
1	0	6	1.24	11	1.51
2	0	7	1.32	12	1.48
3	0.58	8	1.41	13	1.56
4	0.9	9	1.45	14	1.57
5	1.12	10	1.49	15	1.59

The user interface for pair wise comparison method is presented in Fig. 3.31. The user interface consists of a *combo box,* containing numbers from 1 to 15, one *MSFlexgrid control* to display the results and one *command button.* Besides, the list of 1 to 9 point scale has been shown in the main user interface of this module to help the user to enter the weights to the original matrix. Firstly, user enters the number of criteria, after that the framework of the matrix displays to the user. User enters the relative weights and clicks to the "Calculate Weights" command button. Calculated weights are shown in a table. Now user clicks on Lambda (LD), Consistency Ratio (CR) and Consistency Index (CI). If the consistency index in grater than 0.1, user get message to change the original matrix. Now user can check the consistency of the weights by clicking on command button of LD, CI, and CR. The programming code for the module is given in Appendix K.

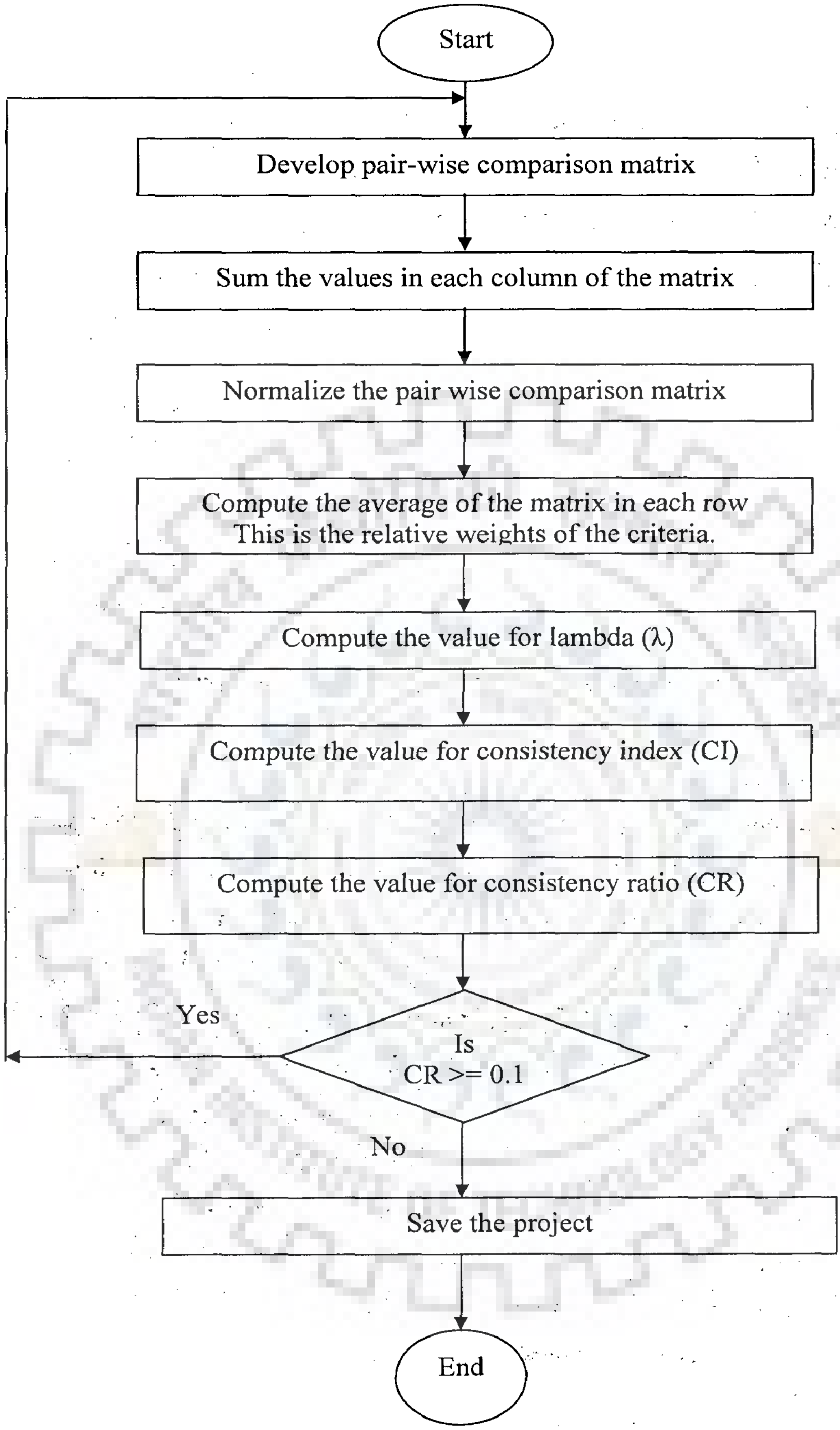


Fig. 3.30 Step-by-step procedure for calculating weights by pair wise comparison method

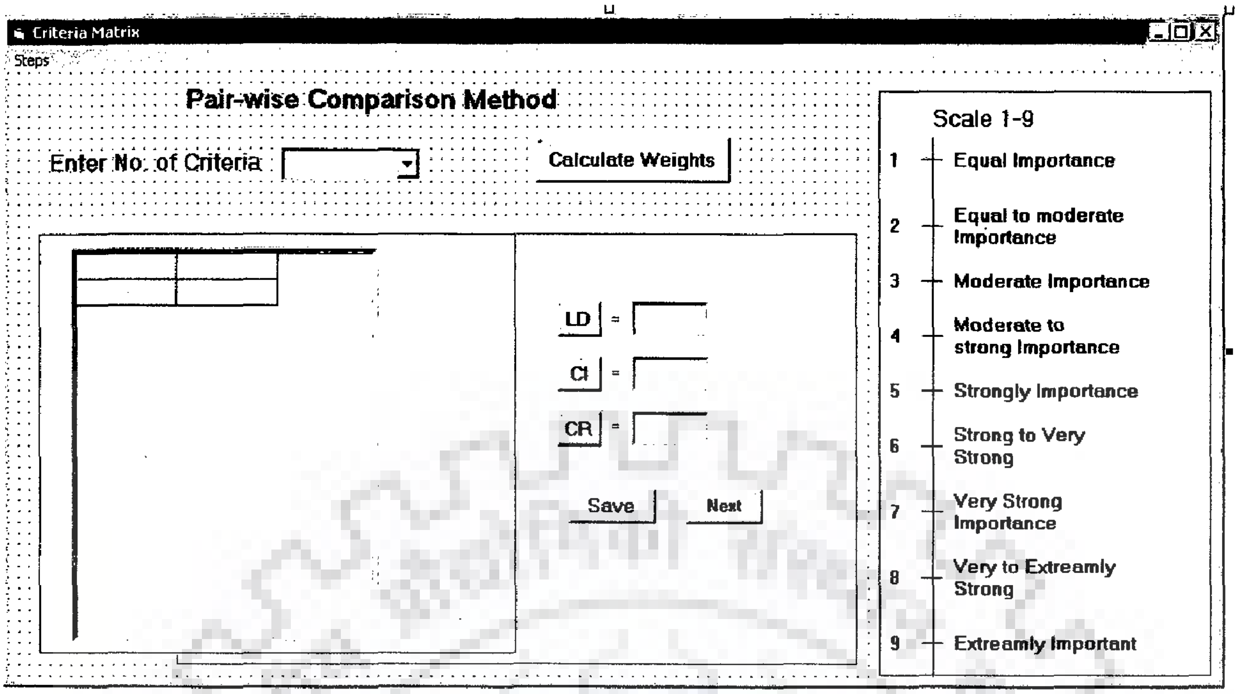


Fig. 3.31 Graphic user interface for pair wise comparison method

3.6.9.2 AHP method

After calculating the weights for the criteria, user can decide the objectives to be minimized or maximized for each criteria. Then total score is calculated based on the impact of each criterion to the objective of decision making. Here, AHP module is developed in a generalized form and can be used for any decision making work. In which option upto 15th criteria's are available. The data input file should be a *.mdb file and user will get the output score, rank and bar-chart. The attribute table and weightings must be integrated to provide an overall assessment. This is accomplished by an appropriate decision rule or aggregation function (Chankong and Haimes, 1983). Since a decision rule provides an ordering of all alternatives according to their performance with respect to the set of evaluation criteria, the decision problem depends on the selection of best outcome. The most often used decision rules are combining the criteria in a linear combination,

$$Total\ Score = \sum_{j=1}^{n} Wi * Xij' \tag{3.27}$$

If the objective function is to maximize criteria, then the attributes a parameter are standardized by dividing raw value by the maximum raw value for a given criteria.

$$Xij' = \frac{Xij}{Max(Xij)} \tag{3.28}$$

If the objective function is to minimize criteria, then the attributes are standardized by dividing minimum raw value by the raw value for a given criteria.

$$Xij' = \frac{Min(Xij)}{Xij} \tag{3.29}$$

where, Xij' = Standardized score for the i^{th} factor and j^{th} attribute

Xij = Value for the i^{th} factor and j^{th} attribute

Wi = the normalized weight of the i^{th} factor

The advantage of this method is that it is a proportional linear transformation of the raw data which means that the relative order of magnitude of the standardized scores remains equal. One disadvantage is that the lowest standardized value does not necessarily equal to zero which makes the interpretation of the least attractive criterion score difficult Figure 3.32 shows the step-by- step procedure of calculating score by the AHP method..

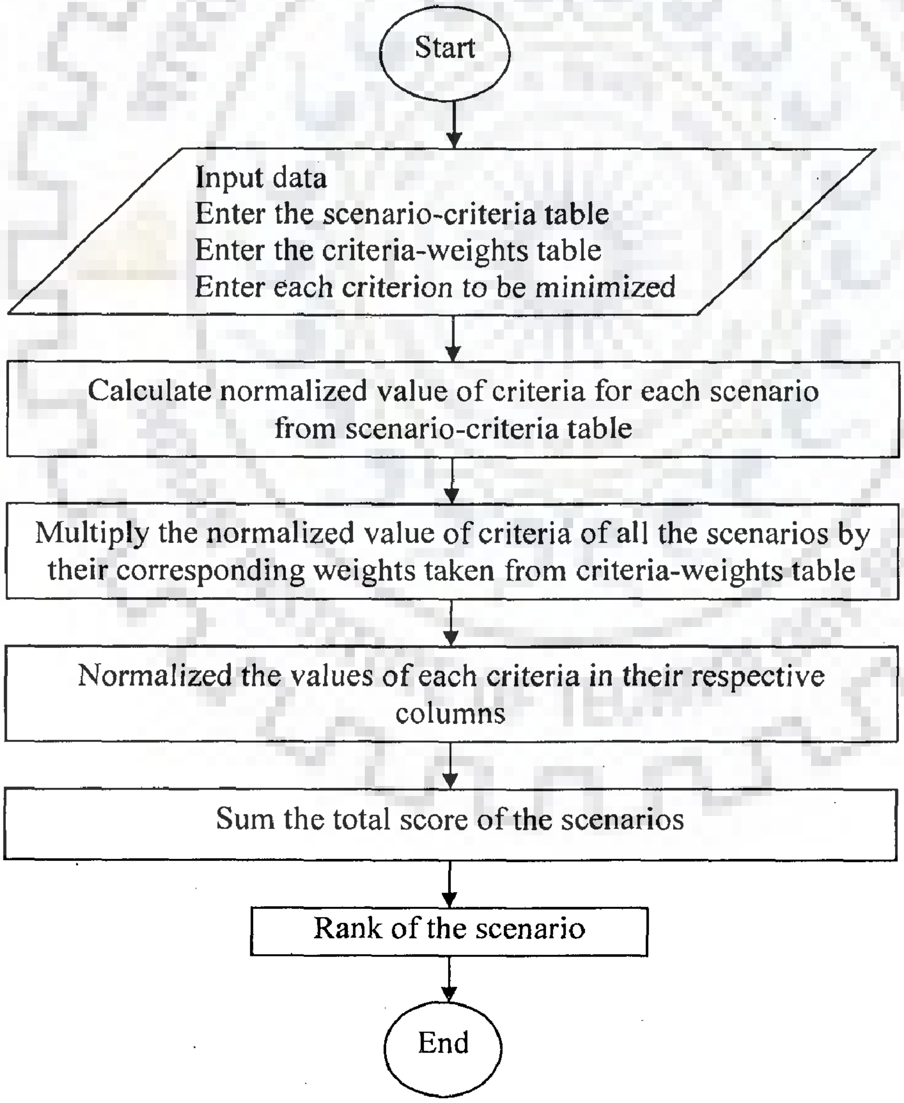


Fig. 3.32 Step-by-step procedure for AHP method

The result of this process can be saved in a table containing score and rank of all the input scenarios. Bar-chart of scenarios and their corresponding scores can be seen to compare the result by visualization.

The user interface of the AHP module is presented in Fig 3.33. The user interface consists of two combo boxes for entering the scenario-criteria table and criteria-weight table. The criteria weight table is generated by the module of pair wise comparison method and the scenario-criteria table is generated by the integrated scenario analysis module, where user generates the scenario and the scenario will be saved in a specified format. Besides, user can generate the table in MS Access and get the results. Then user has to enter the functions to be minimized or maximized to get the scores. Firstly user clicks on the "compute" command button, then "best ranked scenario" and bar-chart and rank will be displayed. Further user can save this score and rank table in the same database. The programming code for the module is given in Appendix L.

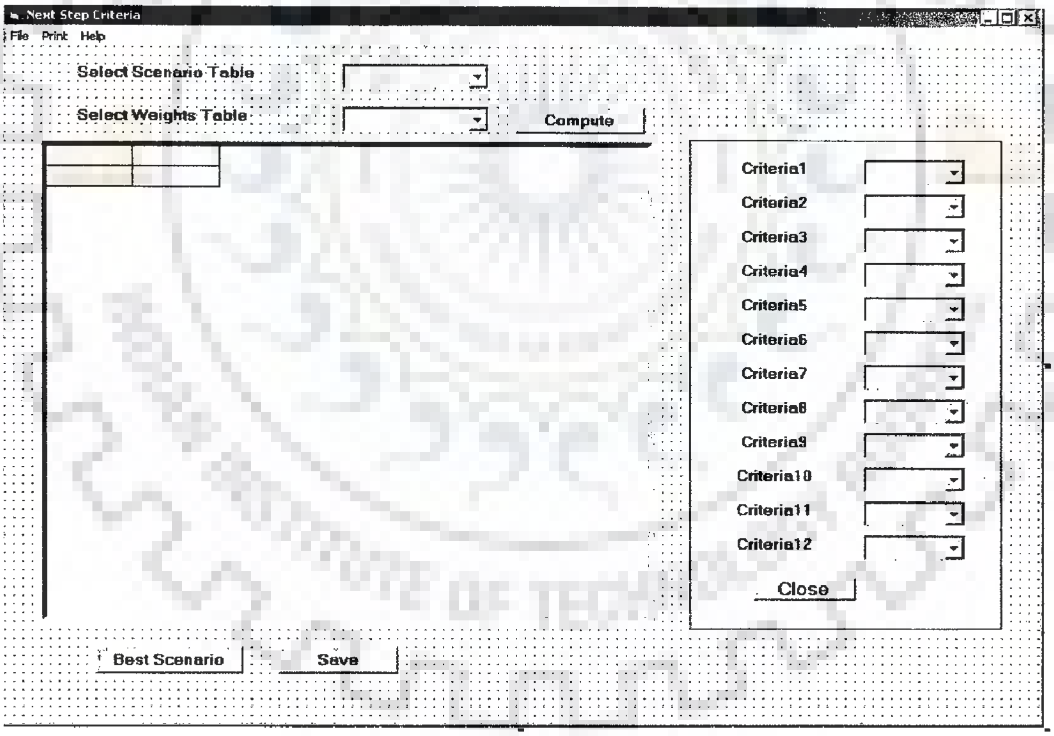


Fig. 3.33 Graphical user interface for AHP module

3.7 Development of Main Interface of DSS

The main interface of the DSS is divided in two parts. The first part comprises a start page giving the details of DSS as shown in Fig.3.34. This page has two controls; (i) Continue command button- User has to click on this command to proceed to the next main screen and (ii) Exit event, which terminates the DSS application before starting. Graphical user interface for the main interface of the DSS is presented in Fig. 3.35.

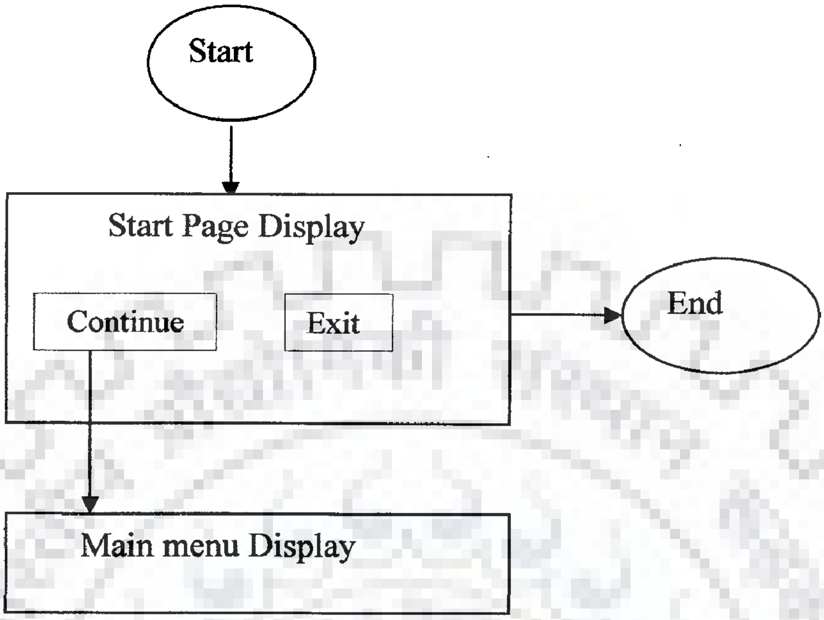


Fig. 3.34 Components of the main interface of the DSS

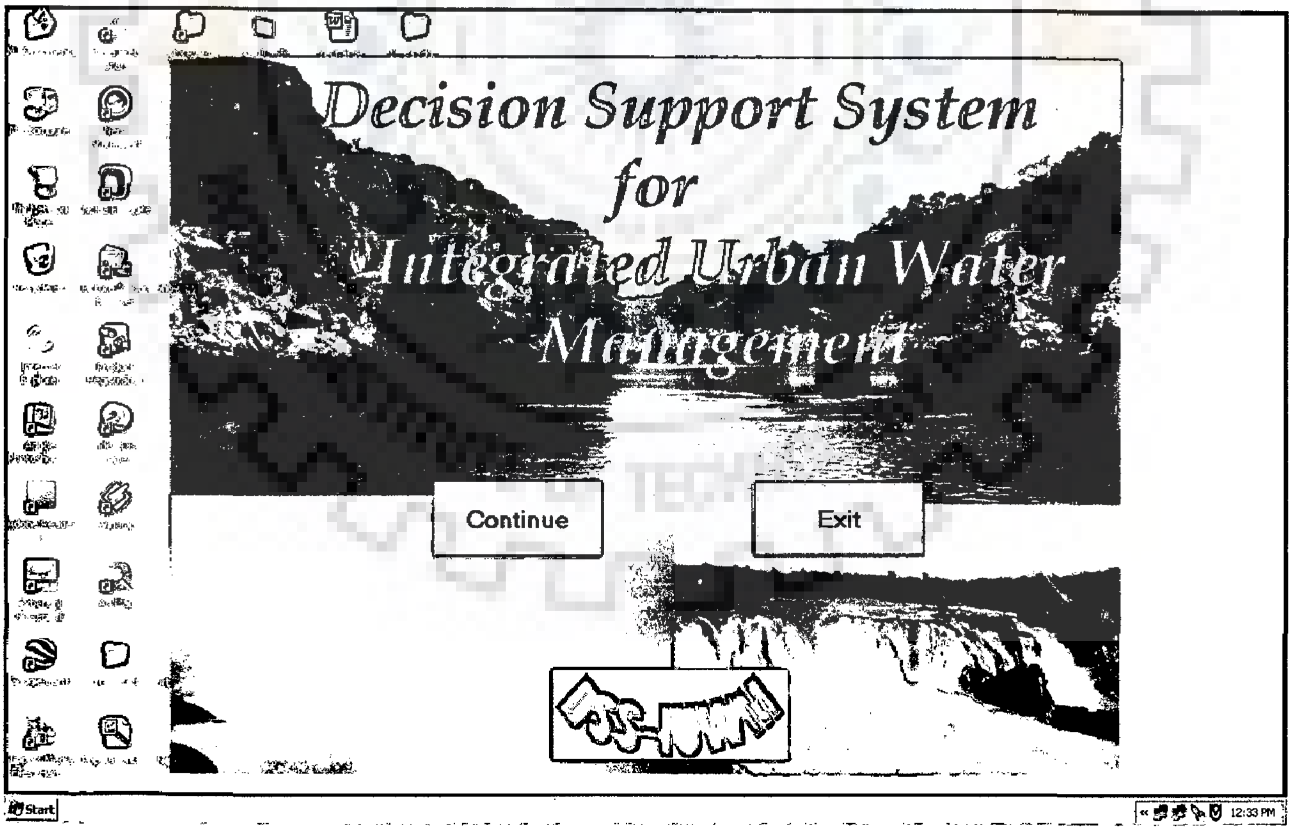


Fig. 3.35 Screenshot of main interface of the DSS-IUWM

The Main menu is the core part of the interface and the most functions in the DSS originate from this menu. The Main menu was designed to have six submenus: Database, Water supply, water deficiency, rainfall-runoff analysis, rooftop rain water harvesting, AHP and scenario generation modules. The submenus may have further submenus that trigger (further) windows forms or functions. The developed software platform is a prototype of the **D**ecision **S**upport **S**ystem for **I**ntegrated **U**rban **W**ater **M**anagement which has been abbreviated and called as **DSS-IUWM**. The programming code for the module is given in Appendix M.

3.8 Summary

A framework of the developed DSS has been presented in this chapter which describes the main components that provide data to supports decision-making. The conceptual design and development of the DSS has been detailed in this chapter. The structure of the DSS and the development of all subsystems have been described in detail. The designs of the user interface and its contents have also been then described. The concepts presented here can be used for any study dealing with integrated water resources management in an urban area. The developed DSS is general in nature with different options, which can be used for integrated urban water management. To demonstrate the application of the developed DSS, an urban area 'Dehradun' Municipal Area is considered. The details of the study area are presented in next chapter.

Chapter 4

STUDY AREA

Dehradun has been selected as study area as it is a rapidly growing city of Uttarakhand state of India. After becoming the capital of newly formed Uttarakhand state in the year 2000, the city has emerged as the premier business as well as service centre within the hilly region of the state. Following sections briefly describe the history, location, physiographic, climatic conditions and water management problem of the study area.

4.1 Brief History of the City

Dehradun is one of the old cities of India, situated on the foothills of Himalayas. It is a large city and also the capital of the newly created hill state of Uttarakhand, India. The city derives its name from the local tradition and is composed of two words "Dehra" and "Dun". Dehra signifying a temporary abode or camp while Dun means the lands at the foot of a mountain range. As the bulk of the district lies in such a tract, there is ample justification for the "dun" part of the name. Dehradun has its old history back to 250 BC. According to Skanda Purana, Dun formed part of the region called Kedar Khand. It was included in the kingdom of Ashoka by the end of the 3rd century B.C. History reveals that for centuries, the region formed part of the Garhwal kingdom with some interruption from Rohillas. For about two decades till 1815, the region was under the occupation of the Gorkhas. In April 1815, Gorkhas were ousted from Garhwal region and Garhwal was annexed by the British. In that year, the area now comprising the tehsil Dehradun was added to district Saharanpur. In 1825, however, it was transferred to the Kumaon Division.

In 1828, Dehradun and Jaunsar Bhabar were placed under the charge of a separate Deputy Commissioner and in 1829; the Dehradun district was transferred from the Kumaon Division to the Meerut Division. In 1842, Dehradun was attached to Saharanpur district but since 1871 it is being administered as separate district. In 1968 the district was taken out from Meerut division and included in the Garhwal Division. During the British era, Dehradun received a thrust of urbanization, being established as a hill station, which attracted large tourist population from world over. With significant enhancement in tourism infrastructure in the region, tourism activities have developed manifold in the region, Dehradun being the nodal point. During the British period, Dehradun became famous as center for education. National headquarters of a number of agencies have added to the growth pattern of the town. Increased developmental activities and economic growth in the region lead to significant urbanization growth in Dehradun as it is also the transportation node for the entire region.

Dehradun had been undergoing a steady growth of urbanization until year 2000 when it received a massive thrust, after it was declared the capital of the state of Uttarakhand. Administrative activities were enhanced manifold, which attracted a much higher growth in all-round urbanization. Migration of population from various parts of Uttarakhand in search of employment has considerable impact on the urbanization pattern of Dehradun.

4.2 Location

Dehradun, the premier city of Uttarakhand, is bounded by latitude 30°15′ to 30°24′ north latitude and 77°59′ to 78°06′ east longitude, with an average altitude of 640 meters above the sea. Figure 4.1 shows the location of the study area. Lowest altitude in the city is 600m in the southern part, whereas the highest altitude is 1000m in the northern part. Mussoorie, a popular hill station, known as the queen of hills, overlooks from the north. Due to this, Dehradun is also termed as gateway to Mussoorie. It is the only municipal corporation of Uttarakhand. The study area falls within survey of India topo sheet no.53J/3 and 53F/15. The Dehradun municipal board was divided into 34 wards as per 1991 census covering an area of 34.04 km^2. In 1995, the numbers of wards were reduced to 33 at the time of municipal election. Again in 1998, Dehradun municipal area was divided into 60 wards and in 2003; wards are again revised for municipal election. There are 45 wards at present and the total area of the city is 65.95 km^2.

The central part of the city is colonial vestiges and comprises of private residential area. Many prestigious educational and research institute are situated outside the city. The eastern part is residential and western part is having the office of Oil and Natural Gas Corporation, Cantonment, Wadia Institute of Himalayan Geology, etc. It is expected that in Dehradun city, population growth and floating tourist population will increase in near future especially in summer months. Dehradun is well connected with the major cities of India by rail, road and airways.

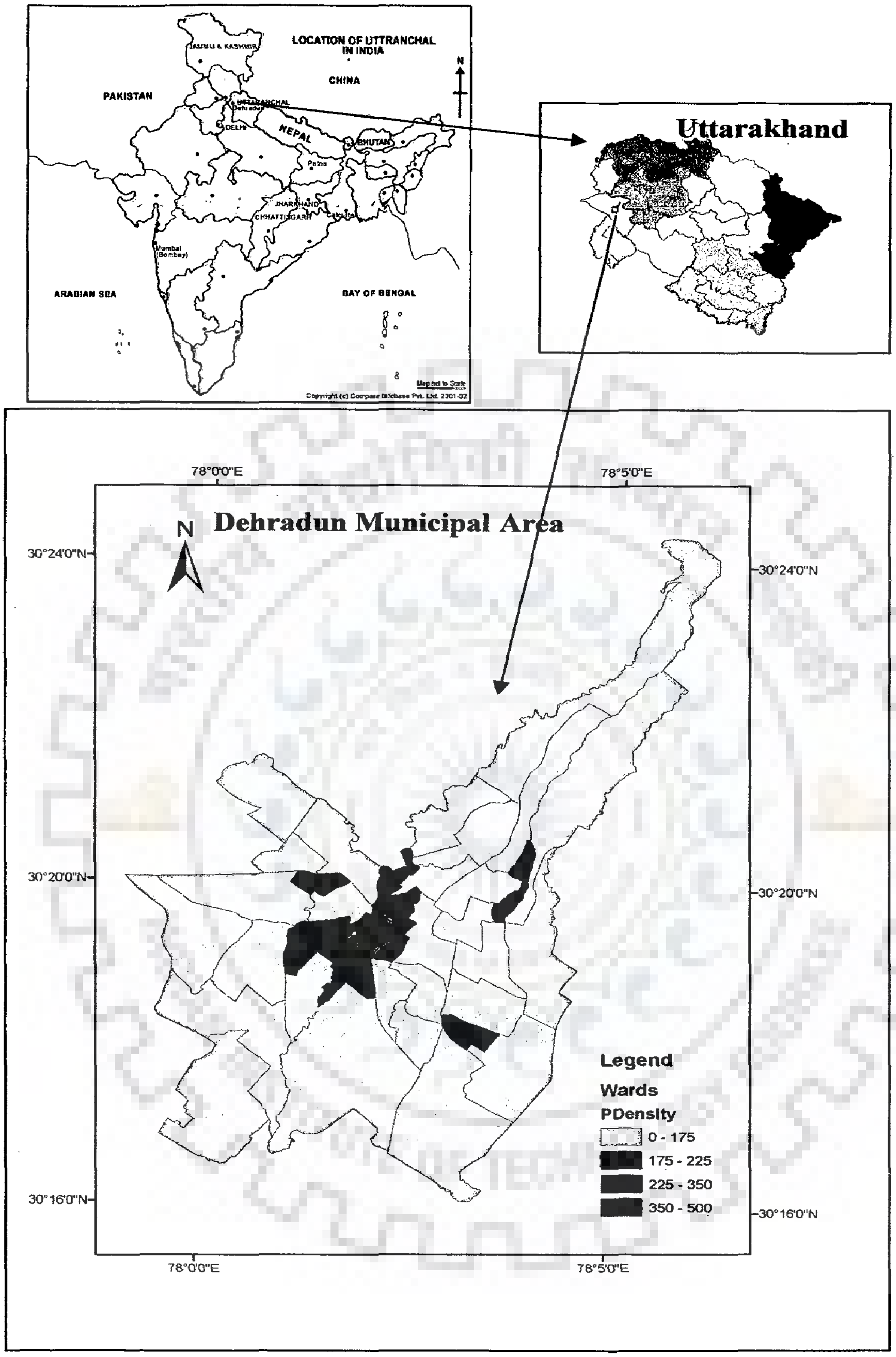


Fig. 4.1 Location of the study area

4.3 Physiography

Dehradun can be divided into two distinct tracts, viz; the mountain tract and the sub-mountain tract. The mountains are very rough with steep slopes. Below the mountain tract, sub-mountain tract is located. The famous Dun valley is bounded by Shiwalik hills in the south and outer scarp of the Himalayas in the north. The whole area is heavily dissected by a number of seasonal streams and nalas, which are locally known as "Khalas". The drainage of the city is borne by two rivers, namely Bindal Rao and Rispana Rao. The direction of flow of these seasonal streams and nalas in the eastern part is north to south and in the western part it is north to southwest. Dense patches of forests exist along the north and in the outer limit of regulated areas.

4.4 Climate

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

4.4.1 Temperature

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

4.4.2 Rainfall

The average annual rainfall of Dehradun City is 2183.5 millimetres. About 87% of the rainfall is received during the months from June to September; July and August being the rainiest months. Monthly total rainfall (mm) and monthly mean minimum and maximum temperature (°C) during the year 2000 and 2001 are given in the Table 4.1.

Table 4.1 Rainfall and Temperature Distribution in Dehradun Municipal Area (2000-01)

Year / Month	2000			2001		
	Rainfall (mm)	Mean Max Temp ^0C	Mean Min Temp ^0C	Rainfall (mm)	Mean Max Temp ^0C	Mean Min Temp ^0C
January	60.6	18.8	5.1	39.3	19.5	4.5
February	107.6	19.0	5.1	3.1	24.8	5.3
March	67.8	26.1	9.4	23.4	28.5	8.9
April	45.2	34.8	13.8	32.2	33.2	14.2
May	108.2	36.5	20.7	49.8	35.9	20.3
June	214.8	31.9	23.0	301.2	31.7	22.8
July	544.2	29.8	24.1	664.0	31.0	24.6
August	215.0	31.1	24.1	307.3	31.3	24.1
September	156.7	31.2	24.4	16.4	32.6	20.5
October	0.0	31.7	15.2	0.9	32.2	16.0
November	1.2	27.0	9.7	2.4	27.4	8.6
December	0.0	22.9	3.6	8.4	22.5	5.0
Total	1521.3			1448.4		

(Annual Report of CSWCRTI, Dehradun for the year of 2000-2001)

4.4.3 Humidity

The relative humidity in the city of Dehradun is high during the monsoon season, normally exceeding 70%. The mornings are generally more humid than the afternoons. Summer season is the driest part of the year and during this season; the relative humidity may fall below 45%.

4.4.4 Prevailing winds

The winds are mostly from direction between southwest and northwest throughout the year except October and November. The annual mean wind speed is 3.2 km/hour. Mountains and valley winds are common throughout the year.

4.5 Present Status of Urbanization

The characteristic of an urban area is defined by its population density and change in landuse pattern. In Indian context, the area having a minimum population of 5000, or a population density more than 400 persons per km^2, is called urban area. As per the census 2001, Dehradun city had population of 5,60,120 and average population density was 7300 persons per km^2. The city had been undergoing a steady growth of urbanization until year 2000 when it received a massive thrust, having being declared as the capital of the state of Uttarakhand.

Population from various parts of Uttarakhand migrated to Dehradun in search of employment and finally settled here. The town is expanding in east, west and south direction. However, development of the city in north direction is limited due to hilly area and so the limit of the city is extended towards south across municipality. Rapid developmental activities and economic growth in the region lead to significant urbanization growth in Dehradun. The town, consequent to ever increasing administrative and economic activities is under a tremendous thrust of urbanization, and urban services need to be upgraded to match the pattern of rapid development.

4.6 Demography

Dehradun was twelfth largest among class I cities of Uttar Pradesh according to size of population before the year 2000 when it was a part of Uttar Pradesh state. It is now largest city in the new state of Uttarakhand. The total population of Dehradun urban agglomeration was 560120 persons in 2001 out of which population of municipal area was 440246. As per the new status of Dehradun, it is expected that the growth rate will be as high as 50% for U.A. and 35% for municipal areas. The absolute figures of population; increase of population and the percentage increase for each decade from 1901-2001 are presented in Table 4.2.

Table 4.2 Population growth of Dehradun urban agglomeration (Master Plan, 2001-2025)

S.No	Year	Population	Increase of population	Percentage increase (%)
1	1901	30995	--	--
2	1911	42568	11573	37.34
3	1921	50858	8290	19.47
4	1931	52927	2069	4.17
5	1941	80580	27653	52.25
7	1951	144216	63636	78.97
8	1961	156341	12125	8.41
9	1971	220571	64230	41.08
10	1981	293010	72439	32.84
11	1991	367411	74401	25.39
12	2001	560120	1,92,709	52.45

The ward wise population for Dehradun municipal area has been presented in Table 4.3. The data was collected from Nagar Nigam (Municipal Corporation), Dehradun.

Table 4.3 Population of Dehradun Municipal Area (2001)

Ward ID	Name of Ward	Population	Ward ID	Name of Ward	Population
1	Rajpur	11389	24	Idgah	11823
2	Sahastradhara Ward	8686	25	Shivaji Ward	7521
3	Arya Nagar	10729	26	Gandhi Gram	12080
4	D L Road	9178	27	Laxman Chowk	7257
5	Rispana	7670	28	Patel Nagar	7487
6	Mansinghwala	7755	29	Lakkhi Bagh	7222
7	Karanpur	8022	30	Ritha Mandi	6990
8	Adhoiwala	17028	31	Jhanda Mohalla	7853
9	Dalanwala (N)	8403	32	Inderesh Nagar	6764
10	Dalanwala (S)	11310	33	Khudbura	8105
11	Rajiv Nagar	13681	34	Dandipura	7779
12	Dharampur	9913	35	Lunya Mohalla	7352
13	Ajabpur	18023	36	Dhamawala	7864
14	Bhandaribagh	9902	37	Chandera Nagar	8758
15	Majra	13400	38	Racecourse (S)	13965
16	Niranjanpur	16573	39	Racecourse (N)	8945
17	Kanwali	15091	40	Mahadevi K P	10124
18	Basant Vihar	11666	41	Chukkhuwala	7737
19	Maharanibagh	12258	42	Bakralwala	8199
20	Ballupur	7428	43	Indra Colony	8257
21	Kaulagarh	7915	44	Vijay Colony	8244
22	Rajender Nagar	8138	45	Salawala	7644
23	Devsuman Nagar	8118		Total	**440246**

4.7 Status of Water Supply

Water supply of the Dehradun city is managed by the Jal Sansthan. Presently domestic water demand of the city is computed @ 220 lpcd. Therefore total demand is 123.23 mld. About 82% of total water supply of the city is met by ground water. There are 26 overhead tanks of varying capacities. The ground water depth varies from 20-90 meters. About 83.95 mld water is supplied by the tube wells, while an amount of 22.63 mld water is supplied from the surface water. Total water supply for the city is 106.32 mld. Hence, it is clear that there is a shortage of about 16.63 mld and the gap is expected to widen in the next decade. The supply situation becomes grim in summers due to the greater use of water for domestic needs, street and lawn sprinkling. Except for a few areas, the rest of the city has problem in getting sufficient drinking water. The existing water supply from springs and rivers has become inadequate and tapping new sources for augmentation for water needs and also extension of distribution system to the new colonies has become essential.

The problem of inadequate pressure in the water supply pipes remains in the areas of higher elevation. This problem is partly due to lack of proper analysis while planning the construction of overhead tanks. Apart from the above reason, the limited economic resources, high expenditure involved in drilling a tube well and the shortage of man power are also the reasons for the sub-optimal operation of the system of water works.

Water quality is an essential parameter of water supply. As per the assessment done by the Jal Sansthan, most of the city's supply comes from ground water, which has passed through the natural filtering medium of soil and gravel. Hence the quality of the groundwater is acceptable. Surface water is treated at Dilaram Bazar and Shaenshahi Ashram in a multi-step procedure: pre-chlorination (only during monsoon or when the chances of contamination are high), a chemical precipitation, sedimentation, filtration and final chlorination. A quality analysis of the drinking water was carried out by the People's Science Institute (PSI). Out of 25-samples, 16 samples showed coliform (total and fecal coliform) contamination in drinking water, above the BIS prescribed limits. Despite the chlorinating in most of supply centers, presence of coliform bacteria indicates that drinking water gets contaminated due to poor and faulty distribution system and/or water gets less exposure to chlorine. Perhaps the problem lies in the layout and state of the water distribution pipes, often laid alongside sewer system into ground or overflows during the monsoon and then into water pipes through the leakage. Moreover, when the water flow in the pipes is interrupted, the low pressure in these pipes allows the sewage or contaminated water to enter the flow. Sewerage pipes serve only 40% area of the city, while rest of the city suffers from the problem of pollution.

Drainage is also a problem in newly developed areas of Dehradun. Several areas of Dehradun come under prolong water logging after heavy rains. These water logging pockets as identified have been investigated through field survey and probable causes have been ascertained. Water logging in these areas is either due to improper planning of drainage system or absence of any drainage system. The Nehru Colony area also contributes run-off to the drains of Dharmpur ward (Fig. 4.2). The area is having almost no drainage in most part. Existing drains are severely chocked. During field visits, interaction was made with the experts and users about the water problem in Dehradun and it was found that the low lying area of Dharmpur, Deep Nagar and Vidhan sabha road and Cantonment area face drainage problems.

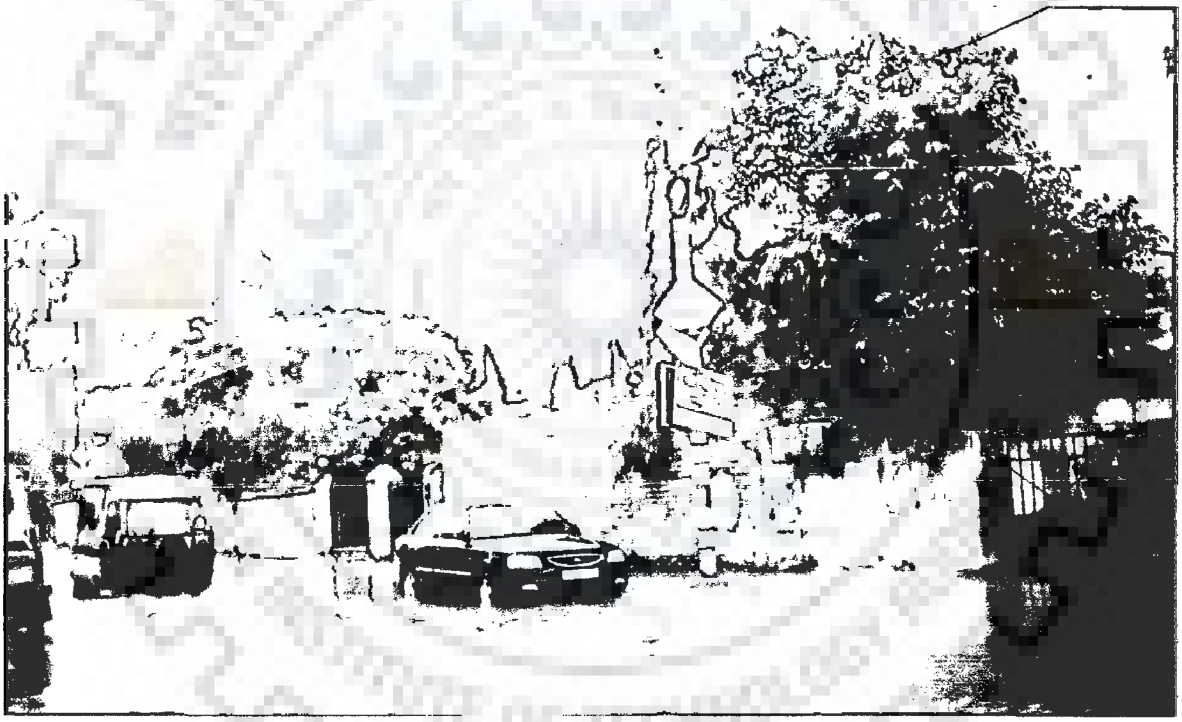


Fig. 4.2 Water drainage problem in Dharmpur ward

The local residents have stated that after becoming the capital city, shortage of water have increased in Dehradun. In summer season water is supplied only for 30 min to 4 hrs. Main water problem in Dehradun city is high water demand due to high population density. Besides water demand per capita is also increasing due to change in lifestyle of people. Total water loss is about 30% of water supply due to leakages in the existing water supply system. Over exploitation of surface water and ground water have created pressure on the sustainability of the available water resources. Hence corrective measures are necessary to fill this gap. Municipal water supply caters to the need of the permanent population of Dehradun and floating population such as tourists, business persons, students etc. Since it is a rapidly growing city, problem is expected to further increase in the future. Water supply problem of Dehradun needs a long-term solution by augmenting the future water supply including ground water recharge, runoff reduction, and water demand reduction measures. All the feasible strategies must be implemented in an integrated way for the sustainable utilization of water resources.

4.8 Summary

Dehradun being the capital of the Uttarakhand state, it is necessary to study the present water supply and demand of the city to find out water shortage areas and to provide an integrated solution for the sustainable development of water resources. Summing up the above issues, it is inferred that a holistic study is needed to find an optimal water supply system keeping in mind the future requirements of the growing population. This can be best done by integrated water management, i.e. optimal utilization of all existing water sources, water conservation and demand management for sustainable development.

Chapter 5
DATABASE PREPARATION

5.1 Prelude

Decision making in planning and management of water resources systems requires information extracted from large amount of spatial and temporal data. To define and understand exactly what is meant by the database, first the data should be described. Data are the facts about an object or a concept. It can be a person or an organization (e.g. the decision maker for water management or a user of a DSS), a place (e.g. catchment, house), an action (e.g. forecasting and warning) and many others, or it can be any combination of above facts. Data needed for the present work are boundary map, ward map, rain-fall, population, water supply sources and potential, geological map, soil map, land use, slope map, satellite data, master plan etc. collected from various organizations. This chapter provides the details of data collection and conversion of spatial and non spatial data to the required digital format.

5.2 Data Collection

Water resources projects require a wide range of information which are collected from records of concerned government organizations, inputs from field visits, and remote sensing images. This information may consist of rainfall data, soil map, landuse map, quantity of water, population, water consumption and environmental data etc. Details of spatial and non-spatial data used in this study are given in Table 5.1. Data were collected from various organizations of Dehradun city, literatures and Master plan of the city. The advancement of computer technology, particularly the invention of GIS, has made it possible to digitize, overlay several maps and to create new sets of maps as per requirements of analysis.

