RAINFALL-RUNOFF MODELLING IN AN UNGAUGED WATERSHED USING GIS

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

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IRRIGATION WATER MANAGEMENT

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled: **"RAINFALL - RUNOFF MODELLING IN AN UNGAUGED WATERSHED USING GIS"** in the partial fulfillment of the requirement for the award of the Degree of Master of Technology in Irrigation Water Management, submitted in Water Resources Development and Management Department, Indian Institute of Technology Roorkee, is an authentic record of my own work carried out during the period from July 2005 to June 2006, under the supervision and guidance of Dr. Deepak Khare.

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

Date : June 27 , 2006

Place : Roorkee

(Ajay Kumar Jha)

Certified that the above declaration given by the candidate is correct to the best of my knowledge.

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ABSTRACT

Hydrological models are powerful tools for the investigation of many hydrological phenomenas. The historical approaches of the development of rainfall-runoff models, with regard to the choice of model structure and the calibration of the free parameters, has been to focus on gauged catchments where sufficient data, in particular stream flow data, are available. Applications of models were then extended to the ungauged catchments. In recent years, it has become apparent that these approaches did not lead to satisfactory results in ungauged catchments, and that the main focus should instead be on ungauged catchments for the implementation of new modelling strategies.

Geographic Information System (GIS) is a computer based system design to store, process and analyzes spatial data and their corresponding attribute information. GIS generates more valuable information from the existing data (digital map) by overlaying two or more data base. User can apply a mathematical model for analysis of data and can get outputs in digital form. The work presented in this study is "Rainfall - Runoff Modelling in an Ungauged Watershed Using GIS". Determination of runoff using SCS (curve number) method is widely used to assess the runoff generated from small agricultural watershed. In this dissertation emphasis is given on the application of GIS for rainfall-runoff modelling using SCS Method.

Some basic principles of GIS have been systematically explained with illustrative figures for general conceptual understanding. Deshgaon (Dist. Khandwa, M.P.) and Ozarkhed watershed of district Nashik, Maharashtra (No. 11/06/05/DC1a) of Damanganga catchment have been taken for the case study. Available maps and data have been compiled for the purpose of this

study. Basic of GIS and SCS runoff methodology have been described in details. ERDAS 8.6 and ARC GIS 8.3 software are used for Image Registration, Digitization and Modelling purposes.

The runoff generated from watershed was estimated using SCS method and historical rainfall data. The model parameters, Curve Number (CN) and Surface Retention (S) were evaluated under different Antecedent Moisture Condition (AMC), hydrological soil group (HSG) and land use conditions. Runoff was estimated using both GIS and Conventional method and results are compared. Sensitivity Analysis was also done to determine the most sensitive parameter for the SCS model.

Finally the results, along with brief discussion, summary and conclusion are presented.

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CHAPTER - 1

INTRODUCTION

1.1 GENERAL

Water is the prime requirement for the existence of life and is also a vital necessity of plant and animal life. Thus it has been man's endeavor from time immemorial to utilize the available water resources. History has instances of civilizations that flourished with the availability of dependable water supplies and then collapsed when the water supply failed.

In the olden days water resources didn't possess the same importance as they have now, as supplies were sufficient to meet all the requirements which then existed. But Now, due to immense increase in the population, and to meet his increasing water needs, man has therefore to find out ways & means of utilizing the water which runoff from the land to the fullest extent , as the rainfall on land is more or less constant.

Rainfall-Runoff models are tools to help in answering the questions like "What happens to the Rain" (Penman 1961)? Despite the simplicity of the question, the answer is anything but not simple due to the complexity of the hydrological processes taking place.

Rainfall-Runoff modeling has two distinct purposes: Scientific purpose - to test theories, and to improve our understanding of hydrological processes and Technological purpose - to help in decision-making by providing estimates of the state of water bodies.

They are employed for

(i) The capacity of storage structures such as reservoirs.

(ii) The magnitude of flood flows to enable safe disposal of the excess flow.

(iii) The minimum flow and quantity of flow available at various seasons.

(iv) The interaction of the flood wave & hydraulic structures, such as levees, reservoirs, barrages and bridges.

They can also be applied to assess the ground water reserves due to climate change or land use change.

Finally, they can be coupled to water quality models to predict the quality of water bodies and be associated to other models such as water quantity and socio-economic models for an integrated approach of the management of water resources at the catchment scale.

1.2 RAINFALL- RUNOFF MODELS IN UNGAUGED CATCHMENTS

In the engineering field the structures fails rarely due to faulty hydraulic design, they mostly fail because the design is not based on correct hydrological principles & observations/data.

Hydrologist could not safeguard the situation presented by inadequate data by introducing as large a factor of safety as employed in structure design, because, if he did so nearly all the projects of hydraulic engineering would become impracticable and uneconomical. Hence, sufficiency of the basic hydrological data is inescapable.

The measurements of stream flow are not available for long periods or not adequate especially in developing countries where costs in time and money to develop reliable networks of gauging stations are too high.

It is likely that the majority of catchments world-wide are ungauged i.e. where there are inadequate records of data in terms of both data quality and quantity. The hydrologist has, therefore to supplement it in most of the cases, by estimating it from meteorological data like rainfall, temperature, wind evaporation etc., which are generally available for long periods. The relationship between these elements and runoff are quite complicated and the process of computations very laborious. Therefore, the transfer of information gained in gauged catchments to ungauged catchments is necessary. This transfer of information is called Regionalisation.

In the absence of data required for parameter estimation for either existing or future conditions, the stream and contributing catchment are declared ungauged.

The problems associated with Ungauged Catchments are;

(i) Runoff data may be missing.

(ii) Rainfall data may be sparse.

(iii) Available data may be unreliable.

In India, stream flow data of various rivers are usually available with the state irrigation departments. Flow in major rivers is monitored by Central Water Commission (CWC). But either these data are available for a few years or they are unreliable.

It is rare, one can find all the necessary stream flow records at the proper site on the stream in question. In general, it is necessary either to use the records obtained at a more or less distant point or to extend the records to cover a long period. Therefore, the need is to shift the main focus of hydrology from gauged to ungauged catchments.

1.3 NEED OF GIS IN RAINFALL- RUNOFF ANALYSIS

Estimation of the expected amount of runoff in a given area is important in planning of any watershed management-program. Unless a good assessment of the available runoff that can be harvested or conserved is made, it is difficult to even start considering watershed management. The availability of runoff is determined by factor such as land surface, soil type and rainfall characteristic.

With others remaining the same, the characteristic of land surface can indicate the extent of runoff that can be expected. However it is not possible to find this kind of runoff in every location or every type of watershed. The non-availability of surface runoff will increase the extent of manipulation necessary on catchments and hence, cost of scheme. The main factors affecting runoff generation are slope, length, vegetation cover and surface roughness of the catchment.

Employing manual techniques to integrate the vast amount of data from a variety of sources for the purpose of obtaining runoff from a watershed is both time consuming and expensive. On the other hand the present advancement of technology made it possible to easily handle and analyze large volume of data using computer based systems. GIS in particular provides enormous potential for effectively storing, handling, manipulating and analyzing multiple spatial data sets in a single analysis at high speed unmatched by any other method.

1.4 OBJECTIVES OF THE STUDY

Runoff is one of the most important hydrologic variables and an indication of availability of water. For designing of any hydrological structure, knowledge of peak and total runoff is required. Thus in situ measurement of runoff is useful; however in most cases such measurements are not possible at the desired time and space as conventional techniques of runoff measurements are expensive, time-consuming and difficult. For overcoming these shortcomings rainfall-runoff modeling are commonly used for computing runoff. Therefore an attempt has been made to estimate the direct surface runoff generated from a watershed.

GIS has been used to incorporate the spatial and temporal variability of different parameters involved in runoff generation. In the present study, SCS Curve Number methodology developed by United States Department of Agriculture (USDA) has been used for the estimation of runoff.

In light of the above, the present study has following objectives;

i. Creation of GIS data base.
ii. Computation of runoff by implementing the SCS Curve Number methodology in GIS in gauged and ungauged watersheds.
iii. Comparison of runoff estimated by GIS and conventional method.
iv. Validation of the model in gauged watershed.
v. Sensitivity Analysis of the model.

1.5 ORGANIZATION OF THESIS

The scope of this work is confined to runoff estimation in ungauged catchment using SCS runoff model. Literature review has been done with respect to various types of rainfall runoff modeling approaches and presented in chapter two. Some basic principles of the GIS are reviewed and presented in chapter three. SCS model is briefly described in chapter four.

A summary of information about data related with Deshgaon and Ozarkhed watershed is presented in chapter five. Implementation of SCS method in GIS for runoff estimation has been presented in the chapter six. A comparison has been made between the runoff obtained using SCS model with parameterization conventionally and using GIS and the same is presented exhaustively in chapter seven. Conclusions and summary is presented in chapter eight. At last, a compiled list of useful earlier works related with the field of study is listed at the end, in the reference section.

LITERATURE REVIEW

2.1 GENERAL

A Mathematical model is an assembly of concepts in the form of mathematical equation(s) that approximate the behavior of a natural system or phenomena. It represents the actual systems to certain degree of accuracy. It is difficult to analyse each and every system for the purpose of meeting the needs of planning and development. Moreover it needs voluminous data, procurement of which is difficult and expensive.

Rosenblueth and Wiener (1945) perhaps best expressed the rationale for model building as

"No substantial part of the universe is so simple that it can be grasped and controlled without abstraction. Abstraction consists in replacing the parts of the universe under consideration by a model of similar but simpler structure. Models, formal or intellectual on the one hand, or material on the other, are thus a central necessity of scientific procedure."

A mathematical model represents the system by a set of equations expressing relationships between system variables and parameters, e.g. -

$$f[x(t), y(t)] = 0.$$

It is common to classify watershed models into three distinct types (Wheater et al., 1993 ;). These are: (a) empirical (also called data-based, metric or black-box), (b) physically-based (also called mechanistic or white box) and (c) conceptual models (also called parametric, explicit soil moisture accounting or gray box).

2.2 EMPIRICAL MODELS

Empirical model uses available time-series of input and output variables (precipitation, streamflow, temperature etc.) to derive both the model structure and the corresponding parameter values. They are purely based on the information retrieved from the data and generally do not include prior knowledge about catchment behavior and flow processes, and hence called black box models. Empirical models are usually spatially lumped, i.e. they treat the catchment as a single unit. (Young, 1992)

Mulvaney (1851) was perhaps, the first person who tried to develop a mathematical method to transfer rainfall into runoff. This method relates the peak discharge to the catchment area, the rainfall intensity and a constant to be defined for the catchment itself (i.e. Q = CIA). This method is still in use to calculate the peak discharge of storms, especially in urban hydrology (design of sewerage system etc).

In the year 1932 the second major method was introduced by Sherman, Unit hydrograph method. The unit hydrograph is a linear method based on the principle of superposition and can be applied to a hyetograph to produce a hydrograph and not only the peak discharge as with the rational method (Todini, 1988).

The applicability of a linear relation between rainfall & runoff, as assumed in the unit hydrograph method, has however proved to be not suited to all cases (Amorocho & Brandstetter, 1971; Sivakumar et al. 2001). Techniques learnt from other branches of science were adopted for the development of non-linear transfer functions. Some authors not only questioned the linearity of the transfer function but also its stationarity in time (Labat et al., 2000).

Other techniques like Artificial Neural Networks (ANN) have been used recently to transform rainfall into runoff (Baratte et al., 2003, Kumar D.N. & Ray Abhijit, 2003, Naidu K.S., 2001).

ANN tries to reproduce the functioning of the human brain: they are composed of nodes connected by neurons. These nodes are organized by layers (an input layer, hidden layer and an output layer). The numbers of hidden layers and of nodes in each layer dictate the degree of freedom of the ANN. Experience and training is necessary to establish the connections among the nodes. It is interesting to notice that unlike any other method (metric, physical-based or conceptual); the output does not only depend on the input but also on the output at previous time steps. (Marechal, 2004).

The biggest drawbacks of metric models are that it is not based on physical laws. A model must describe the physical processes and not only the mathematical formula.

Therefore, all empirical models have some chances of being fortuitous and in principle should not be used outside the range of data from which they were derived.

2.3 PHYSICAL MODELS

Physically based models are based on the laws of the conservation of mass, momentum and energy (Freeze and Harlan, 1969; Abbott et al., 1986). Physical- based models are therefore particularly attractive for studies which require a high level of spatial detail, e.g. studies on soil erosion or diffuse-source pollution (Refsgaard and Abbott, 1996).

The first physically-based models were not completely 3-dimensional models in order to reduce the computing time, e.g. - the System Hydrologique European (SHE) (Abbott, 1986) or IHDM (Rogers et al., 1985). But the latest models are now truly 3-D to make use of the calculation power of modern personal computers (Sudicky et al., 2000). The initial idea underlying these models was that the degree of physical realism on which these models are based would be sufficient to relate their parameters, such as soil moisture characteristics and unsaturated zone hydraulic conductivity functions for subsurface flow or friction coefficients for surface flow, to physical characteristics of the catchment (Todini, 1988), thus eliminating the need for observed system response to condition the parameters of the model. However the currently available physically-based models do not fulfill this theory. They suffer from extreme data demand, scale related problems (e.g. the measurement scales are different from the process and model (parameter scales), over parameterization and questions about the correctness of the equations at a grid scale (Bevan, 1989). It is not proved that equations derived usually in laboratories can be applied to large scale. A number of key parameters – applied to a large number of elements – still has to be estimated from measurements to capture the uniqueness of a specific watershed (Calver, 1988). The expectation that these models could applied to ungauged catchments has therefore not been fulfilled (Refsgaard and Knutsen, 1996).

Despite these problems, physically-based models are still valuable tools when detailed spatial information is available. It can be expected that remote sensing data combined with GIS can helps in providing new source of data suited to physically-based models.

2.4 CONCEPTUAL MODELS

Conceptual models are intermediate between physical and metric models. Generally conceptual models consider physical law but in highly simplified form. The modeler, based on a conceptualization of the real world watershed, specifies the structure of these models *a priori*, e.g. number of and connections between storage elements. These models are usually spatially lumped. This means that large parts of the (heterogeneous) watershed are integrated in a single (homogeneous) element. The consequence of this process is that the model parameters lose some of their physical meaning and cannot be measured at the required scale. (O'Connell, 1991; Wagener et al., 2004).

Conceptual models can be classified into two groups. The first group is composed of storage based models: e.g. Stanford Watershed Model (Crawford and Linsley, 1966), Hydrologiska Byrans Vattenbalansavdelning (HBV) (Bergstrom and Forsman, 1973). Models composing the second group were developed in the 1980's and 1990's and are based on hydrological similarities e.g. TOPOMODEL (Beven & Kirkby, 1979; Beven, 1997), Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998).

Conceptual models provide useful results efficiently and economically for some problems. They contain parameters, some of which may have direct physical significance and can, therefore be estimated by using concurrent observations on input & output. Examples of linear conceptual models are Clark Model (1943), Edson Model (1951), Nash Model (1962), etc.

2.5 USE OF GIS AND REMOTE SENSING

The use of Geographic information Systems (GIS) and remote sensing to facilitate the estimation of runoff from watershed and agricultural fields has gained increasing attention in recent years. This is mainly due to the fact that rainfall-runoff models include both spatial and geomorphologic variations (Melesse and Shih, 2002).

In India remote sensing and GIS has been used for the rainfall runoff modelling. Nayak and Jaiswal (2003) used LISS-II satellite image and GIS for the rainfall-runoff modeling of Bebas river in Madhya Pradesh and found good correlation between the measured and estimated runoff volume.

Pandey et al., (2003) used SCS Curve Number and GIS for Karso watershed (area about 2793ha) a part of Damodar Barakar catchment, situated in Hazaribagh district of Jharkhand State and found the estimated runoff to be close to the observed one (within ± 25%).

Jaiswal et al., (2000) used Remote Sensing data and SCS Curve Number method to compute runoff for Ghaziabad district, Uttar Pradesh, India so as to provide a quick result for decision-makers. This method is less time consuming and also gives more and more reliable result as the imperviousness of the drainage area increases and the value of Runoff coefficient tends to approach unity. This method can be used effectively in the design of storm water drains and small control project.

Pandey and Sahu (2002), worked for generation of curve number using Remote Sensing and GIS for ungauged watersheds. Conventional methods of runoff measurement are not easy for inaccessible terrain. Remote Sensing technology can augment the conventional method to a great extent in rainfall-runoff studies. In the study they have used SCS Curve Number Method modified for Indian conditions for Remi watershed (area 210 km^2) which is located in the East Siang district of Arunachal Pradesh.

Adhikari, (2003) developed GIS-Remote Sensing compatible rainfall-surface runoff model for regional level planning. The model is compatible with both the GIS database and the Remote Sensing (RS). Interactive option is provided to the user for modifying the database; Algorithms have been used in the study to extract watershed features such as overland flow, cascade, channel network, confluence points ridges etc. for a given digital elevation data using Triangulated Irregular Network (TIN). The overland flow is modeled as one–dimensional sheet flow over cascades of overland "flow planes" contributing as lateral inflow to the channels flowing in the valley. The main input to the watershed is taken as the rainfall. The usage of the model for regional level planning is demonstrated for tasks such as determination of waterways for small bridges and culverts, design of spillways of small dams, construction of flood protection levees, agriculture, site planning for micro hydels etc.

Sarangi et al., (2004), used GIS tool in watershed hydrology. To assess runoff from the watershed GIS tool was used to assist in data base development which acted as input to a developed conceptual model (Small Watershed Runoff Generation Model, SWARGEM). The input to the model was in the form of data tables and digitized maps comprising of soil parameters, topological information and land use features of Banha watershed under Damodar Valley Corporation, Jharkhand, India. The model used 4-point pour-input technique to route surface flow from one grid to the other in an overlaid grid array of the Banha watershed. The output of the model generated event based Direct Runoff Hydrographs (DRH) for the watershed. The non-parametric statistical analysis(Wilcoxon's matched pair signed rank test) performed on the predicted value and observed runoff rate at the outlet of the watershed revealed that there is no significant difference between the observed and predicted values at 0.05 probability level.

Poongothai and Thayumanavan (2002) used spectral analysis of time series for a rainfall-runoff model to an ungauged sub-watershed of Gomukhi watershed, Vellar basin, Tamilnadu, India. They showed that spectral analysis is useful in describing a stochastic process in the frequency domain in an ungauged watershed.

Sukheswalla, (2003) used statistical model for estimating mean annual and monthly flows at ungauged locations for the USA.

Marechal, (2004) developed Catchment Resources and Soil Hydrology (CRASH) model to rainfall-runoff modelling in ungauged catchments for England and Wales. He derived a regional set of model parameters from the calibration of CRASH in 32 catchments for England and Wales.

CHAPTER - 3

BASIC PRINCIPLES OF GEOGRAPHIC INFORMATION SYSTEM

3.1 GENERAL

Geographic Information System (GIS) can be defined as a computerized based system designed to accept large volumes of spatial data derived from a variety of sources and to efficiently store, retrieve, manipulate, analyze and display these data according to use specifications (Burrough,1986). Geographical objects include natural phenomena such as lakes, rivers, forests, etc; man made structures like dams, buildings, highways, etc; and other convenient objects that may define the location and extent of a geographical phenomenon such as particular soil type, etc.

In GIS, data captured in the form of existing maps, field observations and satellite sensors are called the coverages which form data input subsystem. Data storage and management provide the storage, organization and maintenance of both spatial data and related attribute data. Data information involves large array of analytical functions, such as classification, overlay and neighborhood analysis, etc. Data output presentation is concerned with the way the data are displayed and the results of analysis are reported to the user (Fig. 3.1).

Today, GIS is considered as an important tool in planning and decision-making. It has been successfully applied in many fields, such as land use planning, forestry, wildlife management, infrastructure planning, military environmental monitoring, network planning etc.

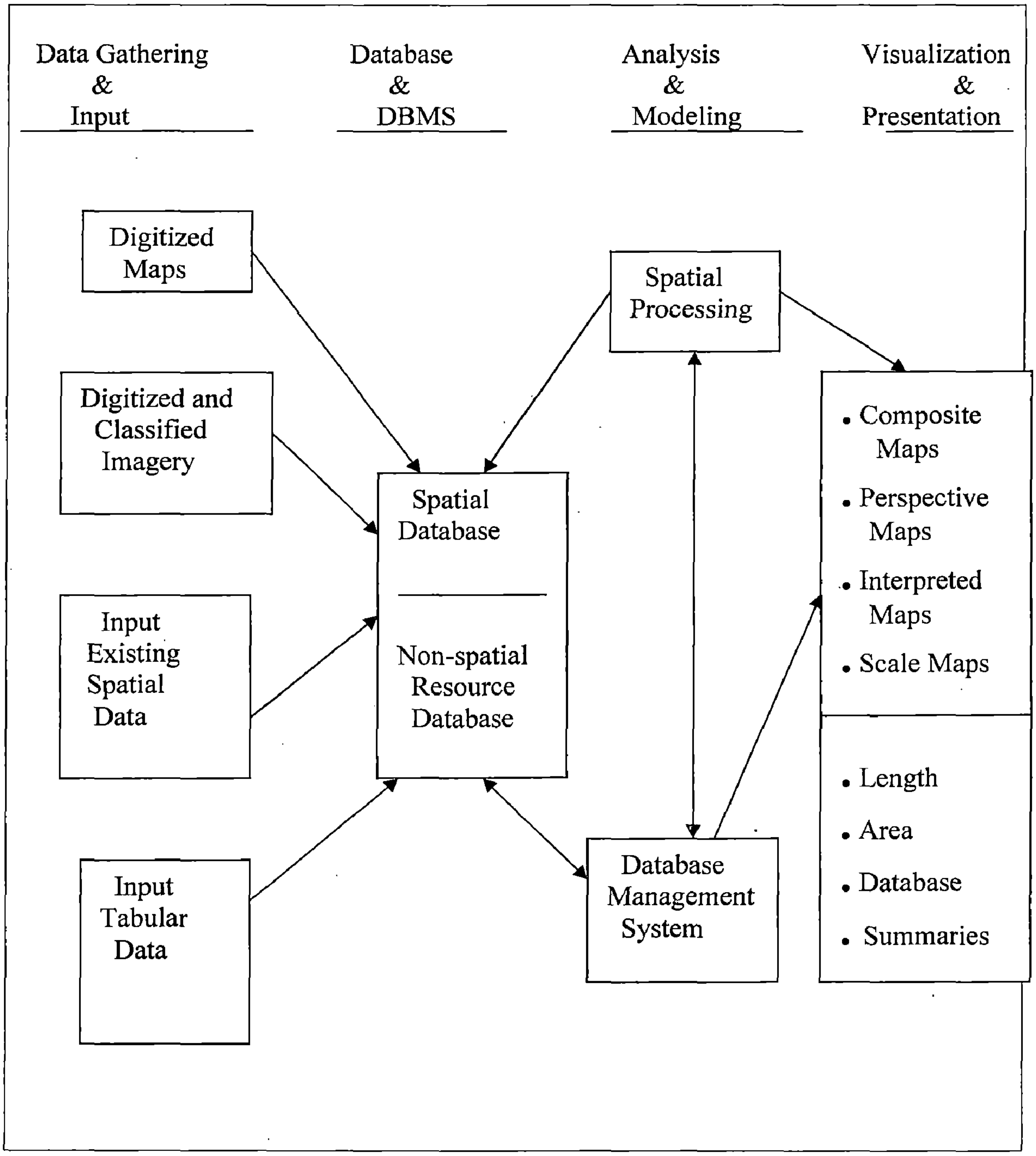


Fig. 3.1 A GIS Schematic Presentation (Marble et al., 1990)

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

The Dataset – Getting the relevant data is important for an efficient GIS and the most cost effective data collection would be to collect only the data we need. The optimum data quality is the minimum level of quality that can be satisfactorily used for intended purpose.

