REMOTE SENSING AND GIS IN LANDUSE MODELLING OF DWARKESHWAR WATERSHED, WEST BENGAL

A THESIS

Submitted in fulfilment of the
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of
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EARTH SCIENCES

By

BISWAJIT SARMA

DEPARTMENT OF EARTH SCIENCES
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 this thesis, entitled **"REMOTE SENSING AND GIS IN LANDUSE MODELLING OF DWARKESHWAR WATERSHED, WEST BENGAL"** in fulfillment of the requirement for the award of the degree of **DOCTOR OF PHILOSOPHY** and submitted in the **Department of Earth Sciences** of the Indian Institute of Technology, Roorkee, is an authentic record of my own work carried out during the period from July 1999 to January 2003 under the supervision of **Dr. A. K. Saraf**.

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

Date : 07/01/2003

(BISWAJIT SARMA)

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

Date : 07/01/2003

(Dr. A. K. SARAF)
Assistant Professor
Department of Earth Sciences
Indian Institute of Technology, Roorkee
Roorkee – 247667

The Ph.D. viva-voce examination of **Mr. Biswajit Sarma**, Research Scholar was held on

23/5/03

Signature of Supervisor **Signature of H.O.D.** **Signature of External Examiner**

ABSTRACT

Land is a non-renewable resource and hence assessment of landuse change in a temporal sequence is essential for planning and development of land and water resources. Integrated remote sensing and GIS technique provides excellent information, understanding of the relationships between different influencing variables and spatial distribution and change of landuse in a cost-effective manner. In the present study, an integrated remote sensing and GIS based methodology have been developed and successfully demonstrated to analyze landuse-groundwater relationship in the Dwarkeshwar watershed, West Bengal, India. There are four components of this study; (a) to evaluate the nature of changes in the selected landuse categories, (b) to identify the factors influencing this change, (c) their role in controlling the groundwater scenario of the study area and (d) to suggest remedial. measures to improve the groundwater regime of the area through delineation of the groundwater potential zones and suitable artificial recharge sites.

The Dwarkeshwar Watershed with a semi-elliptical shape (86°37'E-87°28'E and 23°00'N-23°32' N) occupies the north central part of the Purulia district but the major part of it is situated in Bankura district of West Bengal state,India. The total area of the watershed is 2270 sq.kms. The major river draining the entire watershed is the Dwarkeshwar river, which is the tributary of Damodar river. The Dwarkeshwar river originates from the eastern highlands of Purulia district flows through Bankura district from NW to SE. After leaving Bankura district it confluences with river Silai (or Silabati), and thereafter it falls into river Bhagirathi as river Rupnarayan, just before Bay of Bengal. Physiographically the whole of the watershed forms an intermediate tract between Chotanagpur plateau in the west and the alluvial plains in the east, presenting a variety of landforms varying between the dissected plateau in the west and the undulating alluvial plains in the east. The study area consists of pink granite and granite gneiss of the Pre-Cambrian Shield of India with a thick mantle of laterite and older alluvium lying over it. Towards the eastern part of the area, newer alluviums of recent time basically sand, silt, and clay.

The present study is aimed to achieve the following objectives: (i) to develop an integrated remote sensing and GIS technique to establish and evaluate the relationship between landuse and groundwater hydrology, (ii) to identify factors influencing this relationship and their role in controlling the groundwater scenario of the study area, (iii) to evaluate the nature of changes in selected landuse categories, (iv) to have a quantitative assessment of groundwater recharge, (v) to delineate the groundwater potential zones in the area, (vi) to suggest suitable sites for artificial recharge to augment groundwater in the study area, and (vii) To develop a software in the form of an extension to the Arc View 3.x GIS package for immediate extraction of groundwater related properties of an area.

Three types of data have been used for the present study, namely remote sensing data, e.g. IRS-1B-LISS-II and IRS-1C-LISS-III data, field data, e.g. depth of water level, rainfall data, etc. and the existing maps, e.g., topographic, geological, geomorphological and soil maps, etc. In order to bring these into a single spatial georeferencing scheme, all the data have been registered to the base map, prepared from the Survey of India topographic maps.

Remote Sensing data (IRS LISS – II and LISS – III) have been enhanced to extract pertinent information using suitable image processing techniques. Classified landuse maps have been generated for both the years 1988 and 1996 from the satellite data and landuse change has been determined with area statistics by subtracting the two images. Thematic information layers on geology, geomorphology, lineaments, soil and landuse have been prepared from remote sensing images supported by ancillary data.

Digital Elevation Model has been generated from elevation contour from topographic maps through interpolation. Automatic extraction of drainage network has been performed and analysed with other datasets in GIS. Depth of water level data have been analysed to study in the long-term behaviour of the water level in the area. Groundwater recharge has been calculated by Thornthwaite and Mather Model of water balance and specific yield and water level fluctuation method in GIS environment.

Rainfall data have been analysed and used to estimate runoff depth and peak discharge for the prioritisation of the watershed using SCS curve number method. This is used to prioritise the watershed on the basis of runoff generated due to existing landuse condition and soil type.

Potential soil loss due to erosion for the watershed has been calculated using USLE (Universal Soil Loss Equation) Model. Moreover, Normalized Difference Vegetative Index (NDVI) has been calculated from the classified landuse images for both the years 1988 and 1996 and the NDVI difference image is generated to identify the change in vegetation cover.

All the information layers have been integrated through GIS analysis and the criteria for groundwater prospective zones mapping and artificial recharge site selection have been defined. Each parameter and also each class of the parameters have been assigned appropriate weights on the basis of their relative contribution towards the output.

Finally, the changes in groundwater resources are correlated with the landuse changes. Programs are developed in ArcView Avenue programming language to create an extension for ArcView 3.1 and 3.2 for immediate extraction of groundwater potential zones and artificial recharge sites.

In this study, an integrated remote sensing and GIS technique has been developed for evaluation of landuse groundwater relationship and has been successfully tested for the Dwarkeshwar Watershed, West Bengal, India. This study has illustrated that integrated remote sensing and GIS approach is an appropriate tool for convergent analysis multidisciplinary data sets required for landuse groundwater relationship studies.

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BISWAJIT SARMA

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INTRODUCTION

1.0 PREFACE

Landuse and its change in temporal sequence play an important role in any development activities on the earth. Recent research indicates that human induced conversions and modifications of landcover have significance for the functioning of the earth system (Bouman, 1990; AMBIO, 1992; Turner et al. 1993, 1994). Landuse and landcover can not be synonymous. Landcover consists of the biophysical materials covering the earth's surface and landuse is the human use of the land resources. Most of the landcover modifications and conversions are now being driven by human intervention, rather than natural changes (Houghton et al., 1991). In general, landuse is viewed to be constrained by biophysical factors such as lithology, soil, climate, relief and vegetation. The human activities that make use of or change land attributes are considered as the proximate source of landuse change.

In Indian mythology, the ethics of natural resources management for harnessing the mother earth is an age-old concept as reflected in the 'Vedas'. But the age-old practices were not encouraged substantially to meet the increasing human need for food, fodder and fuel wood combined with industrial activities. Gradually, it is being found that forests are destroyed, lands eroded, water mismanaged and natural resources misused causing environmental degradation. In other words the 'geo-bio-cultural' interactions play an important role in land and water resources management.

At a watershed scale, landuse change can increase runoff, flooding and non point source pollution. Thus it is important to assess the potential hydrologic impacts of landuse change prior to watershed development (Bhaduri et al., 2001). Landuse change particularly urbanization, has significant impacts on hydrology over a range of temporal and spatial scales However, the nature and scale of these impacts on water quality and quantity depend on the form of the landuse change and its climatic context. Hydrologic impacts, in turn affect many aspects of the environment through river channel erosion and widening, loss of riparian, and wetland habitats, declining aquatic community populations, and reduced ecological diversity, and it can also have significance negative impacts on human health and welfare (Gosselink and Turner 1978; Mitsch and Gosselink 1986; Burke et al. 1988).

Watershed managers, planners, and community decision makers need to assess the hydrologic impacts of landuse to offer a design model for every case even though it is very critical to understand and manage the impacts of landuse change over a range of spatial and temporal domain. The human interaction and contribution to the change of landuse / landcover may give rise to two contrastingly different scenarios :

(a) Worst-case scenario: Continuous exploitation of natural resources beyond threshold limit of resilience of the eco-system accelerates various geomorphic processes (both active and dormant) on the earth surface, thereby causing imbalance in natural eco-system and/or hydrodynamic circulation. End Result - Large-scale disaster to present day habitation.

(b) Best case scenario: Conserve, develop and harness land and water resources and minimize the adverse effect of the natural hazards for restoration of the ecological balance in the long run – the 'Sustainable development': efficient and rational utilization of the land – Water resources to meet the present as well as future needs of the human subsystem in ecofriendly manner.

Keeping the above points in mind, 'full featured' spatial information about the changeable landform features and related landuse (i.e. land-water-vegetation inter-relationship) on a natural unit basis is very essential for integrating the same with the related non-spatial data (e.g. demographic, socio-economic etc.) to obtain the real world feature.

The landuse-hydrological interrelationship is primarily based on the 'Hydrological Cycle', 'Hydrodyanamic Circulation' and the river basin. Watershed is a distinct hydrological unit with a well-defined geographical boundary. Each river basin/watershed is having its own characteristic features in terms of rocks / soils, landform, vegetation and natural hazards. Any change in the water-sediment-vegetation regime of the watershed due to natural physical or anthropogenic reasons may cause change in river morphology as well as stability of the area, which in turn may badly affect the existing 'geo-bio-cultural' relationship. In response to that watershed may be considered as the basic unit in development planning on a sustainable basis. The entire approach should be based on to landuse-hydrological interrelationship which can be successfully achieved by integrating remote sensing and GIS technique.

The concept of integrating remote sensing and GIS is not very old. Probably, the fullest utilization of the potential of the two technologies can be realized only when an integrated approach is adopted. Blending of the two technologies has proved to be an efficient tool in groundwater studies (Gustafsson, 1993; Saraf and Jain, 1994; Saraf et al., 1994; Krishnamurthy et al., 1995; Krishnamurthy et al., 1996; Saraf and Choudhury, 1997; Saraf and Choudhury, 1998). Groundwater is a dynamic and replenishable natural resource but in hard rock terrains, availability of groundwater is very limited. Occurrence of groundwater in such rock is essentially confined to fractured and weathered horizons. In India, 65% of the total geographic area is covered by hard rock formations. Therefore, efficient management planning of groundwater in these areas is of the utmost importance. An extensive hydrological investigation is required for thorough understanding of groundwater conditions. Remote sensing data provide most accurate spatial information and it can be economically utilized over conventional methods of hydrological surveys. Digital enhancement of satellite data results in extraction of maximum information and an increased interpretability. GIS techniques facilitate integrated and conjunctive analysis of large volumes of multidisciplinary data, both spatial and non- spatial, within the same georeferencing scheme. Thus, by integrating these two spatial data techniques, groundwater development strategies for a hard rock area can be designed.

1.1 THE BACKDROP

Water, the source of life, is passionate, too passionate to manage. Excess of it leads to flood and lack of it results in drought and famine. There have been considerable imbalances in the quantity of water resources available to the Indian population and their use. This has led to the falling ground water table, followed by declining per capita availability (Fig. 1.1) and wasteful and inefficient use of water. Despite a national average of 2464 m^3 of the water per capita per year, parts of India face water scarcity due to uneven availability of water (Pachauri and Sridharan, 1998). The pressure on groundwater is gradually increasing as modern technology is replacing traditional farming. The increasing share of groundwater in an irrigated area can be visualized from the declining share of tanks in the net irrigated area (Fig. 1.2, Pachauri and Sridharan, 1998).

The larger share of groundwater can be explained in terms of higher productivity of groundwater irrigation compared to canal irrigation. Groundwater is preferred to surface water because farmers have greater control over it. Consequently pressure on groundwater is increasing (Choudhury, 1999).

According to experts, overuse of water for irrigation and over pumping of groundwater threatens India with the world's largest annual water shortage that will affect food supply for the near billion population. One fourth or 50 million tons of India's grain could be lost due to underground water depletion. The Ganges and the Indus have virtually no outflow to the sea during the dry season. Overgrowing demand of water and increasing shortage of it may lead to major conflicts. It is important to make the people value water more so that they will waste less and pollute less (Choudhury, 1999).

Thus, as we enter the twenty-first century, the critical situation calls for a well organized investigation, evaluation and management planning of groundwater in order to avoid any detrimental effect on the groundwater regime and to provide sustainability to the groundwater development process. National water policy (1987) emphasizes setting up of a water information system with a network of databases. The major stress is laid on maximizing the availability of water and developing groundwater recharge projects for augmenting the available supplies, and therefore, multi-disciplinary approach needs to be adopted.

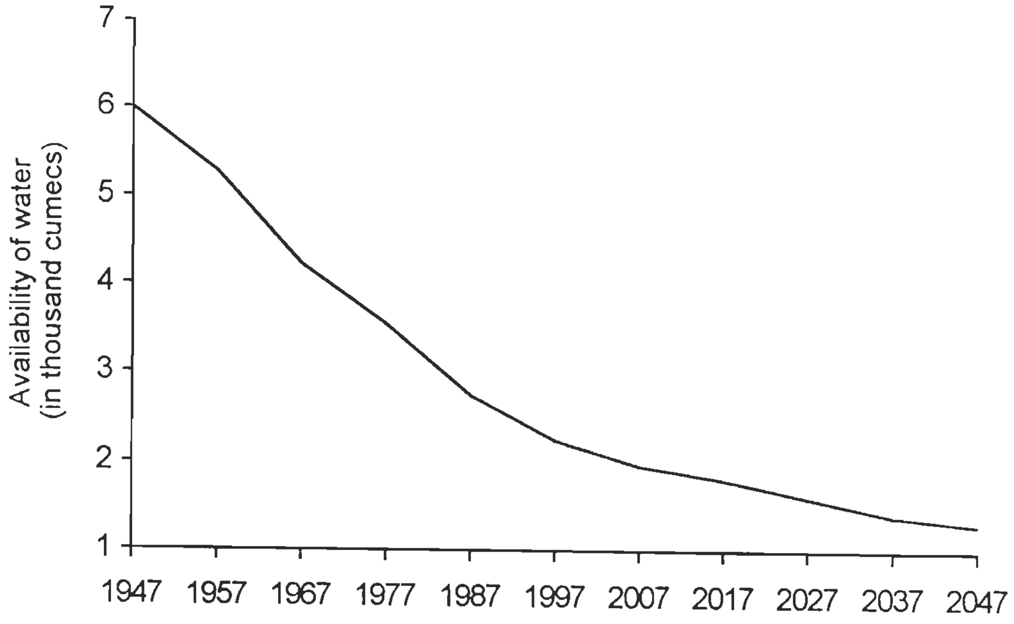


Figure 1.1 : Declining availability of water per capita-from the past towards the future (Pachauri and Sridharan, 1998)

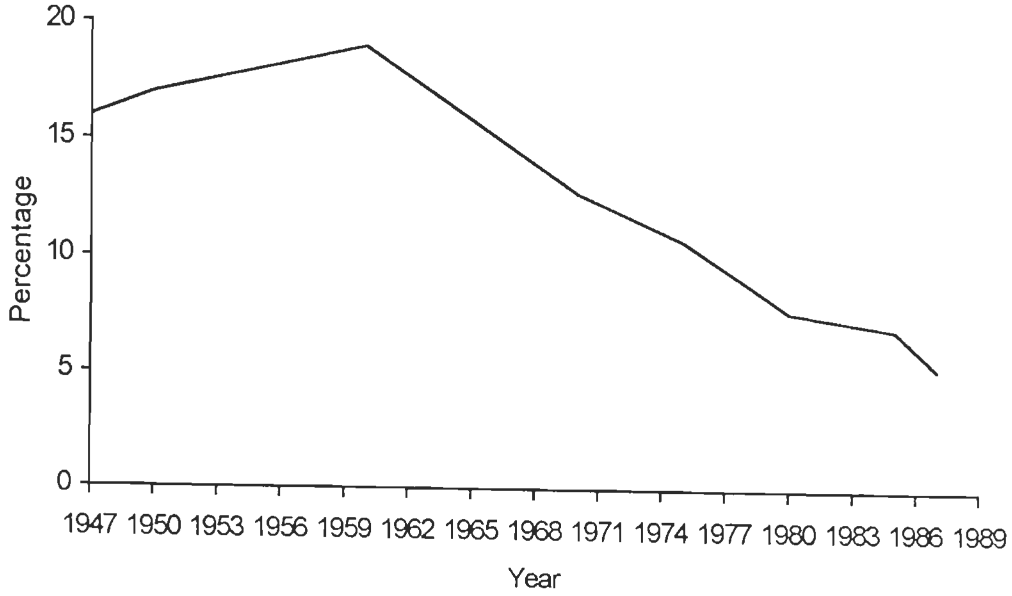


Figure 1.2 : Declining share of tanks in net irrigated area (Pachauri and Sridharan, 1998)

Integrated remote sensing and GIS have been extensively used in exploitation of surface and groundwater in many areas. Now, time has come to use these technologies to realize the concepts such as artificial recharge, water harvesting and watershed management. These technologies have the potential to help in reaching the ultimate goal of water management, so that everyone can get water. The present study has been undertaken keeping in pace with the national scenario of groundwater.

1.2 OBJECTIVES AND SCOPE OF THE STUDY

The present study envisaged achieving the following objectives:

(a) To develop an integrated remote sensing and GIS technique to establish and evaluate the relationship between landuse and groundwater hydrology.

(b) To identify factors influencing this relationship and their role in controlling the groundwater scenario of the study area.

(c) To evaluate the nature of changes in selected landuse categories.

(d) To estimate soil erosion and runoff characteristics of the watershed.

(e) To have a quantitative assessment of groundwater recharge.

(f) To delineate the groundwater potential zones in the area.

(g) To suggest suitable sites for artificial recharge to augment groundwater in the study area by considering landuse and other related parameters.

(h) To develop an extension of Arc View 3.1 and 3.2 GIS package for immediate extraction of groundwater related properties of an area.

As remote sensing is moving from descriptive to a quantitative technology, thus various input parameters for hydrological modeling can be estimated to some extent. This information is utilized in landuse-hydrological modeling in GIS, which requires continuous spatial information. 3D-viewing capability helps greatly in depicting the complex subsurface hydrological system. It can be very useful for impact assessment of groundwater development and the future scenario can be generated based on GIS analysis. Finally, this study can be applied to similar terrain conditions in groundwater resources evaluation directly or with appropriate modifications.

1.3 ORGANIZATION OF CHAPTERS

The entire thesis has been organized into eight chapters.

Chapter 1 is an introduction to the topic with a brief description of the study area.

Chapter 2 provides a review of application of remote sensing and GIS in landuse, groundwater, soil erosion and runoff estimation studies.

Chapter 3 provides a general outline of the methodology developed. Remote sensing data and ancillary information are integrated through GIS analysis.

Chapter 4 describes about the landuse change detection and determination of vegetation index.

Chapter 5 describes processes of soil erosion and its assessment and prediction. In this chapter runoff characteristics of a watershed and determination of runoff depth and peak discharge are also highlighted.

Chapter 6 describes qualitative and quantitative assessment of the groundwater resources in the area. It also evaluates the status of artificial recharge conditions in the area through remote sensing and GIS techniques. Based on this observation and ground truth information, suitable locations for future artificial recharge are suggested.

Chapter 7 deals with the results obtained during the study to determine landuse-hydrological relationship, especially the effect of recharge on landuse changes.

Chapter 8 summarizes the work done and conclusions are drawn.

1.4 THE PROFILE OF THE STUDY AREA

1.4.1 Physiographic setting

The Dwarkeswar Watershed, with semi-elliptical shape (86°37'E - 87°28'E and 23°00'N - 23°32'N) occupies the north-eastern part of Puruliya

District and covers most parts of Chhatana, Bankura I, Bankura II, Onda and Bishnupur of Bankura district from west to east, and small parts of Indpur, Joypur, Saltora, Gangajalghati, Barjora, Sonamukhi, Patrasayer blocks in the southern and the northern flanks. The major part of the Dwarkeswar watershed is situated in a part of Bankura district and only a small part of the watershed falls in Purulia District of West Bengal. The Dwarkeswar watershed is in between the Damodar basin (to the north) and Kangsabati basin (to the south). The Dwarkeswar Watershed in Purulia district represents the upper catchment of the Dwarkeswar River and subsequently the river enters into the adjacent Bankura district in the east. The total area of the watershed is 2270 km^2 (Figure 1.3).

1.4.2 Topography

The watershed can be divided into three major topographic regions:

(a) The hilly areas on the west which is an extension of Chhotanagpur plateau, consist of various slope classes varying from very gentle (1-3%) to very steep (>35%) in accordance with the terrain units. It includes the Tilaboni complex (407m) in the western part of the watershed (the place of origin of River Dwarkeshwar), Mirgipahari (202m) and Pabra Phari (233m) in the central part and Mangura (281m) in the southwest and Paharpur hillocks (212m and 226m) in the eastern part of the watershed.

(b) The connecting tract in the middle consist of scattered isolated hillocks with slope categories ranging between moderately steep (15-35%) to very gentle (1-3%) slopes.

(c) The alluvial plains on the east show undulating/ rolling topography characterized by uniform very gentle slope (0-1%).

1.4.3 Natural Vegetation

The natural vegetation is characterized by a fine stand of 'Sal' (Shorea robusta) forest over an extensive area. The density of the forest increases from north to south and east to west. The northern and northeastern parts of the

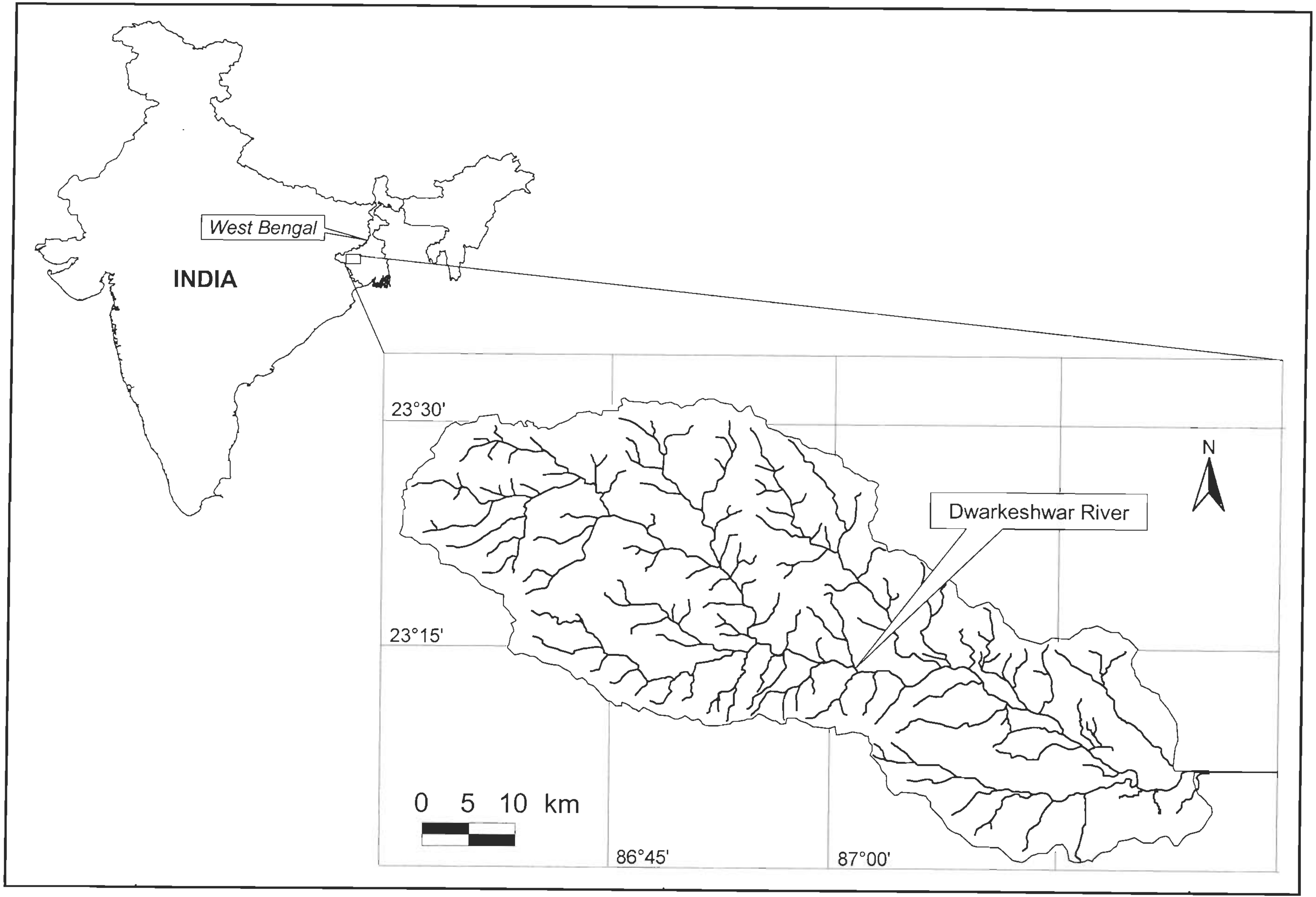


Figure 1.3 : Location map of the Dwarkeshwar Watershed with the drainage network.

watershed are particularly devoid of any natural vegetation. Besides Sal, the other important species is Pterocarpus marsupium along with mixed deciduous vegetation.

1.4.4 Drainage

The major river draining the study area is the Dwarkeswar River, which is the tributary of the Damodar River. The Dwarkeswar is the second major river, after river Damodar as it flows in accordance with the south easterly to easterly direction of the watershed. The Dwarkeswar river originates in the eastern highlands of the adjoining Purulia district, enters Bankura district in Chhatna Block, flows nearly from NW to SE, leaves the district after Kotalpur Block; then after its confluence with river Silai (or Silabati), it falls into river Bhagirathi as river Rupanarayan, just before Bay of Bengal.

1.4.5 Geomorphology

The whole of Dwarkeswar watershed forms an intermediate tract between Chhotanagpur plateau in the west and the alluvial plains in the east, presenting a variety of landform (NBSS & LUP, 1992). The area is characterized by the presence of variety of landforms between the dissected plateau in the west and the undulating alluvial plains in the east. The moderate to high sloping land interspersed with isolated hills to the west are followed by the gently to moderately sloping land interspersed with valleys and mounds to the east which in turn are followed by the upper undulating alluvial plains. Severely gullied land is found along river Dwarkeshwar towards the western margin of Bankura district. Dissected Pediment area is found in the north central part of the watershed (Figure 1.4).

1.4.6 Geology

The geology of the Dwarkeswar watershed can be divided into three broad units. The western part consists of pink granite and granite gneiss with pockets of quartzite and quartz schist, amphibolite, hornblende schist, epidiorite, pyroxenite, and pyroxene granulite body (Figure 1.5) (GSI, 1998). This is a part of the Precambrian shield of India, which is separated from the lateritic upland in the east by the Chhotanagpur Foothill Fault. The thick mantle of laterite and older alluvium that lies over the Precambrian basement is the second prominent geologic unit in the central part of the watershed. These are of Pleistocene to Recent in age. The laterites occur as hard massive blocks or as nodules, these being in-situ partly cemented weathered products of the crystalline rocks. This unit is separated from the fluvial plains of the east by the Medinipur-Farakka Fault. This third unit consists of the gradually eastward thickening newer alluviums of recent time, which are basically sand, silt, and clay.

1.4.7 Soils

The soil of the watershed can be grouped as:

(a) Red and yellow soils – They have limited distribution in the south-central, southeastern, and southwestern parts of the watershed. They are mostly skeletal loamy sand to sandy loam. They are red coloured sedentary soil found mainly on laterites supporting Sal vegetation.

(b) Alluvial soils – They are widely distributed in the east-central and southeastern parts of the watershed and grouped according to soil association. The older alluvial amongst them is unaffected by floods and siltation and show profile development where as the younger or newer alluvial, found mostly in the Damodar flatland areas enriched by silt deposition during floods.

(c) Laterite soils - The laterite soils have wide distribution in the south central to the southwestern part of the district. Such soils are distinguished from the red soils by the occurrence of ferruginous concretions in a definite layer, whereas in the red soils they are distributed throughout the profile.

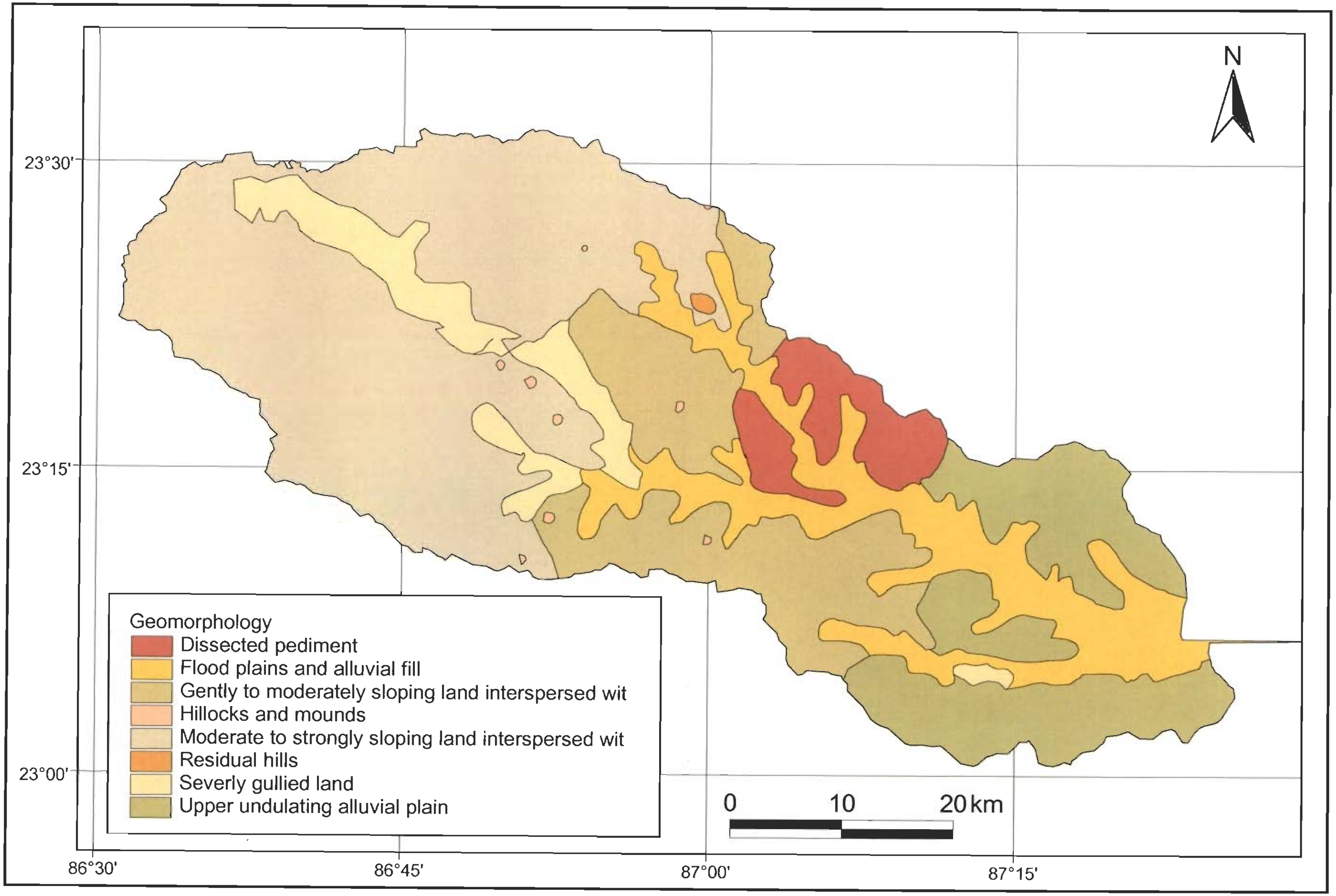


Figure 1.4 : Geomorphological map of the Dwarkeshwar Watershed.

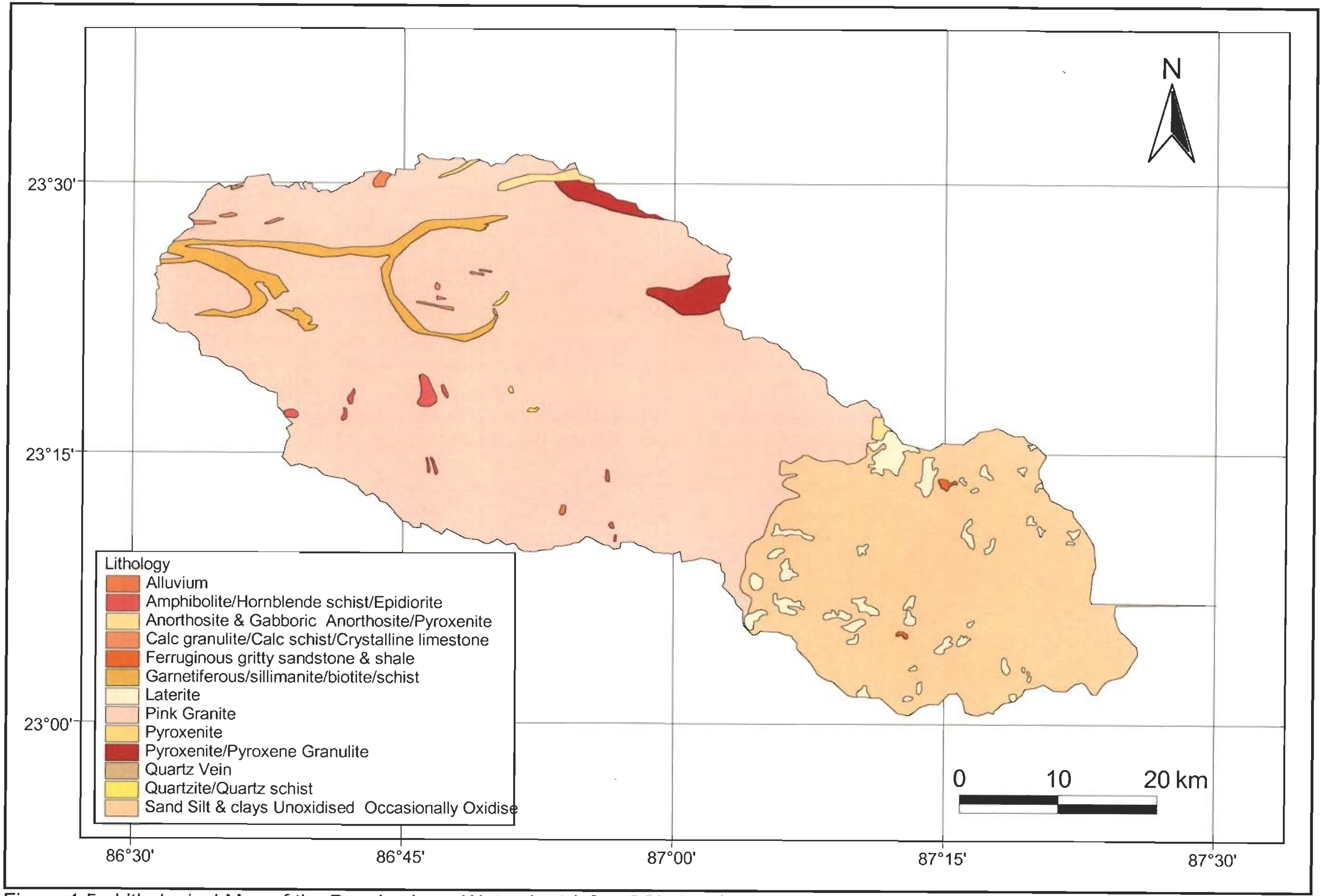


Figure 1.5 : Lithological Map of the Dwarkeshwar Watershed (after GSI, 1998).

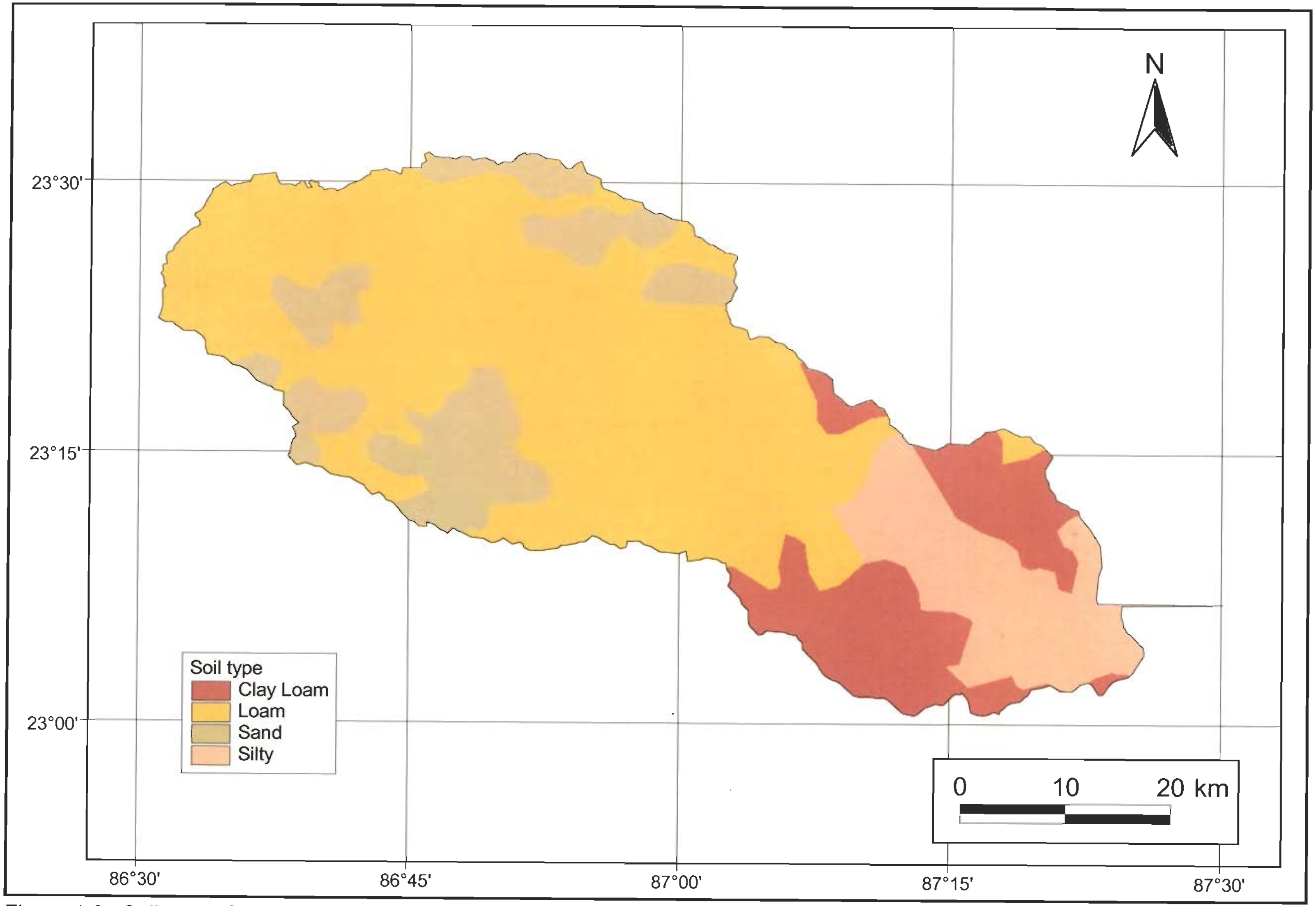


Figure 1.6 : Soil map of the Dwarkeshwar Watershed (After NBSS & LUP, 1992).

According to textural types, soils of the watershed can be classified under following types: (1) sandy (2) sandy loam (3) loam (4) sandy clay loam (5) clay loam (6) clay.

Clay, clay dominated loam and loams are mostly confined to the flood plains of the Damodar and the Dwarkeswar rivers though sporadic occurrences are also seen in other small river valleys (Figure 1.6).

1.4.8 Climate

The watershed experiences rather extreme climatic conditions. Its location over the Tropic of Cancer, remoteness from the sea i.e. the Bay of Bengal, lateritic soil cover, undulating topography and absence of perennial streams are responsible for this extremity. The watershed experiences mean annual temperature of 27°C with highest in the summer around 48°C and lowest in the winter around 5°C (CSME, 1993).

The watershed receives an average rainfall of around 1200mm. 70% of the total annual rainfall comes in the month from June to September. Varied aerial distribution, from east to west, variability from year to year and in months in a year causes widespread drought in the hard rock areas in the western part. Hence, it is very important to utilize rainfall for groundwater recharge by providing some suitable sites.

1.4.9 Groundwater conditions

In the hard rock areas in the western part, groundwater occurs in an unconfined condition within the fractured hard rocks and its weathered mantle. The potential aquifer in this part comprises of a weathered residuum, which is 10 to 20 m thick and the underlying fractured hard rocks with secondary porosity that extends up to 50m from surface. In the laterite and the alluvial areas groundwater is in unconfined state in shallow aquifers, and in confined state below a blanket of clay of varying thickness in deeper aquifers (Saha et. al, 1995).

Although, the annual rainfall in the watershed is moderate, the availability of groundwater is problematic because of the following reasons:

(a) Generally high runoff

(b) Low recharge rate

(c) Unsuitable aquifer conditions over the parts of the western hard rock areas.

(d) Long and hot dry season

(e) Excess withdrawal of groundwater in parts of the eastern alluvial tract, for irrigational purposes has caused continuous lowering of the groundwater table over the years.

1.4.10 Present Landuse

The landuse of the study area is characterized by a mixture of forest cover, agricultural activities and wasteland besides water body and river sediment (Saraf, 1999). Agriculture is the mainstay of the people in the Dwarkeswar watershed. The western part of the watershed has very little forest cover as compared to the eastern part. In the eastern part, large areas are covered by dense forest or degraded forest. Agricultural lands are restricted along the Dwarkeshwar river. Rest of the areas is either fallow or wastelands. The western part has more of wastelands and fallow lands. Also irregular patches of arable land occur in random fashion in the study area. The main water body in the area is the Dwarkeshwar river which is the third major river after Damodar. The utilization pattern of the watershed is constantly under change due to construction of buildings and road network joining previously unconnected areas.

Soil erosion is another important cause affecting land utilization and land management system. The configuration of the terrain being undulating, the clearance of forests for agriculture without the usual safeguards for conservation resulted in abnormal impoverishment of the soil.

In cognition of the problems, the need for the study of Landuse-Hydrological relationship is inevitable. The purport in providing the solution lies in delineating the groundwater potential zones and artificial recharge sites, which can facilitate availability of ground water.

Chapter 2

REVIEW OF LITERATURE

2.0 INTRODUCTION

The main objective of this study is to develop an integrated remote sensing and GIS based methodology to analyze landuse-groundwater relationship in the Dwarkeshwar Watershed, West Bengal, India. Landuse change has significant impacts on the hydrological regime of an area. In this study more emphasis is given on the impacts of landuse changes on groundwater scenario. Moreover, soil erosion and change in runoff characteristics can also be considered as impacts of landuse change. This chapter presents a review of literature for landuse studies and the associated parameters. A section is also devoted to application of remote sensing and GIS in groundwater studies. More elaborate information has also been provided in individual chapters.

2.1 APPLICATION OF REMOTE SENSING AND GIS IN LANDUSE STUDIES

The term landuse can be defined as the human activities that are directly related to the land, making use of its resources or having an impact on it through interference in ecological processes that determine the function of the landcover. The effect of landuse on the cover structure, phenology and composition is more relevant in the context of global change compared with the real purpose or function of the landuse (Mucher et al. 1993).

The human interference in the landcover structure mainly depends on and region related biophysical constraints or drivers and the human perception of these drivers. So, landuse is determined by the interaction in space and time of biophysical drivers (constraints) such a soil type, soil properties, lithoogy, climatic (in micro level) changes, geomorphology etc.

It is important to consider the long-term effects landuse changes have on surface runoff, streamflow, and groundwater recharge. Expansion of urban areas can significantly impact the environment in terms of reduced ground water recharge, and increased water pollution and stormwater drainage. Urbanization leads to creation of impervious surfaces, which increase surface runoff volumes contributing to downstream flooding and a net loss in groundwater recharge.

Remote sensing data are an important source to estimate landuse paramenters effectively over large area at high resolution. They are attractive as means of obtaining temporal variation of landuse and to study its effect on hydrologic parameters. Therefore, it is important to identify the limitations of using satellite data in terms of sensitivity to the classification, especially such techniques are to be used in forecasting effects of landuse changes to the hydrologic techniques are to be used in forecasting effects of landuse changes to the hydrologic environment (Herath and Dutta, 2001).

Effective watershed management requires an understanding of basic hydrologic and biophysical processes in the watershed. A number of simulation models have been developed to evaluate water quality parameters affected by agricultural land management at both field and watershed scale. Widely used field scale models include CREAMS (Chemicals, Runoff, Erosion from Agricultural Management Systems), EPIC (Erosion-Productivity Impact Calculator), and GLEAMS (Groundwater Loading Effects of Agricultural Management System). Watershed scale models include storm event based AGNPS (Agricultural Non-Point Source Pollution Model) and continuous daily time step model SWRRB (Simulator for Water Resources in Rural Basins). Expansion of SWRRB model's capacities to facilitate more sub basins and sophisticated routing structure resulted in a new watershed scale model SWAT (Soil and Water Assessment Tool).

The traditional focus in urban surface water management has been the control of the peak discharges from individual high magnitude storm events that cause flooding. Models such as HEC-1, developed by US army Corps of Engineers (USACE) (1985), TR-20 and TR-55 by the US Department of Agriculture [Soil Conservation Service (SCS) 1983, 1986], and SWMM, by the US Environmental Protection Agency [Metcalf and Eddy, Inc. (MEI) 1971;

Huber and Dickinson (1988)] are routinely used in assessing the impact of proposed landuse changes on runoff quantity as the basis for designing storm water management facilities to prevent flooding problems. Physical process-based models, such as SWMM, can perform sophisticated runoff calculations, but these models require a large number of input parameters and time-consuming data collection and formatting (Huber and Dickinson, 1988). Moreover, due to their computational complexity, most models are not very user friendly and one needs a significant amount of time and expertise to master model application. For example, in addition to formatted precipitation data, SWMM requires monthly evaporation rates, percent imperviousness, slope, Manning's n values, depression storage values for impervious and pervious areas, and maximum and minimum infiltration rates for a watershed. These input data are often difficult to obtain, and it may take days or weeks to collect and format the input data needed to run the model.

Most community flood-prevention ordinances regulating storm-water discharges are based on individual storm events of specific recurrence intervals. However, McClintock et al. (1995) and Roesner (1999) showed that extreme event methods could significantly underestimate long-term storm-water run-off volumes, because the majority of the runoff produced during a year is not the result of large storm events, but rather the sum of runoff generated during minor precipitation events. These more minor events produce runoff more frequently as the watershed becomes increasingly developed and are affected more by landuse change than major events (McClintock et al., 1995). Thus, although event-specific approaches are appropriate for practical, local-scale flood prevention, they may be of limited value for attempting to understand problems that result from the long-term hydrologic impact of landuse change.

In response to the need expressed by landuse planners for a user-friendly impact assessment tool, the Long-Term Hydrologic Impact Assessment (L-THIA) model was developed. Initially this model was developed as a spreadsheet tool (Harbor, 1994). More recently incorporating GIS has been incorporated in this model (Grove, 1997, Bhaduri, 1998). T-THIA uses the

Curve Number (CN) method for calculating runoff because the CN method is the core component of many of the more sophisticated hydrologic models [EPIC (Williams et al., 1984), AGNPS (Young et al., 1989), and SWAT (Arnold et al., 1998)]. The CN method is used in the U.S. Department of Agriculture's TR-20 and TR-55 models (SCS 1983, 1986). However, in comparison to the more sophisticated models, L-THIA requires only readily available data (soil type, landuse and climatic data). In this model the CN method is used to compute daily runoff for a long-term precipitation record in order to calculate the average annual runoff for each CN. Soil and landuse data are then used to determine composite CNs for sub basins of the watershed being studied under existing conditions.

The U.S. Environmental Protection Agency's SWMM (Storm and Water Management Model) is a traditional physical process based hydrologic model and is usually applied to short term hydrologic impact assessment but can also produce long-term runoff estimates. SWMM uses percent imperviousness of a watershed for runoff calculation. Bhaduri et al. (2001) compared the performance of the two models L-THIA and SWSS in calculating runoff for two small watersheds in Chicago (U.S.). Both models predict a linear relationship between average annual runoff and increasing imperviousness. But L-THIA was easier and quicker to use than SWMM, because SWMM required time-consuming data collection and formatting. Result of thus and other analyses suggest that L-THIA can be an appropriate tool for initial assessment of the impacts of the landuse change scenarios (Bhaduri et al. 2001).

2.2 APPLICATION OF REMOTE SENSING IN GROUNDWATER STUDIES

Remote sensing has established itself as a valuable tool for hydrologists to understand the groundwater regime of an area. The upper boundary of shallow groundwater is strongly influenced by features at or near the surface, information about which is provided by remote sensing (Meijerink, 1996). Groundwater is, by definition, subterranean. It is not available for direct observation. Hence, behaviour of groundwater is to be inferred from hydrogeologic clues, i.e. surface expressions of subsurface geological formations comprising the aquifer. Most remote sensing techniques, except airborne geophysical and radar, have no penetrating capabilities. Even long wave radar can sometimes detect groundwater levels only up to depths of a few meters. Therefore, information on hydrological indicators of groundwater is extracted from satellite images. These include structures (shear zones, faults, joints, folds etc.), consolidated and unconsolidated lithology, geomorphology (landform, erosion surfaces etc.), present and palaeo-drainage patterns, vegetation vigour and areas of preserved soil moisture during dry season (Waters et al., 1990). In short it can be said that vegetations are the signature of water below which can be exploited through the help of remote sensing. Remote sensing investigation certainly narrows down the detailed hydrogeologic and geophysical investigation and thus minimises fieldwork and overall cost. Remote sensing based hydrogeologic studies may be regional surveys involving understanding the general groundwater condition of a large area or local surveys for site selection of a borehole or dug well. In most of the cases, local surveys follow regional surveys (Choudhury, 1999).