5.3 Software Used

The spatial and non-spatial data collected from various sources were required to be organized in the desired format. The spatial data need to be extracted and transferred from their current storage media to the shape files. Since vector data in the form of shape file was planned and required for the input to the DSS to generate the various layers, spatial information were converted to the required digital format.

Table 5.1 Description of the spatial and non-spatial data collected from various sources

	S. No	Data	Description	Year	Source
SPATIAL DATA	1.	Toposheet 53f/13 and Toposheet 53J/3	Scale- 1: 50,000	1984 (Year of survey)	Survey of India, Dehradun
	3.	City Guide Map	Scale- 1:20000	1984	Survey of India Dehradun
	4.	Geological Map	-----	2004-2005	Master Plan
	5.	Soil Map	------	1999	NBSSLUP, Nagpur
	6.	Building Map	-----	2001	IIRS, Dehradun
	7.	Wards Map	------	2004	Nagar Nigam Dehradun
	8.	Satellite IRS P6 MX	5.8m resolution.	22 March-2005	NRSA, Hyderabad
	9.	SRTM Data	90 m resolution	2004	CGIAR website
NON-SPATIAL DATA	10.	Population/Demographic data at village level	-	2001	NIC Dehradun
	11.	Decadal Population data at city level	-	1901-2001	Master Plan, Dehradun
	12.	Rainfall and Meteorological data	Daily	1998-2003	India Meteorological Department (IMD), Pune
	13.	Rainfall	Monthly	1971-2001	IMD, Pune
	14.	Rainfall	Hourly	1995-2001	IMD,Pune
	15.	Tubewells data, Surface water supply, Overhead tank, reservoir	-----	2004	Jal Sansthan, Dehradun

In this study, software used for preparing the required shape files are (i) ERDAS Imagine 8.5 and (ii) ArcGIS 9.0. A brief description of both the software is given in the following sections.

5.3.1 E RDAS Imagine 8.5

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. It allows accessing several raster and vector formats. ERDAS also provided several easy-to-use functions for spatial, radiometric and spectral enhancements, as well as for topographic and GIS analysis. Its Spatial Modeler module provided easy-to-use, object-based interface for integrated raster and vector analysis. In the present study ERDAS Imagine is used for making geo-referencing of the maps, analyzing the remote sensing data and for land use and land cover map and other features.

5.3.2 ArcGIS 9.0

ArcGIS has been developed by ESRI, which one of the leading softwares for desktop GIS and mapping. ArcGIS gives the power to visualize, explore, query and analyse data geographically. In this work, it was used for display of vector mapping, digitizing different features and querying the data geographically and for finding attributes of any feature on a map. Different extensions such as geo-referencing, spatial analyst, 3D Scene are used for various analyses. Following section discusses the generation of GIS database whereas generation of non-spatial database will be discussed later.

5.4 Generation of GIS Database

Computer based information technology is beginning to play very important role in water resources planning and management. More and more spatial and temporal data are becoming available from remote sensing satellites and other equipments, requiring advanced data mining techniques for interpretation and analysis. GIS is employed to create and manage large spatial data on computers. It is essential software to handle large amount of spatial data on computers. GIS helps to improve the quality of decision making through its vast capacity to analyze, display and manage the data.

A shape file is a spatial data format developed by ESRI. It stores non-topological geometry and attribute information of the spatial features in the data set. A shapefile consists of at least a main file, an index file and a dBASE file. The main file and index file store the feature geometry and the index of the feature geometry respectively. Attributes of geometric data (e.g. house) are held in the dBASE file. Each attribute record has a one-to-one relationship with the associated shape record. The main file (with the extension "shp") is a direct access, variable-record-length file in which each record describes a shape with a list of its vertices. In the index file (with the extension "shx"), each record contains the offset of the corresponding main file record from the beginning of the main file. The dBASE table (with the extension "dbf") contains feature attributes (e.g. elevation of a house) with one record per feature. Attribute records in the dBASE file must be in the same order as records in the main file.

Each file in a shape file has a specific data structure. For example, the main file (*.shp) contains a fixed-length file header followed by variable-length records. Each variable-length record is made up of a fixed-length record header followed by variable-length record contents. The main file header is 100 bytes long. If one knows the structure of the shapefiles, the program can be written to integrate various elements of the DSS with GIS software, without using any commercial software tools. The shape file can be created in many ways. It can be created by exporting any data source using ArcInfo, PC ARC/INFO, Spatial Database Engine (SDE™), ArcView GIS, or Business MAP software. The second way of creating shape file is directly by digitizing shapes using ArcGIS feature creation tools. Using Avenue in ArcView GIS, MapObjects, ARC Macro Language (AML) in ArcInfo or Simple Macro Language (SML) in PC ArcInfo software, the developer can create shapefiles within their programs.

In the present work, the shape file was prepared from the hard copies of collected map. The process of preparing shape files begins with scanning of maps, georeferenceing, and digitization. After digitization, attributes have been attached to each features of a layer. The step-by-step procedure is described in the following sections.

5.4.1 Scanning of maps

All hard copy maps such as SOI toposheets, ward map, soil map, geology map have been converted into digital form by scanning using software HP Precision Scan Pro & a HP A0 size scanner. Scanned data are stored in JPEG (Joint Photographic Expert Group) format. This format is used since the size of data in this format can be reduced to a large extent without significantly loosing quality. The image quality is further enhanced by adjusting the brightness and contrast of the image in Adobe Photoshop. The scanned map area does not represent the location on the surface of the earth and is inadequate to perform analysis. This data does not contain any information and are merely pixels of color composites of red, green and blue. After scanning, the data is ready for georeferencing in GIS.

5.4.2 Registration

The data used in geographic information system may come from different sources and available in different formats or types, hence a uniform projection system must be used for all these geographic images. In order to provide a common scale to all data and for all measurements, maps and image has to be registered with each other. Firstly, Survey of India toposheet No. 53J/3 and 53F/15 were scanned and registered using ERDAS 8.5 software. Geographical (latitude/longitude) projection WGS 1984 UTM Zone 44N has been selected as the projection system. Four ground control points distributed over whole area, whose latitude and longitude are known, were manually selected from toposheet. After creating enough links, a first order transformation was used for registration with RMS error of 0.25 which is in acceptable range. Resampling is performed by nearest neighbor assignment to give a final geo-referenced map. Then the geo-referenced images were imported to ARC/GIS 9.0 and mosaiced with each other. This mosaic image was used to register the guide map of the city. After geo-referencing the base map, remote sensing image were registered with base map using the same technique of taking four points which were easily identified in both toposheet and image. Details of the remote sensing image collected from the NRSA, Hyderabad is given in Table 5.2.

Table 5.2 Details of the remote sensing image

Satellite	IRSP6
Sensor/ sub-scene	L4MX
Path/ Orbit	7418
Scene No	036
Date of Pass	22MAR-2005
Shift	20%

5.4.3 Digitization

After georefrencing, the imag e was opened in ArcGIS 9.0 for displaying and finally used in background for on-screen digitization. In ArcGIS, different features are digitized in different layers. GIS database has been prepared in vector data format (shape files). In the digital map the spatial relationships are depicted using the topology. In ArcGIS, depending up on type of feature and scale of map, different features can be digitized in three modes: points, line, and polygon. In ArcGIS first an empty layer is created. A layer can contain point, line, polygon features. Here one can prompt to specify a name and location for the new shape. To store features one adds to it with drawing and editing tool. To set the properties of graphics before it is drawn, one can choose legend editor window from the window menu. This allows for modification as to how the active theme is to be displayed. Depending upon the characteristics of the feature, attributes have been defined. Table 5.3 gives the classes of different features and their mode of digitization.

Table 5.3 Mode of digitization of various land features in GIS

Feature class	Mode of Digitization
Ward boundary	Polygon
Ward map	Polygon
Landuse map	Polygon
Slope map	Polygon
Soil map	Polygon
Geology map	Polygon
Tubewell map	Point
Overhead tank	Point

5.4.4 Creation of a ttribute

Attribute information is displayed in cell arrays. 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 such as area and perimeter of polygon are automatically calculated.

5.5 Creation of Different Maps

Toposheets and guide maps were used to find out the accurate ward boundary of the Dehradun Municipal area. Following sections describe the generated maps for the study area.

5.5.1 Wards map of the study area

This map was obtained from Nagar Nigam (Municipal Corporation), Dehradun, which includes wards boundaries. Wards have been divided through roads or river boundary. The shape file was created by digitizing the outer boundary from the roads and other features of toposheets, guide maps and satellite image and finally, wards boundary map have been created. Figure 5.1 shows the registered satellite image of the Dehradun city overlaid with the boundary map of Dehradun municipal area. The boundary map has been used to extract the study area from the available maps of larger area such as geology map, soil map, landuse map etc. After extracting the relevant area from satellite image, the boundaries of different wards have been digitized. Name of the wards and ward's ID have been added as attribute to the tables associated with the shape file. Figure 5.2 shows the wards map of the study area.

5.5.2 Landuse map

Information on existing landuse/landcover and pattern of their spatial distribution is the basis for any development planning. Accurate registration/geo-referencing of maps is preliminary requisite of any GIS database. Land use/land cover map was prepared by digitizing the geo-referenced satellite image of Dehradun city. The image is at 5.8 m resolution. The land use in Dehradun municipal area consists of forest, agriculture, highly built-up area, low built-up area, tea gardens/gardens, and open area and water bodies as shown in Table 5.4. Figure 5.3 shows the landuse map of the study area. The map was used to generate Curve Number (CN) map and thus classes were derived accordingly.

Table 5.4 Land use classes for the study area

ID	Class	Description
1.	Forest	The land on which trees are growing in natural form.
2.	Agriculture	The area of agriculture having main crop as rice.
3.	Highly built-up area	The area having residential, institutional, highly commercial area, road network etc or the area having high imperviousness.
4.	Water bodies	It contains river, lake, pond, etc.
5.	Pastures	Tea plants and gardens.
6.	Low built-up area	It includes mix built-up area covered by vegetation for example residential area where plot have low built-up.
7.	Open area	The land covered by parks, scrub area, and vacant ground have been considered under this category.

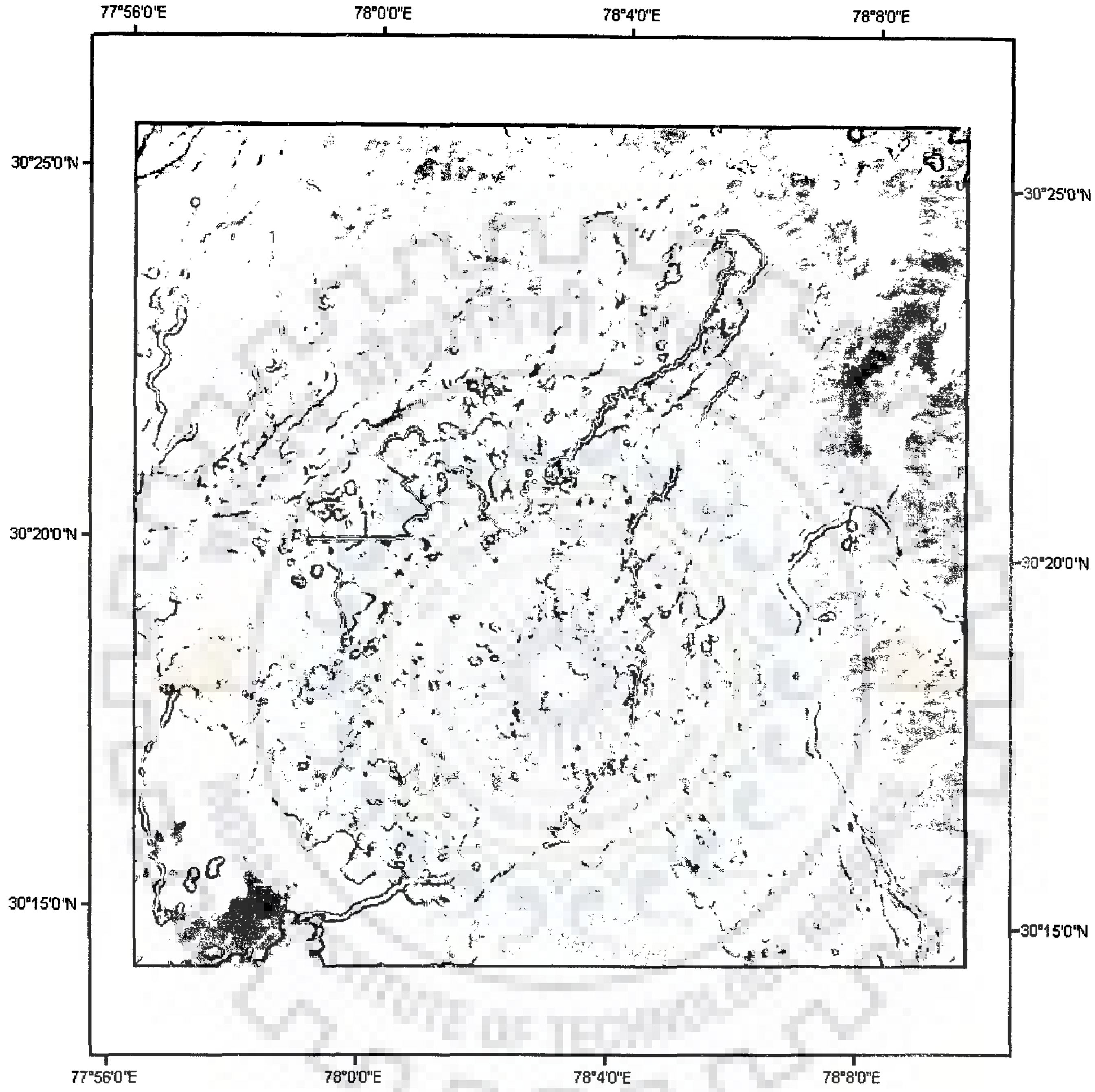


Fig. 5.1 IRS P6 LISS IV Satellite Image for Dehradun City

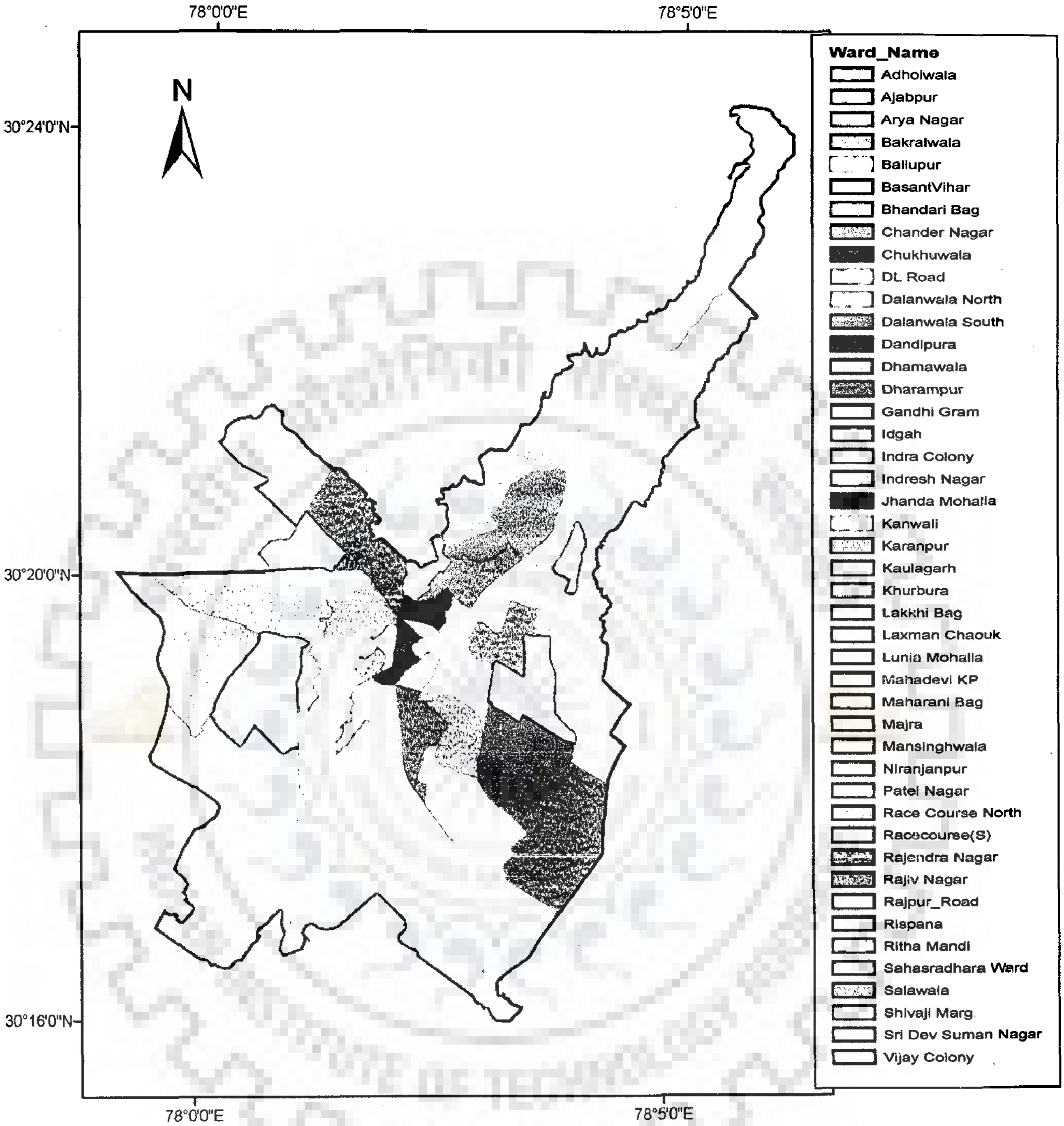


Fig. 5.2 Wards map of the study area (2001)

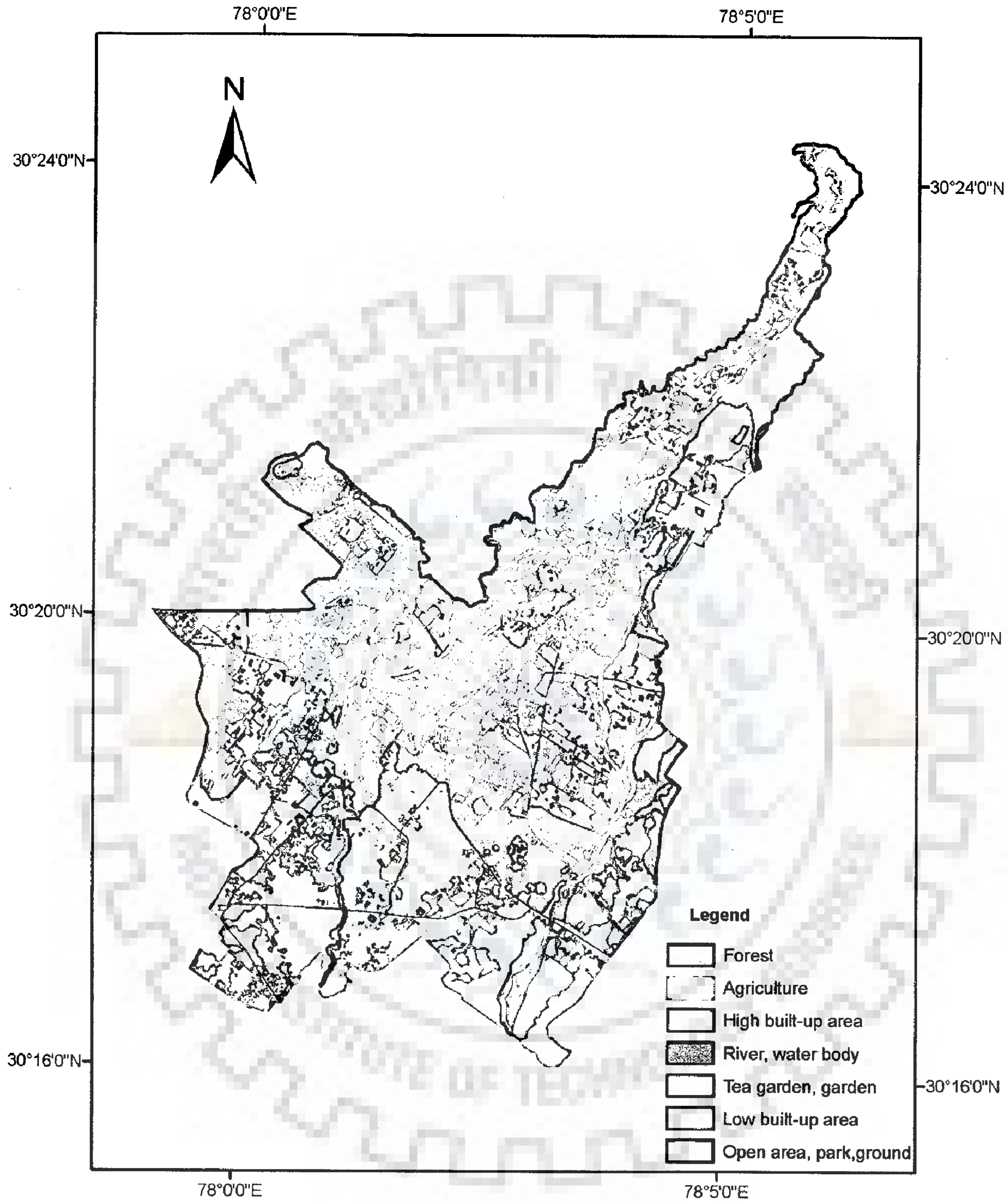


Fig. 5.3 Landuse map

5.5.3 Population map

The ward wise populations have been obtained from National Informatics Center (NIC), Dehradun. The data have been added to the attribute data of the wards map and the classified map has been shown in Fig. 5.4.

5.5.4 Tubewell map

Locations of the tube wells have been obtained from the Garhwal Jal Sansthan, Dehradun. A map has been prepared showing the location of these tube wells in different areas of Dehradun City on 1:20 000 scale. Figure 5.5 shows locations of all the villages having tubewellls in the study area. The map has been prepared and cross checked by the available literatures and field visits. It can be seen that the northern part of the city does not have tubewells, in this part of the area ample surface water is available and the geology does not support digging of tubewells. This map is the main input of water supply module. The tubewell discharge in liter per minute (lpm) has been added to the map as attribute data.

5.5.5 Building map

Building map was collected from IIRS Dehradun, and it was registered as the datum of wards map and edited to the polygon features as per the requirements of the study area as shown in Fig. 5.6. So the roof area in Dehradun city can be determined through this map. This map is the main input data in rainwater harvesting module.

5.5.6 Geology map

Geology plays an important role in ground water resources evaluation of any area. Fraction of rainfall that is going to the aquifer basically depends on type of underlying geology of the area. Geology map of the study area was taken from the Master plan of Dehradun City. The original map was scanned and registered in ERDAS 8.5 then the domestic ward area was extracted from the map and digitized in ARCGIS 9.0. Resulting map is shown in Fig. 5.7, which reveals that the geological foundations of the Dehradun domestic area are of two types: *old doon gravel* and *Blaini-krol*. *Old doon gravel* is composed of boulders and gravels bed that cover the finer deposits of the middle doon surface. *Blaini-Krol* is made of Conglomerate, Carbonaceous Shale, grey Siltstone, varved Argillite, minor Quarzite and purple Dolomitic limestone. *Krol* formation is made of massive sequence of Limestone slates, Siltstone and Dolomites.

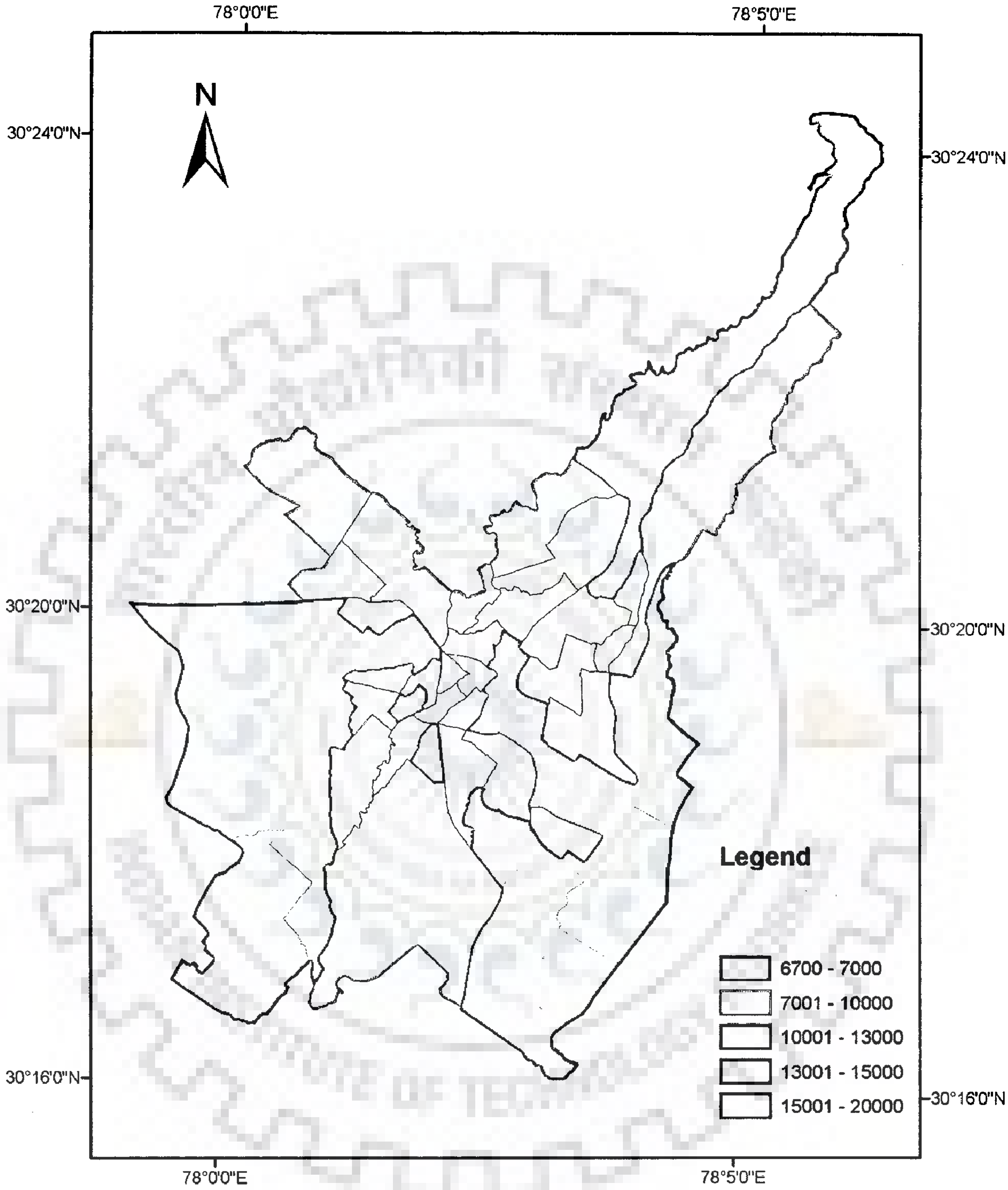


Fig. 5.4 Population map (year 2001)

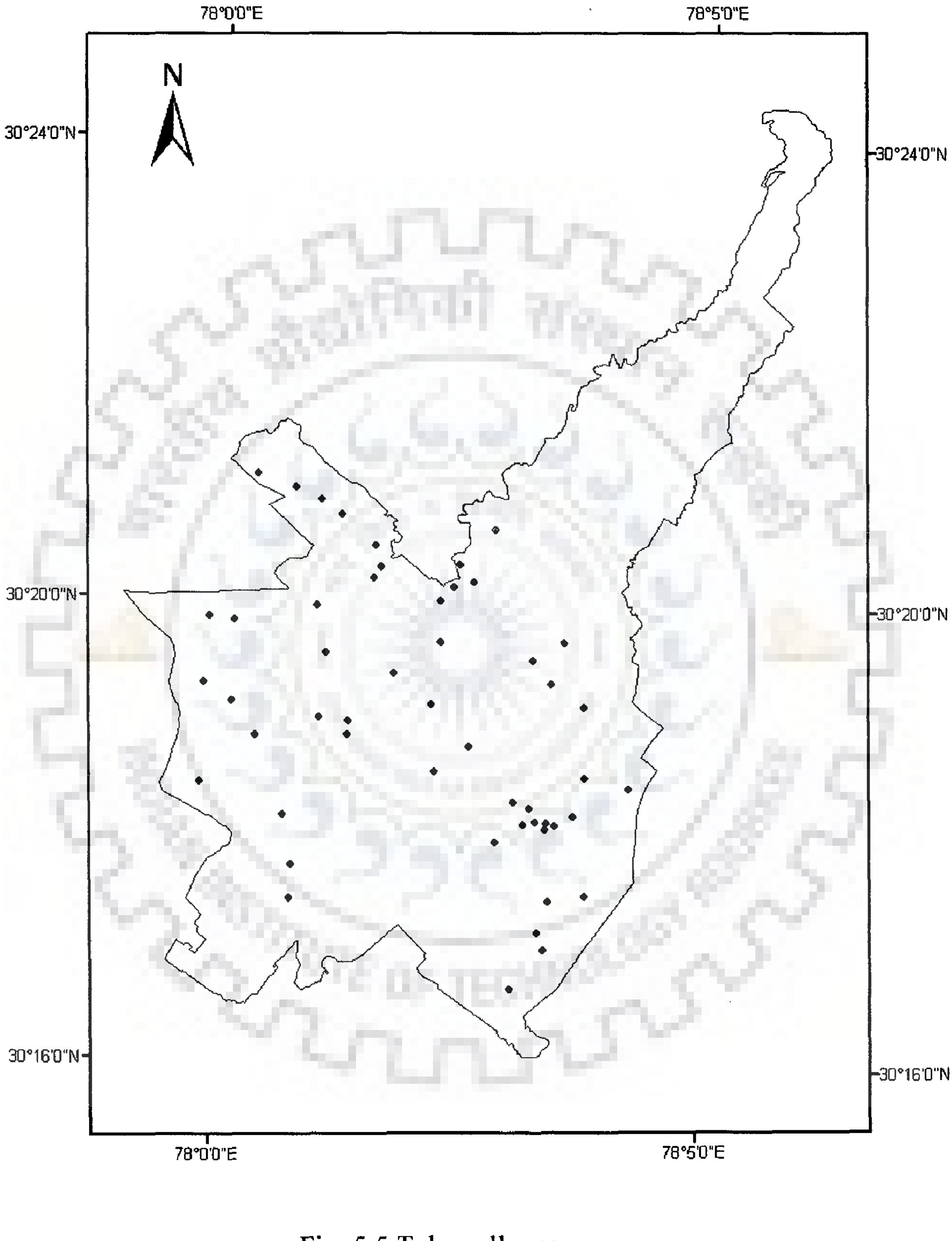


Fig. 5.5 Tubewell map

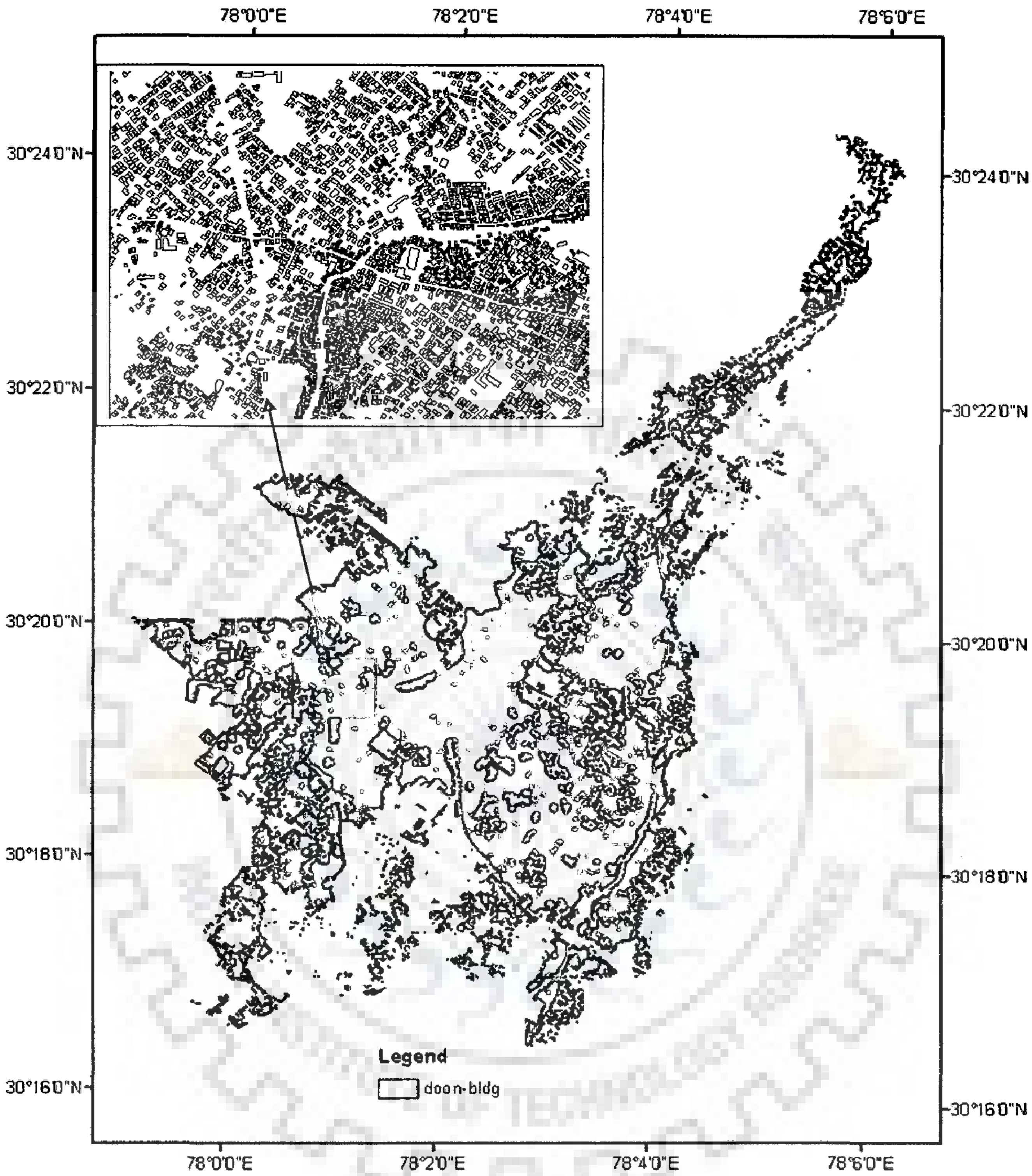


Fig. 5.6 Building map

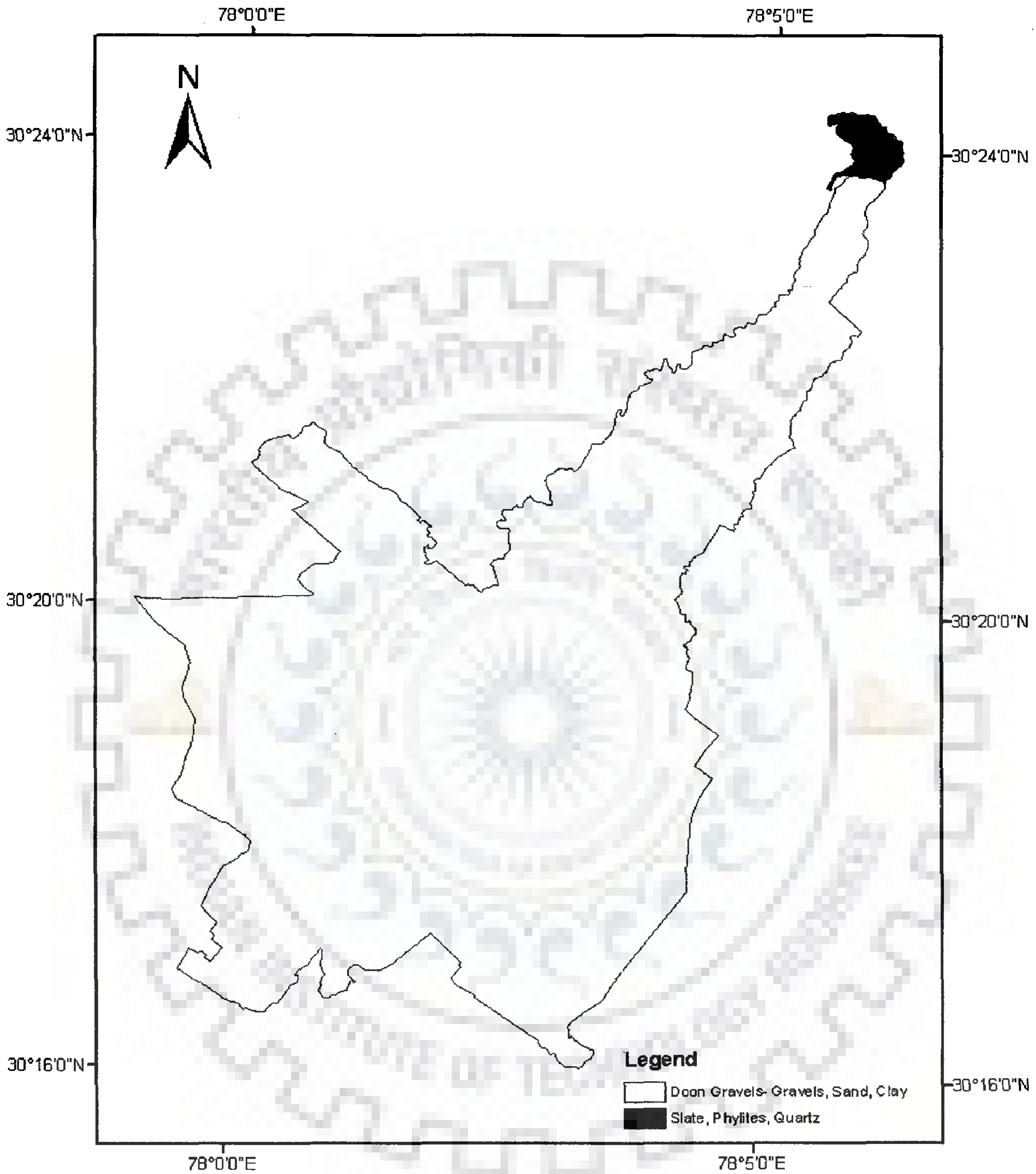


Fig. 5.7 Geology map

5.5.7 Soil map

Although the soil type is mixed red and black as per the general classification, the soils of the basin have been broadly grouped into five categories by the National Bureau of Soil Survey and Land use planning (under Indian Council for Agricultural Research) Nagpur as shown in Fig. 5.8. Description of the available classes in the study is given in Table 5.5.

Table 5.5 Description of classes of soil map (NBSSLUP, 2004)

S.No	Class	Description
1.	25	Soils of lesser Himalayas: soils on side slopes Moderately shallow, excessively drained, thermic loamy skeletal soils on steep slopes with loamy surface, and moderate erosion and moderate stoniness; associated with shallow, excessively drained, loamy soils on very steep slopes with loamy surface, severe erosion and moderate stoniness.
2.	45	Soil on Fluvial Valley Moderately deep, well drained, thermic coarse loamy soils on moderate slopes with loamy surface and moderate erosion; associated with deep well drained, fine loamy soils with loamy surface and slight erosion.
3	50.	Soils of Shiwaliks – soil on summit and ridge Moderately shallow, excessively drained, fine loamy soils on steep slopes with loamy surface, severe erosion and moderate stoniness associated with moderate shallow, excessively drained, coarse loamy surface, moderate erosion and moderate stoniness.
4	60	Soils of Shiwaliks soils on fluvial Valley Deep well drained fine loamy soils on gentle slope with loamy surface and slight erosion; associated with deep, well drained, coarse loamy over fragmental soils with loamy surface and slight erosion.

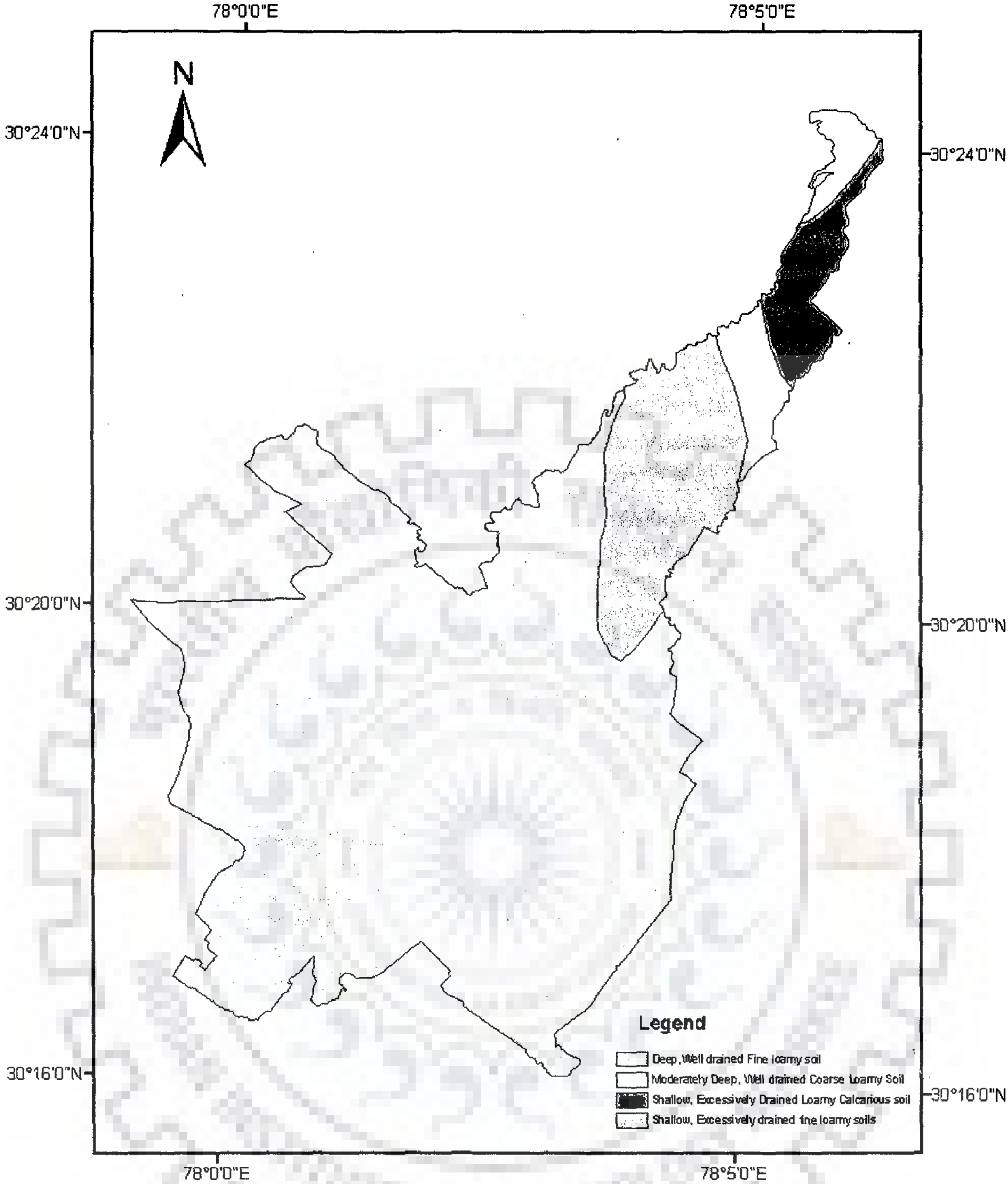


Fig. 5.8 Soil map of the study area

5.5.8 Digital Elevation Model (DEM)

A DEM is simply a digital map of elevation data, which can be used to create, contour map, TIN and slope map of the study area. The Grid DEM data of 90 m resolution was downloaded by the website of Consortium for Spatial Information (CSI) of the Consultative Group for International Agricultural Research (CGIAR). The files can also be downloaded in both Arc-Info ASCII format, and GeoTiff (Grid format), for easy use in most of the GIS and Remote Sensing software applications. Grid DEMs consist of a sampled array of elevations for a number of ground positions at regularly spaced intervals. The downloaded DEM for the study area have been projected to the WGS-84 coordinate system and extracted for the study area as shown in Fig. 5.9.