Data Organisation – Data have no values, unless the right data can be placed in the right place at the right time.

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

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

3.2 COMPONENTS OF GIS

GIS consists of three basic components; computer hardware, application Software module and data organization. These components must be well integrated for effective use of GIS, and the development and integration of these components is an iterative, ongoing process. The selection and purchase of hardware and software is often the easiest and quickest step in the development of a GIS. Data collection and organization, personnel development, and the establishment of protocols for GIS use are often more difficult and time consuming endeavors.

3.2.1 Hardware for GIS

The development, operation and generation of information requires GIS hardware which includes combination of the computer CPU (central processing unit) and operating system, storage media (hard disk), color graphics terminal(s), tape drives, digitizer table (or scanner), line printer, color printer and pen plotter (Fig. 3.2).

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

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

3.2.2 GIS Software

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

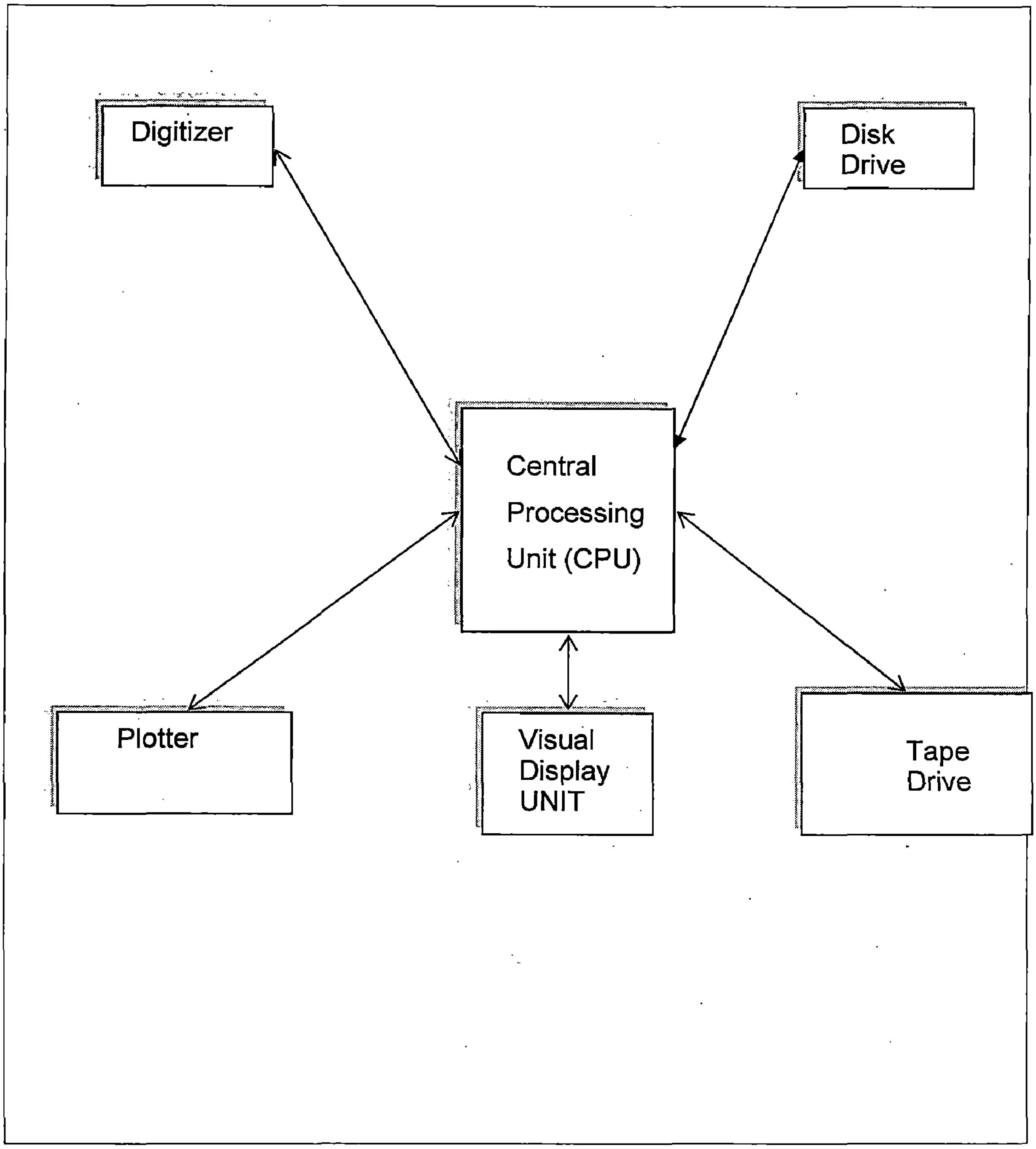


Fig. 3.2 Major Hardware Components of GIS (Burrough, 1986)

developed. GIS software provides the specific tools for some or all of these tasks.

There are many public domain and commercially available GIS software packages, and many of the commercial packages originated at academic or government-funded research laboratories. The Environmental Systems Research Institute (ESRI) line of products, including Arc/info, is a good example.

The function commonly provides by GIS software are:

Data entry - manual coordinate capture - attribute capture - digital coordinate capture - data import Editing - manual point, line and area feature editing - manual attribute editing - automated error detection and editing Data management - copy subset, merge data - Versioning - Data registration & projection	Analysis - spatial query - attribute query - interpolation - connectivity - proximity - proximity & adjacency - buffering - terrain analysis - boundary dissolve - spatial data overlay - moving window analysis - map algebra Output - map design & layout

- Summarization, data reduction - documentation	- hardcopy map printing - digital graphic production - export format generation - metadata output - digital map serving

3.2.3 GIS Data Input

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

(i) GIS Data Sources

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

- Existing maps
- Aerial photographs

- Satellite imagery
- Data from airborne scanners
- Field measurements
- Other GIS database
- GPS observations and
- From existing digital data.

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

(ii) Data Entry System

The method of spatial data input depends primarily on the source of the data. The actual method of data input is also dependent on the structures of the database of the geographical system. There are five data entry methods commonly used in GIS. Key board entry, coordinate geometry, manual digitizing, scanning, and the input of existing digital files. (Fig 3.3)

3.2.4 GIS Database and Data Management System

Geographical database is the collection of spatially referenced data that acts as a model or reality (Valenzuela, 1990). The stored information has certain characteristics by which it can be identified and handled. The information for geographic features has four major components i.e. its geographic position, its attributes, its spatial relationships and time (Aronoff, 1989). More simply they are, where it is, what it is, what is its relationship to other spatial features and when did the condition or feature exists (Fig. 3.4).

Geographic Position (Location): Geographic data input are basically a form of spatial (georeferenced) data. Each feature has a location that must be specified in a unique way. Locations are recorded in terms of coordinate system like the longitude/latitude, Easting and Northings, UTM (Universal Transverse Mercantor) or state plane co-ordinates.

Attributes: It is Non-graphic descriptors of point, line and area entities in a GIS. It is often termed as non-spatial data. An attribute is a characteristic of an entity (a thing that has definite, individual existence in reality, e.g. house number). Its value is the actual measurement that is stored in the database.

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

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

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

3.2.4.1 Database Concepts

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

Some of the advantages that can be gained from database are:

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

3.2.4.2 Types of Geographic Data

There are four types of notations used for representing or encoding geographic data: points, lines, polygons (area) and continuous surface. In general, points, lines and areas are used to explicitly represent real-world objects; where as continuous surfaces are mostly used for volumetric representation such as to represent hills, valleys.

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

Line Data: Features, such as highways, rivers elevation contours, pipelines and power lines exemplify line data. Vector-based GIS system can show line in

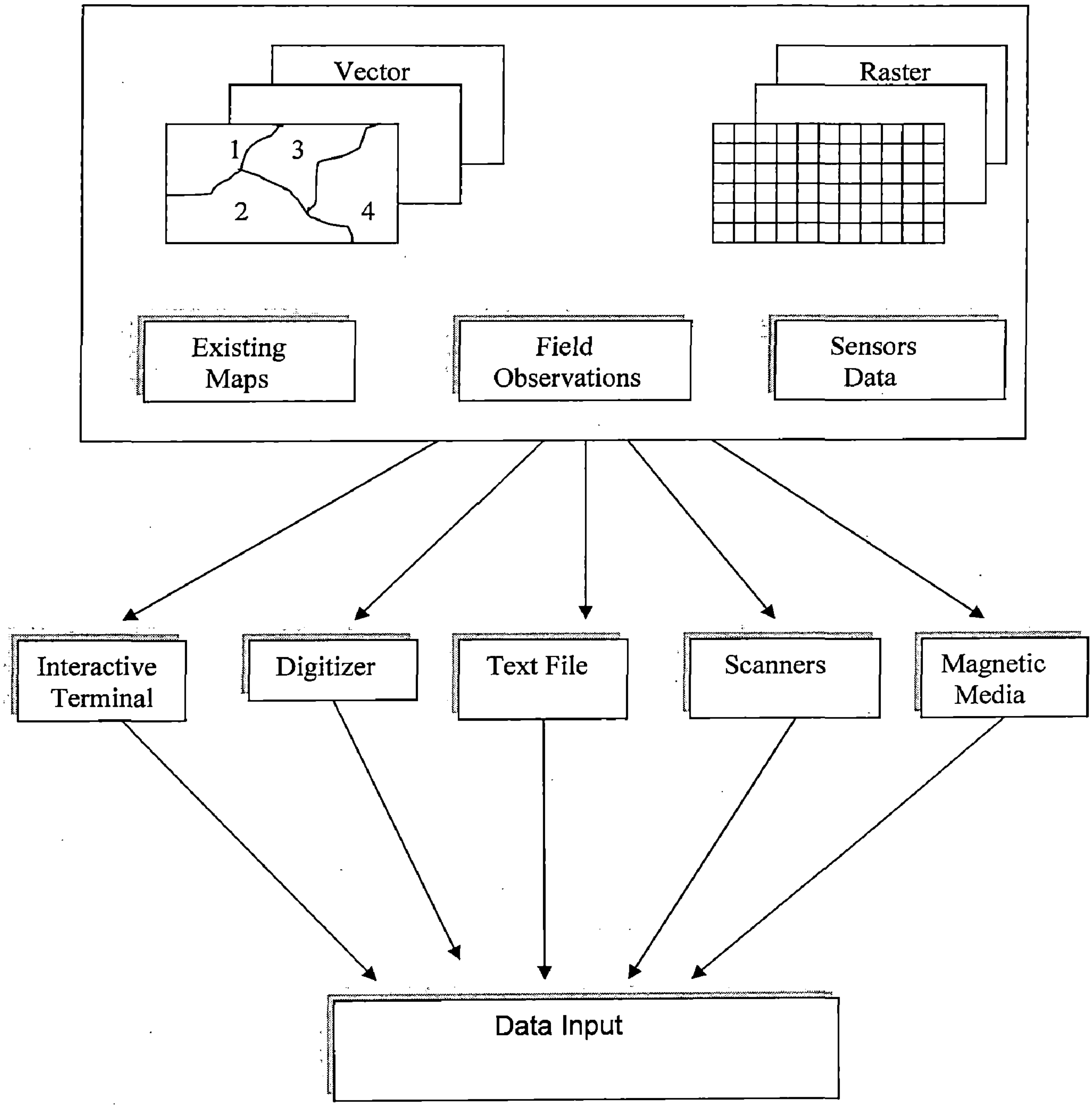


Fig. 3.3 GIS Data Input (Burrough, 1986)

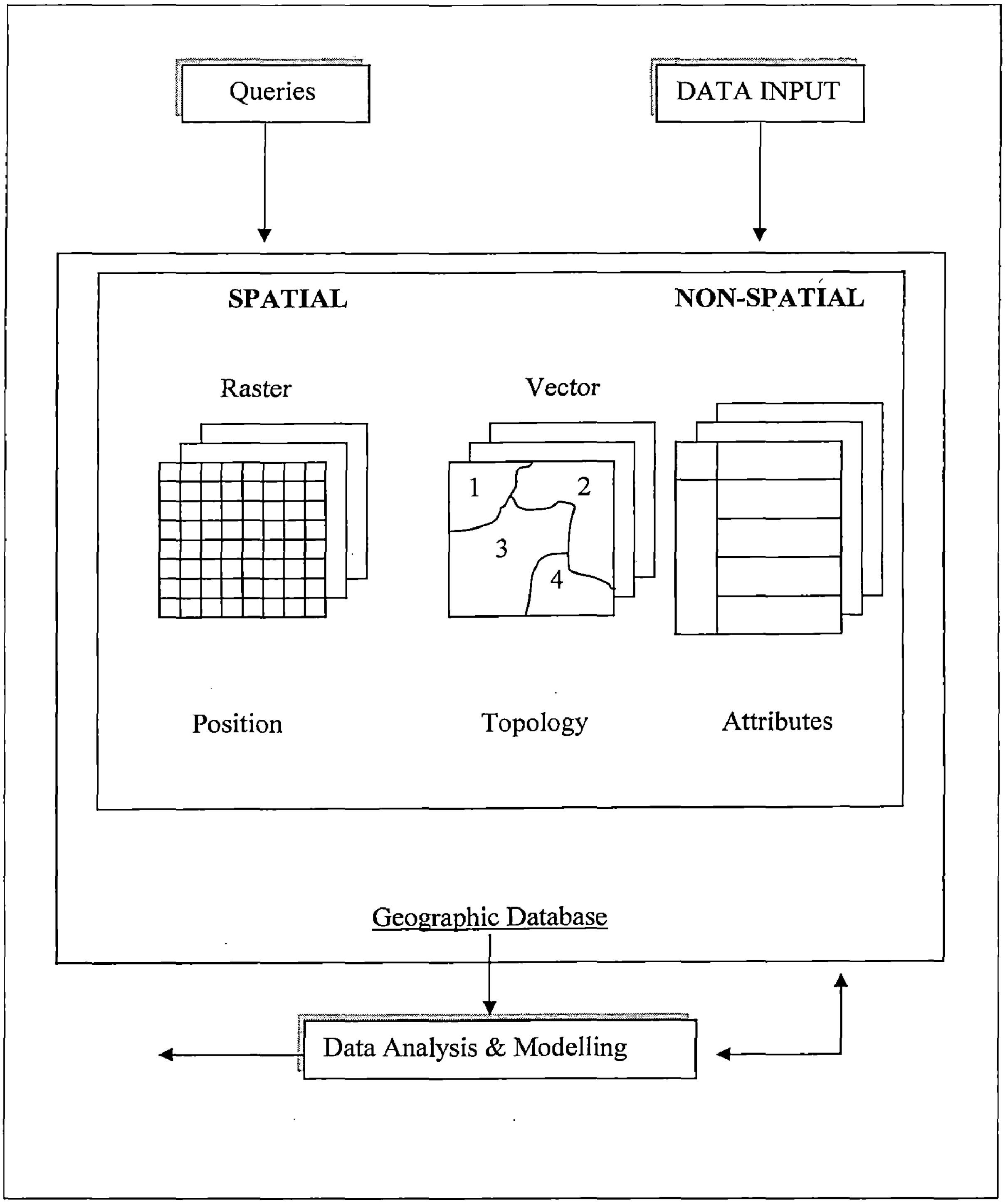


Fig. 3.4 Geographic Database (Valenzuela, 1990)

fine detail, whereas raster based system depicts a linear feature only as chain of grid cells.

Polygon (area) Data: Area is composed of series of lines that begin and end at the same location. Polygon constitutes the most common data type used in GIS. They are bounded regions. The boundaries may be defined by natural phenomena, such as land forms or by man made, such as forest stand or land use unit.

Continuous Surface: surfaces have three dimensions-length, width and height. For e.g. hills, valleys and ridges can be described by citing their locations, amount of area they occupy, how they are oriented and by noting their heights. Most of GIS products cannot handle 3-dimensional data although they can handle topographic data, usually Digital Elevation Model (DEM).

3.2.4.3 Basic Data Models

There are two types of fundamental approaches for representation of the spatial components of geographic information i.e. the vector model and raster/grid model.

Vector Model: In the vector model objects or conditions in the real world are represented by the points and lines that define their boundary such as if they were being drawn on a map. The fundamental primitive in the vector model is the point. Objects are created by connecting points with straight lines. Areas are defined by set of lines. Vector models have the line as the basic logical unit in a geographic context. The data model used by the software like Arc/Info, Arc/View, and Arc/GIS is vector model.

The most common vector models are the whole polygon structure and topologic model.

a) **The Whole Polygon Structure:** In this model each polygon is encoded in the database as one logical record. The paper map is translated line in to a list of X-Y coordinate pair. In this model common boundary between two polygons must be recorded twice, once for each polygon. The main drawbacks of this model are, digitizing and storing common boundaries twice, database edition and updating are carried out by comparing it visually with geographic content and islands are only graphical constructions. This model is also known as Spaghetti Model.

b) **Topologic Model:** The topologic model is the most widely used method of encoding spatial relationship in a GIS. Basic logical entry is the arc, a series of points that start and end at a node- an intersection point where two or more area meet.

Raster Data Model: In raster model, one or group of cell/grid/pixel depending upon the grid resolution represents spatial elements. It consists of a regular grid of square or rectangular cells. The location of each cell or pixel is defined by its row and column numbers. Each cell in the raster file is assigned only one value.

In a raster model a point is represented by a single pixel, a line by several pixels with the same value forming a linear grouping and an area by a clump of cells all having the same value. The Comparison between raster and vector models is presented in Table 3.1.

3.2.5 Data Analysis and Modelling

The most important characteristics of GIS is the provision of the capabilities for data analysis and spatial modelling. These functions use the spatial and nonspatial attribute data of the GIS database to answer questions about the real world. The database in GIS is the model of the real world that can be used to simulate certain aspects of reality. A model may be represented in words, in mathematical equations or as a set of spatial relationships displayed on a map. The general problem in data analysis are user query its link with database and output.

Table 3.1 Vector Vs Raster Data Model

Vector	Raster
Advantages - compact data structure(less data volume) - efficient topology encoding, good for operations, such as network analysis - better graphics for precise expression	- simple data structure - easier and efficient overlay operation - high spatial variability is efficiently represented - efficient in manipulation and enhancement of digital images.
Disadvantages - complex data structure - implementation of overlay operations is difficult - inefficient representation of high spatial variability - not effective for manipulation and enhancement of digital images.	- large data volume(data compression technique can overcome this problem) - difficult to represent topological relationships - less aesthetic graphic output - not good for some operations, such as network analysis.

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

3.2.5.1 Analysis functions

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

3.2.5.2 Retrieval, Reclassification and measurement operations

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

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

- geometry classification,
- symbolic specifications,
- a name of code of an attribute,
- Conditional and logical statement.

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

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

3.2.5.3 Overlay Operation

Overlay operation creates a new data set containing new polygons formed from intersection of the boundaries of the two or more sets of separate polygon layers. There are two common overlay operations which are arithmetic, and logical. Arithmetic overlay includes operation such as addition, subtraction, division and multiplication of each value in a data layer. Logical overlay involves the selection of an area where a set of conditions are satisfied. Figure 3.5 presents the overlay concept in a vector structure (topologic overlay).The logical overlay operation is done using the rules of Boolean logic. Boolean algebra uses the operations of AND, OR, XOR, NOT to see whether a particular condition is true or false (Table 3.2).

3.2.5.4 Neighborhood Operation

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

Table 3.2 Boolean Logical Operation

A	B	NOT A	A AND B	A OR B	A XOR B
1	1	0	1	1	0
1	0	0	0	1	1
0	1	1	0	1	1
0	0	1	0	0	0

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

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

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

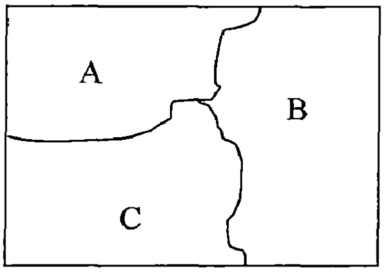
3.2.5.5 Connectivity Functions

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

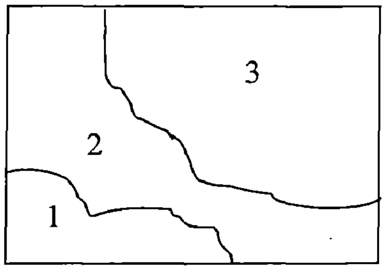
Contiguity: contiguity measures characterized spatial units that are connected. A contiguous area is formed by a group of spatial units that have one or more common characteristics and constitute a unit. Common measures of contiguity are the size of the contiguous area and the shortest and the longest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

Proximity: This involves the measurement of the distance between features. The measurement unit can be distance in length, travel distance in time or other units. The necessary parameters which must be specified to measure proximity are the features or objects (roads, houses, etc.), the unit of measure

Soil Map

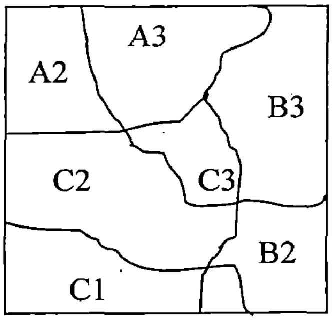


Land Use Map



Soils

Code	Depth
A	150
B	120
C	90



Soil/Land Use Map

Land Use

Code	Name
1	Forest
2	Agrl.
3	Pasture

Land Use / Soils

Soil Use	Use Name	Soil Depth
A2	Agrl.	150
A3	Pasture	150
B2	Pasture	120
B3	Agrl.	120
C1	Forest	90
C2	Agrl.	90
C3	Pasture	90

Fig. 3.5 Overlay Procedure in a Vector System (Valenzuela, 1990)

(meter, length, etc.), a function to calculate proximity (Euclidean distance), and area to be analyzed. A buffer zone may be the result of a proximity analysis.

Network: Network functions are commonly used in analysis that requires moving resources from one location to another. GIS is used to perform network analysis such as prediction of network loading like for instance, transport of water and sediment in alluvial system, route optimization such as air line scheduling, urban transportation etc. In network analysis four components are usually considered i.e. a set of resources (e.g. sediment transport by water), one or more locations where the resources are located (e.g. a fluvial system), a destination (e.g. outlet of the watershed), and a set of constraints (e.g. only permanent steams of higher order).

3.2.5.6 Modelling

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

3.2.6 Data Output

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

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

Output in electronic formats consists of computer compatible files. They are used to transfer data to another computer system either for additional analysis or to produce hard copy at a remote location.

3.3 COORDINATE SYSTEM AND MAP PROJECTION

To analyze, manipulate, measure and store reasonably, geospatial data must be put into one certain spatial coordinate system. There are two kinds of coordinate system for geo-spatial data, *Spherical* and *Cartesian* coordinate system. In *spherical coordinate* system each point feature can be described uniquely with a pair of latitude and longitude value although latitude and longitude are not uniform across the Earth's surface. In *Cartesian or polar coordinate* system, each point feature on the earth will be projected onto a flat surface by a pair of X and Y coordinates on a grid. Using this system, the coordinates at the origin are X=0 and Y=0. On a grided network and equal spacing, the horizontal line in the center of the grid is call the X-axis, and the central vertical is call Y-axis. Therefore, coordinate value, measures of length, angle and area are uniform in this coordinate system.