Various remote sensing techniques are used in groundwater studies, e.g. aerial photographs, multispectral scanner images, radar images operating in different parts of the electromagnetic spectrum, airborne geophysical methods etc.

The concept of integrating remote sensing and GIS is relatively new. Probably, the fullest utilization of the potential of the two technologies can be realised only when an integrated approach is adopted. Blending of the two technologies has proved to be an efficient tool in groundwater studies. Remote sensing data provide the most accurate spatial information and it can be economically utilised over conventional methods of hydrogeological surveys. Digital enhancement of satellite data results in extraction of maximum information and an increased interpretability. GIS techniques facilitate integrated analysis of large volumes of multi-disciplinary data, both spatial and non-spatial, within the same georeferencing scheme (Choudhury, 1999).

2.2.1 Hydrogeological Indicators Derived from Remote Sensing

Use of photogeology contributed much to hydrogeological mapping in the past and it is in use till now (Meijerink, 1974). Photogeology reached a state of maturity during 1960s. A new era in natural resources studies dawned with the launch of ERTS (Earth Resources Satellite Technology) on 23 rd July, 1972 by NASA (National Aeronautic and Space Administration). ERTS imagery offered the first opportunity to apply moderately high-resolution satellite data for nation-wide study of water resources. It proved to be suitable for broad regional survey and reduced fieldwork. Identification of hydrologically significant lineaments is another important application, especially in hard rock terrains where large amount of groundwater can be obtained from wells along fractures. These imageries have advantage over low altitude, high-resolution aerial photographs in detecting regionally extensive faults due to their synoptic view (Choudhury, 1999).

Application of remote sensing in groundwater has been reviewed by many (Sharma, 1983; Gupta and Ganesha Raj, 1986; Waters et al., 1990; Engman and Gurney, 1991; Sahai et al., 1991; Meijerink et al., 1994; Meijerink, 1996; Reddy et al., 1996; Rao and Gupta, 1998). Basically there have been two approaches to the use of remote sensing in groundwater exploration. The first is generally applied to basement and carbonate aquifers, where fracture flow is the characteristic mode of water movement and some linear features correspond to fractures that correlate with the occurrence of groundwater. The second approach integrates remote sensing data with other sources of information to create hydrogeological thematic maps for groundwater exploration (Waters et al., 1990).

Remote sensing has been successfully used in conjunction with other regional information for groundwater investigations. (Gurney et al., 1982, Salman, 1983; Sahai et al., 1985; Chaturvedi et al., 1983; Fransworth et al., 1984; Kaufman et al., 1986; Ramasamy et al., 1989, Kruck, 1981 & 1990). Two aspects of hydrologic variables can be derived from remote sensing. The qualitative aspect comprises understanding of groundwater regime of an area. The quantitative approach attempts to quantify the hydrological indicators e.g.

precipitation, evaporation, soil moisture etc. from remote sensing data (Choudhury, 1999). Detailed discussion on these is beyond the scope of this chapter. Discussion on the estimation of hydrologic variables can be found in Schultz (1993a and 1993b), Kite and Pietroniro (1996).

2.2.2 Hydrogeomorphic Information

Visual interpretation of aerial photographs and photographic products of multispectral remote sensing data has been extensively used for deciphering hydrogeomorphic conditions. In hard rocks there are two types of aquifers, namely granular aquifer and fractured rock aquifer (Raju, 1985). The weathered zone constitutes the former type and the latter is formed by the development of secondary permeability due to fractures. Hydrogeomorphic maps are prepared by combining information on drainage characteristics, landforms, geology, structural features and soil types. Identification of these from remote sensing data helps greatly in selection of drill targets and also to have an understanding of the groundwater circulation system by delineation of recharge and discharge areas (Choudhury, 1999).

Drainage is one of the simplest parameter, which can be extracted through remote sensing. It gives the most recent and accurate information and the seasonal changes can also be mapped using multi date data. The near-infra-red (NIR) band reveals the most contrast between land and water features due to very low to almost photo prints as well as from digital data. Drainage pattern and texture reflect the permeability of the underlying lithology and provide an important indication of groundwater condition. High drainage density is the result of impervious lithology at or near the surface. Some drainage patterns are associated with particular type of rocks e.g. dendritic pattern is usually developed in granitic or other hard rock terrain. Drainage pattern indicates how much water can percolate into the groundwater and thus the recharge conditions can be inferred. Generally, in hard rocks, the drainage density is high except in the weathered areas (Karanth, 1987).

Drainage pattern can be correlated with lineaments and the direction of movement of groundwater can be deciphered where groundwater movement is fracture controlled. Ahmed et al. (1984) prepared lineament intensity and drainage density contours using Landsat data and groundwater target areas were selected where high lineament intensity and low drainage density intersect. El Shazly et al. (1983) described a similar approach in Wadi Araba area of Egypt. Geomorphic features, landcover, vegetation, structural lineaments and drainage were interpreted from Landsat MSS imagery. These information along with the ancillary information were analysed with respect to the pre-existing well sites; lineament intersection in combination with low to medium drainage density appeared to favour groundwater occurrences. However, this combination of low drainage density and high lineament density may not favour groundwater movement in all areas (Choudhury, 1999). Seelan (1983) identified potential groundwater zones from remote sensing data of Karnataka, India based on lithological and morphological factors, which affect groundwater recharge.

Surface manifestation of paleochannels can be identified from remote sensing data. Usually these are potential sites for groundwater (Dhinwa and Majumdar, 1983; Chaturvedi et al., 1983; Ramasamy and Bakliwal, 1983). Chaturvedi et al. (1983) performed an integrated study of remote sensing and conventional techniques in the Bundelkhand area in Uttar Pradesh, India. They delineated a circular feature near the Betwa river, which is interpreted to be a paleochannel. This is confirmed by geoelectrical sounding and a number of potential well sites were marked in this area. Ramasamy and Bakliwal (1983) also detected buried channels in a part of the Banded Gniessic Complex, Rajasthan, which form potential sites for groundwater. Balasubramaniam et al. (1983) mapped hydromorphic features from Landsat imagery in North Arcot district, Tamil Nadu, India. The area is mainly covered by gneisses and charnockites. The alluvial plains and bajadas hold good groundwater prospects. Perumal and Roy (1983) performed a similar kind of study in parts of the Vagai, the Mnaimuthar and Pambar basins of Tamil Nadu. The valley fills, buried pediments and alluvial plains were the potential sites for groundwater. Ravindran and Jeyaram (1997) performed a study in the Shahbad tehsil, Rajasthan covered by Vindhyan sandstones. Groundwater potential was evaluated based on Geomorphology, drainage, springs, lineaments derived from IRS-LISS-II imagery and depth to water level data. Only the valley fill and buried pediments on sandstone form very good prospects for groundwater. Saraf and Choudhury (1998) has developed an integrated remote sensing and GIS based methodology for evaluation of groundwater resources in a hard rock terrain, mainly covered by Deccan Trap basalts. Suitable sites for artificial recharge of groundwater in order to augment groundwater recharge were also suggested in the area, which forms a part of the Betwa river basin in Madhya Pradesh.

2.2.3 Lineament Analysis

The surface expressions of subsurface structures appearing on remote sensing data are in the form of lineaments. These linear features or lineaments are of great interest to hydrogeologists in locating groundwater zones. The correlation of lineament with groundwater depends on the geological nature of the lineament. In hard rock terrains, the primary porosity is practically zero and groundwater occurrence is primarily a function of fracture-induced secondary permeability. The fractures either provide water circulation channels or act as impervious barriers (Vincent et al., 1978). In these areas, surface drainage is also mostly aligned along the fracture system. Recognition of surface expressions of the structural features is, therefore, an important task in groundwater exploration.

Lineament is "a mappable, simple or composite linear feature whose parts are aligned in rectilinear or slightly curvilinear relationship, which differs distinctly from the patterns of adjacent features and which presumably reflects a subsurface phenomenon"(O'Leary et al., 1984). This term, however, is used in a wider sense. A lithological boundary, vegetal or soil boundary, or topographic discontinuity may appear as lineaments on satellite imageries. There are also cultural lineaments. The definition given by Gold (1980) covers a wider perspective as it defines lineament as "any straight or slightly curved feature or alignment of discontinuous features that are apparent on a map." Large lineaments observed on satellite image are often surface expressions of major fracture zones, whereas photolineaments tend to be discrete fracture traces marked by linear drainage or changes in soil tone and vegetation (Waters et al., 1990).

All lineaments are not necessarily traces of fractures. Remote sensing may show the prominent fracture trends correlated to the movement of groundwater. Waters et al. (1990) and Waters (1990) have given a detailed discussion on the hydrologic behaviour of lineaments.

Lineaments are extensively used as a guide for groundwater exploration in hard rocks. Ramasamy and Bakliwal (1983) identified lineaments from remote sensing data, correlated them to the major structural features, and prepared lineament density map. The maximum values were inferred to be potential areas of groundwater accumulation. Further, lineament intersection density map is combined with geomorphology. Ramasamy et al. (1989) mapped structural pattern in part of south India on the basis of relief, drainage, soil tone and vegetation linearity from satellite imagery. These data were integrated by multivariate analysis with water level, transmissivity and yield data, and regional groundwater characteristics were mapped.

2.2.4 Groundwater Resources Estimation and Development Through Remote Sensing

Availability of high-resolution remote sensing data also enables the quantitative estimation of groundwater resources. Multi-date remote sensing data facilitates estimation of groundwater inflow and outflow components.The interest of hydrogeologists is shifting towards the dynamics of water balance and contamination. The appropriate tool is combination of image processing, GIS and numerical modelling. The real hydrologic value of remote sensing data depends on the transfer functions to transform reflectivity data to hydrologic variables (Choudhury, 1999). Rao et al. (1993) used multi-date IRS-LISS-II and Landsat TM data to extract hydrogeomorphic features. Groundwater resources were estimated using the conventional methods and sites for rainwater harvesting structures were suggested in order to recharge the irrigation wells. Reddy et al. (1996) identified zones of over exploitation of groundwater from

LISS-III and PAN data and found these data very useful for groundwater resource estimation and groundwater development planning. Reddy et al. (1998) estimated groundwater recharge, draft and balance of Sharada basin, Andhra Pradesh, India using SPOT MLA data. Crop areas and geomorphic features were extracted from remote sensing data and respective values of infiltration factors were assigned to different geomorphic units.

Karale et al. (1990) carried out a study using IRS-LISS-I and LISS-II data in Nagpur district, Maharashtra to select site for artificial recharge structures to combat overdraft in the area. Geology and geomorphological maps were prepared from visual interpretation of digitally enhanced pre-monsoon LISS-II data. Landuse map was generated from multi-date LISS-I data, of winter (Rabi) and (Kharif) crop seasons. Depth to water level and soil data were also incorporated. Based on hydro geomorphic studies, suitable sites for artificial recharge were suggested.

It is apparent from the above discussion that remote sensing data are to be used in conjunction with other ancillary information in groundwater studies. It can be realised that multi source and multi thematic data are required in groundwater studies. The need of an efficient spatial information analysis system in natural resources studies was perceived by many authors. For optimisation of resource management, planning, merging and integrated analysis of information layers from diverse sources are required. With the application of GIS technology, groundwater resources can be evaluated and monitored more efficiently and management plans can be designed based on the requirements (Choudhury, 1999).

2.3 GIS APPLICATIONS IN GROUNDWATER STUDIES

The hydrogeologic system in most areas is quite complex. In order to have a proper understanding of the groundwater regime, coherent analysis of all the influencing factors are to be performed. Large volumes of data from various sources are required. Remote sensing data alone are not sufficient. Merging of remote sensing data with other ancillary information is of great value and GIS is the appropriate tool. GIS is an efficient tool for manipulating and storing large volumes of data, integrating spatial and non-spatial information within a single system, offering a consistent framework for analysing the spatial variation, allowing manipulation of geographic information, and allowing connections between entities based on geographic proximity (Moore et al. 1991). Further, 3D perspective visualization is extremely valuable for characterization of hydrogeologic framework. This is a unique feature provided in GIS. However, 3D visualisation is not being used in the present study.

2.4 INTEGRATED REMOTE SENSING AND GIS IN GROUNDWATER STUDIES

Remote sensing and GIS are now established tools for natural resources and environmental studies. During the last few years, research has been going on to integrate both the tools. As the demand for spatial information grows there is an ever-increasing synergy between remote sensing and geographical information systems. There are three main ways in which these two technologies are complementary to each other:

(a) Remote sensing data can be used as data set in GIS.
(b) GIS data sets can be used as ancillary information to support remote sensing data.
(c) Remote sensing data and GIS data sets can be used together in environmental modelling and analysis (Wilkinson, 1996).

In most of the cases, either classified remote sensing data are converted to vector or vector data sets are converted to raster for analysis purpose. In groundwater studies, not much work has been done towards integrated approach. Analysis may be descriptive or prescriptive. Attempts have been made to use empirical or physical models embedded in GIS. Some advantages of integrated approach are listed (Choudhury, 1999):

a) Geometric and radiometric correction
b) Improvement of image classification using ancillary data
c) Use of knowledge base or expert system approach
d) Modelling dynamic natural processes

2.4.1 GIS Analysis Functions and Spatial Decision Support

Integrated spatial analysis is the most attractive part of GIS. Merging of image interpretation and GIS has proved quite useful in groundwater exploration and management programme. In groundwater studies, not many studies have been done to integrate all the controlling factors through GIS. Saraf and Jain (1996) used GIS overlay analysis for groundwater exploration in a granitic terrain of Lalitpur district, Uttar Pradesh. Geology and vegetation information derived from remote sensing data are interfaced with soil map and water level map. Groundwater recharge image has been prepared by multiplying water level fluctuation map by the respective specific yield.

The most important use of GIS is the spatial decision support. GIS is a powerful technique in suitability analysis (Burrough, 1986). It facilitates integration of all parameters controlling groundwater through analysis functions like weighted index overlay and Boolean operation. (Saraf and Choudhury, 1997 and 1998) have identified areas of anomalous vegetation growth downstream the reservoirs using dry season IRS-LISS-II data and attributed this to artificial groundwater recharge from the reservoirs. Assigning appropriate weightage to various parameters and overlay analysis, suitable sites for artificial recharge are suggested.

2.4.2 Groundwater Modelling Using GIS

To use hydrologic models within a GIS environment, many attempts have been made. In addition to data integration, GIS facilitates generation, storage and retrieval of large volume of input layers of information in a user defined map extent, projection and scale. Models are metaphors for nature or reality. Models can be stochastic or deterministic (Chow, 1972). Both these model can be subdivided into lumped or distributed depending on the treatment of space. A lumped model represents a spatially homogeneous region and no account is taken of the spatial variability of the input parameters. Distributed parameter model assumes that physical system is made of discrete sub-regions, each characterized by a unique set of properties of input parameters (Tim, 1996). GIS facilitates use of distributed models. In the present study groundwater recharge map has been modelled by the use of weighted index overlay model method.

It can be perceived that remote sensing provides an excellent source of data for groundwater resources evaluation, monitoring and development planning. Especially in developing countries like India, remote sensing data are the source of most accurate terrain information. Remote sensing capabilities has been utilized to a larger extent than that of GIS in groundwater studies. A groundwater resources evaluation programme demands a huge database including water levels, lithologs, and geological characteristics of aquifer material, hydraulic properties, recharge-discharge relationship and chemical concentration. GIS is the appropriate tool for integration of data from diverse sources, scale and projection. Integrated approach certainly enhances the quality of the output because it allows a far broader perspective to answer a large range of questions in spatial context. With the availability of higher spatial and spectral resolution of remote sensing data, and advanced image processing and GIS systems, there is scope for increased utilization of the potential of GIS and improvement in the integrated approach. The handling of time, the fourth dimension is an important issue. The study of dynamic aspects of spatial entities and their properties become increasingly important as modelling of the spatial and temporal changes in the occurrence of natural resources becomes more and more vital for management purpose (Choudhury, 1999).

2.5 SOIL EROSION STUDIES

Soil erosion is the process of dislodgement and transport of soil particles from the surface by water or wind. Because land management practices create a variety of conditions that influence the magnitude of soil erosion, land managers frequently want to predict the amount of soil loss by surface erosion. To ensure optimum and sustained productivity through scientific planning, the watershed needs basic knowledge on appropriate land resources inventories and a scheme for interpretation of landuse capability with risk of land degradation as main criterion (Krishna and Sharma, 1995).

Land degradation has always been associated with failure to identify areas that are prone to soil erosion. Moreover, land surveying using conventional methods is expensive and time consuming. In contrast mapping erosion using the integration of remote sensing and GIS could identify areas that are at potential risk of soil erosion and also provides quantitative soil erosion loss at various scales (Saha et al., 1992).

Surveys for determination of soil erosion rates from catchments and deposition rates in reservoirs are frequently conducted by the various governmental agencies in India (ICAR 1984 and CBIP 1981). Measurements of sediment load are made in many rivers across the country by other governmental agencies (CS&WC, 1991; Sangle 1991). Nevertheless, sediment loads remain ungauged for the majority of the streams, because of the limitation of funds. However, the other hydrologic data, such as rainfall and runoff are available for majority of river basins. Estimation procedures can therefore be used to estimate erosion rates for such catchments (Jain, 2001). In India Joglekar (1965) and Varshney (1975) have suggested a number of enveloping curves for the prediction of sediment yield for different catchment areas. Correlation studies conducted by Jose and Das (1982) revealed that area alone do not have any significant association with sediment production rate and hence there is scope for multivariate analysis using climatic and physiographic parameters. Statistical models on spatially distributed basin have been developed by Mishra and Satyanarayan (1991) and Bundela et al. (1995) for small watersheds in river Damodar in West Bengal, India.

Several models are available for predicting erosion. The simulation models provide a physically based representation of the process occurring in small segments of the catchment and route the response of these segments to the catchment outlet (Jain and Saraf, 1995). The Universal Soil Loss Equation (USLE) developed by Wischmeir and Smith (1978) is the best known and most widely used deterministic erosion prediction model. The spatially distributed parameters involved in this equation such as soil and landuse could be generated by remote sensing techniques (Moore and Wilson, 1992). These can be integrated with other topographic and ancillary data into a GIS environment in order to be analyzed and to produce a soil erosion risk map. Patel et al. (2002) has developed a soil erosion risk map for the Mohan Rao sub-watershed in Northern India using deterministic USLE model, remote sensing and GIS.

Prior to the development of USLE, estimates of erosion rates were made from site-specific data on soil losses. As a result, these estimates were limited to particular regions and soils. However, the need for a more widely applicable erosion prediction technique led to the development of USLE by the USDA Agricultural Research Service. The original USLE of 1965 was based on the analysis of 10,000 plot areas of source data, mostly collected from agricultural plots under natural rainfall. Subsequently because of high costs of collecting data from plots under natural rainfall, erosion research has been conducted on plots with simulated rainfall. Rainfall simulator data are employed in the USLE of 1978 to describe soil erodibility and to provide values for effectiveness on coservation tillage and construction practices for controlling soil erosion (Wischmeier and Smith, 1978).

The basic USLE is (Wischmeier and Smith 1965, 1978) written as:

$$A = RK(LS)CP \tag{2.1}$$

where A = compound soil loss in tons per unit area (acre); R = a rainfall erosivity factor for a specific area, usually expressed in terms of average erosion index (EI) units; K = Soil erodibilty factor for a specific soil horizon; LS = topographic factor, a combined dimensionless factor for slope length and slope gradient, where L is expressed as the ratio of soil loss from a given slope length, S is the slope steepness factor; C = a dimensionless cropping management factor, expressed as a ratio of soil loss from the condition of interest to soil loss from tilled continuous fallow and P = an erosion control practice factor, expressed as a ratio of the soil loss with the practices to soil loss with the farming up and down the slope.

2.6 RUNOFF ESTIMATION STUDIES

Every hydrologic design is different because the factors that affect the design, varies with space and time. It is thus necessary to make measurements of factors that affect the design. Factors such as size, slope, soil type and landuse/cover in the watershed, as well as the amount of storage and vegetation within the channel are of importance. Given Such factors as input to a hydrologic design, the accuracy with which the measurements of these factors are made should be determined. The drainage area, length of longest watercourses and equivalent main stream slope are the most significant variables for prediction of runoff (Taylor and Schwatz 1952). A model should therefore incorporate these factors for accurate assessment of runoff. Accurate runoff modelling is important because the transport of sediment and pollutants from watershed depends to a great extent on runoff processes.

Rapid parameterisation of runoff models is possible using Digital Elevation Model (DEM), Remote Sensing (RS) and Geographical Information System (GIS). Very few first hand information are available in developing countries about runoff modelling using DEM. Garg (1996) generated DEM from topographic maps to compute slope and catchment area which were subsequently used to generate flow direction, network flow pattern and drainage network in a watershed. The extracted watershed parameters were used to develop runoff model. A number of algorithms for automatic extraction of watershed characteristics from DEM were developed and used successfully by various research workers (Jenson and Domingue, 1988, Martz and Garbrecht, 1992, Agestino et al., 1993*)*. Incorporation of GIS into hydrologic modelling provides an increased details of evaluation, minimizes the user subjectivity in parameters selection and reduces cost of analysis due to significant time saving (Ross and Tara, 1993). Moore et al. (1991) partitioned catchment into interconnected elements using a "stream tube" approach and contour based DEM. They were able to structure the hydrologic models based on hydraulics of now within a catchment The effects of topography on runoff producing mechanisms and spatially distributed flow characteristics (such as flow depth and velocity) were directly and realistically included in the models.

White (1988) used a raster GIS to model rainfall runoff for a 421 km^2 watershed in Pennsylvania. He determined the runoff in a cell basis for 10 actual storm events and obtained the total predicted runoff depth for each event. Smith and Andrej (l994) placed an emphasis on developing and processing an urban DEM in tests on an urban watershed. The automatically derived databases were input to a distributed parameter hydrological model to predict the watershed response to 3 rainfall events. Zollweg et al. (1996) developed SMORMOD; a GIS integrated rainfall-runoff model. The model consists of soil moisture balance and runoff generation/transport sub-models. It uses only readily available watershed characteristics such as soil data, topography and landuse. Tiwari et al. (1997) extracted watershed parameters and developed an empirical model for the estimation of seasonal runoff using remotely sensed data and image processing and GIS technique (EASI/PACE).

Remote Sensing provides very useful methods of survey, identification, classification and monitoring severe \ forms of earth resources, and also helps in acquisition of data in a short time at periodic intervals (temporal), at different wavelength bands (spectral) and covering large area (spatial). Remote sensing data acquired from space borne platforms, owing to its wide synoptivity and multi-spectral acquisition offers unique opportunities for study of soils, landuse/cover and other parameters required for hydrologic modelling of large areas (Schultz, 1988). Some of the research workers in India attempted to calculate runoff curve numbers using Landsat, IRS-I A and IRS-I B satellite data. Ragan and Jackson (1980) estimated the runoff curve number of a basin using Landsat data. Hill et al. (1987) generated SCS runoff curve numbers for a 1542 km^2 basin at Louisiana and Mississippi using a raster GIS. Tiwari et al. (1991) modified SCS runoff curve numbers for the Kaliaghti River basin of West Bengal, India from a digitized landuse/cover map derived form the IRS-IA (LSS-II) data. Chakravorty (1993) explained in his review paper a combination of the watershed resource database creation through remote sensing and use of runoff and sediment yield models. GIS provides a digital representation of watershed characteristics used in hydrologic modelling (Burrough, 1986). Remote sensing integrated with commercially available GIS software were efficiently used in generating input parameters of hydrological models (Stuebe and Johnston, 1990, Das et al., 1992, Meyer et al., 1993). Numerous models have been developed to predict runoff from agricultural land and watershed under various management regimes (Singh, 1995). Most of the models developed are empirical in nature. Moreover, they were developed for a particular location under specific physiographic and climatological conditions, which can not be applied elsewhere. They have to be properly updated, tested and validated with observed data before such empirical relations are recommended. Although various empirical techniques are available for prediction of runoff using rainfall data alone, these techniques do not give an accurate prediction, as rainfall alone is not adequate for the purpose. Besides rainfall there are many other watershed parameters which influence runoff production. Studies relating the geomorphic parameters and runoff have also been made for some of the Indian watersheds. In these studies, watershed parameters were extracted manually and correlated with runoff (Jose and Das, 1982; Nagaraju, 1987; Misra, 1988).

Geleta (1993) used a GIS software (ILWIS) for runoff modelling in the Nalota Nala watershed of U.P., India (99.3 ha) by using rainfall, landuse and soil data in SCS curve number method. Bisoyi (1999) performed surface water modelling using SCS curve number method for Chandrabhaga watershed of Tehri-Garhwal District of Uttar Pradesh (now Uttaranchal). The results suggested that when the soil was totally unsaturated with water because of dryness, a good portion of rainwater was recharged to the water table. But when the soil becomes thoroughly wet and completely saturated with water, then approximately 40% of the rainwater are contributed to surface runoff.

2.7 SUMMARY

To summarize it has been observed that remote sensing provides an excellent source of data for landuse change detection, groundwater resources evalution, monitoring and development planning. Application of remote sensing data integrated with GIS systems can be utilized for determining soil erosion and runoff characteristics of any watershed. A groundwater resource evaluation programme demands a huge database including water levels, lithology and geological characteristics of aquifer material, hydraulic properties, recharge-discharge relationship and chemical concentration. GIS is the appropriate tool for integration of data from diverse sources, scale and projection. Integrated approach certainly enhances the quality of the output because it allows a far broader perspective to answer a large number of questions in spatial context. With the availability of higher spatial and spectral resolution of remote sensing data, and advanced image processing and GIS systems, there is scope for increased utilization of the potential of GIS and improvement in the integrated approach. In this study, an attempt has been made to utilize the potentiality of these two technologies in an integrated manner to establish the landuse-hydrological relationship of Dwarkeshwar watershed, West Bengal, India.

Chapter 3
METHODOLOGY

3.0 INTRODUCTION

The present study attempts the development of an integrated remote sensing and GIS technique to analyze the landuse-groundwater relationship in the Dwarkeshwar watershed. The study finally leads to the development of an Arc View extension for evaluation of groundwater resources and selection of suitable sites for artificial recharge structures. Remote sensing data sets have been used to extract information on geologic and geomorphic features controlling groundwater occurrence and movement, and also to visualize the surface expressions of groundwater. Field data e.g., depth to water level data, form an integral part of the study. Thematic information from various sources and scales has been used to support remote sensing data interpretation. GIS provides the appropriate tool to converge this large volume of data into same spatial georeferencing system for integrated analysis and decision support.

A general outline of the methodology followed in the present study has been presented in this chapter. A detailed discussion is given in the succeeding chapters. The methodology is summarized in the following steps (Figure 3.1):

1. Data input
2. Preprocessing
3. Digital image processing of remote sensing data sets.
4. Processing of ancillary and field data to generate thematic information
5. Development of the spatial database
6. Integrated analysis functions
7. Decision making and qualitative assessment of groundwater conditions
8. Selection of suitable site for artificial groundwater recharge
9. Computation of groundwater recharge using GIS

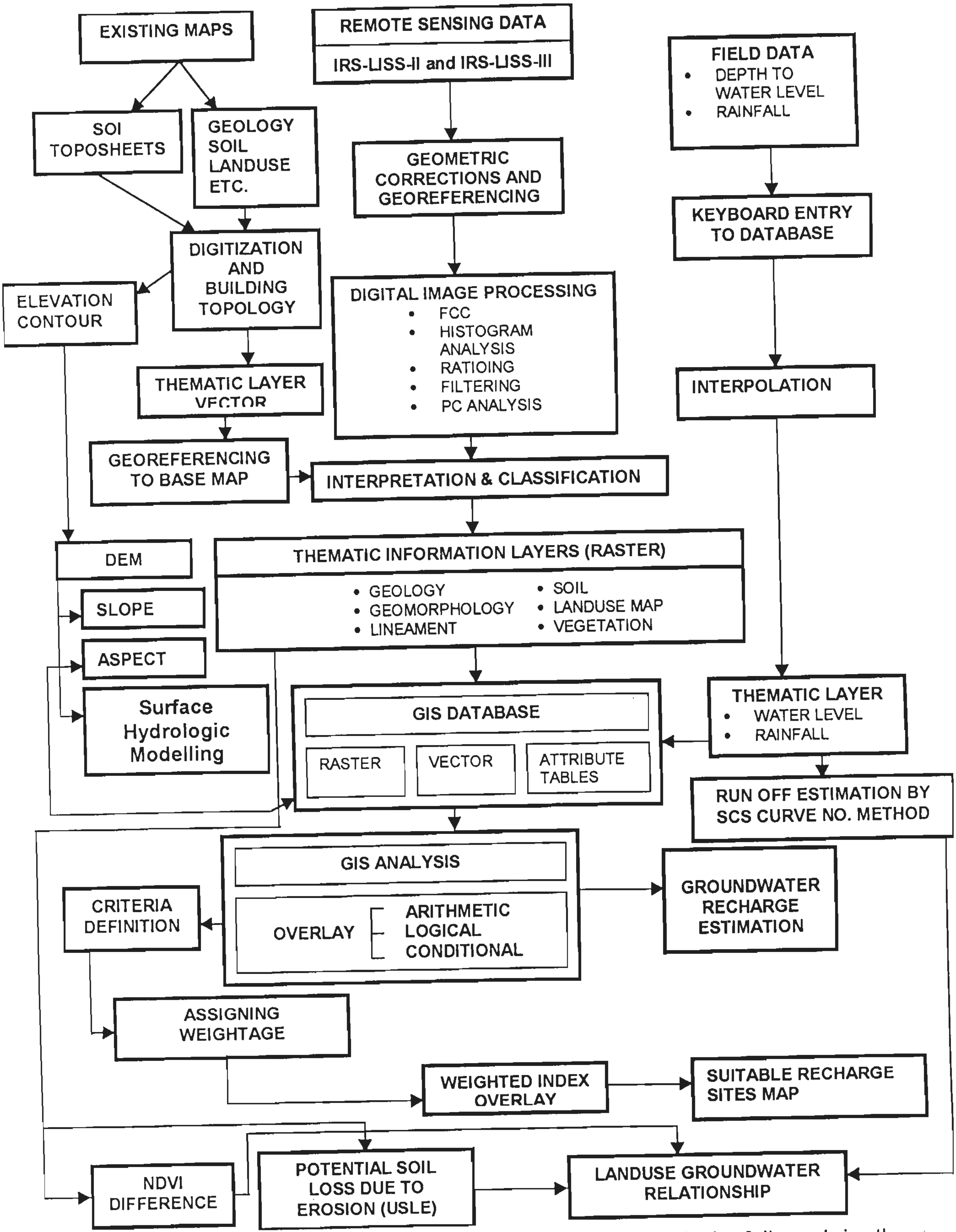


Figure 3.1: Flow chart showing the different GIS analysis followed in the present study.

10. Estimation of soil loss due to erosion
11. Estimation of runoff depth and peak discharge using SCS curve number method.
12. Ground truth check/collection
13. Generation of output

3.1 DATA USED

Three sets of data have been used for the present study:

(a) Remote sensing digital data (Table 3.1).

(b) Existing maps (Table 3.3).

(c) Field data

Table 3.1: Details of remote sensing data used.

Satellite	**Sensor**	**Data format**	**Source**	**Details**			**Date**
				Path	Row	Subscene	
IRS-1B	LISS-II	Band Interleaved by line (BIL)	National Remote Sensing Agency (NRSA)	19 20	51,52 51,52	A1,A2 B1,B2	3-11-88 26-11-88
IRS-1C	LISS-III	Band Interleaved by line (BIL)	National Remote Sensing Agency (NRSA)	106 107	56 56	Full Scene	14-11-96

The choice of time for acquisition of remote sensing data is very important for geohydrological studies. Immediately after the monsoon, spectral signature of vegetation dominates which suppresses geologic and geomorphic features. On the other hand, terrain will be more or less devoid of vegetal cover just before the onset of monsoon. Therefore, an intermediate time has been chosen before the harvesting of the winter crops in order to get the balanced response of vegetation, geologic and geomorphic features. The spectral characteristics and other properties of the sensors are summarised in Table 3.2.

Table 3.2: Details of the IRS-1B & 1C sensors (LISS-II and LISS-III)(after IRS-Data Users Handbook, 1989 & 1995)

Sensor	**Spectral Band**	**Spectral Range (μm)**	**Spatial Resolution (m) Sensor**	**Application**	**Swath (km)**	**Orbital Altitude (km)**	**Repetitive Coverage (days)**	**Quantisation (bits)**
LISS-II (Linear Imaging and Self Scanning Sensor)	B1	0.45-0.52	36.25	a. Coastal environmental studies b. Soil/ vegetation differentiation c. Coniferous/ deciduous vegetation differentiation	141	904	22	7
	B2	0.52-0.56	36.25	a. Vegetation vigour b. Rock/soil discrimination c. Turbidity and bathymetry in shallow waters				
	B3	0.62-0.68	36.25	A strong chlorophyll absorption leading to discrimination of plant species				
	B4	0.77-0.86	36.25	a. Delineation of water features b. Landform / geomorphic studies				
LISS-III	B1	0.52-0.59	23.5	Same as B2 of LISS-II	141	817	24	7
	B2	0.62-0.68	23.5	Same as B3 of LISS-II	141			
	B3	0.77-0.86	23.5	Same as B4 of LISS-II	141			
	B4	1.55-1.70	70.5	a Leaf water content b Canopy water status c Forest and crop type mapping d Lithological studies	148			

Table 3.3: Details of existing maps and field data used in the present study.

Type	Theme	Source	Details	Year	Scale
Existing Maps	Toposheets	Survey of India (SOI)	73 I	1923-28	1:250,000
			73 M	1923-31	
			73 I / 10	1973-74	1:50,000
			73 I / 11	1973-74	
			73 I / 12	1973-74	
			73 I / 14	1973-74	
			73 I / 15	1973-74	
			73 I / 16	1973-74	
			73 M / 3	1971-72	
			73 M / 4	1970-71	
			73 M / 7	1968-69	
			73 M / 8	1968-69	
	Geological Quadrangle Map	Geological Survey of India (GSI)			1:250,000
	Soil Map	National Bureau of Soil Survey and Landuse Planning (NBSS & LUP)			1:250,000
	Block Map	NBSS & LUP			1:250,000
	Geomorphological Map				1:250,000
Field data	Hydrological Data	NRDMS Office, BANKURA & PURULIA	Depth to water level of hydrograph network stations (4 times /year)		SWID Calcutta
	Meteorological data	NRDMS Office, BANKURA & PURULIA	Monthly rainfall data		

Thematic maps are prepared by various organizations under different projects. Naturally, they are in different scales. These maps are mainly used to support the interpretation of remote sensing images. Field data are point information of the hydrologic and meteorological variables. Field data have been converted to areal information in GIS for further use in GIS analysis. The details are given in Table 3.3. All the data were in analogue format.

In addition to all these data sets, some information, derived from existing hydrogeological investigation reports of the present area, have also been used to validate the modelled results (Saraf et al., 1999; Vijay 1999; Integrated Mission for Sustainable development PHASE-II project report, 1997).

3.2 SOFTWARE & HARDWARE USED

3.2.1 Software

- Arc View 3.1 and 3.2 with Spatial Analyst 1.1 Extension and Image Analyst Extension (ESRI, U.S.A)
- Various extensions developed by Dr. A.K. Saraf and available on ESRI website e.g. Grid Analyst, Vector Conversion, Nearest Neighbourhood, Themes intersection to points, Themes tool dialog, Lineament/drainage density analysis etc.
- ILWIS 1.41 and 2.1 (ITC, The Netherlands)
- Aldus Photostyler 2.0 Special Edition
- PC-ARC/INFO 3.5 (ESRI, U.S.A.)

3.2.2 Hardware

Pentium III-300 Mhz, RAM-128MB, 5.5 GB HDD, 17" SVGA Monitor, Windows 95.

Input Devices	:	A0 size Summagraphics Digitizer
Output Devices	:	HP LaserJet 5/5M Printer
		HP Colour Laser 4600 DN Printer

3.3 DATA INPUT

The very first step is to bring all the data (except remote sensing data since these were procured in digital format only) into digital format. Analog maps have been converted into digital format using manual digitization method in ILWIS 2.1 software. Base map for the study has been generated from SOI (Survey of India) toposheets at 1:50,000 scale, digitizing surface drainage features, transportation network, canals, drainage, latitude-longitude and watershed boundary. In case of linear features e.g. roads, railway lines, drainage, elevation contours etc., the corresponding attributes are attached directly during digitization. Polygons digitized from the area features e.g. geological formation, forest cover, soil types, landuse classes etc. have been transformed to PC-ARC/INFO coverage and topology of the features have been built. The point observations comprising hydrologic and meteorological variables have been entered manually through keyboard entry into the GIS database along with geographic coordinates in a tabular form and stored as a database file. Remote sensing data were available in CDs. These data have been directly read off in the system through Photostyler 2.0 into different spectral bands.

3.4 PREPROCESSING

The digitized layers of information as well as remote sensing data needs certain preprocessing. The topology for the vector polygons have been made in PC-ARC/INFO after cleaning the arcs and the respective attribute information was attached. As the data have been collected from diverse sources, the coordinate systems were different. All these maps have been transformed to the geometry of the base map in ArcView 3.1. An affine transformation function was performed based on ground control points in both the layers. Care has been taken to minimise the root mean square (RMS) error.

In order to remove the geometric distortion and for use in GIS analysis, remote sensing data have been georeferenced to the base map. Ground control points have been taken at the junction of road, railway line, and drainage intersection. An affine transformation is performed and resampling was done using the nearest neighbour interpolation method. RMS error was kept within one pixel both with LISS-II and LISS-III datasets.

Data format conversion is another crucial issue. Most GIS systems allow raster-vector overlay operations. Raster data format is preferred for hydrogeological purposes because the boundaries of change in the hydrogeologic variables are often gradational. Hence, the thematic layers on geology, geomorphology, and soils have been rasterized for calculation and analysis. Overlay analysis in vector format has also been done to derive further information.

3.5 DIGITAL IMAGE PROCESSING OF REMOTE SENSING DATA

The next step involves digital image processing of remote sensing data for extraction of pertinent information through visual interpretation and classification for further use in GIS analysis. Various standard digital image processing techniques have been applied to remote sensing data to enhance and extract information on lithology, geomorphology, landuse, structural features and vegetation cover (Jensen, 1986; Drury, 1987). Enhancement in the spatial and spectral domain has been used in combination.

Contrast stretching of individual raw bands is one of the initial steps and is effective in improving interpretability of different features through increasing contrast. To have an idea of the frequency distribution of the data, image histogram of the bands has been studied. Histogram equalization stretch is very useful in increasing the contrast of image.

Standard False Colour Composite (FCC) from bands 4, 3, 2 of LISS-II (3,2,1 in case of LISS-III) coded in red, green and blue colour scheme highlights the geomorphological features, landuse, vegetation cover and soil types.

3.6 PROCESSING OF ANCILLARY INFORMATION AND FIELD DATA

GIS analysis needs spatial information of hydrologic variables, may it be rainfall or depth to water level. Point data are to be converted to areal data.

Various methods of interpolation are in use. Deterministic approach fits a surface through the observation point values, by some mathematical function. Statistical methods examine the spatial correlation of the data set. Choice of interpolation method depends on the nature of variation of the variable. Details about interpolation techniques used in the present study are given in the following sections.

3.6.1 Rainfall

The first task in areal rainfall estimation is the choice of interpolation method. The most familiar and simple method for estimation of areal rainfall are isohyetal method and Theissen polygon method. These are based on simple linear interpolation. The most important factors to be considered are the accuracy of measurement and the gauge density. It is very difficult to measure rainfall even at a point with perfect accuracy. Rodda et al. (1976) after studying the capture of rainfall by different types of gauze environment, defined the true rainfall as "the amount of rain that would have reached the ground if the gauge have not been there".

In the present area, the gauge density rainfall measurement is poor. However, the general trend of monsoon rainfall does not show much variation within the area and a uniform pattern of distribution can be noticed. In this case, inverse distance weighing scheme has been used. In this scheme, the weight of an observation point diminishes as the distance from the point increases. The weights depend on the distance only. The value of intermediate points is calculated from the summation of the product of the observed values Z_{1k} and weights W_k, divided by the summation of the weights, within a given window of m reference points.

3.6.2 Topography

Topography cannot be considered as a true stochastic variable (Meijerink et al., 1994) and statistical methods are not suitable to represent the topographic surface. The present area does not show large variation in elevation. Various interpolation methods e.g. inverse distance weightage were tried. Linear interpolation is found to give good result in areas of dense contours at regular intervals, but areas where sampling density is low, this gives erroneous result. Spline interpolation has been found suitable for a gently varying surface like topographic surface. It fits a minimum curvature surface through the input values by polynomial functions. Spline interpolation gives a fairly good result in the area. Elevation contours have been digitized at 20m interval from SOI toposheets. Spot heights are also entered in the tabular form and subsequently using both contours and spot heights, DEM has been prepared. Calculating the local first derivative in x and y direction, slope map has been generated. Aspect map has also been generated by the direction of slope.

Further, various derivatives of DEM e.g. flow direction and flow accumulation, have been generated using the method presented by Jenson and Domingue (1988). Drainage network and also stream order are derived from flow accumulation grid (discussed in Chapter 6).

3.6.3 Groundwater

Groundwater surface is generally a subdued replica of the topography. Usually, it has a gentle gradient. However, in hard rock terrain, the groundwater surface may be discontinuous due to variable weathered thickness. In the present area, density of observation wells is not very high. Inverse distance weightage is used for interpolation of the water level data. The choice of method was decided based on comparative assessment of results from three different methods e.g. inverse distance weightage, spline and kriging.

3.7 GIS DATABASE DEVELOPMENT

The GIS database has been generated in ArcView GIS 3.2. All the data have been registered to the base map. Tabular database attached to the thematic information layer is continuously upgraded interactively. Many attributes have been attached to one point or polygon data. In ArcView, vector data, raster maps (grid) and image data can be handled simultaneously.

3.8 INTEGRATED ANALYSIS

The ultimate utility of GIS is in spatial decision-making and integrated analysis. There are two important aspects of integration (Rao et al., 1994). These are:

a) The criteria defining the logic of the analysis of composite information set.

b) The relative importance of weightage of each parameter.

GIS analysis operations have been performed in raster (grid) format. However raster-vector overlay and query generation can be performed in integrated GIS analysis. Various methods of combining multi-parameter data sets are in use. In the present study Boolean logic model and weighted index overlay method have been employed. Boolean logic model is the simplest method in GIS analysis. In case of weighted overlay analysis, weightage is assigned to the parameters on the basis of relative contribution towards the output. The strength of this method is that it is very straightforward and it allows incorporation of human judgment in the analysis. Further, weighted index overlay method takes into consideration the relative contribution of each parameter as well as their classes. Ground water potential zones have been mapped through weighted indexing. Suitable sites for artificial recharge structure have been selected through combination of weighted indexing and logical and conditional overlay analysis. For quantitative assessment of groundwater recharge, water level fluctuation method has been used.

3.8.1 Defining the Criterion

Simple overlay analysis of DEM, geology, geomorphology and drainage layers in GIS provides a greater understanding of these in controlling the ground water regime of the area. The time of acquisition of remote sensing data was chosen carefully so that the geologic and geomorphic features can be discriminated from vegetation. Moreover in dry season healthy vegetations are indicators of ground water. Pre- and post- monsoon water table and rainfall grids have been interfaced with geomorphic features in order to understand the response of various geomorphic features to rainfall as expressed by the rise in water table. Ground water recharge areas have been delineated from remote sensing data in conjunction with other datasets (discussed in Chapter 6).

On the basis of this analysis, criterion for ground water potential mapping has been defined. The criterion for suitability analysis of artificial recharge areas has been designed based on the observations from different thematic maps.

3.8.2 Determining Weights

There are various methods of assigning weights. The relative importance of parameters vis-a-vis the objective is represented by a set of weights. Sometimes these are called utility. In case of binary input maps, each map carries a single weight factor. Else weights may be of equal interval or unequal values. Although there is no standard unit of weightage, usually weights are expressed on a scale of 1 to 10. This is the most simple and straightforward method. In the present study, 1 to 10 scale has been adopted with weightage of equal interval and weights are assigned to the parameters on the basis of diminishing influence towards the desired output for 1 to 10. Then different classes of each parameter are assigned again with weight 1 to 5. Finally, the weighted score for a pixel is calculated by the following formula (Bonham-Carter, 1996),

$$\overline{S} = \frac{\sum_{i}^{n} S_{ij} W_i}{\sum_{i}^{n} W_i} \tag{3.1}$$

where, $\overline{S}$ = weighted score

W_i = weight for i^{th} input map

S_{ij} = score for j^{th} class of i^{th} map

j = class occurring at the location.

This is a more flexible method of weighted analysis. The advantage of weighted index overlay method is that individual parameter and scores can be adjusted according to the judgement of an expert. Map scores can be chosen as positive integers or real number. The disadvantage of this method is its linear additive nature.

3.8.3 Logical and Conditional Operation

Logical overlay operation work with AND, OR, XOR, NOT. (Aronoff, 1989; Burrough, 1986). Conditional statements are constructed as the IF, THEN, ELSE format or using two-dimensional tables. Both Conditional and logical statements have been used while selecting the artificial recharge sites. Queries have been generated across multiple themes.

3.8.4 Weighted Index Overlay

Two cases of weighted overlay functions are performed: (a) binary weights and (b) weighted indexing. In case of binary weights, only one parameter has been given weightage. Thus, fulfilling this situation, the map gets a value of 1 else 0 (zero). 1 means suitable and 0 means not suitable. This is highly subjective and cannot be used in case of ground water prospects mapping. Weighted indexing is a more rational method. Here, weighted score is calculated by contributions of human judgement and mathematical functions. This method has been found to give the best results.

3.9 RECHARGE ESTIMATION USING WATER LEVEL FLUCTUATION METHOD

Water level fluctuation caused by monsoon rainfall is considered as the index for groundwater recharge. Difference between post- and pre-monsoon water level gives the water level fluctuation image. Average water level fluctuation of 10 years (1989-98) has been used and interpolated to give rise to a water level fluctuation image. Values of specific yield for the different geological unit have been taken as suggested by Karanth (1987). The recharge map thus generated gives a rough estimation of dynamic groundwater recharge.

3.10 SOIL EROSION ESTIMATION USING UNIVERSAL SOIL LOSS EQUATION (USLE)

The USLE first introduced by Wischemeier and Smith in 1965, is an empirical model most widely used for estimation of soil loss from sheet and rill erosion. In this study the USLE parameters are evaluated for each sub unit and then combined for the total area. In the raster system each cell in the analysis grid serves as a sub unit (discussed in Chapter 5). The output is obtained in the form of a map depicting soil loss of the area.

3.11 ESTIMATION OF RUNOFF BY USING SCS CURVE NUMBER METHOD

Runoff is dependent upon various factors related to the watershed and the atmosphere. The accurate estimation of all these factors are not an easy task. Hence determination of accurate runoff rate and volume for a watershed is difficult. In this study SCS curve number method has been used for the estimation of runoff depth and discharge. At first the antecedent moisture condition and the physical characteristics of the watershed are correlated to give the hydrologic soil groups (discussed in detail in Chapter 5). In the landuse map each landuse class has been assigned a runoff curve number value for different AMC conditions by using Runoff Curve Numbers table given in Appendix A. The runoff depth and the peak discharge after the occurrence of a storm event are calculated.

3.12 GROUND TRUTH CHECK

For ground truth checking of the interpreted results, limited sites were selected. Mainly those areas were visited where diverse landuse categories existed within a small area. The findings from remote sensing data match with real ground conditions. Field photographs were taken at various places to show different landuse practices. The effect of ground water recharge from recharge ponds and basins was clearly visible in the field.

3.13 GENERATION OF OUTPUT

Finally the analysis results have been represented in the form of maps, graphs and tables. The results can be saved as ArcView projects for further use. Hard copies of the maps have been taken through the colour laser printer.

Chapter 4

APPLICATION OF INTEGRATED REMOTE SENSING AND GIS IN LANDUSE CHANGE DETECTION AND VEGETATIVE INDEX

4.0 INTRODUCTION

Landuse and landcover are among the most important and widely used environment data sets. Though often used interchangeably, there is a subtle distinction between the terms landuse and landcover. Landcover consists of the biophysical materials covering the earth's surface and landuse is the human use to which the land is put. The availability of up-to-date landuse/landcover data for the entire country is an issue of concern shared by many resource management agencies at all levels of government. However, in order to understand the landuse changes and various influencing factors, and interrelated intricacies a GIS based modelling approach is required. The main purpose in landuse modelling is to first identify the variables or parameters, which define the landuse in a given watershed and use these parameters to model the landuse. Such model may be used mainly to predict future landuse scenarios (landuse changes) by the change of variables however first task of such modelling to develop the understanding of the present scenario (Vijay, 1999). Although some attempts have been made by some workers to develop GIS based landuse models such as NELUP by O'Callaghan 1996 and CLUE by Veldkamp and Fresco, 1996. However all these models are area and size specific and require very detailed long-term and high resolution data sets and hence do not have direct applicability in the present study. The landuse change evaluation with respect to hydrologic changes is given by its affect on the hydrologic environment and ecosystem. In order to establish the impact of future landuse change on the water resources of a watershed, it is necessary to understand the existing hydrological conditions of the watershed and to quantify the extent to which the water resource will be modified. In addressing these two requirements a hydrological modelling system must account for the processes governing the movement and accumulation of water throughout the watershed and represent the controls on water movement and accumulation imposed by human actions.