5.5.9 Slope map

Most raster GIS packages provide a SLOPE function for estimating slope from a DEM. Here spatial analysts extension of ArcGIS 9.0 software was used to delineate slope map from the downloaded SRTM data. The entire area was divided into five slope categories (i.e. 0-2 degree, 2-5 degree, 5-15 degree, 15-35 degree and > 35 degree), as shown in Fig. 5.10. This map has been used to generate map for slope corrected CN value for AMC II condition for the study area, which are used in computation of runoff.

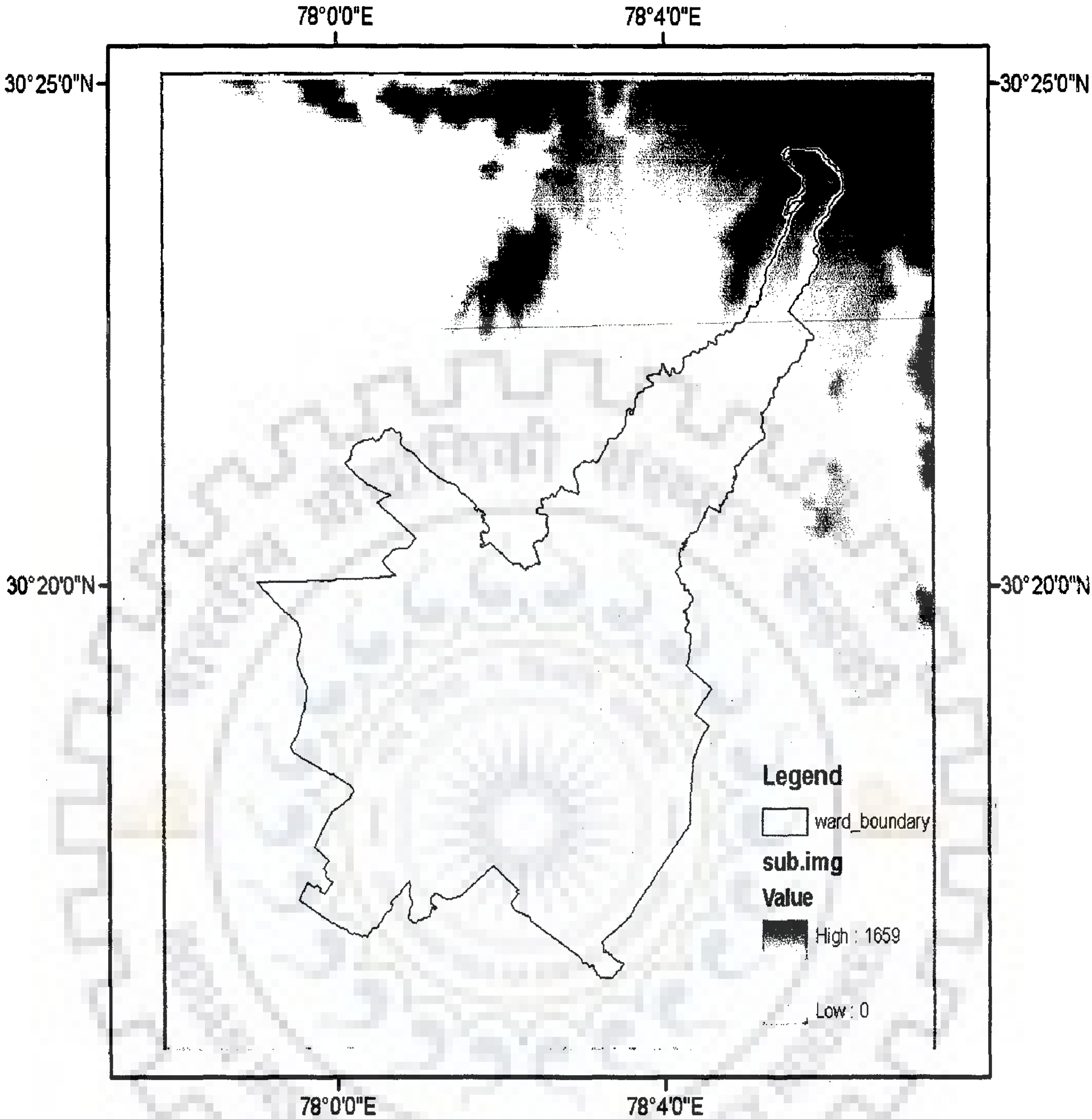


Fig. 5.9 DEM for the study area, downloaded from the CGIAR site (http://srtm.csi.cgiar.org)

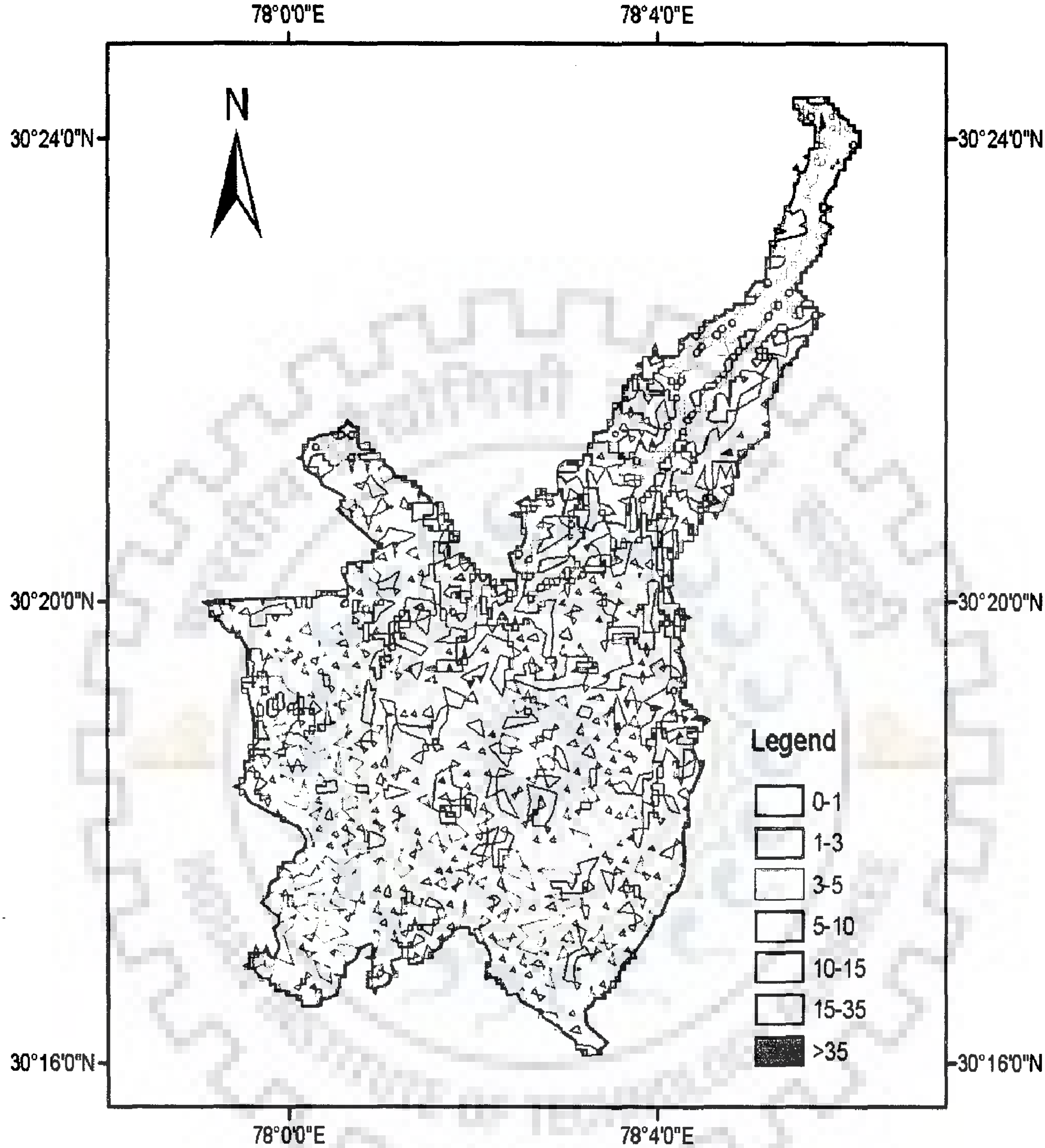


Fig. 5.10 Slope map created from the DEM of the study area

5.5.10 CN map

It is the major input map for runoff estimation. It reflects the effects of soil type, landuse, AMC in computing the runoff. Curve numbers for normal season can be determined from land use, hydrologic soil group, and hydrologic condition of the area (Singh et al., 1990). Soil map was reclassified as hydrologic soil group discussed in article 3.6.5. The entire area comes under soil group 'B' and 'C'. The soil group 'B' contains coarse loamy soil having high infiltration so classes 45 and 25 were classified under this group whereas soil group 'C' contains fine loamy soil i.e. classes 50, 60 were classified under this group, the details of which are already given in Table 5.5. To prepare the CN map for normal season hydrologic soil map and land use map were overlaid. The CN for normal season have been obtained from the table (Appendix N) and CN map has been prepared as shown in Fig. 5.11.

Since, SCS-CN method is applicable for slope < 5% but Dehradun city has slopes ranging from 1% to 35 %. Therefore, to compute the runoff for higher slopes, computed values of CN for normal season have been modified with the slope correction factor as explained in section 3.6.5. Figure 5.12 shows the slope corrected CN map for normal season.

5.5.11 Rainfall infiltration map

To estimate the ground water recharge by rainfall infiltration method, the guidelines as per GEC (1997) have been used in the present study. Geology map is the main input required to estimate the recharge as per the guidelines of GEC, the details of which are already explained in section 3.6.7. In an urban area, landuse also affects the recharge and so, landuse has been overlaid with the geology map of the study area. After that, as per the guidelines of GEC report, rainfall infiltration factors were obtained for the area and added to the overlaid map. The classified rainfall infiltration map is shown in Fig. 5.13. This is the main input map for the groundwater recharge module.

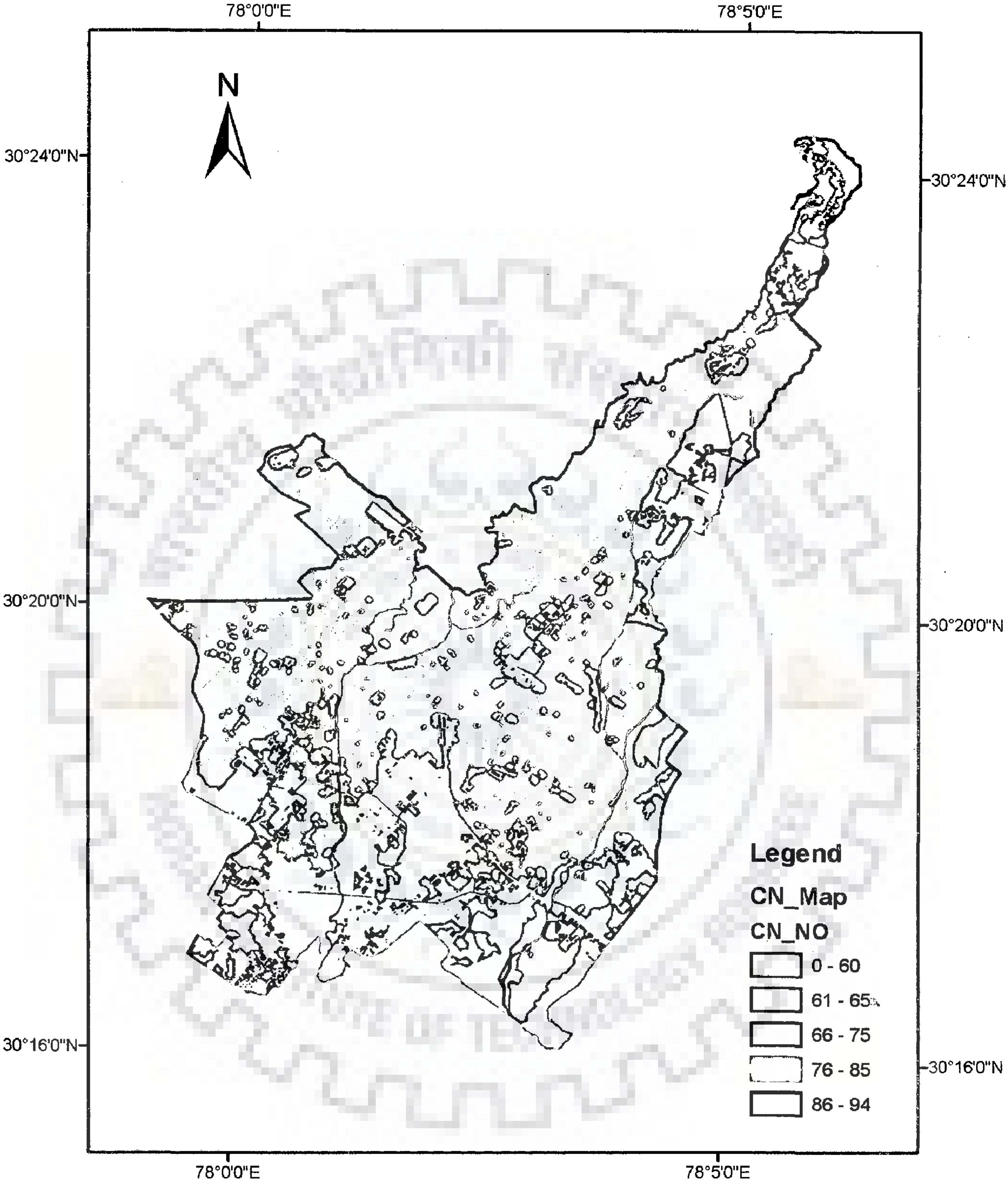


Fig. 5.11 CN values for normal season

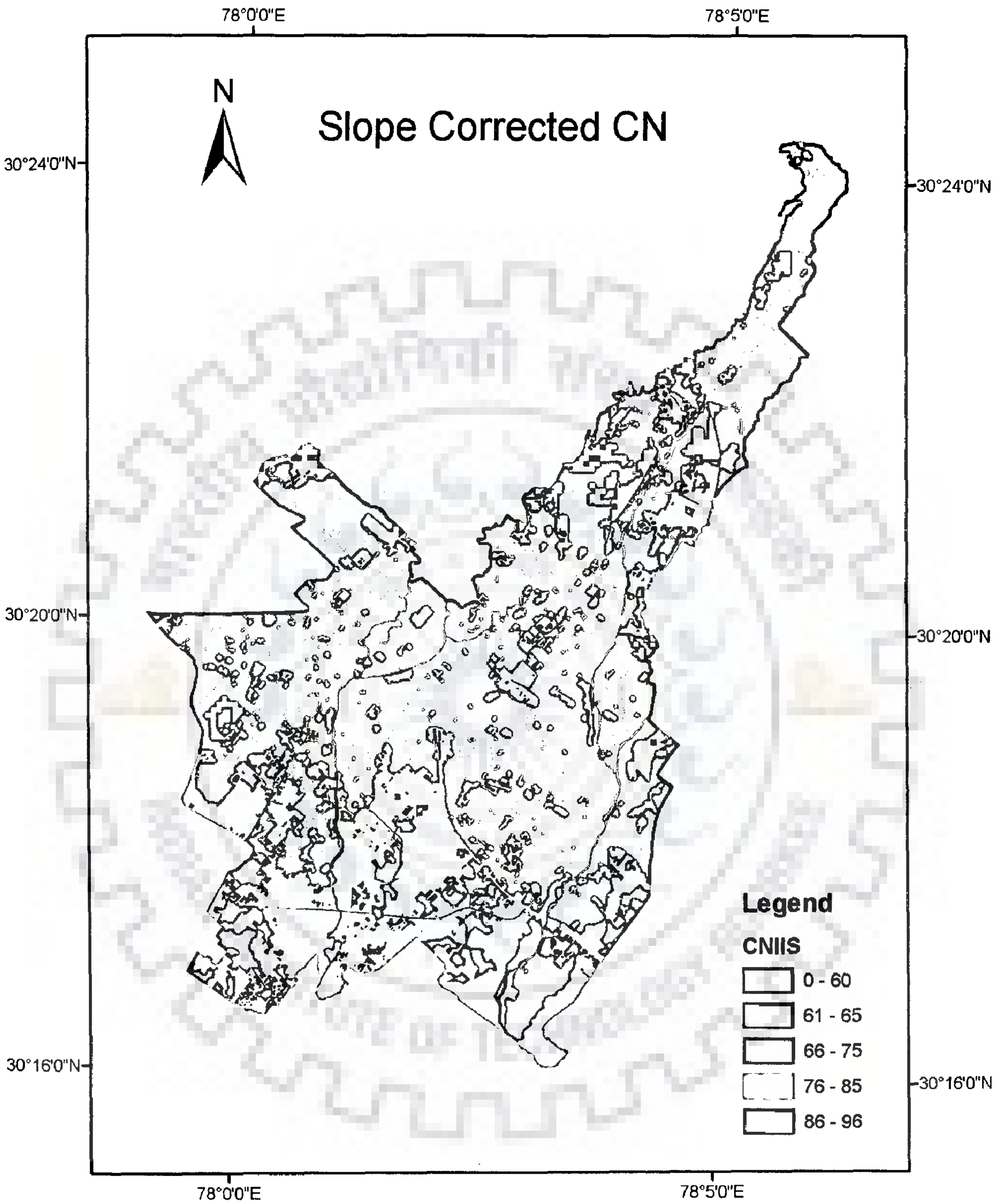


Fig. 5.12 Slope corrected CN values for normal season

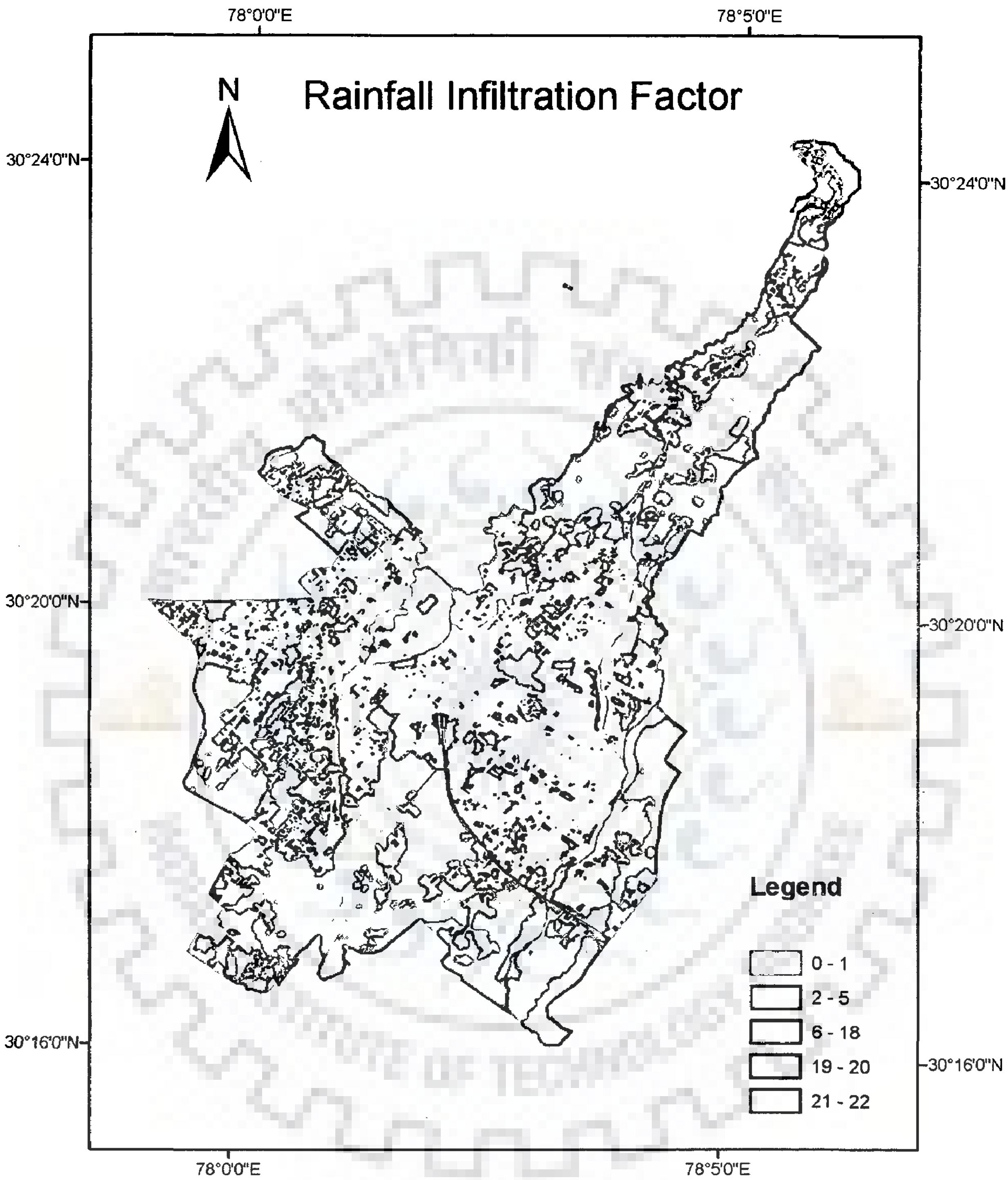


Fig. 5.13 Rainfall infiltration factor map

5.6 Non- Spatial Data

Non spatial data are population data and rainfall data. Both of these are temporal data and so, they need to be updated at regular interval. Therefore the database is created in MS access, as the created database files can be easily used in the developed DSS. Besides, the data can be modified and updated in a user-friendly environment. Microsoft Access is a development environment used to create computer-based databases. It provides most of the tools for creating and managing a tabular database.

Two separate databases have been created in MS Access: one for rainfall data and other for decadal population data. Rainfall database consists of three tables: daily rainfall, monthly rainfall and hourly rainfall. The data have been collected from IMD Pune. Daily rainfall is the main input for runoff estimation whereas monthly rainfall is main input for ground water recharge module. Tables have been generated in a specific format to provide input to the DSS. All the tables must have first field of "ID". Daily rainfall table have only three fields: ID, Date and rainfall in mm. Monthly rainfall has 15 fields; ID, Year, Jan, Feb March, April, May, June, July, August, Sept, Oct, Nov, Dec, and total. First field contains the Serial number, second field contains year of rainfall and from third to fourteenth field contains monthly rainfall in mm and fifteenth field contains total rainfall of the corresponding year in mm. Hourly data table contains 28 fields: ID, Year, month, date, rainfall for Ist hr., 2nd hr., 3rd hr, 4th hr,., 5th hr., 6th hr., 7th hr.............and 24th hr. The rainfall values are in mm.

Similarly decadal population table was also prepared in MS Access. The table named "Population" contains three fields: ID, Year and population. The decadal population data has been used to forecast the population for the year 2011, 2021, 2031...etc.

Some other input non-spatial data are in text form such as surface water withdrawal, number of pumping hours, runoff coefficient, weighted CN, multiplying coefficient to increase the CN value, weighted rainfall infiltration factor, efficiency of roofs to harvest rainwater, reduction coefficient etc. They can be directly written to the text boxes/combo box provided in the related module.

5.7 Summary

The database forms an essential component of the any DSS. Both spatial and non-spatial data are required for water management. The methodologies for creation of database have been described in the chapter. The database has been created as per the requirement of the developed DSS. Using the steps described here, similar database can be created for any other area, where DSS has to applied and demonstrated. For reliable and optimal decision-making, frequent updating of information is essential. Since the present work has been carried out in GIS environment, so data can be easily updated and new results can be obtained for updated values.

Chapter 6
APPLICATION OF THE DSS- IUWM

6.1 General

The developed DSS has been applied to study the urban water management problems of Dehradun city. This involved running different modules by using the input data pertaining to Dehradun city. Analysis has been done to know the present and future water supply, water demand, runoff, potential of rooftop rainwater harvesting, and groundwater recharge. The results for the present scenario and for future scenarios are discussed in this Chapter.

6.2 Database Management Subsystems

Database module has two parts: first one is for non-spatial database and the other is for spatial database management. Key features of both the modules are described in the following sections.

6.2.1 Non-spatial database management subsystem

This module provides general information related to rainfall of the study area. The database prepared in MS Access contains three tables for monthly rainfall, daily rainfall, and hourly rainfall. Different tables were prepared because the availability of the data was different for monthly, daily, hourly and annual rainfall. Monthly rainfall data is available for 30 years, daily rainfall data is available for 10 years, and hourly rainfall data is available for 5 years. User links the database through file menu, then name of all the tables are displayed in the combo box.

It is essential to update the rainfall data timely as it is the main contributing factor for runoff and recharge. This module provides the facility of data adding and updating. Main user interface of the module displaying hourly rainfall data is presented in Fig. 6.1. The data updating can be done directly to the table in daily rainfall data (Fig. 6.2), whereas for monthly rainfall data (Fig. 6.3), another *form* opens and user adds the data. After adding/ editing, updated data can be seen by vertically scrolling down.

An important feature in this module is "Query", where user can get useful information about the rainfall. Sometimes, some information about the rainfall is needed quickly, that can be obtained by the menu "Query". In the hourly rainfall, the module can answer the questions, like- what is the value of maximum rainfall during a day? At what time it occurs? User can enter the date and get the answers as shown in Fig. 6.4. In daily rainfall, user has to enter two dates and can get the maximum rainfall, total rainfall, and a graph between the rainfall vs. date as shown in Fig. 6.5. Maximum rainfall obtained from the 'query' of daily rainfall for different years are presented in Table 6.1.

Table 6.1 Maximum rainfall from year 1993 to 2002

Year	Maximum Rainfall (mm)	Total Rainfall (mm)	Date
1993	150	2266	23rd July, 1993
1994	152	1867	20th July, 1994
1995	114	1717	22nd August,1995
1996	157	2252	28th August, 1996
1997	170	2729	14th July, 1997
1998	211	2931	19th August, 1998
1999	154	2561	6th August, 1999
2000	190	2528	30th July, 2000
2001	152	2330	2nd June, 2001
2002	137	1632	22nd August 2002

It can be seen from Table 6.1 that Dehradun city is receiving very high rainfall, specially in the months of July and August. The query analysis of monthly rainfall provides the information about monthly average rainfall and a bar chart for the desired years as shown in Fig. 6.6. This type of information may be required many times by users.

The non-spatial database module provides the general information about rainfall data. This information may be useful for decision-making.

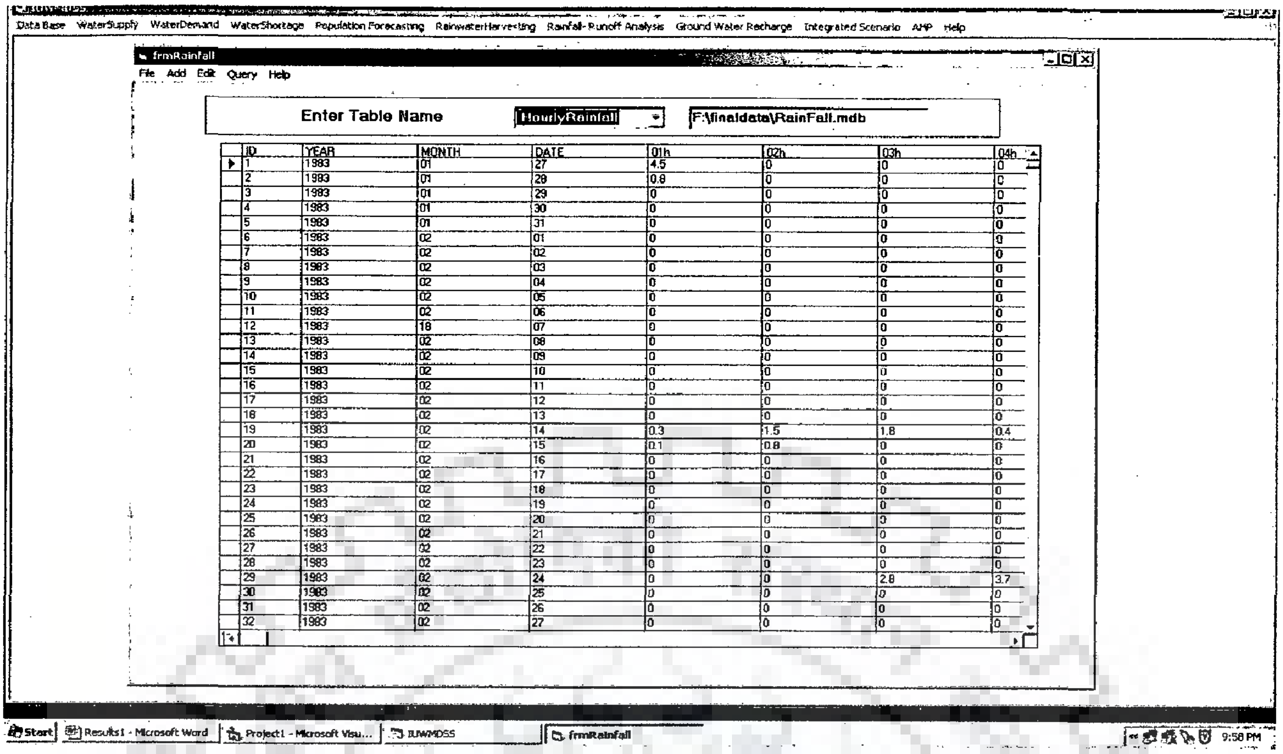


Fig. 6.1 Data editing and updating in hourly rainfall data

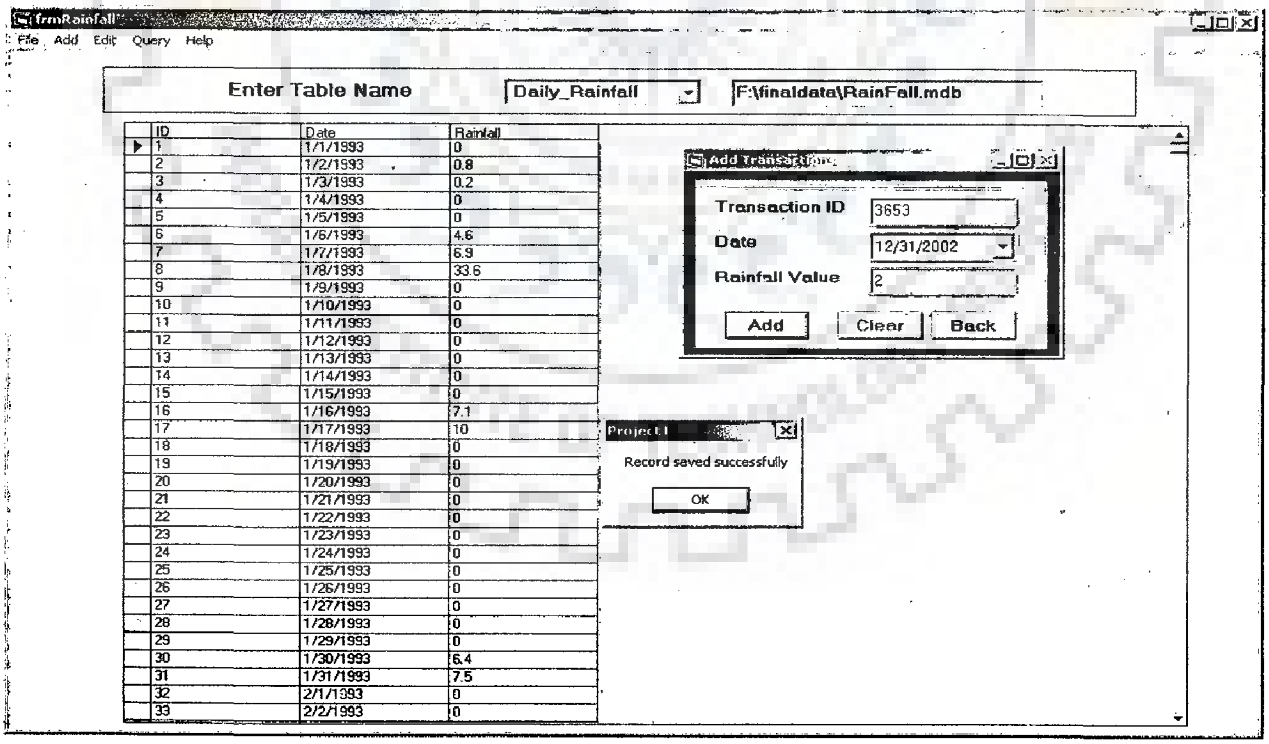


Fig. 6.2 User-interface for editing and updating in daily rainfall data

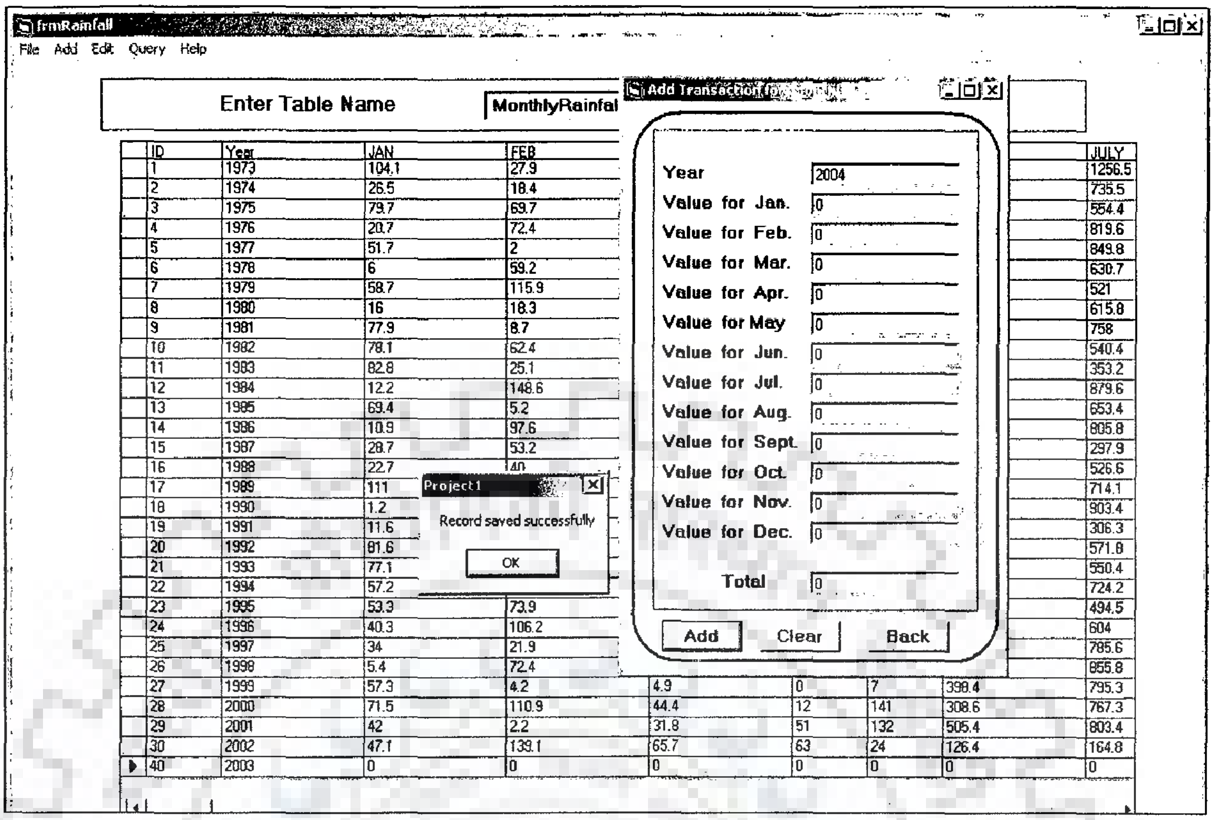


Fig. 6.3 Data editing and updating in monthly rainfall data

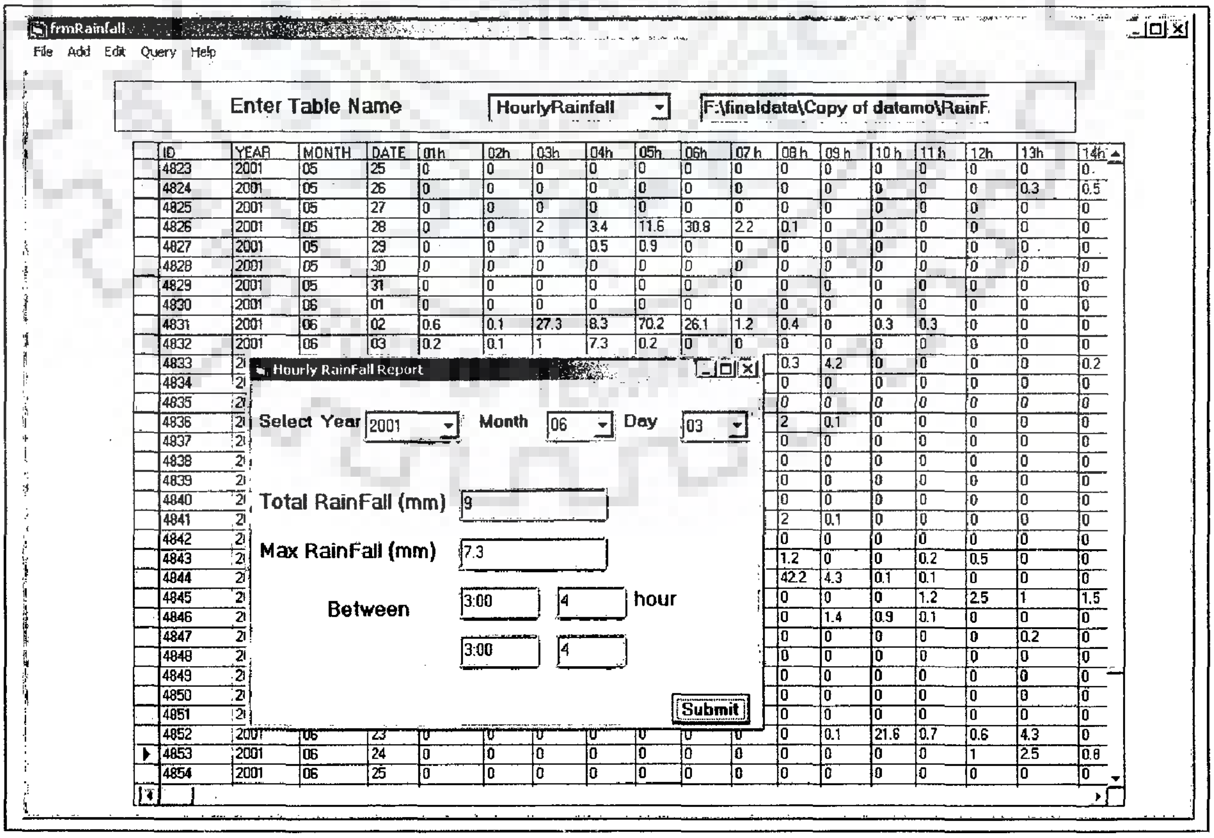


Fig. 6.4 Query analysis for hourly rainfall data

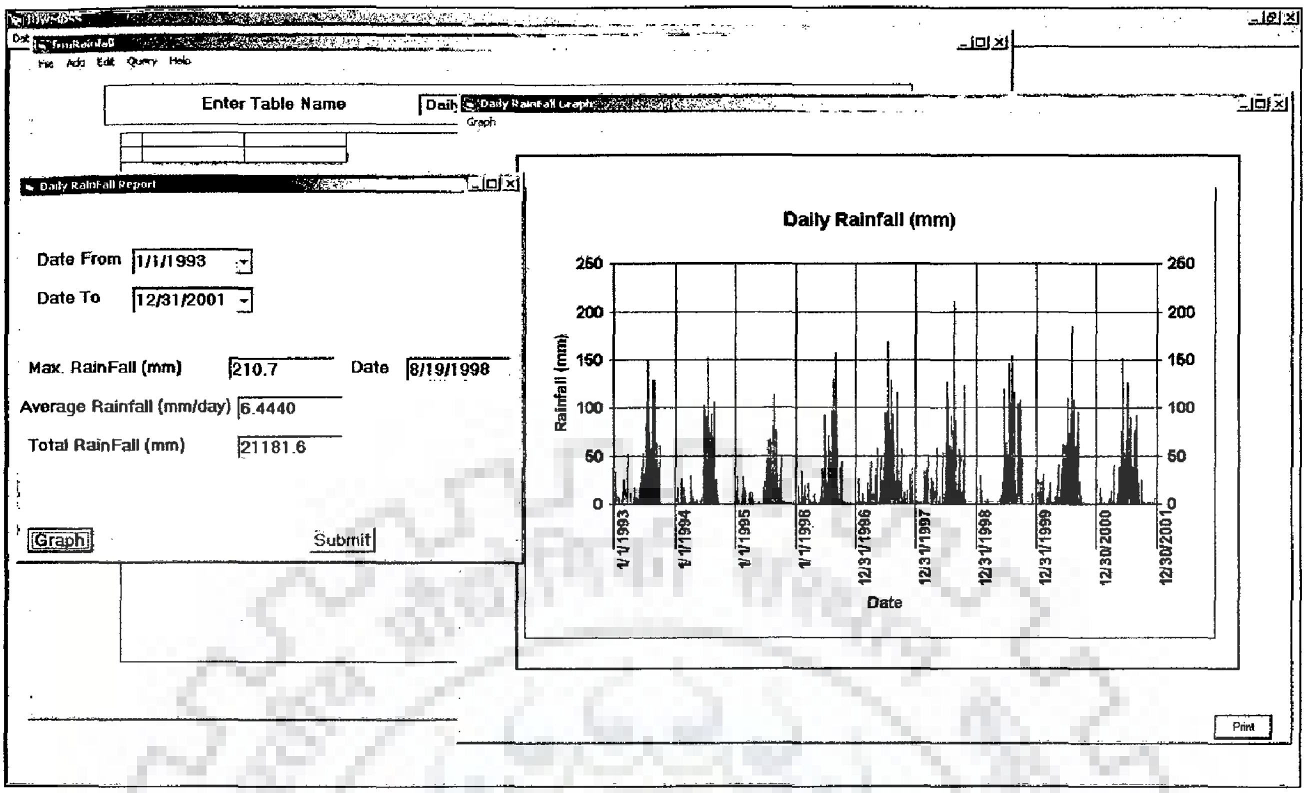


Fig. 6.5 Query analysis for daily rainfall data

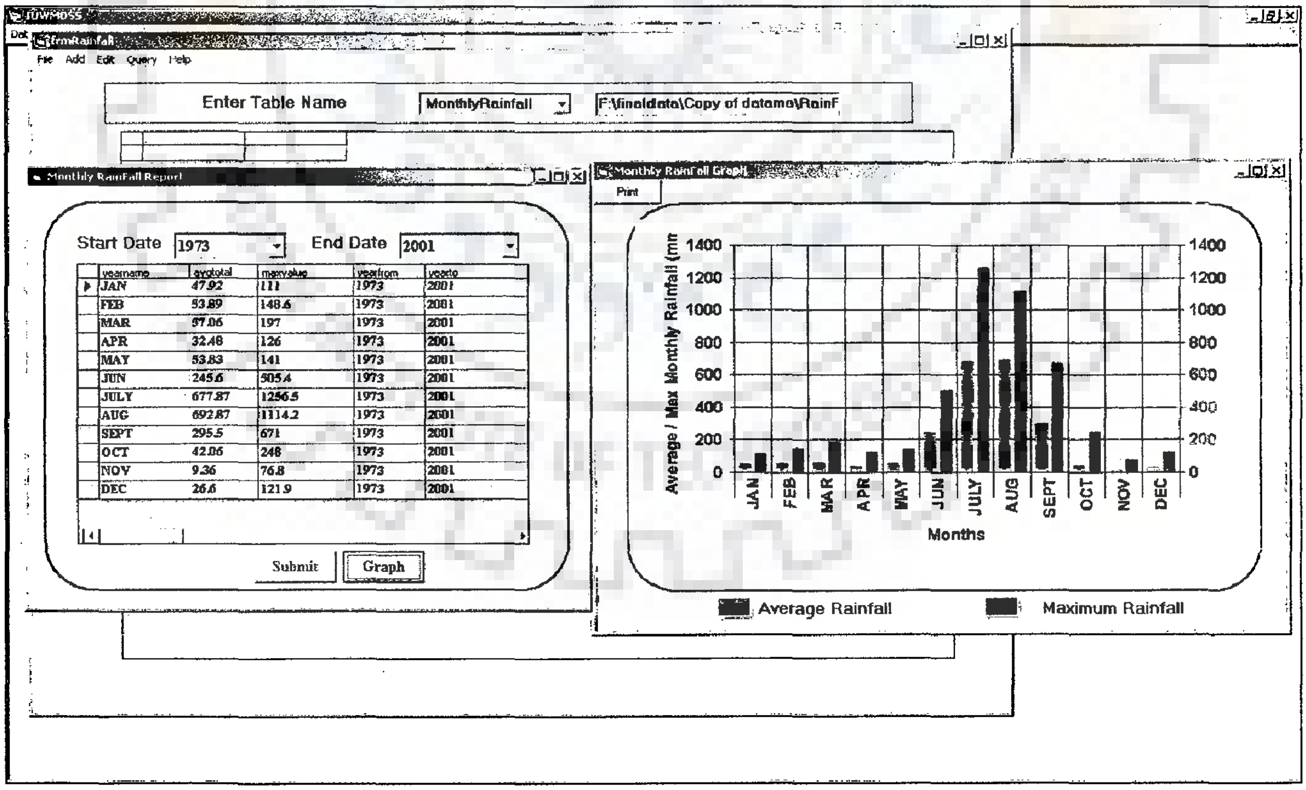


Fig. 6.6 Query analysis for monthly rainfall data from year 1973 to 2002

6.2.2 Spatial database module

The Graphical User Interface (GUI) of Spatial database management module contains one button toolbar and a main menu. A number of shape files can be added to the database through "AddLayer" button of button toolbar. After development, the button toolbar was tested for wards map of the study area and was found efficient while performing the buttons, "Zoom-In" (Fig. 6.7 (a)), "Zoom-Out" (Fig. 6.7 (b)), Full extent (Fig 6.7(c)) "Pan" and "Identify a feature" (Fig. 6.8). These are the basic features required in any user interface of spatial database management. Whereas some information is frequently needed in spatial database i. e. to search a feature in a shape file, to display the attributes of a layer, to display wards name/ID spatially, and to find weighted average value of any field of the map layer. All the submenus of "Query" menu were performed efficiently, and all these information can be seen as shown in Fig. 6.9, Fig. 6.10, Fig. 6.11, and Fig. 6.12 respectively.