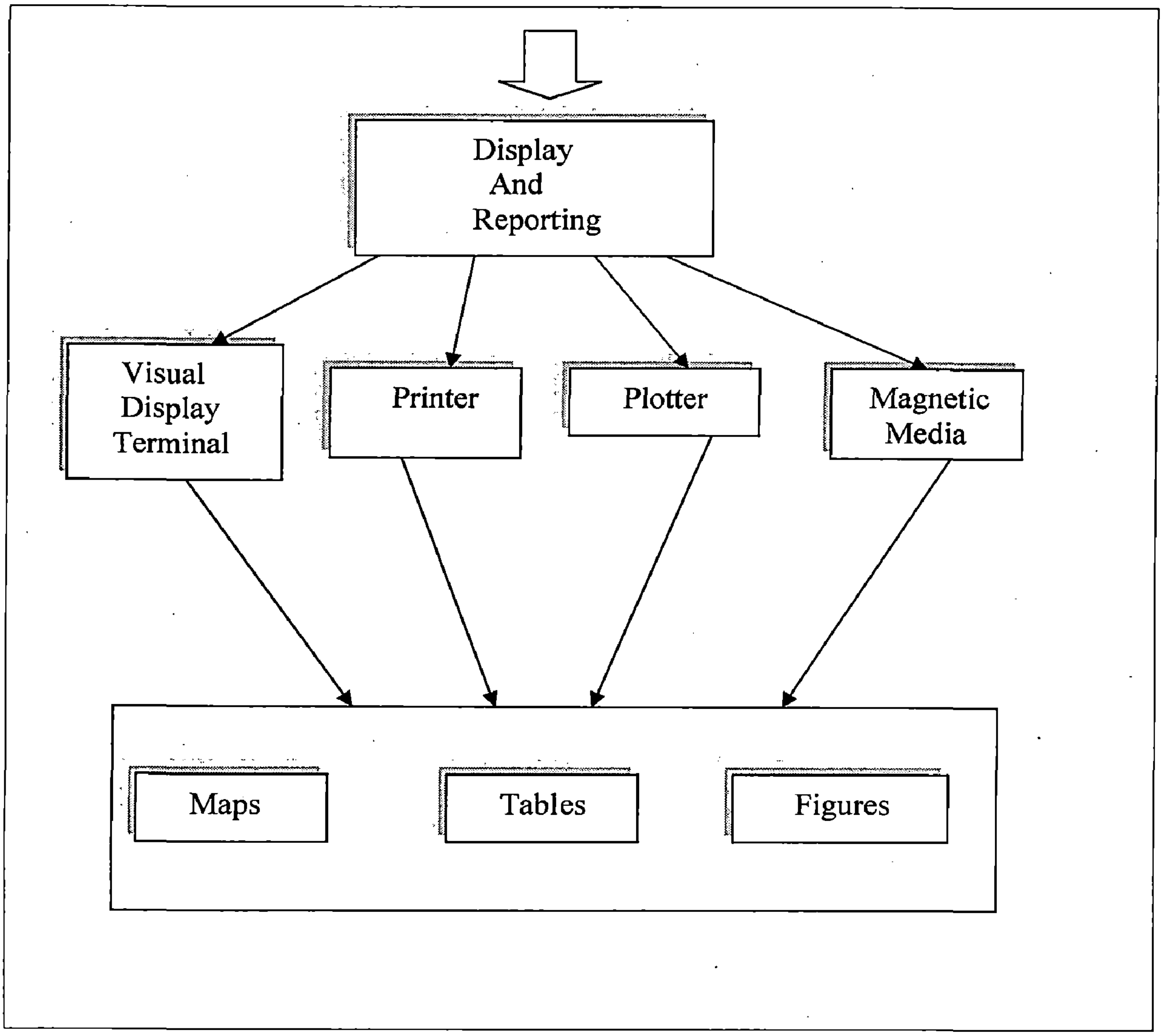


Fig. 3.6 GIS Data Output (Burrough, 1986)

When we try to transform the location information on three-dimensional earth surface into a two-dimensional map, projection is needed. In other words, map projections are used to map the curved surface of an ellipsoid to a plane. This is achieved by transforming the values with mathematical expressions. There are three major projection types, namely planar (also known as Azimuthal), conic, and cylindrical projections depending on the shape of the developable surface.

The two most commonly used projection system are Geographic and Universal Transverse Mercator (UTM). These coordinate systems can be successfully be used in the context of GMS countries.

Selecting a map projection depends on the location of area to be mapped. Virtually any map projection is acceptable while mapping a relatively small area. The choice of map projection becomes more critical while mapping larger areas. Building or storing of data in the context of GMS can be done using geographical coordinate system. For transforming geographic coordinates to other projection system, cylindrical map projections (e.g. UTM) are the appropriate systems to be used.

3.4 GIS AND DECISION SUPPORT SYSTEM

The successful operational applications of GIS require institutional setting and must support the management of resources (Fig. 3.7) or some problem solving processes. Furthermore, it must exist within an organizational setting that is capable of providing it with proper support.

The recent development of decision support system DSS brought a new concept of integrating GIS and resource models into a tightly-coupled system in that the systems more likely to be used to aid decision making. DSS are interactive programs, which integrate resource mode with other systems, which assist in decision-making process. Out of the combination of DSS and GIS emerges an entirely new system called spatial decision support system (SDSS). SDSS are new classes of computer systems that combine the technologies of GIS and DSS to aid decision makers with problems that have spatial dimension. Figure 3.8 presents the melding of GIS and DSS into SDSS. SDSS are oriented towards the decision makers and offers one unifying framework for integrating GIS and DSS including the models within the DSS, i.e., the SDSS framework offers a means to increase the utility of both GIS and DSS to assist decision makers.

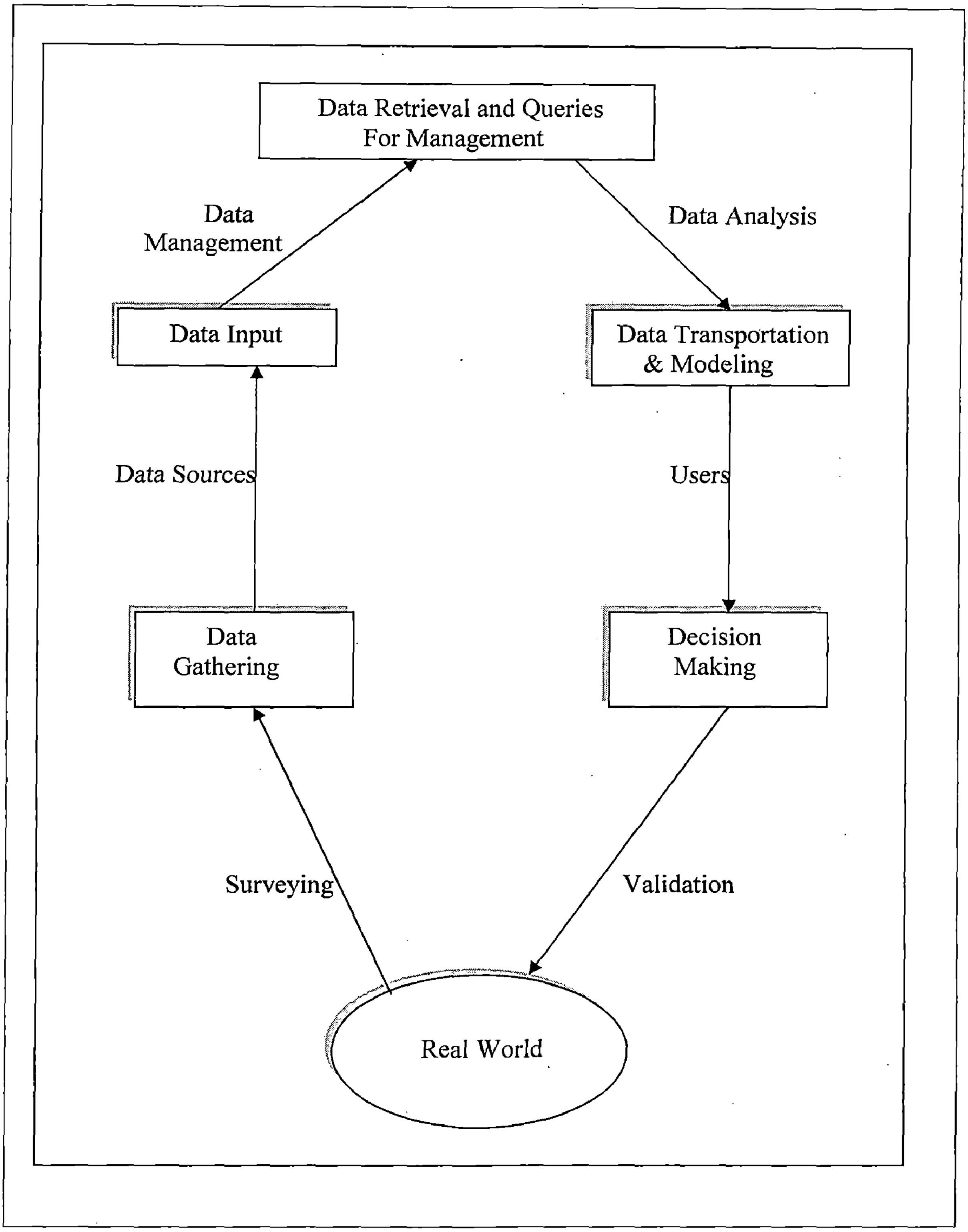


Fig. 3.7 GIS as a Management Tool (Valenzuela, 1990)

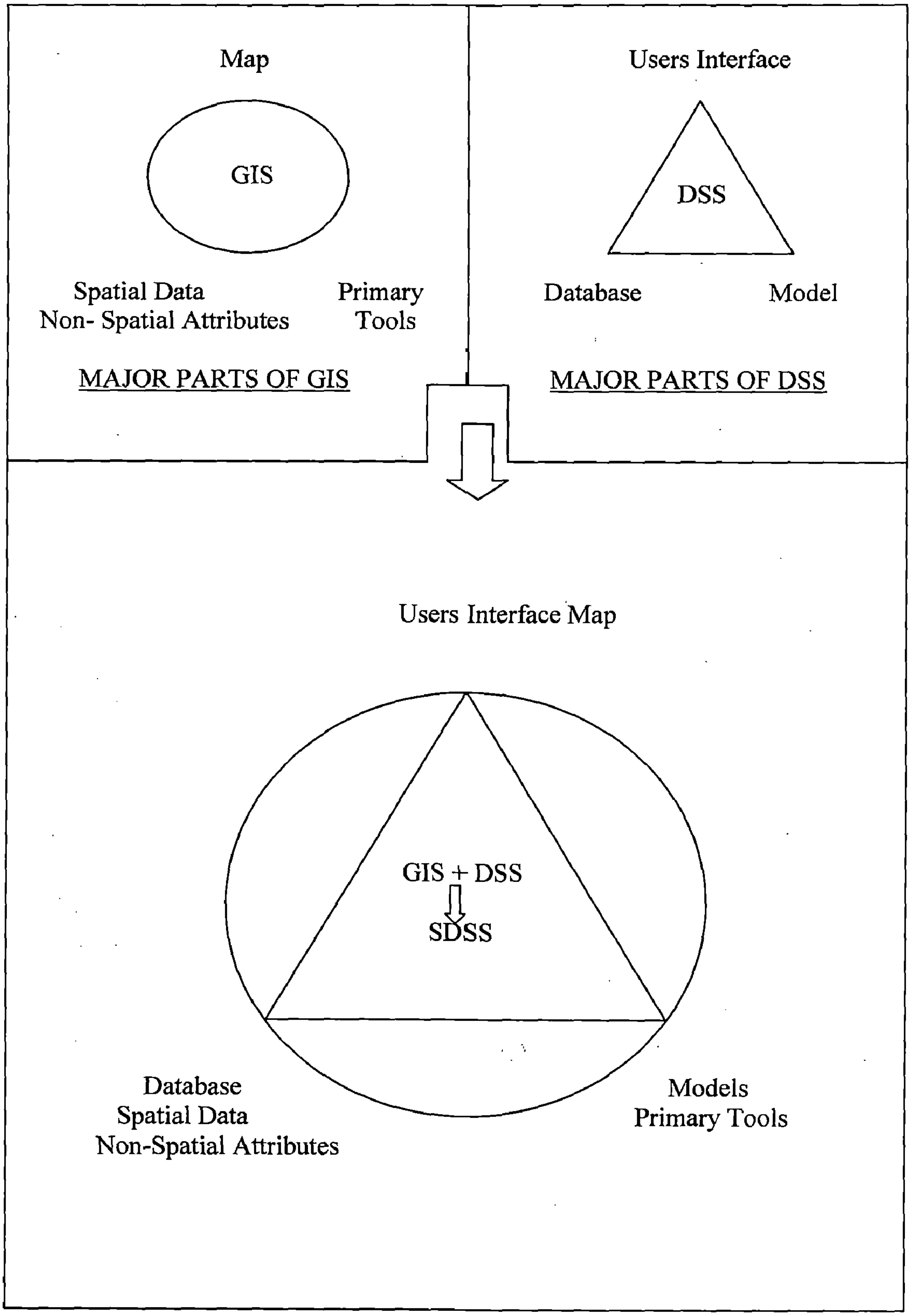


Fig. 3.8 Presentation of SDSS as Combination of GIS and DSS

SCS - CURVE NUMBER METHODOLOGY

4.1 GENERAL

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

4.2 SOIL CONSERVATION SERVICE (SCS) MODEL

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

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

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

4.2.1 Runoff Curve Number Equation

The fundamental hypotheses of the SCS - CN method are

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

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

Mathematically,

$$\frac{F}{S} = \frac{Q}{P - I_a} \qquad (4.1)$$

Where, F = actual retention = P - Q

S = potential maximum retention.

Q = runoff volume uniformly distributed over the drainage basin.

P = mean rainfall over the drainage basin.

I_a = initial abstraction.

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

In a typical case, a certain amount of rainfall, referred to as "initial abstraction", is abstracted as interception, infiltration, and surface storage before runoff begins. In the CN method the initial abstraction I_a is subtracted from rainfall P in Eq. (4.1) to yield

$$\frac{P - I_a - Q}{S} = \frac{Q}{P - I_a} \quad (4.2)$$

Solving for Q in Eq. (4.2) yields,

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \quad (4.3)$$

Which is valid for $P > I_a$, that is, after runoff begins; and Q = 0 otherwise. Equation (4.3) has two parameters i.e. S and I_a. To remove the necessity for an independent estimation of initial abstraction, a linear relationship between I_a and S was suggested by SCS (1985).

$$I_a = \lambda.S \quad (4.4)$$

Where λ = initial abstraction ratio. Equation (4.4) was justified on the basis of measurements in watersheds less than 10 acres in size (SCS, 1985). According to National Engineering Handbook - 4 50% of the data points lay within the limits $0.095 \leq \lambda \leq 0.38$. This led SCS to adopt a standard value of the initial abstraction ratio $\lambda = 0.2$. With $\lambda = 0.2$ in Eq. (4.4), then Eq. (4.3) becomes

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{4.5}$$

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

Now,

Equation (4.5) can be re arranged as

$$Q = P - S\left(1.2 - \frac{S}{(P + 0.8S)}\right) \tag{4.6}$$

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

Equation (4.6) is a form of the hydrologic budget, (an elementary expression of conservation of mass).

i.e. $Q = P - L$

in which L accounts for losses expressed as

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

These losses fall into five categories

i. Interception storage in a rural setting, by vegetation foliage, stems, by cultural features of the landscape.

ii. Surface storage in ponds, puddles and other usually small temporary storage locations.

iii. Infiltration to the subsurface to feed and replenish soil moisture, interflow, and ground-water flow.

iv. Evaporation from water bodies such as lake, reservoirs, streams, and rivers as well as from moisture on bare ground.

v. Evapotranspiration from all types of vegetation.

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

It is important to note that if P ≥ 0.2S than only runoff will occur, otherwise runoff be assumed as Zero. So the above formula (Eq. (4.5)) is valid only when P ≥ 0.2S.

4.2.2 Estimation of S

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

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

$$\text{Or,} \quad S = \frac{1000}{CN} - 10; \qquad (4.7)$$

S is in inches.

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

Substituting Eq. (4.7) into Eq. (4.5) yields,

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

Or,
$$Q = \frac{[CN(P+2) - 200]^2}{CN[CN(P-8) + 800]} \quad (4.8)$$

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

4.2.3 Determination of Curve Number

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

4.2.3.1 Soil Group Classification

The soils are classified on the basis of intake of water at the end of long duration storms occurring after prior wetting and opportunity for swelling without the protective effects of vegetation. The soil group classification is given in Table 4.1.

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

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

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

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

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

Table 4.1 Soil Group Classification

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

4.2.3.2 Hydrologic Soil Cover Complexes

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

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

The curve number has been assigned for watershed condition with AMC II and $I_a = 0.2S$. The numbers show the relative value of the complexes as direct run off. The higher the CN, the greater the amount of direct runoff to be expected from a storm.

Hydrologic condition may be poor, fair or good depending upon percentage of ground cover present.

Poor – heavily grazed land	(50% under ground cover)
Fair – moderate cover	(50% - 75% under ground cover)
Good – heavy or dense cover	(> 75% under ground cover)

4.2.3.3 Antecedent Moisture Condition (AMC)

The amount of rainfall in a period of 5 days prior to a particular storm starts, is termed as AMC. Also, it refers to the water content present in the soil at a given time. The antecedent rainfall values for AMC conditions are given in Table 4.2.

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

AMC I - Soils are dry, lowest runoff potential.

AMC II - The average condition.

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

Table 4.2 AMC for Determining the Value of CN

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

4.2.3.4 Selection of CN

The value of CN for AMC condition II and for a variety of land uses, soil treatment or farming practices can be obtained from the table of runoff curve numbers for hydrologic soil-cover complexes (after soil conservation service 1969). All the areas of a watershed do not fall under AMC II condition. A correction table for CN has been developed by SCS to convert AMC II condition to AMC I and AMC III. The correction table is shown in Table 4.3. After knowing the value of CN for required AMC, Q can be determined.

4.2.4 Assumptions of SCS-CN method

i. The basin is covered with a soil group that has uniform hydrologic characteristics throughout the basin area.

ii. Rainfall is uniform and is distributed uniformly over the basin area.

iii. All other hydrologic characteristic are uniform. Most drainage basin do not satisfy these assumptions and, as a result, the SCS-CN method over predicts by a large magnitude.

4.2.5 Limitation of SCS-CN method

i. Equation (4.5) is valid only for $P \geq 0.2S$; otherwise $Q = 0$.

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

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

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

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

The curve number values for different conditions e.g. urban area, cultivated agricultural, other agricultural, arid & semi arid are given in Tables 4.4 to 4.7.

4.2.6 Summary

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

Table 4.3 Curve Number with different AMC condition

AMC II	AMC I	AMC III
100	100	100
99	97	100
98	94	99
97	91	99
96	89	99
95	87	98
94	85	98
93	83	98
92	81	97
91	80	97
90	78	96
89	76	96
88	75	95
87	73	95
86	72	94
85	70	94
84	68	93
83	67	93
82	66	92
81	64	92
80	63	91
79	62	91
78	60	90
77	59	89
76	58	89
75	57	88
74	55	88
73	54	87
72	53	86
71	52	86
70	51	85
69	50	84
68	48	84
67	47	83
66	46	82
65	45	82

AMC II	AMC I	AMC III
64	44	81
63	43	80
62	42	79
61	41	78
60	40	78
59	39	77
58	38	76
57	37	75
56	36	75
55	35	74
54	34	73
53	33	72
52	32	71
51	31	70
50	31	70
49	30	69
48	29	68
47	28	67
46	27	66
45	26	65
44	25	64
43	25	63
42	24	62
41	23	61
40	22	60
39	21	59
38	21	58
37	20	57
36	19	56
35	18	55
34	18	54
33	17	53
32	16	52
31	16	51
30	15	50

Table 4.4 Runoff Curve Numbers for Urban Area

Cover Type and Hydrologic Condition	Average Percent Impervious Area	A	B	C	D
Open space (lawns, park, golf courses, cemeteries, etc)					
• *Poor condition (grass cover <50%)*		68	79	86	89
• Fair condition (grass cover 50% to 75%)		49	69	79	84
• Good condition (grass cover>75%)		39	61	74	80
Paved parking lots, roofs, driveways, etc (excluding right-of-way)		98	98	98	98
Streets and roads:					
• Paved: curbs and storm drains (excluding right-of-way)		98	98	98	98
• Paved: open ditches (including right-of-way)		83	89	92	93
• Gravel(including right-of-way)		76	85	89	91
• Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
• Natural desert landscaping (pervious areas only)		63	77	85	88
• Artificial desert landscaping (impervious weed barrier, desert shrub with 1-to2 inch *sand or gravel mulch and basin border*		96	96	96	96
Urban districts:					
• Commercial and business	85	89	92	94	95
• Industrial	72	81	88	91	93
Residential districts by average lot size:					
• 1/8 acre or less (town houses)	65	77	85	90	92
• ¼ acre	38	61	75	83	87
• 1/3 acre	30	57	72	81	86
• ½ acre	25	54	70	80	85
• 1 acre	20	51	68	79	84
• 2 acre	12	46	65	77	82
Developing urban areas :					
Newly graded areas (pervious area only, no vegetation)		77	86	91	94

Notes: Values are for average runoff condition, and Ia = 0.2S.
The average percent impervious area shown was used to develop the composite RCNs Other assumptions are: impervious area are directly connected to the drainage system, impervious areas have a RCN of 98, and pervious area considered equivalent to open space in good hydrologic condition

Table 4.5 Runoff Curve Numbers for Cultivated Agricultural Land[1]

Cover Type	Treatment[2]	Hydrologic Condition[3]	A	B	C	D
Fallow	Bare soil		77	86	91	94
	Crop residue	Poor	76	85	90	93
	cover (CR)	Good	74	83	88	90
Row Crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR+CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured ©	Poor	70	79	84	88
		Good	65	75	82	86
	C+CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T +CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR+CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C+CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T + CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded	SR	Poor	66	77	85	89
or broadcast		Good	58	72	81	85
Legumes or C		Poor	64	75	83	85
Rotation		Good	55	69	78	83
Meadow	C&T	Poor	63	73	80	83
		Good	51	67	76	80

Notes: [1] Values are average runoff condition, and $I_a = 0.2S$
[2] Crop residue cover applies only if residue is on at least 5 percent of the surface throughout the year
[3]Hydrologic condition is based on a combination of factors affecting infiltration and runoff: density and canopy of vegetative areas, amount of year-round cover, amount of grass or closes-seeded legumes in rotations, percent of residue cover on land surface (good>20percent), and degree of roughness.
Poor : factor impair infiltration and tend to increase runoff
Good: Factor encourage average and better infiltration and tend to decrease runoff

Table 4.6 Runoff Curve Numbers for Other Agricultural Lands

Cover Type	Hydrologic Condition	A	B	C	D
Pasture, grassland, or range-continuous forage for grazing	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow-continuous grass, protected from grazing and generally mowed for hay		30	58	71	78
Brush-brush-weed-grass mixture, with brush the major element	Poor	78	67	77	83
	Fair	35	56	70	77
	Good	30	48	65	73
Woods-grass combination (orchard or tree farm)	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30	55	70	77
Farmsteads-building, lane, driveways, and surrounding lots		59	74	82	86

Notes: Values are average runoff condition, and $I_a = 0.2S$

Pasture : Poor is <50% ground cover or heavily grazed with no mulch, Fair is 50% to 75% ground cover and not heavily grazed, and Good is>75% ground cover and lightly or only occasionally grazed

Meadow: poor is 50% ground cover, Fair is 50% to 75% ground cover, Good is>75% ground cover.