In this chapter an attempt has been made in three directions. Firstly, it attempts for the evaluation of nature of changes in selected landuse categories. Secondly, to develop an integrated remote sensing and GIS technique to establish and evaluate the relationship between hydrology and landuse, the factors influencing this relationship and their role in controlling the groundwater scenario of the area. Further, a quantitative estimation of groundwater recharge has been performed in a GIS environment. Finally, an attempt has been made to model the influence of soil erosion factor on the landuse-hydrological relationship using an empirical model called universal soil loss equation (USLE) model and runoff characteristics obtained by using SCS curve number method.

4.1 LANDUSE CHANGE DETECTION

Information about change in the landuse provides valuable information on the processes at work. The information may be obtained by visiting sites on the ground and / or extracting it from remotely sensed data. Most change information eventually is placed in a geographic information system where it can be modeled with other data to derive new insight to the problem. Failure to understand the impact of sensor system characteristics and environmental characteristic on the change detection process can lead to inaccurate results. This chapter summarizes how change information is extracted from remotely sensed data. It first evaluates how remote sensing system and environmental parameters affect the change detection process. Some of the important change detection algorithms are identified and demonstrated. The chapter concludes with the evaluation of nature of changes in selected landuse categories.

4.2 REMOTE SENSING SYSTEM CHARACTERISTICS FOR CHANGE DETECTION

a) Temporal resolution

There are two important sensor system temporal resolutions that should be held constant when performing change detection. First, it is best to acquire data on anniversary dates (e.g., May1, 1997 versus May1, 1998). This removes seasonal sun angle differences that can destroy change detection study. Although, it is not always possible to take data on exact anniversary dates because of satellite orbit changes, cloud cover etc. It is good practice to have dates as close as possible to one another. Second, the data should be taken at the same time of the day, which will eliminate diurnal sun angle effect (e.g., Landsat TM data is acquired before 9:45 AM for most of the conterminous United States).

b) Spatial resolution and look angle

Ideally, the instantaneous field of view (IFOV) of the sensor system is held constant on each date, for it is easy to register these two images. Sometimes it is necessary to use data collected from two different sensor system in the change detection project, e.g., IRS-LISS-III data (23.5 x 23.5 m) for date 1 and PAN data (5.8X5.8 m) for date 2. Both datasets are then resampled to an acceptable minimum mapping unit pixel size (e.g., 5.8X5.8 m). However, this resampling will not yield any additional spatial detail as IFOV dictates the information content of the remote sensor data.

The remote sensor data should also be acquired with approximately same look angle whenever possible, e.g., some sensor systems like PAN are pointable and collect data at look angles that are off-nadir by as much as 90 degrees on either side. If our aim is to identify forest cover then a PAN image acquired at off-nadir would directly look down upon the "top" of the canopy. Conversely, a PAN image taken at 90 degrees off-nadir would record reflectance from the "side" of the canopy. Differences in recorded reflectance from the two datasets could cause change to be identified when in fact there was no change.

c) Spectral resolution

Ideally, the spectral resolution is held constant when acquiring multi-date imagery for change detection project. When it is not possible, the analysts should select bands that approximate one another from the two different sensor system. For e.g., IRS LISS III bands 3 2 1 can be used successfully with IRS LISS II bands 4 3 2. Some change detection algorithms do not function well when bands from one sensor system do not match those of another sensor system.

d) Radiometric resolution

Ideally, the remote sensor system used to collect data for change detection study needs to have same radiometric precision. When the radiometric resolution of the data acquired by one system (e.g., IRS-1C-PAN with 6-bit data) are compared with data acquired by a higher radiometric resolution instrument (e.g., IRS-LISS-III with 7-bit data), then the resolution data should be "decompressed" if possible to 7-bits for change detection purposes. It is important to remember that the precision of decompressed brightness values can never be better than the original uncompressed data.

4.3 ENVIRONMENTAL CHARACTERISTIC OF IMPORTANCE WHEN PERFORMING CHANGE DETECTION

It is desirable to hold environmental variable constant as possible when performing multiple-date change detection.

a) Atmospheric conditions

The multi-date data are rarely collected under identical atmospheric conditions. Subtle changes in humidity can have adulterous effect while significant cloud cover on any date can be disastrous to the project. Therefore, anniversary dates ensure general, seasonal agreement between the atmospheric conditions on multi-date imagery.

b) Soil moisture conditions

Soil moisture condition should be held as constant as possible. It is important not only to look for anniversary dates that tend to hold seasonal soil moisture conditions constant, but also to review precipitation records to determine how much rain or snow fell in days and weeks prior to the remote sensing data collection. When soil moisture differences between dates are significant for only parts of the study area (e.g., due to a local thunder storm) it may be necessary to stratify those affected areas and perform a separate analysis that can be added back in the final stages of the project.

c) Vegetation phenological cycle characteristics

Anniversary dates also minimize the effects of seasonal phenological differences that may cause spurious change to be detected in the imagery. One must be careful about two other factors when dealing with man-made agricultural land, rangeland, or forest landscape. First, monoculture crops are not always planted at exactly same time of the year. A fifteen-day lag in planting date between fields having the same crop can yield serious change detection error. Second, the monoculture crops are not always of the same species. Different species of the same crop can cause the crop to reflect the energy differently on the multiple dates of anniversary imagery. Remote sensing of change in vegetated landscapes require careful selection of critical dates in the phenological cycle of the plants and a keen awareness of how the plants reflectance properties change through time.

4.4 CHANGE DETECTION ALGORITHMS

The selection of an appropriate change detection algorithm should be based on an analysis of: (1) the cultural and biophysical characteristics of the study area; (2) the precision with which the multi-date imagery are registered; (3) the utility, flexibility, and availability of change detection algorithms. Five commonly used change detection algorithms are:

1. Post-classification Comparison
2. Write Function Memory Insertion

3. Image Arithmetic (Band Differencing or Band Ratioing)
4. Manual, on-screen Digitization of Change
5. Image Transformation (Multiple-date Principal Component Analysis)

4.4.1 Image arithmetic

Arithmetic operations may be applied to registered bands of imagery acquired on multiple dates to detect the change between images. Band differencing and ratioing are usually performed using a single band of imagery from each date. Image differencing involves subtracting the imagery of one date from that of another. The subtraction results in positive and negative values in areas of radiance change and zero values in areas of no change in a "new" changed image. In an 8-bit analysis with pixel values ranging from 0 to 255, the potential range of difference values is –255 to 255. The results are normally transformed into positive values by adding a constant. The change image produced using pixels of no BV changes are distributed around the mean and pixels of change are found in the tails of distribution. In the landuse change detection for Dwarkeshwar watershed the Image Arithmetic method has been used.

4.5 METHODOLOGY

The methodology followed in this study for landuse change detection involved the following three stages.

a) Data Extraction
b) Data Analysis
c) Results and Discussions

4.5.1 Data Extraction

The primary data extraction is visual interpretation of false colour composites of IRS-1B-LISS-II (Figure 4.1) acquired in November 1988 and IRS-1C-LISS-III (Figure 4.2) in November 1996 for mapping landuse/land cover information. Before generating a landuse map the digital data has

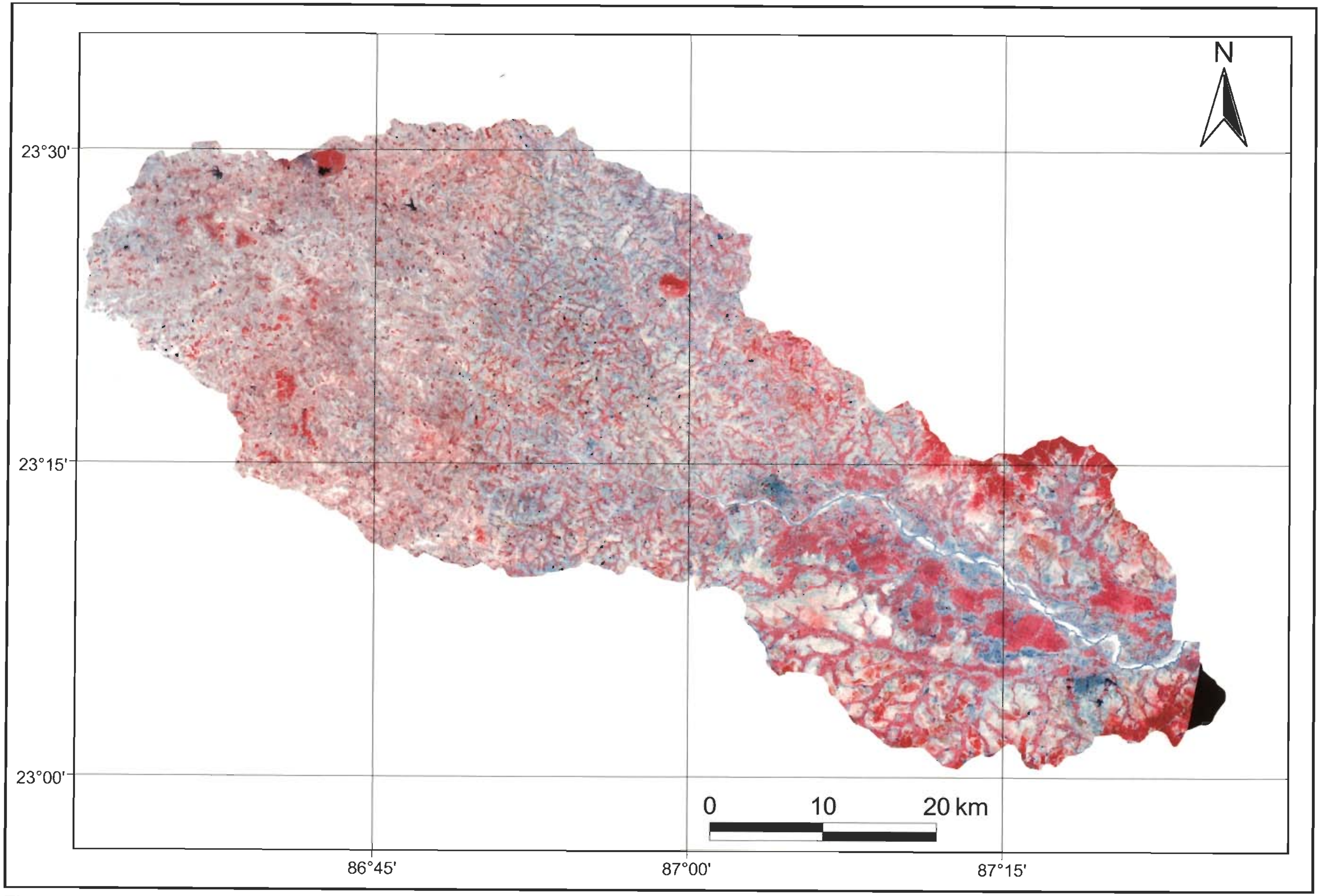


Figure 4.1: IRS-1B-LISS-II-FCC (bands 4,3,2 in RGB) for the Dwrakeshwar Watershed acquired in November, 1988.

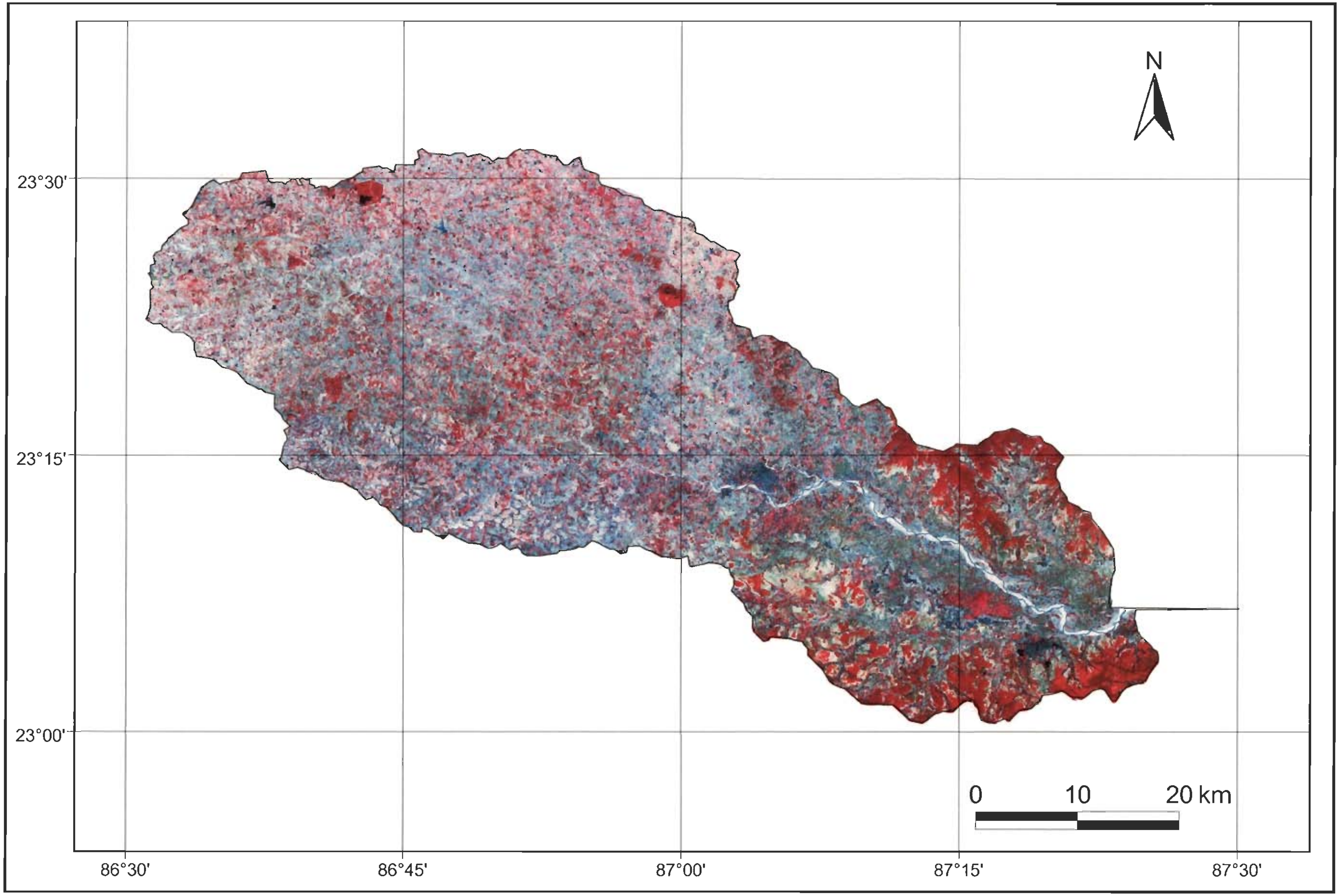


Figure 4.2 : IRS-1C-LISS-III FCC (bands 3,2,1 in RGB) for the Dwarkeshwar Watershed acquired in November, 1996.

to be converted into a valid image format from the raw format. The image translation is done with the help of header information, which describes the format of the data, itself. Typical header information includes the type of data, the size of the image, the image orientation, the application data, and the file storage format. The header information for a specific image might be located at the beginning of the image file or in a separate file. The specification of the two sets of data derived from different sensor is shown in (Table 4.1)

The digital data provides information belonging to a slice of time. Having digital data of two different periods one can visualize the changes that have occurred in the area. However such kind of data involve at least one level of indirection, as parameters are not directly measurable in remote sensing. So they must be related to a property that can be measured to give information about the object. This property is reflectance.

Table 4.1 Specifications of two sets of digital data

Year of launch	1988	1996
Satellite	IRS-1A	IRS-1C
Altitude	904 KM	817 KM
Repetivity	22 DAYS	24 DAYS
Numbering of paths	East To West	West To East
Sensor	LISS-II	LISS-III
Spatial resolution	36.5 m	23.5 m and 70.5 m (SWIR)
Swath (km)	146.98	141 and 148 (SWIR)
Radiometric resolution	7 (bits)	7 (bits)
Date & year of acquisition	3 November, 1988 26 November, 1988	9 November, 1996 14 November, 1996 4 November, 1997
Spectral resolution (μm)	0.45-0.52 0.52-0.59 0.62-0.68 0.77-0.86	0.52-0.59 0.62-0.68 0.77-0.86 1.55-1.70

When the image translation is done the header information of the output images is also created. Image analyst extension of ArcView 3.2 provides easy to use options for image translation. The output image file formed after image translation is segregated into all its bands. The header information of this image file can be read from the menu. The bands of image can now be used to display on the screen. One can open an image file showing single band or can open a composite file using several bands. The composite image can either be true or false colour composite. A standard FCC consist of displaying green, red, and infra-red bands with the help of blue, green and red electron-guns respectively. From the standard FCC information about vegetation condition can be deduced accurately.

The two FCC's were first preprocessed. This included checking of scan line correction and manipulating image geometry. Images are stored as raster data, where each cell in the image has a row and column number. Shapefiles and ARC/INFO coverages are stored in real – world coordinates. In order to display images with coverages or shapefiles, it is necessary to establish an image-to-world transformation that converts the image coordinates to real-world coordinates. This transformation information is typically stored with the image. This process is called image registration or warping.

The whole Dwarkeshwar watershed is covered in four scenes of LISS-II and LISS-III images. In order to display the whole watershed in a single image, a mosaic of the four scenes derived from each sensor has been prepared. This is possible only in case of overlapping images. Finally two registered FCC's have been prepared from the two mosaics.

The next step involves digital image processing of remote sensing data for extraction of pertinent information through visual interpretation and classification for further use in GIS analysis. The contrast between the features has been increased to separate one feature from the others.

4.5.2 Data Analysis

After creating a single mosaic and registered image of the whole area the image is classified using, various unsupervised and supervised

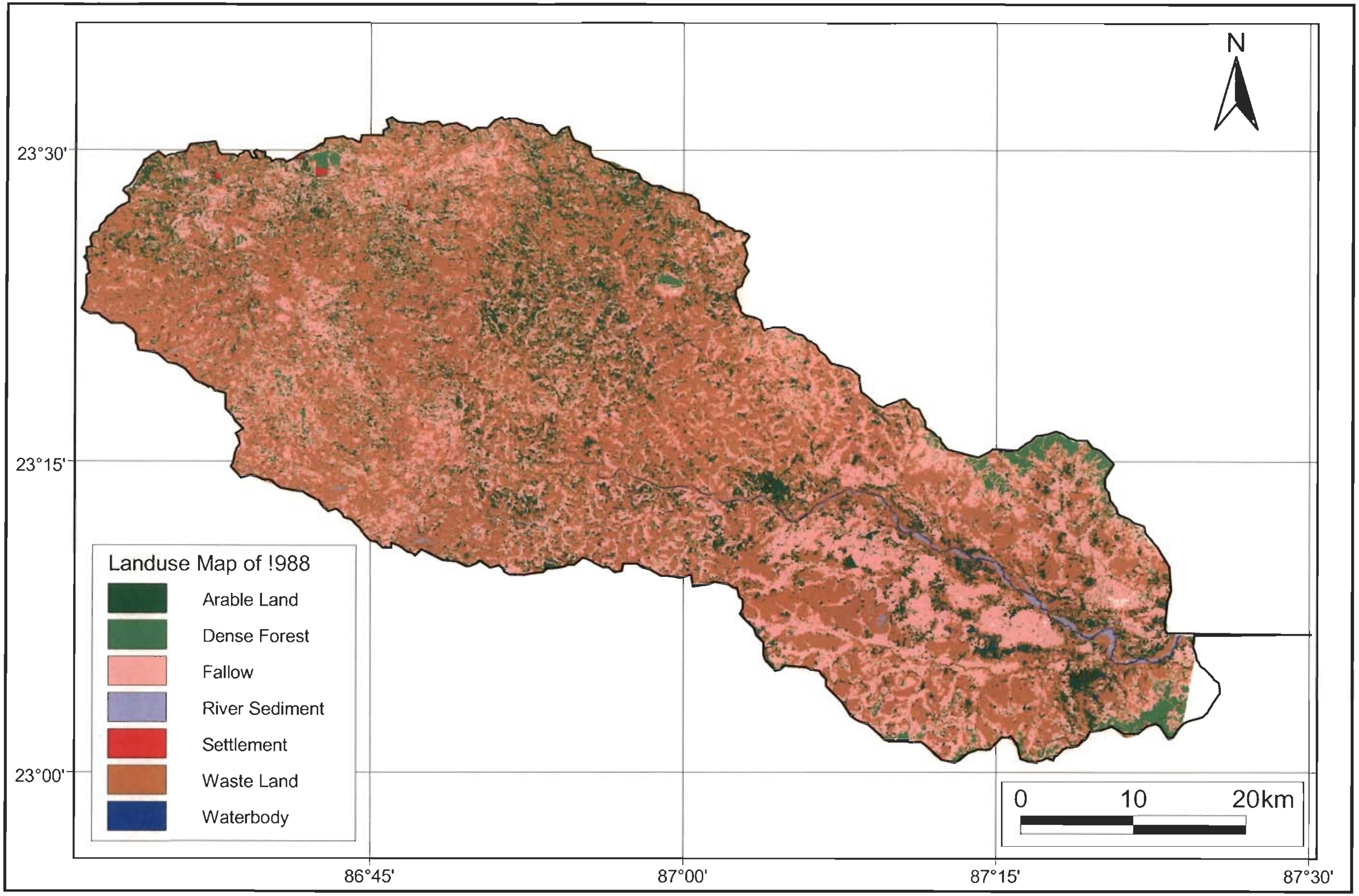


Figure 4.3 : Classified Landuse Map of the Dwarkeshwar Watershed prepared from IRS-IB-LISS-II data of November, 1988.

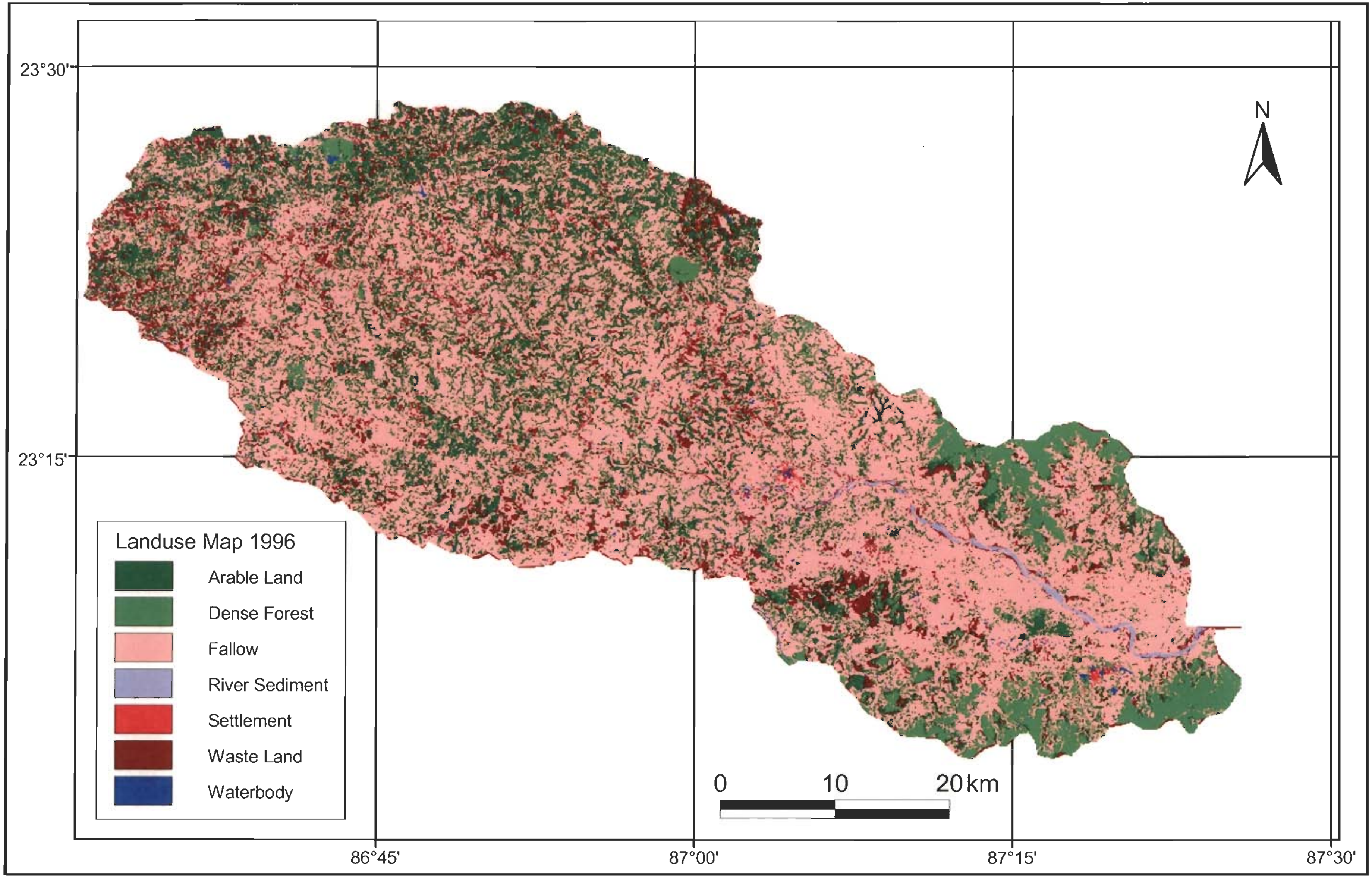


Figure 4.4 : Classified Landuse Map of the Dwarkeshwar Watershed prepared from IRS-IC-LISS-III data of November, 1996.

training options. The unsupervised training has yielded several spectral classes, which are difficult to be identified without ground truth. So the classification based on supervised training is preferred based strictly on those classes for which ground truth is available. From the ground truth knowledge following classes have been identified: -

1. Dense Forest
2. Water body
3. Fallow land
4. River Sediment
5. Arable land
6. Settlement
7. Waste land

The above-mentioned classes form the base on each of the FCC's for studying the landuse change. Prior to classifying the image, a training set is defined in which representative pixels for different spectral classes are defined. Based on these representative pixels, the classification proceeds, If there is misrepresentation of pixels in the training set, there will be corresponding misrepresentation of spectral classes. So the training set should be defined with utmost care and accurate ground truth information in case of supervised classification.

The IRS-LISS-II and LISS-III images are classified using supervised classification technique (Figure 4.1 and 4.2). The landuse maps of the year 1988 and 1996 are prepared (Figure 4.3 and 4.4) and the original extent of the landuse in 1988 is compared with the changes that have occurred in 1996 to compute an overall change patterns in each category.

The next stage of the analysis is to perform image subtraction. First, images of both the years are resampled to an equal size. In this case LISS-II image is resampled to the size of the LISS-III image as the spatial resolution of the latter is higher and hence more information available. If both the images are not of the same size then no image arithmetic can be applied, but after resampling pixels of 1988 landuse image are mapped with the pixels of 1996 landuse image.

The landuse map of 1996 is subtracted from the landuse map of 1988 resulting in the creation of change image/map (Figure 4.5). The subtraction results in positive and negative values in areas of change and zero values in areas of no change in a "new" changed image. The extent of changes from each category is identified from the pixel count of individual maps. Finally, the landuse change map is classified according to the changed status of the various landcover (particularly vegetation) in the watershed. The calculation of the statistics is done during the classification process.

4.6 RESULTS

a) Characteristics of landuse of the study area as interpreted from FCC's: The landuse of the study area is characterized by a mixture of forest cover, agricultural activities and wasteland, which are readily interpretable from the IRS-LISS-II and LISS-III satellite imageries (FCC's). The major part of the study area was predominantly wasteland especially in the western part of the watershed, which decreased significantly within last 8 years. The next predominant category of landuse is fallow land. The total forest cover inclusive of the plantation is found to increase significantly. Irregular patches of arable land occur in a random fashion in the study area. The main water body in the area is the Dwarkeshwar river which is the second major river, after river Damodar.

b) Landuse Change Detection: The landuse maps of 1988 and 1996 generated by the GIS approach are shown in Figure 4.3 and 4.4 It is clear that the wasteland is the most dominant class followed by fallow land in the year 1988. However, on comparing with the landuse map of 1996 reveals a decline in the wasteland from 48.17 percent to 8.65 percent, an increase in fallow land from 33.63 percent to 58.8 percent, dense forest increased from 2.9 percent to 7.1 percent. Water bodies have decreased from 0.8 percent to 0.61 percent. While arable land has increased from 13.88 percent to 24.1 percent, settlement has increased from 0.21 percent to 0.25 percent and river sediment has increased from 0.41 percent to 0.49 percent (Table 4.2).

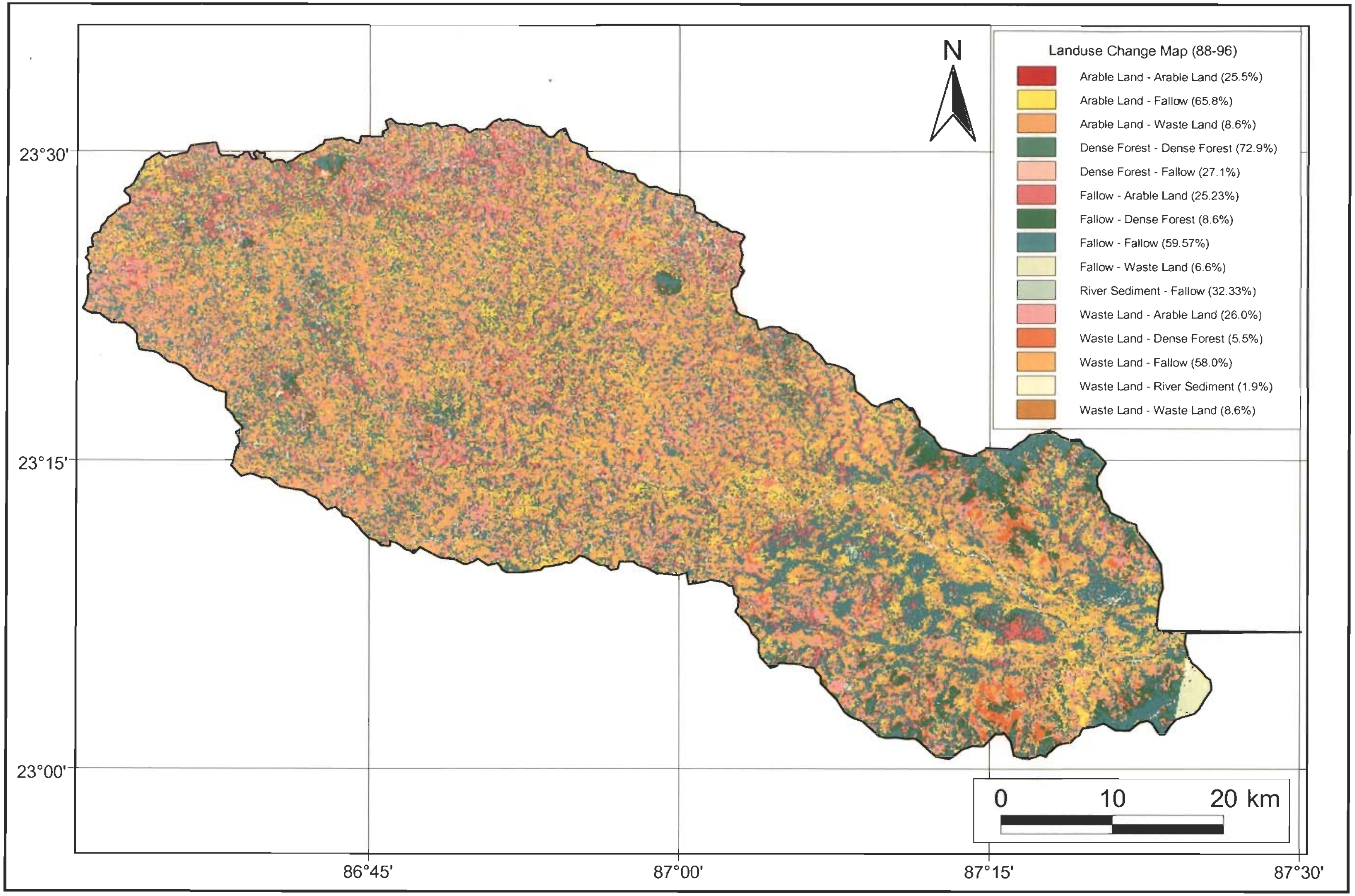


Figure 4.5 : Landuse Change Map (88-96) of Dwarkeshwar Watershed (Prepared from IRS-1B-LISS-II data of 1988 and IRS-1C-LISS-III data of 1996).

Table 4.2: Landuse in years 1988 and 1996

Landuse class	1988		1996	
	Area in sq. km	%	Area in sq. km	%
Dense Forest	65.83	2.90	161.17	7.10
Water body	18.16	0.80	13.84	0.61
Fallow land	763.40	33.63	1334.76	58.80
River Sediment	9.30	0.41	11.14	0.49
Arable land	315.10	13.88	547.07	24.10
Settlement	4.75	0.21	5.67	0.25
Waste land	1093.46	48.17	196.35	8.65
Total	2270	100	2270	100

Table 4.3: Category wise changes in landuse and area statistics

Landuse in 1988	Landuse in 1996	Change (in %)
Waste Land (1093.46 km^2)	Fallow (634.01 km^2)	58.00
	Arable Land (284.20 km^2)	26.00
	Dense Forest (59.26 km^2)	5.30
	River Sediment (20.65 km^2)	1.90
	Waste Land (95.34 km^2)	8.80
Fallow Land (763.4 km^2)	Waste Land (50.62 km^2)	6.60
	Dense Forest (65.61 km^2)	8.60
	Arable Land (192.49 km^2)	25.23
	Fallow (454.68 km^2)	59.57
Arable Land (315.1 km^2)	Fallow (207.57 km^2)	65.80
	Waste Land (27.24 km^2)	8.60
	Arable Land (80.29 km^2)	25.50
Dense Forest (65.83 km^2)	Fallow (17.93 km^2)	27.10
	Dense Forest (47.9 km^2)	72.90
River Sediment (9.3 km^2)	Fallow (2.9 km^2)	32.33
	River Sediment (6.4 km^2)	67.67
Waterbody (18.16 km^2)	River Sediment (4.3 km^2)	23.75
	Waterbody (13.84 km^2)	76.25

c) Nature of landuse change: The maps pinpointed the spatial locations where landuse changes have taken place. These landuse maps show the areal extent of landuse change (1988 to 1996) of a single particular category into other categories. Table 4.3 show category wise changes in landuse and area statistics from the year 1988 to 1996

4.7 FACTORS INFLUENCING LANDUSE CHANGE

The term landuse signifies optimum, efficient and dynamic use of soil. In other words, it implies utilization of land according to its capacity aiming at its best and sustainable use. The basic objectives of landuse change studies are as follows:

a) To restore productivity of the land.
b) To prevent deterioration of land resources.
c) To allocate land for different uses.
d) To install efficient and effective administrative structure for prescribing landuse.
e) To invoke the community for increased productivity.
f) To create greater awareness about conservation of land.
g) To prevent degradation of grassland for the livestock population.
h) To motivate farmers for cultivation of appropriate crop, fodder and trees.
i) To take up survey on land and soil.
j) To meet consumption need of the growing population.

Landuse is generally a man-land relationship. Also as human existence is not only controlled by biophysical variables but also by economic conditions. Hence, it is a function:

Landuse = f (economic, biophysical variables)

Therefore, landuse is not only an economic concept but also an environmental concept and ensures a proper land management whereas landcover is a parcel of land defined by biophysical variables only:

Landcover = f (biophysical variables)

Landuse is the use of this landcover only. Due to use of these landcovers these variables may change, rather will change with time and activity. The concept of efficient landuse implies that a change in these variables does not affect the environment drastically (O'Callaghan, 1996).

4.8 CONCEPT OF LANDCOVER TRIANGLE

Landuse is mainly related to the optimum use of the limited land between the alternative major types of landuse. Decisions about the allocation of land between competing uses are influenced to a large extent by market forces, which may put emphasis on short term results because to show adequate returns on the investments, which may have long term implications on the hydrology and ecology of the area.

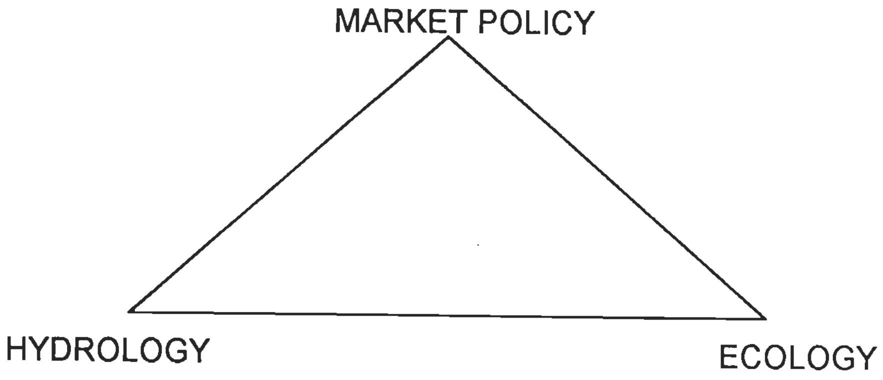


Figure 4.6: The interaction of economics, hydrology and ecology as shown in the landcover triangle (source: O'Callaghan, 1996)

Therefore, there are basically three variables that govern landuse as shown in Figure 4.6. The three corners of the triangle represent these variables. So any landuse study should include :

a) the way in which the land is allocated between different activities.

b) the impact of these activities on the environment.

As shown in Figure 4.6 the landcover triangle has three factors namely, market forces at the apex of the triangle and two other corners of this triangle having hydrology and ecology. It is assumed that a landuse change is governed purely by economic reasons. Therefore, modelling the cause of landuse change, thus has to precede analysis of the ecological and hydrological impacts of that change. This places economics at the apex of the landcover triangle (O' Callaghan, 1996).

4.9 ECONOMICS AS A VARIABLE

The whole land of the earth surface has potential value for some use or group of uses, although the area suited for any one use is often quite limited. Each piece of land has some inherent characteristics or capabilities that determine the value of land for any required use. Therefore, the use of land is also determined by the cost involved and the incurred profit. Again the purpose of landuse studies is to maximize the value returns. If a land can be used for more than one purpose then landuse will be such that profit incurred from that use is greater than alternative landuse and ideally should be maximum (Moxey et al., 1995).

The profit incurred is dependent on demand and supply relationship. This demand and supply relationship is directly dependent on market forces and indirectly on policy bodies. Therefore landuse is not only driven by market forces but also by policy changes. Hence the role of economics within landuse is to model the response of agriculture and forestry landuse to changing market and policy conditions.

4.10 HYDROLOGY AS A VARIABLE

The landuse change evaluation with respect to hydrologic changes is given by its affect on the hydrologic environment and ecosystem. For example;

a) What will happen if we remove the forest cover from the watershed; or half the forest cover, or one third of the forest cover in small patch cuts?

b) How will the water yield and flood frequency change, if a house site development and shopping center are constructed in a natural watershed?

In order to establish the impact of future landuse change on the water resources of a watershed, it is necessary to understand the existing hydrological conditions of the watershed and to quantify the extents to which the water resources will be modified.

4.11 ECOLOGY AS A VARIABLE

The basic ecological unit is that of the individual species. The aim of the ecological modelling can, therefore, be rationalized into achieving two objectives. Firstly, predicting where species are found in the landscape and secondly, predicting what effect landuse change has on these distributions. Thus, the ecological modelling can be seen as a large scale multi-attribute response model linking the distribution of species to landuse change (Rushton et al., 1995).

The land surface is subjected to continuous change due to natural and man-made causes. As the landuse in a watershed is altered in both space and time, the factors that influence the hydrologic response of the watershed also change. Evaluation of the relationship between landuse changes and such factors is one of the goals of the study of landuse-hydrology.

4.12 HYDROLOGICAL FACTORS

The hydrological factors influencing the landuse change are:

a) Rainfall
b) Recharge
c) Depth to water level
d) Soil erosion

4.12.1 Rainfall

The rainfall is one of the major factors in causing the landuse change (Figure 4.7). The main source of increasing the groundwater potential is recharging of rainwater and also in few extents from irrigation water, canal network, surface ponds, reservoirs etc. The Dwarkeshwar watershed experience an average rainfall during monsoon months, from June to September, constitutes about 78% of the annual precipitation. Despite sufficiently high annual rainfall, droughts are a major problem owing to the uneven distributions of rainfall. One out of every four years (on average) may be termed as a drought year. High run-off of rainwater, inadequate storage and the low moisture retentive capacity of the light textured soil accentuate the drought situation.

The average annual rainfall volume for ten years (1989-98) had been calculated (Figure 4.8). It may be inferred from the rainfall characteristics that the change in landuse may be partially due to the minor variation in rainfall.

4.12.2 Recharge

Water level fluctuation is the very simple method for seasonal groundwater recharge estimation. Water level fluctuation due to monsoon rainfall is considered as the index for groundwater recharge. Difference between post and pre-monsoon water level gives the water level fluctuation image. In the present area the southeast monsoon comes from June to September and the interval from October to the middle November constitutes the Post-monsoon period. Hence, water level data of April and November have been taken and the fluctuation has been computed. Quantitative assessment of groundwater resources is an important issue in groundwater development. The recharge volumes for the years (89-98) have been calculated. Figure 4.9 shows groundwater recharge volume from the year 1989 to 1998.

The year 1995 shows the maximum recharge volume compared to other years from 1989-1998. When average annual rainfall volume and the recharge volume for the years 1989-98 was compared, it was found that runoff has been more in the year 1993 than subsequent years where the recharge have increased sufficiently causing changes in landuse.

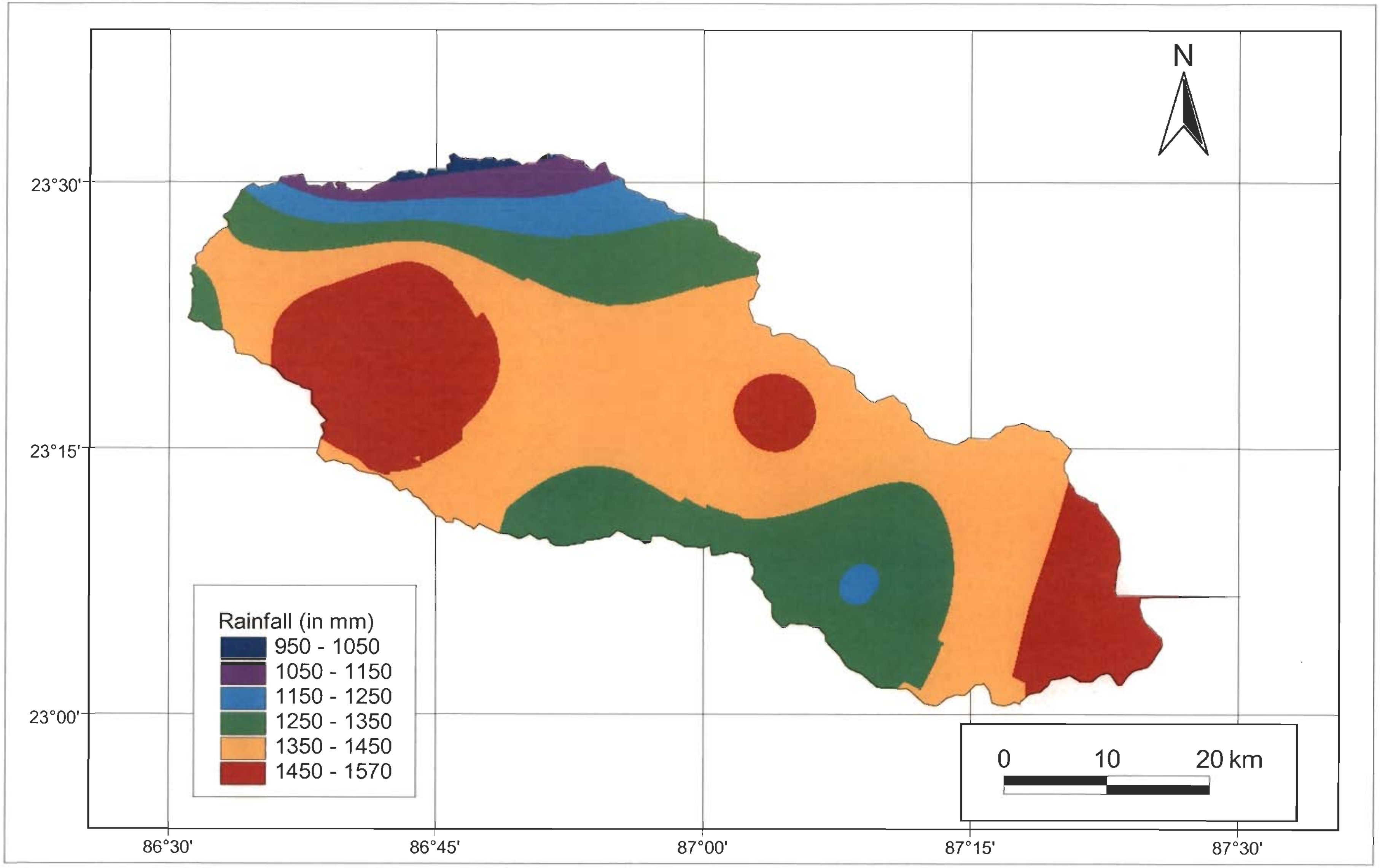


Figure 4.7 : Average Annual Runfall map of the Dwarkeshwar Watershed.

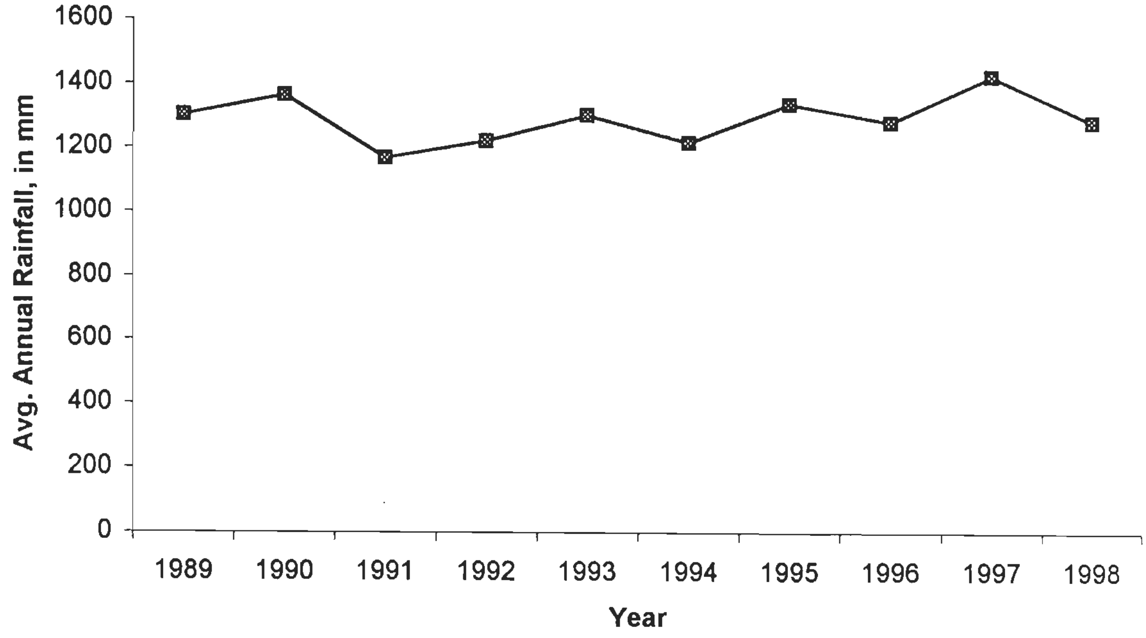


Figure 4.8 : Average annual rainfall of Dwarkeshwar watershed

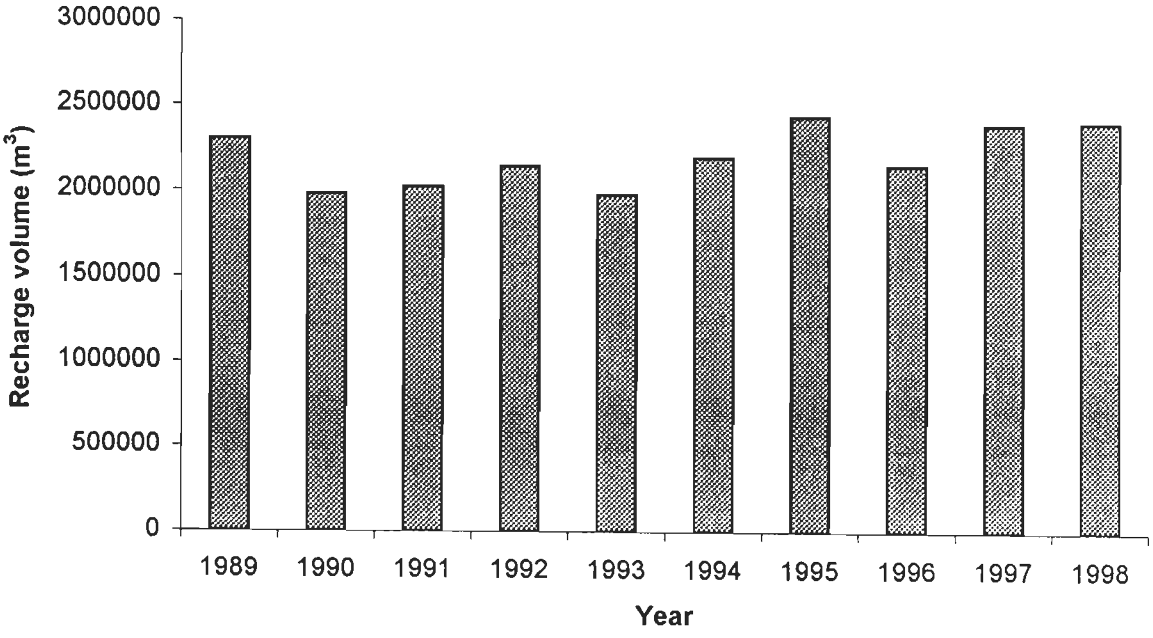


Figure 4.9 : Recharge volume of Dwarkeshwar watershed.