Spatial data need to be displayed by some legend classification. The features to classify a map have been provided in the classification menu. This menu contains three submenus of "Basemap", "Classification" and "User defined classification". The wards map is displayed by "Basemap" using field "Wards Name", as shown in Fig. 6.13. The classified population map of the study area is shown in Fig. 6.14 . Population density map of the city has been prepared using user defined classification as per the Master Plan of the city as shown in Fig. 6.15 and a spatial-barchart for population density is shown in Fig. 6.16. The values of population density can be seen by clicking the 'Identify' button to that feature. The study area contains 45 wards. The wards having high population are Kanwali, Ajabpur, Adhoiwala and Niranjanpur situated in the south side of the study area but population density is higher in the center part the city. As per the Master Plan of the city, the population densities of the wards have been classified as presented in Table 6.2. The developed features are limited by the limited functionality of MapObjects but are working efficiently to provide the necessary information about the input spatial data.

Table 6.2 Classification of population density as per the Master plan of the city

Class	Wards ID	No. of wards
Low density	1, 2 ,3, 6, 7, 8, 9, 10, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 28, , 37, 38, 39, 40, 44, 45	28
Medium	41, 42, 43, 27, 29, 30,12	7
Medium to high	4, 6, 32 ,35, 36, 25	6
High density	26, 31, 33, 34	4

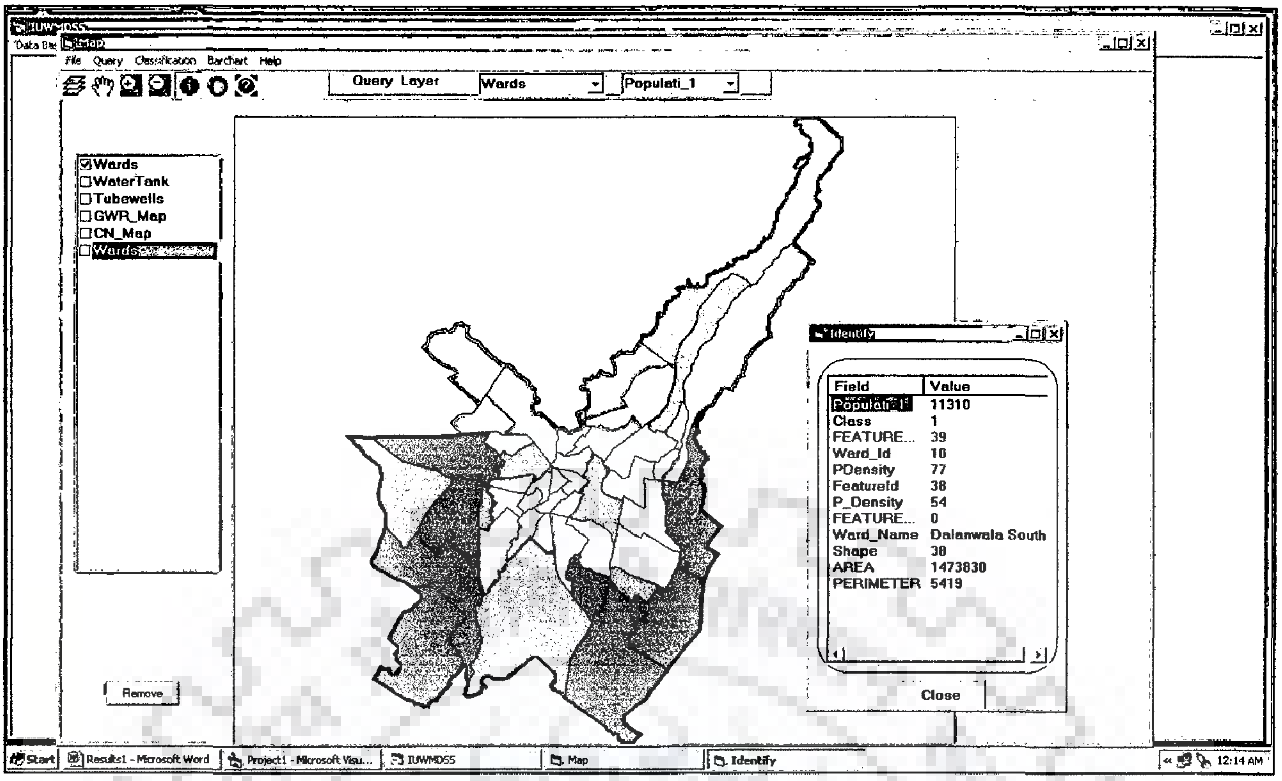


Fig. 6.8 Screenshot of wards map and records of a selected ward by "Identify" button

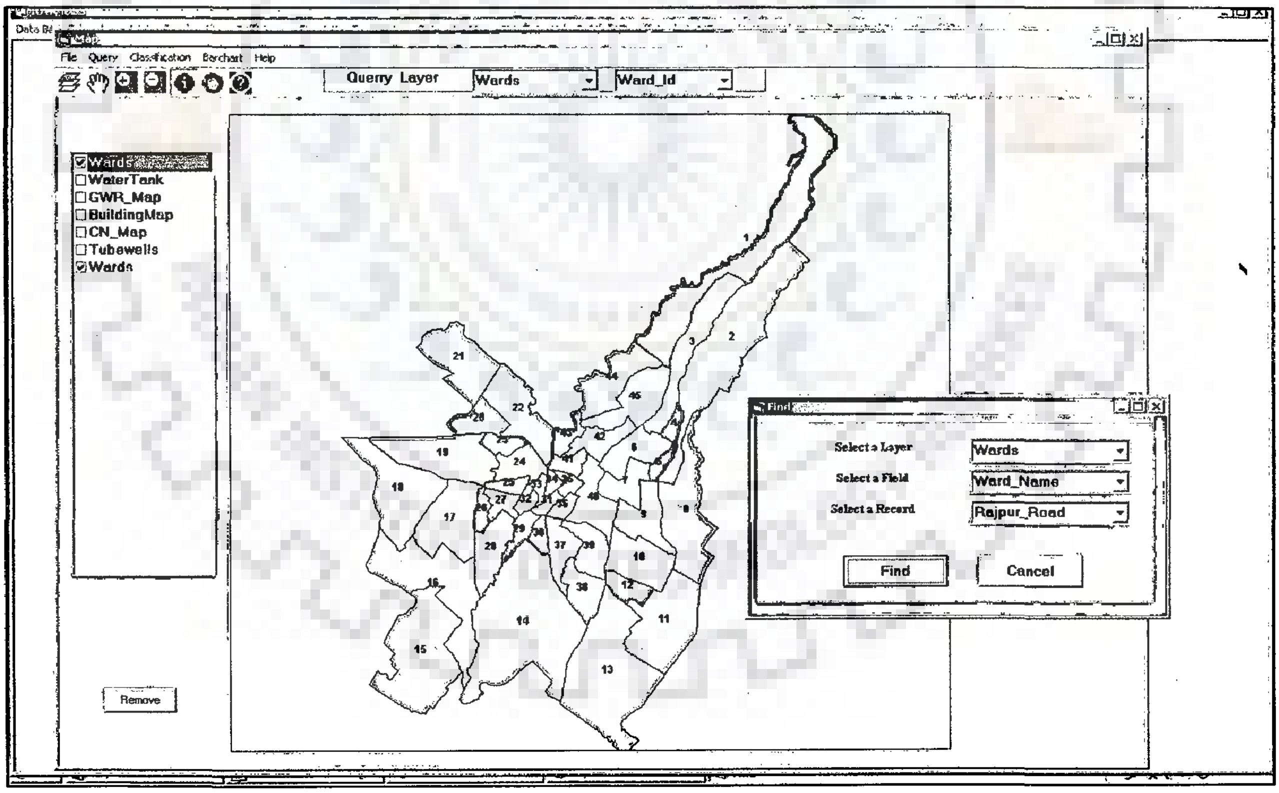
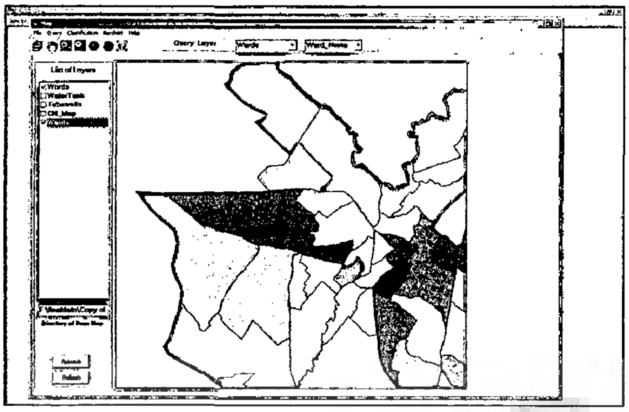
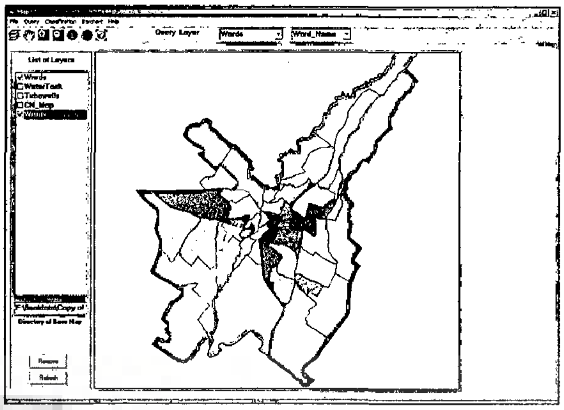


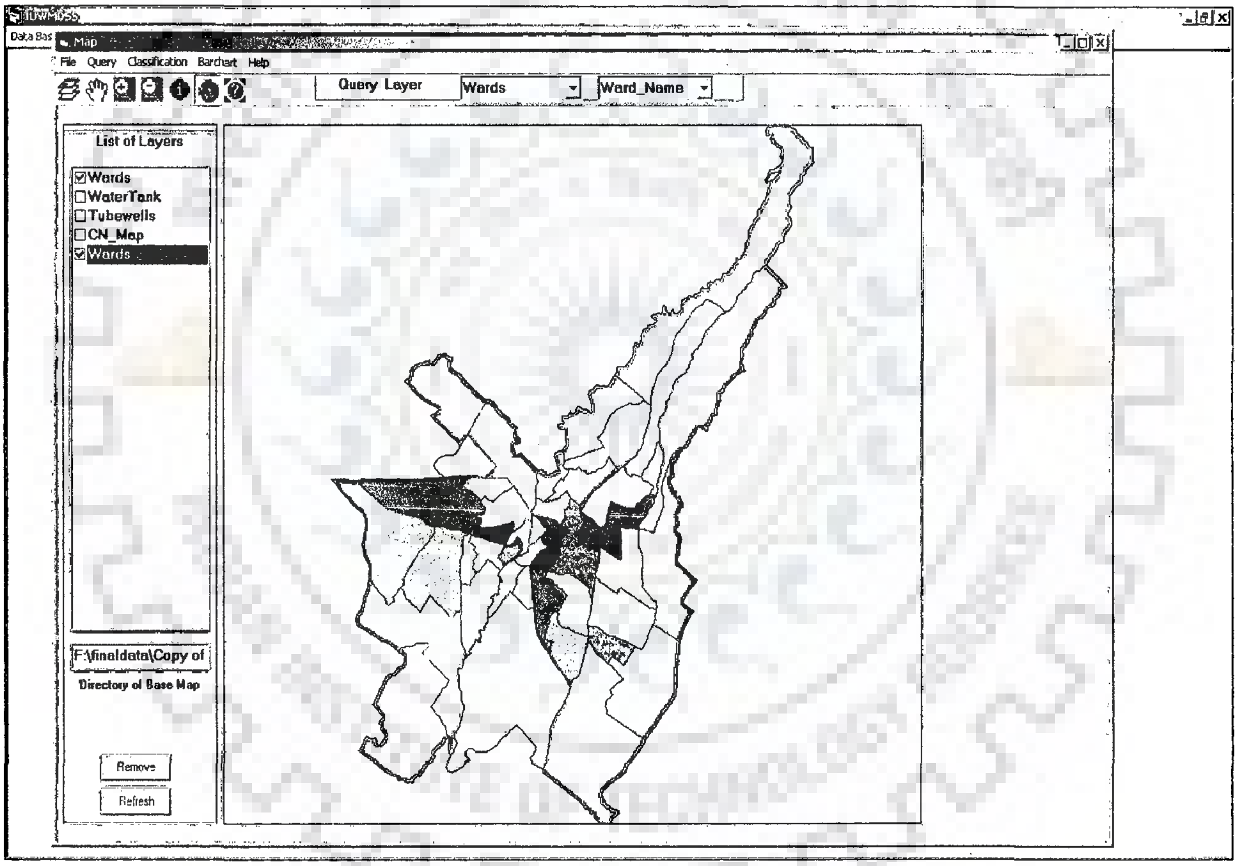
Fig. 6.9 User interface for submenu "Find" to search record of selected map layer



(a)



(b)



(c)

Fig. 6.7 Results of spatial button toolbar menu (a) Zoom-in (b) Zoom-out (c) Full extent

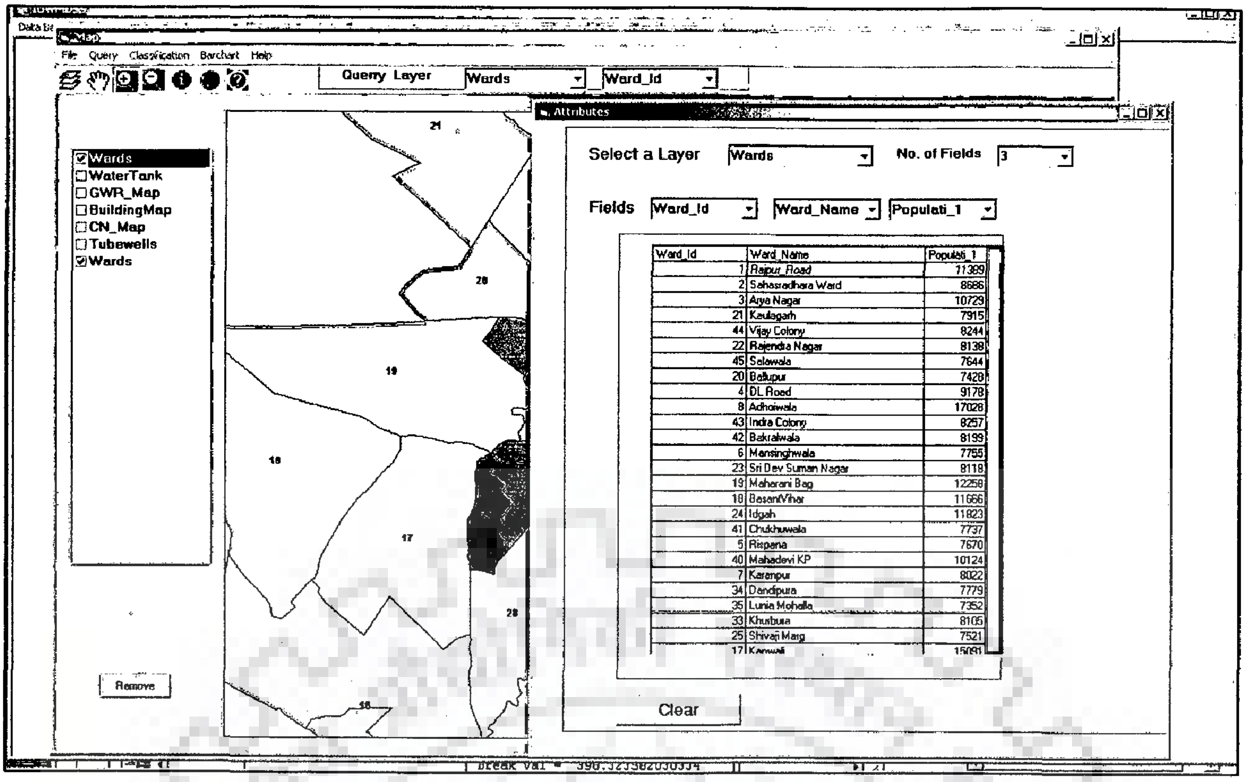


Fig. 6.10 Ward map and attributes table for three selected fields

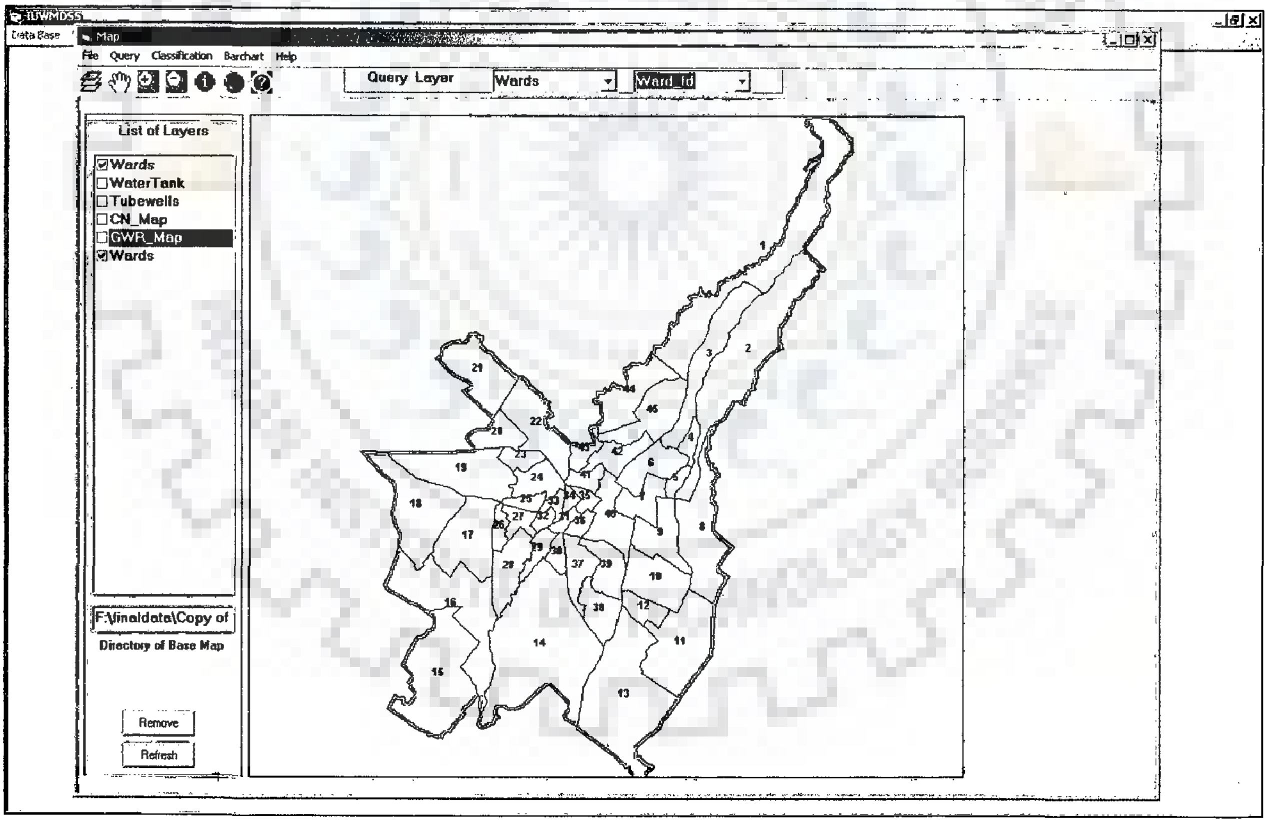


Fig. 6.11 Screenshot of wards map and wards-ID

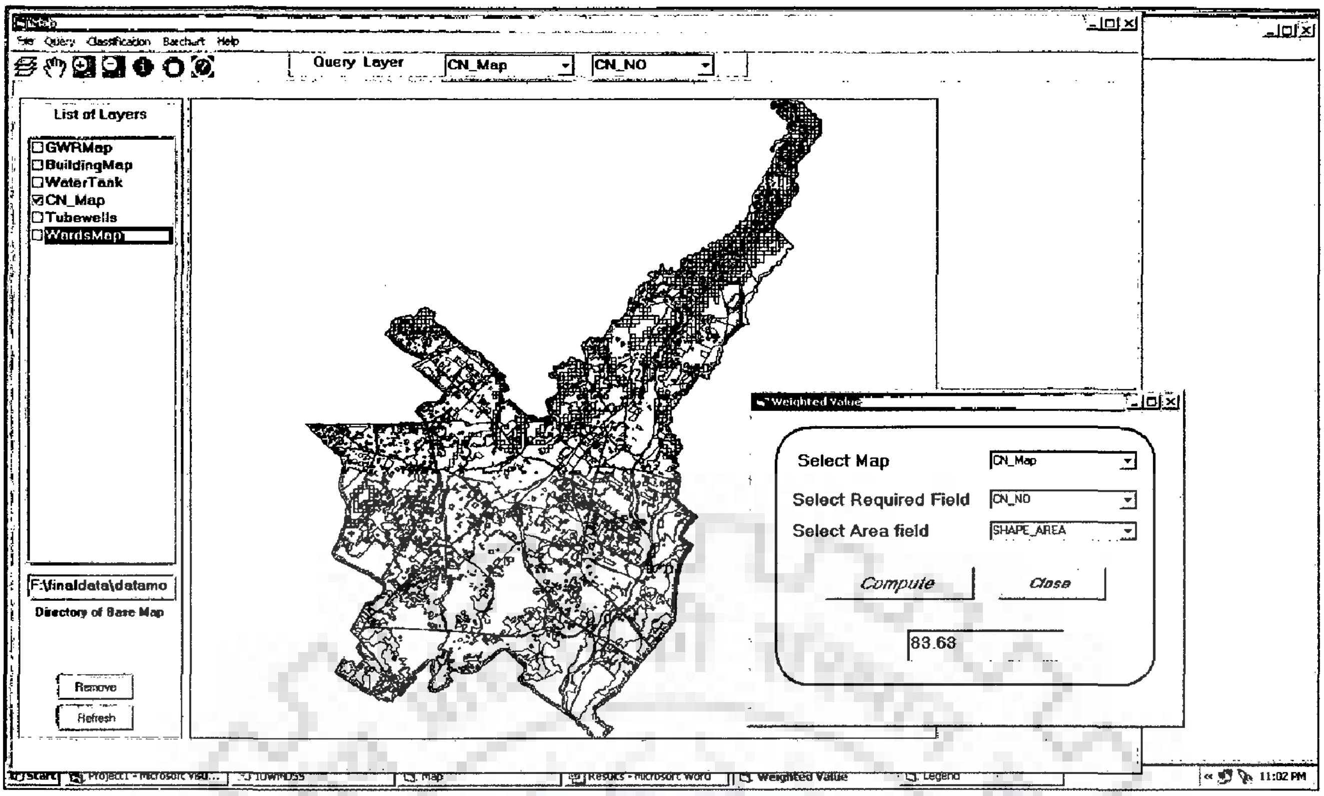


Fig. 6.12 Weighted CN value for AMC II condition for the year of 2005

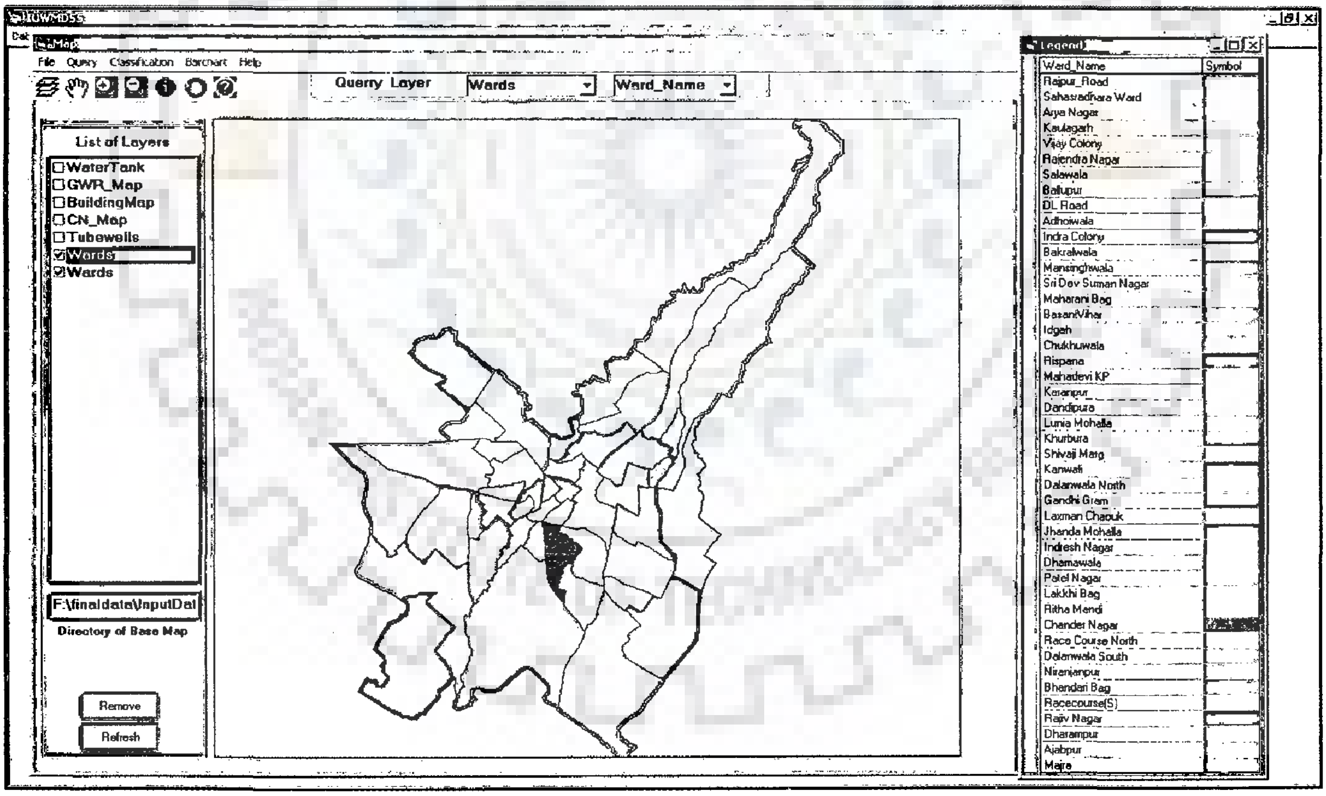


Fig. 6.13 Screenshot of wards map and wards name

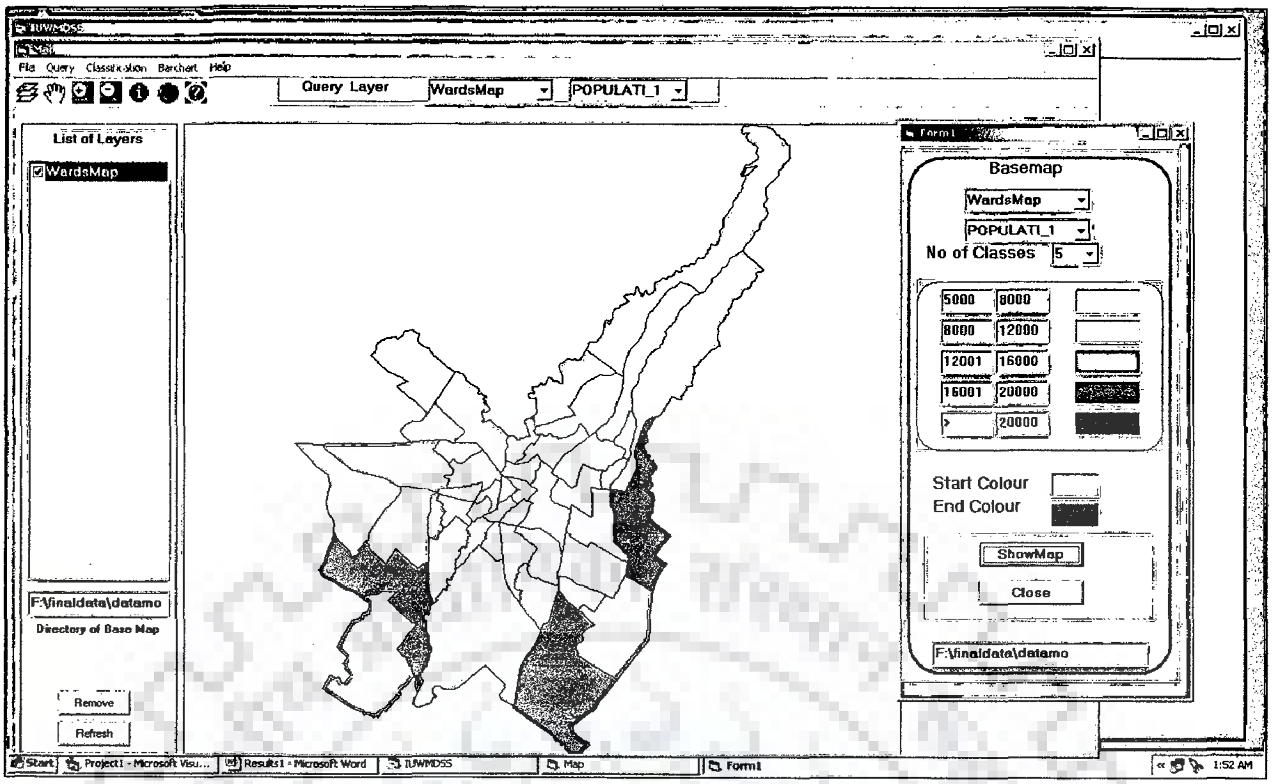


Fig. 6.14 Classified population map of the study area

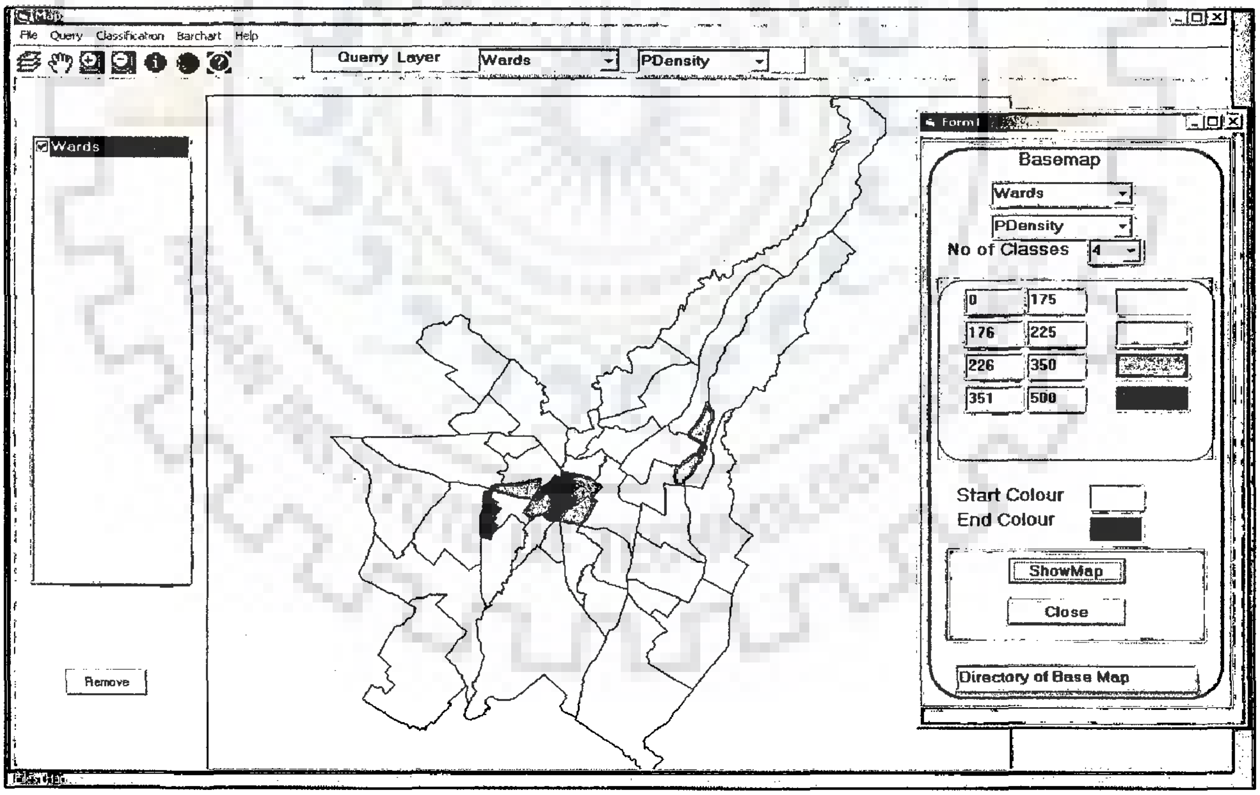


Fig. 6.15 Classification of population density according to Master Plan of the city

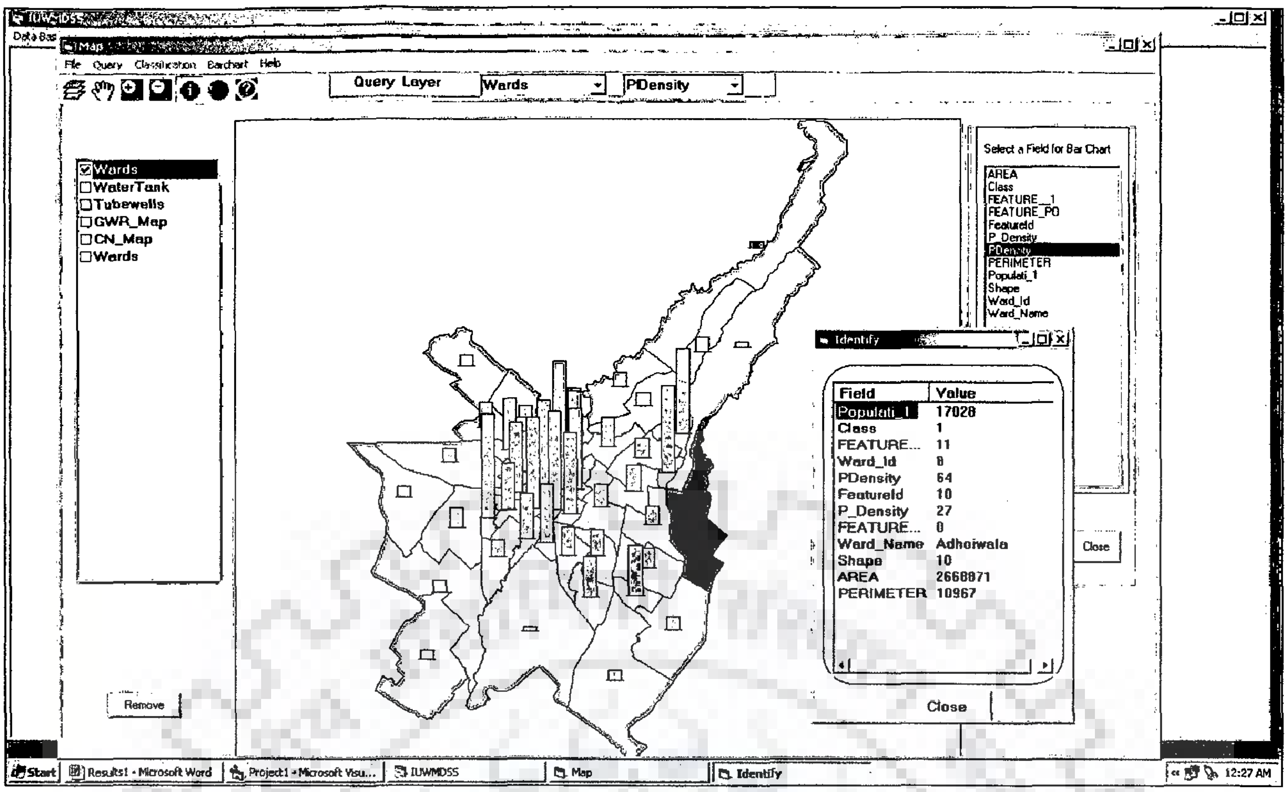


Fig. 6.16 Spatial barchart for population density

6.3 Present Water Supply and Demand

The input maps for the water supply modules are tubewell map, ward map, and water tank map, whereas the non-spatial data are surface water capacity and number of pumping hours for tubewells, floating/surrounding population of the city. Total population of the city was 560120 in the year of 2001, out of which 420446 was the population of municipal area as per the census data. The water is supplied to population of municipal area as well as adjoining institutes of area. Screenshot of water supply module is presented in Fig. 6.17. It can be seen that in the study area, total numbers of tube wells are 52, withdrawing 83.95 mld of ground water. Total water supply for the city is 106.58 mld. Thus, groundwater supply is about 80% of total supply of the area. Presently municipality is supplying water at the rate of 190 lpcd including all the domestic needs, institutional requirements and other requirements. Ward-wise water supply can be seen by clicking to the command button of "Ward-wise water supply".

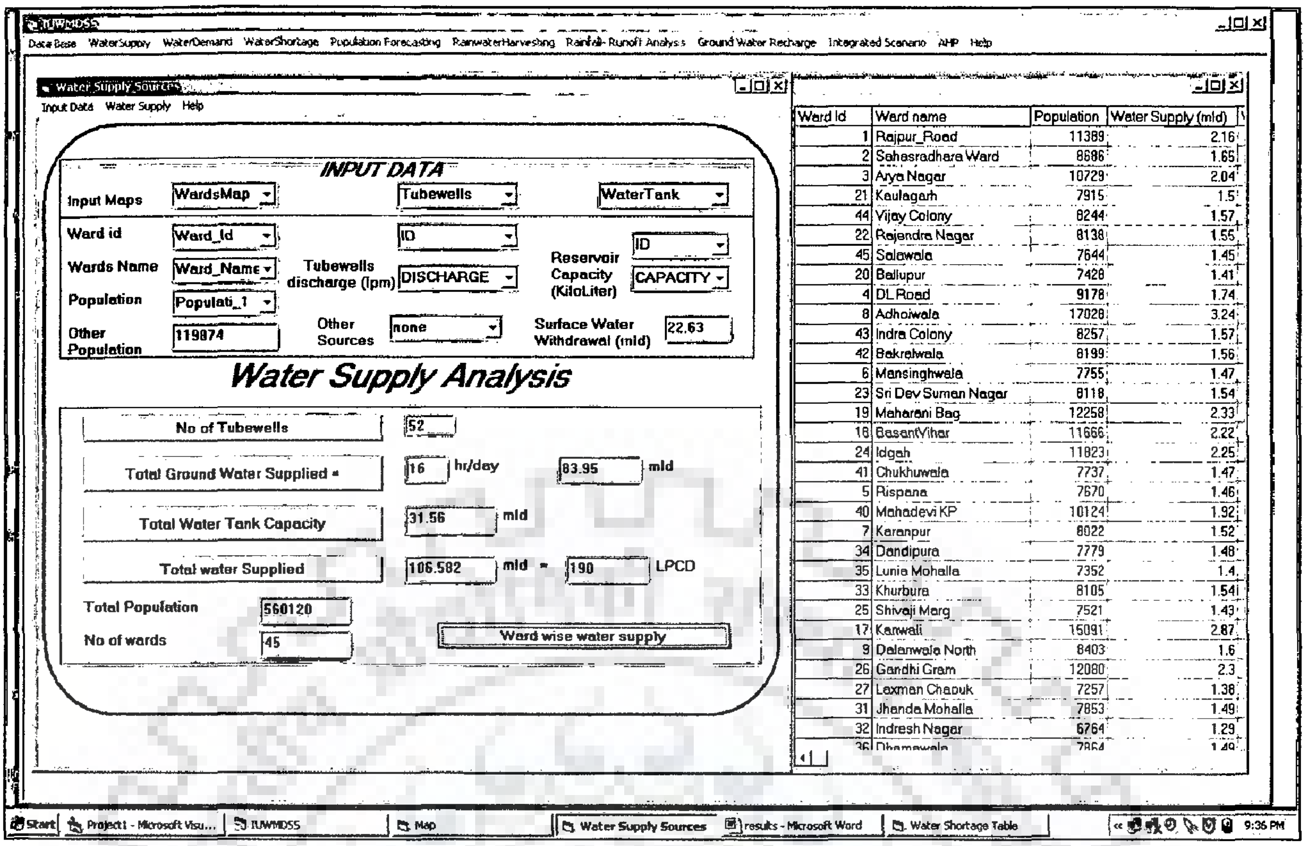


Fig. 6.17 Screenshot of ward-wise water supply

Screenshot of the water demand module displaying total water demand of the study area is presented in Fig. 6.18. User enters the corresponding water demand in lpcd and gets the total water demand in lpcd. Total water demand of the study area is 220 lpcd. Further, user can see the ward-wise water demand of the area in mld in the same user interface of ward-wise water supply.

Screenshot of the water shortage module displaying total water shortage of the study area is shown in Fig. 6.19. This module must be run after running water supply and water demand module because it takes input from that module and displays total water shortage as well as ward-wise water shortage of the study area. Total water shortage of the city was 16.66 mld in the year of 2001. Further, ward-wise shortage map can be prepared by entering the field name to save water supply, water demand and water shortage values. Clicking on save button saves the values in the basemap or the ward map of the area. In the spatial database module, the user can see the classified water shortage map as shown in Fig. 6.20. It can be seen that Maharani bag, Kanwali, Niranjanpur, Majra, Ajabpur, Rajiv Nagar, Racecourse (S), Adhoiwala, Arya nagar and Raipur are the areas having high shortage of water.