Woods/grass: RCNs shown were computed for areas with 50 percent grass (pasture) cover. Other combination of conditions may be computed from RCNs for woods and pasture.

Woods: poor is forest litter, small trees, and brush destroyed by heavy grazing or regular burning. Fair is woods grazed but not burned and with some forest litter covering the soil. Good is woods protected from grazing and with litter and brush adequately covering soil.

Table 4.7 Runoff Curve Numbers for Arid and Semi Arid Rangelands

Cover Type	Hydrologic Condition	A	B	C	D
Herbaceous-mixture of grass, weeds, and low-growing brush, with brush the minor element	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen-mountain brush Mixture of oak brush, aspen, Mountain mahogany, bitter brush, Maple, and other brush	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper- pinyon, juniper, Or both; grass undersory	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Saltbush, greasewood, creosote Bush, black brush, bursage, Palo Verde, mesquite, and cactus	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

Notes: Values are average runoff condition, and $I_a = 0.2S$
Hydrologic Condition: Poor is <30% ground cover (litter, grass, and bush over story), fair is 30% to 70% ground cover, Good is >70% ground cover.
Curve Number for Group A has been developed only for desert shrub.

CHAPTER - 5

THE STUDY AREA AND DATA ACQUISITION

5.1 GENERAL

For the present study two watershed namely Deshgaon (Distt. Khandwa) and Ozarkhed (Distt. Nashik) are considered and the location maps are given in Fig. 5.1 and Fig. 5.2 respectively. Deshgaon watershed is a part of Narmada basin while Ozarkhed is that of Damanganga basin.

5.2 DESHGAON WATERSHED

Deshgaon watershed is a part of Narmada basin. It is situated in the Khandwa (East Nimar) district of Madhya Pradesh. Khandwa District is situated south West of the state of Madhya Pradesh covers an area of 10779 sq. km. The District is in Indore Division of Madhya Pradesh. It is situated between 21°11' and 22°18' north latitude and 75°59' and 77°14' east longitude in Survey of India topo sheet nos. 46O, 55B, 55C and 55G. Maximum and minimum height above mean sea level is 905.56 m and 180.00 m respectively. The District is bounded on the east by the Betul and Hoshangabad District of Hoshangabad division, and Amaravati District of Maharashtra, on the south by the District of Jalgaon (East Khandesh) Buldhana and Amaravati of the Maharashtra State, on the west by West Nimar District of Indore division, and on the north by Dewas District of the Indore Division. Omkareshwar temple, is a major centre for pilgrimage, while Asirgarh fort, Jamir masjid, Bibi masjid constructed during medieval period are centres of tourist attraction in the district.

5.2.1 Natural Division

The District lies, for the most part, on the uplands between and valleys of the two major rivers, the Narmada and Tapti are flowing parallel to each other from east to west through the District. The Hatti hill range border and overlooks the Tapti valley in the south throughout its length in the District. The major natural divisions of the District correspond to the four distinct physiographic divisions, viz;

- The Narmada Valley
- The Tapti Valley
- The main Satpura ranges and
- The Hatti range or the southern flank of the Satpura south of river Tapti.

The general height of the contour in Khandwa is about 1,000 Ft. (304.8 m.) above means sea level but the elevations range from 618 Ft. (188.4 m.) in the bed of the Narmada in the extreme north west to 3,010 (917.5 m.) at Pipardol peak of the Hatti range.

- **Narmada Valley**

The Narmada flows through the northern part of the District, roughly in an east-west direction. Among the streams joining the Narmada within the District from the north are Khari and Kanar (Lohar). These are the only perennial streams in the tract. The hills in the Chandgarh and Selani tracts rise conspicuously from 220' to 500' (61 to 152 m.) above the adjacent plains. The general height of Selani tract is about 750' (228 m.) and that of Chandgarh is about 850' (285 m.). The north south chain of hills in Chandgarh and Selani tracts continues across the Narmada in the south.

Fig. 5.1 Location Map of Deshgaon Watershed

The conspicuous of these is sand stone hill. It occupies the elbow formed at the junction of the Chhota Tawa and the Narmada and which rise about 500' (152.4 m.) above the surrounding country. The southern tributaries of the Narmada flows towards north or north west revealing the general slope of that part of Narmada Valley, which lies within the District. The average height in the eastern part of valley is about 800' (243 m.). The plain country in the extreme west, below Mandhata, lies at a level of about 700' (213.4 m.) above Mean Sea Level.

❖ Tapti Valley

The Tapti flows in a narrow valley between two parallel ranges of the Satpura in the southern parts of the District. It stretches to about 50 miles from East-north to west-Southwest.

Drainage

The drainage of the District falls under the Narmada and the Tapti river systems. The water-parting line between the two river-systems runs along the crest of the northern rang of the Satpura. The major portion of the District, north of this line, except the low tracts of Chandgarh and Selani, drains towards the north onto the Narmada through the Chhota Tawa and Kaveri rivers and a large number of small streams. The tracts north of the Narmada slope towards the south and the rills and rivulets joining the Narmada to the south represent the drainage. The area between the northern and the southern forks of the Satpuras in the District, mostly falling in Burhanpur Tehsil, is drained by a large number of streams descending into a hollow country (syncline) occupied by the

Tapti. As the southern boundary of the District lies mainly along crest of the Hatti range, the southern slopes of the range drain into the left bank tributary of the Tapti river in the East.

5.2.2 Hydro-meteorological data

Climate

The climate of the study area is semi-arid, sub-tropical monsoon type. The District falls in the drier part of India. Average annual rainfall in the District is 980.75 mm as compared to the entire Malwa Region, which is 1267 mm. The northern part of the District receives more rainfall than the southern part. Deshgaon watershed lies in the north west part of the district. The monsoon season starts approximately by 10th June every year and extends up to early October. The rest of the year being almost rainless except for light showers which sometimes occur in the cold weather, usually towards December. Much of the precipitation is over by the mid of September. August is the wettest month during which relative humidity is as high as 87%. The days are quite humid. Extreme heat is experienced during summer, during winter the climate is cool. The average maximum temperature recorded in the month of May is 42^{O} C and average minimum recorded in the month of December as 10^{O}C. However, the summer temperature in May has touched of 48^{0} C (Year 1959), while the minimum temperature recorded in the month of December was 3.30^{0} C (Year 1936) at Khandwa observatory.

Humidity

The relative humidity is very low throughout the non-rainy season. In April the relative humidity is as low as 33.1%. In the monsoon season the maximum humidity recorded at Khandwa and Punasa observatories is above 87.5%.

The average humidity at Khandwa station in different months is given in Table 5.1.

Table 5.1 Average Humidity (in %)

Month	Morning	Evening
January	56.9	32.3
February	43.8	24.3
March	37.4	22.1
April	33.1	19.0
May	47.3	23.1
June	68.0	40.4
July	81.3	64.2
August	85.0	72.9
September	78.6	59.2
October	61.0	33.5
November	53.8	31.1
December	53.0	37.0

Wind Velocity

The study area is relatively free from storm. It has storms during hot summer of May and June, but the velocity of wind is not very high. During the month of June, the average wind speed is around 13 km per hour. The lowest wind speed is in the month of November and December, when it touches the lowest mark of about 4 km per hour. The sky in general is heavily clouded during monsoon months. It remains clear in the rest of the year.

The prevailing wind is westerly. Average wind velocity during the various months is given in Table 5.2.

Table 5.2 Wind Velocity

Month	Wind Velocity km/hr.	Month	Wind Velocity km/hr.
January	5.5	July	13.5
February	6.2	August	12.2
March	7.4	September	9.8
April	8.1	October	5.7
May	13.3	November	4.3
June	16.0	December	4.5

5.2.3 Topography

In general the topography of the study area is plain. The slope of more than 80% of the area is within 3%, which shows that area is almost flat suitable for agriculture and other social activities. Rest of the study area has rolling and undulating topography having slope percentage up to 15%.

5.2.4 Soils

The soils vary in color, texture and depth depending upon the rock and topography. The hilly area has reddish brown loamy soil. Such areas are not particularly favorable to tree growth. Such soil affords poor quality teak forest or similar type of salai forests. The flat portion has either recent alluvial deposits or black clays, useful for agriculture purposes. Forest areas have sandy loam soil. The soils of the study area have been broadly classified as Clayey Loam (Black Soil) or Regur and it falls under hydrological soil group C.

5.2.5 Geology and Minerals

The area is geologically classified into three zones i.e. Basaltic flow I, Basaltic flow II and Alluvium. The alluvium area occurs on the northern portion adjacent to the Narmada River. There are several dikes (generally running East-West) in the Northern portion. The dikes act as flow barrier.

Lead ore comprising galena and pyrite occur in the northern part of the area. The ores occurs as veins and disseminations in dolomite are chert bodies of Bijawar Group. Disseminations of fluorite reported from granitoids are of academic interest only. The Bijawar dolomite and Bagh limestone are extensively quarried for lime burning.

A few minor earthquakes are reported in the district. In recent years (1993-1994 and 1998-99) swarm type activity within magnitude range of 1.0 to 3.0 on the Richter scale occurred in and around Khandwa and Pandhana.

5.2.6 General Information

Deshgaon watershed is considered in the present study. The general hydro-meterological data of the watershed is given in the Table 5.3. Other informations are given in Table 5.4. The salient features of the study area are given below;

Deshgaon Watershed:

i.	Name of Watershed:	Deshgaon
ii.	Name of River/River basin:	Waker/ Narmada
iii.	Name of Village:	Deshgaon,Torni,Bhatalpura, Banjhar, Somla, Roshiya
iv.	Land Use:	
-	Agriculture Area:	773.34 ha.
-	Pasture:	1839.8 ha.
-	Forest/Plantation:	1386.41 ha.
-	Fallow/Rocky area:	1977.44 ha.

- Settlement: 1172.86 ha.

v. Geography

- Coordinate: $21^0 51' 58''$ N - $21^0 59' 31''$ latitude

  $76^0 06' 49''$ E - $76^0 11' 49''$ longitude

- S.O.I. Toposheet No. used: 55B, 55C, and 55C/1
- Elevation: 260 - 400m. from M.S.L.
- Land form: Mild slope.
- Average slope: 5.6%
- Soil type: Clayey Loam
- Hydrological Soil Group: C

Table 5.3 Hydrology and Climatology

Description	Rainfall	Climate			
		Temperature	Humidity	Sunshine	Wind Velocity
Yearly Average	1195mm.	25.4^0 C**	47.4%**	10.09 hr*	8.8 km/hr.**
Name of station	Deshgaon	*Bhopal data **District data			
Observation period	1993-2003			2000	

Table 5.4 Other Details

Description	Deshgaon Village	Torni Village
Population (2001)	3318	688
No. Of Household	608	138
Total Agricultural land	1015.98	200
Main Kharif crops	Cotton, soyabean,	Cotton,soyabean jawar
Main Rabi crops	Wheat, gram	wheat
Total Wells	141	48
Source of Irrigation	Wells, ponds, &Tube Wells	Wells, ponds
Rivers and canal	3	8

5.3 OZARKHED WATERSHED

Ozarkhed watershed is a part of Damanganga catchment. This watershed has been assigned code No. as 11/06/05/Dc1a by the Department of Soil Conservation and Watershed Management Pune, Maharashtra. Major portion of the watershed is situated in the Nashik district of Maharashtra state and rest of the area is in Gujrat state.

Nashik is one of the most important cities of Northern Maharashtra. Nashik is situated at a distance of 200 km from Mumbai (Bombay) and Pune. The city has become the center of attraction because of its beautiful surroundings and cool and pleasant climate. Nashik has a personality of its own due to its mythological, historical, social and cultural importance. The city, vibrant and active on the industrial, political, social and cultural fronts, has influenced the lives of many a great personalities. The river Godavari originates from Trimbakeshwar in Nashik flows through the city. Temples and ghats on the banks of Godavari have made Nashik one of the holiest places for Hindus all over the World.

Nashik District is located between 18.33 degree and 20.53 degree North latitude and between 73.16 degree and 75.16 degree East Longitude at Northwest part of the Maharashtra state, at 565 m. above mean sea level covering an area of 15530 km^2, second largest in Maharashtra after Mumbai. Jalgaon and Aurangabad districts lie to the east of Nashik. To its south lies Ahmednagar, to its west Thane district and a part of Gujarat state, Dhule district and a part of Gujarat lie to its North. There are various types of land forms in Nashik district. In the western part of the district lie the Sahyadri Mountains. Vani and Chandwad hill ranges lie in the central part, while the

Kalsubai hill range is to the south. In the hilly regions of the district, there are several peaks such as Hanuman, Salher, Mulher and Saptashringi. The two main rivers in Nashik district are the Godavari and the Girna. The Darna, Godavari, Aram, Kadwa and Mosam rivers all have their source in the hilly parts of the Sahyadris and flow eastwards. Only the river Damanganga flows westwards and the Vaitarna southwards. The District has great mythological background. Lord Rama lived in Panchvati during his vanvas. Agasti Rushi also stayed in Nashik for Tapasya.

5.3.1 Climate

Nashik has a pleasant climate, warm in summer and slightly humid during the rainy season. Igatpuri, Surgana and Peth talukas in the western part of the district receive more rainfall. The rainfall decreases as we move towards the east. Average rainfall of the District is between 2600 and 3000 mm, Most of the rainfall is received from June to September. The maximum temperature in summer is 42.5^0 C and minimum temperature in winter is less than 5.0^0 C. Relative humidity ranges from 43% to 62%. Climate of the Nashik is generally compares with that of Bangalore and Pune because of its pleasant nature. Winter is severe in the eastern parts of the district. Igatpuri, Saptashringi and Trimbakeshwar are cool even during summer.

5.3.2 Natural wealth

Nashik abounds in forest wealth. The forests lie in the western part of the district. Surgana, Kalvan, Peth, Dindori, Nashik and Igatpuri talukas have a number of forests. Teak and sissoo trees are found in large numbers in these forests. Besides these, trees and shrubs like anjan, agave and bamboo are also found here. The forests are inhabited by animals such as wolves, hyenas,

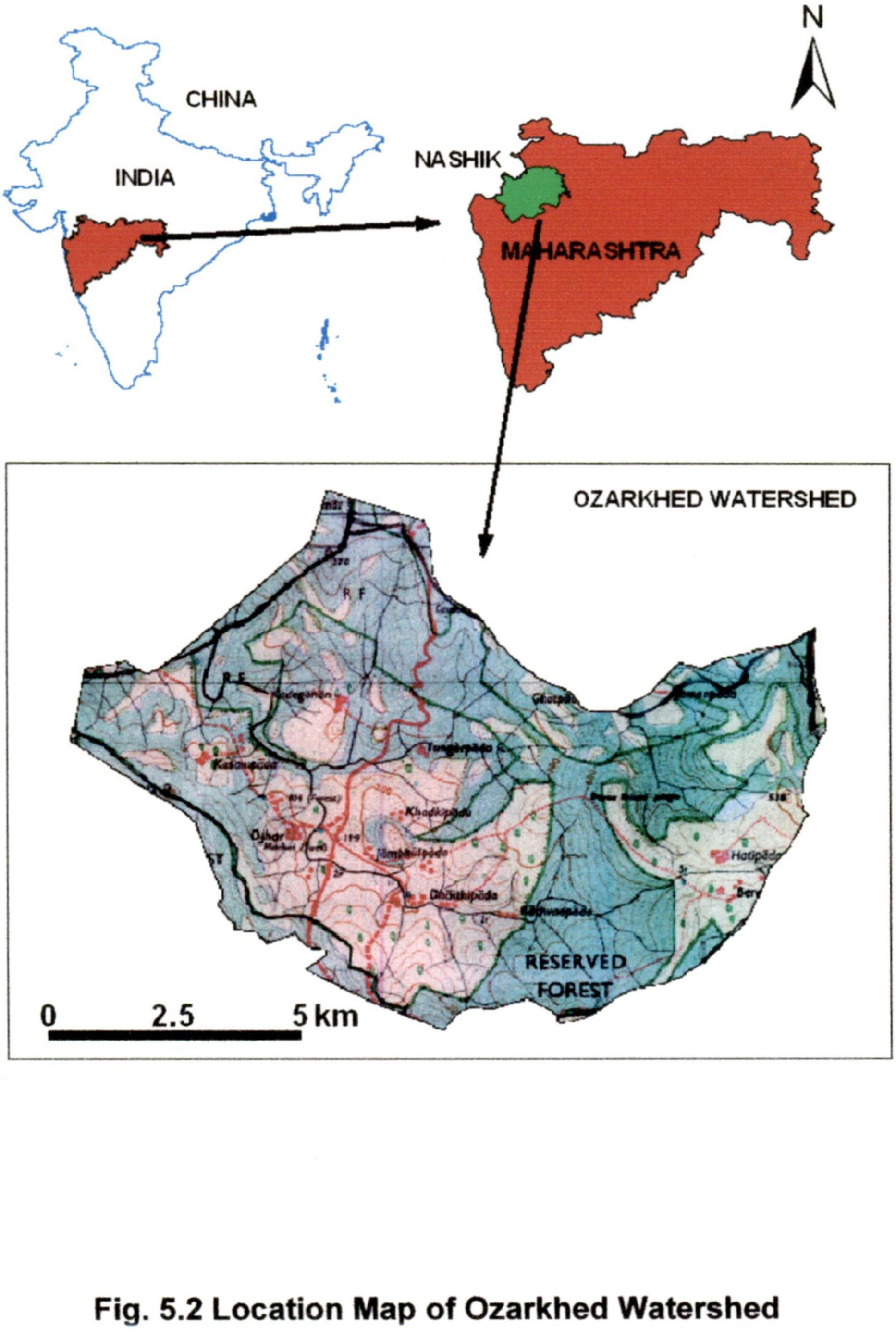


Fig. 5.2 Location Map of Ozarkhed Watershed

sambars, foxes and birds like koels, kingfishers and peacocks.

5.3.3 Soils

Soils vary in texture, color and depth depending upon the topography and land use. Agricultural are has silty loam while, forest area has clay loam. Waste and open land has sandy loam. Bajra is important crop of the District. However other crops like wheat, paddy and other cereals are also grown in various parts of the District. Paddy is mainly grown in Tribal belt i.e. Igatpuri, Peth, and Surgana Blocks. Vegetables and Onion are main cash crops for last 30 years and being exported to the other part of the country due to its best quality.

5.3.4 General Information

(a) *Ozarkhed Watershed*

i.	Name of the watershed	: Ozarkhed
ii.	Name of catchment	: Damanganga
iii.	Village covered	:Ozarkhed, Khadakohol, Berval Kadegavan
iv.	Geographical area (ha)	: 2690.00
v.	Annual average Rainfall	: 2275 mm.
vi.	Soil type	: Silty and Clay Loam.
vii.	Soil temperature	: 26.5^0 C
viii.	Slope	: Moderate to very steep
ix.	Type of erosion	: severe
x.	No. of wells	: 15
xi.	Average land holding	: 1.65ha.

(b) *Land use (Maharashtra only):*

1. Agriculture : 658ha.
2. Forest : 1478ha.
3. Waste land : 34ha.

(c) *Geographic and physical information:*

I. Longitude of watershed : 73^0 16.5' to 73^0 19' E

II. Latitude of watershed : 20^0 2.7' to 20^0 6' N

III. Temperature

a) Summer season

- Max. 36^0 C
- Min 29^0 C

b) Winter season

- Max. 24^0 C
- Min 14^0 C

c) Rainy season

- Max. 27^0 C
- Min 22^0 C

IV. Potential evapotranspiration (mm/hr.)

a) Summer 0.31 mm/hr

b) Winter 0.20 mm/hr

c) Rainy 0.29mm/hr.

V. Slope of watershed

Slope (%)	Area (ha)
0 – 3%	174
3 – 8%	369

8 – 25%	1381
> 25%	246

(d) *Socio –Economic Parameters:*

i.	Population	: 5426
ii.	No. of household	: 425
iii.	Animal population	: 2904
iv.	Type of crop	: Paddy, finger millet, vegetable

CHAPTER - 6

APPLICATION OF GIS IN RUNOFF MODELLING

6.1 GENERAL

To assess storm runoff from watershed under consideration GIS based SCS rainfall runoff empirical equation model are used.

All the parameters of SCS runoff empirical methods are geographic in character, so that they can be referenced to a particular location. Rainfall distribution, land use and land cover, soil type and information on conservation practices are often available in the form of maps or can be mapped through collection of data from possible sources or field investigation or/ and remote sensing studies. Due to the geographic nature of these parameters, SCS runoff models can be easily be modeled into GIS.

6.2 SOFTWARE USED

The softwares used in this study are ERDAS 8.6 (Earth Resource and Data Analysis System) and Arc GIS 8.3 developed by ESRI (Environmental Systems Research Institute). ERDAS and Arc GIS software provides users with state of art of data gathering, data input, data storage, data manipulation and analysis and data output capabilities, merging, overlaying, intersection, modelling and integrating conventional GIS procedures with image processing capability and a relational database. ERDAS software is good for image processing and analyzing while Arc GIS is good for vector graphics data.

6.3 METHODOLOGY

The methodology followed in this study was preparation of base map involving map acquisition, conversion into digital form, creating Digital Elevation

Model (DEM) from contour map, preparing slope and aspect map from DEM, polygonizing polygon map, and overlaying operation. From the map prepared modeling of rainfall runoff in watershed was done. The flow chart presented in Fig. 6.1 illustrates the complete methodology used for rainfall-runoff modelling.

6.3.1 Scanning and Importing

In developing SCS runoff model database the very first step is to scan the original source (hard copy) map. For this purpose survey of India topo sheet no. 55B, 55C, 55C/1 were scanned in TIF (tag image file) format and the same were imported in *img (imagery) format by using import command in ERDAS 8.6 software.

6.3.2 Georeferencing (Registration)

It is the technique of coordinate's transformation. A coordinate system define the possible XY-coordinate or lat/long coordinates that can be used in maps and thus stores information on the kind of coordinates which may have information on the map's projection, ellipsoid and datum.