4.12.3 Depth to water level

Groundwater level data indicate the status of groundwater. Water level data from 34 hydrostations have been collected from the CGWB. Depth to water level measurement are taken at the hydrograph network stations and monitored by the CGWB four times in a year. These data have been analysed. The pre-monsoon depth to water level ranges from 2 m to 10.8 m b.g.l. The post-monsoon depth to water level ranges from 0.5 m to 7.8 m b.g.l. Since seasonal fluctuation of water table is directly related to groundwater recharge, subtraction of pre-monsoon water level from post monsoon water level below ground level yields a water level fluctuation image (Figure 4.10).

This image shows a low and high fluctuation zone (05-1.9 and 6.3 m) along the central part of the watershed. It gradually increases towards southwest and southeast. The maximum fluctuation in the southeast is 4.9 m b.g.l. This fluctuation could be attributed to the presence of agricultural tracts in these areas where sizable extraction of water takes place.

4.12.4 Soil Erosion

Soil erosion can be defined as removal of soil by forces of nature more rapidly than various soil-forming processes can replace it, particularly as a result of man's ill-judged activities. The main cause of soil erosion is the presence of susceptible soils on undulating topography with a poor cover by vegetation or crops. Important factors in the soil erosion process are the climate, slope, gradient, landuse, urbanization, ploughing direction, soil stability, soil sealing, infiltration capacity and the recent intensification of agriculture.

4.13 VEGETATION STUDIES

Multispectral satellite data has been found very useful in determining vegetation cover in an area. The application of multispectral scanner data to vegetation can be facilitated by the use of data transformations which reduces the number of channels to be considered, provide a more direct association

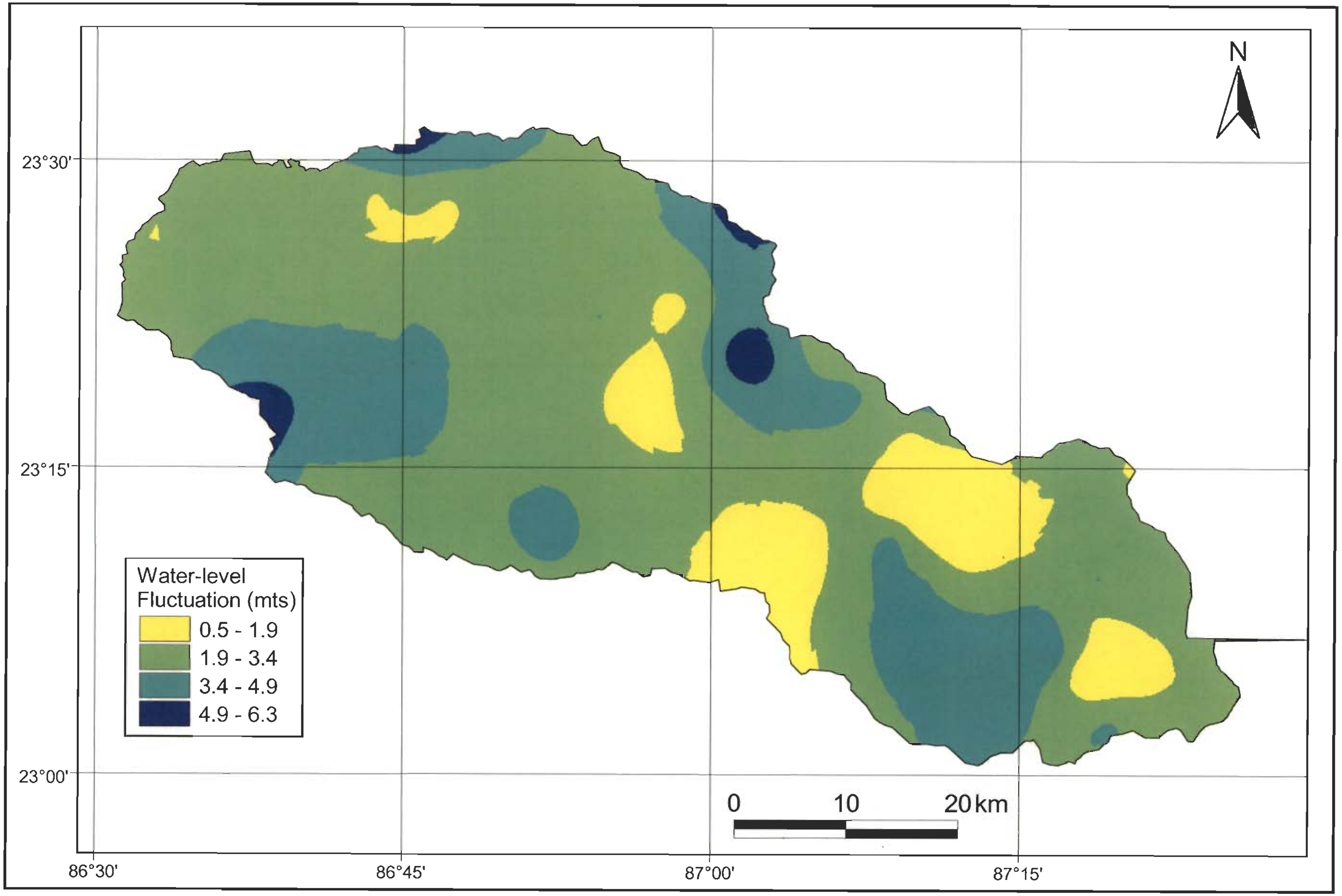


Figure 4.10 : Average Water level Fluctuation Map of Dwarkeshwar Watershed for the period 1989 - 1998.

between signal response and physical processes on the ground, and highlight the particular types of information of greatest interest to the user (Crist et. al., 1986). IRS-LISS-II and LISS-III multispectral data are used successfully to extract the vegetation information of different type of terrains (Choudhury, 1999; Roy, 2001; Kumar, 2001).

4.13.1 Spectral Properties of Vegetation

Electromagnetic radiation incident on an object is, either reflected, absorbed or transmitted, the proportion of the three being different for different objects as well as the sensors. The spectral properties of the materials depend on the physical and physiological nature. The most important are vegetation and soil properties. The spectral reflectance properties of leaf which is the simplest component of vegetation in the visible and infrared region is a function of the leaf pigments, the leaf cell morphology, internal refractive index discontinuities and the water content (Raines and Canny, 1980). The factors responsible for reflectance properties of vegetation canopy in the visible and near infrared region are different cell structures, proportions of chlorophyll and other pigments, surface morphology and water content. A plant leaf typically has a low reflectance in the visible spectral region because of strong absorption by chlorophyll, a relatively high reflectance in the near infrared because of internal scattering and a relatively low reflectance in the infrared beyond 1.3µm because of strong absorption by water (Knipling, 1970). Since organisms have life cycle of various duration, spectral properties change in response to temporal changes. Towards the end of the functional life of a plant, the tissues deteriorate and chlorophyll breaks down. This leads to a marked increase in reflectance at the end of the visible region (0.6-0.7 µm) as the chlorophyll absorption reduces. Near infrared, reflectance falls during senescence. In general, lower the water content of a plant the higher the reflectance in the middle infrared, with reflectance peak between moisture absorption band at around 1.6 µm and 2.2 µm (Belward, 1991).

4.13.2 The Normalized Difference Vegetation Index (NDVI)

Differences and similarities in sensitivity to vegetation conditions were compared among various spectral vegetation indices (VIs). All VIs show a qualitative relationship to variants in vegetation. However there are significant differences among the VIs in desert, grassland and forested biomes (Huete et. al., 1997). The Normalized Difference Vegetation Index (NDVI), which has been derived from the satellite data, has most widely been used to detect changes in global vegetation (Justice et. al., 1985). NDVI is computed from the difference between the near IR, L_{NIR} , and the red L_{RED} radiances reflected from the surface through the atmosphere.

$$NDVI = (L_{NIR} - L_{RED}) / (L_{NIR} + L_{RED})$$

The difference is sensitive to the presence of vegetation, since green vegetation usually decreases the signal in the red channel due to the Chlorophyll absorption and increases the signal in the Near-IR regions (Kaufman and Tanre, 1992).

Despite the presence of atmospheric effects NDVI has most successfully been used in vegetation variation studies. It is primarily due to the normalization involved in it's definition. The normalization reduces the effect of degradation of the satellite calibration from 10-30% to a single channel and 0-6% for the normalized index (Holben et. al., 1990). The effects of the angular dependence of the surface bi-directional reflectance and of the atmospheric effects are also reduced significantly in the normalized index (Kaufman and Tanre, 1992).

In this study the Normalized Difference Vegetation Index (NDVI) has been found to be very useful in detecting the changes in vegetation. NDVI images for both the satellites data sets were prepared in Arc View 3.2 using Image Analyst extension. The NDVI difference image is also prepared by subtracting the NDVI image of 1996 prepared from IRS-1C-LISS-III FCC from the NDVI image of 1988 prepared from IRS-1B-LISS-II FCC (Figure 4.11 and 4.12).

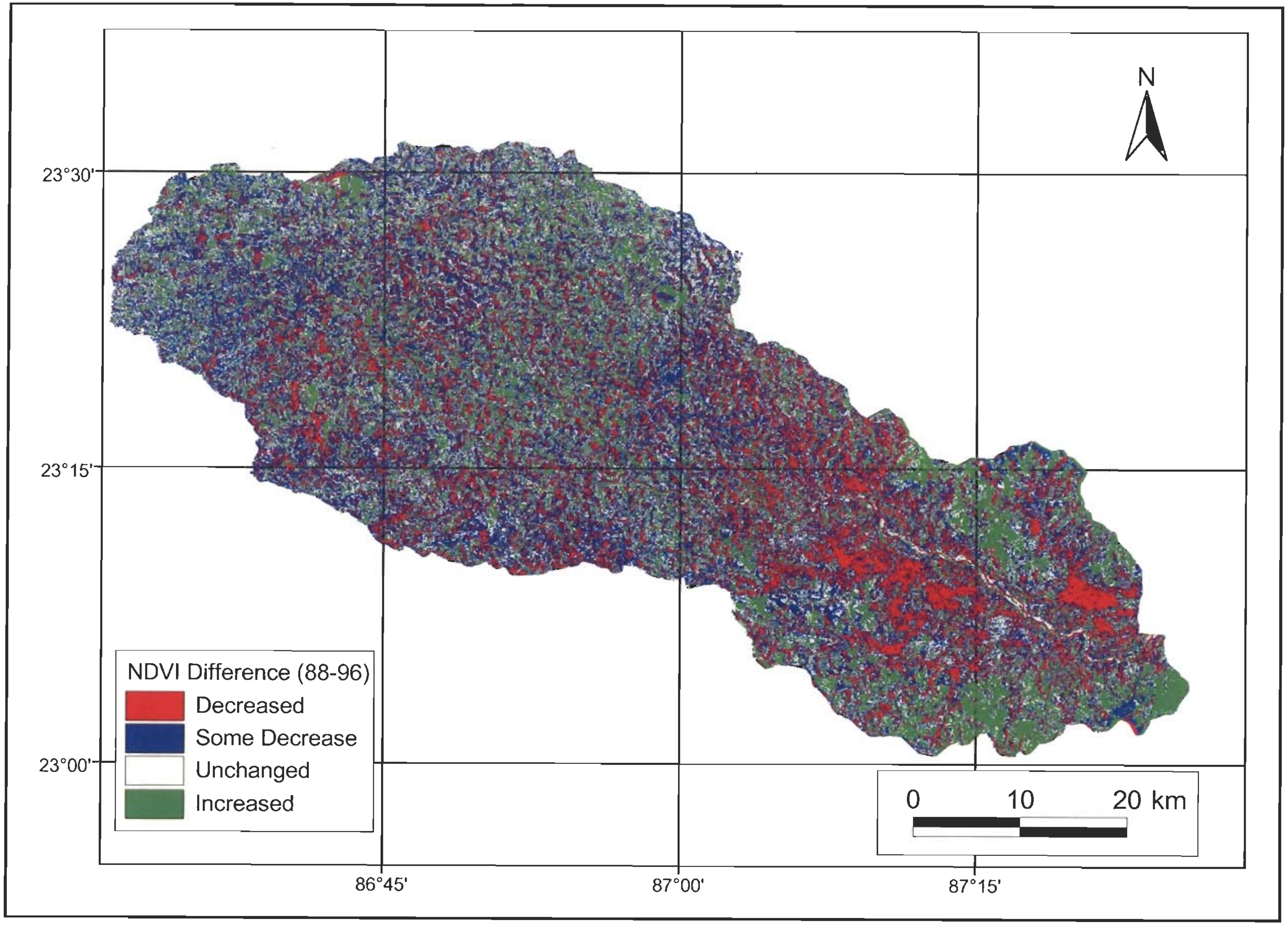


Figure 4.11 : Difference in NDVI (Normalized Difference Vegetative Index) of the Dwarkeshwar Watershed from 1988 to 1996 (in detail).

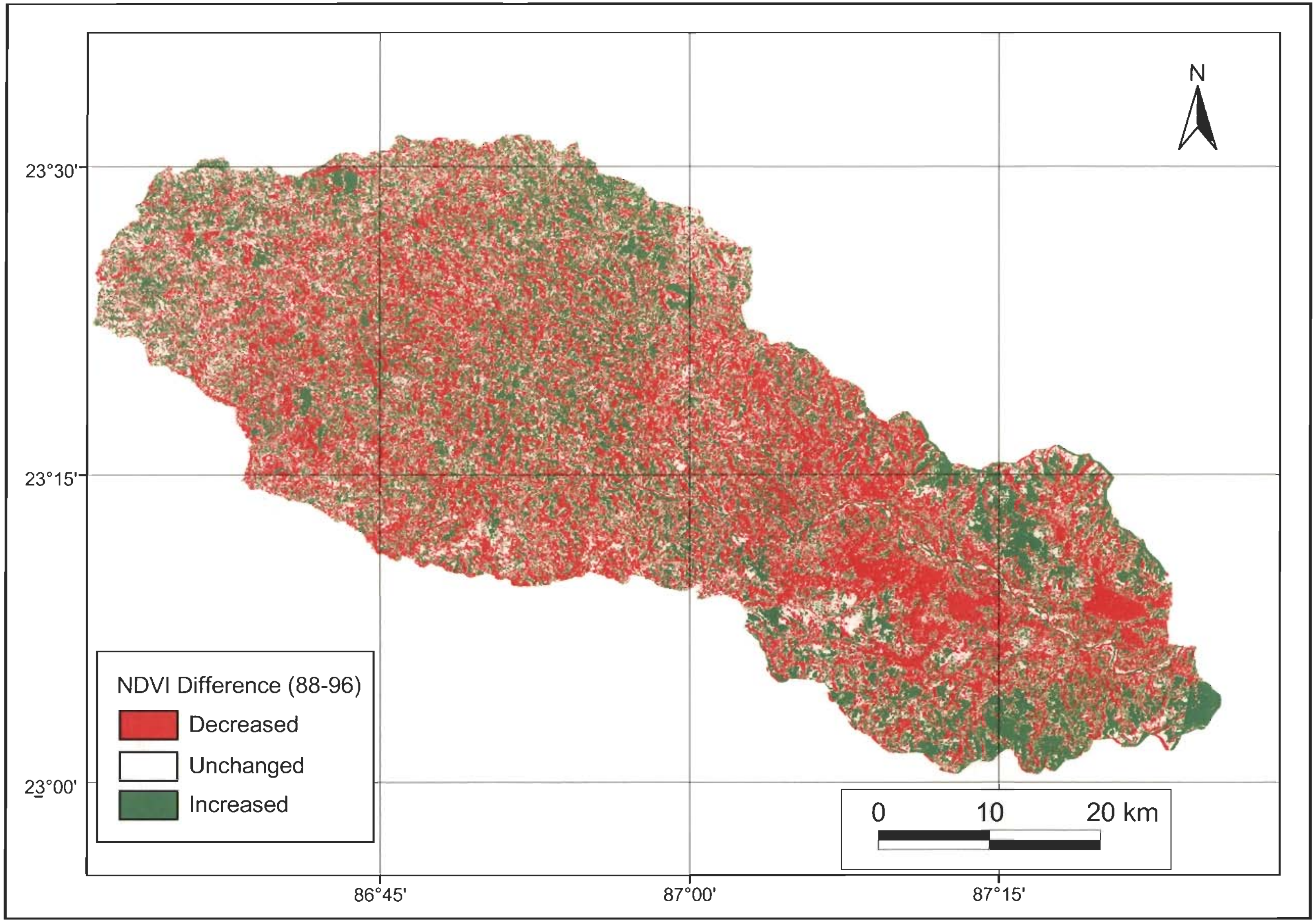


Figure 4.12 : Difference in NDVI (Normalized Difference Vegetative Index) of the Dwarkeshwar watershed from the years 1988 to 1996.

Figure 4.13 (a) : A glimpse of the Dwarkeshwar River.

Figure 4.13 (b) : Major economic activity of the watershed - Agriculture.

Figure 4.13 (c) : Isolated hillocks and mounds present in the watershed.

Figure 4.13 (d) : Large scale removal of forest cover in the watershed for urbanization.

Figure 4.13 (e) : Land reclaimation by planting trees on wasteland.

Figure 4.13 (f) : Large scale "Sal" (Shorea robusta) plantation on red soil of the watershed.

4.13.2.1 Discussion

The NDVI images of both the years (1988 and 1996) give an idea of the distribution of vegetation in the watershed at that particular period of time. More significantly the NDVI change image has highlighted the change in the distribution pattern in the vegetation cover in the watershed. It is quite apparent from the NDVI difference image that there has been significant decrease in vegetation in the east central part of the watershed along the Dwarkeshwar River. This has been verified on the ground and it was found that there has been significant increase in the settlement area due to increase in population (Saraf, 1999). New constructions have come up in the watershed with growth of new villages and small townships.

Moreover, it is evident from the NDVI change image that there are certain areas in the watershed where there is increase in vegetation. During the last ten years large scale afforestation measures are taken up by the district authorities in the watershed. In the originally waste and fellow lands as well as degraded forest lands new plants mainly "Sal" (Shorea robusta) are being planted as a part of the afforestation programme. The conversion of fellow and wasteland to arable land has also contributed in the change in NDVI. Figure 4.13(a) to 4.13(f) show the various activities found in the watershed.

Chapter 5

INTEGRATED REMOTE SENSING AND GIS TECHNIQUE TO ESTIMATE SOIL EROSION AND RUNOFF

5.0 SOIL EROSION

Soil erosion can be defined as removal of soil by forces of nature more rapidly than various soil-forming processes can replace it, particularly as a result of man's ill-judged activities. The main cause of soil erosion is the presence of susceptible soils on undulating topography with a poor cover by vegetation or crops. Important factors in the soil erosion process are the climate, slope, gradient, landuse, urbanization, ploughing direction, soil stability, soil sealing, infiltration capacity and the recent intensification of agriculture.

The USLE model discussed in this chapter shows the ability of spatially distributed modelling over traditional lumped modelling approach. Presently, GIS not only helps in development and building of such models but also evaluates different scenarios which is helpful in decision-making. The assessment and prediction of soil loss from a given watershed depends upon various factors, both natural as well as human. The study of these factors are very indispensable in watershed management planning. Linking or integrating hydrological and soil erosion models to the GIS results in a powerful tool to calculate the effects of landuse changes.

5.1 THE UNIVERSAL SOIL LOSS EQUATION (USLE)

Prediction of soil loss by USLE was first introduced by Wischmeier Smith (1965). The USLE is an empirical model most widely used for estimation of soil loss from sheet and rill erosion. USLE is given by the following equation:

Soil Loss = F (Rainfall Erosivity, Soil Susceptibility, Topography
And Management)

$$\mathbf{A = R * K * L * S * C * P}$$

Where,

A = Annual soil loss from specific site (t / ha),
R = Rainfall Erosivity factor,
K = Soil susceptibility factor (t / ha / EI_{30}),
L, S = Topographic factor
C = Crop management factor,
P = Erosion control practice factor,
EI_{30} = Rainfall erosivity index

The USLE model can be evaluated in two ways: aggregated or disaggregated. An aggregated model uses a spatial database management system to store the six factors for each field, then solving the equation through database query. The USLE implementation provides several advancements such as geo-query access, automated acreage calculations and graphic display over the current procedures.

There is an extensive spatial variation in all the USLE variables. Such spatial variation is known to the GIS (e.g., soil and slope maps) but not used by the aggregated model. A disaggregated model breaks an analysis unit into spatially representative sub-units. The equation is evaluated for each sub-unit, and then combined for the total area. In a vector system, the sub-units are derived by overlaying maps of the six USLE factors. In a raster system, each cell in the analysis grid serves as a sub-unit.

The output of solving this equation mathematically is the soil loss map of the area (Figure 5.1).

5.1.1 USLE Factors

(a) Topographic Factor (LS)

The topographic of the terrain is important in determining levels of precipitation erosion. Included among the factors of topography, which are

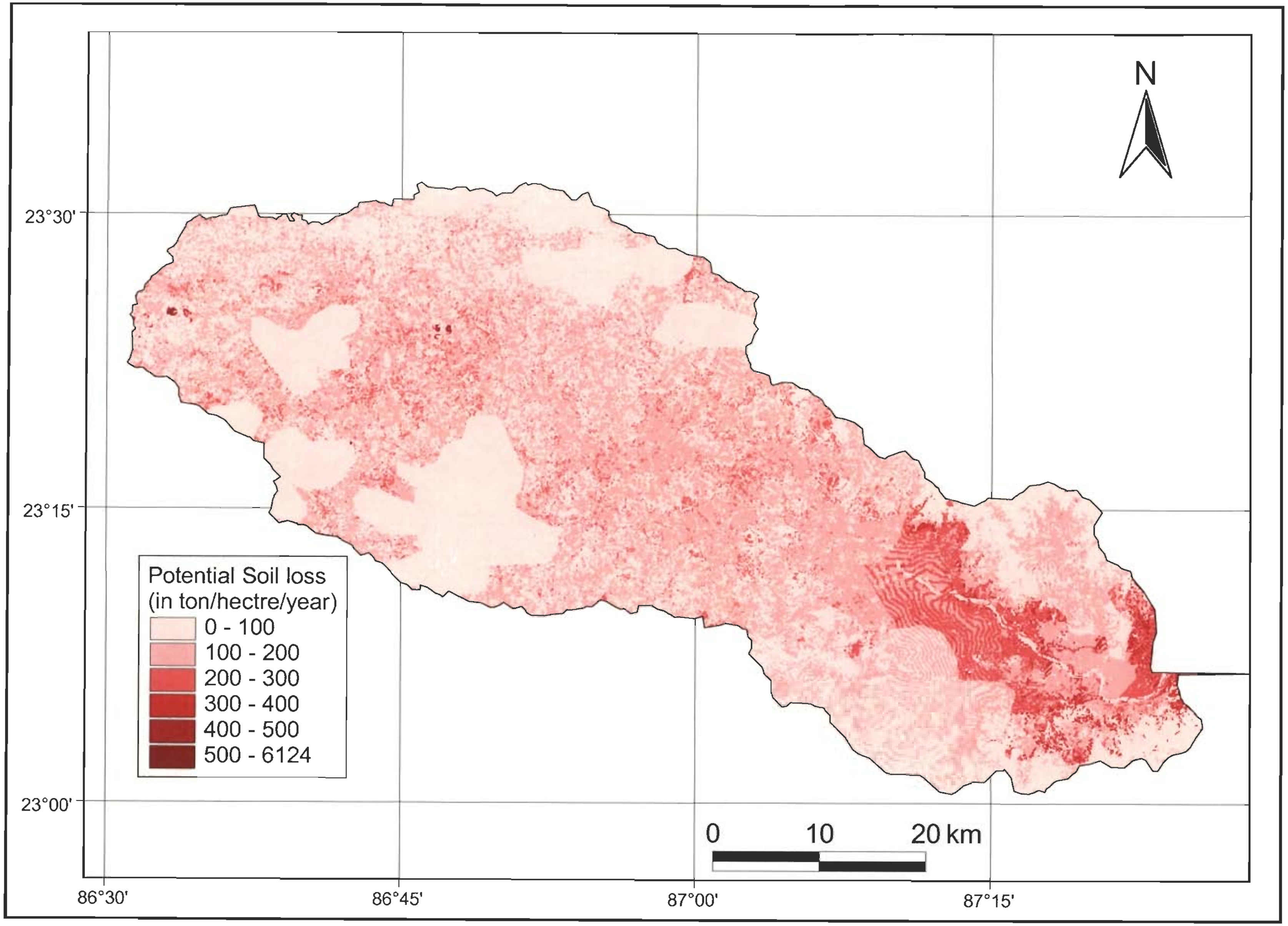


Figure 5.1 : Average Annual Soil Erosion Hazard Map of Dwarkeshwar Watershed prepared by using USLE method.

represented in the Universal Soil Loss Equation are the slope length and the slope gradient.

(i) Slope Length (L)

The slope length factor, L, which is the ratio of the soil loss from field of slope length to that from a 22.13 meters long plot on the soil and gradient was defined by Wischmeier and Smith (1965). Elevation data (contours), which represent the topography of the watershed, are interpolated to create digital elevation model (DEM). Calculating the local first derivative in x and y direction, slope map has been generated. Aspect map has also been generated by the direction of slope. The slope map is classified into four classes of gradient percentage (Table 4.4) as given by Wischmeier and Smith, 1978. The map obtained is reclassified and assigned corresponding values of m to the classes. This will give a map of m value. The **L** factor map is derived using the equation given below in map calculator.

$$\mathbf{L=(\lambda / 22.13)^m}$$

Where L = slope length factor S = slope gradient factor λ = slope length measured from the watershed divide of the slope (meters) m = exponent dependent upon slope gradient and may also be influenced by soil properties, type of vegetation, etc.

Recommended exponent values (Wischmeier and Smith, 1978) are given in the table 5.1.

Table 5.1: Recommended value of m (after Wischmeier and Smith, 1978)

Slope gradient (%)	m
$S < 1.0$	0.2
$1.0 \le S < 3.5$	0.3
$3.5 \le S < 4.5$	0.4
$4.5 \le S < \infty$	0.5

(ii) Slope Gradient Factor (S)

The ratio of soil loss on actual gradient to that from 9% slope under otherwise identical condition is termed as slope gradient factor. This has been empirically derived by Wischmeier and Smith (1962). The S factor map was derived using the equation given below in the map calculator.

$$\mathbf{S = [0.43+0.30*sw+0.043*(sw)^2] / 6.613}$$

sw = Slope gradient factor (%)

Combined Effect of slope Gradient and Slope Length (LS)

The effect of the slope gradient and slope length on the intensity of the erosion process is significant for deciding the type and location of erosion control measures. The combined effect for slope length and slope gradient was calculated by multiplying S factor map with L factor map to get LS factor map.

(b) Rainfall Erosivity Index (R)

The term rainfall erosion index implies a numerical evaluation of a rainstorm or of a rainfall pattern, which describes its capacity to erode soil from unprotected field. In India, using 45 stations, distribution in different rainfall zones, simple linear relationship between erosivity index and annual or seasonal (June to September) rainfall has been developed.

$$\mathbf{R\ (annual) = 79+0.363*X}$$
$$\mathbf{R\ (seasonal) = 50+0.389*X}$$

Where, R = annual or seasonal erosivity index
X = average annual or seasonal rainfall

The average annual rainfall map of the watershed derived by interpolation method is multiplied with the above equation and finally the R, factor is derived.

(c) Soil Erodibility Factor (K)

The soil erodibility factor (K) in the USLE is the quantitative measure of the inherent erodibility of a particular soil. It indicates the susceptibility of soil to erosion and is expressed as soil loss per unit of R for a unit plot. Under situations from which detail input soil information to the above equations and/or monographs are not available a table (Table 5.2) proposed by Vladimir et al. (1981) has been used. From this table knowing the organic content and textural class of the soil, the magnitude of soil erodibility can be found out. The values shown are estimated averages of specific soil values.

Table 5.2: Magnitude of soil erodibility (adopted from Vladimir et al., 1981).

Textural class	**O.C < 0.5 %**	**O.C = 2.0 %**	**O.C = 4 %**
Sand	0.05	0.03	0.02
Loamy sand	0.12	0.10	0.08
Sandy loam	0.27	0.24	0.19
Loam	0.38	0.34	0.25
Silt loam	0.48	0.42	0.29
Silt	0.60	0.52	0.42
Clay loam	0.28	0.25	0.21
Silty clay	0.25	0.23	0.19
Clay	0.13-0.20	0.13-0.20	0.13-0.20

O.C= organic content

Assessment of soil erodibility factor in USLE model requires the knowledge of soil characteristic. As detailed soil data were not available, based on the assumption that the O.C is 2 and soil condition for the Dwarkeshwar watershed are Loam, Clay loam, Silt, Sandy loam and Sand (Soils Bulletin, NBSS & LUP Pub. 33) the K values which are given in Table 5.3 have been used. The first step followed is to create a column of percent organic matter in the attribute of soil map and then the K values for the corresponding soil are entered. Finally the K factor map is derived.

(d) Crop Management Factor (C)

The cropping management factor (C) of the USLE represents an integration of several factors that affect erosion, including vegetative cover, plant litter, soil surface, and land management. It is expressed as a numerical ratio that relates soil loss from land having specified cropping management to soil loss from continuous cultivated fallow with identical soil, slope and rainfall. In most cases the value of C is not constant over the year. Although treated as an independent variable in the equation, the true value of this factor is dependent on all other factors. Therefore the value of C should be established experimentally. To develop the C value for the watershed various landuse classes were considered. Landuse input data was used to assign the C value to each cover type or group of covers. The C factor for permanent covers like dense forest, high intensity cultivation, low intensity cultivation, waste land were taken from Shrestha (1997).

(e) Conservation Support Practice Factor (P)

The P factor in the USLE is expressed as a ratio, which compares the soil loss from the investigated plot with soil loss from the standard plot cultivated up and down the slope gradient. The amount of the soil loss from a given land is substantially influenced by the land management practice adopted. Based on the results of intensive studies from runoff plots Wichmeier and Smith (1978) suggested the erosion control factor value for various situations (Table 5.3).

Table 5.3 : P values for contouring on different slope gradients (Wichmeier and Smith, 1978)

Slope (in %)	P value	Max. Slope length
1 - 2	0.6	131.2
3 – 5	0.5	98.4
6 – 8	0.5	65.6
8 – 12	0.6	39.4
13 – 16	0.7	26.2
17 – 20	0.8	19.7
21 - 25	0.9	16.4

To create P-factor map for the study area the slope map is classified according to the slope classes given in the Table 4.6 and these classes were assigned corresponding values of P. This will give the P map for the watershed.

5.1.2 Application of USLE

The USLE is universally applicable because it identifies all the causative factors of soil erosion inspite of its weakness in addressing socio – economic cultural factors that may contribute to erosion problems or the constraints that prevent effective implementation of conservation measures. In watershed management it serves as a tool for soil conservation planning to reduce erosion by predicting annual or seasonal soil erosion hazard. The use of USLE in management or conservation planning deserves the establishment of the permissible limits (soil loss tolerance T) the maximum rate of soil erosion that will ensure a high level of sustained productivity indefinitely and economically and without detrimental effect on the environment. Following the establishment of T values for different conditions the soil loss equation can be rewritten as given below and then proper cropping management system and appropriate conservation practice can be selected.

$$\mathbf{C * P = T / R * K (LS)}$$

Where T = soil loss tolerance limit (t/ha/yr)

The output map derived from mathematically solving the USLE gives the soil loss per unit area at every location of the map (Figure 5.1). However, much more information can be derived from this map. Areas of high soil loss can be isolated from this map and then combined with the C and P maps to locate areas out of compliance. This information can be used to locate portions which may require different management action. Also reverse calculation of the USLE equation will provide insight on the crop and management practices. In this case, it is established for the watershed and combinations meeting the standard are derived. Because the climatic and physiographic factors (R, K, L, S) are beyond control, so attention is focussed on C and P. In short, the approach generates a map of a set of crop and farming practices that keeps the area within the soil loss compliance – a good information for decision making.

5.1.3 Discussion

In order to make an accurate prediction of hydrologic response due to landscape changes, it is required (a) to be able to track changes as they actually occur, and (b) to quantitatively understand the effects caused by such changes. Remote sensing and GIS have become powerful tools for detecting, managing and analyzing landuse and landcover data. The USLE model discussed shows the applicability of spatially distributed modelling over traditional lumped modelling approach.

The maximum potential soil loss estimated using the physical components of USLE (RKLS) indicate high values. This was due to the erosive rainfall and rugged topography. The total quantity of soil loss approximately calculated from the watershed is 6124.74 t/year. The erosion risk is more prominent along the western part and also along the banks of the Dwarkeshwar River in the eastern portion of the watershed. The wastelands occurring in the watershed represent the culmination of the adverse effect of erosion process. In the forest areas, the risk is relatively low. The wide range of values obtained for the potential soil loss was due to the variation of erosion factors in the watershed. Table 5.4 shows the variation extremes of erosion factors.

Table 5.4: Variation extremes of erosion factors

Erosion Factor	**Values Interval**
Rainfall erosivity (R)	1400
Soil erodibility (K)	0.03-0.52
Topographic factor (LS)	0.003-0.323
Coverage value (C)	0.002-0.80
Conservation practice (P)	0.5-0.9

Soil losses computed by USLE are considered reliable estimates. The results will generally be more accurate for medium textured soils, slope length less than 120 meters, gradient of 3 to 18% and consistent cropping and management practices. Further, if these limits are exceeded, the greater will be the probability of significant extrapolation error. In this contest it could be expected that certain errors may be introduced in computation of the soil loss for area steeper than 18%. The computed values may also deviate from the actual values due to the assumptions made in evaluation of coverage values for some crops and average values assumed in K factor. However, exaggerated error may not be expected. To estimate more accurately the soil loss within the area, detail information on various parameters are required.

5.2 GROUNDWATER RESOURCES EVALUATION AND ARTIFICIAL RECHARGE

In hard rock areas the evaluation of the relationship between landuse-hydrology becomes immense importance as the primary porosity is practically zero, and groundwater occurrence and movement is largely controlled by the geology, geomorphology, soil, topography, landuse practices and climatic conditions.

The major part of Dwarkeshwar watershed represents a typical hard rock terrain, as the pink granite, granite gneiss with pockets of quartzite, quartz schist, amphibolite, hornblende schist, epidiorite, pyroxenite and pyroxene granulite body covers most of the area of the watershed in the western part with eastern and south eastern margins of the watershed covered by alluvium. The groundwater occurrence is mainly confined to (a) the fractures and weathered mantle; (b) shallow aquifers in unconfined state and in confined state below a blanket of clay of varying thickness in deeper aquifers. In these areas, groundwater is an extremely valuable resource of limited extent. Proper utilisation of groundwater and management planing demands a thorough understanding of the groundwater resources. This chapter is an attempt to develop an integrated remote sensing and GIS technique to understand the interrelation of the landuse influencing factors and their role in controlling the groundwater scenario of the area. Further, a quantitative estimation of groundwater recharge has been performed in a GIS environment.

5.3 SCOPE OF THE WORK

In this chapter an attempt has been made to develop an integrated remote sensing and GIS based method for identifying prospective zones for groundwater and evaluation of groundwater resources in the area. The main objectives are:

a) To have an understanding of the interrelationship of various factors influencing landuse and groundwater occurrence and movement.

b) To develop an integrated remote sensing and GIS based approach for identification of groundwater potential zones.

c) To estimate groundwater recharge.

5.4 RUNOFF AND ITS ESTIMATION

Rainfall is the major source of water for runoff generation over the land surface. During occurrence of rainfall and the vegetation, buildings and several other objects lying over the land surface, intercept a part of it. Some portion of the rainfall also infiltrates into the soil, and lastly, the rest of the water makes a head over the ground surface which tend to move from one place to another under the effect of land gradient, and ultimately meet the streams, channels etc. called as runoff. Thus, runoff may be defined as that portion of rainfall which makes its way towards the rivers, streams, oceans etc. (Suresh, 1997).

The potential for applying geographic information system to hydrologic modelling is considerable. Many hydrologic models have parameters defined in terms of landuse, soils, topography, and their utility lies in simulating watershed behaviour for different combinations of these parameters (Muzik, 1988).

GIS can be used to store and manipulate such parameters and have the potential to allow planners to interactively simulate different management or landuse scenarios and estimate their impacts on the hydrology of an area (Stuebe and Johnston, 1990). GIS have been applied to hydrologic modelling in several studies. e.g. Silfer et al. (1987), developed a vector GIS to model rainfall-runoff processes on a personal computer. Vieux et al. (1988), used another vector GIS (ARC/INFO) to model runoff.

5.4.1 Types of Runoff

Runoff is broadly classified into following three types (Suresh, 1997):

(a) Surface runoff

It is that portion of rainfall, which enters the streams, channels etc. immediately after the occurrence rainfall. The process may be described as when all losses are satisfied and if rain is still continued with the rate greater than infiltration rate, then excess water makes a head over the soil surface, which tends to move due to land slope, known as overland flow. The overland flow joining the stream, channel or ocean etc. is called as surface runoff.

(b) Sub-surface runoff

It is that amount of rainfall, which first infiltrates into the soil and then starts flowing laterally without joining the water table to the streams, rivers etc., called as sub-surface runoff. Sometimes sub-surface runoff is also treated as surface runoff due to the fact that it takes very little time to reach the rivers, like the surface flow.

(c) Base flow

It is a delayed flow, defined as part of the rainfall, which after falling over the ground surface, percolates into the soil and meets to the water table, and finally joins to the rivers, streams etc.

5.4.2 Factors Affecting Runoff

The factors affecting the type of runoff and its volume resulting from a watershed are (i) types of precipitation, (ii) rainfall intensity, (iii) forms of precipitation, (iv) duration of rainfall, (v) rainfall distribution, (vi) direction of prevailing wind, (vii) size, shape, and orientation of watershed, (viii) landuse, (ix) soil moisture, (x) soil type, and (xi) topography (Suresh, 1997).

5.4.3 Methods of Runoff Estimation

Determination of accurate runoff rate or volume from the watershed is a difficult task, because runoff is dependent upon several factors related to the watershed and atmosphere, and getting an accurate estimation of all these parameters is not so easy. However, some common methods for runoff estimation are (a) Rational method, (b) Cook's method, (c) Hydrograph method, (d) SCS curve number method etc. In the present study, SCS curve number and Rational method have been used for the estimation of runoff depth and rate of discharge, respectively, using remote sensing data, precipitation data, infiltration data etc.

5.5 RUNOFF MODELLING USING REMOTE SENSING AND GIS TECHNIQUES

A model is a simplified representation of reality in which it presents significant features or relationships in a generalized form, i.e., it is the selective approximation of reality (Valenzuela, 1990). Models can be broadly divided into three types, descriptive (describes the real world, e.g. map), predictive (predicts what might occur under certain conditions, e.g. USLE soil erosion model), or decisive model.

As mentioned earlier in section 5.4.3, various hydrologic models are available for estimation of the amount of runoff that will be produced from a given precipitation in a watershed which range from complex to simple having different structures and input data requirements. Many parameters used in these models can be successfully extracted using an integrated remote sensing and GIS technique.

5.6 RAINFALL-RUNOFF MODELLING USING SCS CURVE NUMBER METHOD

The SCS curve number method is most widely used for estimating direct runoff volume. It was developed by the US Department of Agricultural – Soil Conservation Service (SCS) in 1950 (Geleta, 1993). Many workers have used this model in GIS environment for the computation of runoff from precipitation, e.g. Muzik (1988) described a personal computer based raster GIS designed for use with the SCS runoff curve number model. The GIS was used primarily for storing data on physical land characteristics and rainfall data. An associated software program retrieved information from the GIS, then, with further input from the user, computed several runoff parameters. Hill et al. (1987), generated SCS runoff curve numbers for a 1542 km^2 basin at Louisiana and Mississippi using a raster GIS. They combined classified Landsat multispectral scanner satellite information with digital photo interpreted landuse data to produce a landuse map layer. They then computed rainfall runoff volumes outside the GIS for several rainfall events and compared them to the observed volumes calculated from USGS runoff data. White (1988) used a raster GIS to model rainfall runoff for a 421 km^2 watershed in Pennsylvania. He input rainfall data, soil data, landuse/landcover information into the SCS curve number with the GIS to determine runoff on a cell by cell basis for ten actual storm events. Geleta (1993) used a ILWIS GIS software for runoff modelling in the Nalota Nala watershed of U.P., India (99.3 ha) by using rainfall, landuse and soil data In SCS curve number method.

The reasons for the widespread acceptance of this method are as follows (Ferreira and Smith, 1988; Foster, 1988):

1) Its use has been mandated by the USDA-SCS,
2) It provides reasonable, useful results for average conditions,
3) There is a large user base available to assist new users and much is known about how to vary parameters for non-standard conditions,
4) It is easy to understand and use, and
5) It requires few resources to use.

5.6.1 Data Used For the Application of SCS Curve Number Method

Mainly three types of data have been used for the application of SCS curve number method in the Dwarkeshwar watershed:

(a) Landuse data (1988 and 1996) derived from IRS-LISS-II and IRS-LISS-III image.

(b) Rainfall data for the month of June and August, 1988 and 1996 (source: NRDMS, Bankura and SWID, Calcutta).

(c) Soil data from NBSS & LUP.

5.6.2 Methodology

In this method, the estimation of runoff depth in a watershed is based on the recharging capacity of the area, which is predicted by knowing the wetness status (Le. antecedent moisture condition), and physical characteristics of the watershed. The assessment of antecedent moisture condition (AMC) is based solely upon 5-day antecedent precipitation. The SCS has devised a hydrologic soil classification system, which divides identified soil into four hydrologic groups on the basis of minimum infiltration exhibited by it after prolonged wetting. Landuse and treatment classes were developed to consider the effect of the surface conditions in a watershed on runoff potential (Geleta, 1993).

5.6.2.1 Hydrologic Soil Group

Based on the hydrologic characteristics, the SCS developed a soil classification system, which divides the soils into four classes (Suresh, 1997; Geleta, 1993):

I. **Soil (A):** It is characterized by low runoff potential, i.e. soils involve high infiltration rate. They include deep sand, deep loess, aggregated soils, deep, well to excessively drained sands or gravels.

II. **Soil (B):** The soils of this group have moderate infiltration rate even when thoroughly wetted. The soils are mainly composed of deep, moderately well to well drained soils with moderately fine to moderately coarse textures, e.g. sandy loam, shallow loess etc.

III. **Soil (C):** This hydrologic soil group involves those soils, which have low infiltration rate. This group includes those soils, which have low infiltration rate. The soils consist of a thin hard layer, which impedes the downward movement of water and are constituted with moderately fine to fine textures. e.g. clay loams, shallow sandy loam, soils low in organic matter content, soils usually high in clay content.

IV. **Soil D:** This group of soils is characterized by high runoff potential, i.e. soils involve very low infiltration rate even when thoroughly wetted. The soils consists chiefly of clay soils with a high swelling potential, soils with permanent high water table, soils with clay pan or clay layer at or near the surface and shallow soils over nearly impervious matter.

Another method of classifying the soils into major hydrologic soil groups is based on the use of minimum infiltration rate, which is discussed below in Table 5.5 (Geleta, 1993).

Table 5.5: Classification of soils on the basis of minimum infiltration rate exhibited by them.

Group	**Minimum Infiltration Rate (cm/hr)**
A	0.76-1.14
B	0.38-0.76
C	0.13-0.38
D	0.00-0.13

In the present study, due to the unavailability of detailed soil information, the whole watershed has been divided into two hydrologic soil zones on the basis of the results of infiltration tests carried out by NRDMS in different landuse classes. The areas under dense forest cover have high infiltration capacity of about 5 cm/hr and hence the soil type of this landuse class is considered to belong to the hydrologic soil group A, where as 'the infiltration rate in other landuse classes suggests that they should be classed under the hydrologic soil group B category.

5.6.2.2 Hydrologic Soil Cover Complex

Three parameters are used for hydrologic soil cover complex classification in SCS curve number method, (a) landuse, (b) treatment of practice and (c) hydrologic condition which is discussed in detail in Appendix A. The hydrologic condition reflects the level of land management and it is categorized into three classes, viz. poor, fair and good. (Geleta, 1993). Under the existing management practice, the hydrologic condition was assumed to be poor for all landuse classes except the forest land, where it is assumed to be fair, because of its high recharge capacity which can be observed from the recharge potential map, which is derived by weighted index overlay method (discussed in Chapter 6).

5.6.2.3 Antecedent Moisture Condition

It is defined as the wetness index of the watershed after the occurrence of antecedent rainfall over the watershed. The antecedent rainfall is the amount of rainfall in a period of 5 to 30 days preceding a particular storm event. There are following three levels of AMC conditions used in SCS method (Suresh, 1997):

I. **AMC I :** This indicates the lowest potential for runoff generation due to dryness of the soil.

II. **AMC II :** Average condition regarding potential for runoff generation.

III. **AMC III :** This includes highest runoff potential of the watershed, which is saturated from antecedent rains.

The antecedent moisture condition of the watershed can be determined by using Table 5.6 (Geleta, 1993) and comparing it with the actual amount of rainfall that has occurred before the storm event for which the depth of discharge has to be estimated.

In the present study, the rainfall data for the months of May to September have been used. As it is the growing season for the Kharif crops, hence the AMC condition is determined according to column 3 of Table 5.6.

Table 5.6 : Determination of antecedent moisture condition on the basis of seasonal rainfall limits.

AMC	Rainfall Amount in Dormant Season (mm)	Rainfall Amount in Growing Season (mm)
I	< 12.7	< 35.6
II	12.7-28.0	35.6-53.3
III	> 28.0	> 53.3

5.6.2.4 Curve Number (CN)

Curve number is a function of hydrologic soil group and landuse. SCS curve numbers are typically determined by using a table relating landuse to hydrologic soil type (Appendix A). The hydrologic soil type can be either A, B, C, or D, where the infiltration capacity decreases from A to O. The curve numbers for each soil group for a given landuse are given in most books on hydrology. A composite curve number for a basin can be computed by taking an area - weighted average of the different curve numbers for the different regions (soil type and landuse combinations) within a basin (WMS, 1997). The curve number values for different landuse classes, treatment and hydrologic conditions for AMC II condition is given in Appendix A. The corresponding curve numbers for AMC I and AMC III condition can be obtained by identifying the curve number for AMC II condition first and then converting it according to Appendix B. The curve numbers thus obtained for different landuse classes of the study area according to Appendix A are shown in Table 5.7. The weighted curve number for the entire watershed can be obtained by the following formula:

$$\text{Weighted curve number} = \Sigma(\text{Area x Curve Number}) / \Sigma (\text{Area})$$

Table 5.7: Curve Number for Different Landuse Classes

Landuse	Hydrologic Soil Group	AMC I	AMC II	AMC III	Area (km^2) 1988	Area (km^2) 1996
Dense Forest	A	19	36	55	65.83	161.17
Arable land	B	40	60	79	315.1	547.07
Waste land	B	57	75	91	1093.46	196.35
Fallow	B	62	79	93.	763.4	1334.76
River sediment	A	63	80	94	9.3	11.14
Settlement	B	95	87	99	4.75	5.67

5.6.3 Determination of Runoff Depth in SCS Curve Number Method

This method assumes that, before starting of runoff generation through the area, the initial losses must be satisfied. The ratio of direct runoff to rainfall depth minus initial losses (i.e. $P - I_a$) is equal to $(P - Q - I_a)/S$ (Suresh, 1997). It is given by,

$$\frac{Q}{P - I_a} = \frac{P - Q - I_a}{S} \tag{5.1}$$

where,

Q = Depth of direct runoff (mm)

P = Depth of rainfall (mm)

S = Storage capacity of the soil (mm)

I_a = Initial abstractions such as interception, infiltration and depression storage made (mm).

In this equation, if value of I_a is taken as 0.2S, then the equation is reduced to:

$$\frac{Q}{P - 0.2S} = \frac{P - Q - 0.2S}{S}$$

or $$\frac{Q}{P - 0.2S} = \left\{\frac{P - 0.2S}{S}\right\} - \frac{Q}{S}$$

or $$\frac{Q}{P - 0.2S} + \frac{Q}{S} = \frac{P - 0.2S}{S}$$

or $$\frac{\{Q * S + (P - 0.2S) * Q\}}{S\,(P - 0.2S)} = \frac{P - 0.2S}{S}$$

or $$\{Q * S^2 + Q * S(P - 0.2S)\} = S(P - 0.2S)^2$$

or $$\{Q * S + Q(P - 0.2S)\} = (P - 0.2S)^2$$

or $$Q(S + P - 0.2S) = (P - 0.2S)^2$$

or $$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{5.2}$$

Equation (5.2) is the final expression for computing the runoff rate and can be used if 'P' and 'S' are known. The recharge capacity of the watershed is determined using the curve number, given as under

$$S = \left(\frac{25400.0}{CN}\right) - 254 \tag{5.3}$$

The above expression given in equation (5.3) representing the relation between S and CN (Curve Number) was developed from empirical analysis.

Equation (5.2) representing the direct runoff depth is most often assumed to be zero when $P < 0.25$ (Suresh, 1997).

5.6.4 Application of SCS Curve Number Method in the Study Area

The rainfall data for monsoon months (June to September, 1998) were used for the estimation of runoff depth in the study area using GIS environment. A programme was prepared in Avenue language for Arc View 3.x GIS software to estimate the runoff depth generated from each rainfall amount by using equation (5.2). The input parameters used in the programme for estimation of rainfall depth are listed below:

(i) Daily rainfall depth (in mm) for the months of July and August, 1988 and 1996.

(ii) Weighted curve number (CN) value for three different antecedent moisture conditions, i.e. (a) AMC I, (b) AMC II and AMC III conditions.

The Avenue programme was so designed that, it first computes the previous five days' rainfall amount to decide the AMC condition of the desired day and modify the curve number (CN) value accordingly. The flow chart (Figure 5.2) describes the methodology adopted in the programme to compute the runoff depth.