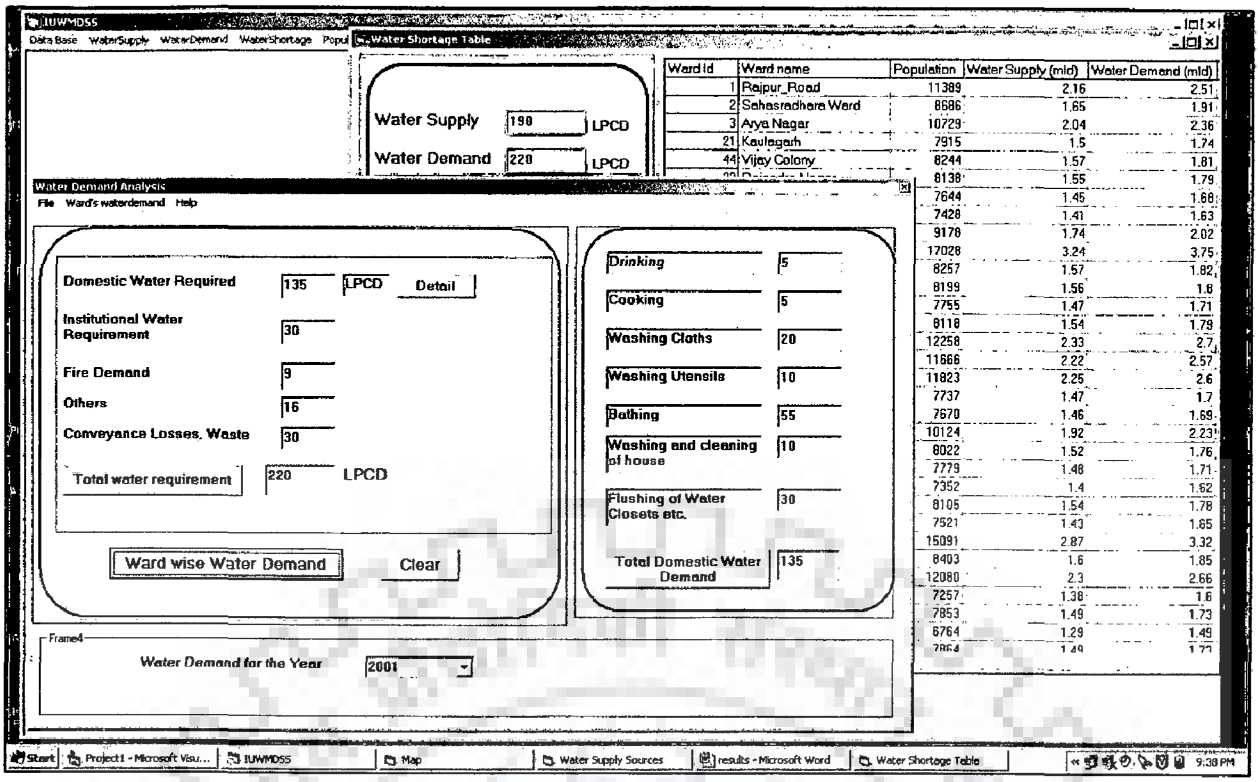


Fig. 6.18 Screenshot of water demand module

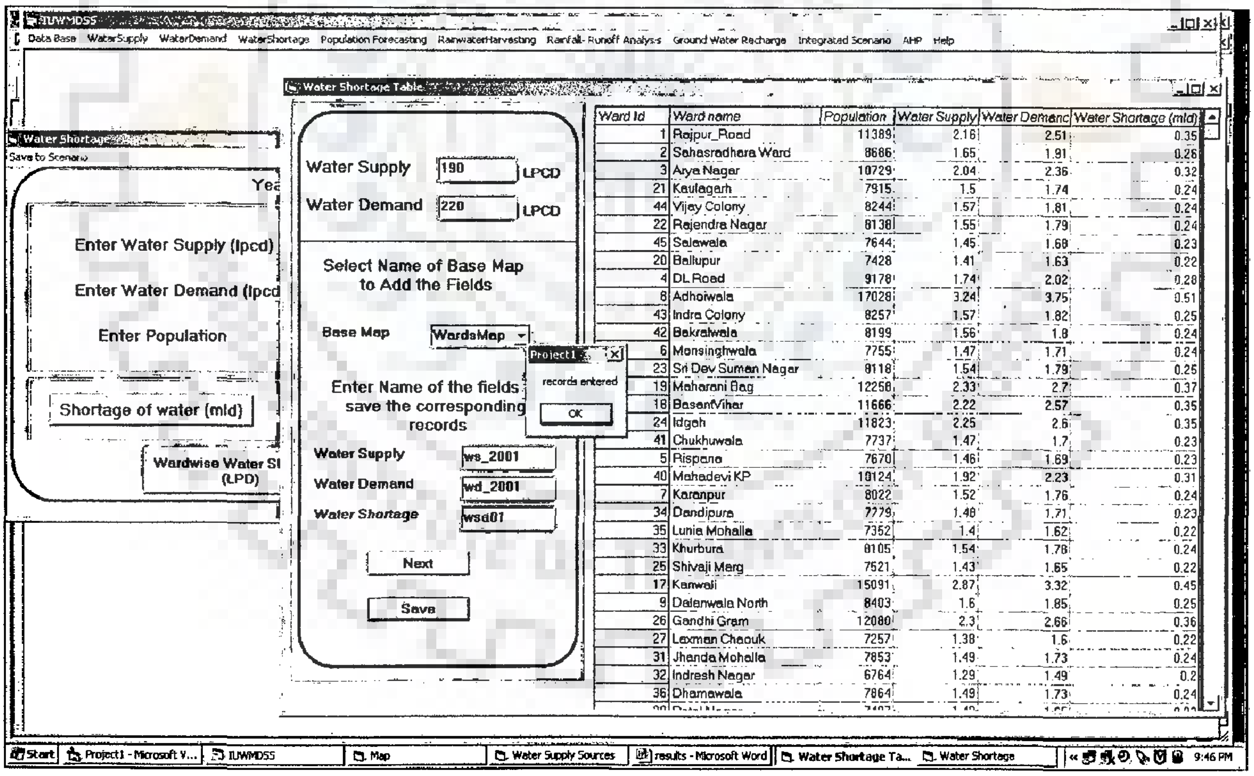


Fig. 6.19 Screenshot of the water shortage module

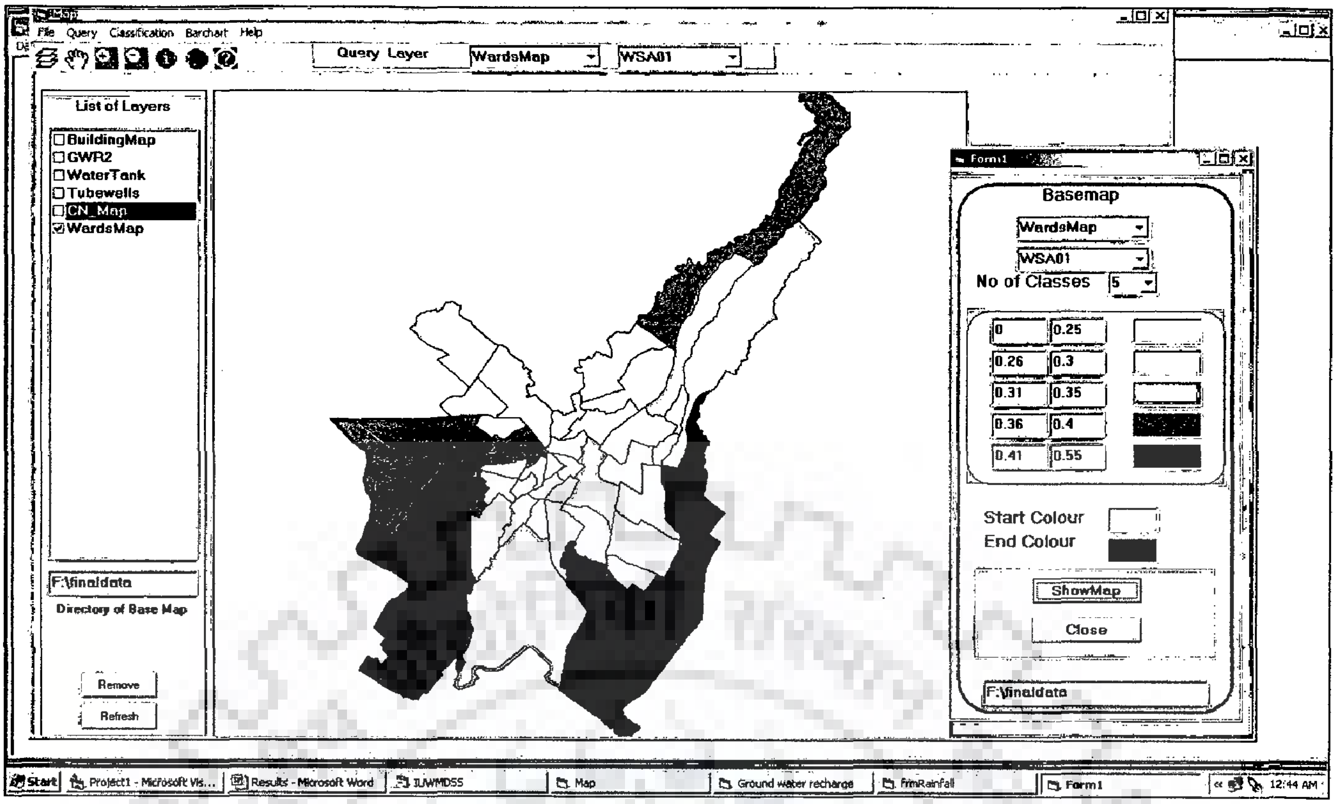


Fig. 6.20 Screenshot of ward-wise water shortage map

6.4 Estimation of Future Water Demand

Forecasting future water demand is an important part of water resources planning and management. It can be estimated by forecasting population of the study area. A module was developed to forecast population for the desired year and water supply, water demand, and water shortage module can be run using the forecasted population to find out the future water demand and shortage in the area.

6.4.1 Population forecasting

The population forecasting module has been tested by forecasting the population of the study area for year 2011, 2031 and 2041 by all the forecasting methods. This module provides three methods of population forecasting, Arithmetic Increase Method (AIM), Geometric Increase Method (GIM) and Incremental Increase Method (IIM). As the study area is a rapidly growing city, GIM has been selected to forecast the population. Decadal data of the last 100 years have been taken to study the trend of the population change in Dehradun city. The population growth rate (R) has been found to be 26.4% by considering the population from 1901 to 2001 while it is 36.7% by considering the population from year 1961 to 2001. The results considering decadal population data from year 1901 to 2001, by all the three methods along with the average population by all the three methods are presented in Table 6.3.

In Dehradun municipal, geographical area is 65.65 km^2, which contains 45 wards and population of 440246; which is about 79% of the total population of the city (560120) as per the census data of India 2001. Therefore, it is assumed that 80% of the population lies in Dehradun municipal area, while the other population is from adjoining institutions or is floating population. Figure 6.21 shows the screenshot for the population forecasting by GIM. It is seen by the graph that from 1901 to 1961, the growth rate was very slow, but after that the population growth rate is increasing fast. Population of Dehradun is increasing rapidly after it became the capital of Uttarakhand. The module has been again run for the decadal population of 1961 to 2001 and the results are shown in Table 6.4.

Table 6.3 Population projection for low growth rate

Year	Projected Population (Using data for 1901 to 2001)					
	AIM	GIM (R =26.4%)	IIM	Average Population	Ward-wise Population	Adjoining/floating population
2011	613032	709672	633159	651954	521563	130391
2021	633159	899154	726324	763808	611046	152762
2031	718858	1139229	839615	899234	719387	179847
2041	771770	1443403	973032	1062735	850188	212547

Table 6.4 Population projection for high growth rate

Year	Projected Population (Using data for 1961 to 2001)					
	AIM	GIM (R=36.7%)	IIM	Average Population	Ward Population	Adjoining/floating population
2011	661065	765180	703891	710045	568036	142009
2021	762010	1045312	890488	899270	719416	179854
2031	862954	1428001	1119912	1136956	909565	227391
2041	963899	1950792	1392162	1435618	1148494	287124

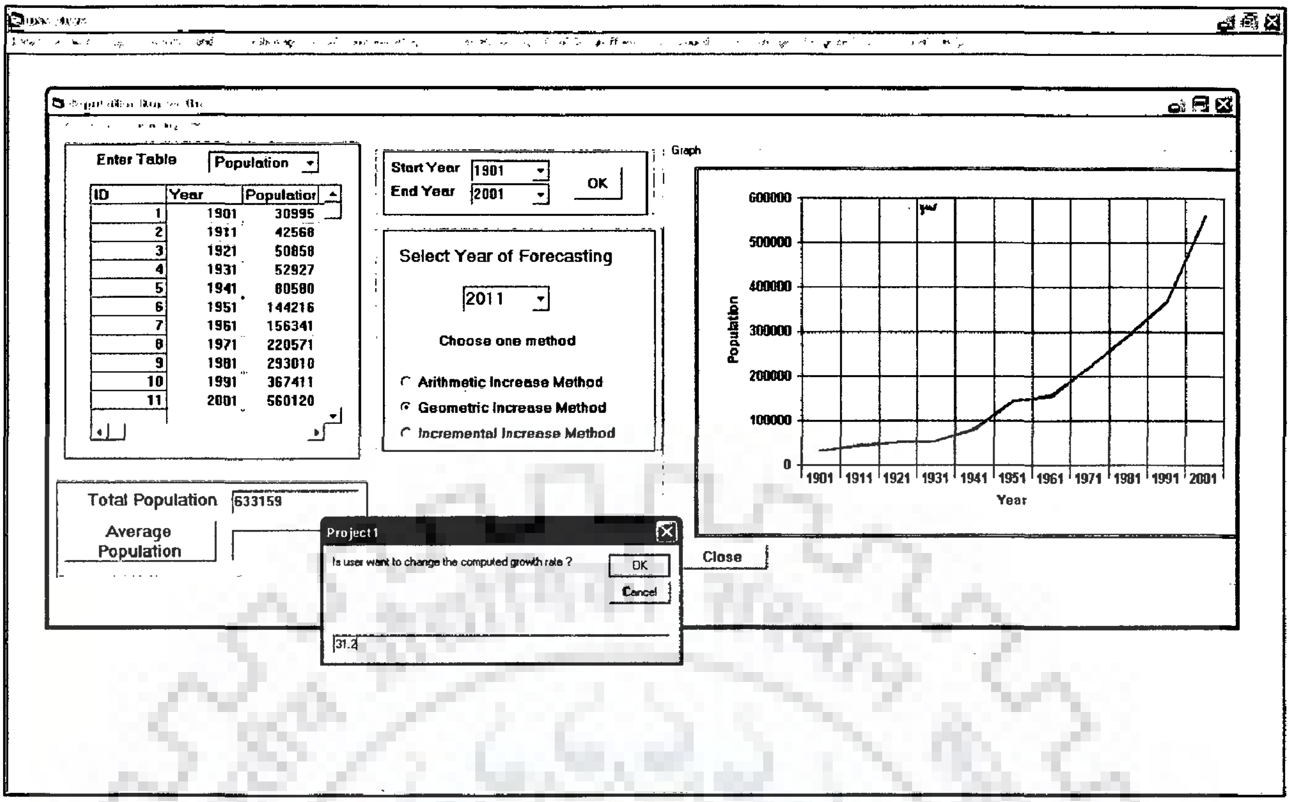


Fig. 6.21 Population forecasting by GIM for the year of 2011

Further, the module has been run for the medium growth rate of 31.1% [=(26.4%+36.7%)/2] for the GIM, and the results are presented in Table 6.5.

Table 6.5 Population projections by medium growth rate (31.1%)

Year	Population (GIM) (R= 31.2%)
2011	734877
2021	962690
2031	1262087
2041	1654596

The population estimates by different methods are shown but results of GIM method are taken for forecasting water demand since this method is suitable for a growing city. Besides, GIM method is used in the Master Plan of the city for forecasting population. If water supply from groundwater and surface water is same as present (106.6 mld), and at same water demand of 220 lpcd, the estimation of water shortage for the future is presented in Table 6.6. It can be seen that acute water shortage will occur as availability of water supply will be from 190 lpcd to 93 lpcd at low population growth rate and 75 lpcd at higher growth rate of population in the year 2031. Thus water shortage of about 144 mld at low population growth rate and 207 mld at high population growth rate in the year 2031 is estimated.

Table 6.6 Water shortage projections at low (I), medium (II), and high (III) population growth rate

Year	Water supply (lpcd)			Water demand (mld)			Water shortage (mld)		
	I	II	III	I	II	III	I	II	III
2011	150	145	139	156.13	161.67	168.34	49.60	55.14	61.81
2021	118	111	102	197.81	211.79	229.97	91.28	105.26	123.44
2031	93	84	75	250.63	277.66	314.16	144.10	171.13	207.63

6.4.2 Ward-wise population

User can obtained the ward-wise distributed population by clicking on the *command button* of "Wards wise population". Since the 80% of the projected population is of Dehradun's municipal area, while other population is from the surrounding area: adjoining institutes, floating population etc. Therefore, only 80 % of total projected population has been distributed to all the wards according to the study area.

Ward-wise projected population for the year 2011 at high growth rate is shown in Fig. 6.22. It can be seen that the ward Bhandaribag will be the ward of highest population; Raipur Road, Sahastradhara wards will have very high population; and Majra, Ajabpur, Niranjanpur wards will have high population with high water demand.

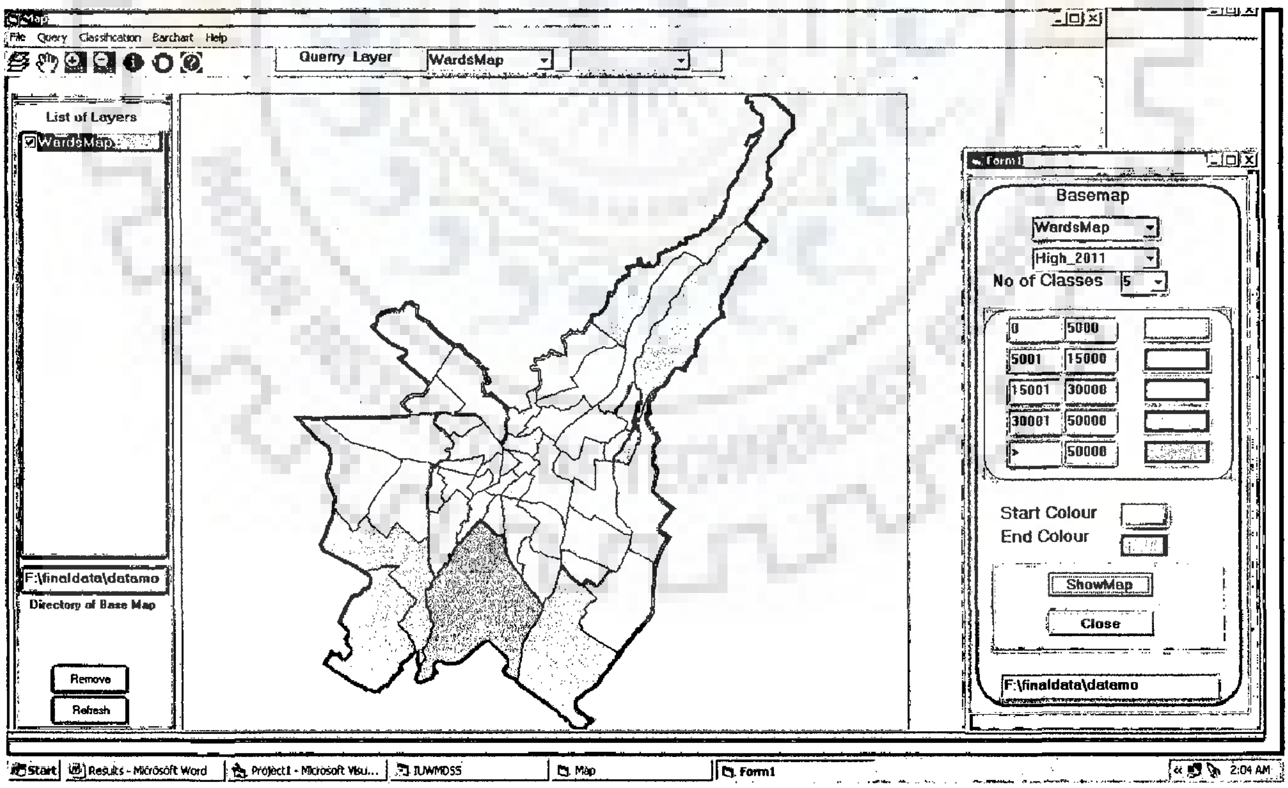


Fig. 6.22 Ward-wise population map for the year 2011

6.5 Rainfall-Runoff Assessment

This module estimates the runoff depth by SCS-CN method and weighted CN methods (Mishra and Singh, 1997). Main inputs for estimating runoff depth by SCS-CN method are CN map and daily rainfall data. The method of generating CN map has been described in Chapter 5. The CN maps of the study area without slope correction (Fig. 5.11) and with slope correction (Fig. 5.12) were generated for the year of 2005. The weighted CN value for AMC II condition is 83.6 (Fig. 6.12) without slope correction and 83.9 (Fig. 6.23) with slope correction. Since very small area of the city has slope more than 5%, the difference is not significant. The weighted runoff depth for normal CN map is 822 mm whereas for slope corrected CN map, it is 830mm (Fig. 6.24) which is 35 % of total daily rainfall in the year 2005.

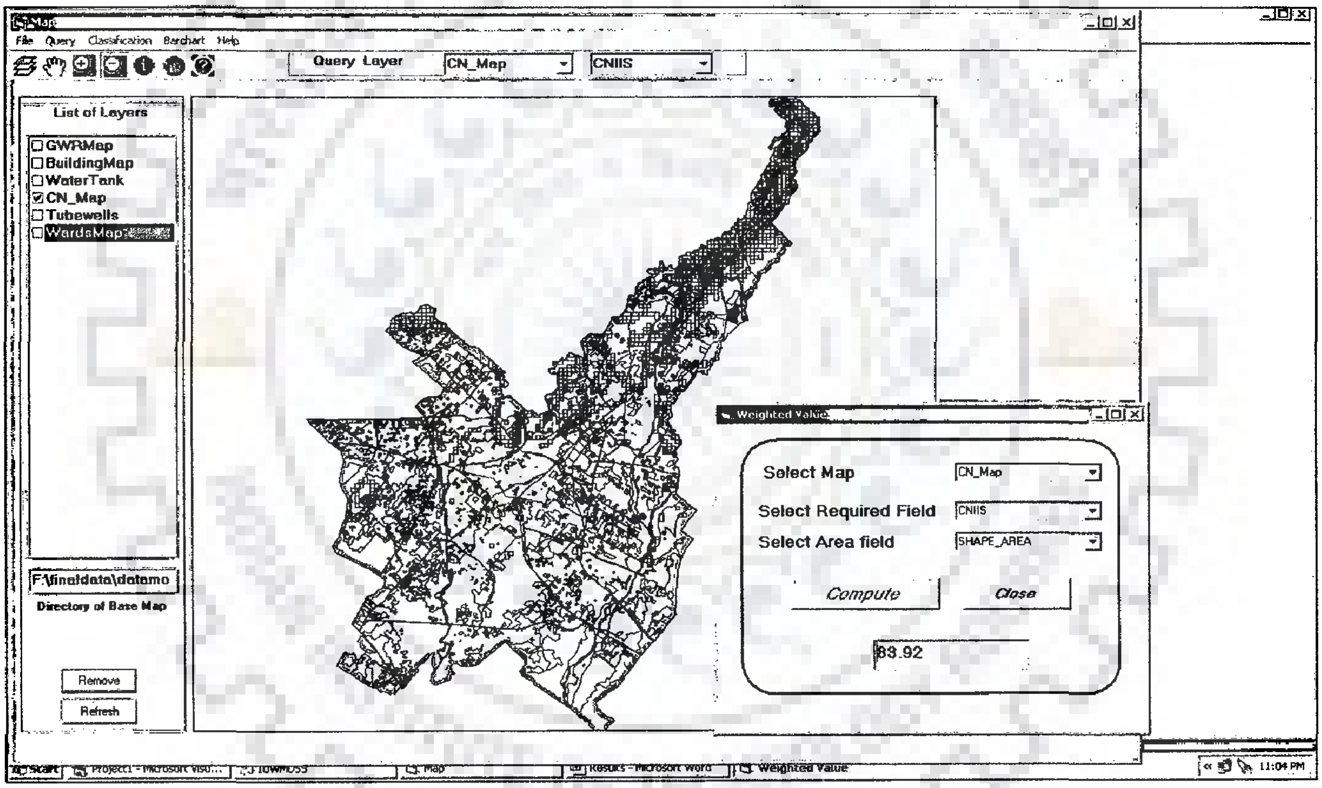


Fig. 6.23 Slope corrected weighted CN for AMC II condition

Many-a-times, land use map for a particular year may not be available. To overcome this problem, weighted CN method has been used to estimate the runoff. A provision was made in the DSS to consider a multiplying coefficient due to linear yearly variation in the weighted CN as discussed in Chapter 3. To estimate the runoff user can multiply the weighted CN value of a year by a coefficient to get the CN value for the desired year.

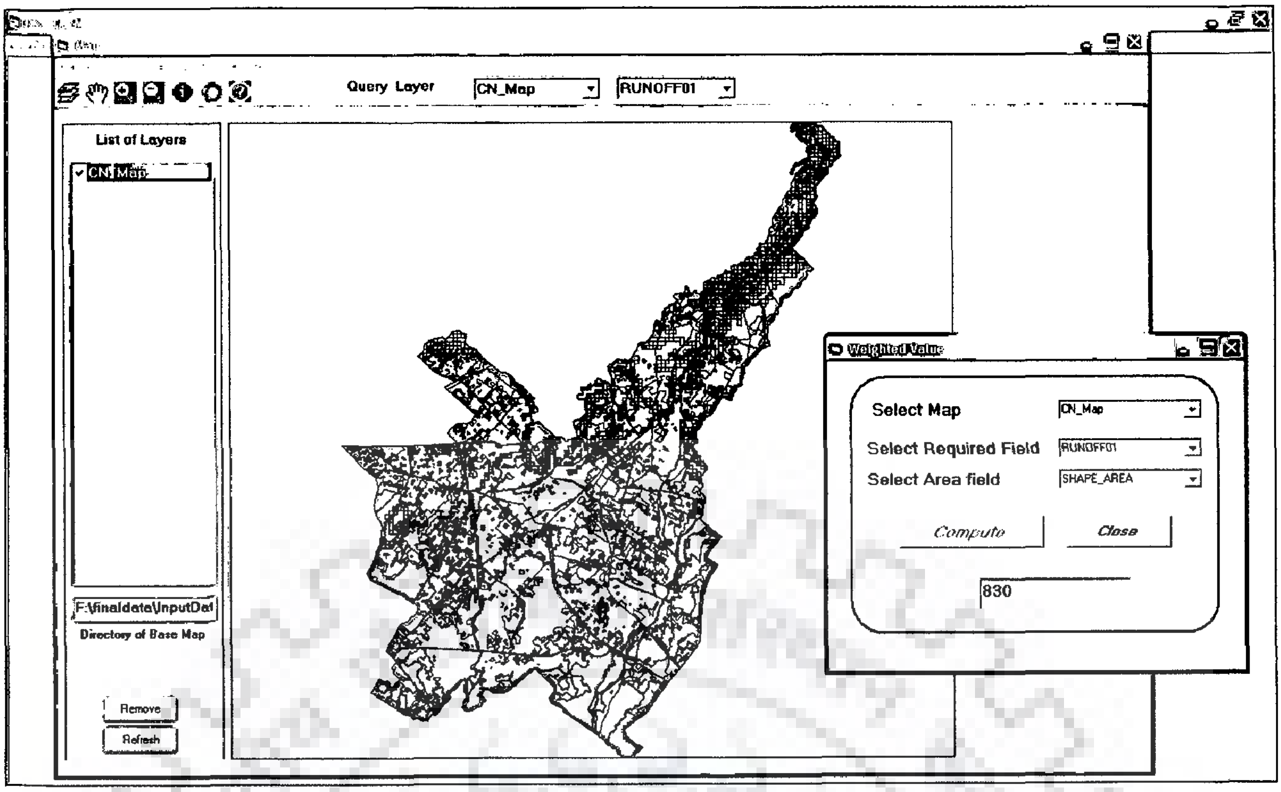


Fig. 6. 24 Weighted runoff depth (mm) by SCS-CN method

Weighted CN value represents the condition of landuse, soil type and hydrologic condition of the area. Trend of the change in weighted CN values can be estimated using the available landuse data. To see the trend of the weighted CN for AMC II condition for different years, weighted CN values have been taken from previous landuse data of Dehradun city, reported in a study conducted at IIT Roorkee (Soni et al., 2003). In that study, the land use for Dehradun municipal area has been evaluated for the year of 1965, 1988, 1997 and 2001. The assumed hydrologic soil group was 'C' and the weighted CN values have been calculated and given in Table 6.7.

An increasing trend has been found in weighted CN for AMC II condition because the imperviousness is increasing in the area and a linear variation has been assumed. Further, the multiplying coefficient has been determined by taking an initial value of weighted CN as 78.5 (The value was assumed slightly higher then 78.2 assuming slope corrections) for the year 1965, and the initial guess of the coefficient as 1.002. The weighted CN for year 2005 was found to be 85 using Eq. 3.20, for i =1 (for year 1965) to i= 40 (for year 2005), which does not match with the weighted CN value as 83.9 for year 2005, calculated from the Fig. 5.12.

In this study many values of coefficients have been assumed, and by trial & error the coefficient of 1.00167 was found to be suitable as it gives the weighted CN as 83.9 in the year 2005, which was same as calculated from Fig. 5.12. It can be seen that there is a mismatch in intermediate weighted CN values calculated by previous data and calculated by multiplying coefficient, but the errors are within acceptable limits. .

Table 6.7 Weighted CN values for the years 1965, 1988, 1997, and 2001

Year	Area(km^2)					Calculated Weighted CN	Weighted CN by multiplying coefficient	% Error
	Urban	Agriculture	Forest	Scrub	River			
1965	16.6	34.7	4.2	6.4	3.9	78.2	78.5	<1%
1988	19.5	33.6	3.5	5.7	3.5	79.2	81.57	<1%
1997	27.8	28.2	3.3	4.8	1.7	82.5	82.8	<1%
2001	30.61	26.1	3.2	4.5	1.6	83	83.35	<1%

Daily rainfall data was available for the study area from year 1993 to 2001. The value of weighted CN for AMC II condition was found to be 82.5 by using the multiplying coefficient. These data value was entered to the rainfall runoff module and the results are shown in Fig. 6.25. It can be seen that by weighted CN method the runoff depth for the year 2001 was 938 mm which is 40% of the total rainfall.

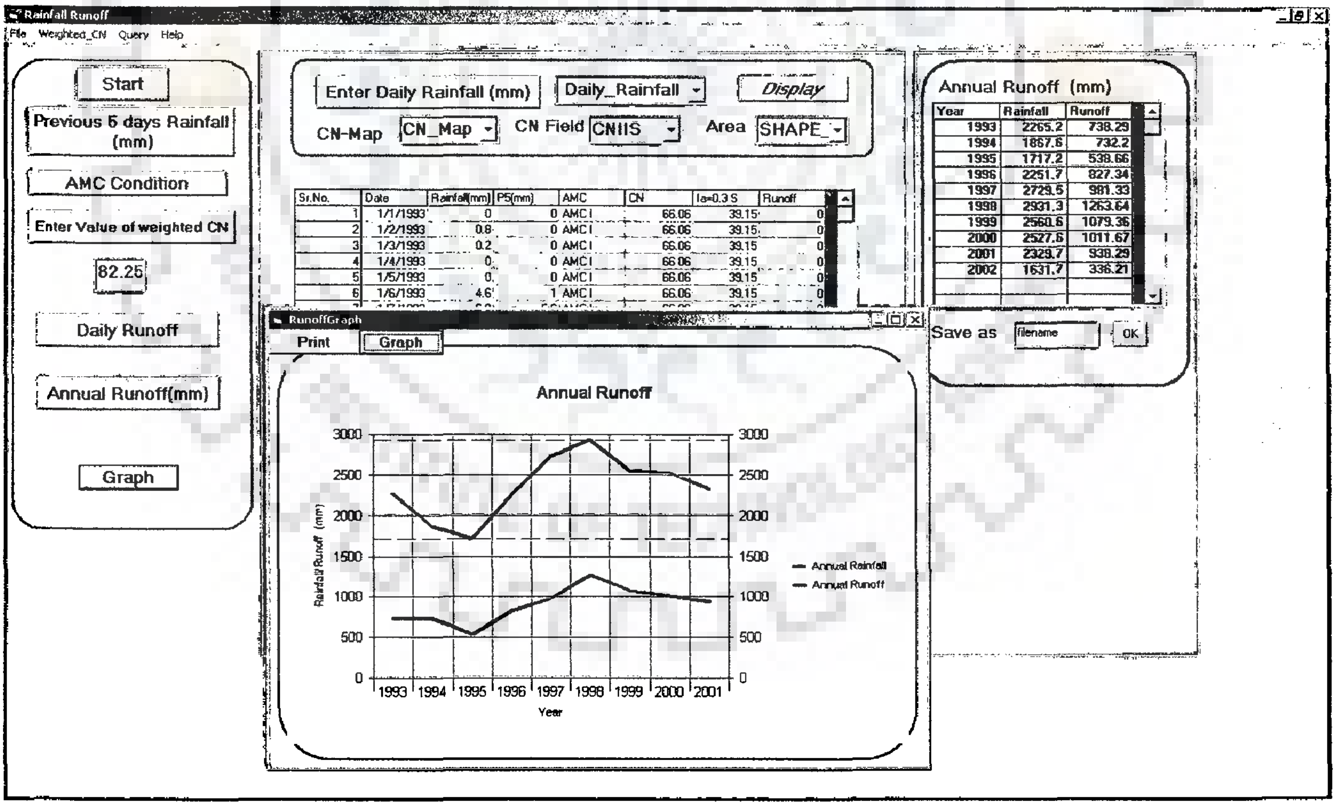


Fig. 6.25 Runoff estimation by weighted CN method

The runoff from SCS-CN method is 830 mm (i.e.155 mld) for year 2001 and 938 mm (170 mld) from weighted CN method for Dehradun city. For high rainfalls, the weighted-CN computes runoff values that deviate from those computed by SCS-CN method in the range from 10 to 15 %, which is an acceptable range.

According to the third assessment report of the IPCC (2007), impacts of climate change on rainfall for Asia are summarized (under highest future emission trajectory) for 2010 to 2039, as shown in Table 6.8. An increase in area averaged annual mean rainfall over Asia is projected. Increased rainfall intensity, particularly during the summer monsoon, could increase flood prone areas in temperate and tropical Asia (Cruz et al., 2007).

Table 6.8 Change in rainfall (IPCC, 2007)

Season	Change in rainfall due to likely climate change (%)
December, January, February	-3
March, April, May	+7
June, July, August	+1
September, October, November	+5

Percentage change in rainfall due to likely climate change was applied to the daily rainfall of the year 2001 and the runoff has been assessed by the weighted CN method in rainfall-runoff module of DSS-IUWM. The estimated runoff is shown in Table 6.9.

Table 6.9 Assessment of runoff for the years 2011, 2021, and 2031

Year	Rainfall (mm)	Runoff	
		(mm)	(mld)
2011	2365	1016	184
2021	2404	1104	200
2031	2440	1224	224

6.6 Rooftop Rainwater Harvesting

An attempt has been made to estimate the potential of rainwater harvesting in the study area. It is clear that rainwater harvesting at best may partly help in reducing the gap between the supply and demand of water. Generally, the success of adopting the concept of rainwater harvesting relies on people's awareness and participation.

Runoff coefficient for roofs varies from 0.7 to 0.95 according to the type of roof catchment. In urban area, mostly RCC slab roof is available, so runoff coefficient is taken as 0.9 (Pacey and Cullis, 1986). Further, some runoff is wasted due to first flush. The initial spell of rainwater carries with it a larger amount of pollutants from air and catchment surface and so, it is not allowed to the storage tank or to the bore to recharge the ground water aquifer. It is flushed out to drains. Therefore, the coefficient of runoff is modified as 0.8. Total roof area of the buildings has been computed from the building map, which is the main input for this module.

Total roof area = 9904037.28 m^2

Runoff coefficient = 0.8

Normal rainfall = 2.213m

Figure 6.26 shows the screenshot of rooftop rainwater harvesting module to compute the rainwater harvesting potential at 25% efficiency of roof area Rainwater harvesting potential at different efficiency of roof area is shown in Table 6.10

Table 6.10 Rainwater harvesting potential at different efficiency of rooftop

Efficiency to harvest rainwater (%)	25	35	50	75	85	100
Rainwater harvesting potential (mld)	12.01	16.37	24	36	40.8	48

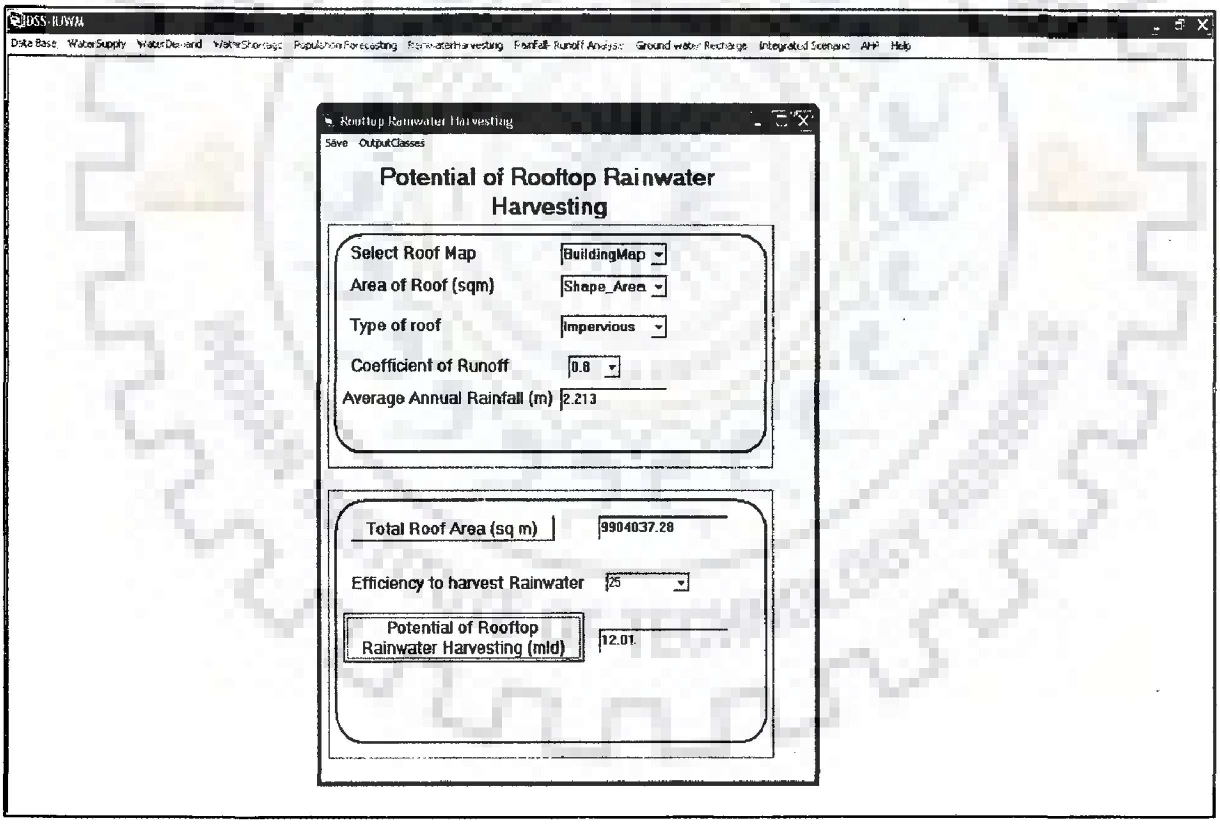


Fig. 6.26 User-interface for rooftop rainwater harvesting module

Further, classified map of rainwater harvesting potential can be seen through the spatial database management sub module. The classification can be done on the basis of size of roof, user can get the information about the, number of buildings, potential of rooftop rainwater harvesting, maximum area, minimum area, as presented in Fig. 6.27.

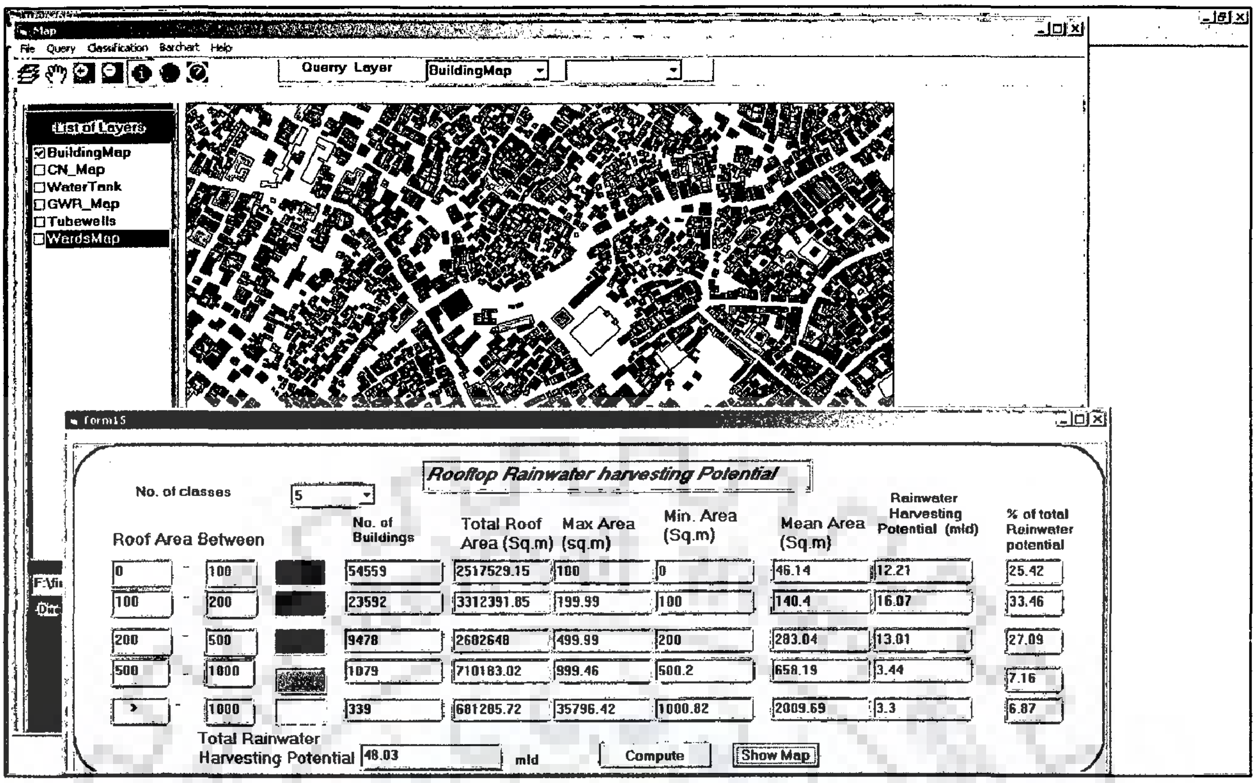


Fig. 6.27 Classified rooftop rainwater harvesting potential

6.7 Groundwater Recharge

Ground water recharge has been estimated by Ground Water Estimation Committee (GEC, 1997). Based on the geology and landuse of the study area, the rainfall infiltration factor (RIF) was presented in Fig. 5.13 and the weighted area RIF is computed as 9%. To estimate the ground water recharge for other years, the land use area of previous years has been evaluated from a previous study (Soni et al., 2003) and assuming the geology of the whole area as same. The weighted rainfall infiltration factor for the year 1965, 1988, 1997 and 2001 is presented in Table 6.11.

A decreasing trend can be seen in the weighted rainfall infiltration factor. Therefore, a reduction constant has been found to take into account of change in landuse pattern and the resulting rainfall infiltration factor as already given in Eq. 3.24.

$$Wi = W_{i-1} - P_r \qquad (3.24)$$

where, Wi = Weighted Rainfall infiltration factor for i^{th} year

W_{i-1} = Weighted Rainfall infiltration factor for $(i-1)^{th}$ year

P_r = Reduction constant for rainfall infiltration factor

By trial and error, the reduction constant was found as 0.125. The initial value of weighted rainfall infiltration factor was taken as 14 for the year of 1965 and it was decreased by a value of 0.125 yearly. While the weighted rainfall infiltration factor for the year 2005 is 9%, which is same as the calculated weighted RIF from the Fig. 5.13.