The procedure involves the selection of distinguishable ground control points (GCP's) in the image, such as road intersections. These points are then assigned the appropriate coordinates. This reference data have been obtained from available topo sheet of that area, which are initially georefrenced using ERDAS imagery 8.6 software. After a certain number of GCP's (ground control points) have been entered and referenced, the computer program resamples the original pixels into the desired projection. The importance of rectification is that the image can now be used in conjunction with other data sets. For example, the rectified image could be opened in a GIS program such as

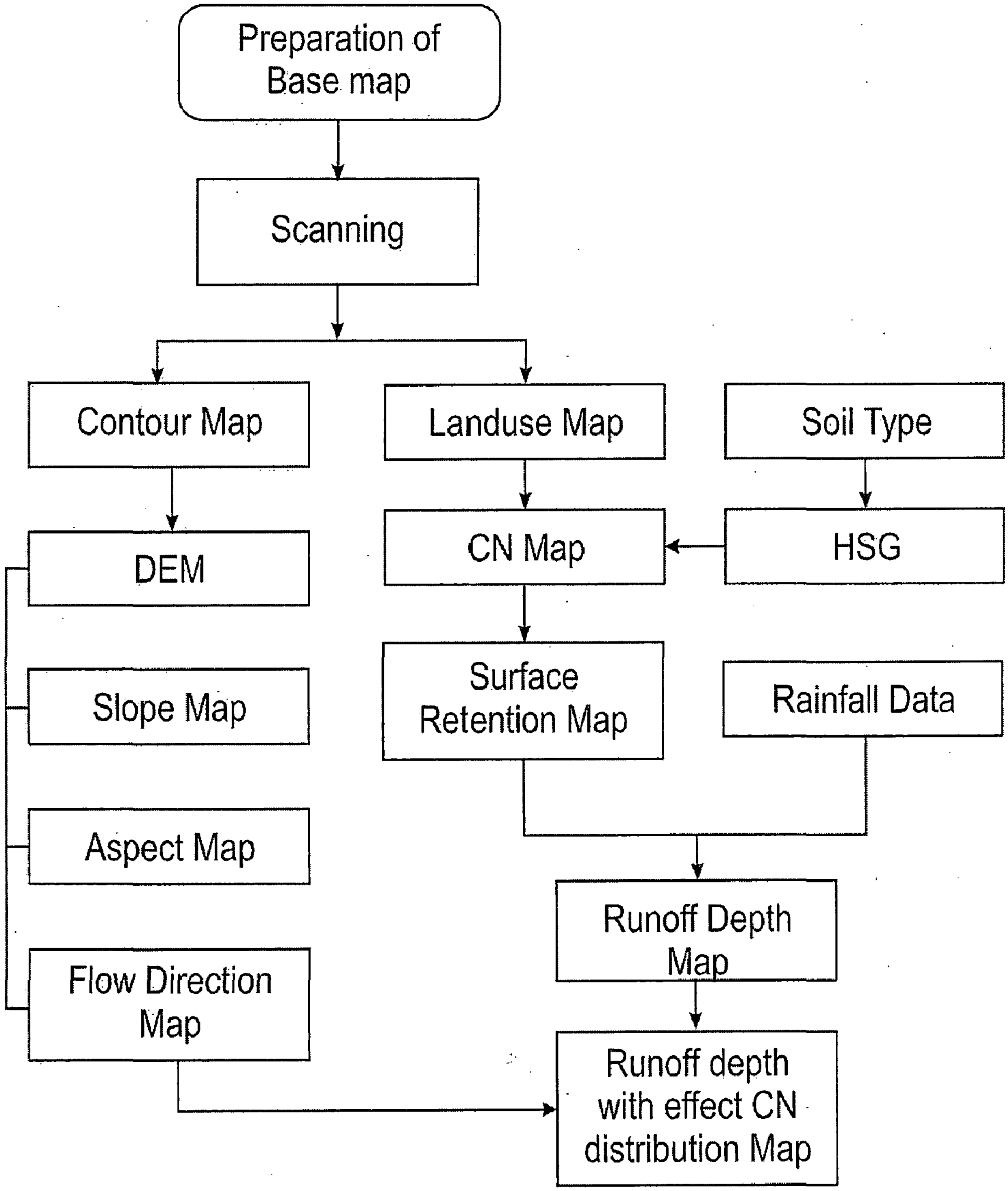


Fig. 6.1 Flow Chart of the Methodology used for this Study

ArcGIS. Since the image is now in a certain map projection, it should line up perfectly with other projected layers of data, such as political boundaries, land use, road networks, drainage systems, etc.

6.3.3 Digitization

Digitization means acquiring, connecting, storing and providing information in a computer format that is standardized, organized and available on demand from common system. For creating GIS data, the first step is to enter map into digital format. The digitizing procedure is used to transform data from map (analogue) into a computer compatible form (digital). For this work, "On-Screen" (heads-up) method of digitization and Arc GIS software was used. On screen digitizing involves bringing a scanned map into the GIS software and tracing the features using a mouse. The first step in on-screen digitizing is to create new shape files or geodatabase feature classes to store the map feature one wants to trace. Following layers were created by digitizing to create the spatial vector layers required for analysis under GIS techniques. The details of these layers (maps) are given in Table 6.1. Contour and drainage maps for Deshgaon and Ozarkhed watershed were prepared by using GIS and are presented in Figs. 6.2 and 6.3 respectively.

Table 6.1 List of Input Database created during Study

Sl. No.	Name of Layer	Format Layer	Source	File type	Software used
1.	Contours	Polyline	Toposheet	.shp file	Arc GIS 8.3, ERDAS 8.6
2.	Boundary	Polygon	Toposheet	.shp file	Arc GIS 8.3, ERDAS 8.6
3.	Stream	Polyline	Toposheet	.shp file	Arc GIS 8.3, ERDAS 8.6
4.	Soil map	Polygon	Toposheet	.shp file	Arc GIS 8.3, ERDAS 8.6
5.	Land use map	Polygon	Satellite Imagery	.shp file	Arc GIS 8.3, ERDAS 8.6

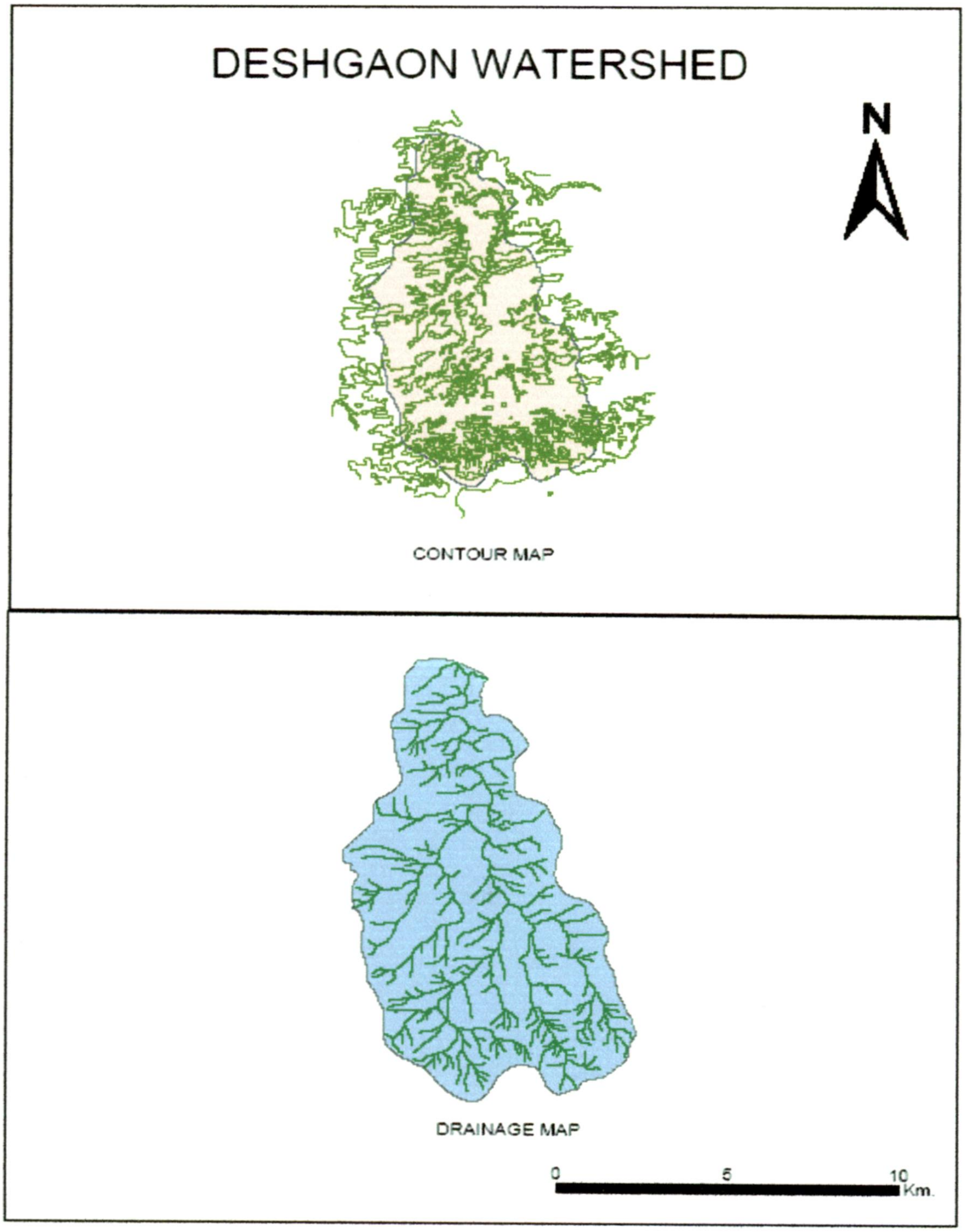


Fig. 6.2 Contours and Drainage Map of Deshgaon Watershed

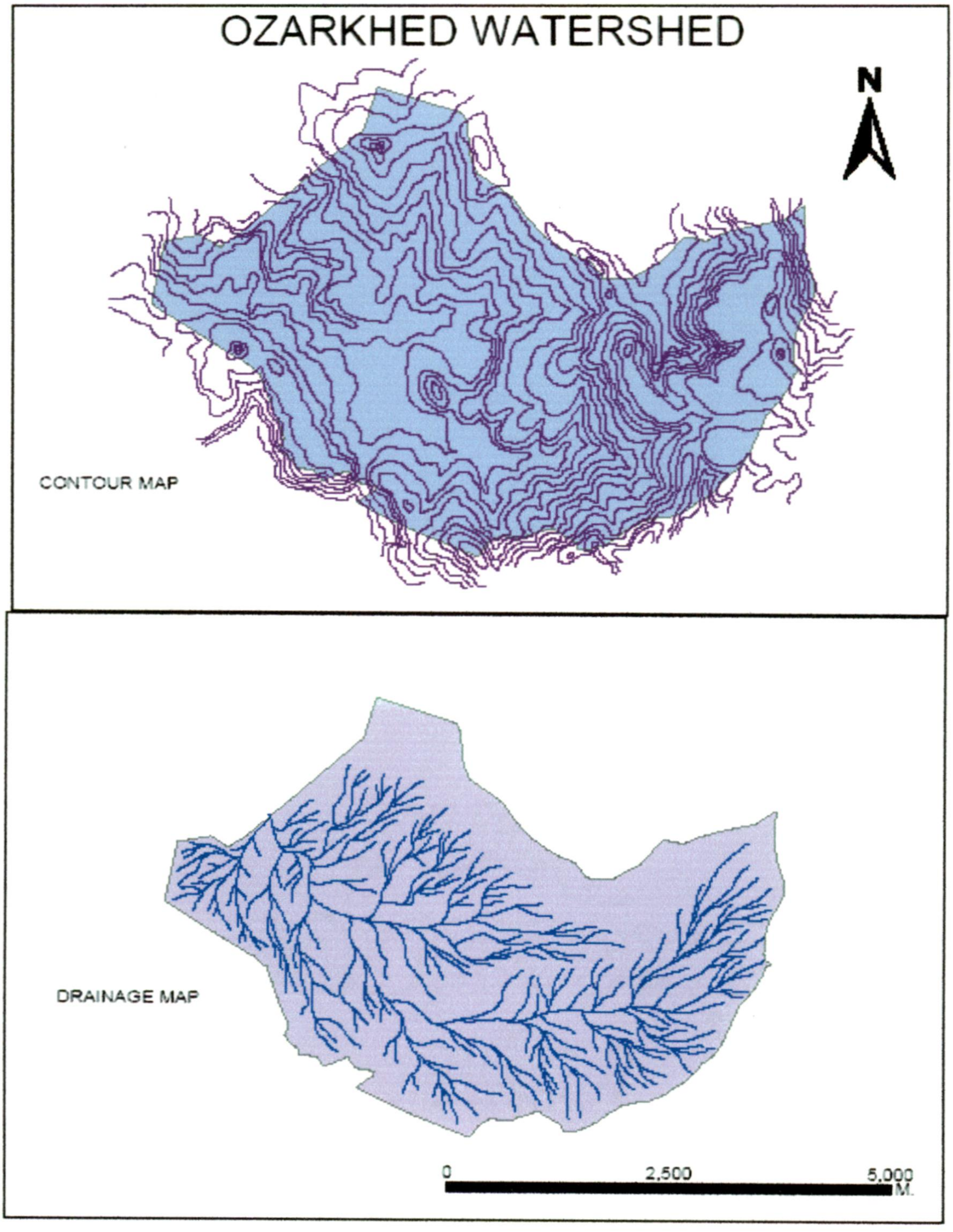


FIG. 6.3 Contours and Drainage Map of Ozarkhed Watershed

6.3.4 Error involved in Digitization

The most important errors that may occur during digitization are dead end segment, the segment being not connected to another segment, intersection without node, segment overlays another segment without node, same segment is digitized twice, self overlap etc. But, in Arc GIS the above error can be easily controlled. For e.g. two segments can be joined by using snapping command of Editor Tool bar in Arc GIS.

6.3.5 Vector to Raster Conversion (Rasterization)

Most of the analysis and overlay operation are easily and efficiently done in raster model and therefore, all maps in vector structure were converted into raster structure (Rasterization) using Arc GIS software. Boundary, Soil, and land use maps which were already in polygon form were rasterized through polygon to raster mode.

6.3.6 Digital Elevation Model

Digital elevation model (DEM) refers to any digital representation of a topographic surface. However, most often it is used to refer specifically to a raster or regular grid of spot heights. The best resolution available is 30m with a vertical resolution of 1m.

Following are the uses of DEM

- Determining attributes of terrain, such as elevation at any point, slope and aspect.
- Finding features on the terrain, such as drainage basins and watersheds, drainage networks and channels, peaks and pits and other landforms.
- Modelling of hydrologic functions.

DEM was created in Arc Scene by using the digitized contour layer of the watershed. After creation of DEM Slope and Aspect map of the watershed were prepared in Arc scene of Arc GIS 8.3 software. The DEM, slope map and aspect map for Deshgaon and Ozarkhed watersheds are presented in Figs. 6.4 to 6.6 and Fig. 6.7 to 6.9 respectively.

6.3.7 Land Use Classification

Land use/land cover map was prepared using IRS (LISS-III DATA) imageries having resolution of 23.5m. Unsupervised classification was done using ERDAS 8.6 software. Five different classes of land use were generated namely: agriculture land, pasture, forest, fallow and settlement for Deshgaon watershed, and three classes for the Ozarkhed watershed. These layers of land use were in raster form and therefore the same were converted into vector using ERDAS 8.6 software. Clean and build operation were done to obtained Area and Perimeter of the different classes which are given in Table 6.2. The land use maps for both the watersheds i.e. Deshgaon and Ozarkhed are given in Fig. 6.10 and 6.11 respectively.

Table 6.2 Land Use Class

Sl.No.	Class Name	Area(ha)	Perimeter (m.)
1.	Agriculture	775.10	292604
2.	Forest	1402.91	791388
3.	Pasture	1851.56	1283204
4.	Rocky land	1987.57	1198652
5.	Settlement	1182.05	528164