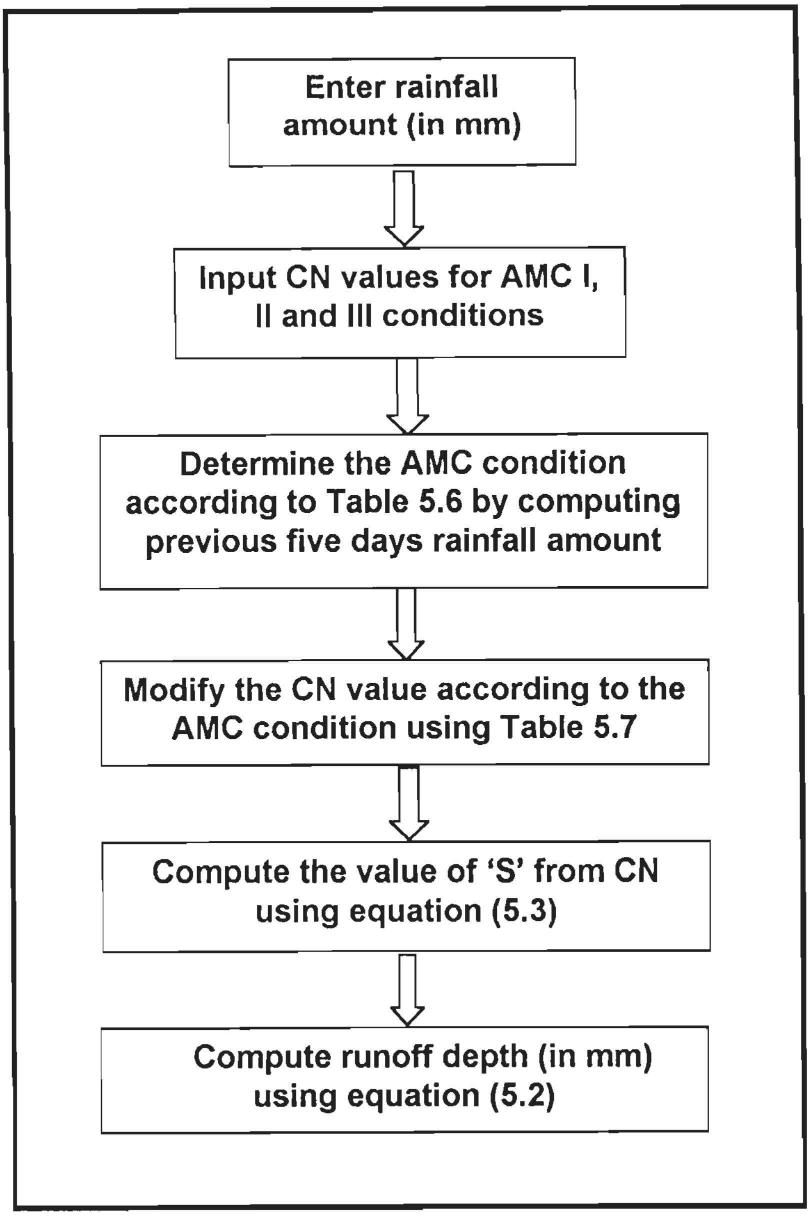


Figure 5.2 : Flow Chart showing the methodology for computing the runoff depth (in mm) from rainfall data using SCS curve number method.

The runoff depth from the data of 1988 and 1996 were obtained by this method and the difference in runoff depth is also calculated (Figure 5.3). The peak discharge for the watershed is determined by taking the rainfall as 11.28 cm and the time to reach the peak as 24 hours rainfall for the data of both 1988 (Figure 5.4) and 1996 (Figure 5.5). Moreover, the difference in the peak runoff is also calculated by subtracting the peak discharge of 1996 from that of 1988 (Figure 5.6).

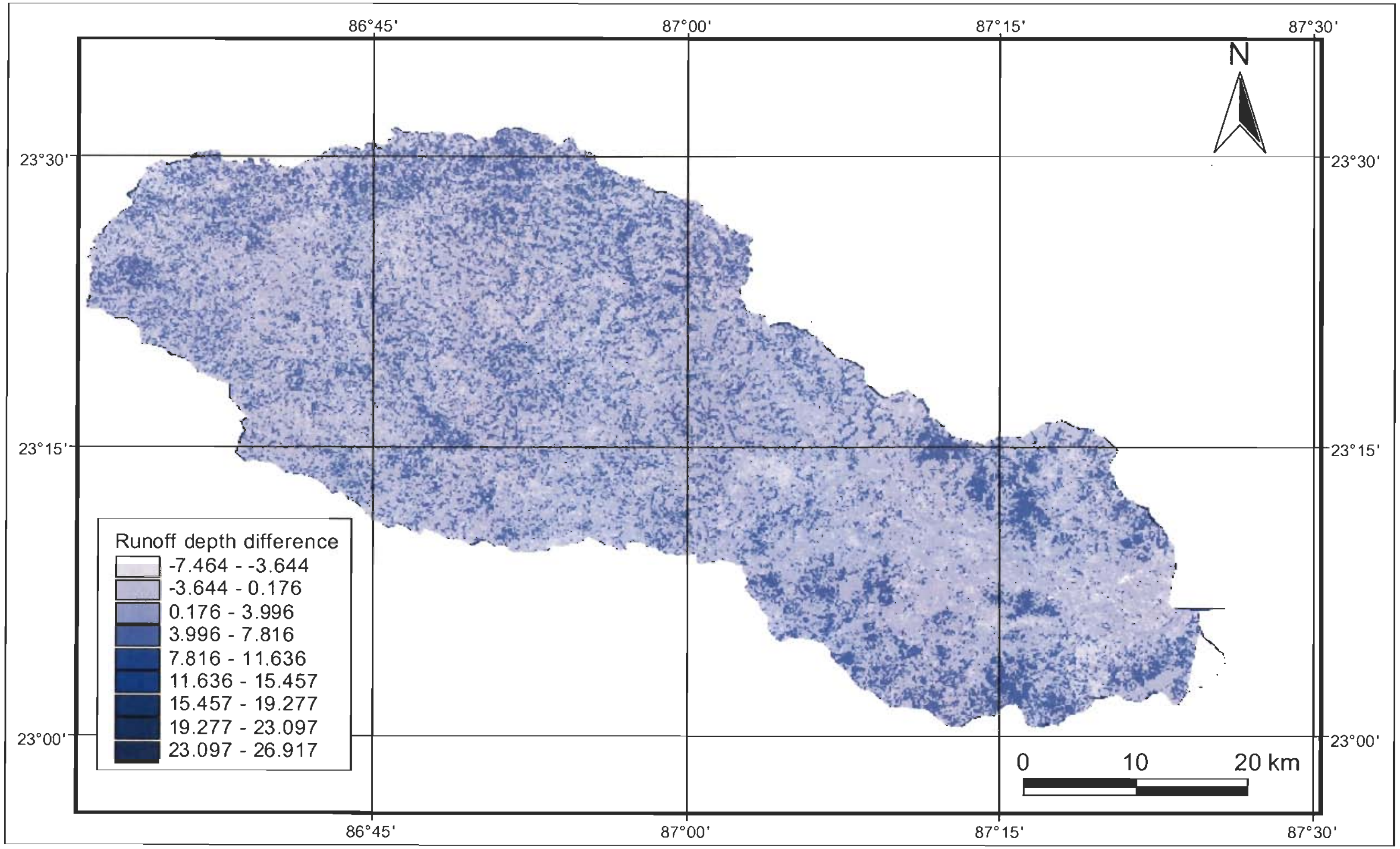


Figure 5.3 : Runoff Depth Difference (1988-1996) Map of the Dwarkeshwar Watershed.

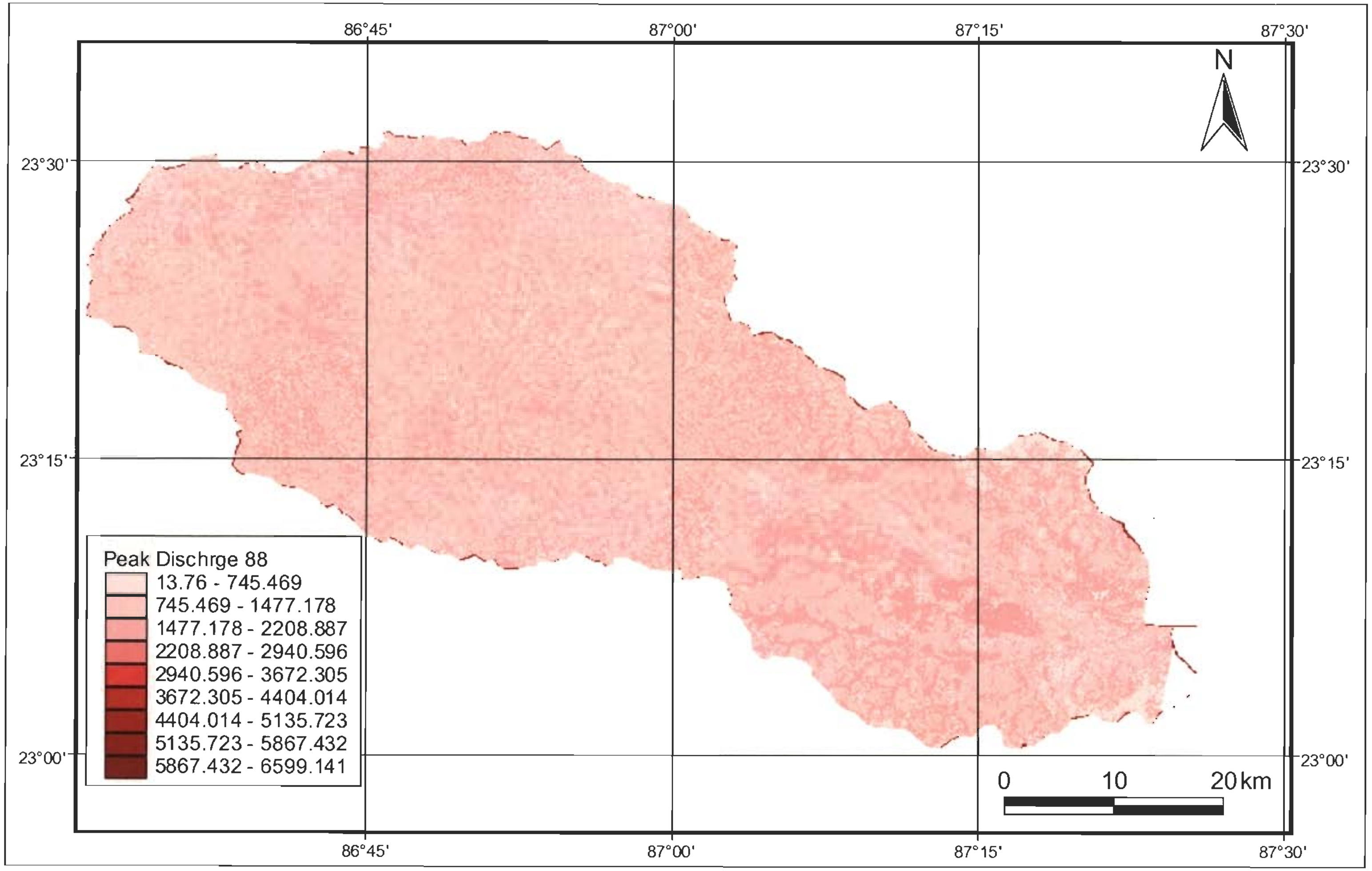


Figure 5.4 : Peak discharge calculated by SCS Curve Number Method for 1988 data.

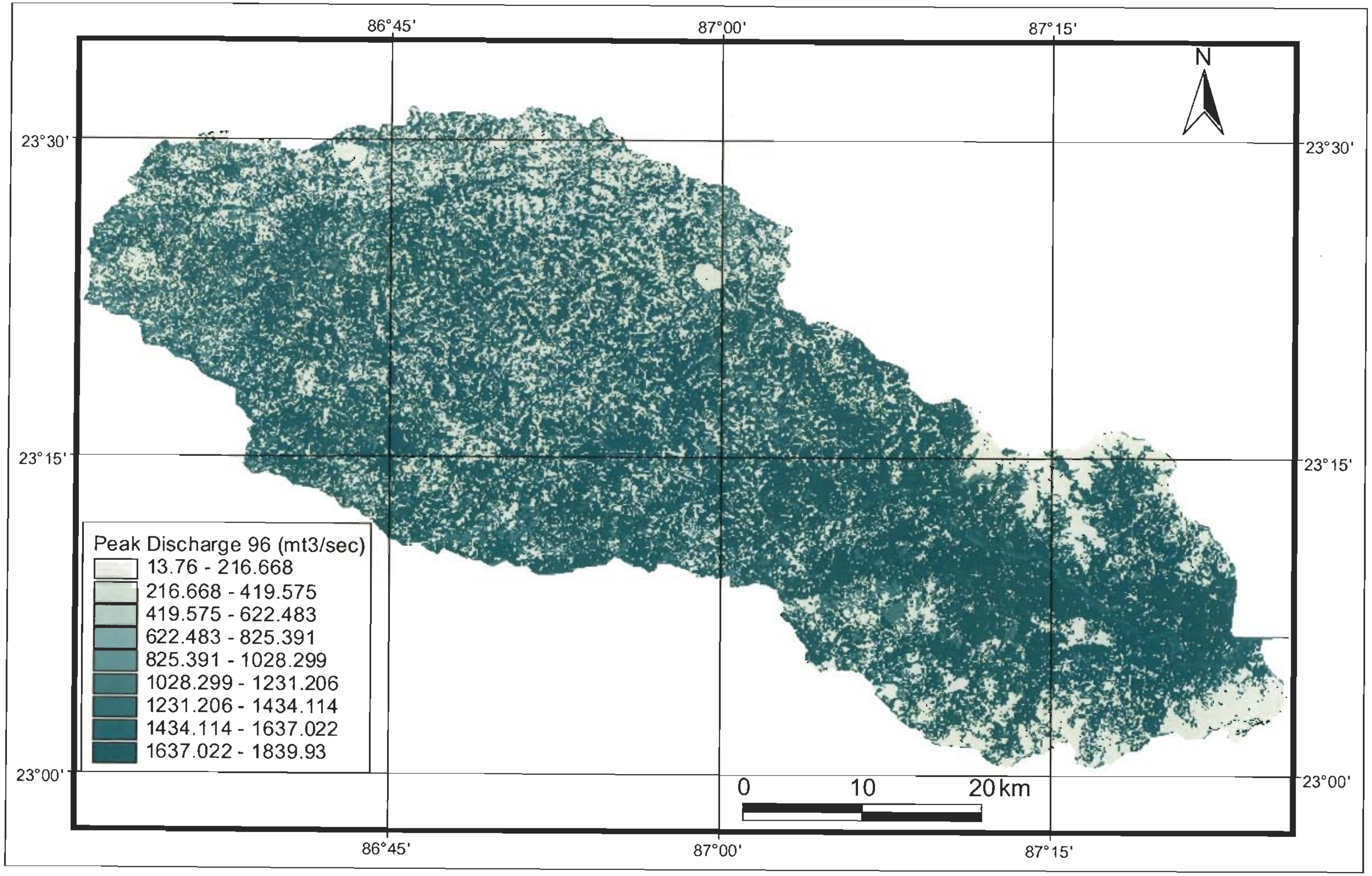


Figure 5.5 : Peak discharge calculated by SCS Curve Number Method for 1996 data.

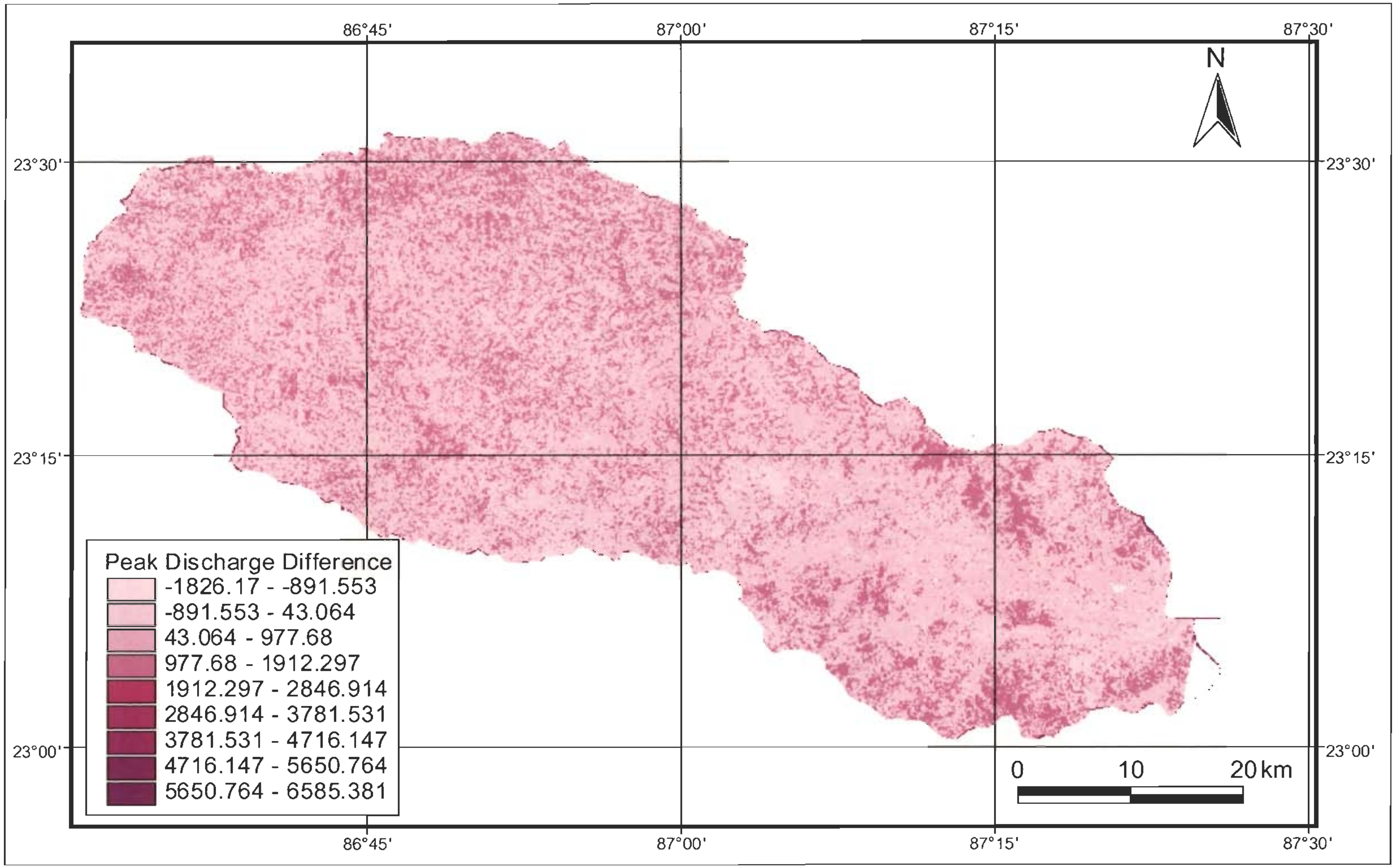


Figure 5.6 : Difference in Peak Discharge (1988-1966) for the Dwarkeshwar Watershed.

Chapter 6

GROUNDWATER RECHARGE STUDY

6.0 INTRODUCTION

Groundwater can be considered as an extremely valuable resource of limited extent in a hard rock terrain. It constitutes one portion of the earth's water circulatory system known as the hydrologic cycle. Water bearing formations of the earth's crust act as conduits for transmission and as reservoirs for storage of water. Water enters these formations through the ground surface or from bodies of surface water, after which it travels for varying distances until it returns to the surface by action of natural flow, plants or man.

The precipitation reaching the water table is called recharge. Principal sources of natural recharge include precipitation, stream flow, lakes and reservoirs. Even seawater can enter underground along coasts where hydraulic gradients slope downward in an inland direction.

In places where occurrence of groundwater is not adequate, it is essential to artificially recharge the aquifers in order to increase the natural supply of groundwater. Artificial recharge may be defined as augmenting the natural movement of surface water into underground formations by some methods of construction, by spreading of water or by artificially changing natural conditions. The choice of a particular method is governed by local topographic, geologic and soil conditions, the quantity of water to be recharged and the ultimate water use.

A large number of factors control groundwater recharge viz. intensity, distribution and duration of rainfall; evapotranspiration; soil moisture; infiltration capacities of soils; geology; geomorphology; landuse; slope; area and shape of watershed; type of drainage network extent of indirect drainage; artificial drainage; etc. (Kundu, 2000). Anyone seeking a simple and convenient equation for determining maximum recharge will appreciate the difficulty of such a procedure when he realizes that any such equation has to be expressed in terms of all the above variables, and that almost any of the factors may affect the result to a considerable extent. Furthermore, if recharge is expressed in terms of only one variable, the result obtained will be with enormous error. From this it follows that a trustworthy appraisal must be based upon a careful consideration of the influence of all the foregoing factors and cannot possibly be determined by the use of a simple equation involving only one, or at best, two or three variables.

6.1 HYDROGEOLOGIC SETTING

A substantial part of Dwarkeshwar watershed represents a typical hard rock terrain as the pink granite, granite gneiss with pockets of quartzite, quartzite schist, hornblende schist and mica schist cover most of the western part of the watershed. The eastern and southeastern margins of the watershed are covered by alluvium. As such the occurrences of groundwater are restricted to (a) the fractures and weathered mantle, (b) shallow aquifers in unconfined state and (c) the deeper aquifers in confined state, below a blanket of clay of varying thickness.

In the present area, average annual rainfall varies between 1100-1400 mm. Most of the rainfall is contributed in monsoon months starting from June to September. Groundwater recharge takes place only during this period. The monsoon recharge cannot meet the demands of agriculture and drinking water till the end of dry season. Most of the dug wells/tube wells go dry in the month of May. In an area like this, groundwater is an extremely valuable resource of limited extent. Proper utilization of groundwater and management planning demands a thorough understanding of the groundwater resources.

6.2 SCOPE OF THE PRESENT WORK

In this section an attempt has been made to develop an integrated remote sensing and GIS based method for groundwater recharge investigation. The main objectives are:

(i) To have an understanding of groundwater resources in the given study area, its occurrence and movement.

(ii) To identify the interrelationship of recharge areas with geology, geomorphology, soil, landuse and structure of the area.

(iii) To identify the groundwater potential zones.

(iv) To have qualitative and quantitative assessment of groundwater recharge.

(v) To suggest suitable sites and methods for artificial recharge.

6.3 METHODOLOGY

The methodology developed for the present study has been explicitly summarized in Chapter 3. The following steps have been followed to accomplish the above objectives (Figure 3.1):

(a) IRS-LISS-II and IRS-LISS-III data have been enhanced by using suitable digital image processing techniques and thematic maps on geology, geomorphology, soil, lineament and landuse have been prepared. The NATMO (National Atlas and Thematic Mapping Organisation) maps were also used for the generation of thematic layers.

(b) Depth to water level data has been analyzed to study the long-term behavior of water level in the area.

(c) Each of the above mentioned information layers have been assigned appropriate weightages based on their relative importance and an weighted index overlay operation have been performed to generate groundwater potential map.

(d) Groundwater recharge has been estimated by water level fluctuation method.

(e) IRS-LISS-II and LISS-III data supported by DEM, geology, geomorphology, drainage, lineament etc. have been studied to identify the areas of artificial recharge.

(f) The criterion for suitability of recharge has been identified and the information layers have been assigned with weightage on the basis of their relative contribution in influencing artificial recharge.

(g) Weighted index overlay analysis has been performed in order to demarcate zones of suitability for artificial recharge.

(h) Boolean logic analysis has been performed to suggest artificial recharge sites.

6.3.1 Generation of Thematic Information Layers

6.3.1.1 Lithology

The lithological map of the watershed (Figure 2.3) has been prepared from remote sensing data supported by published geological maps of GSI. FCC 432 of LISS-II (Figure 4.1) and 321 of LISS-III (Figure 4.2) help to distinguish different lithological units. The northwestern part of the watershed is covered by crystalline rocks of Precambrian age represented by pink granite. Isolated bodies of quartzite/quartz-schist lie within the pink granite unit. The mica-schists, hornblende-schists and granite gneisses lie to the south of the pink-granite unit. A thick mantle of laterite and alluvial deposits of Pleistocene age occur to the east of these Precambrian units. The laterite occurs as hard massive blocks or as nodules, being partly cemented weathered products of crystalline rocks. Older alluvium represents transported weathered products of Precambrian rocks. Patches of ferruginous gritty sandstone also occur in the central portion of the watershed.

6.3.1.2 Geomorphology

Geomorphic features have been identified from remote sensing data in conjunction with DEM and slope map. FCC (bands 432) of LISS-II and (bands 321) of LISS-III (refer Figure 4.1 and 4.2) have been quite useful in the delineation of different features.

The Dwarkeshwar watershed forms part of an intermediate tract between the Chotanagpur plateau in the west and the alluvial plains in the east (refer Figure 2.4). The western part of the watershed consists of strongly to moderately sloping landforms with isolated hillocks, mounds and valleys. Severely gullied lands are common along the river courses. Pediments show nearly flat to gently sloping topography with skeletal soil. These are mainly wastelands with rocky knobs with/ without sparse vegetation. Towards the east, the slopes become gentle and finally grades into a vast alluvial plain. Flood plains and alluvial fills run parallel along the river and merges with the upper and lower alluvial plains.

6.3.1.3 Soil

The soil map for the watershed (Figure 2.5) was prepared from NBSS & LUP map. In the western part of the watershed lies red and yellow soils with gravelly texture. The intermediate tract is covered by lateritic soil. The eastern part is covered by older and newer alluvium. The older alluvium shows profile development.

6.3.1.4 Landuse

The classified landuse maps (Figure 4.3 and 4.4) were prepared from LISS-II (1988) and LISS-III (1996) FCCs. The entire watershed was classified into eight classes using supervised classification scheme. The numbers of different classes of landuse were chosen after extensive ground realities.

The entire watershed consists of various land classes viz. dense forest, degraded forest, arable land, fallow land, wasteland, river sediment, water body and settlement. Most of the dense and degraded forests are restricted to the eastern part of the watershed. The arable lands are generally restricted alongside the river channels.

6.3.1.5 Digital Elevation Model (DEM)

Topography plays an important role in the spatial distribution of groundwater. Water table generally follows the topography. The classified DEM has been generated after digitizing the elevation contours (at 10 m interval) from SOI toposheets by interpolation as discussed in Chapter 3 (Figure 6.1). The area does not show much variation in relief. The maximum and minimum elevations are 220 m and 40m above m.s.l. respectively. The eastern and central part of the area is nearly flat and rises to hills and plateaus along the western, northwestern and northeastern boundary. DEM is quite useful in such studies as it provides various derivatives describing the terrain.

6.3.1.5.1 Slope Map

The slope map (Figure 6.2) has been generated by calculating local first derivative in X and Y directions. About 80% of the total watershed area has slope of less than 10°. Isolated mounds and hillocks in the central and western part of the watershed have higher slopes. The slope map acts as an important variable in the derivation of other DEM derivatives and catchment hydrologic properties.

6.3.1.5.2 Aspect Map

The aspect map (Figure 6.3) shows the direction of the slope. In the Dwarkeshwar watershed, the dominant aspect is towards southeast direction. A little change in aspect is noticed towards the eastern margin of the watershed. However, the aspect map has not been used in the GIS analysis.

6.3.1.5.3 Extraction of Catchment Hydrologic Properties

Digital elevation models can provide a wealth of information about the geomorphic and hydrologic properties of an area (Saraf & Choudhury, 1998). In the present study, flow direction and flow accumulation have been derived using the method presented by Jenson and Domingue (1988). The flow direction for a cell is the direction in which water flows out of the cell. Of the eight possible directions, the one with the maximum downward slope is selected and stored in the flow direction matrix. The flow accumulation matrix represents the sum of the weights of all elements in the matrix, which drain to that element. Simulated drainage network at threshold value 450 and stream order have been derived from the DEM data assuming the surface to be insulated, i.e. neglecting loss of water upward by evapotranspiration or downward by infiltration into the surface.

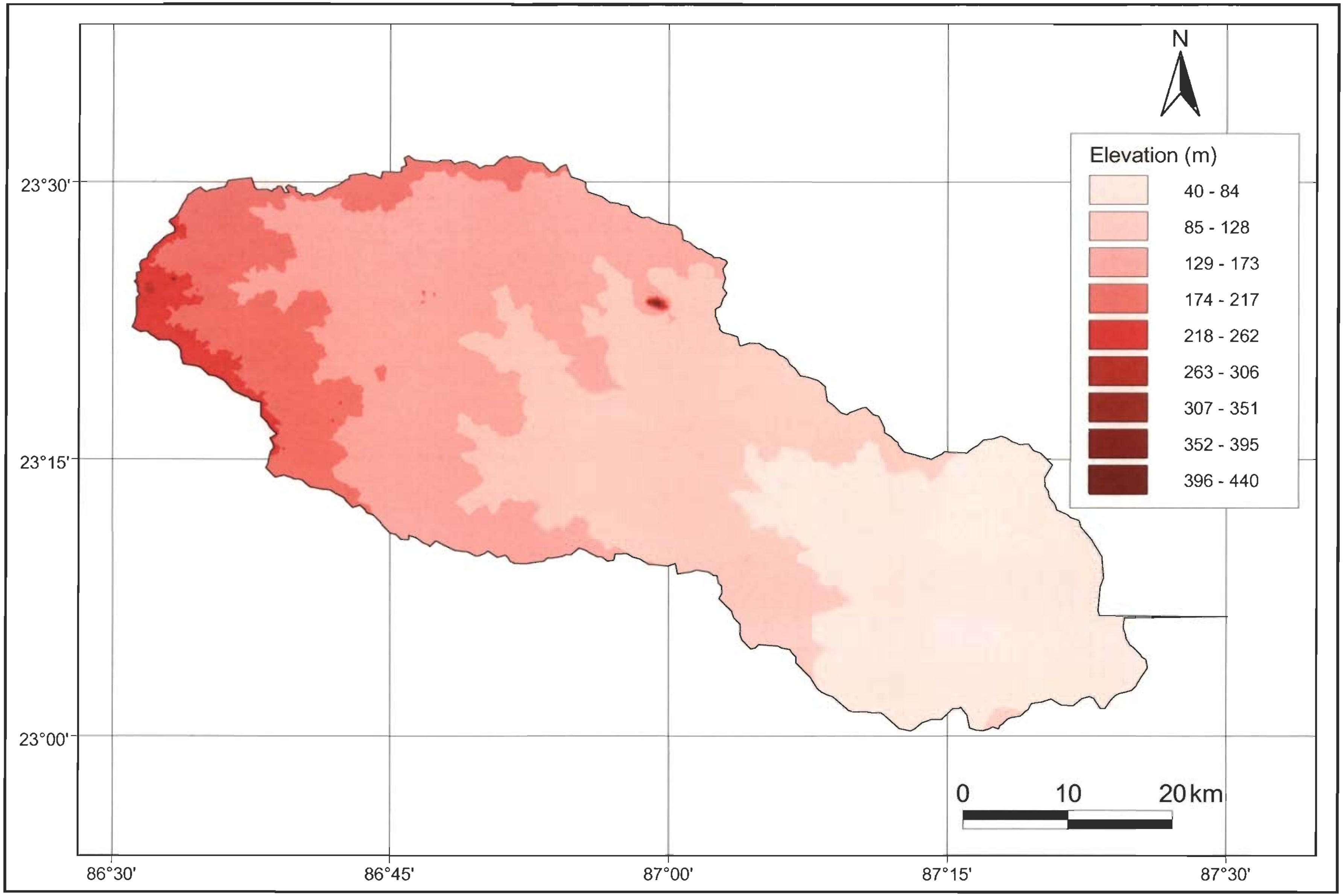


Figure 6.1 : Digital Elevation Model (DEM) for the Dwarkeshwar Watershed obtained by interpolating contours from SOI toposheet.

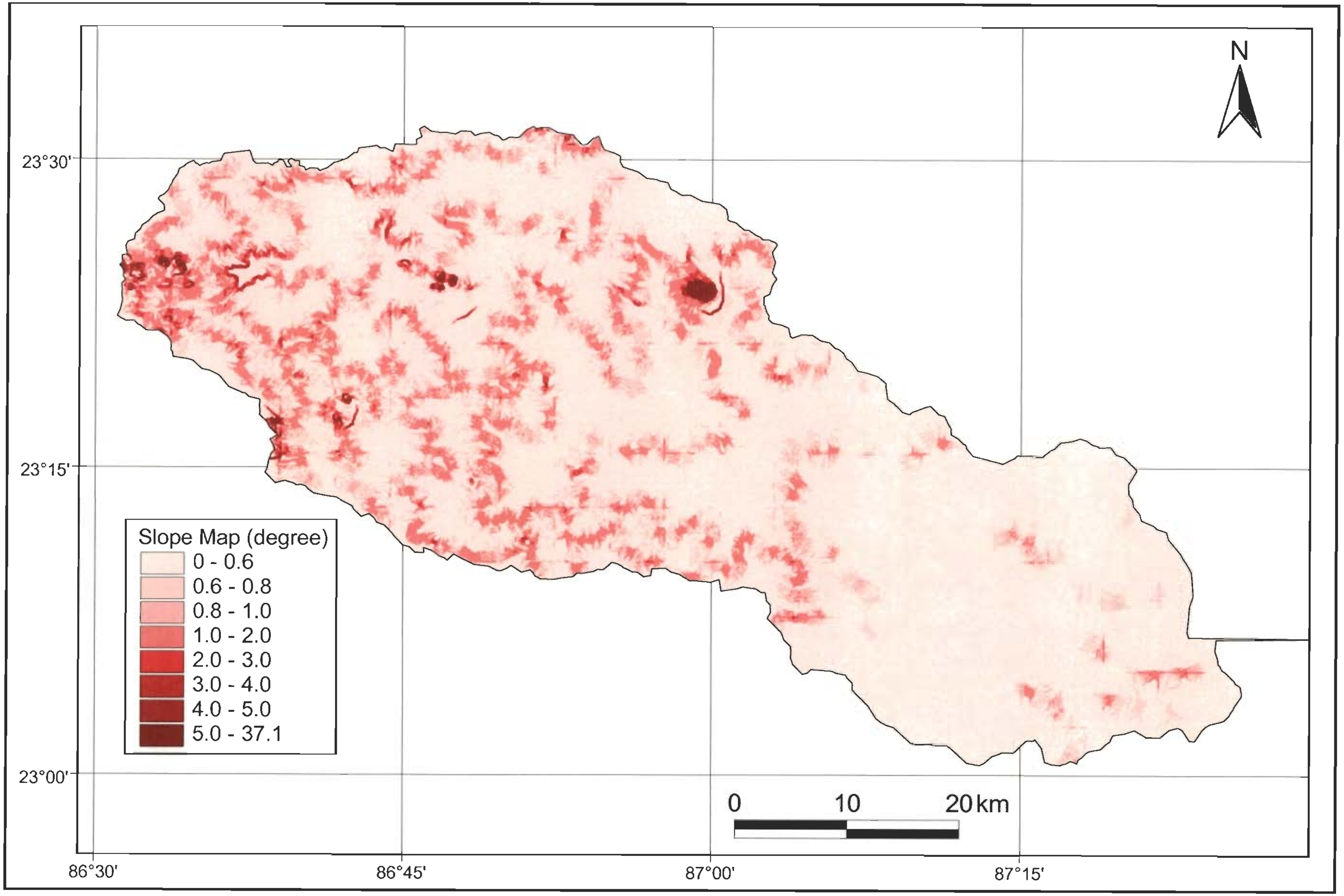


Figure 6.2 : Slope Map (in degree) of the Dwarkeshwar Watershed prepared from DEM.

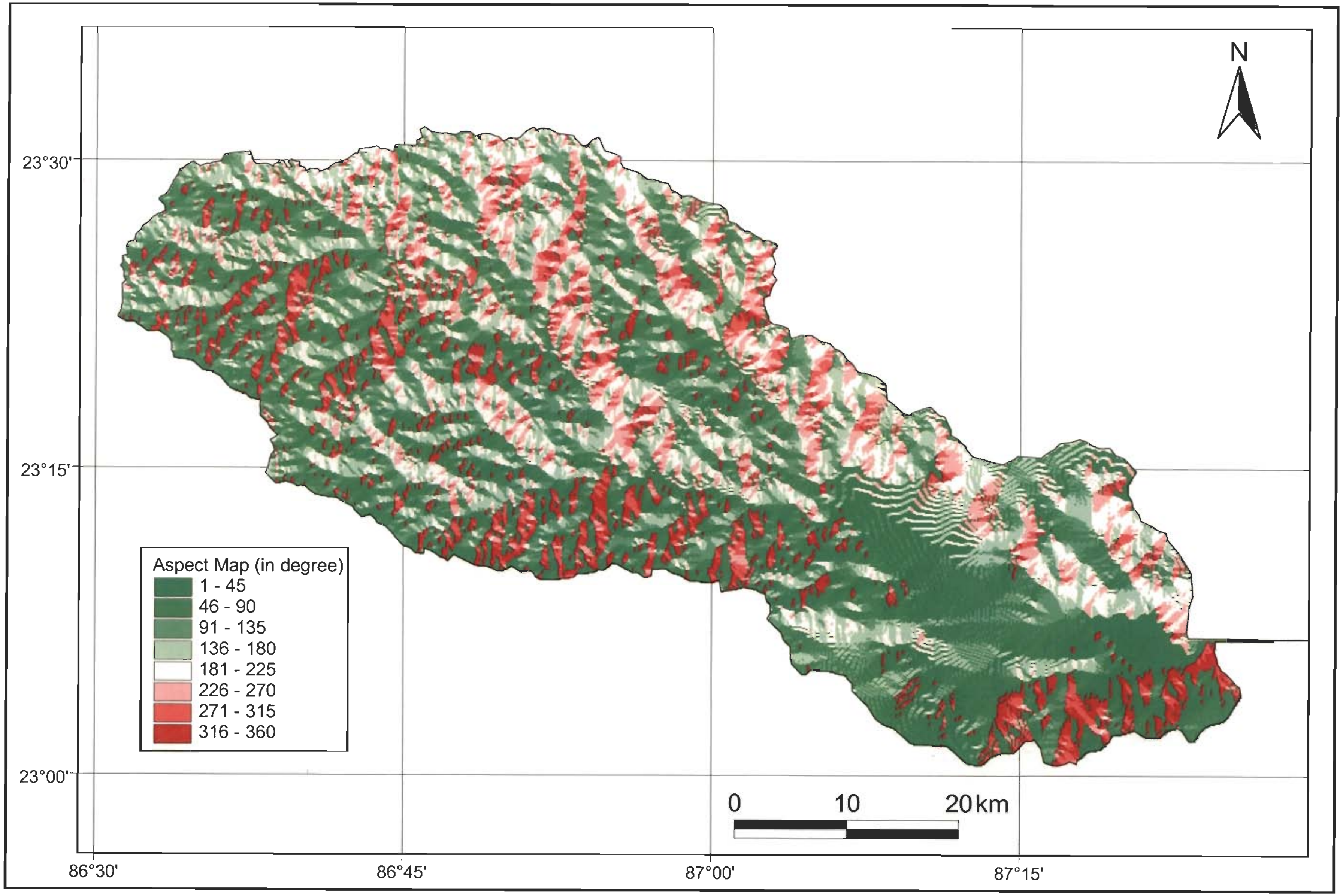


Figure 6.3 : Aspect Map (in degree) of the Dwarkeshwar Watershed prepared from DEM.

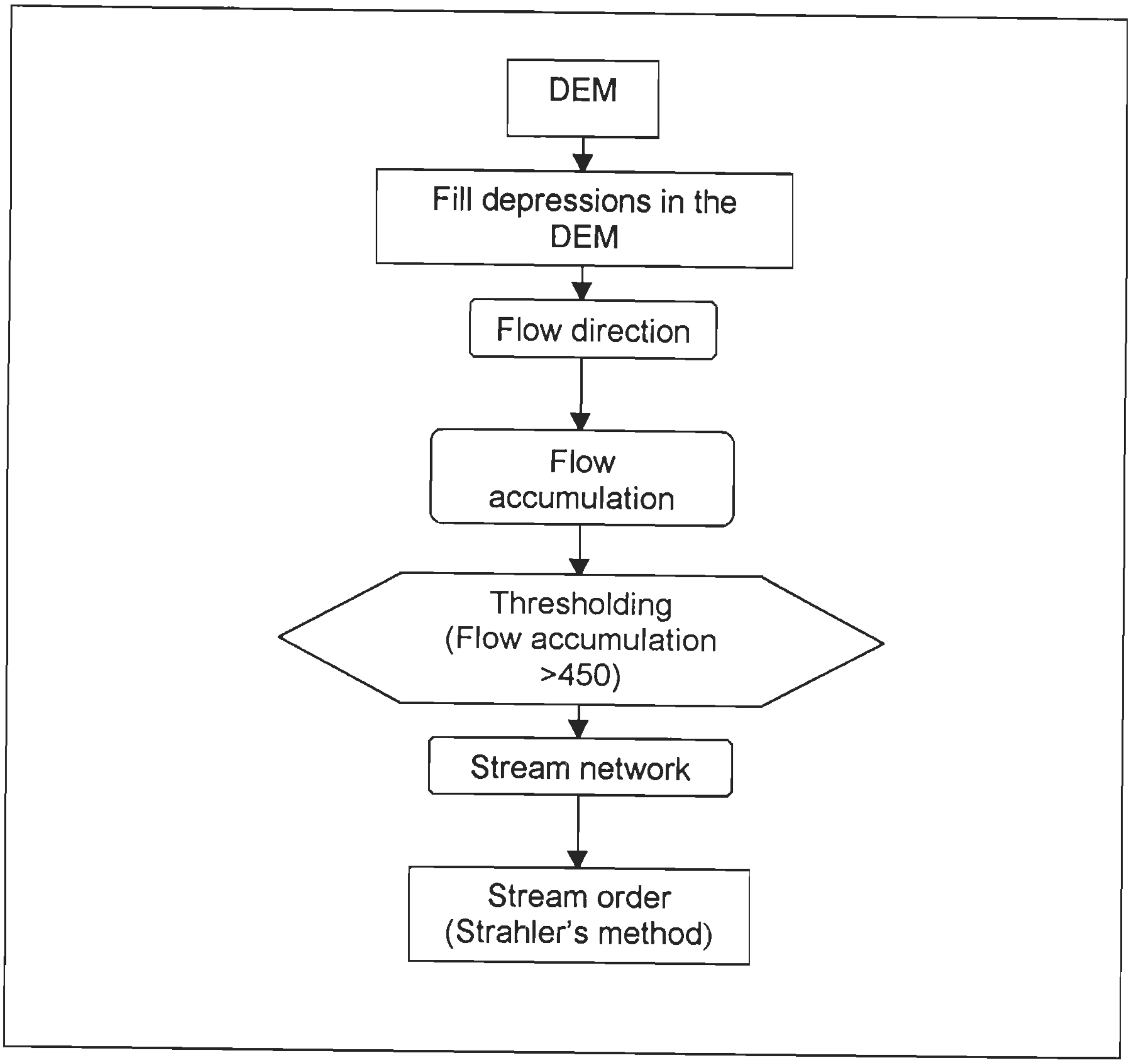


Figure 6.4. Methodology adopted for derivation of stream network from DEM.

Figure 6.4 depicts the flowchart for deriving stream network and stream order from the DEM. Naturally, there will be some degree of misfit between the surveyed and the simulated drainage from DEM.

Depression areas surrounded by neighbouring pixels of higher values are always considered as hindrance for the determination of hydrologic flow direction. Some depressions are data errors while some other exist in reality, e.g. queries etc. There are two approaches to remove depression. One is by smoothing the DEM (O'Callaghan and Mark, 1984; Mark, 1984). The second approach is to fill the depression by raising them to the lowest elevation value on the rim of depression (Jenson and Domingue, 1988). The second approach is followed in the present study.

Flow direction data (Figure 6.5) are used to create flow accumulation grid (Figure 6.6), where each cell is assigned the value of the number of cells flowing to it. Cells having flow accumulation value of zero generally correspond to local topographic highs, whereas cells with high flow accumulation correspond to stream channels. The flow accumulation has been utilized to produce a drainage network (Figure 6.7) applying a suitable threshold value. Threshold value (taken as 450 in the present study) indicates the minimum number of cells contributing to form a stream. The density of the network increases as the threshold value decreases. The stream ordering has been derived (Figure 6.8) using the drainage network grid and the flow direction grid. Strahler's stream ordering scheme has been followed. Stream order increases when the same order streams intersect. When two first order streams meet, the down slope stream is assigned an order of 2. The intersection of the first and second order streams remains a second order stream.

Figure 6.9 shows a comparison of the surveyed drainage from toposheets with drainage derived from DEM in the Dwarkeshwar watershed. There is considerable degree of match in the western hilly part. In the flat central and eastern areas, drainage lines are straight due to low gradient. To have a quantitative idea of the amount of matching between the surveyed and simulated drainage, the two themes are allowed to intersect (using themes intersection to points extension) and the resultant point theme (Figure 6.10) is analysed.

The analysis (using Nearest Neighbour Analyst extension developed by Dr. A. K. Saraf and available on ESRI Web site) applies a simple test of significance for deviation from randomness, using the standard error of the expected difference. R-values relate how clustered or dispersed points are within the polygon theme specified (refer Table 6.1). In case of the present study the R-value comes out to be 0.426, which means there is a strong tendency towards clustering. Hence there is an acceptable degree of match between the surveyed and the simulated drainage. For more discussion on this

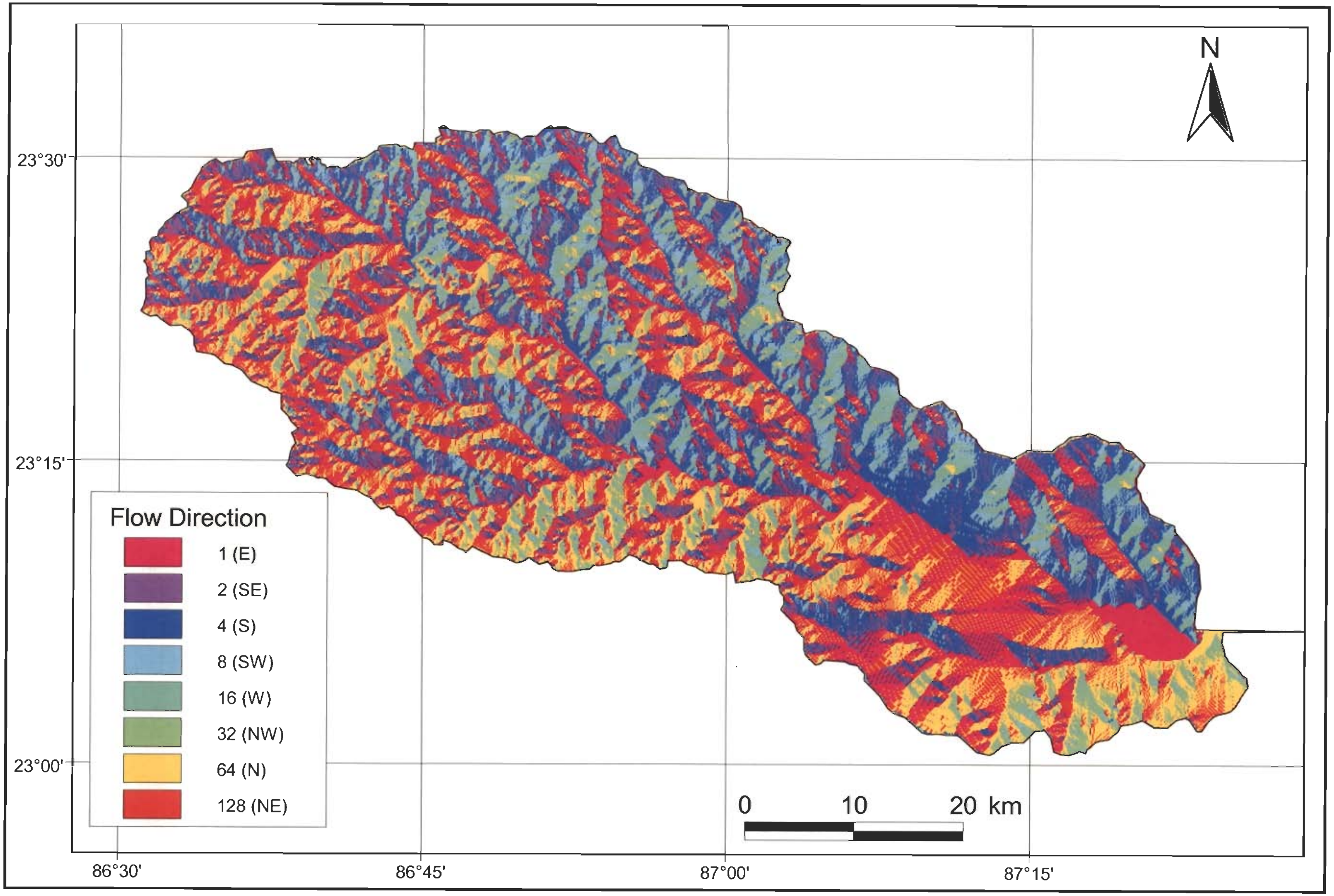


Figure 6.5 : Flow Direction Map for the Dwarkeshwar Watershed prepared from DEM.