Table 6.11 Weighted RIF for the year of 1965, 1988, 1997 and 2001.

Year	Area(Km^2)					Weighted RIF	Weighted RIF (by reduction constant)	% Change
	Urban	Agriculture	Forest	Scrub	River			
1965	16.6	34.7	4.2	6.4	3.9	14	14	Nil
1988	19.5	33.6	3.5	5.7	3.5	13	11	22
1997	27.8	28.2	3.3	4.8	1.7	10.78	10	7.8
2001	30.61	26.1	3.2	4.5	1.6	9.8	9.5	3

Landuse data for year 1988 was taken from IRS LISS II data, so the chances of accuracy is low. Hence, this value is assumed to be correct as calculated by the reduction constant. Whereas for the year of 1965, 1988, 1997 and 2001; source of land use map was Toposheets and satellite images of IRS 1D PAN and IKONOS (Soni et al., 2003). Although the number of classes were not sufficient for estimating the rainfall/recharge for urban area, so results are deviating slightly (<10%).and as per the Indian conditions, results are in acceptable range.

Ground water recharge method is described in section 3.6.7. Here, the main input data were monthly rainfall data that contains rainfall from the year 1973 to 2002. So, the value of RIF for 1973 was estimated as 13% using reduction constant. The average recharge has been found to be 210 mm for monsoon and 33 mm for non-monsoon period, which is about 11% of total rainfall, as shown in Fig. 6.28. The groundwater recharge is very low due to the impervious cover of landuse. Although the geology of the maximum area is old doon gravels contains sand, gravels, mix with clay contents, which suppose to be recharge 18%-22% of the total rainfall. Screenshot of bar-chart of rainfall and groundwater recharge is presented in Fig. 6.29.

If rainfall infiltration map and rainfall data are available for a particular year, the groundwater recharge map can be prepared in this module, as presented in Fig. 6.30. The groundwater recharge values can be saved to the shape file by giving a fieldname in the given textbox. The map can be seen by spatial database management module. Ground water recharge has been estimated for the year 2011, 2021 and 2031 (Fig. 6.31) and it found that the recharge will be 6% of the total rainfall in the year of 2031; due to the increasing imperviousness and climatic change. The recharge as percentage of total rainfall is given in Table 6.12.

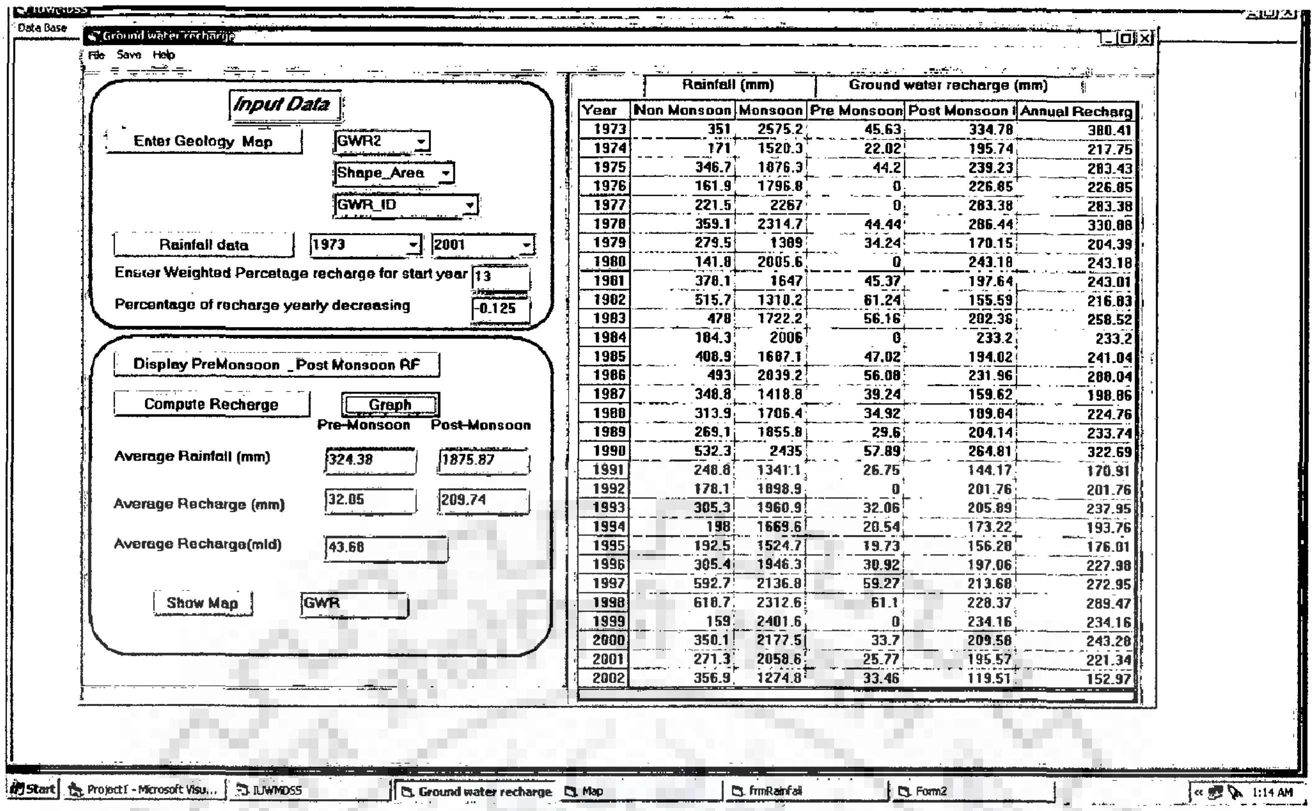


Fig. 6.28 User interface for groundwater recharge

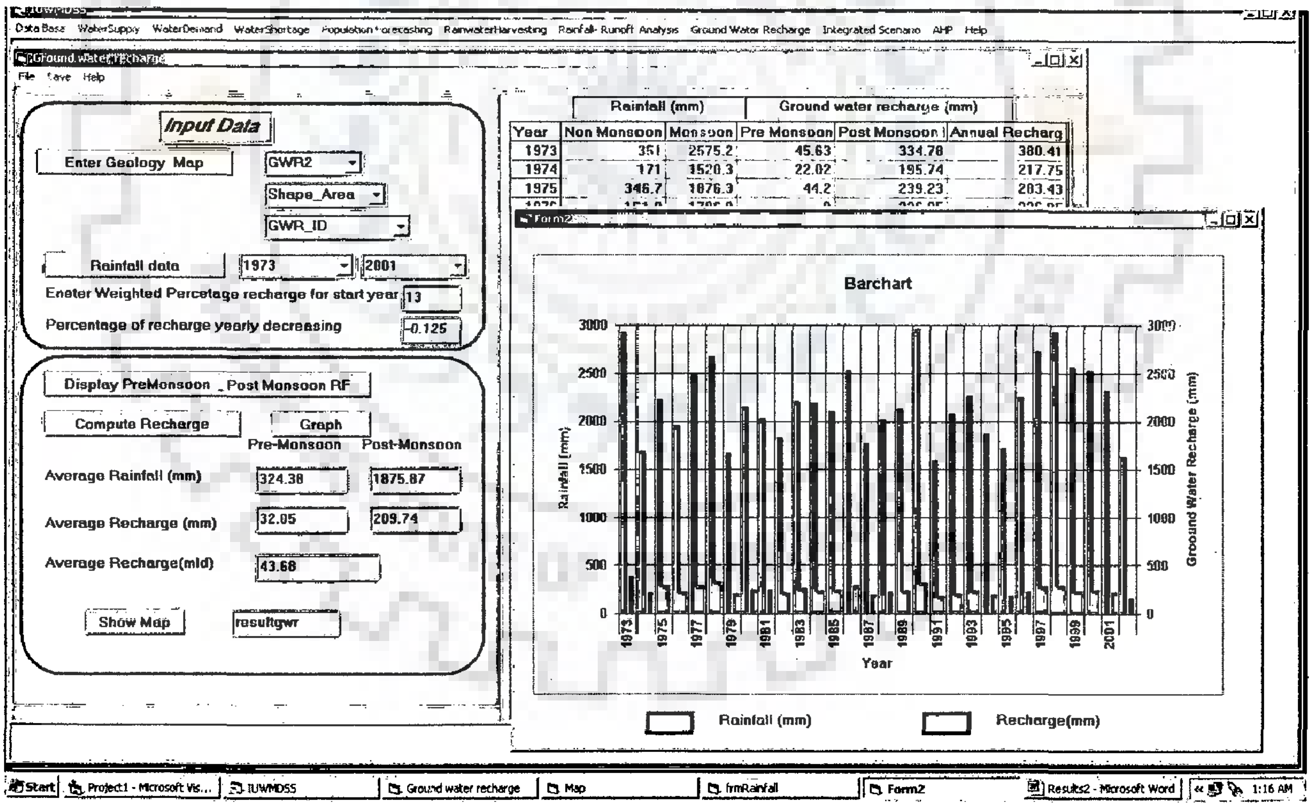


Fig. 6.29 Screenshot of bar-chart for groundwater recharge

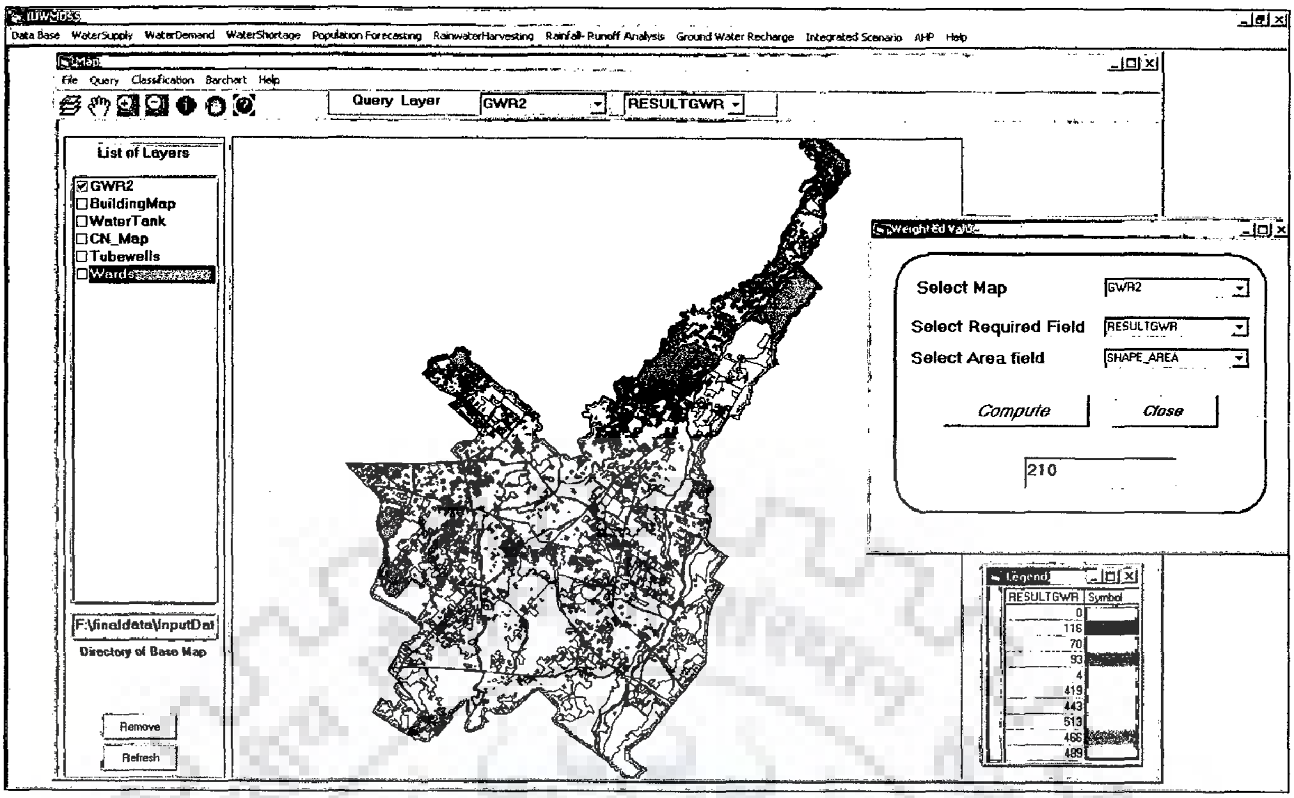


Fig. 6.30 Ground water recharge map

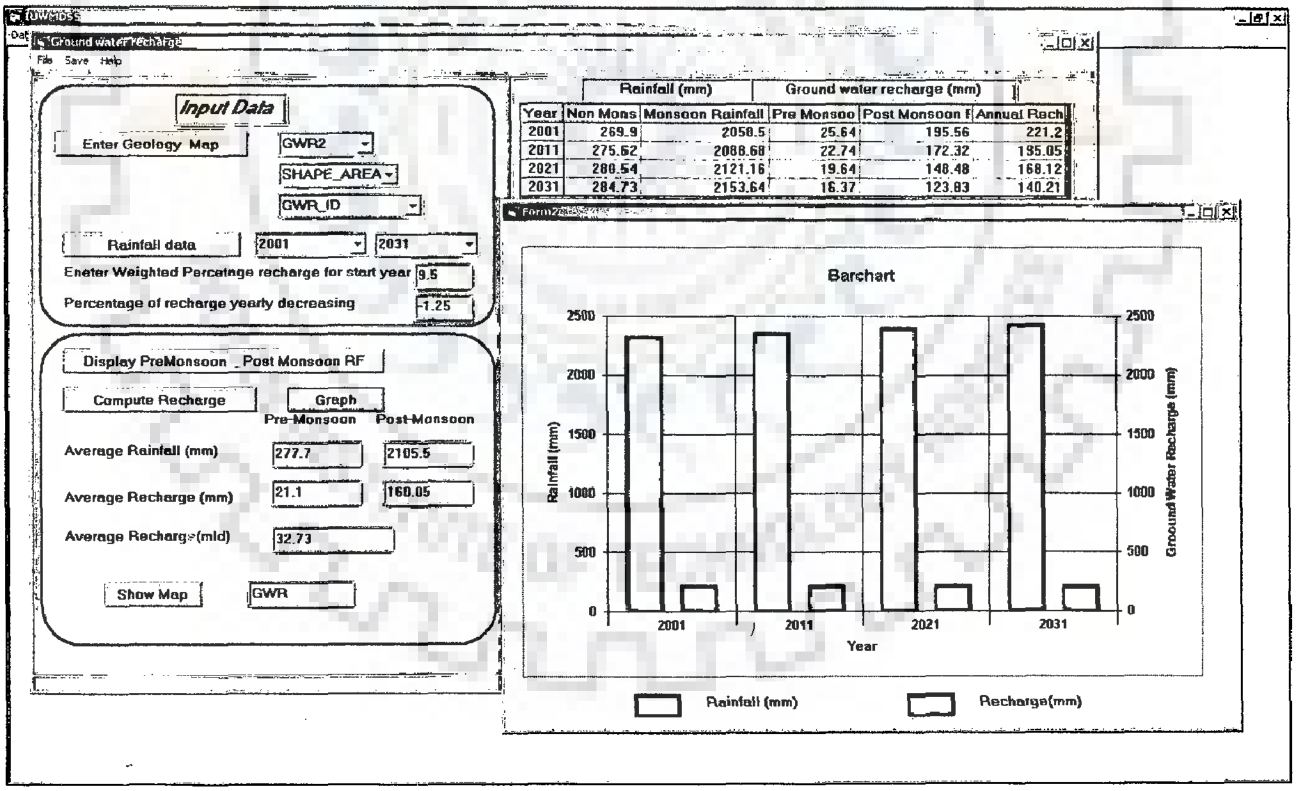


Fig. 6.31 Assessment of groundwater recharge for the year 2011, 2021 and 2031

Table 6.12 Assessment of groundwater recharge for the years 2011, 2021, and 2031

Year	Rainfall (mm)	Recharge (mm)	Recharge (mld)	Recharge as percentage of rainfall
2011	2365	195	35	8%
2021	2404	168	30.37	7%
2031	2440	140	25.33	6%

6.8 Integrated Scenario

This module has the provision of displaying all the information in an integrated way. User can see all the information together and can save the values in tabular form. This module can be used to generate different scenarios considering various options of water management. In the present study, various scenarios have been generated to arrive at suitable water supply plan. All these scenarios shall be presented in next Chapter. The screenshot of integrated scenario for existing water supply sources are shown in Figure 6.32. The water supply sources of the year 2001 were groundwater and surface water. Assuming both the sources remain same, results can be seen in an integrated manner.

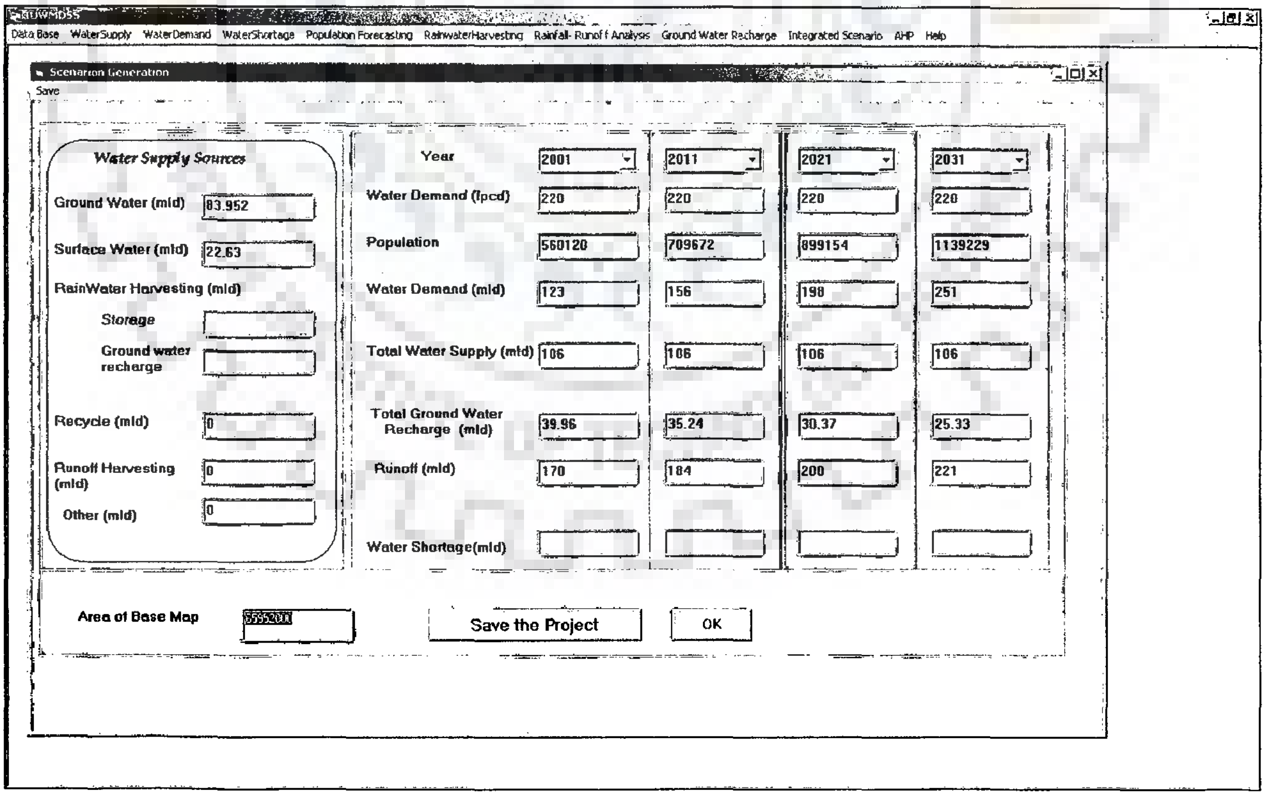


Fig. 6.32 Integrated scenarios for existing water supply sources

6.9 Results and Discussions

Data management modules were tested successfully for all the developed features. Spatial data management module was tested for the five input shape files i.e. wards map, buildings map, CN map, rainfall infiltration map, tubewell map and water tank map of the study area. Non-spatial data management module was tested for daily, monthly and hourly rainfall data.

Analytical modules were run to estimate the present water supply scenario, future water demand at different growth rate of population, estimation of runoff, ground water recharge and rainwater harvesting potential. It has been found that presently water supply is being done almost 80% from groundwater and 20% from surface water. Total water supply is 190 lpcd, whereas demand is 220 lpcd. Therefore, water shortage is 16.6 mld, which is expected to increase upto 314 mld in the year 2031 at high growth rate of population. Total rooftop RWH at 35% efficiency of the roof is 16 mld. It can be seen that in the present condition rooftop rainwater harvesting can be a solution to fulfill the gap of water demand and supply.

Besides, in urban area high rate of runoff is estimated as in the year 2001, it was of about 40% of the total rainfall that would be upto 50% of the annual rainfall in the year 2031 which can lead to high flood problem in future. Groundwater recharge is only 11% of the total rainfall, and predicted to be remain as 6% of the total rainfall in the year 2031. If the recharge decreases as it is and the over-exploitation of groundwater is continued due to high water demand, then groundwater will no longer be sufficient to fulfill the demand of water.

There is an urgent need for taking an appropriate strategy for the sustainability of natural water resources. This leads to the concept of integrated water management, which integrates water supply from all the existing and alternate water resources to reduce the water shortage, water demand measures to reduce water demand, runoff reduction, and groundwater recharge to achieve the aim of sustainability. A thorough study is needed to make the optimum water supply considering scenario based approach discussed in next Chapter.

Chapter 7

SCENARIO GENERATION, ANALYSIS & INTERCOMPARISON

7.1 General

This chapter is devoted to the presentation of the results obtained from the application of the DSS-IUWM to the water supply scenario selection of the Dehradun municipal area. In this section, scenario based approach has been discussed in brief. Next, generation of different management scenarios considered in this study are presented and the results of different scenarios are discussed in subsequent sections. Potential of recycled water and demand management options have been examined for sustainability of water resources system of the study area.

Scenario analysis is an important aid in decision-making when IWRM is to be implemented. Analytical Hierarchal Process (AHP) is a multi-criteria decision-making process that provides a systematic framework for the comparison of various alternatives and helps in selection of the best alternative. Therefore in the DSS-IUWM, a module has been developed that compares the scenarios by AHP method. This chapter demonstrates the utility of the DSS-IUWM by scenario analysis.

Scenario analysis usually tries to identify a set of possible futures; each of the occurrences is plausible, but not assured. The idea of providing a set of preferred future scenarios amongst a list of scenarios is essential for scenario analysis. The key question in scenario analysis is whether it works better than other alternative approaches. Many studies involving decision-making have used scenario analysis viz: urban environmental management (Fedra, 1999); future landuse scenario (Kepner et al., 2008), water resources management in a lake by the WEAP model (Alfarra, 2004); urban water supply for Hyderabad city, India (George et al., 2008) etc. Many simulation models have been used to test the dynamics of future scenarios; for instance, assessment of the impact of future climate scenarios (Leavesley, 1994; Wolf and Diepen, 1995; and Fowler and Kilsby, 2007), future land use scenarios on water quantity and water quality (Kepner et al., 2004; Semmens et al., 2004), and identification of future thrust area (Rao et al., 2005).

7.2 Scenario Generation and Analysis

In this chapter, alternate scenarios have been generated based on an understanding of the problems likely to arise in the study area. Scenarios have been generated by integrating different combinations of potential water supply sources with existing water supply sources. The potential future water sources could be rainwater harvesting, recycling, runoff harvesting and different water demand reduction measures. The generated scenarios can address a broad range of 'What if' questions such as

- What if population growth rate changes?
- What if rainwater harvesting is introduced?
- What if recycling of water in different quantum is implemented?
- What if runoff harvesting is introduced at different magnitude?

On the basis of the water supply, demand, runoff, groundwater and population growth rate an existing or 'business as usual' scenario projection has been discussed in the next section. This is followed by the management of future scenarios to predict the sustainable water supply scenario for the years 2011, 2021 and 2031.

7.2.1 Existing scenario and future prediction (2001-2031)

In the existing scenario (year 2001, as per the decadal data), the following parameters are considered as already discussed in Chapter 6.

Water supply sources: 83.9 mld groundwater, 23.66 mld surface water,

Water demand : 220 lpcd

Runoff : 170 mld or 938 mm (40% of total rainfall)

Groundwater recharge: 42 mld (11% of total rainfall)

Water shortage : 16 mld

Population (Year 2001): 560120

The existing water supply scenario at low, medium and high growth rate of population and the corresponding demand and shortages are given in Table 7.1. The objective of analyzing existing scenario is to visualize the real situation and to make the decision-maker aware about what could likely occur, if current trend continues i.e. water supply sources remain same. Also runoff (Table 6.8) and groundwater recharge (Table 6.11) are considered same for low, medium and high population growth.

Table 7.1 Analysis of the existing water supply scenario by the DSS-IUWM

Population growth rate (GIM)	Year	Population	Water Demand (mld)	Water shortage (mld)
Low (26.4%)	2011	709672	156.13	49.60
	2021	899154	197.81	91.28
	2031	1139229	250.63	144.10
Medium (31.1%)	2011	734877	161.67	55.14
	2021	962690	211.79	105.26
	2031	1262087	277.66	171.13
High (37.4%)	2011	765180	168.34	61.81
	2021	1045312	229.97	123.44
	2031	1428001	314.16	207.63

7.2.2 Management of Scenarios

A sustainable water supply scheme consists of keeping the balance between water supply and water demand by increasing water supply potential and reducing water demand, balance between groundwater withdrawal and recharge, runoff reduction to reduce flood problem, for the present as well as future. IWRM consists of increasing water supply by additional sources such as rainwater harvesting, runoff harvesting, recycling, import of water from other sources etc. Demand management measures are required to reduce the water demand. There should be a balance between groundwater withdrawal and recharge to achieve sustainability with the aspects of groundwater. Besided, runoff reduction is also an important measure, which must be integrated with water supply schemes by runoff harvesting (Carmon et al., 1997; Apostolidis, 2004).

In the present study, scenarios have been generated considering different cases as given in Table 7.2 for water supply system of the study area. Each case consists of integration of different combinations of alternate water supply sources, demand measures with existing water supply scenario at different population growth rate. Cases have been made considering the feasible water supply sources and water demand in the year of 2011, 2021 and 2031. In this way, a short term solutions as well as long term vision of the alternative water supply scenarios have been considered.

Table 7.2 Description of the cases considered for scenario generation

Year	Case	Description
2011	I	Integration of rooftop rainwater harvesting, and recycling with Existing scenario
2021	II	Integration of rooftop rainwater harvesting, recycling and other sources (Importing 10 mld), with existing scenario
	III	Integration of 10% water demand reduction, rooftop rainwater harvesting, recycling and other sources (10 mld), with existing scenario
	IV	Integration of rooftop rainwater harvesting, recycling, from other sources (10 mld), and runoff harvesting, with existing scenario
2031	V	Integrating rooftop rainwater harvesting, recycling, other sources (10 mld), water demand reductions (10%), and runoff harvesting with existing scenario
	VI	Integration of rooftop rainwater harvesting, recycling and water demand measures to the existing scenario

In Case-I, scenarios have been generated for the year of 2011 includes integration of the feasible alternate water supply source viz: rooftop rainwater harvesting, recycled water for non potable use, with the existing water supply scenario for the short term planning.

In the year 2021, other source will be required as the demand will be high due to increasing population. Therefore, three cases have been considered integrating water demand reduction, imported source and runoff harvesting. The data computed from previous Chapter have been used to generate the scenarios.

Further, in the year of 2031, the scenarios have been generated to keep in view the concept of sustainability of water resources. Two cases have been considered: Case-V and Case-VI. Case-V was similar to Case-IV as this case was suppose to be the best Case for the year of 2021 and second case i.e. in the Case-VI, water demand measures and recycling have been taken as major input. All the scenarios have been analyzed for the parameter considered for sustainable water supply scenario and further compared in AHP module.

7.2.3 Scenario analysis and intercomparison

In the present study, scenarios have been generated and analyzed as per the article 3.6.8. Integration of different water supply sources and water demand reduction measures for the analysis of scenarios is presented in Fig. 7.1. The calculations for the criteria have been shown in boxes having grey colours.

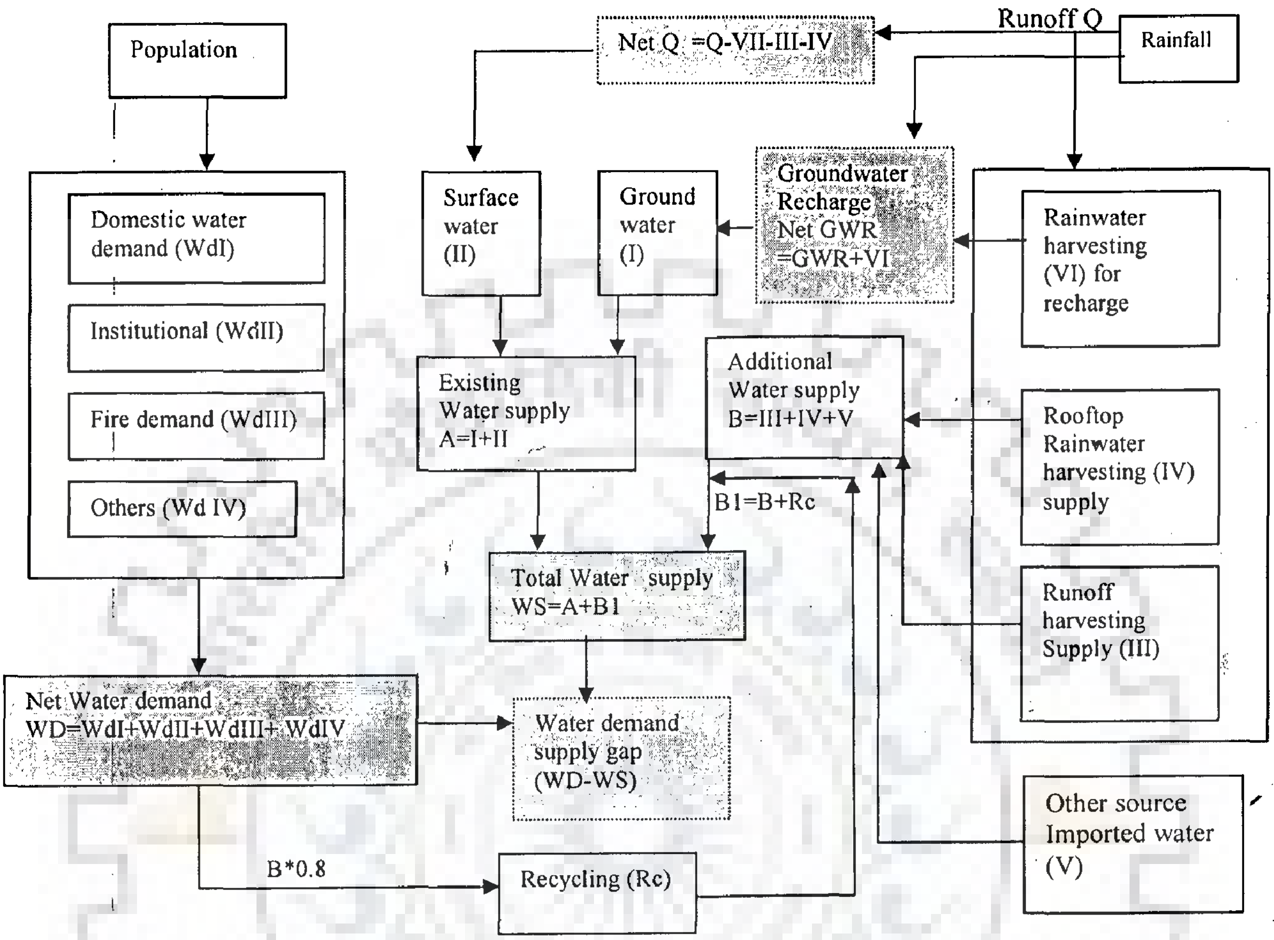


Fig. 7.1 Conceptual diagram of IWRM. Boxes, with grey colour show important calculations

It can be seen that main factors to be analyzed in an integrated water resources management are water shortage reduction, net water demand, net groundwater recharge and net runoff. Urbanization is mainly characterized by the high population density and increased imperviousness. Therefore all the water supply strategies have been analyzed for different population growth rate. In the DSS-IUWM, different scenarios have been generated to identify an optimum water supply schemes for the year of 2011, 2021 and 2031. Each scenario has been analyzed for the above factors and compared in AHP module. Following section describes the AHP method to compare the scenarios.

7.3 Analytical Hierarchal Process

A set of scenarios can be compared by AHP method considering some factors. A factor is a criterion that enhances the suitability of a specific alternative for the activity under consideration (Rao, 2005). AHP procedure for assigning rank to different scenarios is presented in Fig. 7.2. The decision hierarchy is designed to find a sustainable water supply scheme by IWRM for an urban area. To achieve the aim of sustainable water supply, the criteria factors under consideration are water shortage reduction, water demand reduction, increasing groundwater recharge, runoff reduction and to prefer low population growth of the area.

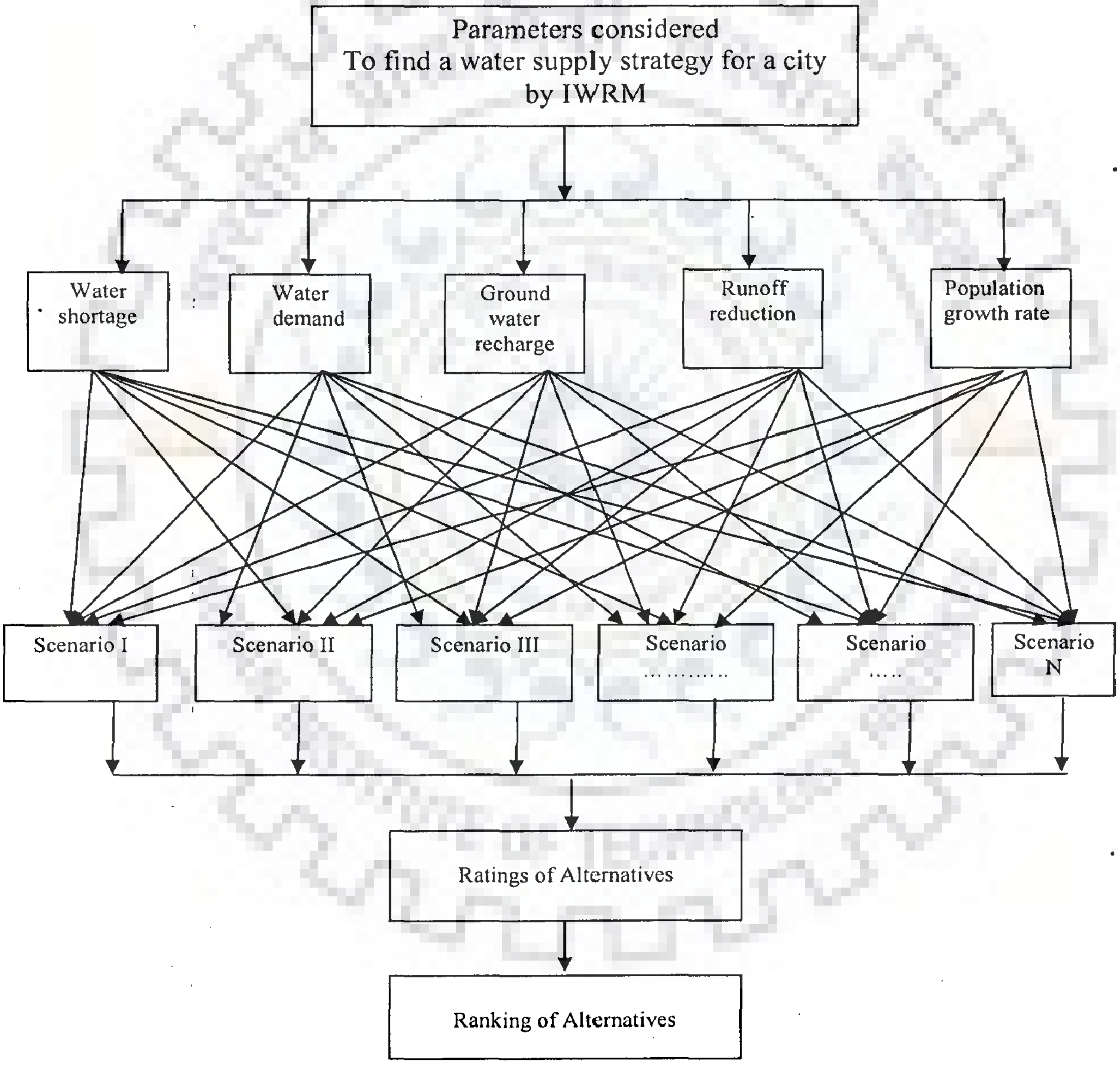


Fig. 7.2 AHP procedure for calculating rank for the management of water supply

Different scenarios were generated integrating different options for water supply and demand and analyzed for the above factors and compared in AHP. All the factors are assigned weights and this weight is multiplied with their normalized value in scenarios table. Total scores have been calculated by the Eq. 3.26. On the basis of scores, ranks are assigned to each water supply scheme. These scores of the scenarios can be viewed simultaneously through a table and bar-chart for easy comparison. Here, the highest ranked scenario does not mean that the scenario is fulfilling all the criteria of sustainability, but overall it is comparatively better than other scenarios. The method requires calculation of weights by pair-wise comparison method. Calculation of weights has been discussed in the following section.

7.3.1 Calculation of weights

To compare the scenarios by AHP method, weights have been calculated by pair-wise comparison method as already explained in Chapter 3. The scenarios have been compared on the basis of the criteria of minimization of water shortage, water demand minimization, ground water recharge, runoff reduction and low population growth rate.

The weights were assigned according to the relative priority of the criteria with respect to each other in water supply schemes. The priorities were decided as per people's opinion, suggestion from experts and field officers, colleagues, and previous studies. The first priority in a water supply scheme is given to supply desired quantity of water with quality of water meeting the standards set for drinking water supply. The acute water shortage can create a social unrest in future. Next priority is water demand reduction as without implementing demand reduction strategies, it will not be possible to fulfill the water demand supply gap in future (Biswas et al., 2008, Khare et al., 2006). To achieve sustainability, water saves measures such as leakage reduction, reuse of water, public awareness about value of water and reduction of misuse the water, setting the price of water need to be implemented.

The next priority is ground water recharge through rainwater harvesting or runoff harvesting. In the study area, 80% water is supplied through ground water and recharge rate is reducing every year due to urbanization. Therefore groundwater plays an important role in water supply, which must be recharged to maintain the sustainability of the source. Further, in an urban area, due to high imperviousness, volume of runoff generated is high and this may cause flood problems. Therefore, reduction of runoff must be integrated to the water supply schemes through rainwater harvesting.

The weights were assigned on a scale of 1 to 9. Water shortage reduction has been given three times more importance than water demand minimization, five times more importance than ground water recharge, six times more importance then runoff reduction and seven times more importance then population growth of the area. Similarly other weights have been assigned as presented in Table 7.3. Calculated weights by pair-wise comparison module of the developed DSS have been shown in Fig. 7.3. The weights are 0.475, 0.275, 0.137, 0.073 and 0.04 respectively for reducing water shortage and water demand, increasing groundwater recharge, reducing runoff and minimizing population growth of the area.

Table 7.3 Original weights for pair-wise comparison matrix

Criteria	Water Shortage	Water demand	Ground water recharge	Runoff reduction	Population growth rate
Water Shortage	1	3	5	6	7
Water demand	1/3	1	4	5	6
Ground water recharge	1/5	1/4	1	3	5
Runoff reduction	1/6	1/5	1/3	1	3
Population growth rate	1/7	1/6	1/5	1/3	1

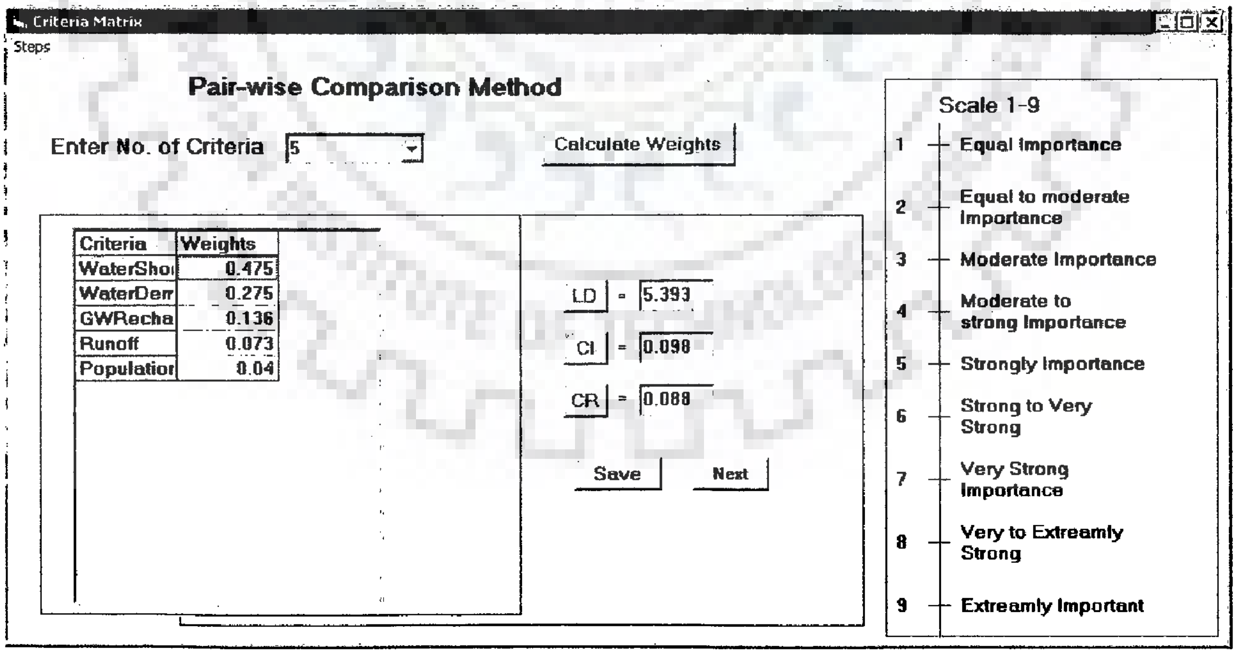


Fig. 7.3 Calculation of weights by pair-wise comparison module

7.3.2 Comparison of different scenarios

After calculating weights, six cases consisting different scenarios as already discussed in article 7.2.2 have been generated, analyzed and compared by AHP method. The results are discussed in the following sections. Each case includes integration of additional water supply sources or demand measures with the existing scenario.

7.3.2.1 Integration of rooftop RWH, and recycling

Case-I contains integration of rooftop RWH potential at different efficiencies and recycling at different potential amount with the existing water supply sources (2001). Different scenarios have been generated considering low, medium and high population growth for the year 2011.

The rainwater harvesting module provides the flexibility to the user to generate rainwater harvesting potential at different efficiency of total rooftop area as shown in Table 6.9. Rainwater harvested at the rooftop can be used to recharge ground water or to supply water through storage tank. Due to high consumption, a large amount of waste water is being generated which can be recycled partly or totally for water supply. Therefore, rooftop rainwater harvesting and recycling were integrated in urban water management in the present case. This can reduce the load on the existing water supply sources (year 2001) to reduce the problem of water shortage.

In the Case I, different scenarios have been generated at different efficiencies of rainwater harvesting potential and recycled water to fulfill non potable water demand. Total domestic water demand includes 95 lpcd potable water demand and 40 lpcd non-potable water demand (Fig. 6.18) which includes requirement for floor washing and flushing of water closets etc. This later requirement can be fulfilled by recycle/reuse of water. It is assumed that 20% of total water demand can be fulfilled by using recycled water as additional source.

Figure 7.4 presents schematic of different water supply scenarios, which were analyzed for low, medium and high population growth rate for the year 2011. Here, S1, S2, S3........ represent the 1st, 2nd, 3rd,...... scenario. First scenario is the existing water supply scenario (year 2001) using 83.9 mld groundwater and 22.63 mld surface water.