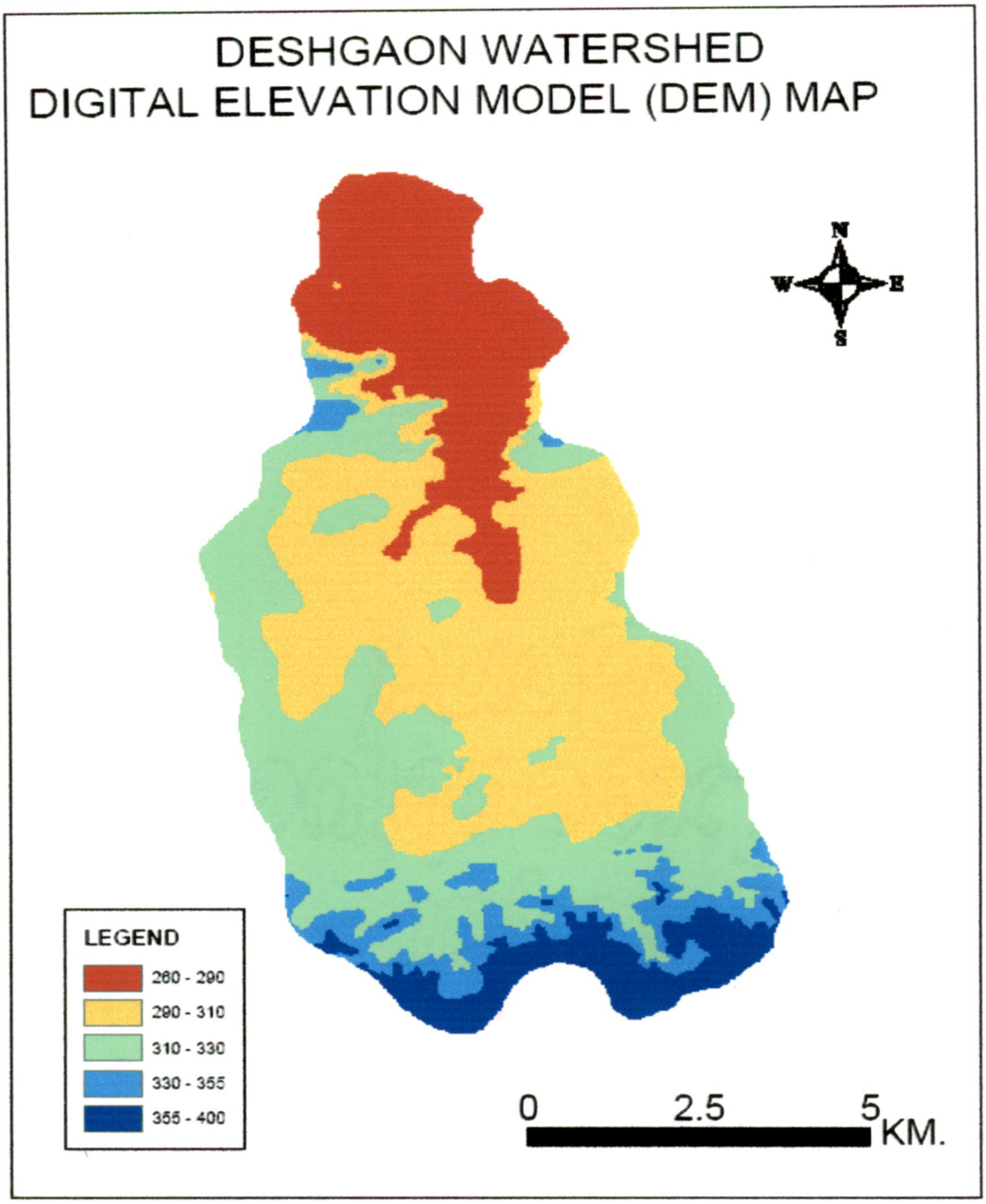


Fig. 6.4 Digital Elevation Model (DEM) of Deshgaon Watershed

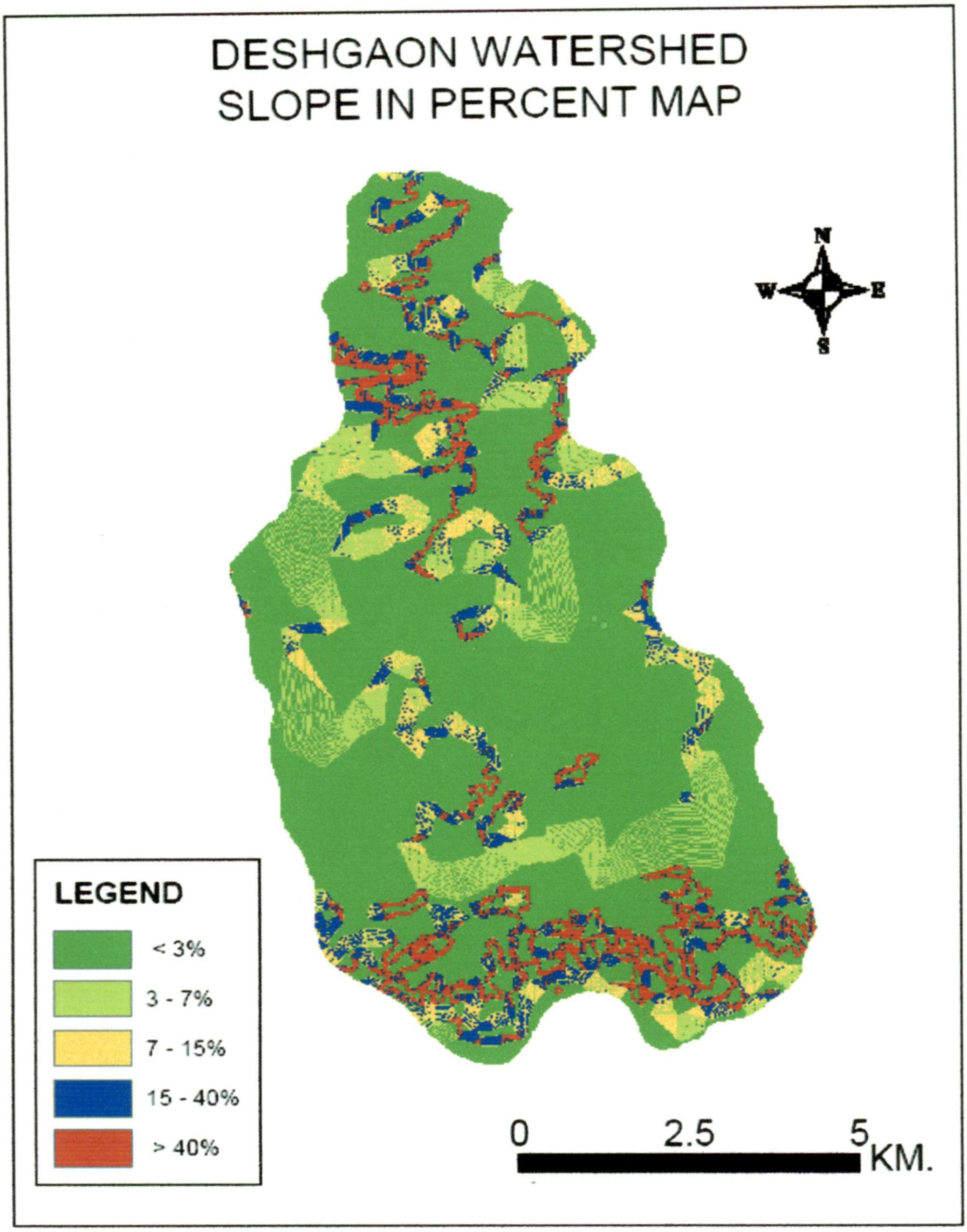


Fig. 6.5 Slope Map of Deshgaon Watershed

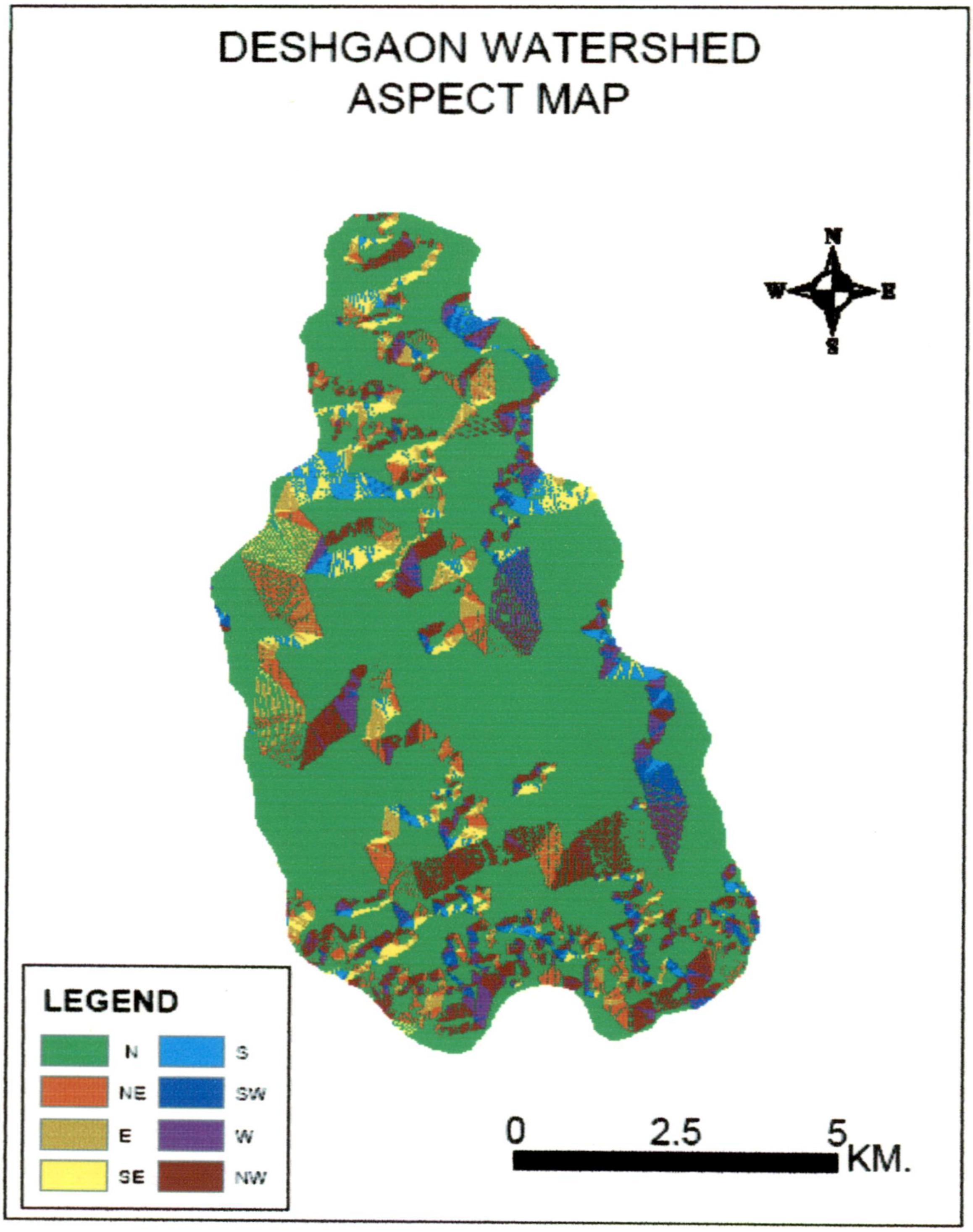


Fig. 6.6 Aspect Map of Deshgaon Watershed

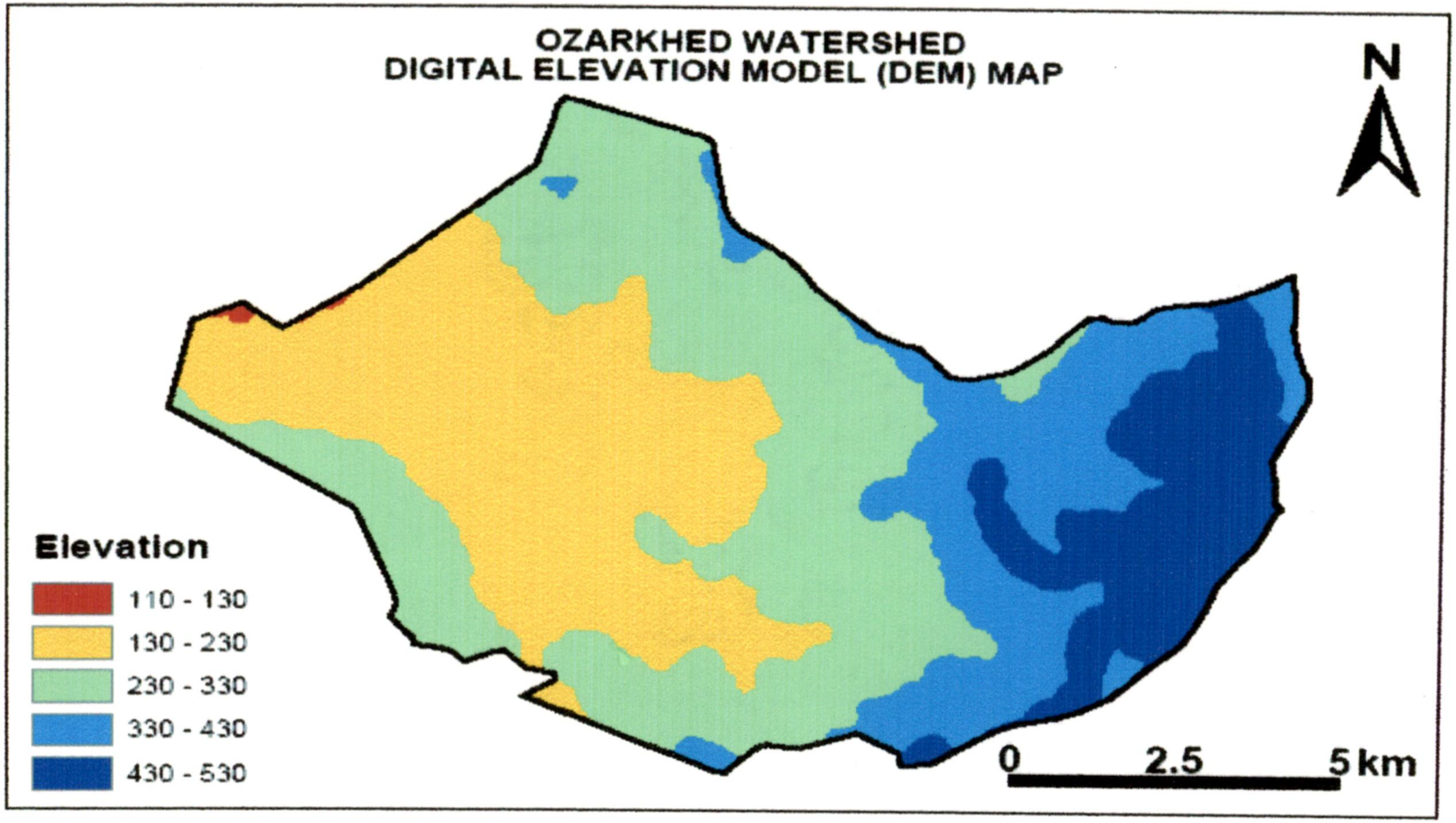


Fig. 6.7 Digital Elevation Model (DEM) of Ozarkhed Watershed

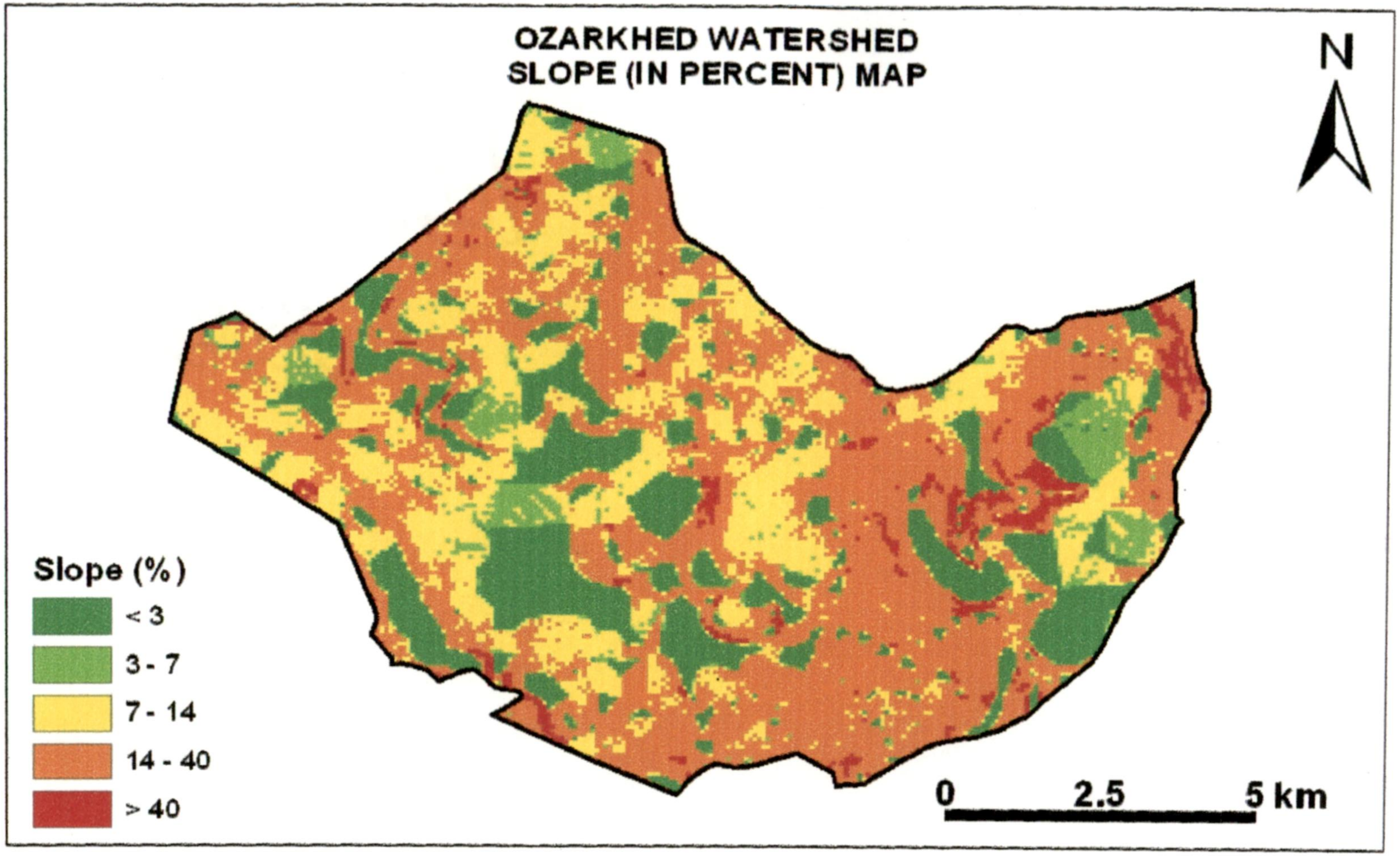


Figure 6.8 Slope Map of Ozarkhed Watershed

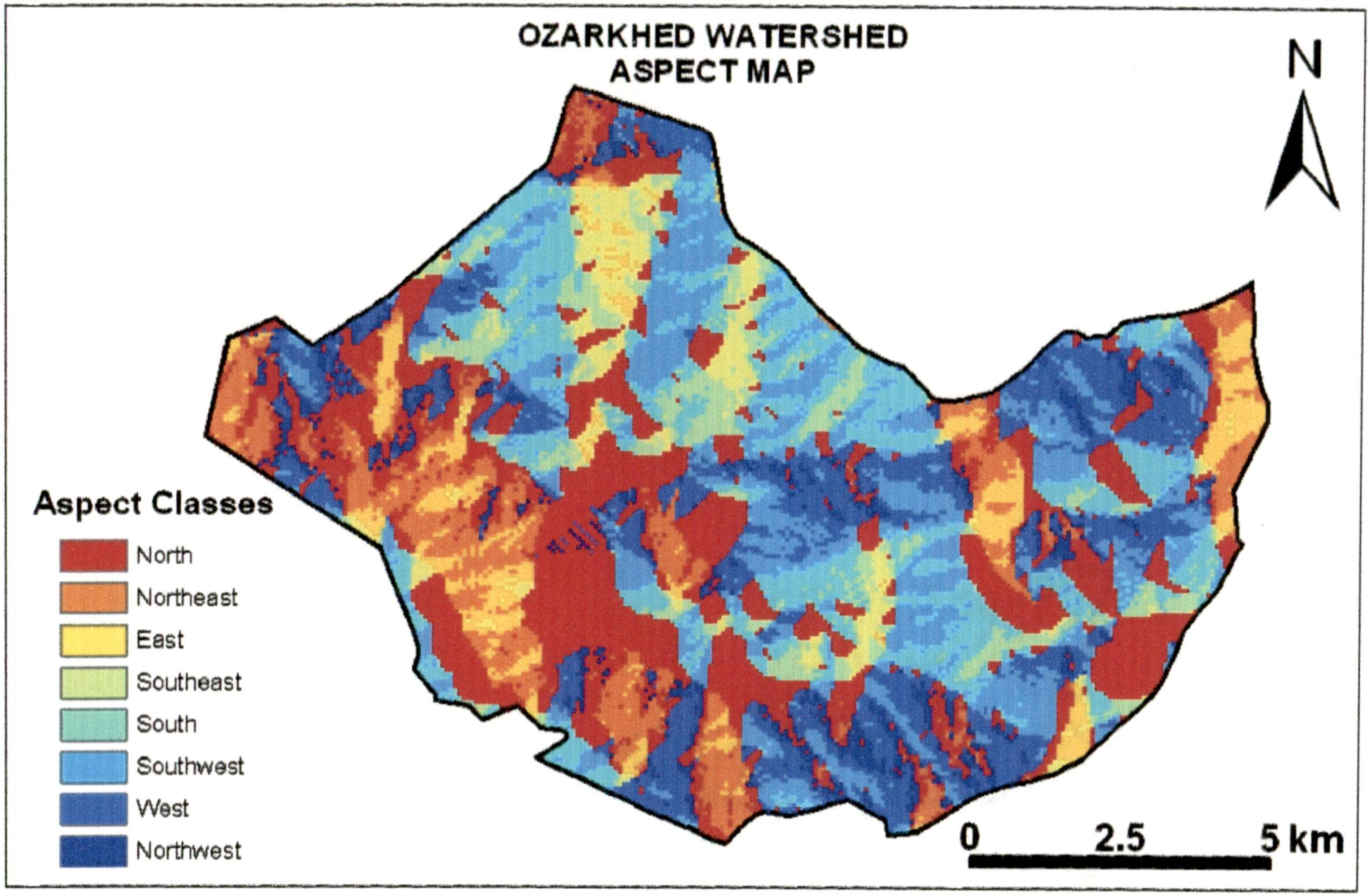


Figure 6.9 Aspect Map of Ozarkhed Watershed

6.3.8 Generation of Curve Number Map

Soil and land use map were intersected in command tools of Arc GIS. The areas of different land use class and soil combinations were obtained in the attributes selection menu by using logical expression and accordingly different CN (curve-Number) values were assigned. Table 6.3 shows the different Hydrological Soil Group (HSG) and accordingly the Curve Number (CN) of different land use classes of the watershed. Curve Number maps of Deshgaon and Ozarkhed watersheds are presented in Figs. 6.12 and 6.13 respectively.

Table 6.3 Hydrological Soil Group and CN in the Study Area

Sl. No.	Land Use	Hydrological Soil Group	Curve Number(CN)
1.	Agriculture	Poor	84
2.	Forest	Good	62
3.	Pasture	Fair	79
4.	Rocky/Fallow land	Fair	94
5.	Settlements	Good	82

6.3.9 Generation of Corrected CN Map

The above CN values are based on AMC II condition. All the areas and the storm events are not under this condition. Therefore correction has been made to give curve number as per the three AMC conditions prevailed in the watershed. CN values for AMC I and AMC III with respect to average AMC II were entered into the attributes of the intersected layer by adding field command in Arc GIS. For values of corrected CN, Table 4.1 is referred and corrected CN values are given in Table 6.4.

Table 6.4 Corrected Curve Number

CN with AMC II	CN with AMC I	CN with AMC III
84	68	93
62	42	79
79	62	91
94	85	98
82	66	92

6.3.10 Generation of "S" Map

Maximum potential retention (S) in mm is given by the equation

$$S = \frac{25400}{CN} - 254 \qquad (6.1)$$

Taking corrected CN (as per the different AMC conditions) as input, "S" map was generated using spatial analyst command in Arc GIS. S maps are shown in the Fig. 6.14 and 6.15.