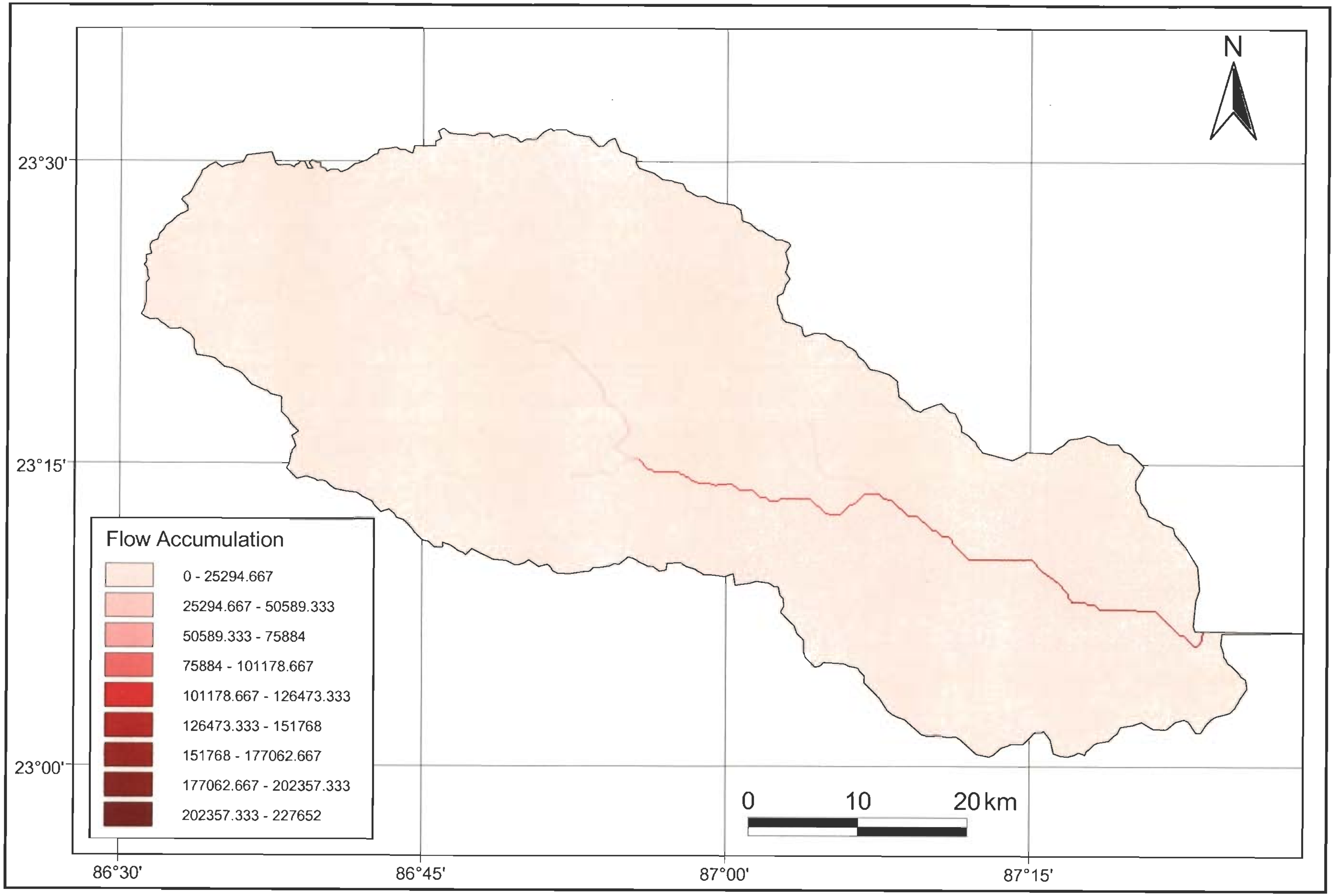


Figure 6.6 : Flow Accumulation Map of the Dwarkeshwar Watershed derived from Flow Direction grid.

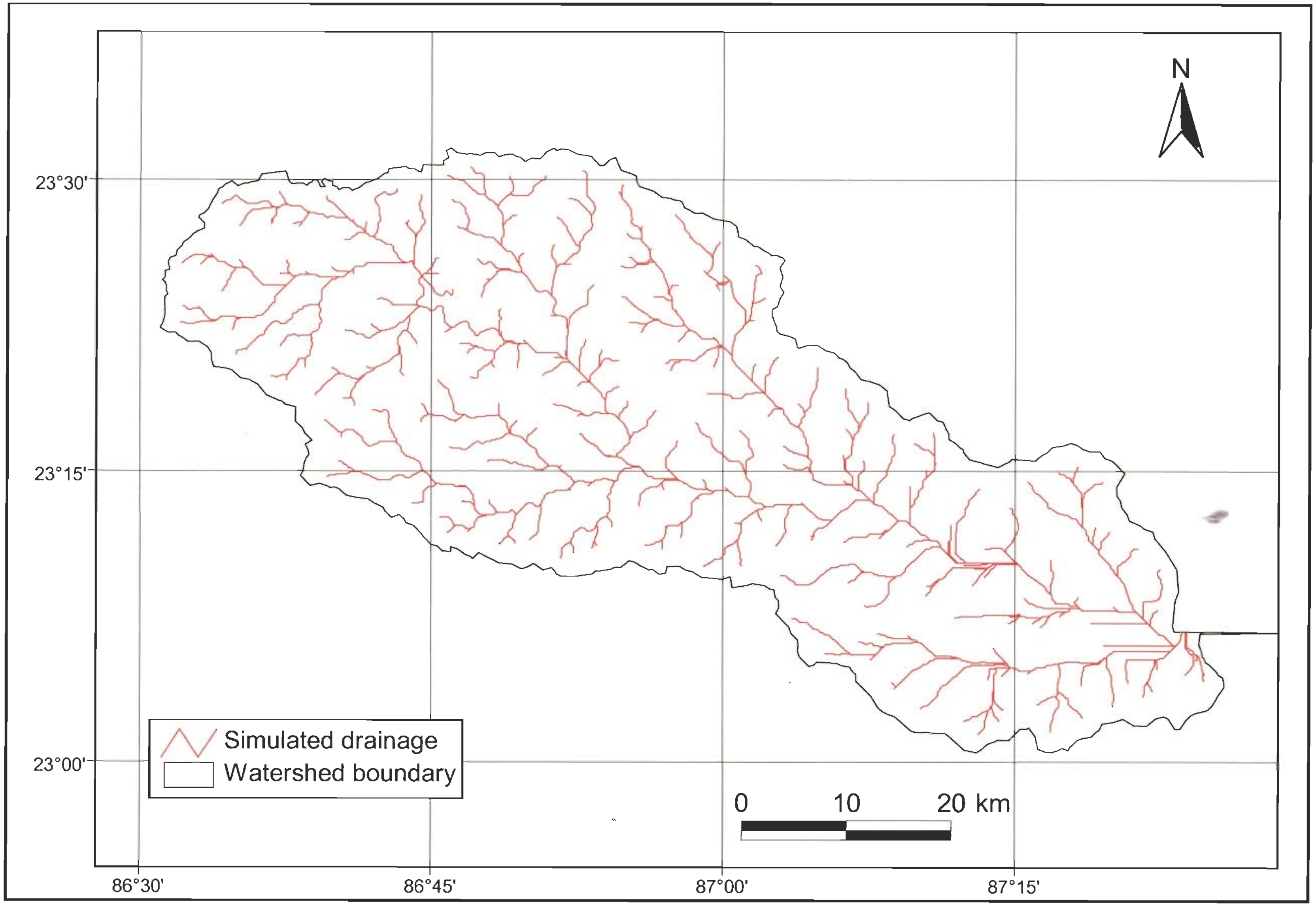


Figure 6.7 : Drainage network simulated from DEM of the Dwarkeshwar Watershed (threshold value 450).

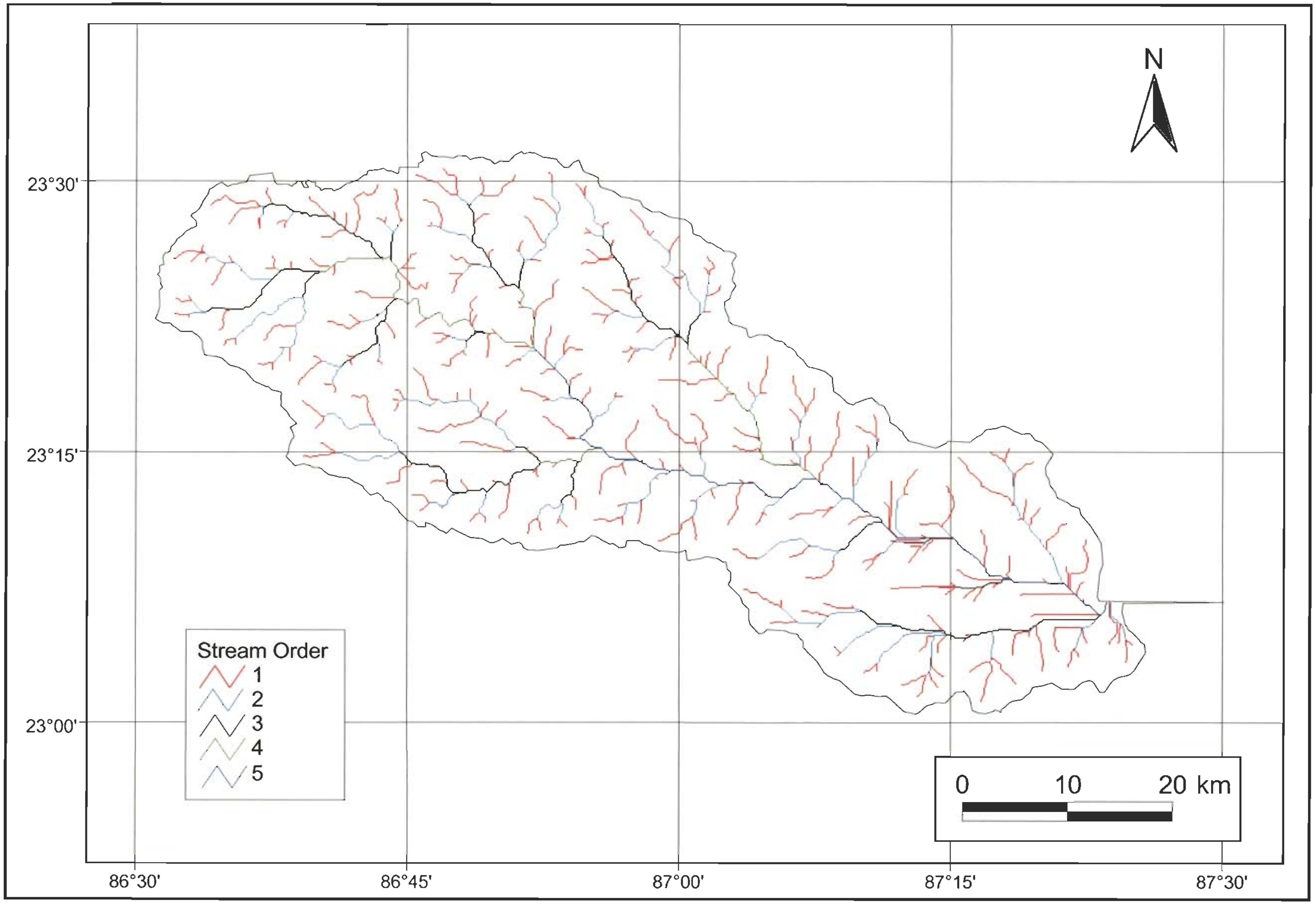


Figure 6.8 : Stream Order Map (Strahler's Scheme) of the Dwarkeshwar Watershed derived from drainage and flow direction grid.

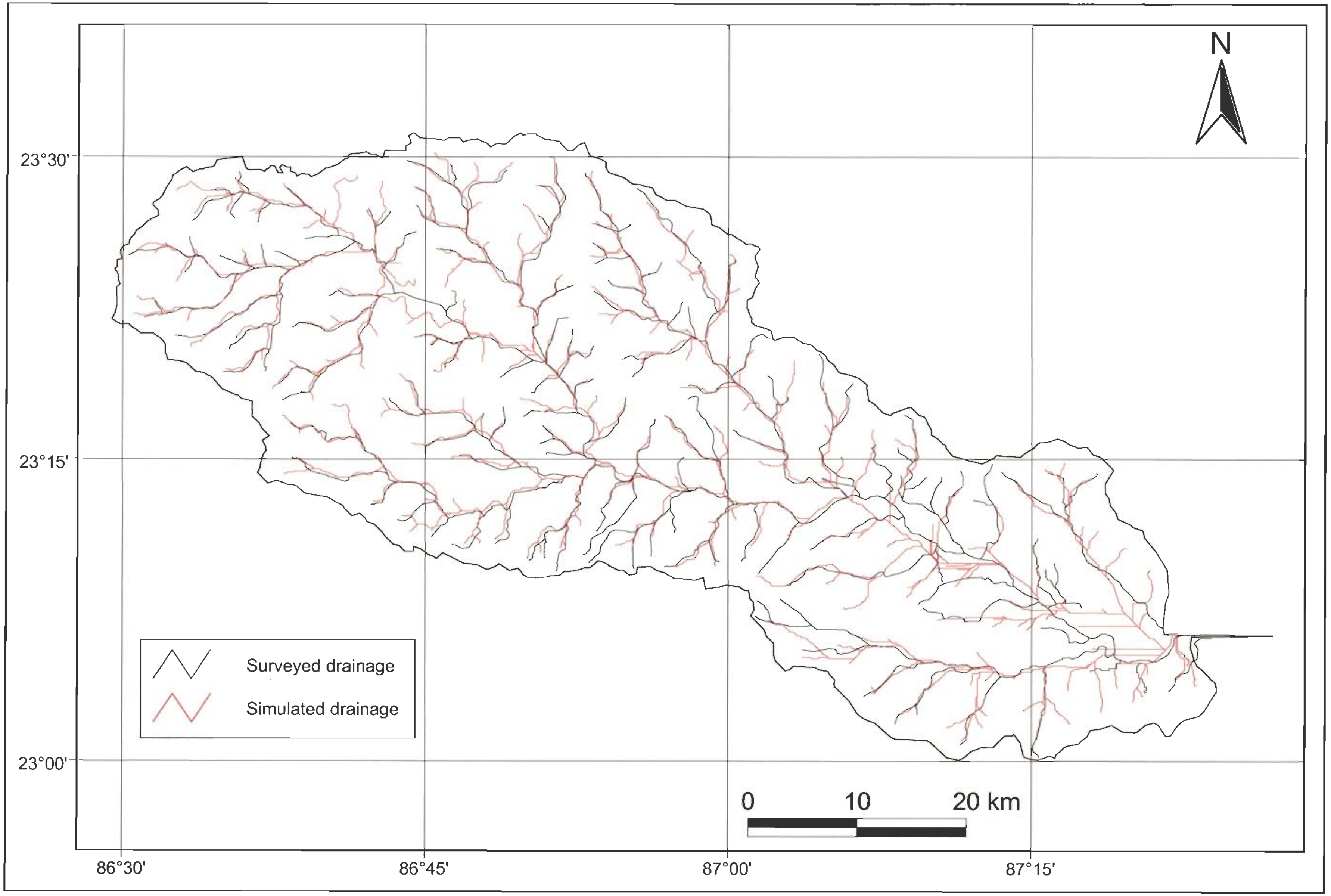


Figure 6.9 : Comparison between surveyed drainage network of Dwarkeshwar Watershed and drainage network simulated from DEM.

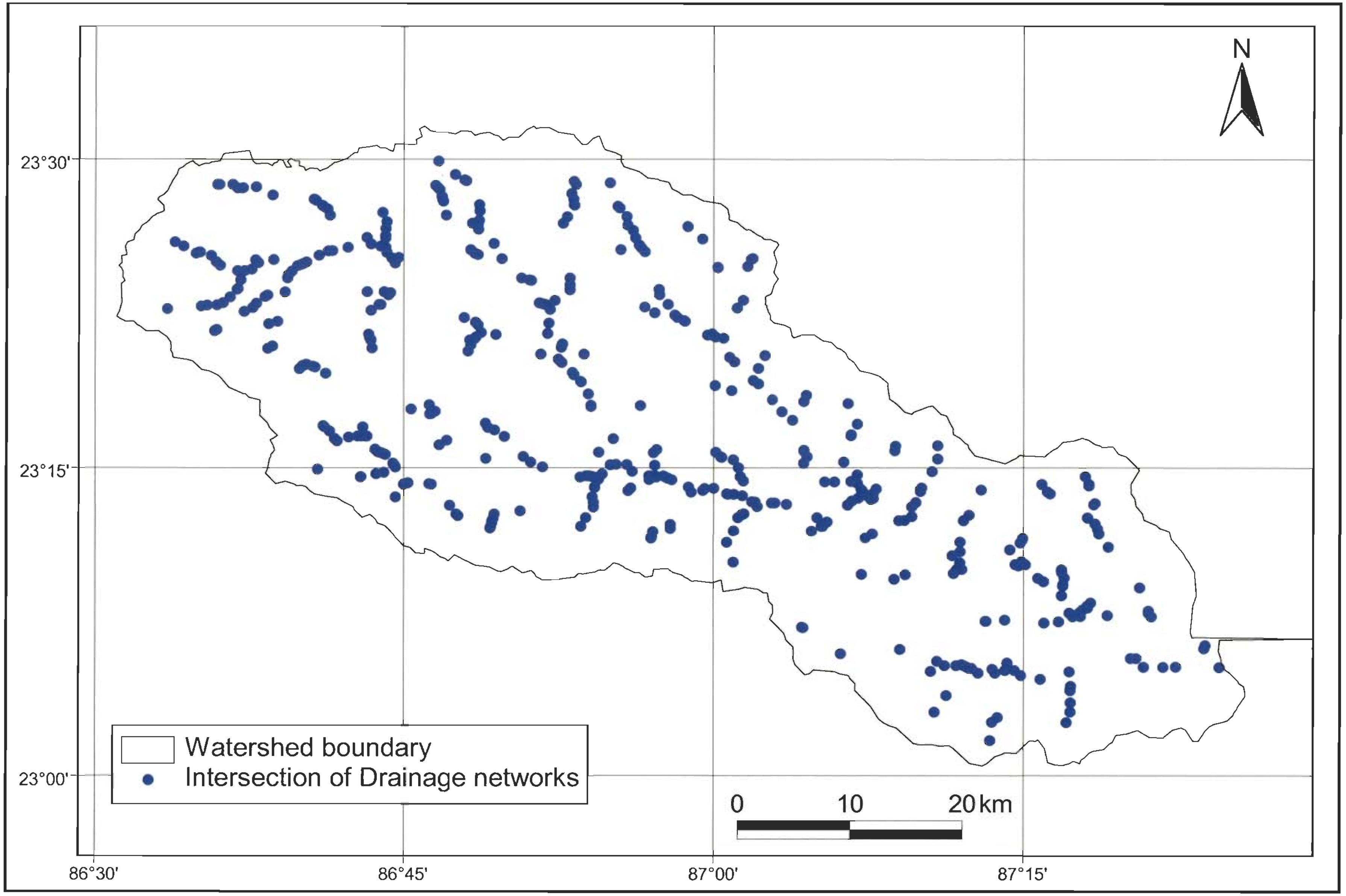


Figure 6.10 : Intersection points between the surveyed drainage and drainage simulated from DEM of Dwarkeshwar Watershed.

please refer to the script developed by Colin Brooks (Nearest Neighbor Script, v.1.8 available on ESRI Web site).

Table 6.1: Table showing cluster pattern tendency corresponding to different R-values.

R-Value	Cluster Pattern Tendency
R < 1	Clustered Pattern
R = 1	Random Distribution Pattern
R > 1	An organized (uniform) Pattern

There are some limitations of this method of automated extraction of drainage. Firstly, the infiltration loss and evapotranspiration loss are not taken into account while deriving flow accumulation. Secondly, in the process of removal of depressions, actual DEM data are modified. The density of the network depends on the threshold value used for flow accumulation.

However, this misfit can be linked to recharge areas. In this area, evapotranspiration is more or less uniform. Thus, it can be inferred that towards the eastern and south-eastern part of the Dwarkeshwar watershed, water is infiltrating and these are the recharge areas.

6.3.1.6 Lineaments

Structural features are mapped from remote sensing data supported by existing geological maps. The surface expressions of subsurface structures appearing on remote sensing data are in the form of lineaments. These linear features or lineaments are of great interest to hydro geologists in locating groundwater zones. The correlation of lineament with groundwater depends upon the geological nature of the lineament. Fractures generally act as water circulation channels and are often the sites for natural recharge of groundwater. In the Dwarkeshwar watershed the lineaments show diverse orientations ranging from NW-SE to N-S to NE-SW. So they run either along or across the drainage.

In order to understand the spatial variability in distribution of the lineaments, a lineament density map (Figure 6.11) has been prepared using the 'Lineament/ Drainage/Road Density Analyst Extension' (Saraf, 2001).

6.3.1.7 Drainage

Drainage development has direct linkage to the geology of an area, and it indirectly indicates groundwater conditions. Drainage map has been prepared from SOI toposheets at 1:50,000 scale. The area is drained by the Dwarkeshwar River and its tributaries. The drainage pattern is mainly dendritic. In the Dwarkeshwar watershed, streams up to 5th order have been found (Figure 6.8). Higher order streams indicate greater degree of weathering and represent zones of higher recharge.

In order to compute the drainage density (using the 'Lineament/Drainage/Road Density Analyst Extension'), the area has been subdivided into roughly 400m x 400m grid. Within each grid the length of the drainage has been represented in meters (Figure 6.12). It has also been noticed that high drainage density is associated with higher order streams. In general higher drainage density indicates less permeable underlying lithology and higher erodability of the surface material. However, low drainage density does not always indicate more permeable lithology. Drainage density is high at the junction of two or more streams. The misfit between the surveyed and DEM derived drainage network is minimum in the lower order streams and maximum in the higher order streams. It is because that the areas where lower order streams are predominant have a very low permeability and hence most of the precipitated water flows as surface flow. But as the stream order increases, the area becomes flatter and flatter and some of the precipitated water infiltrate into the ground showing the misfit.

6.3.1.8 Groundwater Level

Groundwater level data indicate the status of groundwater. Depths to water level data of pre- and post-monsoon dates were available for 12 permanent hydrograph stations within the watershed (Figure 6.13). In total, data for 117 hydrograph stations were available. Since separate analysis in GIS needs pixel-by-pixel information, both average pre and post monsoon water level maps were generated from available data sets by interpolation (Figure 6.14 and 6.15). The direction of groundwater movement can be inferred

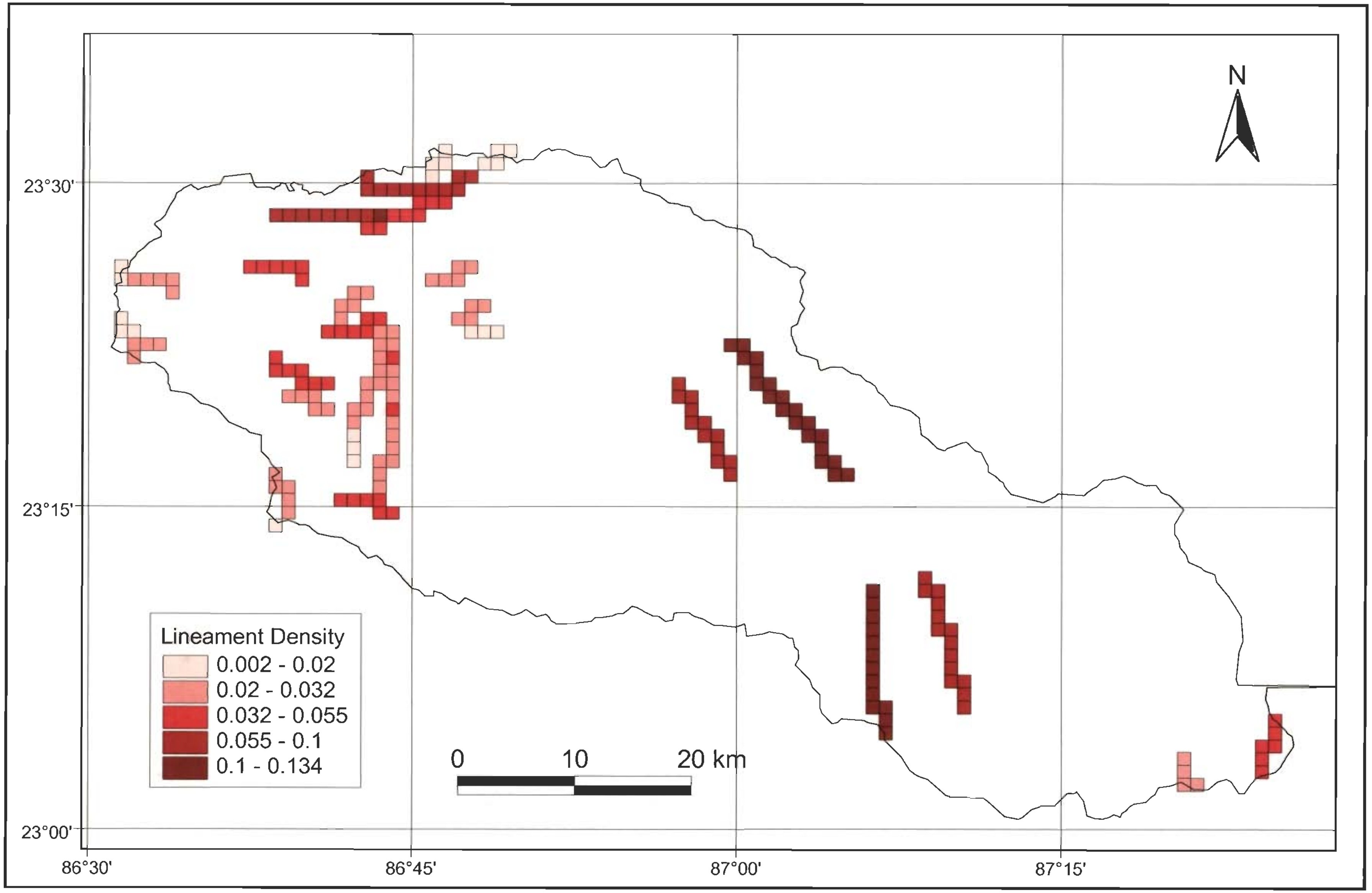


Figure 6.11 : Lineament Density Map of the Dwarkeshwar Watershed.

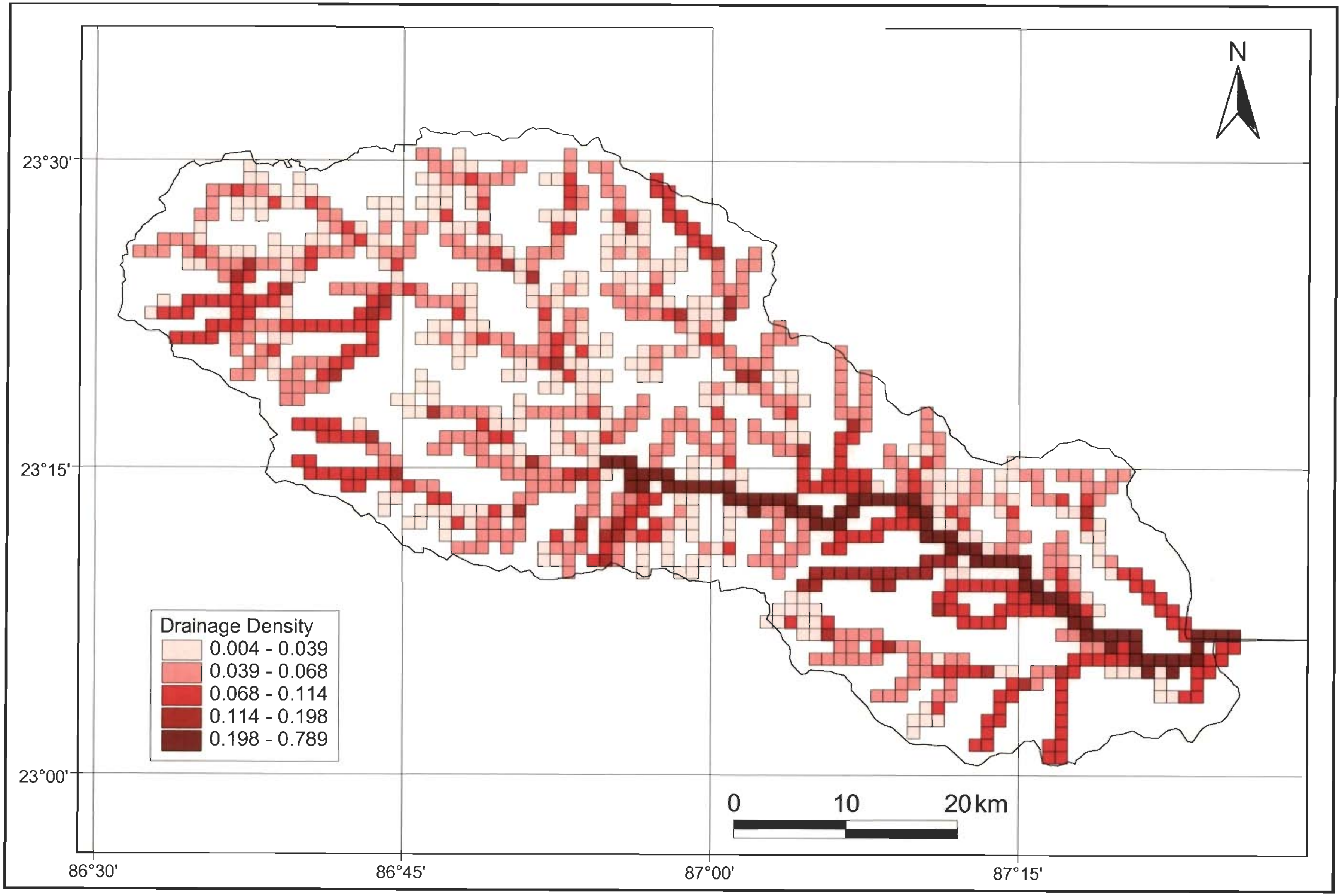


Figure 6.12 : Drainage Density Map of the Dwarkeshwar watershed.

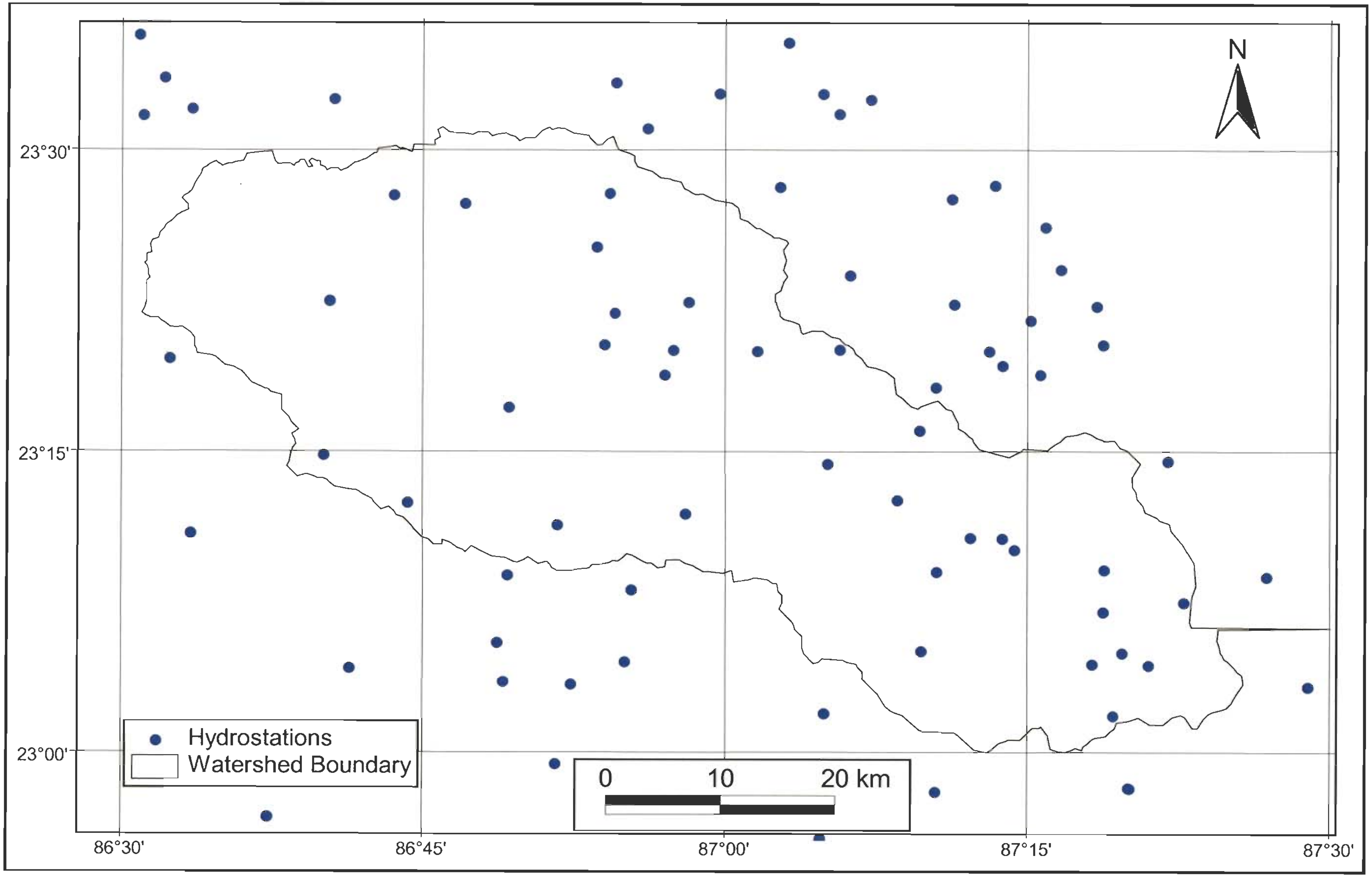


Figure 6.13 : Positions of hydrostations in and around the Dwarkeshwar Watershed.

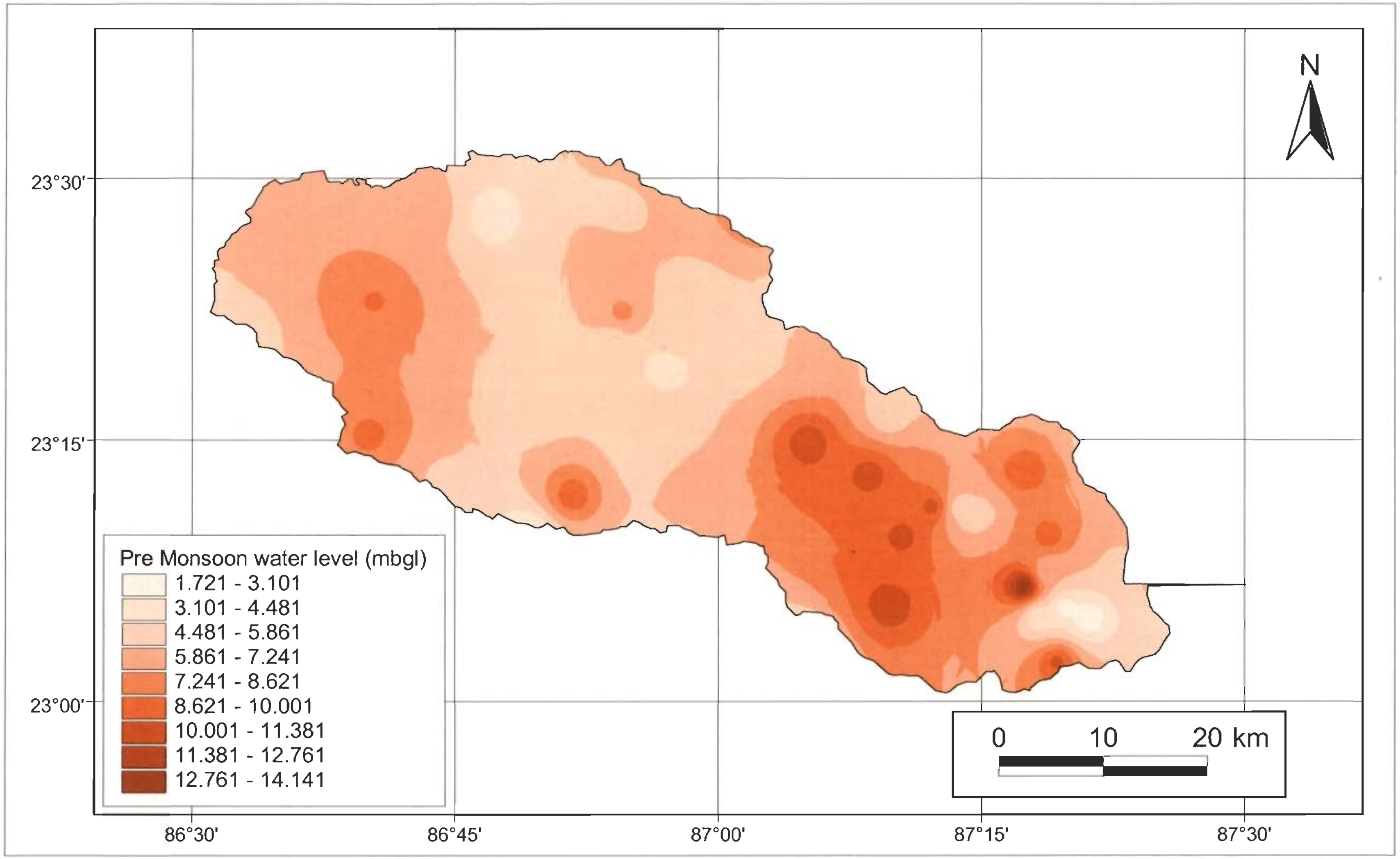


Figure 6.14 : Average pre-monsoon depth to water level map (in mbgl) of the Dwarkeshwar Watershed from 1989 to 1998.

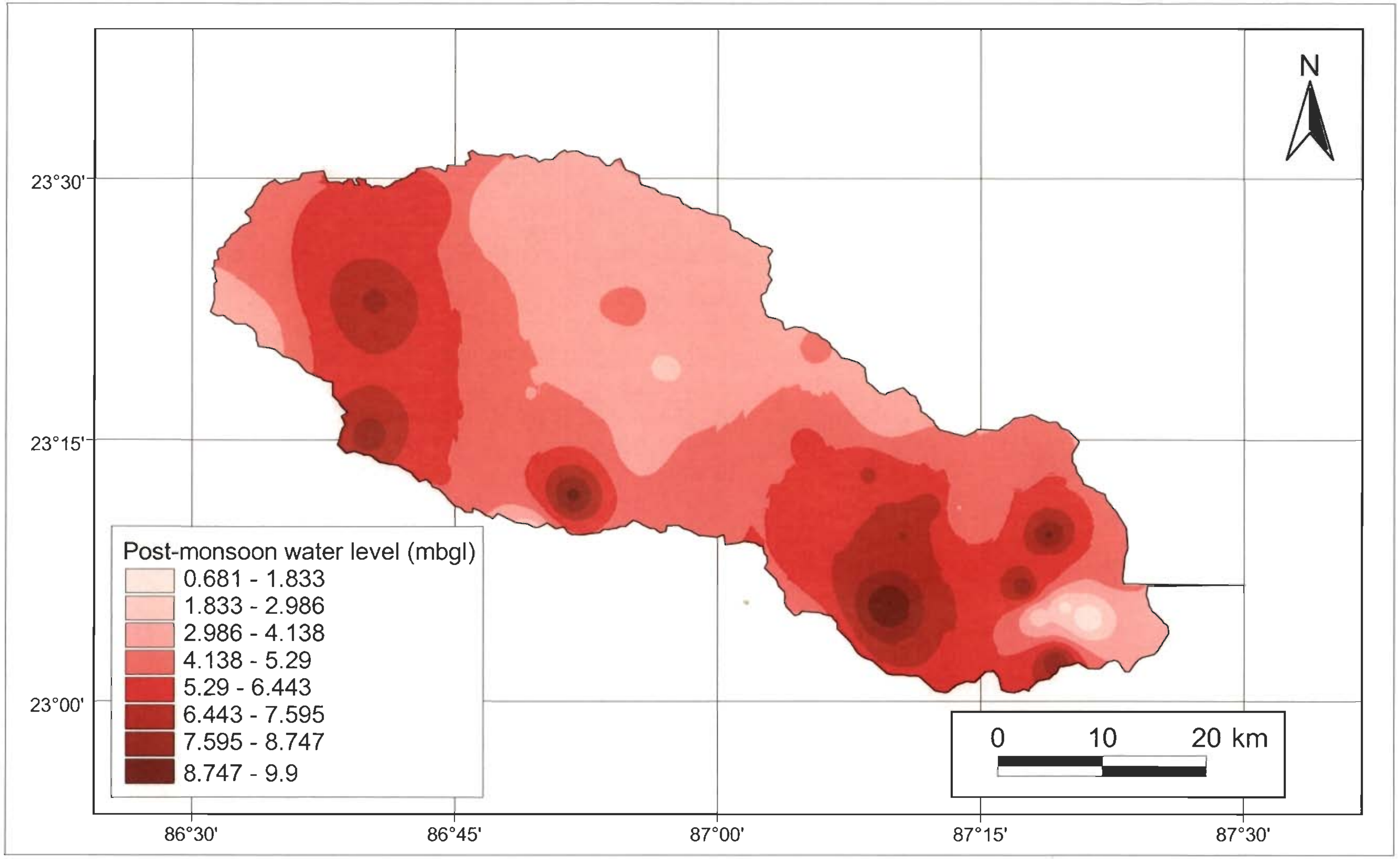


Figure 6.15 : Average post-monsoon depth to water level map (in mbgl) of the Dwarkeshwar Watershed from 1989 to 1998.

from these maps at right angles to the water table contours. Since seasonal fluctuation of water level is directly related to groundwater recharge, subtraction of pre-monsoon water level from post-monsoon water level below ground level yields a water level fluctuation image (Figure 4.10).

6.3.2 Weighted Index Overlay Model for Groundwater Prospects

The fundamental aspect of the integrated analysis is the spatial combination of multiple features so as to characterise the area for all the parameters. Weighted overlay analysis is a simple and straightforward method for a combined analysis of multi-class maps. The efficacy of this method lies in that human judgement can be incorporated in the analysis. Each class of the input maps is assigned different weightage (score or ranking), as well as the maps themselves receive different weightage (as discussed in Chapter 3, section 3.8.2). A weight represents the relative importance of a parameter vis-à-vis the objective. In case of binary weights, all the parameters are assumed to have equal importance. Weighted index overlay method takes into consideration the relative importance of the parameters and the classes belonging to each parameter. This is a more flexible weighting method compared to binary weightage (Choudhury, 1999). There is no standard scale for a simple weighted overlay method. For this purpose, criteria for the analysis should be defined and each parameter should assigned importance (Sarma & Saraf, 2002).

A criterion is a definition of a relationship amongst the different parameters in commensurate terms i. e. expressing the different parameters in the same units or scale. A criterion could be categorised as statement criterion and table criterion (Rao et al., 1994). Several statement criteria are to be made in order to encompass all the classes of different parameters. Table criterion is more organized as the relationship among the parameters and their categories are defined.

Determination of weightage of each parameter is the most crucial in integrated analysis, as the output is largely dependent on the assignment of appropriate weightages (Saraf et al., 1997 & 1998). Consideration of relative importance leads to a better representation of the actual ground situation. Groundwater prospective zones have been demarcated in the Dwarkeshwar watershed. The method used has been summarised in Figure 6.16. For this, the relative importance of each parameter for groundwater prospective zone mapping has been derived by overlay analysis in GIS.

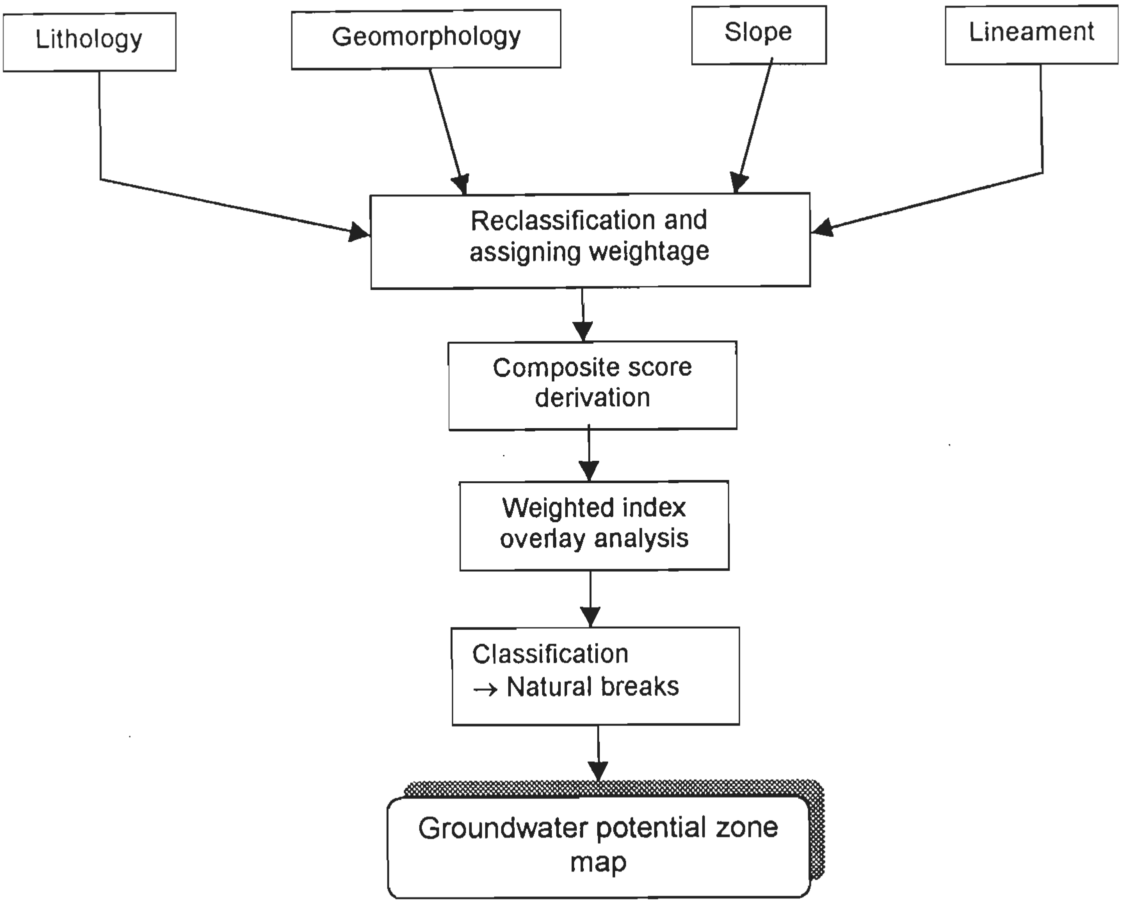


Figure 6.16 Schematic representation of the Weighted Index Overlay analysis to delineate groundwater prospective zones.

In the present study, the following parameters have been considered for weighted overlay analysis for groundwater prospective zone mapping:

(a) Lithology
(b) Geomorphology
(c) Slope
(d) Lineament

These parameters are assigned with appropriate weightage (Table 6.2) and then the individual classes within each parameter have been given weightage.

Table 6.2 : Criterion table for groundwater prospects in the Dwarkeshwar watershed.

Sl. No.	**Criteria**	**Classes**	**Weights**
1	Lithology	Alluvial deposits (sand, silt, clay)	3
		Ferruginous gritty sandstone & shale	2
		Pyroxenite	1
		Pink granite	1
		Quartzite/ Quartz schist	1
		Laterite	2
2	Geomorphology	Lower alluvial plain	5
		Flood plains and alluvial fill	5
		Upper undulating alluvial plain	4
		Gently to moderately sloping land interspereed with mounds and valleys	3
		Moderate to strongly sloping land interspersed with isolated hills	2
		Rock outcrops	1
		Hillocks and mounds	1
		Residual hills	1
3	Slope	0 - 5°	4
		5 – 10°	3
		10° - 20°	2
		>20°	1
4	Distance to Lineament	<1 km	3
		1 – 2 km	2
		>2 km	1

Composite score or index for each pixel has been derived using equation 3.1 (Chapter 3, Section 3.8.2). For generalisation of weightages 0-10 scale has been followed in this study. 0 denotes not suitable and 10 denotes most suitable. These parameter weights are divided by the sum of parameter weights for normalisation. Finally, the composite scores for each map are added and the higher values indicate better groundwater prospect. Now, for better interpretability, the groundwater prospective zone map has been classified into 5 classes, Different schemes of classification have been tried, however, natural breaks method has been found to give a better representation of the grouping and inherent pattern of the data set. Basically, this method minimizes the sum of variances within each of the classes. The number of natural breaks and the multi-modal appearance of a data set can depend greatly on the number of classes used (Burrough, 1986).

The groundwater prospective zone map (Figure 6.17) of the Dwarkeshwar watershed shows that the channel fills have the highest priority in groundwater occurrence. The alluvial plains rank next, followed by the pediments. The channel fills along with lineament have good prospect.

6.3.3 Estimation of Groundwater Recharge

6.3.3.1 Introduction

In any groundwater development project, quantitative assessment of groundwater recharge is an important issue. Estimation of groundwater recharge requires proper understanding of the recharge and discharge process and their interrelationship with geological, geomorphological, soil, landuse and climatic factors. There are various methods in use for the quantitative evaluation of groundwater recharge e.g.:

a) Groundwater level fluctuation and specific yield method
b) Rainfall infiltration method and
c) Soil moisture balance method (Thornthwaite and Mather,1957).