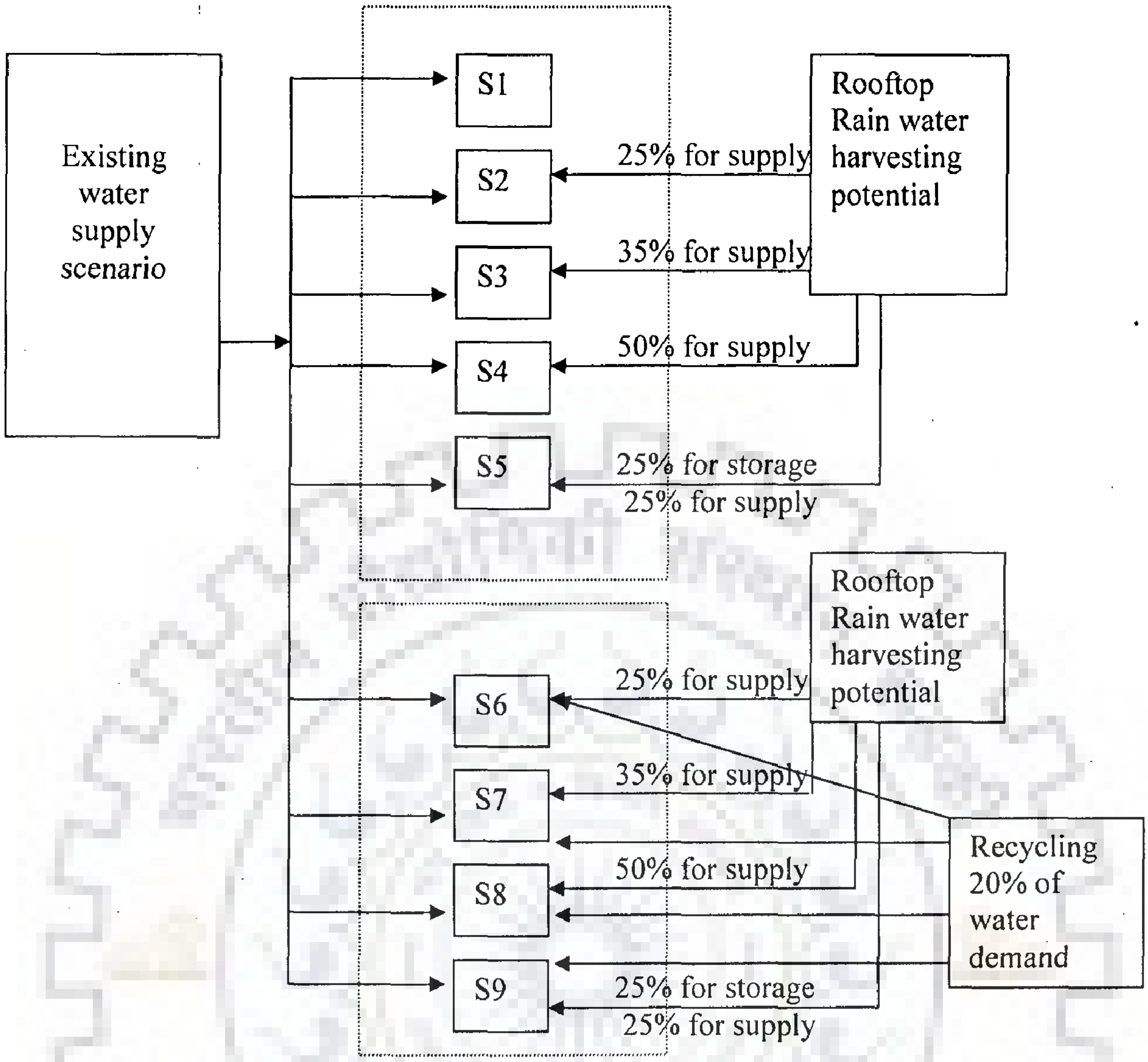


Fig. 7.4 Schematic of water supply scenarios 1st to 9th (Case-I)

Scenarios 2nd to 5th have been generated considering rooftop rainwater harvesting, and low growth rate of population. Total rooftop harvesting potential is 48 mld at 100% efficiency of rooftops. But the use of entire roof area of the city is not feasible in any urban area. Therefore, it is assumed that initially only 25%, 35%, or 50% efficiency of rooftops can be attained for rainwater harvesting. In 5th scenario, 25% of rainwater harvesting potential has been taken for recharge and 25% of total rainwater harvesting potential has been taken for storage to supply water.

Scenarios 6th to 9th have been generated taking rooftop rainwater harvesting as already discussed with 20% of recycled water supply at low growth rate of population. Scenarios 10th to 18th have been generated same as scenarios 2nd to 9th at medium growth rate of population and scenario 19th to 27th have generated at higher growth rate of scenario. All the scenarios generated to analyze the water supply scheme for the year of

2011 are presented in Table 7.4. All the scenarios were analyzed for water shortage, net water demand, net groundwater recharge, runoff reduction and population as explained in section 3.6.8. and are shown in Table 7.5. These were compared in AHP module to evaluate the highest ranked scenario shown in Fig. 7.5.

Table 7.4 Water supply scenarios, year 2011 (Case-I)

SN	Existing water supply (mld)		Rainwater harvesting (% of total RWH s potential)		Recycling (% of Water demand)	Population growth rate
	Ground water	Surface water	Storage	Recharge		
1	83.9	22.63	0	0	0	Low
2	83.9	22.63	25	0	0	Low
3	83.9	22.63	35	0	0	Low
4	83.9	22.63	50	0	0	Low
5	83.9	22.63	25	25	0	Low
6	83.9	22.63	25	0	20%	Low
7	83.9	22.63	35	0	20%	Low
8	**83.9**	**22.63**	**50**	**0**	**20%**	**Low**
9	83.9	22.63	25	25	20%	Low
10	83.9	22.63	0	0	20%	Medium
11	83.9	22.63	25	0	20%	Medium
12	83.9	22.63	35	0	20%	Medium
13	83.9	22.63	50	0	20%	Medium
14	83.9	22.63	25	25	20%	Medium
15	83.9	22.63	25	0	20%	Medium
16	83.9	22.63	35	0	20%	Medium
17	83.9	22.63	50	0	20%	Medium
18	83.9	22.63	25	25	20%	Medium
19	83.9	22.63	0	0	20%	High
20	83.9	22.63	25	0	20%	High
21	83.9	22.63	35	0	20%	High
22	83.9	22.63	50	0	20%	High
23	83.9	22.63	25	25	20%	High
24	83.9	22.63	25	0	20%	High
25	83.9	22.63	35	0	20%	High
26	83.9	22.63	50	0	20%	High
27	83.9	22.63	25	25	20%	High

Table 7.5 Analysis of water supply scenarios, year 2011 (Case-I)

S N	Water shortage (mld)	Water demand (mld)	Groundwater Recharge (mld)	Runoff (mld)	Population
1	49.6	156.1	35.0	184.0	709672
2	37.6	156.1	35.0	172.0	709672
3	32.8	156.1	35.0	167.2	709672
4	25.6	156.1	35.0	160.0	709672
5	37.6	156.1	47.0	160.0	709672
6	9.2	156.1	35.0	172.0	709672
7	4.4	156.1	35.0	167.2	709672
8	**-2.8**	**156.1**	**35.0**	**160.0**	**709672**
9	9.2	156.1	47.0	160.0	709672
10	55.1	161.7	35.0	184.0	734877
11	43.1	161.7	35.0	172.0	734877
12	38.3	161.7	35.0	167.2	734877
13	31.1	161.7	35.0	160.0	734877
14	43.1	161.7	47.0	160.0	734877
15	13.7	161.7	35.0	172.0	734877
16	8.9	161.7	35.0	167.2	734877
17	**1.7**	**161.7**	**35.0**	**160.0**	**734877**
18	13.7	161.7	47.0	160.0	734877
19	61.8	168.3	35.0	184.0	765180
20	49.8	168.3	35.0	172.0	765180
21	45.0	168.3	35.0	167.2	765180
22	37.8	168.3	35.0	160.0	765180
23	49.8	168.3	47.0	160.0	765180
24	19.2	168.3	35.0	172.0	765180
25	14.4	168.3	35.0	167.2	765180
26	**7.2**	**168.3**	**35.0**	**160.0**	**765180**
27	19.2	168.3	47.0	160.0	765180

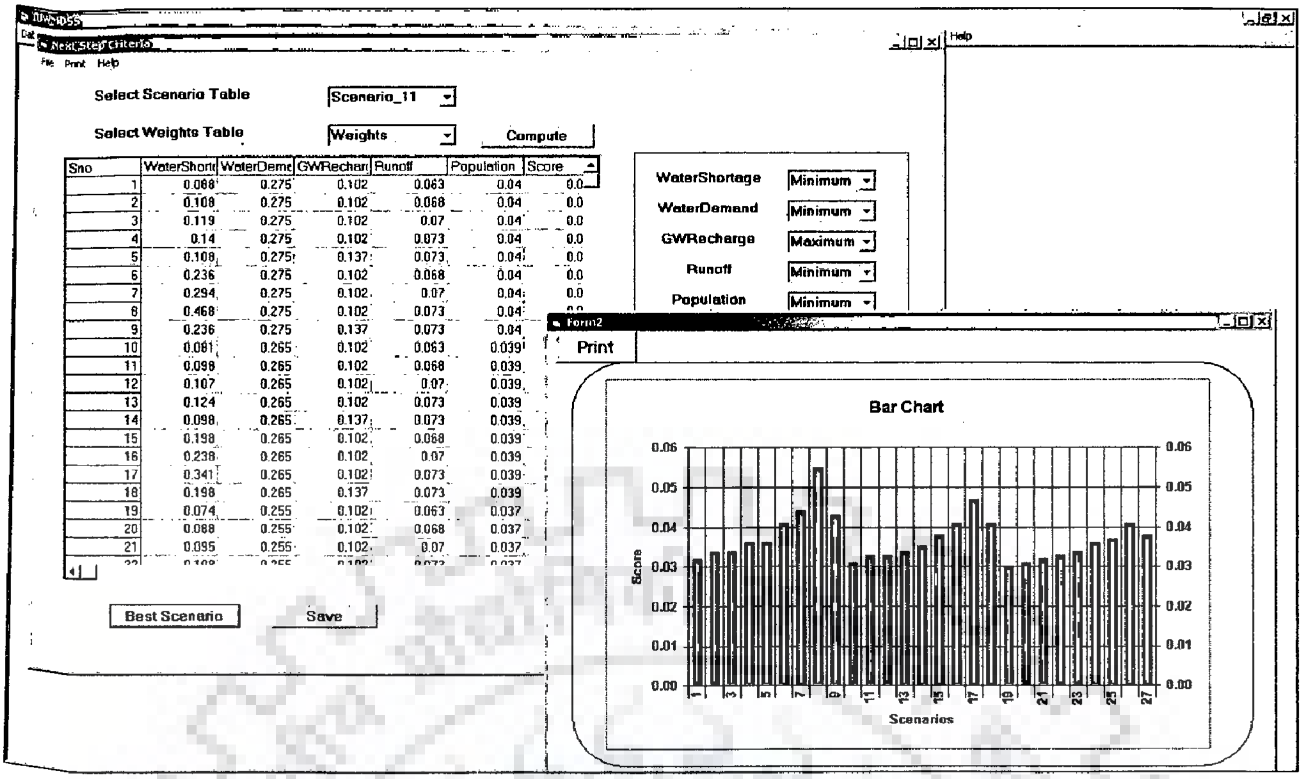


Fig. 7.5 Screenshot of scenarios comparison, Case-I (year 2011)

It can be seen that scenario 8th is the highest ranked scenario according to AHP method, which includes existing water supply scenario(year 2001), 50% rainwater harvesting for storage and 20% recycling with low population growth rate. It can be seen that only scenario 8th resulting surplus water of 2.8 mld, thus meeting the water shortfalls which is the major priority of any water supply scheme. In this scenario, runoff reduction is 13% (from 184 mld to 160 mld), and groundwater recharge is 40% of withdrawal. Further, scenario 17th is the second ranked scenario. This is similar to scenario 8th except that the medium population growth rate and scenario 26th is also same scenario at higher population growth rate.

Therefore it can be said that at medium or higher growth rate these water supply schemes are not appropriate as water shortage of 1.7 mld and 7.2 mld do exist under 17th, and 26th scenarios. It can be said that rooftop RWH and use of recycled water for non potable water demand can be a temporary solution to meet the water demand at low population growth rate. Therefore to meet demand for the year 2021, additional measures will be necessary as discussed in next section.

7.3.2.2 Integration of rooftop rainwater harvesting, recycling and other sources

Case-II with integration of rooftop rain water harvesting, recycling and other sources has been studied under different options for the year of 2021. Figure 7.6 shows schematic of the generated water supply scenarios for the water management of the study area for the year 2021. Here. S1, S2, S3.....represent the 1st, 2nd, 3rd.....scenarios. Different scenarios have been generated by integrating rooftop rainwater harvesting at different efficiencies, recycling and imported water from other sources with the existing water supply sources.

The import option has been given in the developed DSS, so that as per field condition and available options, decision maker can decide the appropriate water supply plan. Scenarios 1st to 9th are same as scenarios taken for the year 2011 except that population is high in the year of 2021. In the study area, some other sources of water are needed for the sustainable development of water resources. It is assumed that 10 mld of surface water can be imported from the other area. Table 7.6 shows the list of scenarios generated to analyze the water supply scheme for the year 2011.

The scenarios have been analyzed considering same parameter of water shortage, water demand reduction, groundwater recharge and runoff reduction as shown in Table 7.7. Comparison of the scenarios by AHP method is shown in Fig. 7.7. It can be seen that the scenario 12th was the highest ranked scenario which includes existing water supply scenario, 50% rainwater harvesting for storage, and 20% recycling with low population growth rate. It can be seen that this scenario results in 21 mld of water shortage, which is very high.

Therefore, all the scenarios of Case-II, integrating rooftop rainwater harvesting, 20% recycling and other sources (10 mld) will not be able to meet the water shortfalls in the year 2021. Therefore, some water demand reduction measures will be required to reduce the shortfalls and these are described in subsequent sections.

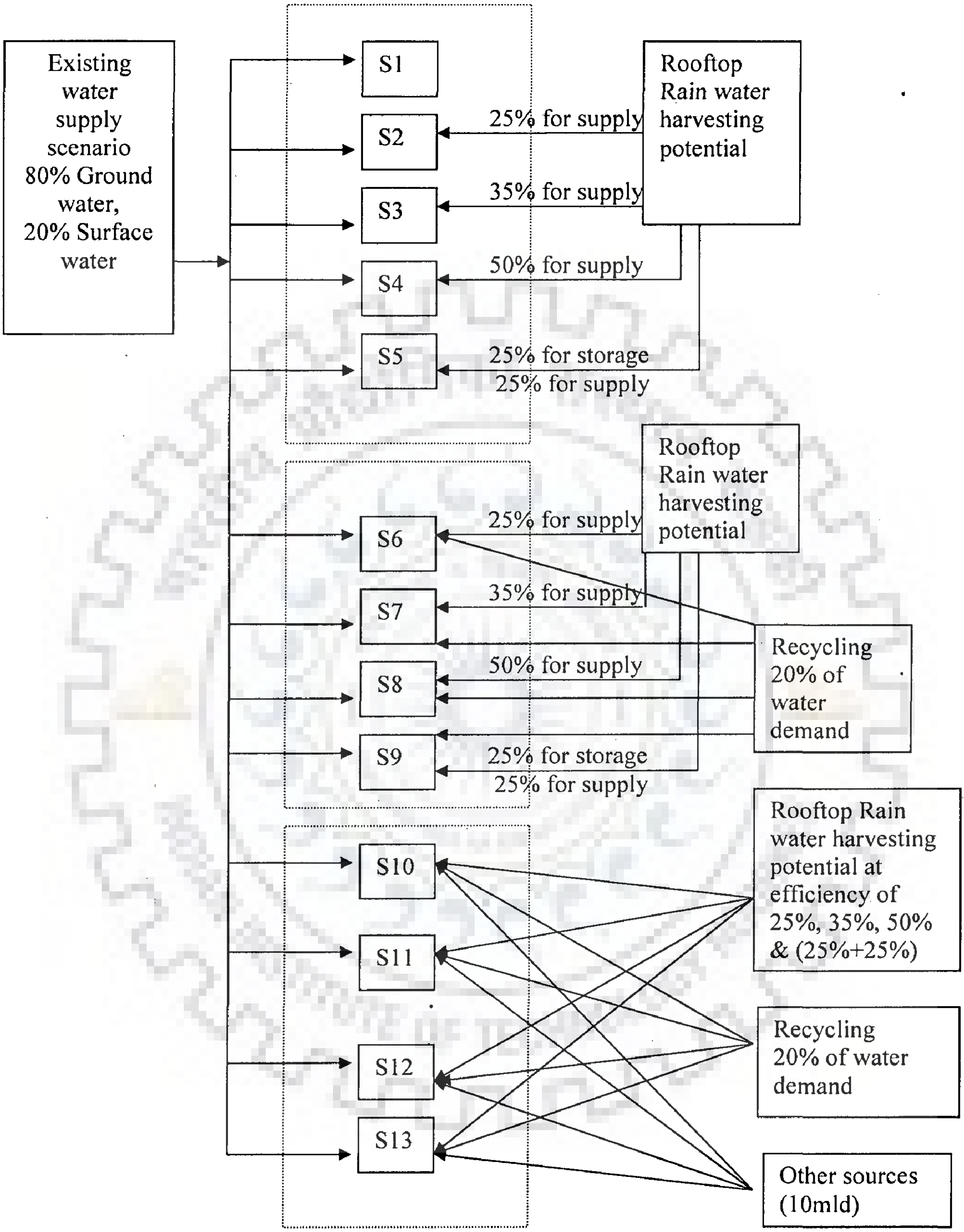


Fig.7.6 Schematic of scenarios 1st to 13th for Case-II

Table 7.6 Water supply scenario, year 2021 (Case-II)

SN	Existing Sources		Rainwater potential (% of total rainwater harvesting potential)		Recycling (% of Water demand)	Other (mld)	Population growth rate
	Ground water (mld)	Surface water (mld)	Storage	Recharge			
1	83.9	22.63	0	0	0	0	Low
2	83.9	22.63	25	0	0	0	Low
3	83.9	22.63	35	0	0	0	Low
4	83.9	22.63	50	0	0	0	Low
5	83.9	22.63	25	25	0	0	Low
6	83.9	22.63	25	0	20	0	Low
7	83.9	22.63	35	0	20	0	Low
8	83.9	22.63	50	0	20	0	Low
9	83.9	22.63	25	25	20	0	Low
10	83.9	22.63	25	0	20	10	Low
11	83.9	22.63	35	0	20	10	Low
12	**83.9**	**22.63**	**50**	**0**	**20**	**10**	**Low**
13	83.9	22.63	25	25	20	10	Low
14	83.9	22.63	25	0	0	0	Medium
15	83.9	22.63	35	0	0	0	Medium
16	83.9	22.63	50	0	0	0	Medium
17	83.9	22.63	25	25	0	0	Medium
18	83.9	22.63	25	0	20	0	Medium
19	83.9	22.63	35	0	20	0	Medium
20	83.9	22.63	50	0	20	0	Medium
21	83.9	22.63	25	25	20	0	Medium
22	83.9	22.63	25	0	20	10	Medium
23	83.9	22.63	35	0	20	10	Medium
24	83.9	22.63	50	0	20	10	Medium
25	83.9	22.63	25	25	20	10	Medium
26	83.9	22.63	25	0	0	0	High
27	83.9	22.63	35	0	0	0	High
28	83.9	22.63	50	0	0	0	High
29	83.9	22.63	25	25	0	0	High
30	83.9	22.63	25	0	20	0	High
31	83.9	22.63	35	0	20	0	High
32	83.9	22.63	50	0	20	0	High
33	83.9	22.63	25	25	20	0	High
34	83.9	22.63	25	0	20	10	High
35	83.9	22.63	35	0	20	10	High
36	83.9	22.63	50	0	20	10	High
37	83.9	22.63	25	25	20	10	High

Table 7.7 Analysis of the water supply scenarios, year 2021 (Case-II)

SN	Water shortage (mld)	Water demand (mld)	Ground water recharge (mld)	Runoff (mld)	Population
1	91.3	197.8	30.4	200.0	899154
2	79.3	197.8	30.4	188.0	899154
3	74.5	197.8	30.4	183.2	899154
4	67.3	197.8	30.4	176.0	899154
5	79.3	197.8	42.4	176.0	899154
6	43.3	197.8	30.4	188.0	899154
7	38.5	197.8	30.4	183.2	899154
8	31.3	197.8	30.4	176.0	899154
9	43.3	197.8	42.4	176.0	899154
10	33.3	197.8	30.4	188.0	899154
11	28.5	197.8	30.4	183.2	899154
12	**21.3**	**197.8**	**30.4**	**176.0**	**899154**
13	33.3	197.8	42.4	176.0	899154
14	93.3	211.8	30.4	188.0	962690
15	88.5	211.8	30.4	183.2	962690
16	81.2	211.8	30.4	176.0	962690
17	93.3	211.8	42.4	176.0	962690
18	54.7	211.8	30.4	188.0	962690
19	49.9	211.8	30.4	183.2	962690
20	42.7	211.8	30.4	176.0	962690
21	54.7	211.8	42.4	176.0	962690
22	44.7	211.8	30.4	188.0	962690
23	39.9	211.8	30.4	183.2	962690
24	32.7	211.8	30.4	176.0	962690
25	44.7	211.8	42.4	176.0	962690
26	111.4	230.0	30.4	188.0	1045312
27	106.6	230.0	30.4	183.2	1045312
28	99.4	230.0	30.4	176.0	1045312
29	111.4	230.0	42.4	176.0	1045312
30	69.6	230.0	30.4	188.0	1045312
31	64.8	230.0	30.4	183.2	1045312
32	57.6	230.0	30.4	176.0	1045312
33	69.6	230.0	42.4	176.0	1045312
34	59.6	230.0	30.4	188.0	1045312
35	54.8	230.0	30.4	183.2	1045312
36	47.6	230.0	30.4	176.0	1045312
37	59.6	230.0	42.4	176.0	1045312

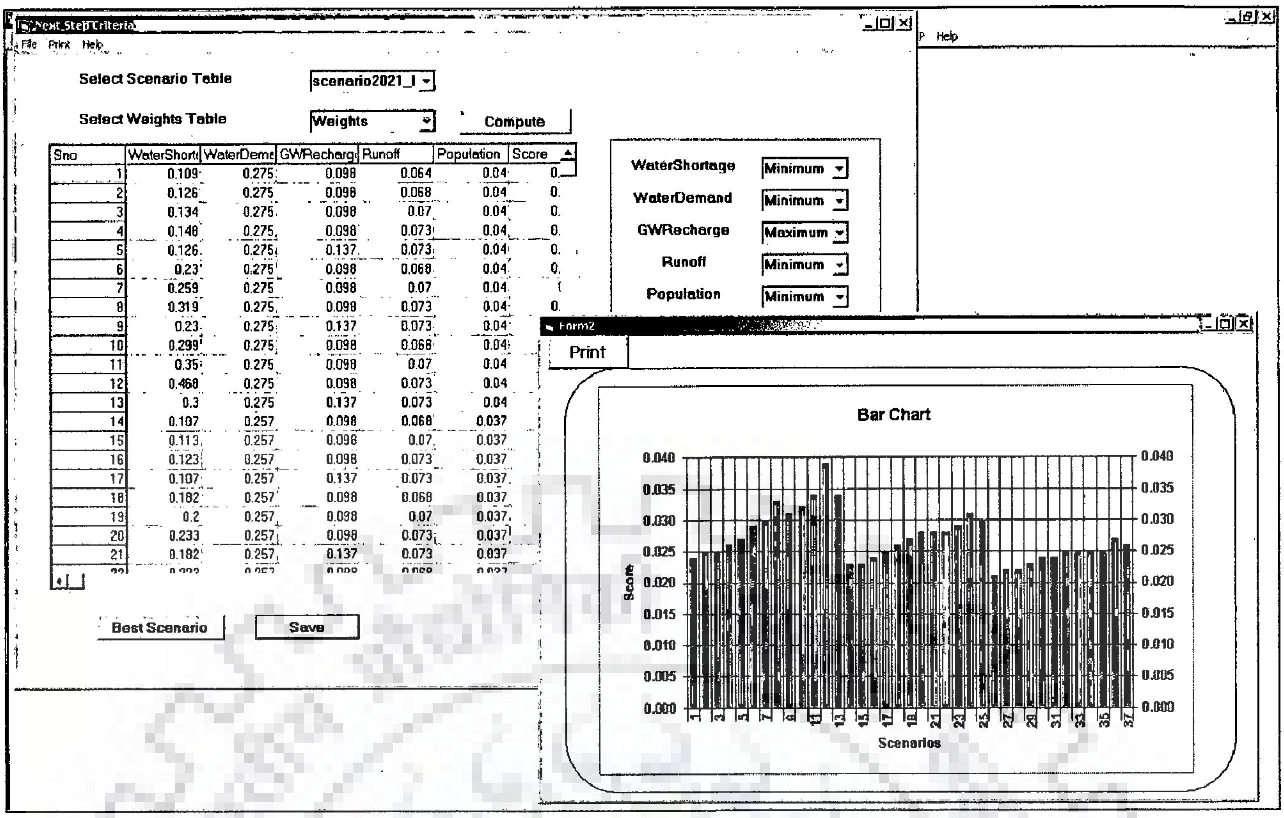


Fig. 7.7 Screenshot of scenarios comparison, Case-II (year 2021)

7.3.2.3 Integration of 10% water demand reduction, rooftop rainwater harvesting, recycling and other sources (10 mld)

Schematic of scenarios integrating rooftop rainwater harvesting at different efficiencies, recycling, other sources (import 10 mld from distant source) and water demand reduction are shown in Fig. 7.8. Here, S10, S11, S12 and S13 represent scenarios 10th, 11th, 12th and 13th. It can be seen that schematic of the scenarios are same as Case-I, except integration of water demand reductions in present scenario. As it is already discussed in article 3.6.2, about 21% of total water demand is due to leakage in the existing water distribution system. To demonstrate the application of the DSS under reduction of losses conditions, it is assumed that by adopting 50% remedial measures for leakage control, 10% of water demand can be reduced i.e. water demand will be reduced from 220 lpcd to 200 lpcd. All the generated scenarios have been given in Table 7.8.

Hence, the 1st scenario contains only water demand reduction by 20 lpcd. It can be seen that only by solving the problem of leakage, water shortage will be reduced from 91 mld to 73 mld in 2021. Still the shortfall is significant and therefore integration of other water supply sources would be necessary to meet the shortfalls of water in future.

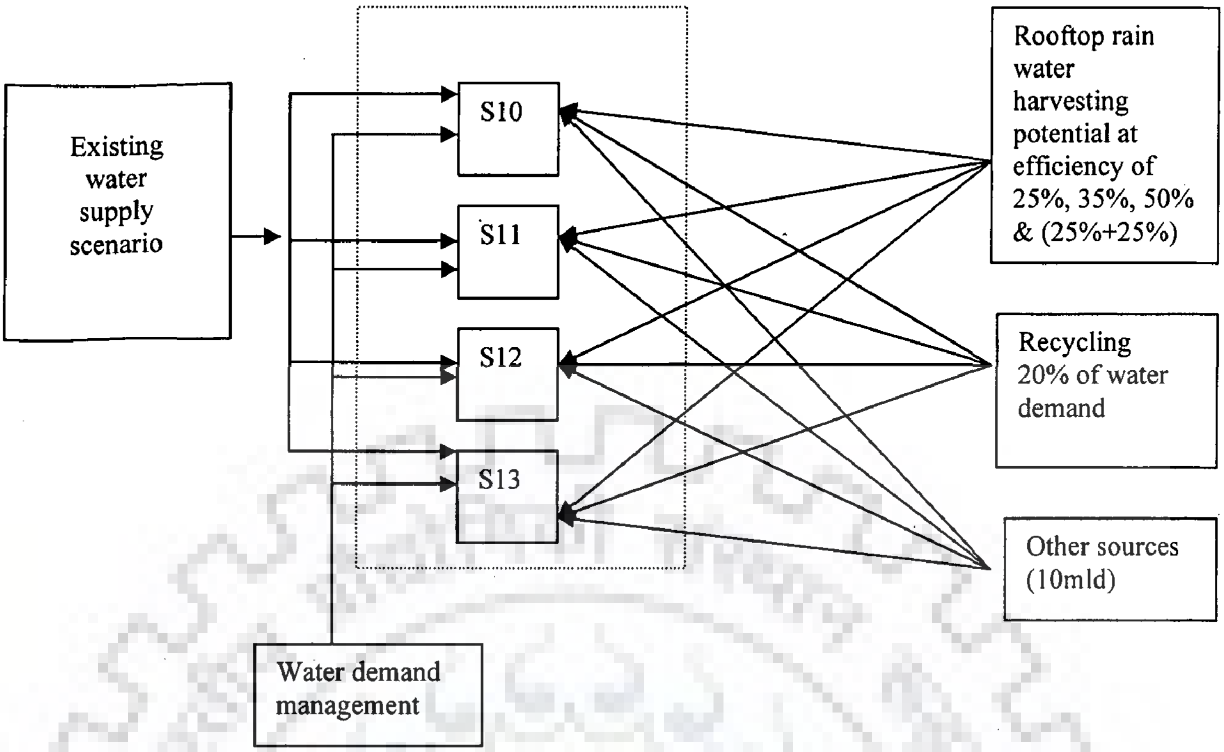


Fig. 7.8 Schematic of scenarios 10th, 11th, 12th and 13th (Case-III)

The scenarios from 2nd to 5th consider the integration of the rooftop rain water harvesting potential at different efficiencies, and water demand reduction by 20 lpcd. Next scenarios 6th to 9th are integration of rooftop rainwater harvesting at different efficiencies, water demand reduction by 20 lpcd, and recycled water for non potable water demand.

Scenarios 10th to 13th integrates rooftop rainwater harvesting at different efficiencies, water demand reduction by 20 lpcd and recycled water (20% of water demand) and 10 mld from other imported sources. Scenarios as already discussed in the previous sections are considered with water demand reduction measures through distribution losses reduction.

Analyses of the scenarios are presented in Table 7.9 and it can be seen that these scenarios are unable to fulfill the water demand in the year 2021. Screenshot of comparison of scenarios is shown in Fig. 7.9.

Table 7.8 Water supply scenarios, year 2021 (Case-III)

SN	Existing Sources (mld)		Rainwater potential (% of total RWH potential)		Recycling (% of Water demand	Other sources (mld)	Population growth rate	Water Demand (lpcd)
	Ground water	Surface water	Storage	Recharge				
1	83.9	22.63	0	0	0	0	Low	200
2	83.9	22.63	25	0	0	0	Low	200
3	83.9	22.63	35	0	0	0	Low	200
4	83.9	22.63	50	0	0	0	Low	200
5	83.9	22.63	25	25	0	0	Low	200
6	83.9	22.63	25	0	20	0	Low	200
7	83.9	22.63	35	0	20	0	Low	200
8	83.9	22.63	50	0	20	0	Low	200
9	83.9	22.63	25	25	20	0	Low	200
10	83.9	22.63	25	0	20	10	Low	200
11	83.9	22.63	35	0	20	10	Low	200
12	**83.9**	**22.63**	**50**	**0**	**20**	**10**	**Low**	**200**
13	83.9	22.63	25	25	20	10	Low	200
14	83.9	22.63	25	0	0	0	Medium	200
15	83.9	22.63	35	0	0	0	Medium	200
16	83.9	22.63	50	0	0	0	Medium	200
17	83.9	22.63	25	25	0	0	Medium	200
18	83.9	22.63	25	0	20	0	Medium	200
19	83.9	22.63	35	0	20	0	Medium	200
20	83.9	22.63	50	0	20	0	Medium	200
21	83.9	22.63	25	25	20	0	Medium	200
22	83.9	22.63	25	0	20	10	Medium	200
23	83.9	22.63	35	0	20	10	Medium	200
24	83.9	22.63	50	0	20	10	Medium	200
25	83.9	22.63	25	25	20	10	Medium	200
26	83.9	22.63	25	0	0	0	High	200
27	83.9	22.63	35	0	0	0	High	200
28	83.9	22.63	50	0	0	0	High	200
29	83.9	22.63	25	25	0	0	High	200
30	83.9	22.63	25	0	20	0	High	200
31	83.9	22.63	35	0	20	0	High	200
32	83.9	22.63	50	0	20	0	High	200
33	83.9	22.63	25	25	20	0	High	200
34	83.9	22.63	25	0	20	10	High	200
35	83.9	22.63	35	0	20	10	High	200
36	83.9	22.63	50	0	20	10	High	200
37	83.9	22.63	25	25	20	10	High	200

Table 7.9 Analysis of water supply scenario, year 2021(Case-III)

SN	Water shortage (mld)	Water demand (mld)	Groundwater recharge (mld)	Runoff (mld)	Population
1	73.3	179.8	30.4	200	899154
2	61.3	179.8	30.4	188	899154
3	56.5	179.8	30.4	183.2	899154
4	49.3	179.8	30.4	176	899154
5	61.3	179.8	42.4	176	899154
6	25.3	179.8	30.4	188	899154
7	20.5	179.8	30.4	183.2	899154
8	13.3	179.8	30.4	176	899154
9	25.3	179.8	42.4	176	899154
10	15.3	179.8	30.4	188	899154
11	10.5	179.8	30.4	183.2	899154
12	**3.3**	**179.8**	**30.4**	**176**	**899154**
13	15.3	179.8	42.4	176	899154
14	74	192.5	30.4	188	962690
15	69.2	192.5	30.4	183.2	962690
16	62	192.5	30.4	176	962690
17	74	192.5	42.4	176	962690
18	35.5	192.5	30.4	188	962690
19	30.7	192.5	30.4	183.2	962690
20	23.5	192.5	30.4	176	962690
21	35.5	192.5	42.4	176	962690
22	25.5	192.5	30.4	188	962690
23	20.7	192.5	30.4	183.2	962690
24	13.5	192.5	30.4	176	962690
25	25.5	192.5	42.4	176	962690
26	90.5	209.1	30.4	188	1045312
27	85.7	209.1	30.4	183.2	1045312
28	78.5	209.1	30.4	176	1045312
29	90.5	209.1	42.4	176	1045312
30	48.7	209.1	30.4	188	1045312
31	43.9	209.1	30.4	183.2	1045312
32	36.7	209.1	30.4	176	1045312
33	48.7	209.1	42.4	176	1045312
34	38.7	209.1	30.4	188	1045312
35	33.9	209.1	30.4	183.2	1045312
36	26.7	209.1	30.4	176	1045312
37	38.7	209.1	42.4	176	1045312

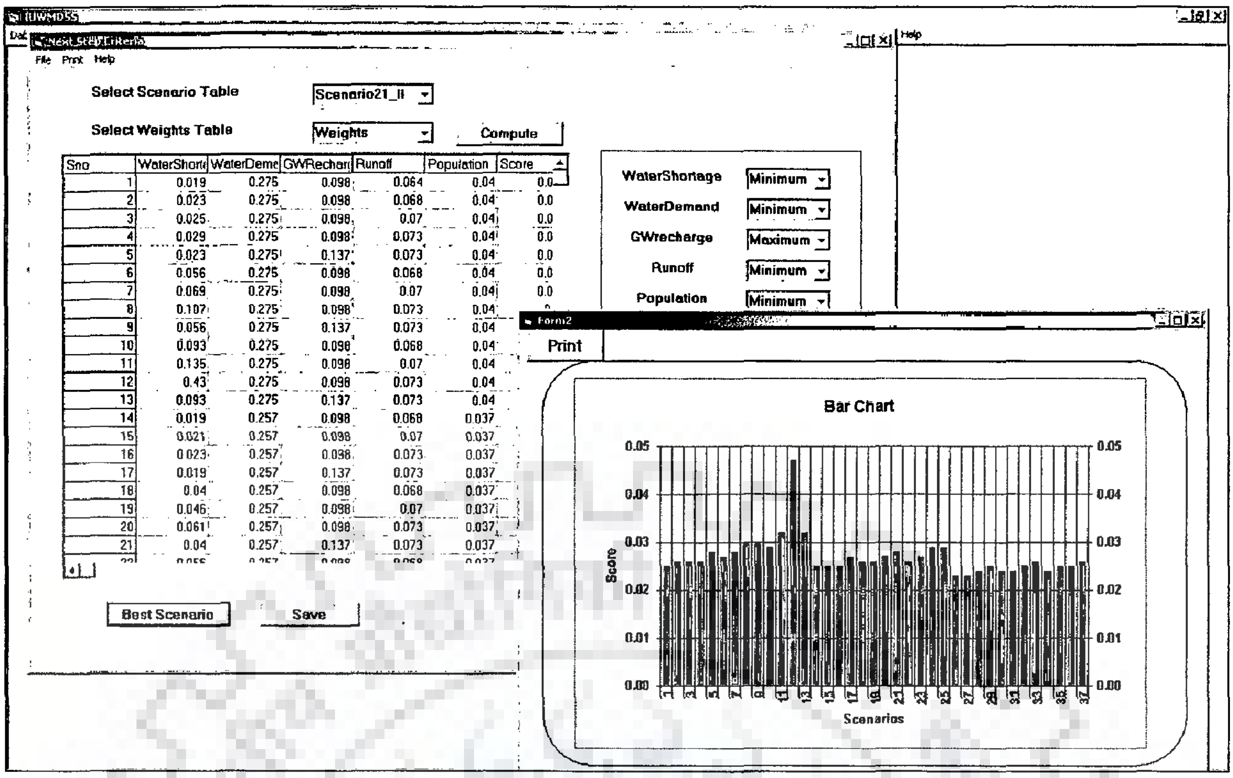


Fig. 7.9 Screenshot of scenarios comparison, Case-III (year 2021)

Scenario 12th is the highest ranked scenario and there is still a shortage of 3.3 mld. Although this is very less amount that can be fulfilled by taking public awareness about not misusing fresh water, water saving etc. Runoff would be from 200 mld to 176 mld , but the scenario is unsustainable with the aspects of groundwater as groundwater recharge is only 30.4 mld which is very less than the withdrawal of 83.9 mld. To achieve the aim of sustainability, few other strategy options are considered and discussed in subsequent section.

7.3.2.4 Integration of rooftop RWH, recycling, other sources (10 mld), and runoff harvesting

Urban development increases impervious surfaces which lead to high rate of runoff. Water-Sensitive Urban Planning utilizes runoff as a potential resource of water supply (Carmon et al., 1997). Another case study conducted by Apostolidis (2004) on the Gold Coast, Australia, shows that integration of water supply, wastewater management and stormwater planning reduces over 80% of potable water demand. Therefore runoff harvesting can provide a valuable source of water while reducing the volume of runoff and better utilization of available water resources. Rainfall should be captured close to where it falls, before its quality becomes impaired.

Keeping these aspects in view, scenarios have been developed by integration of runoff harvesting to the existing water supply scenario, rooftop rainwater harvesting, recycling and others. Figure 7.10 shows the schematic of scenarios integrating runoff harvesting (25% of net runoff), rooftop rainwater harvesting at different efficiencies, recycling, import 10 mld from other sources and water demand reduction. Here, S11 to S14 represents the scenarios 11th to 14th. Schematic of scenarios 1st to 10th are same as Fig. 7.6 except integration of runoff harvesting. List of all the generated scenarios has been given in Table 7. 10.

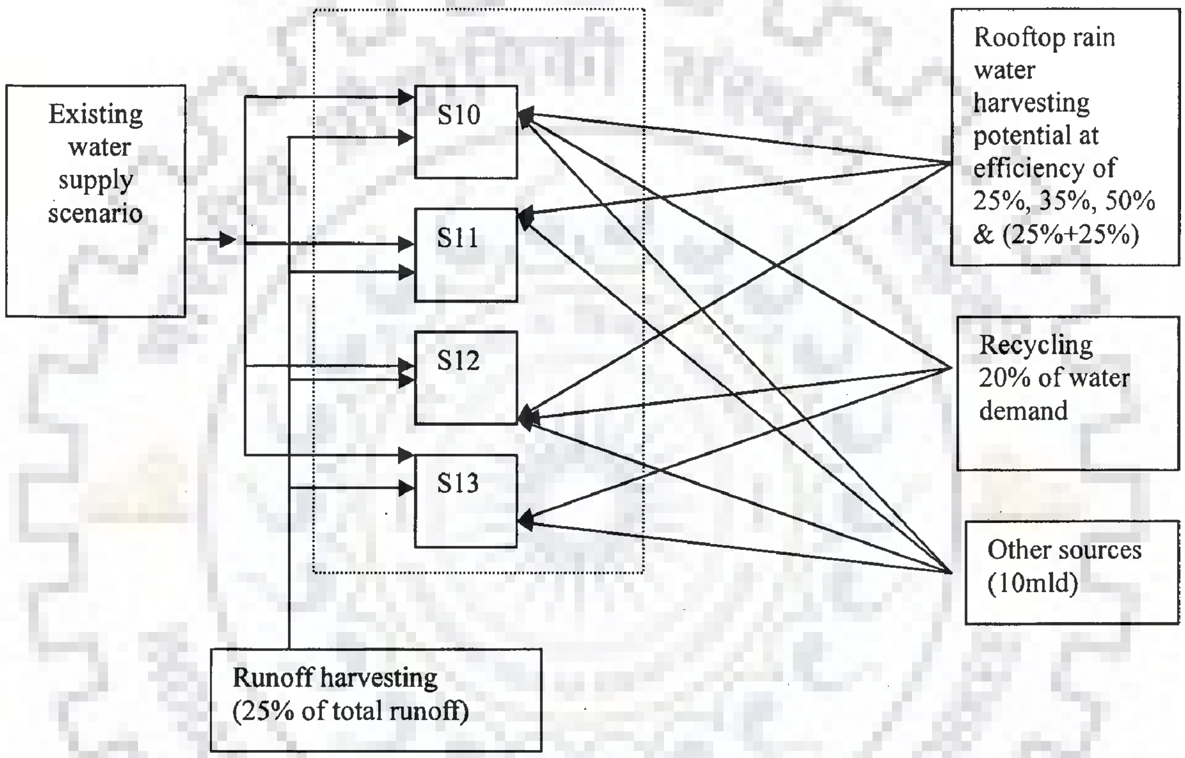


Fig. 7.10 Schematic of scenarios 10th to 13th for Case- IV

The scenarios were analyzed considering some factors and presented in Table 7.11. The scenarios were compared to get the best ranked scenario and the scenario 12th was the highest ranked scenario. The scenarios 11th and 13th were next ranked scenarios. The scenario 12th includes high amount of surplus water to be supplied so this 22 mld water can be used to recharge the ground water or groundwater supply can be reduced from 83.9 mld to 61.9 mld. Screenshot of comparison of the scenarios by AHP module is shown in Fig. 7.11.