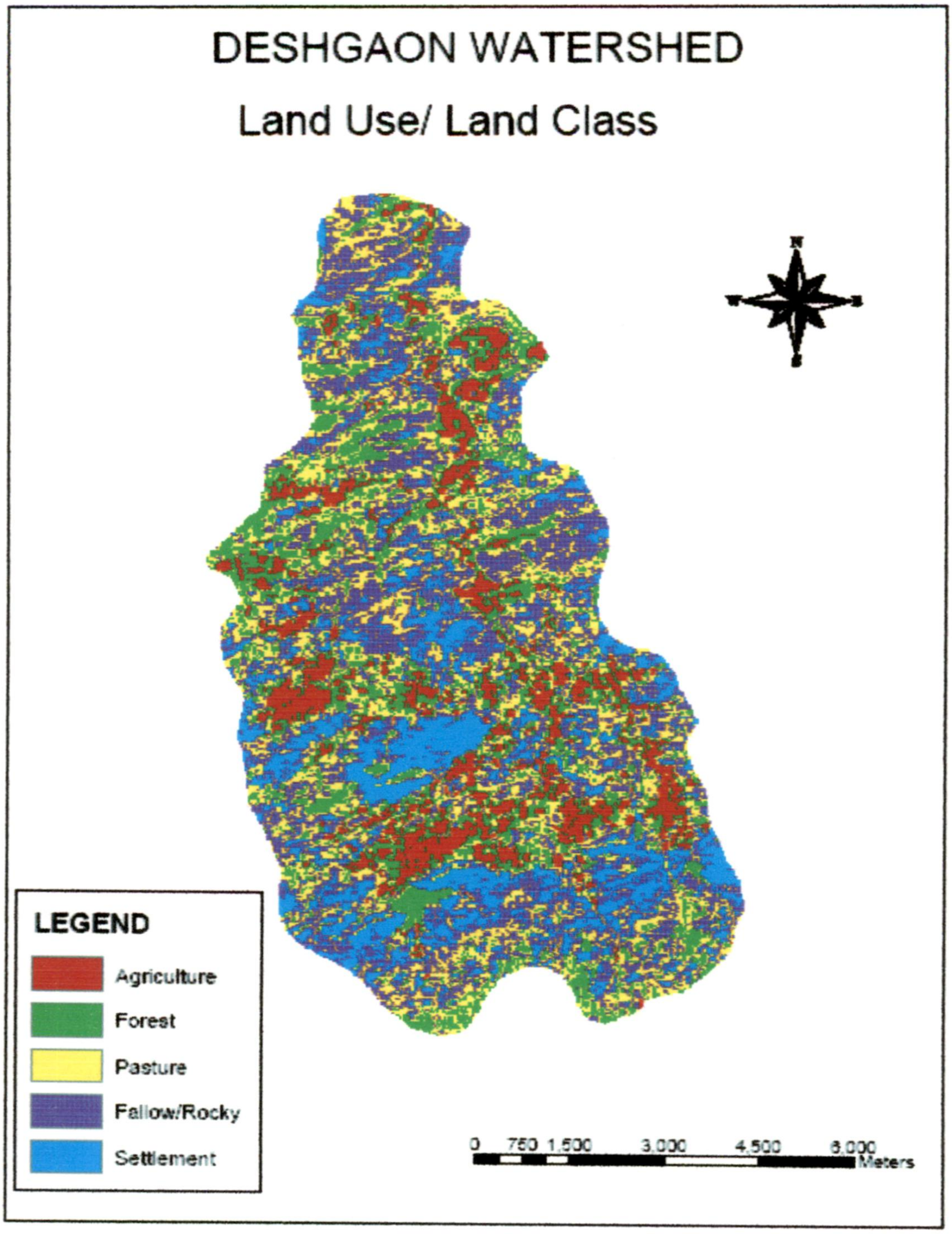


Fig. 6.10 Land Use Map of Deshgaon Watershed

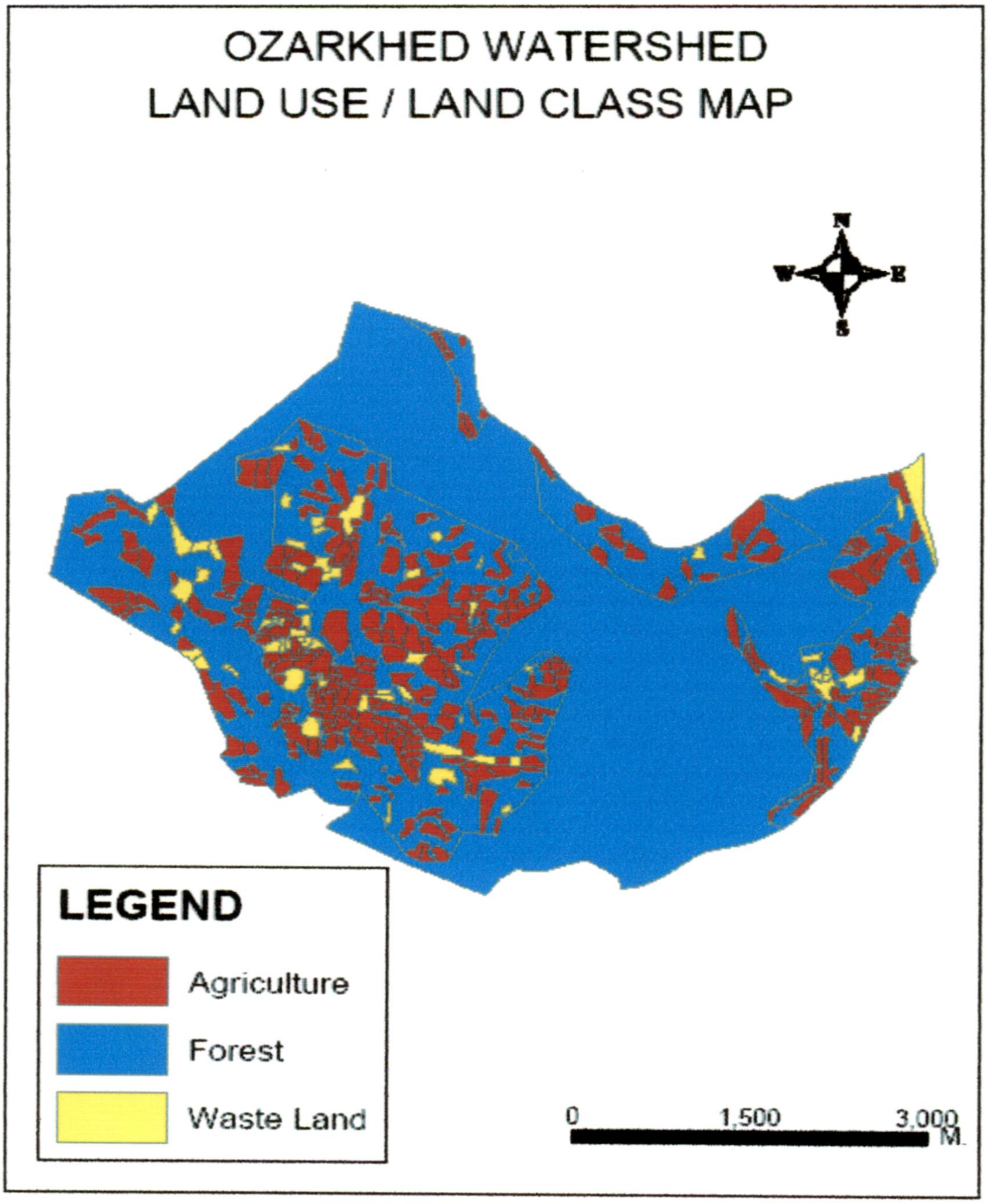


Fig. 6.11 Land Use Map of Ozarkhed Watershed

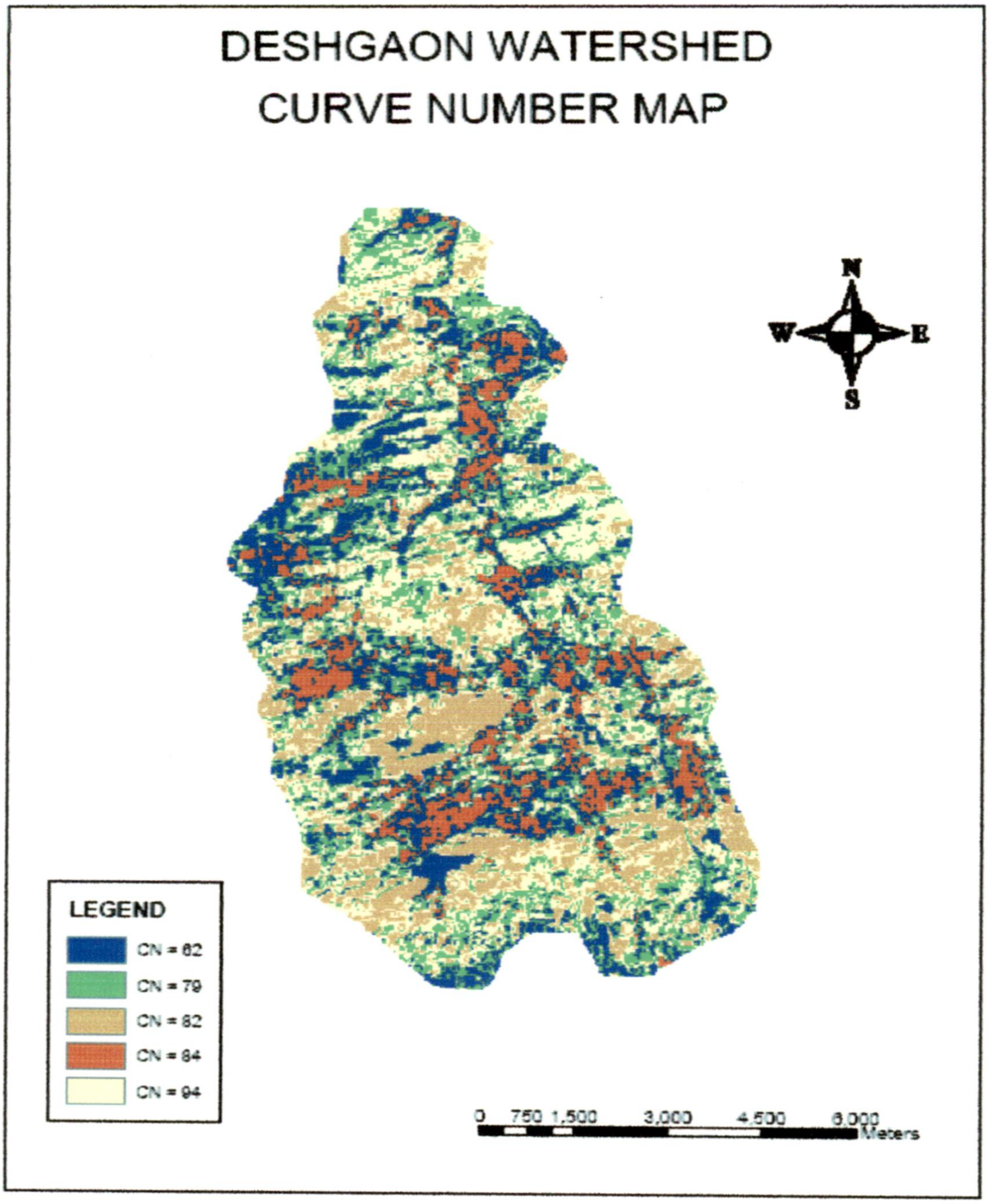


Fig. 6.12 Curve Number (CN) Map of Deshgaon Watershed

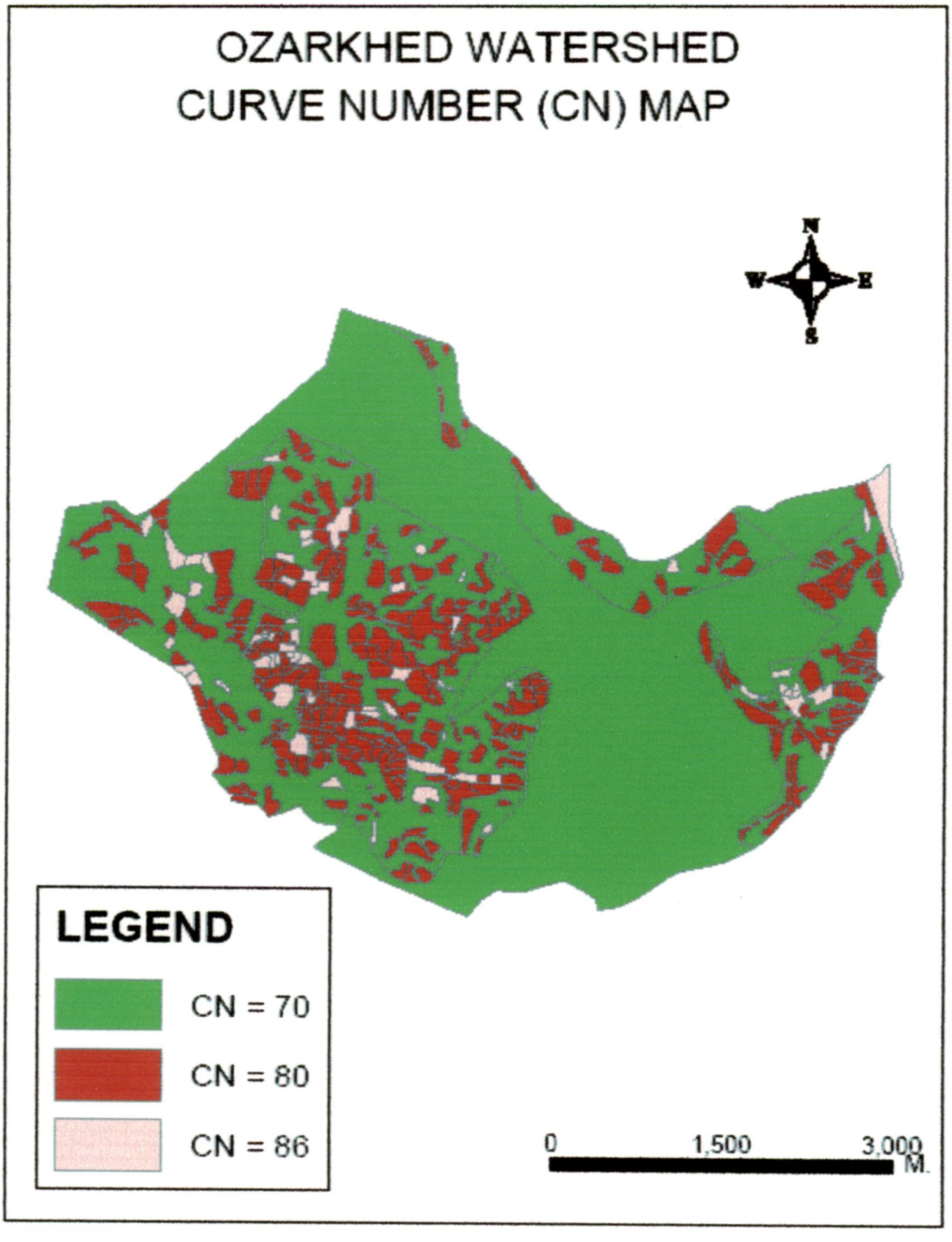


Fig. 6.13 Curve Number (CN) Map of Ozarkhed Watershed

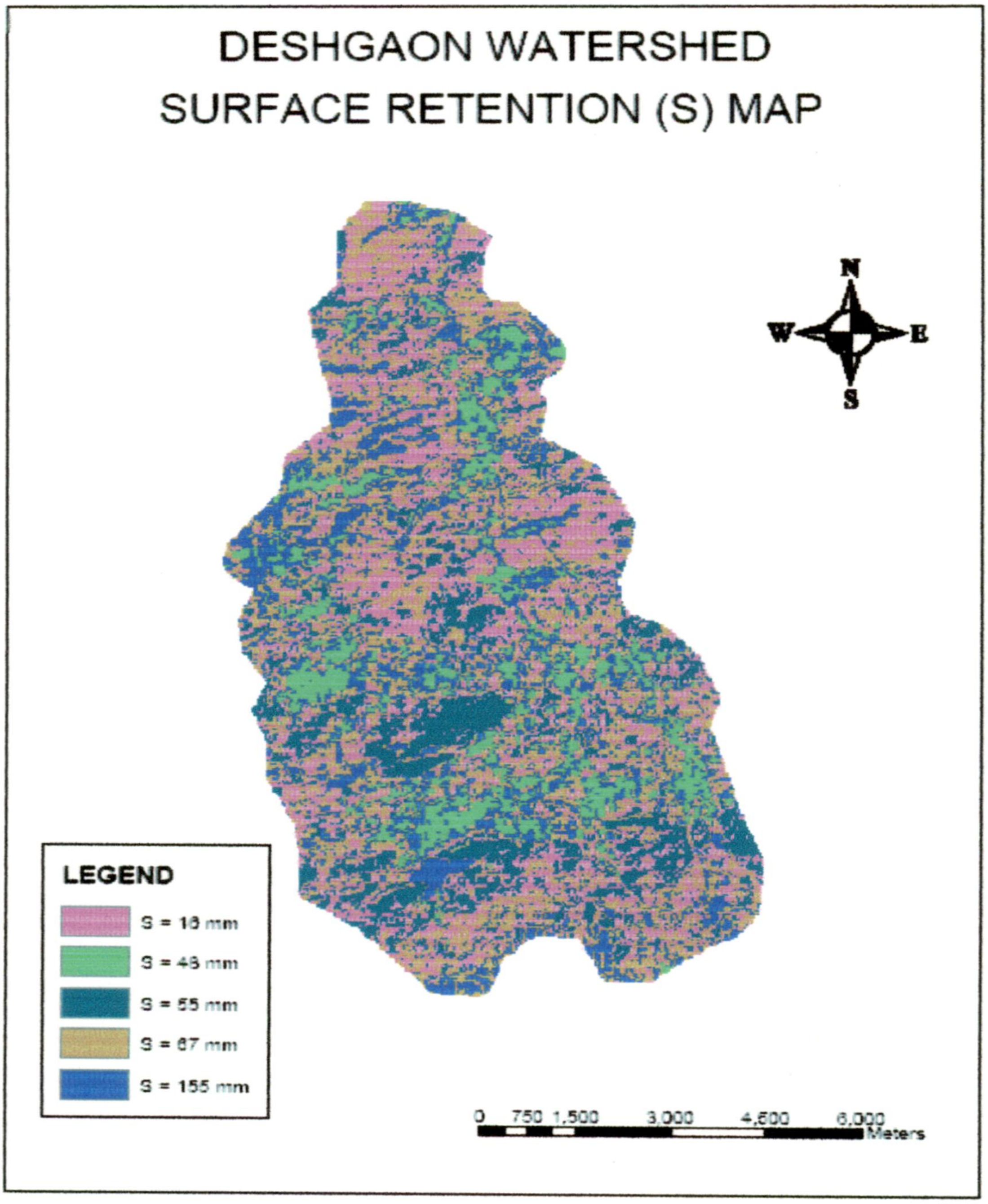


Fig. 6.14 Surface Retention (S) Map of Deshgaon Watershed

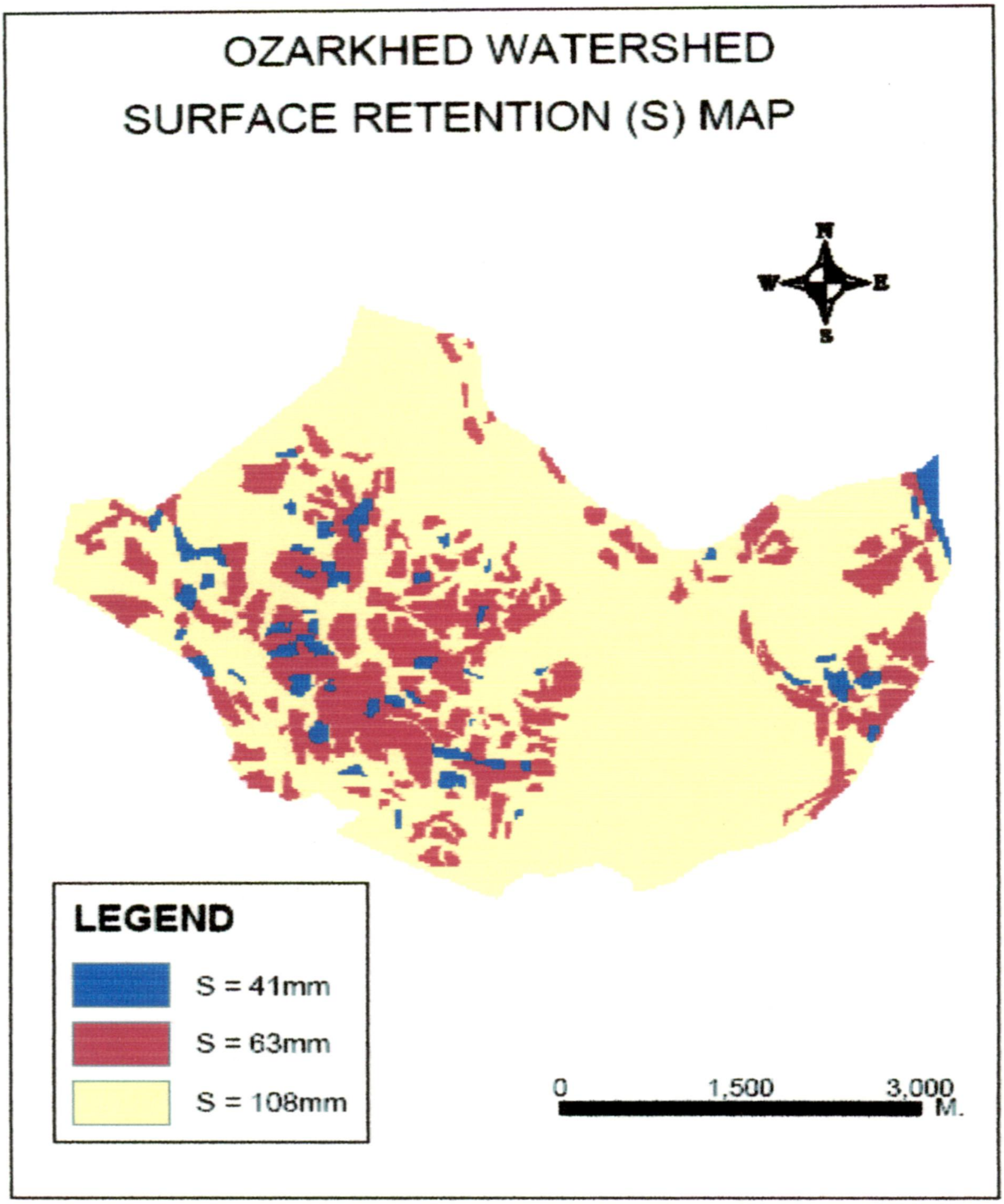


Fig. 6.15 Surface Retention (S) Map of Ozarkhed Watershed

6.3.11 Generation of Runoff maps

Daily rainfall (in mm) was entered in the attributes of intersected layers of land use and soil map. Separate fields are created for 22 different storms selected for the runoff calculation in the year 2003 and 2004 for the Deshgaon watershed and 24 storms selected in the year 2002 and 2003 for the Ozarkhed watershed. It is assumed that no runoff will produce if rainfall is less than 0.2S. Also, if S value is zero then rainfall equals runoff; otherwise runoff is determined by the equation

$$Q = \frac{(P - 0.2 * S)^2}{(P + 0.8 * S)} \tag{6.2}$$

Using the same model by editing only the rainfall day runoff produced on different days is calculated and the same are presented in subsequent chapter.

CHAPTER - 7

RESULTS AND DISCUSSION

7.1 GENERAL

In the previous chapter SCS rainfall - runoff equation was used to assess runoff from Deshgaon and Ozarkhed watershed. Considering the existing land use plan, the runoff capabilities of the watersheds were assessed by applying GIS methodology. The estimated runoff of Ozarkhed watershed is compared with the observed runoff given in the Watershed Project Report prepared by Department of Soil Conservation and Watershed Management, Pune (Maharashtra).

7.2 RUNOFF USING GIS FOR DESHGAON WATERSHED

Results obtained by GIS are in the form of maps or tabular form (attributes of the map). The various input maps such as land use, soil type, curve number, S value etc. map which has been used to get the runoff maps as given in the previous chapter. Rainfall received in the watershed during various periods i.e. for 2003 and 2004 are given in Table 7.1 and 7.2 along with the different AMC conditions.

Runoff maps obtained from the daily rainfall storm received for Deshgaon watershed are given in the Fig. 7.1 to 7.3. The maps are self explanatory and properly classified as per the runoff depth classes in the particular colour coded areas. The runoff depth and volume generated from each class of areas has been given in Table 7.3 to 7.23.

Table 7.1 AMC and Rainfall data for events in the year 2003

Date	Rainfall(mm)	Last 5 days Rainfall	AMC condition
20-6-2003	25.8	50	II
21-6-2003	35.0	75.8	III
22-6-2003	70.0	60.8	III
25-7-2003	20.32	38.1	II
27-7-2003	55.08	65.46	III
22-8-2003	40.00	0	I
23-8-2003	100.00	40	II
24-8-2003	5.00	140	III
24-9-2003	73.66	0.76	I

Table 7.2 AMC and Rainfall data for events in the year 2004

Date	Rainfall(mm)	Last 5 days Rainfall	AMC condition
12-6-2004	12.7	49.48	II
13-6-2004	29.1	51.78	II
18-7-2004	74.8	0	I
24-7-2004	18.0	0.2	I
25-7-2004	150.6	18.0	I
4-8-2004	80.0	30.0	I
5-8-2004	42.0	80.0	III
6-8-2004	12.5	122.0	III
7-8-2004	7.0	134.5	III
11-8-2004	50.0	24.5	I
12-8-2004	40.0	50.0	II
19-8-2004	64.0	0.0	I
21-8-2004	50.0	64.0	II

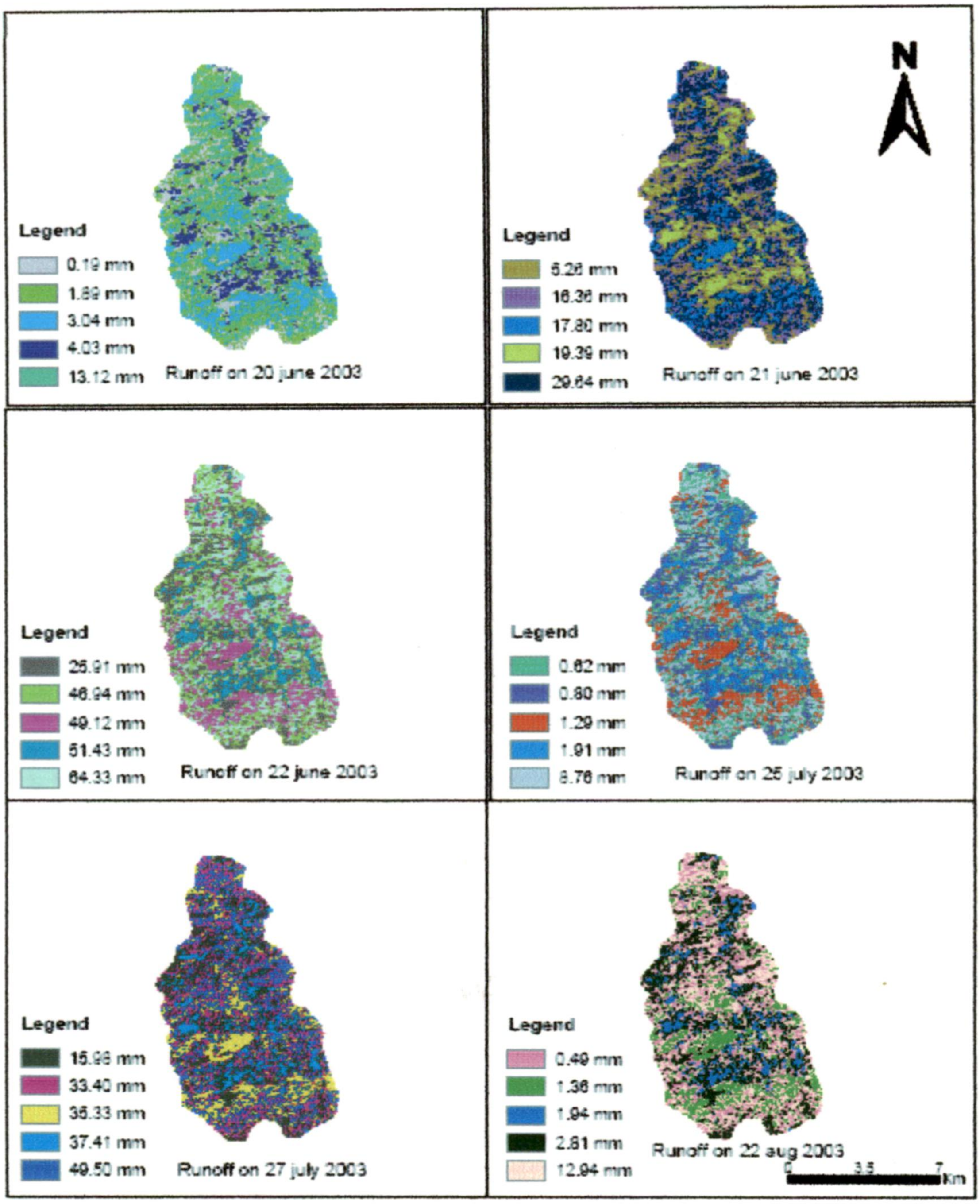


Fig. 7.1 Runoff maps of Deshgaon Watershed (Year 2003)