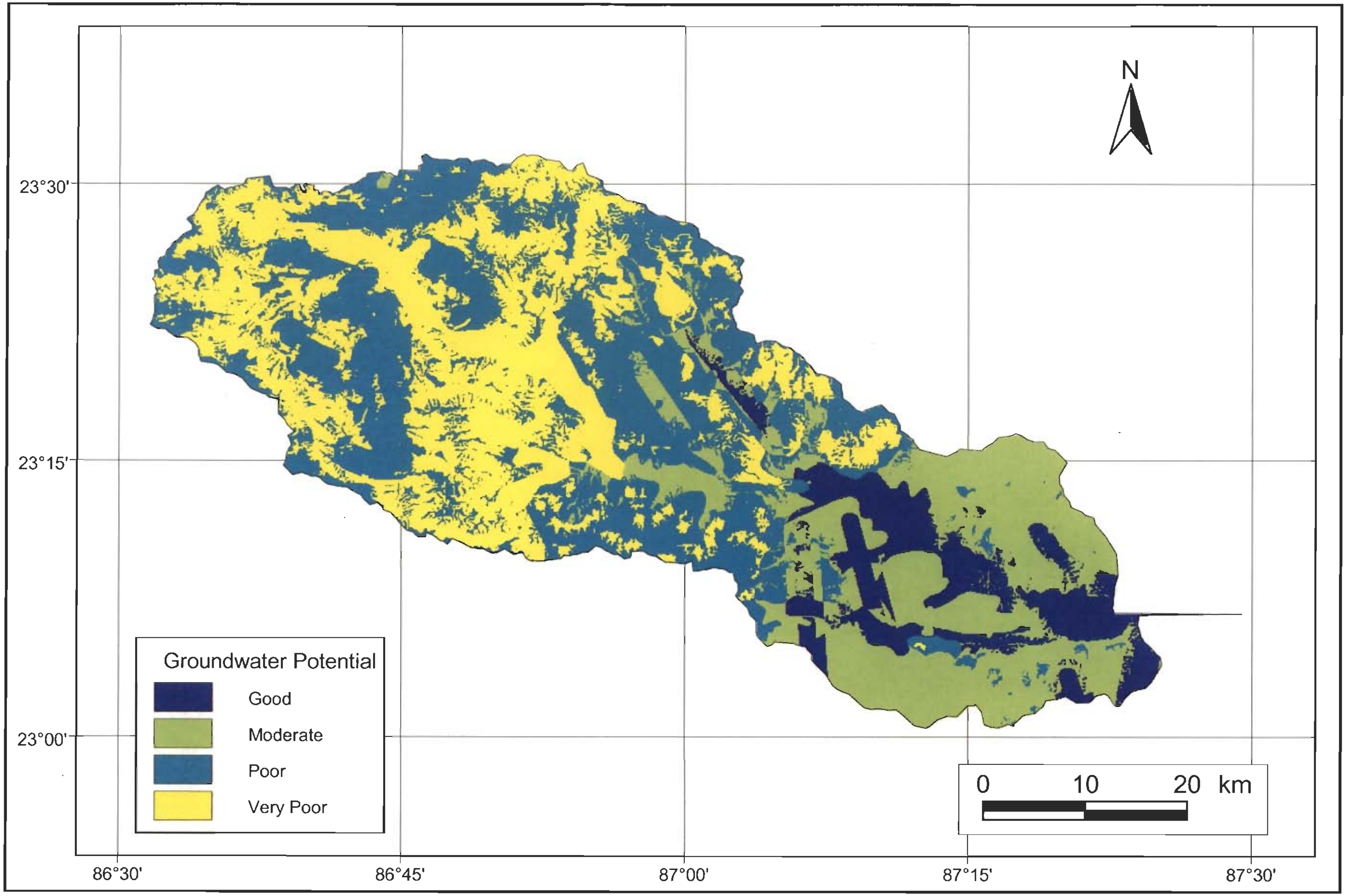


Figure 6.17 : Groundwater Potential Zone Map of Dwarkeshwar Watershed prepared by using Weighted Index Overlay Method.

In the present study, an attempt has been made to estimate recharge in the Dwarkeshwar watershed by groundwater level fluctuation method (Saraf and Jain, 1996).

6.3.3.2 Conventional vis-à-vis Remote Sensing and GIS

The conventional approach for groundwater recharge assessment has some limitations in spite of its simplicity and wide applicability in varied hydrogeological setup. Groundwater movement is controlled by natural boundaries like valleys and ridges. Hence, watershed is the most appropriate unit for groundwater recharge estimation.

In case of conventional methods like rainfall infiltration method or water level fluctuation method average values of rainfall or water level fluctuation is taken for a part of the land. The spatial variability in the components of recharge is not considered. In case of remote sensing and GIS based method spatial distribution of the variables are taken into account, thus preparing an information layer for the whole of a watershed (Saraf and Choudhury, 1998). Further remote sensing data provides most accurate information of the ground, thus minimising fieldwork. Seasonal information is required for estimation of recharge. Remote sensing data of different dates e.g. pre- and post-monsoon can provide information about the cropping pattern and landuse, which influence groundwater recharge (Saraf et. al. 2001).

6.3.3.3 Recharge Estimation by Water Level Fluctuation Method

This is the simplest method for seasonal groundwater recharge estimation. Water level fluctuation caused by monsoon rainfall is considered as the index for groundwater recharge. In the Dwarkeshwar watershed, monsoon precipitation occurs between the months of June and November. Hence, pre- and post- monsoon water level data have been taken for computing fluctuation. Average water level fluctuation of 10 years has been taken and interpolated to give rise to a water level fluctuation image (Figure 4.10). The map displaying specific yield values for different formations in the area is prepared (Figure 6.18). Values of specific yield for the area have been taken from

Karanth (1987). The distribution of groundwater recharge was then prepared by multiplying water level fluctuation map by specific yield of different formations. The recharge image thus generated (Figure 6.19) gives a rough estimation of dynamic groundwater recharge. Figure 6.20 shows groundwater recharge volume map for the Dwarkeshwar watershed.

However this method is not an accurate one, because groundwater recharge depends not only on the specific yield of the aquifer material, but also on many other factors viz. soil properties, geomorphic features and landuse. The present method doesn't take into account the other variables.

6.3.4 Artificial Recharge

6.3.4.1 Introduction

Artificial recharge is the process of augmenting the natural movement of surface water into underground formations by some artificial methods. This is accomplished by constructing infiltration facilities or by inducing recharge from surface water bodies. In hard rock areas, the underlying lithological units do not have sufficient porosity and permeability. In these areas, groundwater recharge falls short of the water that is being taken out of the aquifers. Hence, groundwater cannot suffice the requirement for agriculture or drinking water. Thus, additional recharge by artificial methods becomes necessary to meet the water deficit.

In India, artificial recharge measures are taken in the vast hard rock terrains, mostly in Maharashtra and south India. The performance of these efforts can be immensely increased if they are performed through proper scientific planning. Integrated remote sensing and GIS can be a very powerful tool for planning of suitability for artificial recharge structures (Saraf and Choudhury, 1998). However, this powerful tool has not attained wide applications for this purpose till now in India. This part of the chapter demonstrates remote sensing and GIS techniques to suggest suitable locations for future artificial recharge structures in the Dwarkeshwar watershed .The site selection is purely based on hydrogeological point of view, the engineering aspects are not considered here.

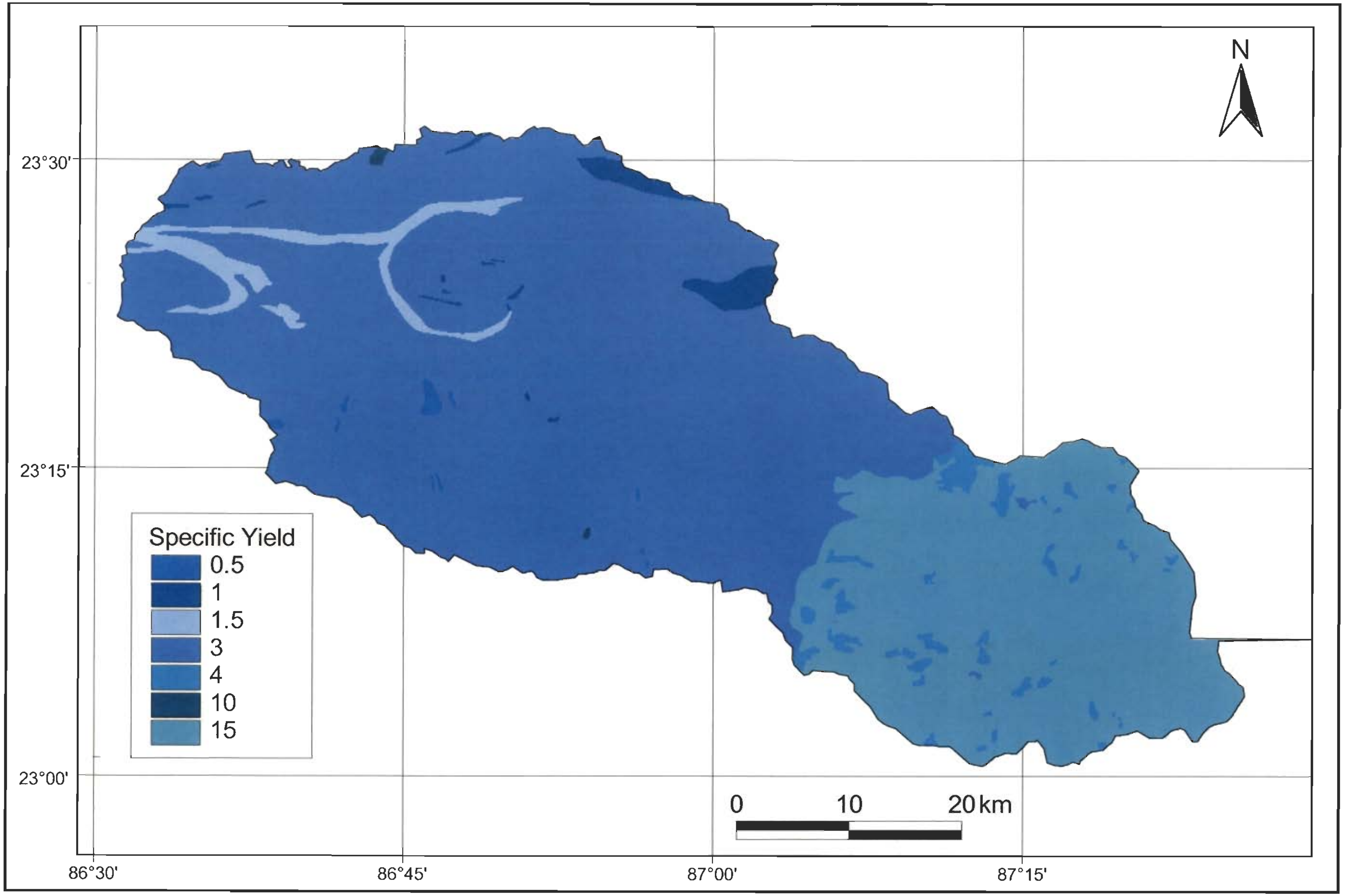


Figure 6.18 : Specific Yield Map (After Karanth, 1987) of the Dwarkeshwar Watershed.

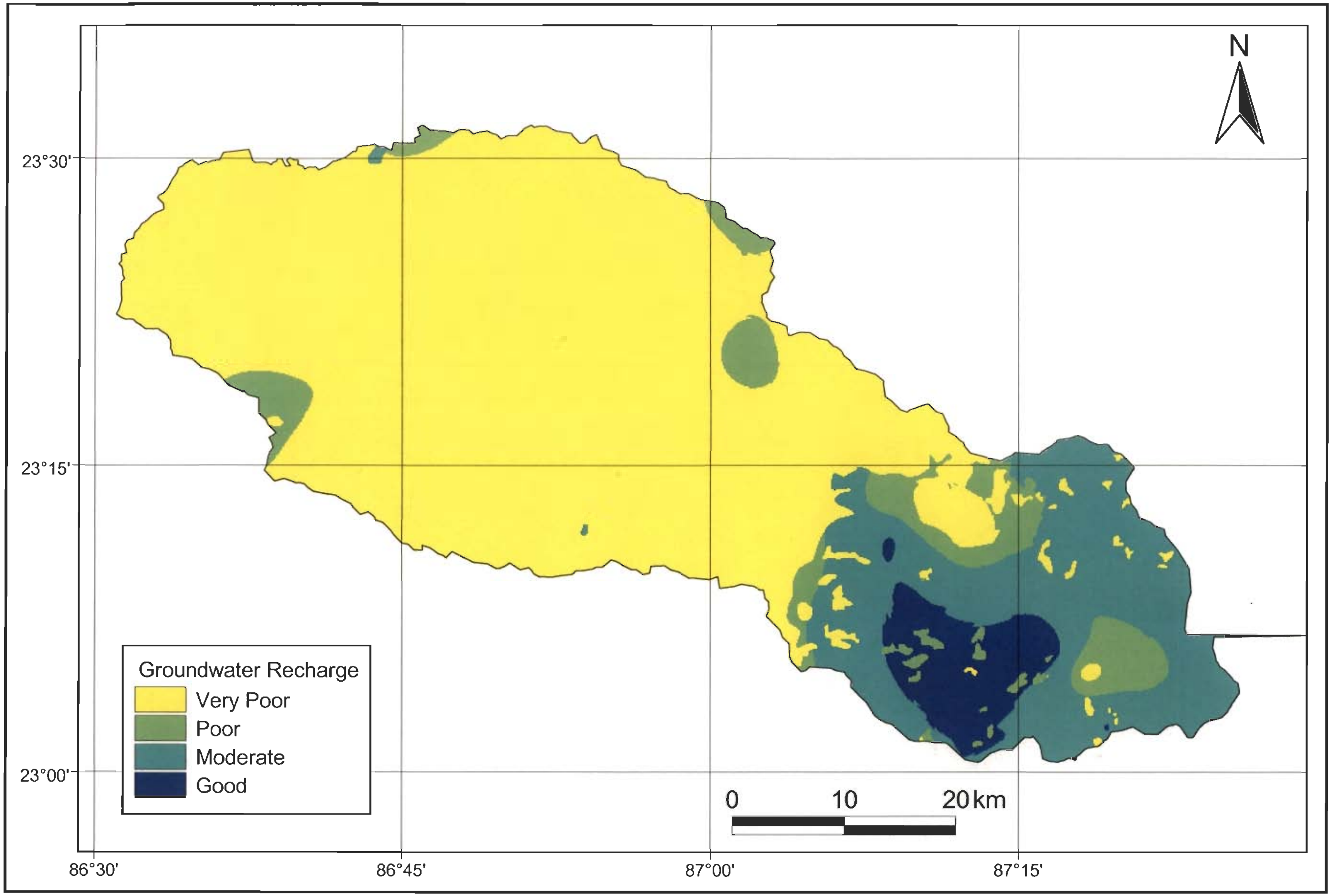


Figure 6.19 : Groundwater Recharge Map of the Dwarkeshwar Watershed prepared by Water Level Fluctuation Method.

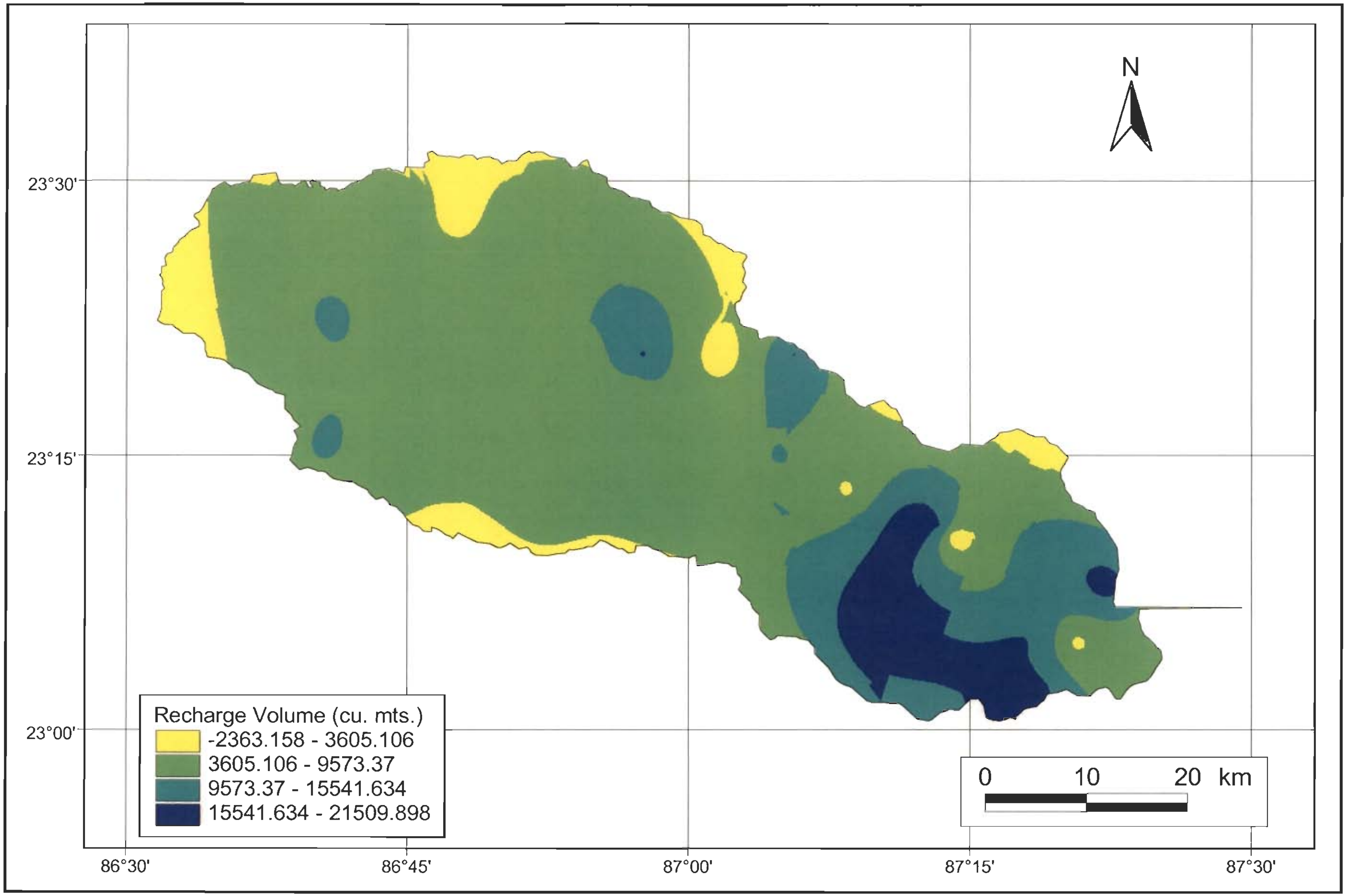


Figure 6.20 : Recharge Volume Map of the Dwarkeshwar Watershed.

6.3.4.2 Methodology

In this chapter suitable sites for artificial recharge have been suggested using a combination of weighted index overlay analysis and Boolean logic analysis (Figure 6.21). With the spatial database already built up, some other information layers are generated through GIS operations.

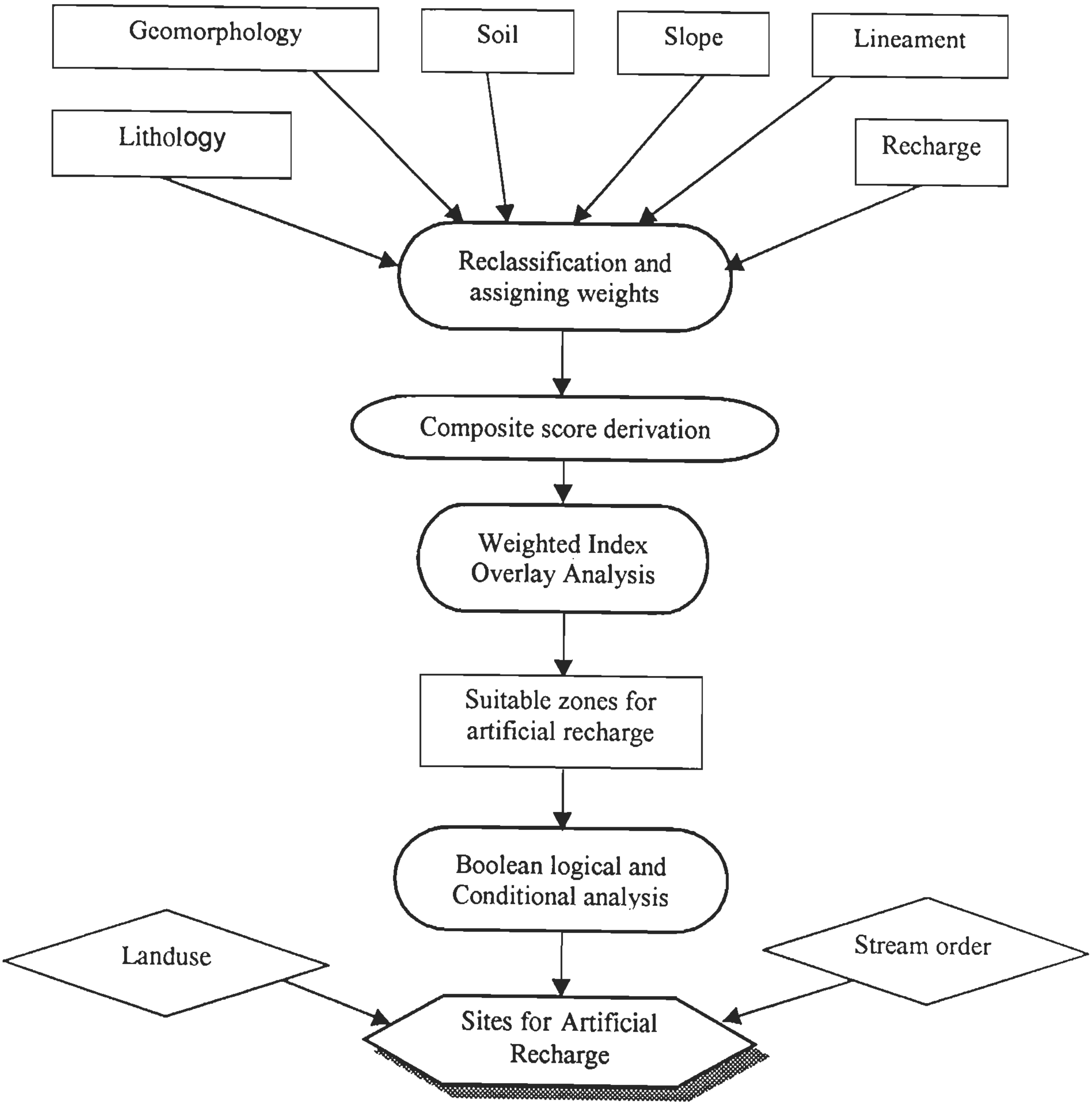


Figure 6.21 Flowchart of steps for Weighted Index Overlay Method and Boolean Logic Model for identification of artificial recharge sites (after Choudhury, 1999).

The following steps have been followed:

(a) IRS-LISS-II and LISS-III data supported by DEM, lithology, geomorphology, lineament etc. have been studied to identify the areas of artificial recharge from the existing structures.

(b) The criterion for the suitability of recharge has been identified and the information layers have been assigned with weightage on the basis of their relative contribution in influencing artificial recharge. Each class of individual information layers has been assigned weightage as well as the class itself.

(c) Weighted index overlay analysis has been performed in order to demarcate the zones of suitability for artificial recharge.

Boolean logic analysis has been performed to suggest the artificial recharge sites.

6.3.4.3 Artificial Recharge Methods

Various methods are in use for artificial recharge. Table 6.3 shows these methods. Karanth (1987) provides detailed discussion on this topic.

6.3.4.4 Selection of Future Artificial Recharge Sites

The first task in the selection of a suitable artificial recharge site is to identify the factors facilitating recharge. The existing artificial recharge system in the area has been studied with respect to its hydrogeology, topography and water level of the wells. Based on these observations, a set of rules has been formulated to demarcate the most suitable zones and also to find out the exact sites for artificial recharge structures. The following thematic information layers are used in this suitability analysis:

(a) Lithology
(b) Geomorphology
(c) Slope
(d) Soil
(e) Lineament
(f) Recharge

Table 6.3 : Different categories of artificial recharge methods (after Raju, 1998)

Direct methods	
Surface spread techniques	(1) Flooding (2) Ditch and furrows; (3) Recharge basin (4) Run-off conservation structures (i) Gully plugs, (ii) Bench terracing (iii) Contour bund, (iv) Nala bund, (v) Percolation tank, (vi) (Individual well Recharge (5) Stream modification; (6) Surface irrigation
Sub-surface techniques	(1) Injection wells; (2) Gravity head recharge wells; (3) Aquifer Storage and Retrieval (ASR); (4) Soil Aquifer Treatment (SAT)
Indirect methods	
Induced Recharge	(1) Pumping wells; (2) Collector wells; (3) Infiltration gallery
Aquifer Modification	(1) Bore blasting; (2) Hydrofracturing
Combination methods	
Groundwater conservation structures	(1) Groundwater dams, underground bandharas (percolation tanks); (2) Fracture Sealing Cementation techniques (FSC)

Boolean logic model and weighted overlay model have been applied. In Boolean logic model, the areas, where a certain set of conditions are satisfied, are delineated through the logical operations AND, OR, XOR, NOT. In weighted index overlay, the individual thematic layers and also their classes are assigned weightage on the basis of their relative contribution towards the output (Saraf et.al., 2001). In the present study, weighted indexing method has been used to demarcate the suitability zones. For artificial recharge structures Boolean logic model is used to suggest the sites in the suitable zones for these structures. At the initial stage, all parameters were considered to be of equal importance and the most favorable class of each parameter had been given rank 1; increasing ranks indicating decreasing importance. Then, weighted overlay was performed to give the zones of suitability for artificial recharge, where minimum value indicated highest suitability. In reality, however, all the parameters do not have equal importance. In this type of ranking there was no option for the unsuitable class. One or more classes of a parameter may be unsuitable for a particular analysis. Therefore, a 0-10 scale has been used (discussed in Chapter 3 in detail). In this scale of ranking, each parameter is assigned an appropriate weightage and each class within a parameter is also assigned a weightage. In this scheme, the unsuitable classes are assigned a zero value, with rank 10 indicating highest suitability.

6.3.4.5 Criteria for Artificial Recharge in the Area

The basis for suitability analysis for artificial recharge is mainly dependent on the hydrogeomorphic condition of the existing artificial recharge facilities in the area. In the following section the parameters used in this analysis are discussed. These themes are described in descending order of their importance. Although, hydrogeologic characteristics of the rock control the rate of recharge, geology has not been given the highest weightage. Instead, slope has been given a weightage of 10. This can be explained by the following two reasons. Firstly, topography plays a very important role in maintaining a steady rate of recharge. Secondly, lithology alone does not control the recharge capabilities. Although both alluvial plains and channel fills develop on the weathered basement rock, the channel fills provide better recharge conditions compared to alluvial plains. Geomorphic classes within the same geologic unit have different characteristics. Thus, geomorphology shows absolute importance over lithology and it has been assigned a weightage of 9. Generally, presence of lineament is considered favourable for the movement of groundwater since these are surface expressions of joints and other fractures. Hence distance to lineament has been given appropriate weightage. But lineament density has not been included for the present study because the number of such lineaments in the present area is very less. Geology has been assigned a weightage of 8. Soil properties have equal importance as geology. Here groundwater recharge has been calculated by the methods discussed earlier and groundwater suitability map has already been prepared. Since the artificial recharge sites should be placed in areas, which are conducive for good recharge, hence the recharge factor has been given more weightage. The controlling factors are discussed hereunder:

(a) Lithology

Considering the relative primary porosity and permeability, the alluvial deposits are given high preferences. The rocky units towards the west namely the pink granites, granite gneisses and the schists because of their impermeability are given less weightages.

(b) Geomorphology

Flood plains and alluvial fills provide the highest potential for recharge due to the presence of unconsolidated material. These are the areas that receive the highest recharge from rainfall. Alluvial plains have good prospects except in the areas of yellow clay layer (which hinders the flow of water into the sub surface). Pediment has lower potential in comparison to the alluvial plain and receives lower weightage. The isolated hillocks and the strongly sloping land in the western part of the watershed receives the least weightage.

(c) Slope

Slope is a very important factor in controlling the hydraulic gradient for the movement of water. Generally, a flat area is preferred for artificial recharge sites by many. It has been observed that a very gentle slope instead of null slope helps to maintain the steady hydraulic gradient and it provides better recharge conditions. Hence a slope of 2°-5° has been given the highest weightage of 10 followed by a slope of 0°-1°. Steep slopes are given the lowest weightage, as water does not have the chance to infiltrate, and flows downstream as runoff.

Table 6.4 : Weightage of different parameters for suitable site for artificial recharge in the Dwarkeshwar watershed.

No.	Criteria	Weights	Classes	Weights
1	Lithology	8	Alluvial deposits(sand, silt, clay)	3
			Ferruginous gritty sandstone & shale	2
			Laetrite	2
			Pyroxenite	1
			Pink granite	1
			Quartzite/ Quartz schist	1
2	Geomorphology	9	Dissected pediment	4
			Flood plains and alluvial fill	3
			Upper undulating alluvial plain	3
			Lower alluvial plain	3
			Severely gullied land	2
			Gently to moderately sloping land interspersed with mounds and valleys	2
			Rock outcrops	1
			Hillocks and mounds	1
			Residual hills	1
			Moderate to strongly sloping land interspersed with isolated hills, pediments and valleys	1
3	Slope	10	0 - 5°	4
			5° – 10°	3
			10° - 20°	2
			>20°	1
4	Soil	8	Lateritic soil	3
			Older alluvial soil	4
			Red gravelly soil	5
			Red and yellow soil	2
5	Distance to Lineament	7	<1 km	3
			1 – 2 km	2
			>2 km	1
6	Recharge	10	35 – 25	3
			25 – 15	2
			0 – 15	1

(d) Soil

The red gravelly soils because of their high porosity and permeability are given the highest weightage followed by the alluvial soils. Red and yellow soils as well as the lateritic varieties receive lesser weightage.

(e) Distance to Lineament

As discussed earlier, lineaments in the area facilitate the movement of groundwater. The presence of lineament in is considered as a suitable condition for recharge basins. Distance to lineament on a distance buffer is a quantitative measure of the lineaments in relation to the increasing distance. The higher the value better is the prospect of recharge.

(f) Recharge map

The alluvial plains of the Dwarkeshwar watershed show high degree of recharge potential than the western rocky units and hence are given higher weightage for delineating artificial recharge sites.

6.3.4.6 Weighted Index Overlay

All the information layers discussed are combined using weighted index overlay method to give rise to zones of suitability for artificial recharge structures. Figure 6.22 shows the output map of this analysis in the Dwarkeshwar watershed. The most suitable zones are along the channel fills and the flood plains in the eastern part. On the hills, suitability is poor. Now, in order to suggest the exact location for an artificial recharge structure, Boolean logic and conditional methods are employed.

6.3.4.7 Boolean Logic Analysis

The first task in this method is to identify the criteria and to formulate the set of logical conditions to extract the suitable zones. In this case, the output will have only two classes – suitable or unsuitable (Figure 6.23). Where the defined conditions of the information layer fulfilled together, a value of 1 is given. The remaining part will have a zero value. This analysis is suitable for objective criterion but is not suitable to show gradational values. In order to have a comparison of the results with weighted indexing method, suitability analysis has been done using Boolean logic model. The criteria for site selection are:

1. The sites should be over a slope of 2°-5°.
2. The sites should be on channel fills of alluvial plains.
3. The soil should be either gravelly or alluvial in nature.
4. Geologically, the area should be covered with sand, silt or clay.
5. The sites should be on the 2nd or 3rd order stream.

Different artificial recharge methods are suitable for different conditions. Detailed study on the choice of a method is beyond the scope of this study. However, an attempt has been made to suggest a few methods for the proposed sites through GIS analysis. Recharge tanks are suitable for the tributaries having a gentle slope. These collect the runoff to facilitate gradual seepage into the groundwater. Subsurface dykes are suitable for forested areas along tributaries. This can avoid the problem of forest submergence and at the same time provide recharge to groundwater. Check dams are suitable in areas of high runoff on the main stream to check the runoff (Kundu, 2000). Of course, detailed field investigation of the sites is necessary for implementation of these methods.

The integrated analysis through a combination of weighted indexing and Boolean logic method has been found to be very suitable for selection of suitable sites for artificial recharge. Detailed litholog information and geophysical data of the proposed sites and the surrounding areas are likely to improve the results of this analysis. 3D-perspective views give a clear picture of the terrain features (Saraf et.al 2001). Further, GIS has immense potential to simulate the future scenario. Integrated remote sensing and GIS can simulate recharge tank at a particular site and also evaluate the effect of an artificial recharge structure in a particular area.

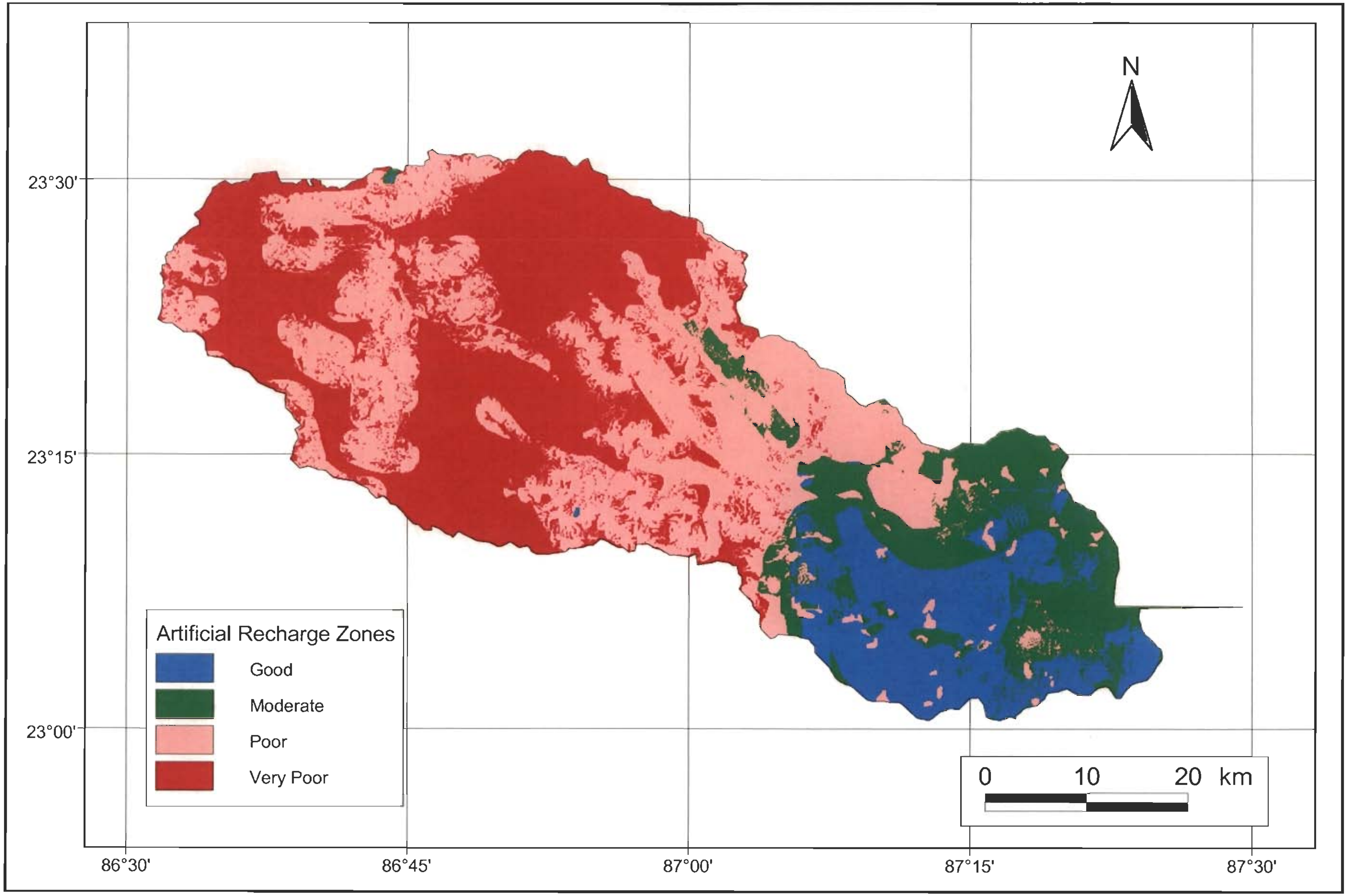


Figure 6.22 : Artificial Recharge Zone Map of the Dwarkeshwar Watershed prepared by using Weighted Index Overlay Analysis.

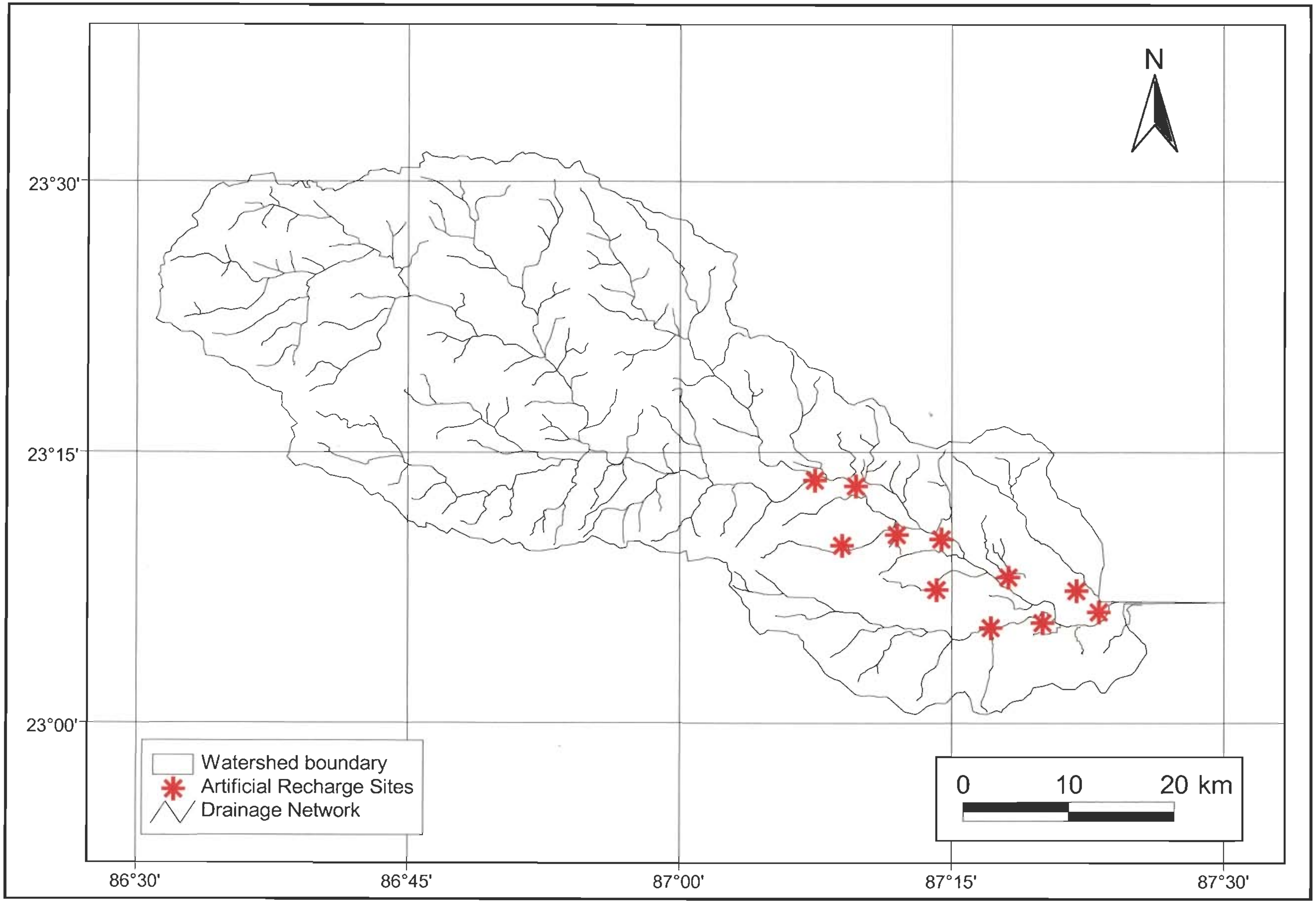


Figure 6.23 : Map showing the Artificial Recharge Sites for the Dwarkeshwar Watershed derived by using Boolean Logic Analysis.

Chapter 7

RESULTS AND DISCUSSION

In the arid and semi-arid tropics, low annual rainfall together with high intensity of rains has resulted in excess runoff, soil erosion and low moisture intake leading to poor crop yields. Therefore, adoption of soil and water conservation measures is necessary for the optimal utilization of natural resources and to increase the productivity of land on a sustainable basis. Remote Sensing and GIS techniques can be used for generating development plans for the watershed area in consonance with the production potential and limitation of terrain resources, and can also be used for assessing the impact of these measures before actual implementation in the field.

In order to make an accurate prediction of hydrologic response due to landuse changes, two important points are to be considered: (a) to be able to track changes as they actually occur and (b) to quantitatively understand the effect cause by such changes. As landuse change studies with respect to the hydrological changes have become necessary for any development activity, a GIS based modelling approach is required to understand the various influencing factors and interdependent intricacies of landuse change.

The land surface is subjected to continuous change due to natural and man-made causes. As the landuse in a watershed is altered in both space and time; the factors that influence the hydrologic response of the watershed also change. Evaluation of the relationship between landuse changes and such factors has been the goal of the present study on landuse-hydrological relationship.

From the landuse maps prepared from the satellite data, it is observed that the major part of the study area was predominantly wasteland, especially, in the western part of the watershed. The next predominant category of landuse is fallow land. The total forest cover inclusive of the plantation increased significantly. Irregular patches of arable land occur in a random fashion in the watershed. The main water body in the area is Dwarkeshwar River, which is the second major river after Damodar.

However a comparison of the landuse map of 1996 with that of 1988 reveals a decline in the wasteland from 48.17 percent to 8.6 percent, an increase in fallow land from 33.63 percent to 58.8 percent, and dense forest increased from 2.9 percent to 7.1 percent. Water bodies have decreased from 0.8 percent to 0.61 percent, while arable land has increased from 13.88 percent to 24.1 percent, settlement has increased from 0.21 percent to 0.25 percent, and river sediment has increased from 0.41 percent to 0.49 percent.

In order to establish the impact of future landuse change on the water resources of a watershed, it is necessary to understand the existing hydrological conditions of the watershed and to quantify the extents to which the water resources will be modified. As discussed earlier in Chapter 4, the hydrologic factors influencing the landuse change are rainfall, recharge and depth to water level and soil erosion. The rainfall is considered as one of the major factors in causing landuse changes. Despite having sufficiently high rainfall, the watershed is experiencing drought like situation. This is due to the uneven distribution of rainfall. It is apparent from the rainfall map that both the western and the eastern part of the watershed receive a good amount of rainfall. However, compared to the recharge map (Figure 6.19), it is found that the amount of recharge in the eastern part is quite high in comparison to the other parts of the watershed. The comparatively high recharge in the eastern pat of the watershed is due to the presence of dissected pediment, flood plain, alluvial plain and alluvial fill, which facilitate infiltration and subsequently increase the recharge. Towards the western part of the watershed which is a hard rock terrain, recharge is less or even nil because of the non-conducive nature of the terrain for infiltration. This can be attributed to the changes in the landuse along the eastern part, where there is higher conversion of wasteland into other categories of landuse than the western part which is mostly dominated by wasteland due to the lithology being impermeable with a very little chance of recharge and most of the water flow as runoff.

The DEM of an area generated from elevation contours acts as the basis for extracting a wealth of hydrologic information. Slope is a very important parameter in groundwater studies. Further, tracing the path of the steepest slope of eight neighbouring cells, the drainage network is derived from DEM data (Chapter 6). This method is based on the assumption that there is no upward or downward loss of water obtained from precipitation, i.e. there are no infiltration of evaporation losses of water obtained from precipitation. Hence there is always a possibility to have a misfit at different places when compared with the surveyed drainage. The drainage network derived from the DEM data and the surveyed drainage (Figure 6.9) show a good fit in the hilly areas in the western part of the watershed but towards the eastern part, there is a considerable amount of misfit. In these flat areas parallel channels due to low gradient are developed in the simulated drainage. Excluding the flat areas, the misfit has been utilized to link with recharge areas. Overlay analysis of surveyed drainage and simulated drainage with information layers on geology, soil, lineament, geomorphology reveals that these are the areas (a) having sand, silt and clay cover; (b) having very gentle slope; (c) having high lineament density; and (d) covered by flood plains and channel fills. Further, recharge estimation shows that these are the areas receiving higher recharge. Hence, it may be concluded that the misfit is an indicator of recharge areas. The higher grounds, covered by the hard and compact crystalline rocks show a good match. These areas are not favourable for recharge as the lithology does permit water to infiltrate. On the other hand, flood plains and channel fills provide the most suitable recharge sites.

The availability of water is one of the major factors in causing landuse change. In the Dwarkeshwar watershed, the main source of increasing the groundwater potential is recharging of rainwater. The average rainfall map for the Dwarkeshwar watershed is shown in Figure 4.7. In the present study, water level fluctuation (Figure 4.10) due to monsoon rainfall (difference between post- and pre-monsoon water level) has been considered as the index for groundwater recharge (Figure 6.19). The average annual rainfall and recharge volume have been calculated from the available data (for the years 1989-1988).

Figures 4.8 and 4.9 show the average annual rainfall and the recharge volume for the years 1989-98. Despite having a regular trend in the yearly rainfall the recharge volume shows an upward trend i.e. more infiltration of water into the ground. In these areas considerable change in landuse has been observed.

The water level fluctuation characteristic of the watershed is different in different locations. The fluctuation can be as low as 0.5 meter to 1.9 meters and as high as 6.3 meters (Figure 4.10). The fluctuation gradually increases from the central part of the watershed to the southwest and southeast. This fluctuation can be attributed to the presence of agricultural tracts in these areas where a sizeable amount of water being extracted for irrigation purposes. This can be justified from the landuse change map/image (Figure 4.5) where it is observed that eastern part of the watershed has been converted to arable and fallow land.

Linking or integrating hydrological and soil erosion models with a GIS dataset results into a powerful tool to evaluate the effects of landuse changes. The USLE model discussed in Chapter 5, shows the maximum potential soil loss estimated (Figure 5.1) using the physical component of USLE (RKLS). The comparatively high values obtained in this area is due to erosive rainfall and rugged topography. The risk of erosion is more prominent in the western part of the watershed and also along the banks of the Dwarkeshwar River in the eastern part. The wasteland occurring in the watershed represents the culmination of the adverse effect of erosion processes. In the forest covered areas the risk is relatively low. However referring to the maximum potential soil loss from the area, it would be difficult to intensively develop the area without exceeding the tolerance limit due to limitations in agronomic practices and cost effectiveness.

The runoff characteristics of the watershed are also determined from rainfall data combined with landuse and soil parameters by using the SCS curve number method. The results show the run off depth and peak discharge characteristics of the watershed. The output images of runoff depth difference (Figure 5.3) and peak discharge difference (Figure 5.6) obtained by the respective images calculated by subtracting the values of the 1996 from those of 1988, show that at many places the values comes out to be in negative which means that the runoff depth and the peak discharge is more in the later case. It has also been observed that the dense forest areas have less discharge than the wasteland and fallow land.

From the above discussion, it has been found that the changes in landuse practices have played a significant role in the hydrological regime of the area. The prediction of potential soil loss by using USLE method and the changes in runoff depth and peak discharge obtained by using SCS curve number method have landuse as the basic input parameter. It has been observed from the NDVI difference map (Figure 4.6) and potential soil loss map using USLE (Figure 5.1) that the areas where vegetation cover is decreased significantly show a higher rate of soil erosion particularly towards eastern and south-eastern part of the watershed. Moreover, towards the north-eastern fringes of the watershed there is some increase in forest cover due to recent aforestation activities which is evident from Figure 4.5 and 4.6. These areas show very little soil erosion (Figure 5.1) and this can be extended to all the places in the watershed where even minor changes of landuse have occurred. When compared to the runoff depth difference (Figure 5.3) and difference in peak discharge maps (Figure 5.6) prepared by subtracting the corresponding values for runoff depth and peak discharge for the years 1988 and 1996, show that the areas with increased vegetation are having higher runoff depth difference and peak discharge difference. This in turn, may be explained in a different manner. The areas in which vegetation cover has increased in 1996 show lesser runoff and discharge than 1988 for the same amount of rainfall and time to reach the peak. Hence changes in landuse practices are controlling the soil erosion runoff characteristics of the watershed.

Landuse change in a watershed may involve an increase in the amount of impervious surface areas (Bhaduri et al., 2001). In the Dwarkeshwar watershed the easternmost part which is covered by alluvial fill has undergone significant changes in landuse practices. It involves urbanization, depletion of vegetation cover, changes of agricultural practices etc. From Figure 5.1, it is evident that these are the areas having higher soil erosion potential as well as higher runoff depth and discharge. This can be explained in two different ways : (a) due to very high soil erosion the top soil is removed and the amount of impervious surface areas has increased and (b) time of concentration of precipitated water to infiltrate beneath the ground is not enough in these areas due to loss of surfacial obstruction to flow by plants, etc. In this study, the second explanation seems to be more significant in the eastern part of the watershed and the first one is more significant in the western part of the watershed which is predominantly consist of hard rock with less soil cover.

The above observations can be directly utilized to determine the groundwater scenario of the watershed. The eastern/south-eastern part of the watershed show a good potential for groundwater recharge (Figure 6.19). The rest of the watershed show low to moderate potential for groundwater recharge because of the predominant lithology (Figure 1.5) which is not conducive for recharge. The situation in these places is further worsened by the large scale depletion of vegetation cover (Figure 4.12 and Figure 4.13d).