Table 7.10 Water supply scenario, year 2021 (Case- IV)

SN	Existing Sources (mld)		Rainwater potential (% of total RWH potential)		Recycling (%of Water demand)	Runoff harvesting (% of net runoff)	Other sources (mld)	Population growth rate
	Ground water	Surface water	Storage	Recharge				
1	83.9	22.63	0	0	0	25	0	Low
2	83.9	22.63	25	0	0	25	0	Low
3	83.9	22.63	35	0	0	25	0	Low
4	83.9	22.63	50	0	0	25	0	Low
5	83.9	22.63	25	25	0	25	0	Low
6	83.9	22.63	25	0	20	25	0	Low
7	83.9	22.63	35	0	20	25	0	Low
8	83.9	22.63	50	0	20	25	0	Low
9	83.9	22.63	25	25	20	25	0	Low
10	83.9	22.63	25	0	20	25	10	Low
11	83.9	22.63	35	0	20	25	10	Low
12	**83.9**	**22.63**	**50**	**0**	**20**	**25**	**10**	**Low**
13	83.9	22.63	25	25	20	25	10	Low
14	83.9	22.63	25	0	0	25	0	Medium
15	83.9	22.63	35	0	0	25	0	Medium
16	83.9	22.63	50	0	0	25	0	Medium
17	83.9	22.63	25	25	0	25	0	Medium
18	83.9	22.63	25	0	20	25	0	Medium
19	83.9	22.63	35	0	20	25	0	Medium
20	83.9	22.63	50	0	20	25	0	Medium
21	83.9	22.63	25	25	20	25	0	Medium
22	83.9	22.63	25	0	20	25	10	Medium
23	83.9	22.63	35	0	20	25	10	Medium
24	83.9	22.63	50	0	20	25	10	Medium
25	83.9	22.63	25	25	20	25	10	Medium
26	83.9	22.63	25	0	0	25	0	High
27	83.9	22.63	35	0	0	25	0	High
28	83.9	22.63	50	0	0	25	0	High
29	83.9	22.63	25	25	0	25	0	High
30	83.9	22.63	25	0	20	25	0	High
31	83.9	22.63	35	0	20	25	0	High
32	83.9	22.63	50	0	20	25	0	High
33	83.9	22.63	25	25	20	25	0	High
34	83.9	22.63	25	0	20	25	10	High
35	83.9	22.63	35	0	20	25	10	High
36	83.9	22.63	50	0	20	25	10	High
37	83.9	22.63	25	25	20	25	10	High

Table 7.11 Analysis of water supply scenarios, year 2021 (Case-IV)

SN	Water Shortage (mld)	Water demand (mld)	Groundwater Recharge (mld)	Runoff (mld)	Population
1	41.3	197.8	30.4	150.0	899154
2	32.3	197.8	30.4	141.0	899154
3	28.7	197.8	30.4	137.4	899154
4	23.3	197.8	30.4	132.0	899154
5	35.3	197.8	42.4	132.0	899154
6	-3.7	197.8	30.4	141.0	899154
7	-7.3	197.8	30.4	137.4	899154
8	-12.7	197.8	30.4	132.0	899154
9	-0.7	197.8	42.4	132.0	899154
10	-13.7	197.8	30.4	141.0	899154
11	-17.3	197.8	30.4	137.4	899154
12	**-22.7**	**197.8**	**30.4**	**132.0**	**899154**
13	-10.7	197.8	42.4	132.0	899154
14	46.3	211.8	30.4	141.0	962690
15	42.7	211.8	30.4	137.4	962690
16	37.2	211.8	30.4	132.0	962690
17	49.3	211.8	42.4	132.0	962690
18	7.7	211.8	30.4	141.0	962690
19	4.1	211.8	30.4	137.4	962690
20	-1.3	211.8	30.4	132.0	962690
21	10.7	211.8	42.4	132.0	962690
22	-2.3	211.8	30.4	141.0	962690
23	-5.9	211.8	30.4	137.4	962690
24	-11.3	211.8	30.4	132.0	962690
25	0.7	211.8	42.4	132.0	962690
26	64.4	230.0	30.4	141.0	1045312
27	60.8	230.0	30.4	137.4	1045312
28	55.4	230.0	30.4	132.0	1045312
29	67.4	230.0	42.4	132.0	1045312
30	22.6	230.0	30.4	141.0	1045312
31	19.0	230.0	30.4	137.4	1045312
32	13.6	230.0	30.4	132.0	1045312
33	25.6	230.0	42.4	132.0	1045312
34	12.6	230.0	30.4	141.0	1045312
35	9.0	230.0	30.4	137.4	1045312
36	3.6	230.0	30.4	132.0	1045312
37	15.6	230.0	42.4	132.0	1045312

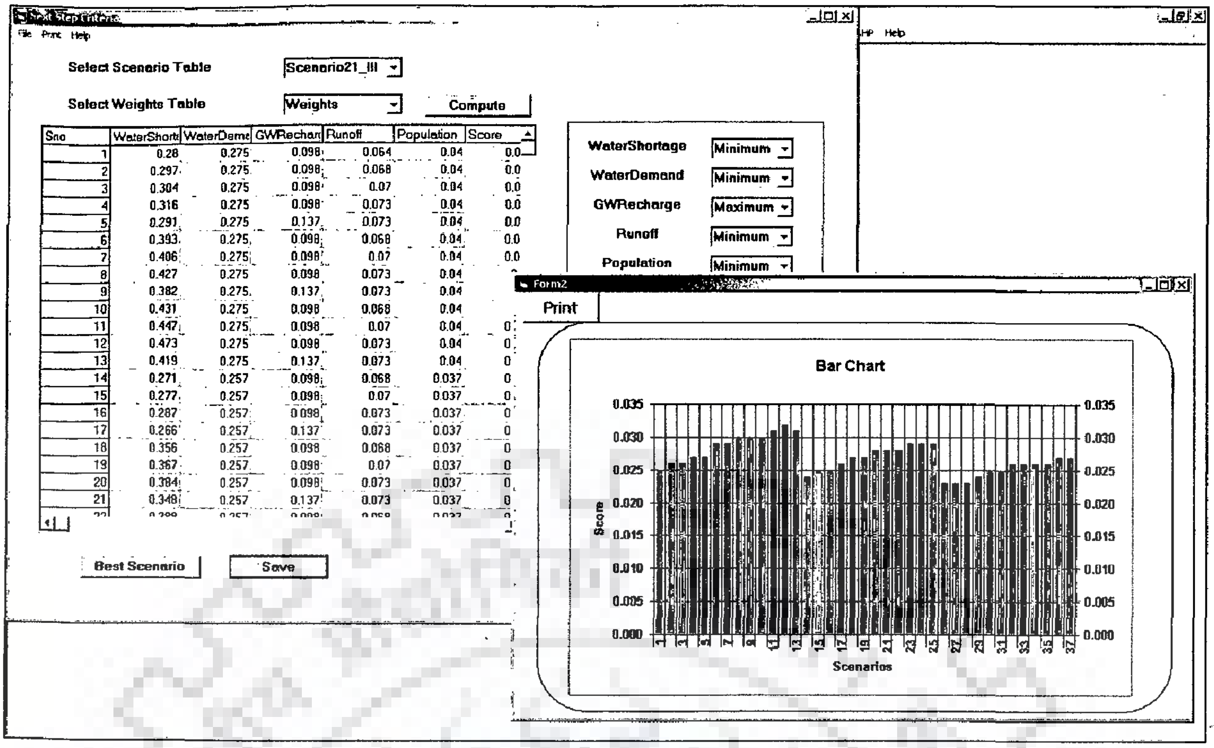


Fig. 7.11 Screenshot of scenarios comparison, Case IV(year 2021)

7.3.2.5 Integrating rooftop rainwater harvesting, recycling, other sources (10 mld), water demand reductions (10%), and runoff harvesting

The scenarios of Case IV (2021) were again analyzed in Case V with the integration of 10% water demand reduction, for the year 2031. The scenarios were generated considering rooftop RWH at different efficiency, recycling of 20% of total water demand, other sources (importing 10 mld from distant source), runoff harvesting as 25% of net runoff and 10% water demand reduction; at low, medium and high population growth for the year 2031. Schematics of the scenarios are shown in Fig. 7.12, where S10, S11, S12 and S13 represent the scenario 10th, 11th, 12th and 13th at low population growth rate. The details of various scenarios are given in Table 7.12.

The 1st scenario integrated 25% runoff harvesting and 10% water demand reduction at low population growth. The scenarios 2nd to 13th are considered for low population growth rate, 13th to 25th are the same scenario, considered at medium population growth rate and 26th to 37th are considered at higher population growth rate.

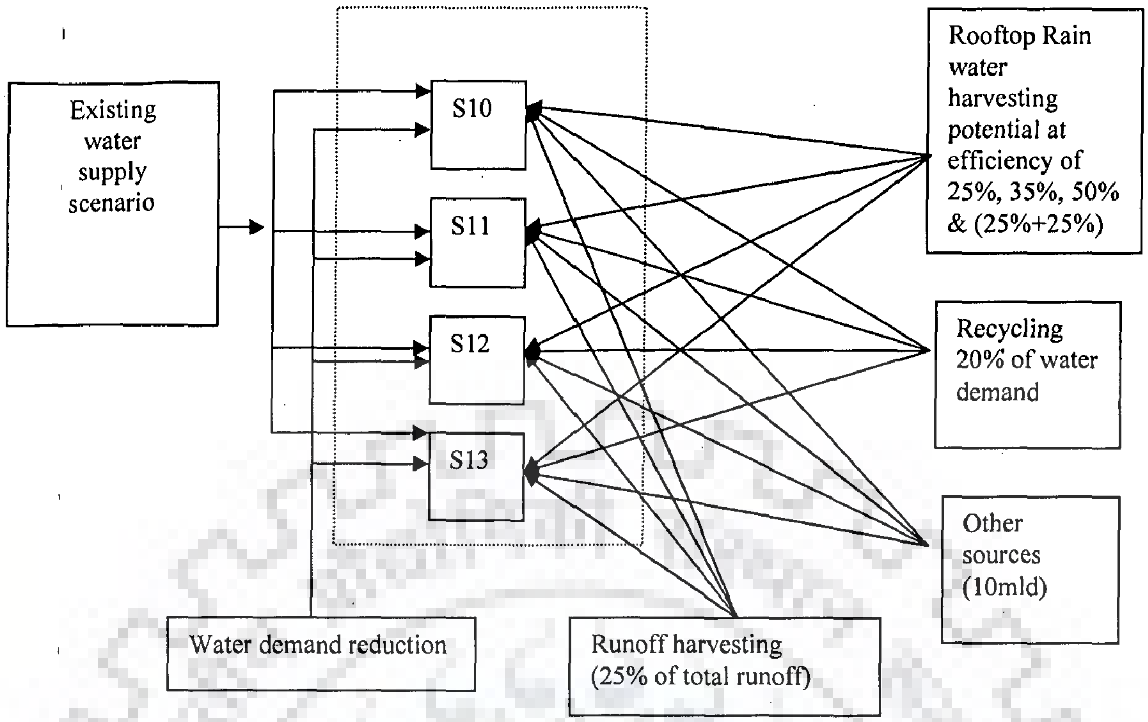


Fig. 7.12 Schematics of the scenarios10th, 11th, 12th and 13th for Case-V, year 2031.

It can be seen that these scenarios were not fulfilling the criteria of sustainability for the year of 2031. To meet the criteria of sustainability, some other measures are required as by increasing the percentage of runoff harvesting, recycling and water demand measures. Next scenarios have been generated for achieving the goal of sustainability integrating some demand measures and by increasing the percentage of recycling of water.

In this case the results of the analysis considering the parameters for the year of 2031 presented in Table 7.13. The scenarios were compared in AHP module and the screenshot of scenarios comparison is shown in Fig. 7.13. Again scenario 12th is the highest ranked scenario, meets the first criteria of reducing water shortage. Besides, surplus water of 7 mld can be used to recharge ground water; runoff reduction is from 150 mld to 137 mld; but still this scenario is also not sustainable with the aspects of ground water recharge.

Table 7.12 Water supply scenarios, year 2031 (Case-V)

SN	Existing Sources (mld)		Rainwater potential (% of total RWH potential)		Recycling (%of water demand)	Runoff Harvesting (mld)	Other sources (mld)	Population growth rate	Water Demand (lpcd)
	Ground water	Surface water	Storage	Recharge					
1	83.9	22.63	0	0	0	25	0	Low	200
2	83.9	22.63	25	0	0	25	0	Low	200
3	83.9	22.63	35	0	0	25	0	Low	200
4	83.9	22.63	50	0	0	25	0	Low	200
5	83.9	22.63	25	25	0	25	0	Low	200
6	83.9	22.63	25	0	20	25	0	Low	200
7	83.9	22.63	35	0	20	25	0	Low	200
8	83.9	22.63	50	0	20	25	0	Low	200
9	83.9	22.63	25	25	20	25	0	Low	200
10	83.9	22.63	25	0	20	25	10	Low	200
11	83.9	22.63	35	0	20	25	10	Low	200
12	83.9	22.63	50	0	20	25	10	Low	200
13	83.9	22.63	25	25	20	25	10	Low	200
14	83.9	22.63	25	0	0	25	0	Medium	200
15	83.9	22.63	35	0	0	25	0	Medium	200
16	83.9	22.63	50	0	0	25	0	Medium	200
17	83.9	22.63	25	25	0	25	0	Medium	200
18	83.9	22.63	25	0	20	25	0	Medium	200
19	83.9	22.63	35	0	20	25	0	Medium	200
20	83.9	22.63	50	0	20	25	0	Medium	200
21	83.9	22.63	25	25	20	25	0	Medium	200
22	83.9	22.63	25	0	20	25	10	Medium	200
23	83.9	22.63	35	0	20	25	10	Medium	200
24	83.9	22.63	50	0	20	25	10	Medium	200
25	83.9	22.63	25	25	20	25	10	Medium	200
26	83.9	22.63	25	0	0	25	0	High	200
27	83.9	22.63	35	0	0	25	0	High	200
28	83.9	22.63	50	0	0	25	0	High	200
29	83.9	22.63	25	25	0	25	0	High	200
30	83.9	22.63	25	0	20	25	0	High	200
31	83.9	22.63	35	0	20	25	0	High	200
32	83.9	22.63	50	0	20	25	0	High	200
33	83.9	22.63	25	25	20	25	0	High	200
34	83.9	22.63	25	0	20	25	10	High	200
35	83.9	22.63	35	0	20	25	10	High	200
36	83.9	22.63	50	0	20	25	10	High	200
37	83.9	22.63	25	25	20	25	10	High	200

Table 7.13 Analysis of water supply scenarios, year 2031 (Case-V)

SN	Water shortage (mld)	Water demand (mld)	Ground water recharge (mld)	Runoff (mld)	Population
1	66.1	227.8	25.33	165.8	1139229
2	57.1	227.8	25.3	156.7	1139229
3	53.5	227.8	25.3	153.1	1139229
4	48.1	227.8	25.3	147.7	1139229
5	60.1	227.8	37.31	147.7	1139229
6	11.5	227.8	25.3	156.7	1139229
7	7.9	227.8	25.3	153.1	1139229
8	2.5	227.8	25.3	147.7	1139229
9	14.5	227.8	37.32	147.7	1139229
10	-1.5	227.8	25.3	156.7	1139229
11	-2.1	227.8	25.3	153.1	1139229
12	-7.5	227.8	25.3	147.7	1139229
13	4.5	227.8	37.32	147.7	1139229
14	31.2	252.4	25.3	156.7	1262087
15	27.6	252.4	25.3	153.1	1262087
16	22.1	252.4	25.3	147.7	1262087
17	34.2	252.4	37.31	147.7	1262087
18	31.2	252.4	25.3	156.7	1262087
19	27.6	252.4	25.3	153.1	1262087
20	22.1	252.4	25.3	147.7	1262087
21	34.1	252.4	37.32	147.7	1262087
22	21.2	252.4	25.3	156.7	1262087
23	17.6	252.4	25.3	153.1	1262087
24	12.1	252.4	25.3	147.7	1262087
25	24.1	252.4	37.32	147.7	1262087
26	57.7	285.6	25.3	156.7	1428000
27	54.1	285.6	25.3	153.1	1428000
28	48.7	285.6	25.3	147.7	1428000
29	60.7	285.6	37.31	147.7	1428000
30	57.7	285.6	25.3	156.7	1428000
31	54.1	285.6	25.3	153.1	1428000
32	48.7	285.6	25.3	147.7	1428000
33	60.7	285.6	37.32	147.7	1428000
34	47.7	285.6	25.3	156.7	1428000
35	44.1	285.6	25.3	153.1	1428000
36	38.7	285.6	25.3	147.7	1428000
37	50.7	285.6	37.31	147.7	1428000

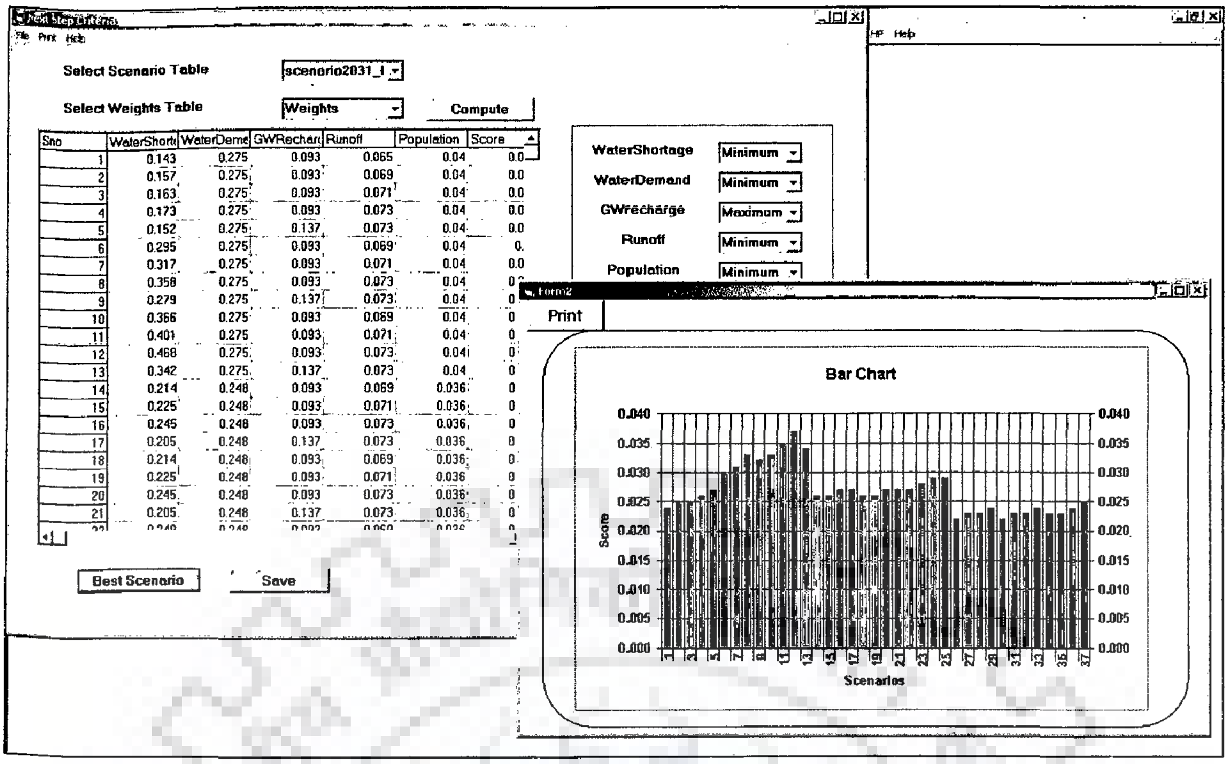


Fig. 7.13 Screenshot of scenarios comparison, year 2031 (Case-V)

7.3.2.6 Integration of rooftop rainwater harvesting, recycling and water demand measures

The Case-VI (for year 2031) contains the scenarios integrating the rooftop RWH for recharging groundwater, different quantum of recycling and water demand measures with the existing water supply scenario. Figure 7.14 shows the schematic of the generated scenario for Case-VI. Here, S1, S2, S3 represents 1st, 2nd, and 3rd scenarios at low population growth rate. The same scenario is considered for medium and high population growth rate. Therefore total numbers of scenarios are nine, considered for this case. The Case has been considered to display the potential of water demand reduction and recycling as the main sources of water to achieve the aim of sustainability.

In urban area, high use of water produces 80% of the supplied water as waste water. Recycling of this water requires treatment facility. To generate the scenarios, recycling has been considered as 40%, 60% and 80% percentage of water supply. Here, 80% recycling of water supply means 100% recycling of wastewater as in India, wastewater is assumed to be 80% of water supply. Water demand management techniques implemented in different countries have been found effective in reducing the water demand such as: metering reduces 20% of the demand (Maddause, 2001); Public awareness reduces the demand by 8% (Renwick and Green, 2000); leakage control reduces the demand as 20%; and improving pricing 10 % can reduce the demand by 3.4%

(Agthe et al., 2003). Therefore net water demand can be reduced to approximately 50%. This seems to be very effective for sustainable water management.

The scenario 1st is integration of 50 % of rooftop rainwater harvesting for groundwater recharge, recycled water (40% of water supply) and 50% water demand reduction through water demand measures. Similarly scenario 2nd contains the same water supply scenario except recycling of water 60% of net water supply whereas scenario 3rd contains 80% recycling. The scenarios 1st, 2nd, 3rd have been analyzed for low population growth rate. In addition to that other scenarios for medium and high population growth are considered. The scenarios 4th, 5th, 6th are similar to 1st, 2nd and 3rd scenarios except analyzed for medium population growth and Scenarios 7th, 8th, 9th are also similar except analyzed for high population growth rate for the year 2031. The analysis of all the scenarios is presented in Table 7.14 and comparison of scenarios is shown in Fig. 7.15.

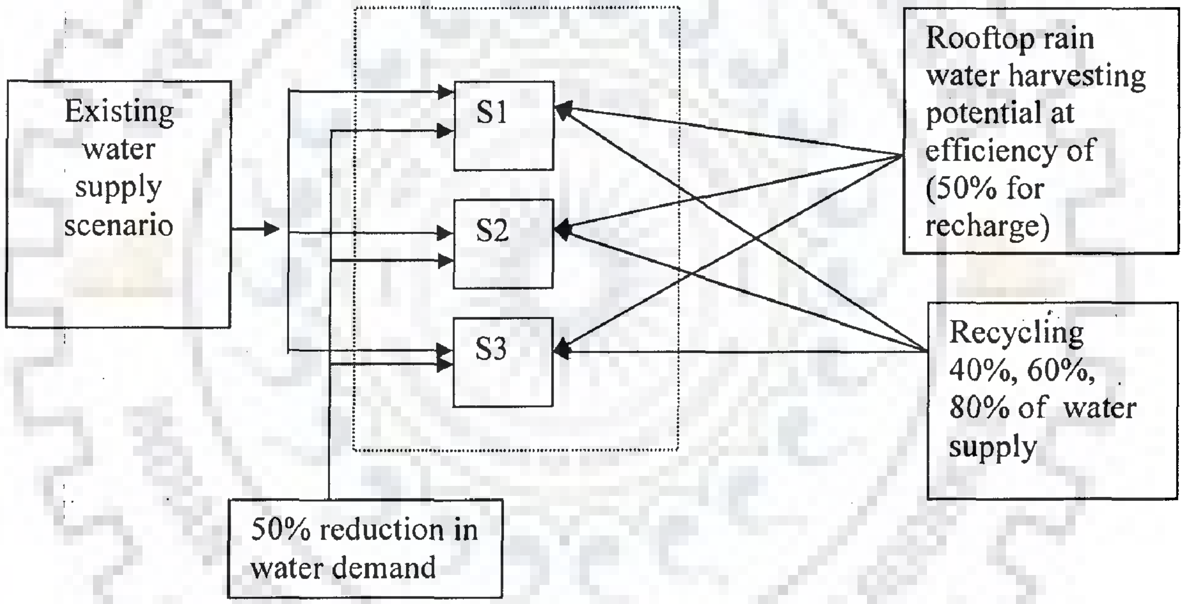


Fig.7.14 Schematic of scenario 1st, 2nd, and 3rd for Case-VI, year 2031

It can be seen that scenario 3rd is the highest ranked scenario, meets the criteria of reducing water shortage, water demand reduction, and groundwater recharge and runoff reduction. The surplus water may be used to recharge ground water or groundwater withdrawal can be reduced up to the amount of surplus water. Therefore, this scenario shows the balance between ground water withdrawal and recharge. Groundwater withdrawal is about 84 mld and recharge is about 50 mld. The surplus amount water i.e. 66 mld can be used to recharge ground water or the ground water withdrawal can be reduced up to 66 mld. The scenarios 2nd and 6th are at second and third ranked scenario, also sustainable with the aspects of groundwater resources.

It can be said that by reducing water demand up to 50%, and 60% recycling option aim of sustainability can be achieved with high population growth rate in the year of 2031 whereas for medium and low population growth rate, 40% recycling with 50% demand reduction is sufficient.

Table 7.14 Analysis of water supply scenarios, year 2031 (Case-VI)

SN	Water shortage (mld)	Water supply (mld)	Water demand (mld)	Groundwater recharge (mld)	Runoff (mld)	Population
1	-24	149	125	49.33	197	1139229
2	-45	170	125	49.33	197	1139229
3	-66	192	125	49.33	197	1139229
4	-10	149	139	49.33	197	1262087
5	-32	170	139	49.33	197	1262087
6	-53	192	139	49.33	197	1262087
7	8	149	157	49.33	197	1428000
8	-13	170	157	49.33	197	1428000
9	-35	192	157	49.33	197	1428000

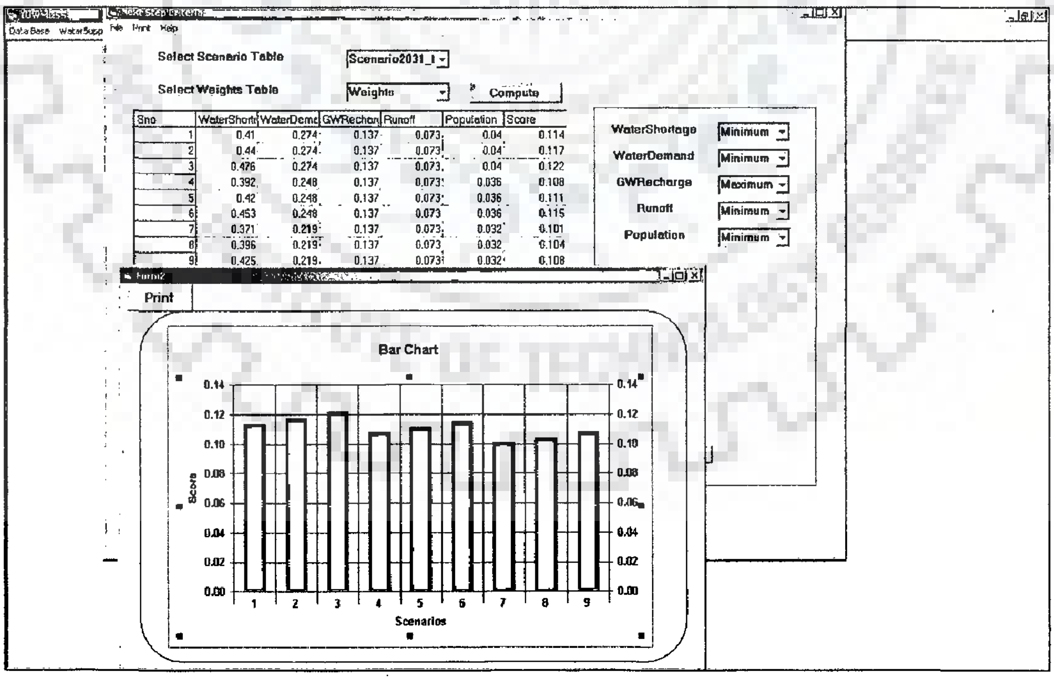


Fig. 7.15 Screenshot of scenarios comparison, year 2031 (Case-VI)

7.4 Summary of Decision Scenarios

The capabilities of DSS-IUWM have been demonstrated for the existing and various scenarios, considering different water supply options. Best scenarios of different cases, their options, analysis and results have been presented in this Chapter. The scenarios have been developed for different water supply options for the year 2011, 2021 and 2031. These scenarios have been developed by integrating all the water supply sources and water demand measures to achieve the aim of sustainability. The criteria factors for analyzing the scenarios are reducing water shortage, water demand reduction, ground water recharge, runoff reduction at low, medium and high population growth rate of the study area.

The water supply scenarios have been generated integrating existing water supply sources (83.9 mld groundwater and 22.6 mld surface water) with the additional supply sources such as rooftop rainwater harvesting, runoff harvesting and recycling. The scenarios have been generated by integrating many combinations of different efficiencies of potential of water supply sources to quantify the water supply, reduction in leakage, groundwater recharge, and runoff reduction. Water demand management includes different measures and policies to reduce the water demand such as increasing price, metering and creating public awareness for saving the water. Water demand management techniques implemented in different countries have been found effective in reducing the water demand.

For the year of 2011, scenarios have been generated considering rooftop rainwater harvesting as a source for water supply and groundwater recharge and assuming that 20% of water demand can be fulfilled by recycled water. Non potable water requirement for residential area are 40 lpcd (20% of 220 lpcd), that can be fulfilled by recycled/reuse of water. It has been found that the use of about 50% of total rainwater harvesting potential for storage and satisfying 20% of the water demand by recycled water can be a solution to meet the shortfall of water. Although the scenario is not sustainable with the aspects of groundwater recharge.

For the year of 2021, three cases of different scenarios were considered. First case consists of scenarios considering water supply through integration of rooftop rainwater and 20% recycled water and importing 10 mld from other sources. These scenarios were not meeting shortfalls. Therefore, in Case-III, water demand reduction by leakage control and integration of imported source were also considered and it was found that 50% of rooftop rainwater harvesting, 20% recycling and 10 mld from other sources would be very close to overcoming water shortage. But the aim of sustainability was not being achieved. Further, Case III was considered integrating runoff harvesting (25% of total runoff) as a source of potential water supply to the existing scenario, different efficiencies of rooftop rainwater harvesting, 20% recycling, and 10 mld from other sources. The scenario considering 50% rooftop rainwater harvesting with other water supply, fulfills the criteria of water shortage and the criteria of sustainability to some extent.

The scenarios of Case-IV (year 2021) were considered as Case-V except that Case-IV integrates water demand reduction by 10% in addition to runoff harvesting, for the year 2031, and it was found that the scenario (12^{th}) was able to fulfill the criteria of water shortage only. Therefore after investigating many feasible combinations of water supply sources, the attention was given to water demand reduction measures. Based on review of case studies on water demand management that some demand reduction is feasible by metering, increasing the water price, leakage control, and public awareness. In some (rare) cases, water demand can be reduced by up to 50%. Case-VI for 2031 includes the water demand reduction with recycling at 40%, 60% and 80% and 50% rooftop rainwater harvesting fro recharge. The scenarios considering 60% recycling and rooftop rainwater harvesting meets the criteria of sustainability at low and medium population growth rate, whereas for higher population growth rate 80% recycling was required. It may be noted that recycling 80% of water supply means recycling 100% of waste water generated from the water supply which is quite difficult to achieve. Comparisons of the high ranked scenarios for all the cases for low, medium and high population growth are presented in Table 7.15. It can be concluded that at low population growth rate Case-VI, scenario 2^{nd} is sustainable water supply scenario, which contains 50% reduction in demands, 50% rooftop rainwater harvesting and recycling 60% of water supply.

At medium growth rate, 60% and 80% of recycling is needed to achieve the aim of sustainability. Whereas at higher growth rate sustainability is possible at 50% rooftop RWH for recharge, 50% demand reduction recycling 80% of water supply.

It can be said that the aim of sustainability can be achieved by integrating water demand measures, recycling 100% of waste water and rooftop rainwater harvesting. Further runoff harvesting is also a good option for water supply and to reduce the runoff.

Table 7.15 Summary of best scenarios at different population growth rate

Population growth rate	Case	Year	Scenarios	Water shortage	Water demand reduction	Ground water Recharge (%of total withdrawal)	Runoff reduction (%of total runoff)
Low	I	2011	8th	NIL	nil	40%	13%
	II	2021	12th	10%	nil	40%	13%
	III	2021	12th	1%	nil	40%	13%
	IV	2021	12th	NIL	nil	60%	12%
	V	2031	12th	NIL	20%	40%	33%
	VI	2031	2nd	NIL	50%	100%	10%
Medium	I	2011	17th	1%	nil	40%	13%
	II	2021	24th	15%	nil	40%	13%
	III	2021	24th	7%	nil	40%	13%
	IV	2021	24th	nil	nil	48%	12%
	V	2031	24th	4%	nil	40%	33%
	VI	2031	5th, 6th	NIL	50%	100%	10%
High	I	2011	26th	5%	nil	40%	13%
	II	2021	36th	15%	nil	40%	13%
	III	2021	36th	13%	nil	40%	13%
	IV	2021	36th	1.5%	nil	40%	12%
	V	2031	36th	13%	nil	40%	33%
	VI	2031	9th	NIL	50%	99%	10%

7.5 Concluding Remarks

The DSS-IUWM has been demonstrated for its utility by scenario based approach. The scenarios have been generated by the computed parameters in Chapter 6. Different water supply scenarios have been considered integrating existing water supply sources to all the additional water supply sources. Further, integration of water demand management strategies with the water supply strategies have been done to achieve the aim of sustainability. It can be seen that users have the flexibility of calculating the normalized weights by assuming different weights according to the study area and requirement.

It has been found that integration of rooftop rainwater harvesting for recharge, water demand reductions through public awareness, existing water supply sources (year 2001), leakage control and increasing pricing; and recycled water of 60% water supply can achieve the aim of sustainability in the year of 2031. Further, runoff harvesting can be used as a potential source of water supply.

Chapter 8
CONCLUSIONS AND RECOMMENDATIONS

8.1 Prelude

Water supply systems in many urban areas are in poor conditions particularly in developing countries. Rapid and unplanned growth of urbanization has created tremendous pressure on existing water supply sources which may lead to acute water shortage in future. This brings the concept of sustainable development as a principal goal of water management, which can be achieved by the approach of IWRM. In accordance with the research objective, thorough review has been done to identify the problems of urban water management. Traditional urban water management strategies in a fragmented planning and decision-making manner are unable to fulfill the needs of rapidly growing urban area. This leads to the concept of IWRM for urban water management. The implementation of IWRM is a complex task and requires various computing tools and technology. Review of literature shows that DSS is one of the best tools for IWRM. Keeping this in view, a study was undertaken for the development and demonstration of a DSS for integrated water management in an urban area and the application has been demonstrated on Dehradun city.

The essential characteristics of a DSS, as appropriate for IWRM for urban area, were first identified to decide the framework of the DSS, which contains database management subsystem, analytical modules and a user friendly GUI. The database management subsystem is the core component of the DSS, as it contains all input database and provides sufficient information from the available data to the user.

A comprehensive search on methods of various components of water management has been done keeping in view their data needs and type of output generated. Before implementing any water resources strategy, the basic information is required about available water resources, available water supply and deficiency of water. To determine the water supply and water demand, appropriate methods have been applied. Further, population forecasting module has been developed to forecast water demand and this module is provided with options for three methods i.e. Arithmetic Increase Method (AIM), Geometric Increase Method (GIM) and Incremental Increase Method (IIM). Urban water management requires assessment of runoff, groundwater recharge and potential of rooftop Rainwater Harvesting (RWH), so the modules for each aspect have been developed considering the appropriate methods. The methods were selected as per the input data limitations, capability of the software for programming the mathematical algorithm and to generate the output.

Keeping these aspects in view, the user has been provided flexibilities in all the modules to enter some desirable data, that can be knowledge based and from experiences about the study area. Since most of the catchments are ungauged for runoff, therefore weighted SCS–CN method has been selected for the runoff assessment. For groundwater recharge assessment, rainfall infiltration method of GEC norms of 1997 has been implemented in the DSS. Rooftop RWH module provides the flexibility of considering extent of roof area at the city for RWH. Rooftop RWH potential can be estimated for different efficiency starting from zero when there is no rooftop for RWH to 100% when the entire city is considered. Finally, all the results can be seen in an integrated scenario form, where user can save the scenario in a table. Further, scenarios can be compared with AHP module, where weights for different parameters can be calculated by pair-wise comparison method.

8.2 Conclusions

A DSS software has been developed in Visual Basic language (Over 5,000 lines) consisting of 10 modules and many sub-modules having 35 GUIs. To incorporate the spatial component in the DSS, ActiveX control MapObjects was used in programming. A separate module or an interface was developed for each of the identified components of DSS. These interfaces or modules were integrated to the common GUI. The developed software platform is a prototype of the **D**ecision **S**upport **S**ystem for **I**ntegrated **U**rban **W**ater **M**anagement which has been abbreviated and called as **DSS-IUWM**. The capabilities of the developed DSS-IUWM have been successfully demonstrated for the integrated water management of the Dehradun municipal area. The salient features of the study and conclusions drawn are given below:

1. The study fulfills the main objective the development of DSS for integrated urban water management. The developed DSS in the study is user friendly and capable of handling both the spatial and non-spatial data. An overview of the developed DSS-IUWM in the pictorial form has been shown in Fig. 8.1.

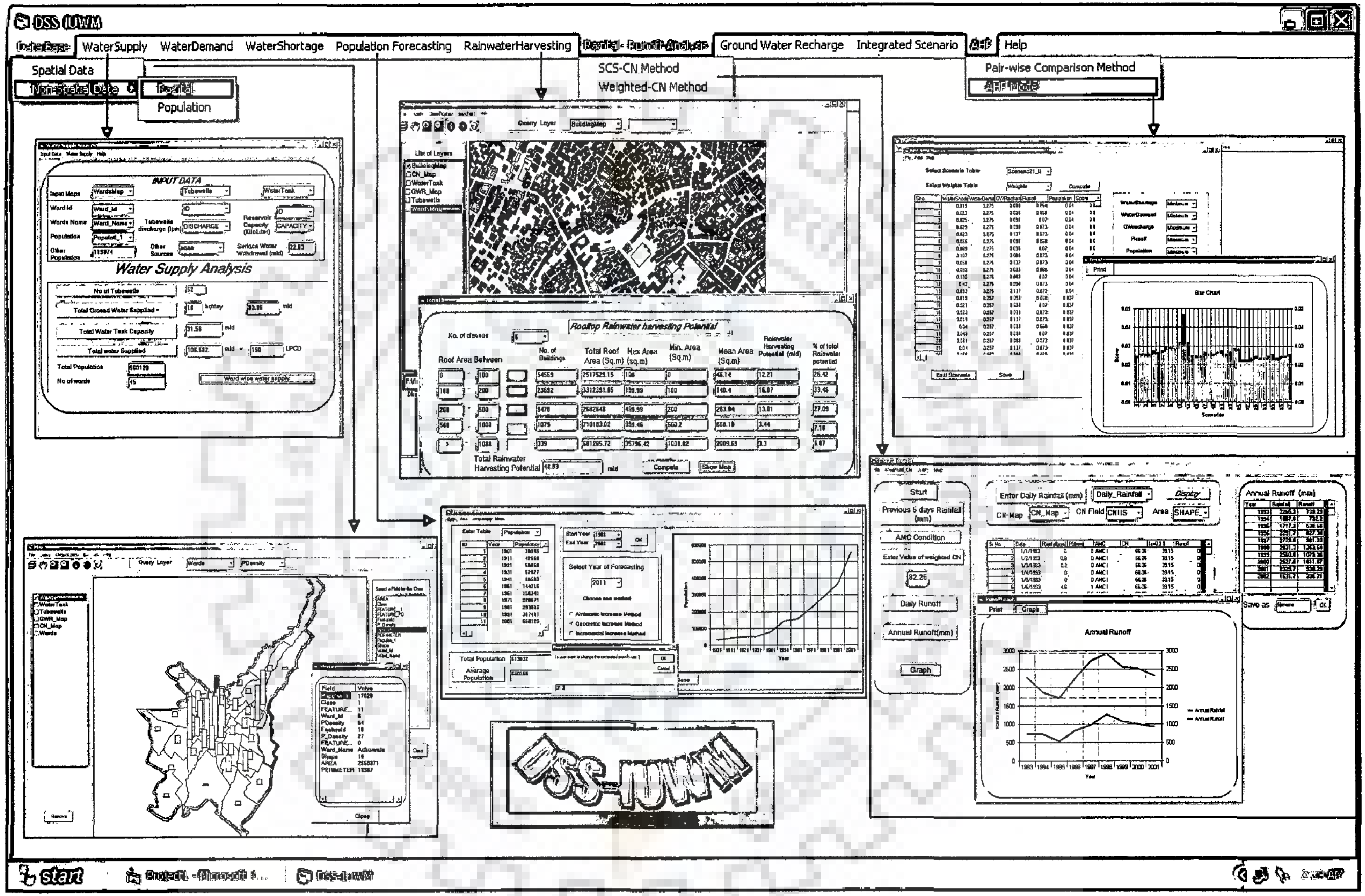


Fig. 8.1 An overview of the developed DSS-IUWM

2. An interactive GUI for spatial data has been developed where user can open all the input shape files and can retrieve the required information. The GUI provides basic tools viz. classification of a map using different options, search a feature, annotation, spatial bar-chart, identifying features and many basic features require to manage shapefiles.
3. Three modules for water supply, water demand and water shortage have been developed and successfully demonstrated using input data for the study area. The modules provide the overall information about the status of water supply sources as well as ward-wise water demand, supply, shortage.

   Through water shortage module, total water shortage of the area has been found as 16 mld in the year of 2001. It can be seen that Maharani bag, Kanwali, Niranjanpur, Majra, Ajabpur, Rajiv Nagar, Racecourse (S), Adhoiwala, Arya nagar and Rajpur are the areas having high shortage of water, that require immediate solution to fulfill the demands. The ground water can be used to fulfill the water demand of southern areas, such as Maharani bag, Kanwali, Niranjanpur, Majra, Ajabpur, Rajiv Nagar, Racecourse (S), and Adhoiwala as these areas have good ground water potential (CGWB, 2003) and rooftop rainwater harvesting can be used to recharge the groundwater. In the northern part of the city viz. Rajpur and Aryan Nagar, rooftop rainwater harvesting can be used as storage to supply water or the surface water from river Rispana can be used to supply the water. Demand reduction measures also need to be initiated in the city.
4. A user-friendly interface for population forecasting has been developed to forecast population by the methods of AIM, GIM and IIM. The module has been successfully demonstrated for all the methods using input data of study area. User has been given flexibility of using computed as well as desirable growth rate of population in GIM, selecting any one method as well as calculating average population by all the methods. Again using modules of water supply, water demand and water shortage, user can predict the future water thrust area at ward level as well as overall future shortfalls of the area.
5. Rainfall-runoff module estimates the weighted annual runoff by SCS-CN method and annual runoff by weighted CN method. The runoff by SCS-CN method has been found 155 mld whereas by weighted CN method, it was 170 mld for the study area. Study area receives high rainfall and so, results from both the methods deviate by 10-15%, which is

an acceptable range. Ground water recharge module has been developed to estimate groundwater recharge by rainfall infiltration method. Groundwater recharge was only 11% of the total rainfall for the year of 2001, and if the urbanization growth rate at the current rate, groundwater recharge will be as 6% of the total rainfall in the year of 2031. The GUIs developed for both the modules are simple, easy to follow and provide output in the form of shape files.

6. The Rainwater harvesting module has been successfully demonstrated to compute the rooftop rainwater harvesting potential. The GUI provides flexibility to user taking results at desired efficiency of roofs to harvest rainwater for the study area.
7. A decision module has been developed to compare different scenarios by AHP method. The GUI provides flexibility to the user to calculate weights upto 12th criteria by pair-wise comparison method and to calculate rank by AHP method. The module can be used for any water related problems using different parameters and weights.
8. The utility of the DSS-IUWM has been shown by adopting a scenario based approach to get the optimum water supply strategy by IWRM. Different scenarios have been generated integrating existing scenario with different combinations of rooftop rainwater harvesting, water demand measures, runoff harvesting, recycling at low, medium and high population growth rate. Different factors for selecting the best scenario considered are water shortage reduction, water demand minimization, increasing groundwater recharge, runoff reduction at different growth rate of population. It has been found that sustainability can be achieved only by recycling 60% and 80% of water supply and adopting water demand reduction upto 50% by adopting suitable measures such as leakage control, increasing price, public awareness about saving water and metering.
9. The study has integrated spatial technologies, analytical models and water resources decision policies in the form of standalone software. The DSS-IUWM provides easy and fast computations for all the complex analytical methods and help to a decision-maker.

8.3 Suggestions for Future Work

The following suggestions for further research and refining of the DSS components/interface are identified during the course of the present study:

1. The possibilities of integration of spatial data to the DSS presented in this research were limited to some GIS vector shape files; they can be further extended by adding raster data types.
2. The developed DSS integrates quantity of water supply sources, water demand, runoff estimation and groundwater recharge. In urban area, water quality is also an important parameter that can be further integrated to the DSS-IUWM. Some improved analytical modules for groundwater, runoff estimation can be added with the existing modules.
3. The DSS-IUWM has the capability of generating outputs in spatial manner. Therefore, ward-wise scenarios can be developed in the present DSS, but it may require huge amount of ward-wise data. The study can be extended with long term field data by using the developed DSS.
4. The population forecasting module of the DSS-IUWM has been developed considering decadal population data for the present study. Further, the module can be modified to forecast the population on yearly basis and by integrating any upgraded model that includes death rate, birth rate, migration of people and other factors affecting the population growth of a city.

Use of GIS and DSS in IWRM is yet to be implemented by planners and managers in the developing countries particularly in urban areas. The developed DSS in the form of user friendly software (named DSS-IUWM) is expected to be useful for decision-maker and various government and non government agencies as it provides many basic information and analysis for urban water management.

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