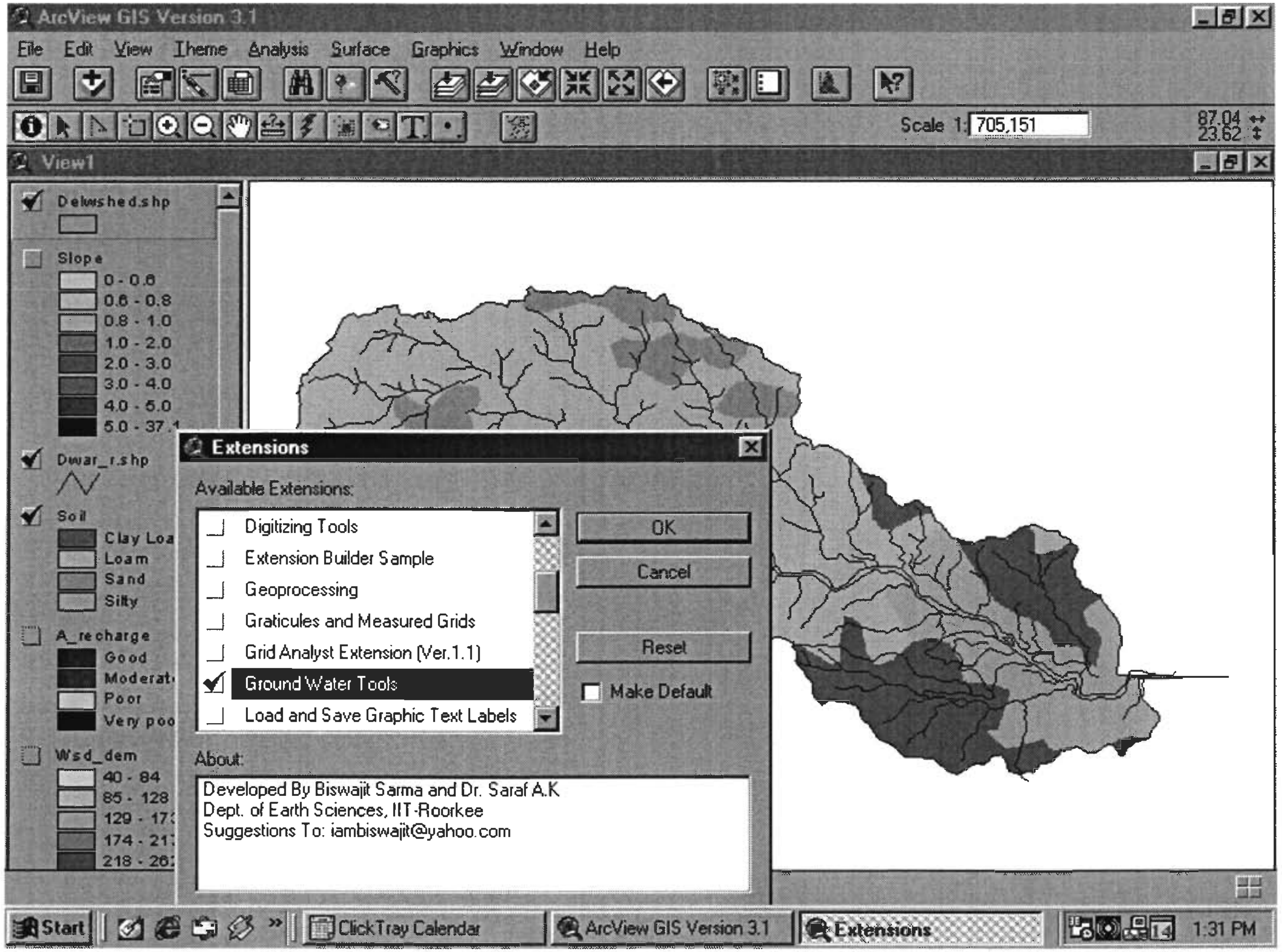
However, in the eastern and south-eastern part of the watershed the areas are filled with dissected pediment, flood plain and alluvial fill (Figure 1.4) which is ideal situation for infiltration. It has also been observed from the landuse change map (Figure 4.5) and the NDVI difference map (Figure 4.11) that these areas have undergone an extensive change in landuse. But because of its highly permeable lithology (Figure 1.5) groundwater recharge is quite substantial. Despite being a much flatter part of the watershed these areas are having high soil erosion potential (Figure 5.1) and high runoff. Being at the lower reach of the watershed most of the surface water flow during the high monsoon season and directed towards these areas. Since the runoff depth and peak discharge are calculated considering a particular storm event in year for the watershed, the amount of water flowing in these areas will definitely be very high. Moreover the landuse changes or depletion of vegetation cover has increased the runoff potential in the upper reaches of the watershed. Hence these areas are having access of surface water which is much more than its capability to infiltrate. The access surface water during the storm events in high monsoon period will flow as surface runoff and also facilitate soil erosion. This can well explain why these areas are getting relatively higher recharge (Figure 4.9) for no significant change in average annual rainfall (Figure 4.8). The factor of landuse change has played a great role in it.

By analysing all the conditions cited above, the areas for potential artificial recharge (Figure 6.22) were delineated and finally artificial recharge sites were identified (Figure 6.23).

To get the output as discussed in this chapter, programs are developed in Avenue language of the Arc View 3.1 and 3.2 GIS software. These programs have been further developed with complete graphical user interface to create an extension named as "Groundwater Tools" for the Arc View GIS software. The extension is provided with two different menus with two different buttons at the toolbar, (1) to extract the groundwater potential zones and artificial recharge sites and (2) to predict runoff depth and peak discharge for a watershed.

The basis for menu (1) is the combination of Weighted Index Overlay method and Boolean logic analysis and is made very easy for the user to extract the output immediately according to the user specified weights for different watershed parameters. Figures 7.1 to 7.4 show the way of operation of the extension in a sequential manner.

The basis for the menu (2) is the Rainfall runoff modelling using SCS curve number method. Here the user has to prepare the classified landuse map on the basis of assigned curve number. Taking the Curve Number theme as the main input the extension predicts the runoff depth of the watershed. Moreover it predicts the peak discharge after any storm event. The user has to provide only the rainfall amount and the time in hours to reach the peak. Figures 7.5 to 7.9 show the way of operation of the extension in a sequential manner.



Available Extensions:

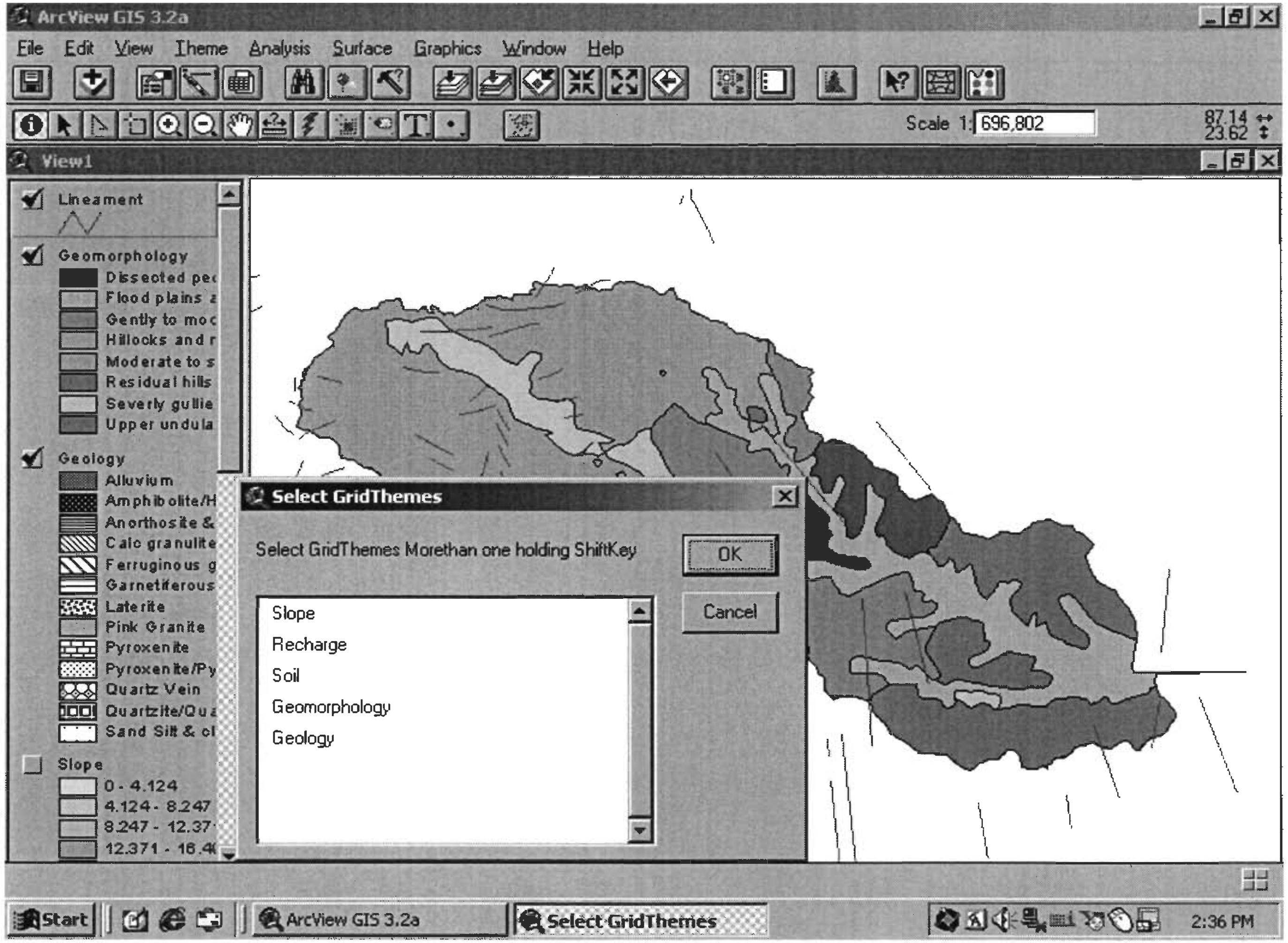
- ☐ Digitizing Tools
- ☐ Extension Builder Sample
- ☐ Geoprocessing
- ☐ Graticules and Measured Grids
- ☐ Grid Analyst Extension (Ver.1.1)
- ☑ Ground Water Tools
- ☐ Load and Save Graphic Text Labels

☐ Make Default

About:

Developed By Biswajit Sarma and Dr. Saraf A.K
Dept. of Earth Sciences, IIT-Roorkee
Suggestions To: iambiswajit@yahoo.com

Figure 7.1 : Window showing the first step to make the extension ‘Groundwater Tools’ active.



Select GridThemes Morethan one holding ShiftKey

Slope
Recharge
Soil
Geomorphology
Geology

Figure 7.2 : Window showing the option to choose necessary layers for analysis

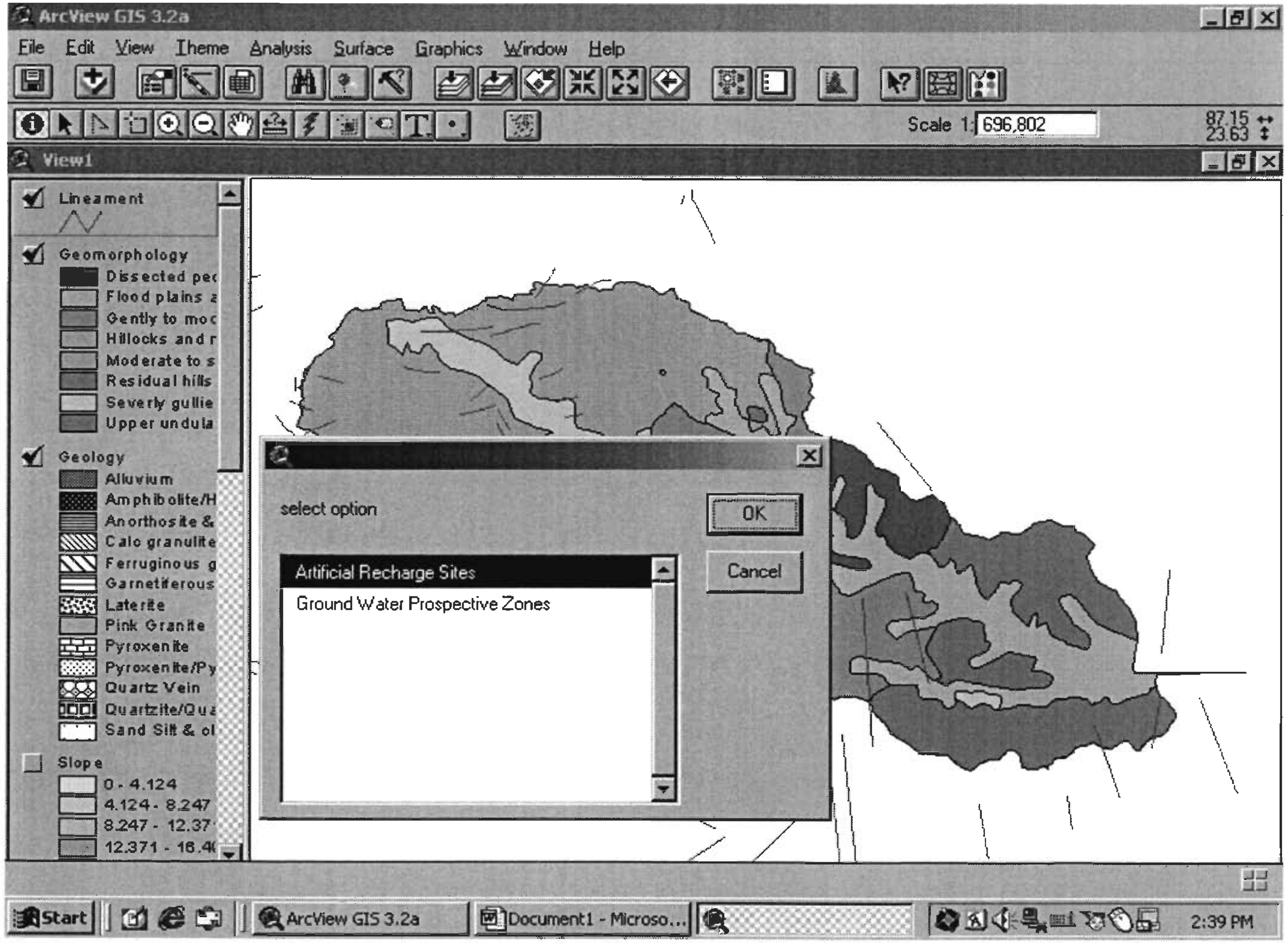
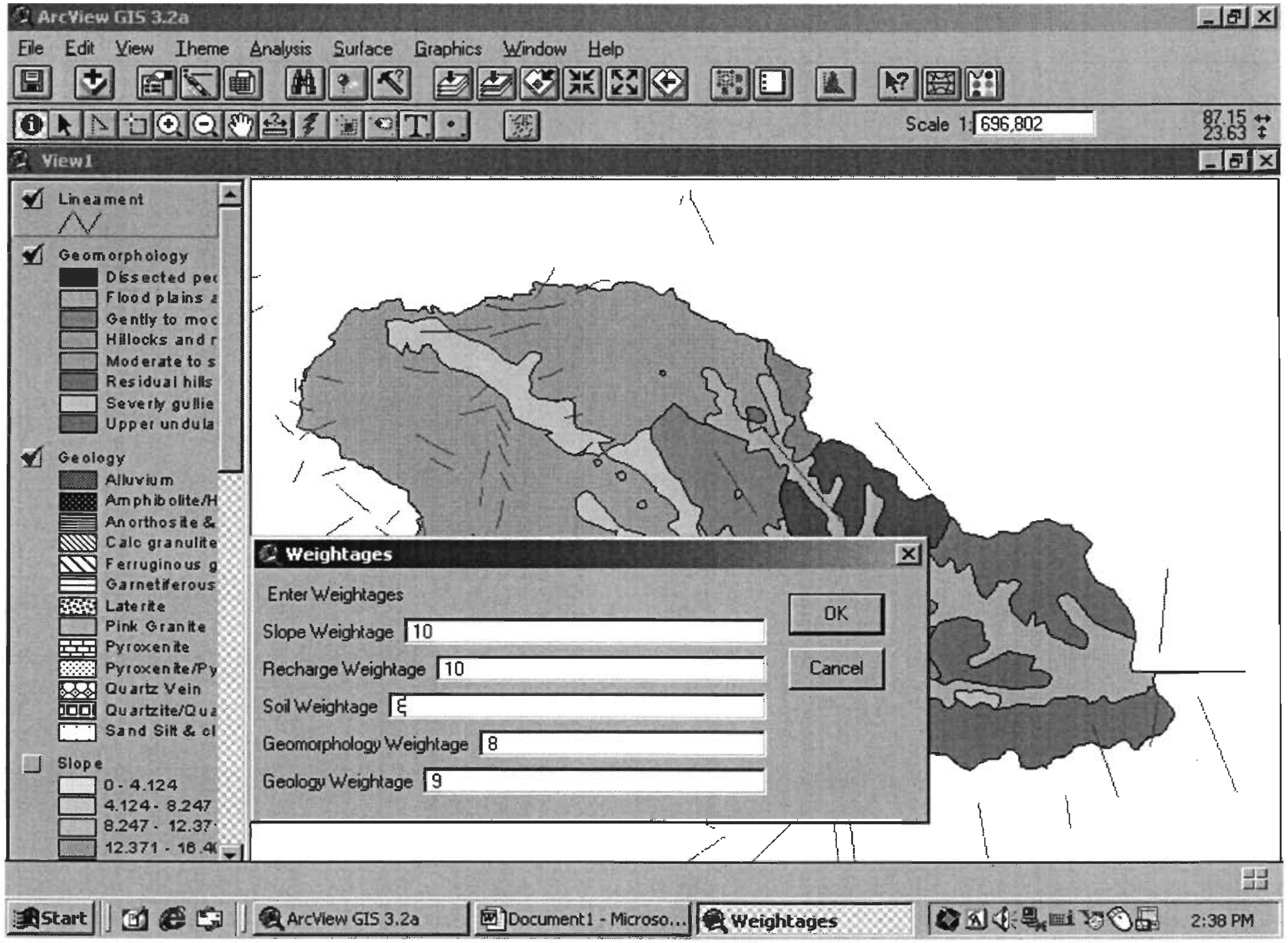


Figure 7.3 : Window showing the two different output options for the user in groundwater studies



Enter Weightages

Slope Weightage: 10

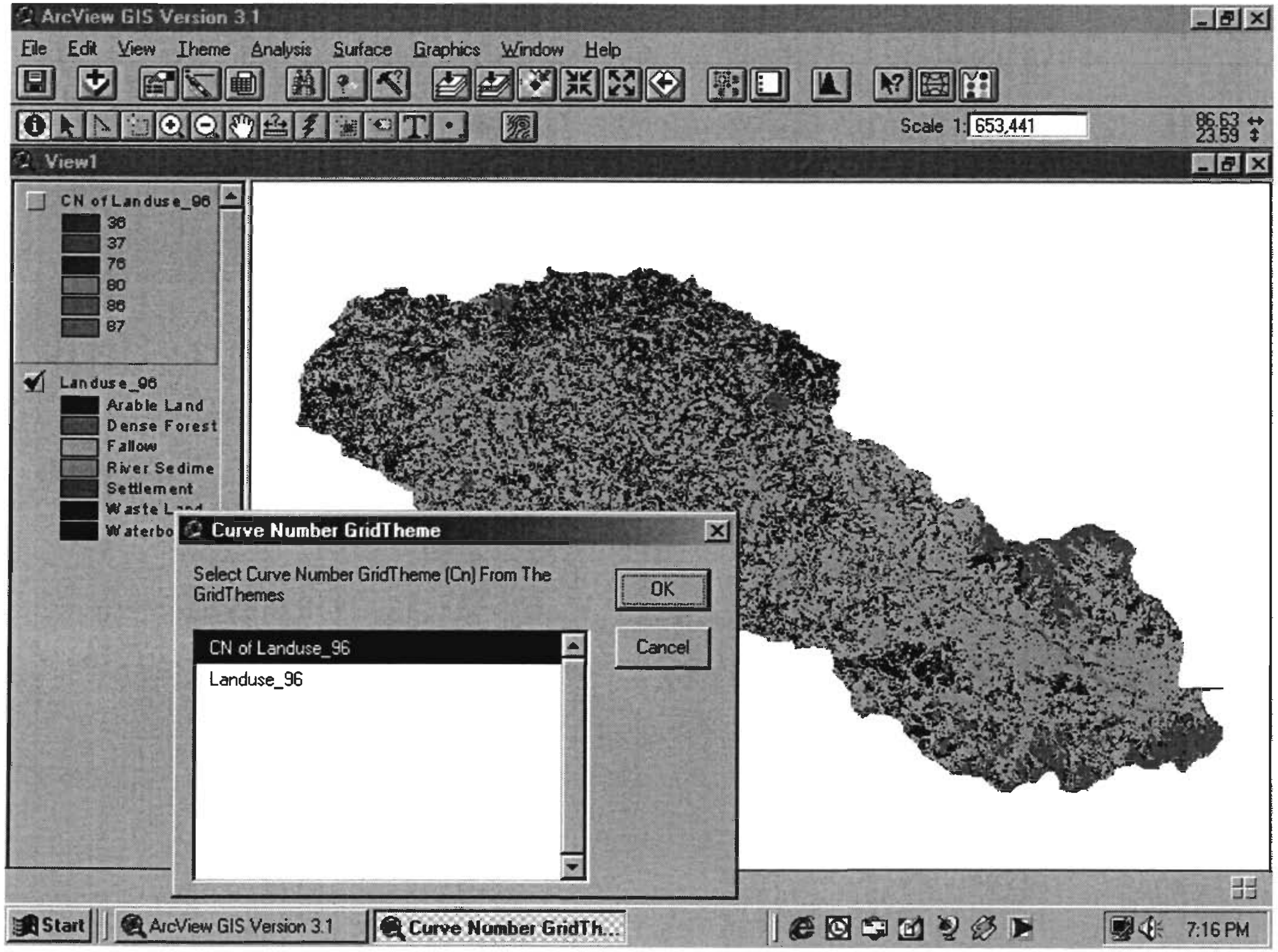
Recharge Weightage: 10

Soil Weightage: 6

Geomorphology Weightage: 8

Geology Weightage: 9

Figure 7.4 : Window showing options for the user to give weightages to different parameters for the specified analysis

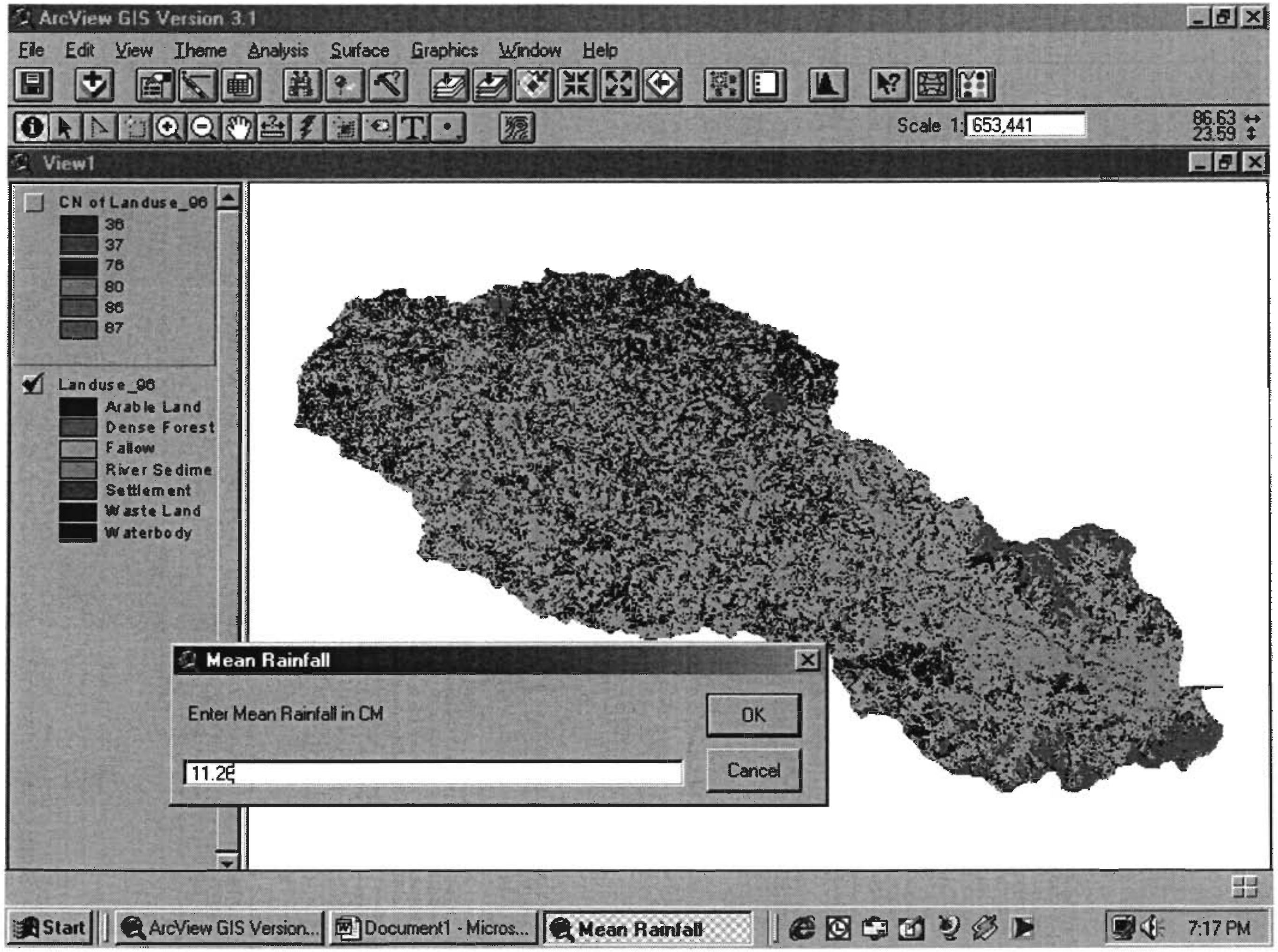


Curve Number GridTheme

Select Curve Number GridTheme (Cn) From The GridThemes

- CN of Landuse_96
- Landuse_96

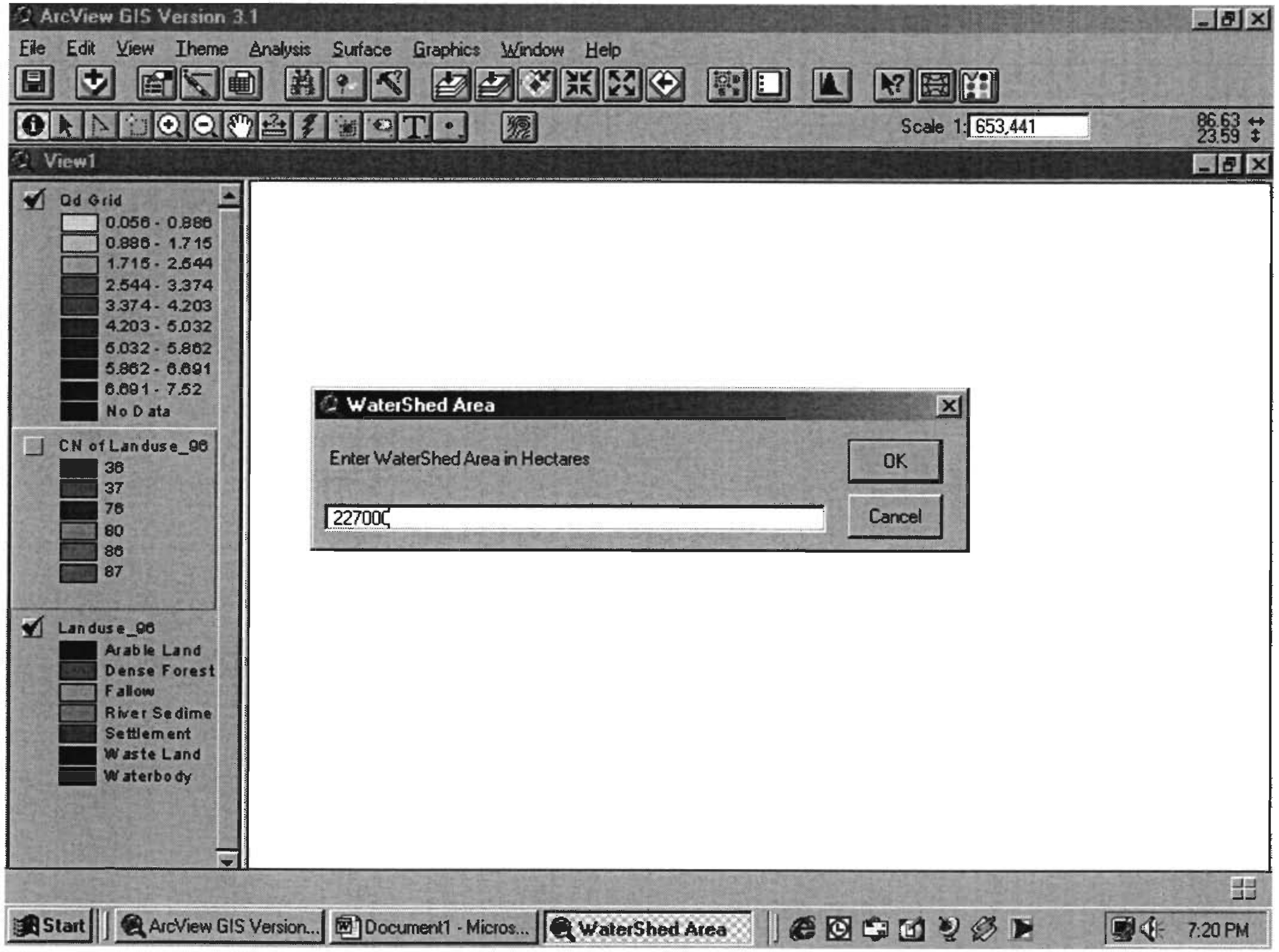
Figure 7.5 : First step for calculating runoff depth by using SCS curve number method.



Enter Mean Rainfall in CM

11.26

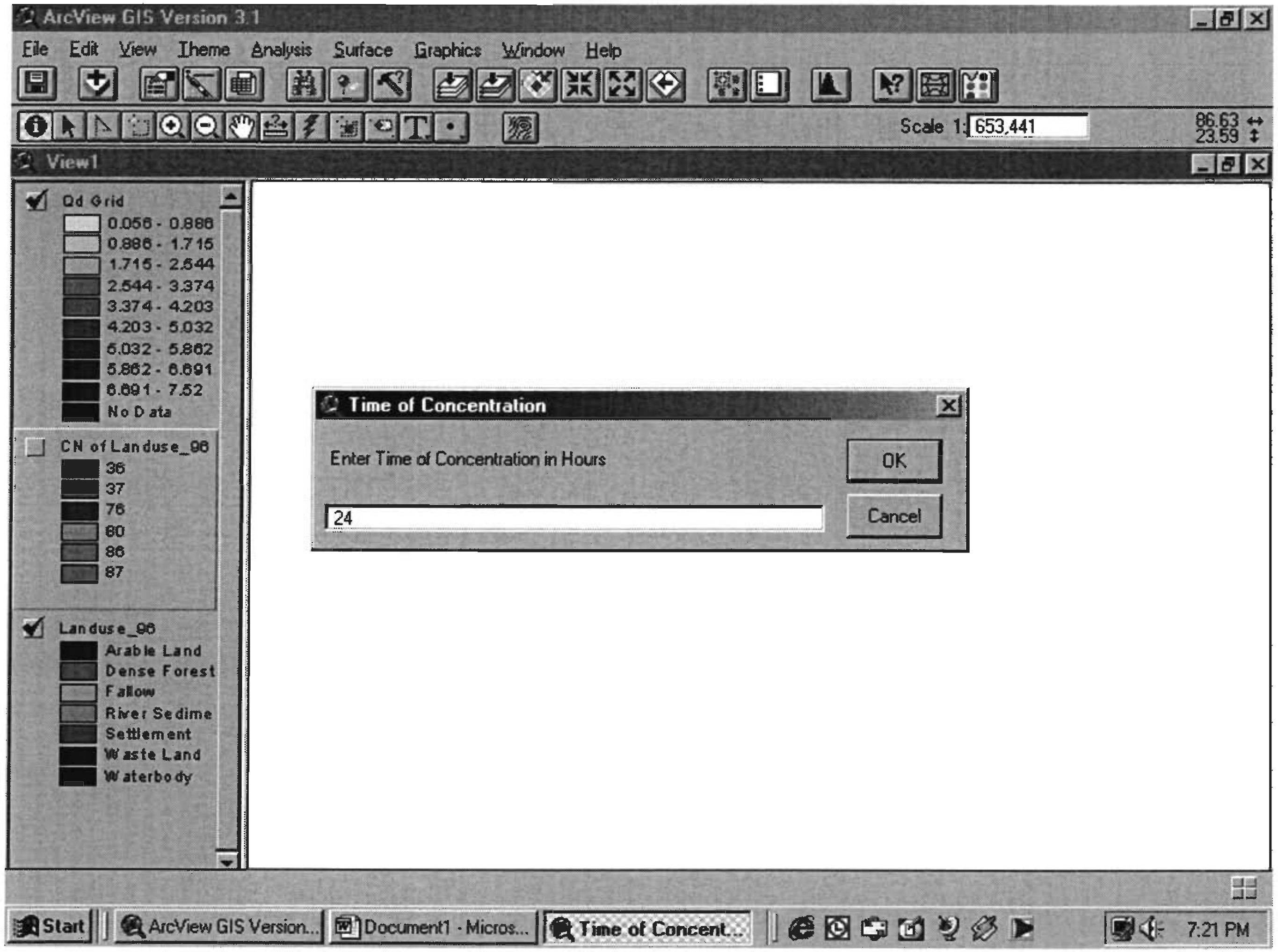
Figure 7.6 : Window asking the user to specify rainfall amount.



Enter WaterShed Area in Hectares

227000

Figure 7.7 : Window asking the user to specify watershed area.



Enter Time of Concentration in Hours

24

Figure 7.8 : Window asking the user to specify the concentration to reach the peak.

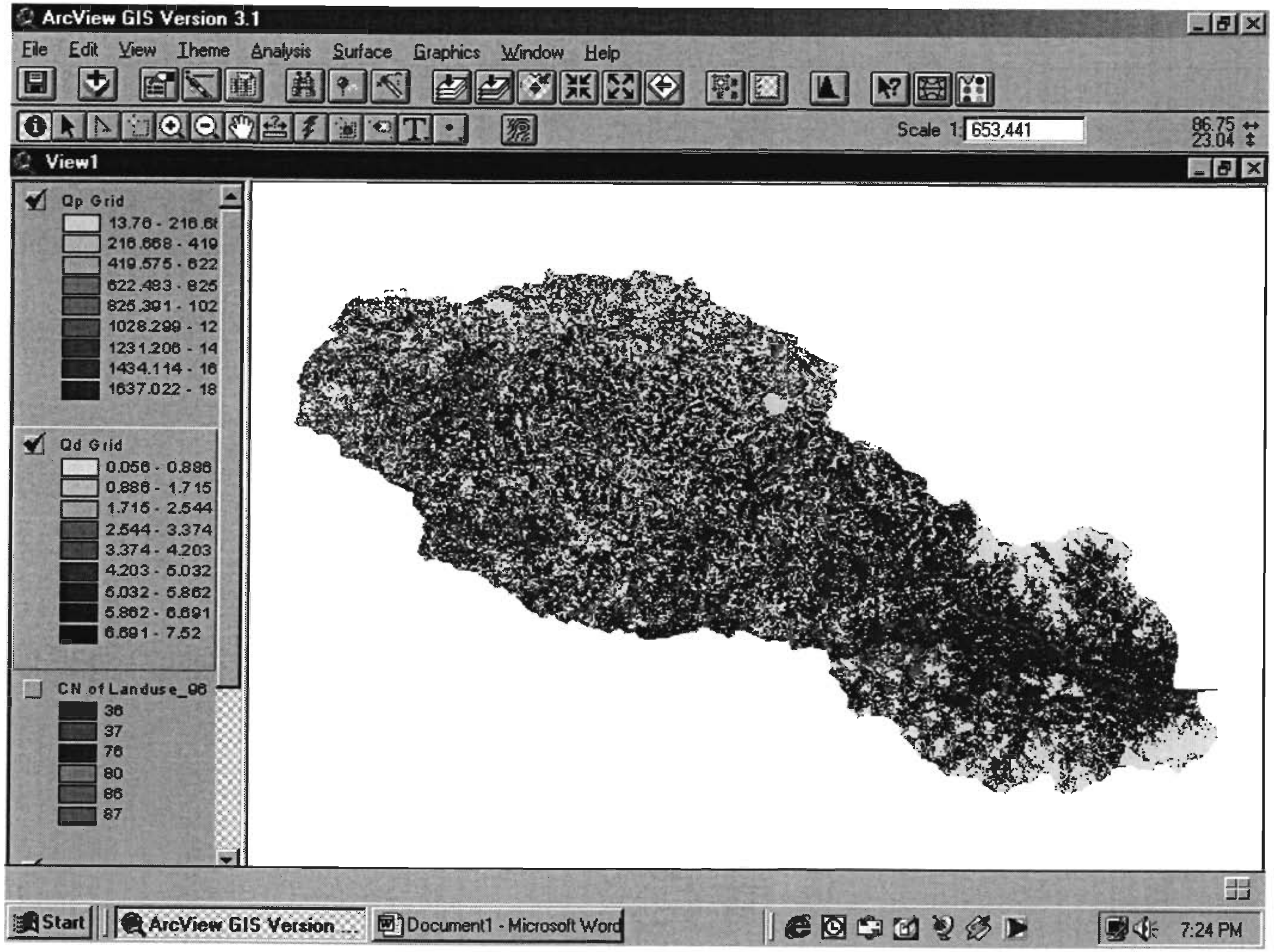


Figure 7.9 : Generated output in the form of Peak Discharge.

Chapter 8

SUMMARY AND CONCLUSIONS

8.1 SUMMARY

Land is a non-renewable resource and hence assessment of landuse change in a temporal sequence is essential for planning and development of land and water resources. Haphazard and unplanned use of land resources can create disaster like situation too the environment. Rapid urbanization, deforestation, faulty cultivation practices etc. have a great impact on the prevailing hydrological condition of an area. As successfully demonstrated in the present study that integrated remote sensing and GIS technique provide excellent information, understanding change of landuse in a cost-effective manner.

Changes in landuse practices influence lot of changes in the existing groundwater scenario of a watershed. Groundwater is considered to be a precious resource of limited extent. It provides the main source of water supply and irrigation in most areas. In general water resources in India are very unevenly distributed, both spatially and temporally. Idiosyncrasies of monsoon and diverse physiographic conditions give rise to unequal distribution of water. Over the years, increasing population, urbanization and expansion in agriculture has accentuated the situation. The aftermath of unscientific exploitation of groundwater is that we are moving towards water stress condition. This alarming situation calls for a cost and time-effective technique for proper evaluation of groundwater resources and management planning. Groundwater development program needs a large volume of data from various sources. Integrated remote sensing and GIS can provide the appropriate platform for convergent analysis of large volume of multi-disciplinary data and decision making for groundwater studies. In the present study, an integrated remote sensing and GIS based methodology have been developed and successfully demonstrated to analyze landuse-groundwater relationship in the Dwarkeshwar watershed, West Bengal, India.

The study area comprises of Precambrian crystallines and recently deposited alluvium connected by an intervening tract. In this area, monsoon groundwater recharge cannot meet the demands for groundwater throughout the year. Artificial recharge is necessary to improve the groundwater conditions in the area. In the past, very little thought had been given to utilize artificial recharge methods at suitable locations. The present work is an attempt in this direction.

The objectives of the present study were :

(a) To develop an integrated remote sensing and GIS technique to establish and evaluate the relationship between landuse and groundwater hydrology.
(b) To identify factors influencing this relationship and their role in controlling the groundwater scenario of the study area.
(c) To evaluate the nature of changes in selected landuse categories.
(d) To have a quantitative assessment of groundwater recharge.
(e) To delineate the groundwater potential zones in the area.
(f) To suggest suitable sites for artificial recharge to augment groundwater in the study area.
(g) To develop an extension for Arc View 3.1 and 3.2 GIS package for immediate extraction of groundwater related properties of an area.

The following data sets have been used for the study:

(a) IRS-LISS-II data (3-11-88 & 26-11-88) and IRS-LISS-III data (9-11-96),
(b) Survey of India topographic maps at 1:250,000 & 1:50,000 scale,
(c) Existing maps on geology, geomorphology, soil etc.,
(d) Groundwater data e.g. depth to water level data (1994-1996), and
(e) Meteorological data e.g. rainfall.

The time of acquisition of remote sensing data has been carefully chosen. Immediately after monsoon, data are dominated by reflectance of vegetation and the geologic, geomorphic features and structure are suppressed. On the other hand, during the end of dry season, the vegetation cover is generally very low. Hence, data acquired in the month of November has been used. In these data, a balanced response of vegetation, geologic and structural features are found.

IRS-LISS-II and LISS-III sensors acquire data in the visible, NIR and SWIR regions of the electromagnetic spectrum. LISS-II and LISS-III have spatial resolution of 36.25 m and 23.5 m respectively. These data have been processed using suitable digital image processing methods. These include various combinations of false colour composite, stretching and spatial filtering. Thematic information layers on geology, geomorphology, lineament, soil etc. have been generated from digitally processed images supported by toposheets, maps and ancillary information.

A wealth of hydrogeologic information have been extracted from the DEM, generated from elevation contours. Slope is a very important parameter in groundwater studies. Further, tracing the path of the steepest slope of eight neighbours. The drainage network has also been simulated from the DEM data with the assumption that there is no upward or downward loss of water due to precipitation. A more or less perfect match has been found in the hilly areas but there is a misfit between the actual surveyed drainage and simulated drainage in flat areas. This misfit has been utilized to link with recharge areas and found that these are the areas for groundwater recharge

Lineaments in this area represent joints and other fractures, which act as conduits and passageways for the underground recharge. Groundwater potential is more in the fractured areas. Weighted index overlay method is found suitable for mapping groundwater prospective zones. Criteria for the analysis have been defined on the basis of the knowledge gained from integrated analysis supported by ground truth. Each parameter has been assigned with a weightage, and each class of the parameters is assigned with a weightage on the basis of its relative contribution in controlling the occurrence of groundwater in the area. For weightage assignment, a scale of 1-10 has been used, indicating least suitable to most suitable. Slope and recharge potential receive the highest weightage followed by geomorphology, lithology, soil and distance to lineament to delineate artificial recharge areas. Boolean logic method for suitability analysis has been applied to determine potential sites for artificial recharge by defining suitable criterion.

The potential soil erosion is predicted by using USLE model and different areas with erosion risk were found out. The runoff characteristics of the watershed were also determined by using the Rainfall-Runoff modelling by using SCS curve number method. All these characteristics have a direct link with the landuse change because the main input in these models are different landuse classes.

An Arc View extension called "Groundwater Tools" is developed in Avenue language for Arc View 3.1 and 3.2 GIS software for immediate determination of groundwater potential zones and artificial recharge sites. This extension also computes runoff characteristics of a watershed, i.e. the runoff depth and peak discharge.

8.2 CONCLUSIONS

To conclude with the following remarks can be made :

1. In the present study, an integrated remote sensing and GIS technique has been developed and successfully demonstrated for evaluation of landuse groundwater relationship and has been successfully tested for the Dwarkeshwar Watershed, West Bengal, India. This study has also illustrated that integrated remote sensing and GIS approach is an appropriate tool for convergent analysis multidisciplinary data sets required for landuse-hydrological relationship studies.
2. It is obvious that rainfall is the prime factor affecting the hydrological regime of the area, but this study clearly shows that not only rainfall, but also the landuse practices in the watershed is causing significant changes to the hydrological regime.
3. The soil erosion hazard and the changes in the runoff processes with the watershed are primarily due to the changes in landuse. The areas where plantation of trees are taken up have shown low surface water discharge and low soil erosion. But the areas where

deforestation as well as urbanization activities are prevailing show high soil erosion and high surface water discharge.

4. An analysis approach based on comparative study of the surveyed drainage vs. simulated drainage for identification of groundwater recharge areas has been applied and the results obtained from the approach are in match with other derived information on groundwater recharge.
5. Combination of Weighted Index Overlay and Boolean-Logic Model has been found very useful in the selection of suitable sites for artificial recharge. The present study has demonstrated that recharge sites situated on a gentle slope and lower order streams are likely to provide artificial recharge to a larger area.
6. Moderately high resolution remote sensing data (IRS-LISS-II and LISS-III) have been found very useful in generating information regarding landuse, vegetation and other terrain parameters which can be used as primary inputs for soil erosion and runoff calculations.
7. The Arc View extension named as "Groundwater Tools", developed in the present study provides tools for immediate extraction of groundwater potential areas, artificial recharge zone, run off estimation and their relationship with change in landuse.
8. The methodology developed may be applied to similar terrain conditions with some local considerations and modifications.

8.3 SCOPE FOR FUTURE WORK

From the present study, it is found that the contribution from landuse changes is very significant in affecting the hydrological scenario of a hard rock terrain. The changes in landuse practices can change the erosion and runoff characteristics of the hard rock terrain. The methodology developed in this study can be applied to similar terrain conditions to understand the effects of landuse over the hydrological regime.

The weighted index overlay analysis in combination with Boolean-logic model can be applied to estimate the groundwater potential and recharge areas in a hard rock terrain. Depending upon the type of the terrain, the parameters as well as their individual weightages will vary to some extent. Moreover, there is much scope to incorporate more and more updated data from various sources for an in depth analysis of the groundwater condition in a terrain like the study area. Extensive geophysical surveys can provide useful information regarding the aquifer condition in a terrain predominantly consisting of hard rock where groundwater is very scarce. Though this type of surveys are very costly and time consuming to be applied in a large watershed, but smaller watersheds can be taken up for a detailed study. Use of high resolution remote sensing data for different periods can provide much updated information regarding landuse and its related parameters.

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APPENDIX A

Runoff Curve Numbers (Average Watershed Conditon, $I_a = 0.2S$) (Geleta, 1993)

Landuse Description	Curve Number for Hydrologic Soil Group			
	A	B	C	D
Fully developed urban area (vegetation established), Lawns, open space, parks, cemetries, etc.				
Good condition, grass cover on 75% of more area	39	61	74	80
Fair condition, grass cover on 50% to 75% of the area	49	69	79	84
Poor condition, grass cover on 50% or less of the area	68	79	86	89
Paved parking lots, roofs, driveways etc., streets and roads				
Paved with curbs and storm sewers	98	98	98	98
Gravel	76	85	89	91
Dirt	72	82	87	89
Paved with open ditches	83	89	92	93
Commercial and business areas	89	92	94	95
Industrial districts	81	88	91	93
Row houses, town houses and residential lot sizes 1/8 acres or less	77	85	90	92
Residential : average lot size				
1/4 acre	61	75	83	87
1/3 acre	57	72	81	86
1/2 acre	54	70	80	85
1 acre	51	68	79	84
2 acre	46	65	77	82
Developing urban areas (no vegetation established)				
Newly graded area	77	86	91	94

Landuse	Treatment Practice	Hydrologic Condition	Curve Number for Hydrologic Soil Group			
			A	B	C	D
Cultivated agricultural land						
Fallow	SR		77	86	81	91
Row crops	SR	Poor	77	81	88	91
	SR	Good	67	78	85	89
	CT	Poor	71	80	87	90
	CT	Good	64	75	82	85
	C	Poor	70	79	84	88
	C	Good	65	75	82	86
	C & CT	Poor	69	78	83	87
	C & CT	Good	64	74	81	85
	C & T	Poor	66	74	80	82
	C & T	Good	62	71	78	81
	C & T and CT	Poor	65	73	79	81
	C & T and CT	Good	61	70	77	80
Small Grain	SR	65	76	84	88	
	SR	63	75	83	87	
	CT	64	75	83	86	
	CT	60	72	80	84	
	C	63	74	82	85	
	C	61	73	81	84	
	C & CT	62	73	81	84	
	C & CT	60	72	80	83	
	C & T	61	72	79	82	
	C & T	59	70	78	81	
	C & T and CT	60	71	78	81	
	C & T and CT	58	69	77	80	

Close Seeded Legumes or Rotation Meadow	SR	Poor	66	77	85	89
	SR	Good	58	72	81	85
	C	Poor	64	75	83	85
	C	Good	55	69	78	83
	C & T	Poor	63	73	80	83
	C & T	Good	51	67	76	80
Non cultivated Agricultural land (Pasture or Range)	No MT	Poor	68	79	86	89
	No MT	Fair	49	69	79	84
	No MT	Good	39	61	74	80
	C	Poor	47	67	81	88
	C	Fair	25	59	75	83
	C	Good	6	35	70	79
Meadow	-	-	30	58	71	78
Forest land-grass or Orchards-Evergreen	-	Poor	55	73	82	86
Bush	-	Poor				
	-	Good				
Woods	-	Poor				
	-	Fair				
	-	Good				
Farmstead	-	-				
Forest-range Herbaceous	-	Poor				
		Fair				
		Good				
Oak-aspen	-	Poor				
	-	Fair				
	-	Good				
Juniper-grass	-	Poor				
	-	Poor				
	-	Fair				
	-	Good				
Sage grass	-	Poor				
	-	Fair				
	-	Good				

SR-Straight row, CT – Conservation tillage, C – Contoured, C & CT – Contoured and conservation tillage, C & T – Contoured & terraces, MT – Mechanical treatment, C & T and CT – Contoured & terraces and conservation tillage.

APPENDIX B

Adjustment of Curve Numbers for Dry (AMC I) and Wet (AMC III) Antecedent Moisture Conditions

CN for Condition II	**Corresponding CN for Condition**	
	I	**II**
100	100	100
95	87	99
90	78	98
85	70	97
80	63	94
75	57	91
70	51	87
65	45	83
60	40	79
55	35	75
50	31	70
45	27	65
40	23	60
35	19	55
30	15	50
25	12	45
20	9	39
15	7	33
10	4	26
5	2	17
0	0	0

Value of C Used in Rational Method (Suresh, 1997; Tideman, 1996, WMS, 1997)

Landuse and Topography	**Soil Types**		
	Sandy Loam	**Clay and Silt Loam**	**Tight Clay**
Cultivated Land			
Flat	0.30	0.50	0.60
Rolling	0.40	0.60	0.70
Hilling	0.52	0.70	0.82
Pasture Land			
Flat	0.10	0.30	0.40
Rolling	0.16	0.36	0.55
Hilling	0.22	0.42	0.60
Forest Land			
Flat	0.10	0.30	0.40
Hilling	0.30	0.50	0.60
Populated Land			
Flat	0.40	0.55	0.65
Rolling	0.50	0.65	0.80
Pavements (asphaltic and concrete, hard and barren)		0.70-0.95	