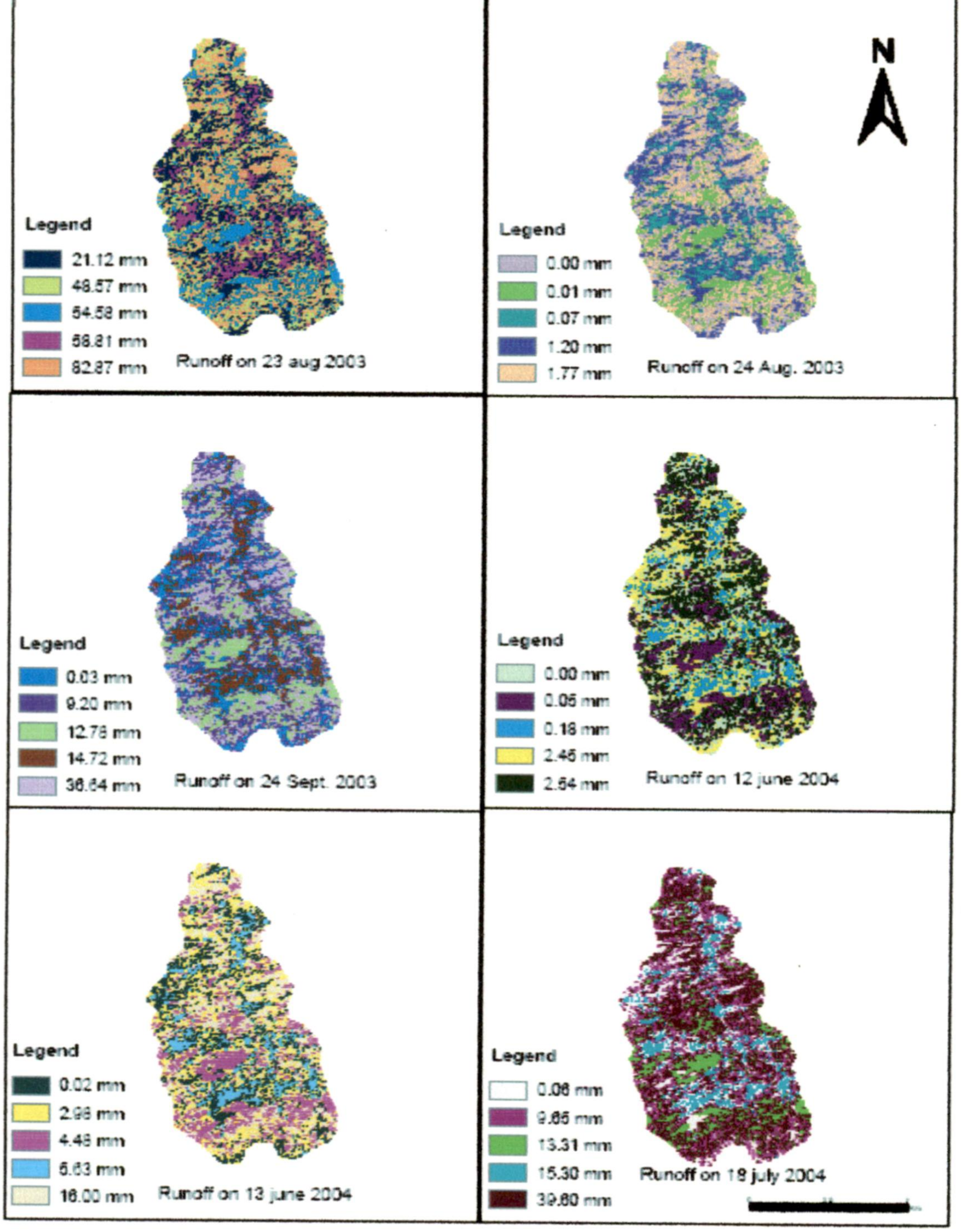


Fig. 7.2 Runoff maps of Deshgaon Watershed (2003&2004)

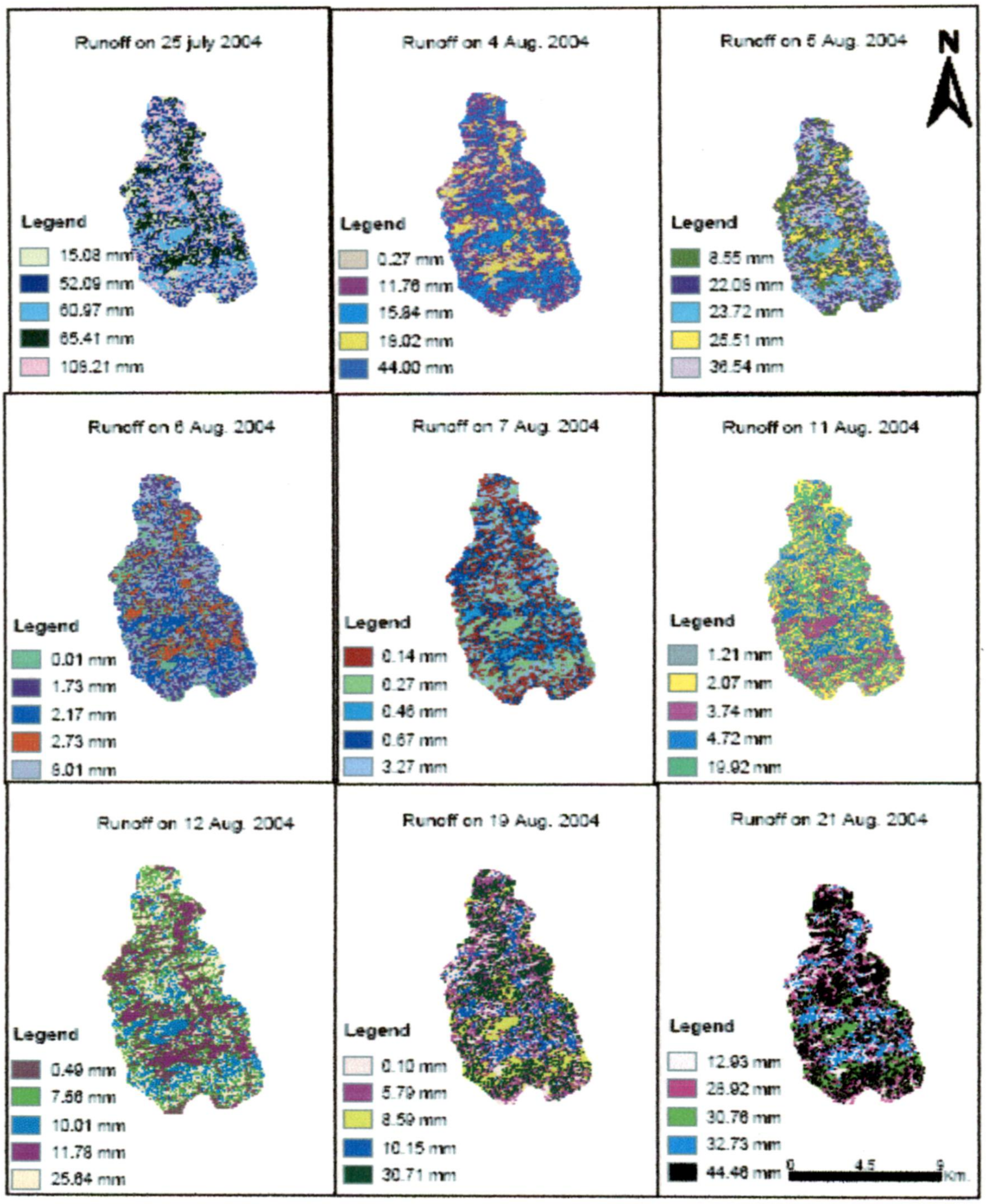


Fig. 7.3 Runoff maps of Deshgaon Watershed (Year 2004)

Table – 7.3 Runoff generated on 20th June 2003 In Deshgaon watershed

Class	Area (in ha.)	Runoff Depth (in m.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Agriculture	773.34	0.0	0	0
Forest	1386.41	0.001	1.39	1.39
Pasture	1839.8	0.003	5.52	6.91
Rocky Land	1977.44	0.004	7.91	14.82
Settlements	1172.86	0.013	15.25	30.06
Total	7149.85		30.06	

Table – 7.4 Runoff generated on 21st June 2003 In Deshgaon watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Agriculture	773.34	0.005	3.87	3.87
Forest	1386.41	0.016	22.18	26.05
Pasture	1839.8	0.017	31.28	57.33
Rocky Land	1977.44	0.019	37.57	94.90
Settlements	1172.86	0.029	34.01	128.91
Total	7149.85		128.91	

Table – 7.5 Runoff generated on 22nd June 2003 In Deshgaon watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Agriculture	773.34	0.025	19.33	19.33
Forest	1386.41	0.046	63.77	83.11
Pasture	1839.8	0.049	90.15	173.26
Rocky Land	1977.44	0.051	100.85	274.11
Settlements	1172.86	0.064	75.06	349.17
Total	7149.85		349.17	

Table – 7.6 Runoff generated on 25th July 2003 In Deshgaon watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Agriculture	773.34	0.0	0.0	0.0
Forest	1386.41	0.0	0.0	0.0
Pasture	1839.8	0.001	1.84	1.84
Rocky Land	1977.44	0.002	3.95	5.79
Settlements	1172.86	0.008	9.38	15.18
Total	7149.85		15.18	

Table – 7.7 Runoff generated on 27th July 2003 In Deshgaon watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Agriculture	773.34	0.016	12.37	12.37
Forest	1386.41	0.033	45.75	58.12
Pasture	1839.8	0.035	64.39	122.52
Rocky Land	1977.44	0.037	73.17	195.68
Settlements	1172.86	0.049	57.47	253.15
Total	7149.85		253.15	

Table – 7.8 Runoff generated on 22nd August 2003 In Deshgaon watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Agriculture	773.34	0.0	0.0	0.0
Forest	1386.41	0.001	1.39	1.39
Pasture	1839.8	0.002	3.68	5.07
Rocky Land	1977.44	0.003	5.93	11.00
Settlements	1172.86	0.013	15.25	26.25
Total	7149.85		26.25	

Table – 7.9 Runoff generated on 23rd August 2003 In Deshgaon watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Agriculture	773.34	0.021	16.24	16.24
Forest	1386.41	0.049	67.93	84.17
Pasture	1839.8	0.054	99.35	183.52
Rocky Land	1977.44	0.059	116.67	300.19
Settlements	1172.86	0.083	97.35	397.54
Total	7149.85		397.54	

Table – 7.10 Runoff generated on 24th August 2003 In Deshgaon watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Agriculture	773.34	0.0	0.0	0.0
Forest	1386.41	0.0	0.0	0.0
Pasture	1839.8	0.0	0.0	0.0
Rocky Land	1977.44	0.001	1.98	1.98
Settlements	1172.86	0.002	2.35	4.32
Total	7149.85		4.32	

Table – 7.11 Runoff generated on 24th September 2003 In Deshgaon watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Agriculture	773.34	0.0	0.0	0.0
Forest	1386.41	0.009	12.48	12.48
Pasture	1839.8	0.013	23.92	36.40
Rocky Land	1977.44	0.014	27.68	64.08
Settlements	1172.86	0.037	43.40	107.48
Total	7149.85		107.48	

Table – 7.12 Runoff generated on 12th June 2004 In Deshgaon watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Agriculture	773.34	0.0	0.0	0.0
Forest	1386.41	0.0	0.0	0.0
Pasture	1839.8	0.002	3.68	3.68
Rocky Land	1977.44	0.002	3.95	7.63
Settlements	1172.86	0.003	3.52	11.15
Total	7149.85		11.15	

Table – 7.13 Runoff generated on 13th June 2004 In Deshgaon watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Agriculture	773.34	0.0	0.0	0.0
Forest	1386.41	0.003	4.16	4.16
Pasture	1839.8	0.004	7.36	11.52
Rocky Land	1977.44	0.005	9.89	21.41
Settlements	1172.86	0.016	18.77	40.17
Total	7149.85		40.17	

Table – 7.14 Runoff generated on 18th July 2004 In Deshgaon watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Agriculture	773.34	0.0	0.0	0.0
Forest	1386.41	0.009	12.48	12.48
Pasture	1839.8	0.013	23.92	36.40
Rocky Land	1977.44	0.015	29.66	66.06
Settlements	1172.86	0.039	45.74	111.80
Total	7149.85		111.80	

Table – 7.15 Runoff generated on 25th July 2004 In Deshgaon watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Agriculture	773.34	0.015	11.60	11.60
Forest	1386.41	0.052	72.09	83.69
Pasture	1839.8	0.061	112.23	195.92
Rocky Land	1977.44	0.065	128.53	324.45
Settlements	1172.86	0.108	126.67	451.12
Total	7149.85		451.12	

Table – 7.16 Runoff generated on 4th August 2004 In Deshgaon watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Agriculture	773.34	0.0	0.0	0.0
Forest	1386.41	0.011	15.25	15.25
Pasture	1839.8	0.016	29.44	44.69
Rocky Land	1977.44	0.018	35.59	80.28
Settlements	1172.86	0.044	51.61	131.89
Total	7149.85		131.89	

Table – 7.17 Runoff generated on 5th August 2004 In Deshgaon watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Agriculture	773.34	0.008	6.19	6.19
Forest	1386.41	0.022	30.50	36.69
Pasture	1839.8	0.023	42.32	79.00
Rocky Land	1977.44	0.025	49.44	128.44
Settlements	1172.86	0.036	42.22	170.66
Total	7149.85		170.66	

Table – 7.18 Runoff generated on 6th August 2004 In Deshgaon watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Agriculture	773.34	0.0	0.0	0.0
Forest	1386.41	0.002	2.77	2.77
Pasture	1839.8	0.002	3.68	6.45
Rocky Land	1977.44	0.003	5.93	12.38
Settlements	1172.86	0.008	9.38	21.77
Total	7149.85		21.77	

Table – 7.19 Runoff generated on 7th August 2004 In Deshgaon watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Agriculture	773.34	0.0	0.0	0.0
Forest	1386.41	0.0	0.0	0.0
Pasture	1839.8	0.0	0.0	0.0
Rocky Land	1977.44	0.0	0.0	0.0
Settlements	1172.86	0.003	3.52	3.52
Total	7149.85		3.52	

Table – 7.20 Runoff generated on11th August 2004 In Deshgaon watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Agriculture	773.34	0.001	0.77	0.77
Forest	1386.41	0.002	2.77	3.55
Pasture	1839.8	0.003	5.52	9.07
Rocky Land	1977.44	0.004	7.91	16.98
Settlements	1172.86	0.020	23.46	40.43
Total	7149.85		40.43	

Table – 7.21 Runoff generated on 12th August 2004 In Deshgaon watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Agriculture	773.34	0.0	0.0	0.0
Forest	1386.41	0.007	9.70	9.70
Pasture	1839.8	0.010	18.40	28.10
Rocky Land	1977.44	0.011	21.75	49.85
Settlements	1172.86	0.025	29.32	79.18
Total	7149.85		79.18	

Table – 7.22 Runoff generated on19th August 2004 In Deshgaon watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Agriculture	773.34	0.0	0.0	0.0
Forest	1386.41	0.006	8.32	8.32
Pasture	1839.8	0.008	14.72	23.04
Rocky Land	1977.44	0.010	19.77	42.81
Settlements	1172.86	0.030	35.19	78.00
Total	7149.85		78.00	

Table – 7.23 Runoff generated on21st August 2004 In Deshgaon watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Agriculture	773.34	0.013	10.05	10.05
Forest	1386.41	0.029	40.21	50.26
Pasture	1839.8	0.060	110.39	160.65
Rocky Land	1977.44	0.032	63.28	223.93
Settlements	1172.86	0.044	51.61	275.53
Total	7149.85		275.53	

It was found that the runoff produced in the watershed was 30.06 ha-m, 128.91 ha-m, 349.17 ha-m, 15.18 ha-m, 253.15 ha-m, for 20th, 21st, 22nd June 2003 and 25th, 27th July 2003 respectively. Similarly runoff produced for other days have been estimated and given in the Table 7.3 to 7.23.

7.2.1 Runoff without using GIS

Runoff for Deshgaon Watershed is also calculated analytically using SCS model. In this case average catchment values (parameters) were used.

Considering the AMC of the watershed the weighted average CN is calculated and given in Table 7.24. The estimated runoff for the events of the year 2003 and 2004 are given in Tables 7.25 and 7.26 respectively.

Table 7.24 Weighted Average Curve Number

Land Use	Area (A)	Hydrological Condition	CN (C)	A * C
Agriculture	773.34	Poor	84	64960.56
Forest	1386.41	Good	62	85957.42
Pasture	1839.8	Fair	79	145344.2
Rocky area	1977.44	Fair	94	185879.36
Settlement	1172.86	Good	82	96174.52
Total	7149.85			578316.06

$$\text{Wt. Av. Curve Number} = \frac{578316.06}{7149.85} = 80.88 \approx 81$$

Therefore, weighted average CN = 81 (For AMC II)

Modified CN for AMC I = 64

Modified CN for AMC III = 92

Table 7.25 Runoff calculation for Deshgaon watershed without using GIS (Year 2003)

Date	Rainfall (mm)	Last 5 days Rainfall	AMC	CN	Modified CN	S	0.2*S	0.8*S	Runoff** (mm)
20-6-2003	25.8	50.0	II	81	81	59.58	11.91	47.66	2.62
21-6-2003	35.0	75.8	III	81	92	22.09	4.41	17.67	17.76
22-6-2003	70.0	60.8	III	81	92	22.09	4.41	17.67	49.06
25-7-2003	20.32	38.1	II	81	81	59.58	11.91	47.66	1.04
27-7-2003	55.08	65.46	III	81	92	22.09	4.41	17.67	35.28
22-8-200-	40.00	0.0	I	81	64	142.87	28.57	114.3	0.84
23-8-2003	100.00	10.0	II	81	81	59.58	11.91	47.66	52.54
24-8-2003	5.00	140.0	III	81	92	22.09	4.41	17.67	0.01
24-9-2003	73.66	0.76	I	81	64	142.87	28.57	114.3	10.81

** Runoff is calculated by using formula Q = $\frac{(P-0.2*S)^2}{(P+0.8*S)}$ subject to P > 0.2*S

Table 7.26 Runoff calculation for Deshgaon Watershed without using GIS (Year 2004)

Date	Rainfall (mm)	Last 5 days Rainfall	AMC	CN	Modified CN	S	0.2*S	0.8*S	Runoff** (mm)
12-6-2004	12.7	49.48	II	81	81	59.58	11.91	47.66	0.01
13-6-2004	29.1	51.78	II	81	81	59.58	11.91	47.66	3.84
18-7-2004	74.8	0.0	I	81	64	142.87	28.57	114.3	11.3
24-7-2004	18.0	0.2	I	81	64	142.87	28.57	114.3	-----***
25-7-2004	150.6	18.0	I	81	64	142.87	28.57	114.3	56.21
4-8-2004	80.0	30.0	I	81	64	142.87	28.57	114.3	13.61
5-8-2004	42.0	80.0	III	81	92	22.09	4.41	17.67	23.67
6-8-2004	12.5	122.0	III	81	92	22.09	4.41	17.67	2.16
7-8-2004	7.0	134.5	III	81	92	22.09	4.41	17.67	0.27
11-8-2004	50.0	24.5	I	81	64	142.87	28.57	114.3	2.79
12-8-2004	40.0	50.0	II	81	81	59.58	11.91	47.66	9.00
19-8-2004	64.0	0.0	I	81	64	142.87	28.57	114.3	7.04
21-8-2004	50.0	64.0	III	81	92	22.09	4.41	17.67	30.70

** Runoff is calculated by using formula Q = $\frac{(P-0.2*S)^2}{(P+0.8*S)}$ subject to P > 0.2*S

*** No runoff as P < 0.2*S

7.2.2 Comparison of Runoff with and without Using GIS

Comparison is made between the estimated runoff using GIS and without using GIS and it is found that percentage variation is within acceptable range. Comparison is shown in the Table 7.27 and 7.28 for the Year 2003 and 2004 respectively. Comparison is also presented in the Fig. 7.8 for the year 2003 and 2004.

Table 7.27 Comparison of Runoff with and without GIS for the year 2003

Date	Runoff Using GIS (mm.)	Runoff without using GIS (mm.)	Percentage Variation
20-6-2003	4.20	2.62	60.3
21-6-2003	18.02	17.76	1.46
22-6-2003	48.83	49.06	0.47
25-7-2003	2.12	1.04	103.84
27-7-2003	35.40	35.28	0.34
22-8-2003	3.67	0.84	336.9
23-8-2003	55.60	52.54	5.82
24-8-2003	0.60	0.01	----
24-9-2003	15.03	10.81	39.03

Table 7.28 Comparison of Runoff with and without GIS for the year 2004

Date	Runoff Using GIS (mm.)	Runoff without using GIS (mm.)	Percentage Variation
12-6-2004	1.15	0.01	-----
13-6-2004	5.61	3.84	46.09
18-7-2004	15.63	11.3	38.31
24-7-2004	No Runoff	No Runoff	----
25-7-2004	63.10	56.21	12.25
4-8-2004	18.44	13.61	35.48
5-8-2004	23.86	23.67	0.80
6-8-2004	2.96	2.16	37.03
7-8-2004	0.49	0.27	81.48
11-8-2004	5.65	2.79	102.51
12-8-2004	11.07	9.00	23.0
19-8-2004	10.9	7.04	54.82
24-8-2004	38.53	30.70	25.50

From the above comparison table it is inferred that the estimated runoff by the two methods is almost same when there is AMC III condition and rainfall in the watershed is more than 35 mm. Variation is more when rainfall is low and AMC is of type I.

7.3 RUNOFF USING GIS FOR OZARKHED WATERSHED

Analysis has been performed for Ozarkhed watershed where observed data of runoff is available, in the similar manner as have been done for Deshgaon watershed. Rainfall received in the watershed during various periods is shown in Table 7.29 and 7.30 along with the different AMC conditions.

Runoff maps generated from the daily rainfall storm received for Ozarkhed watershed are presented in Figs. 7.4 to 7.7. The runoff depth and volume generated from each class of areas has been given in table 7.31 to 7.54.

Table 7.29 AMC and Rainfall data for the events in 2002

Date	Rainfall(mm)	Last 5 days Rainfall	AMC condition
19-7-2002	44.4	39.0	II
20-7-2002	21.5	76.7	III
23-7-2002	13.6	79.8	III
24-7-2002	12.0	88.6	III
26-7-2002	63.8	39.7	II
7-8-2002	33.3	79.9	III
8-8-2002	23.9	113.1	III
9-8-2002	58.6	122.6	III
10-8-2002	49.4	174.6	III
1-9-2002	30.5	60.3	III
2-9-2002	56.9	89.0	III

Table 7.30 AMC and Rainfall data for the events in 2003

Date	Rainfall(mm)	Last 5 days Rainfall	AMC condition
5-8-2003	45.0	84	III
6-8-2003	89.0	129	III
7-8-2003	35.0	214	III
8-8-2003	17.0	240	III
9-8-2003	39.0	243	III
19-8-2003	19.0	77.0	III
20-8-2003	17.0	79.0	III
29-8-2003	21.0	85.0	III
30-8-2003	38.0	91.0	III
31-8-2003	18.0	82.0	III
3-9-2003	18.0	95.0	III
4-9-2003	18.0	92.0	III
5-9-2003	13.0	72.0	III

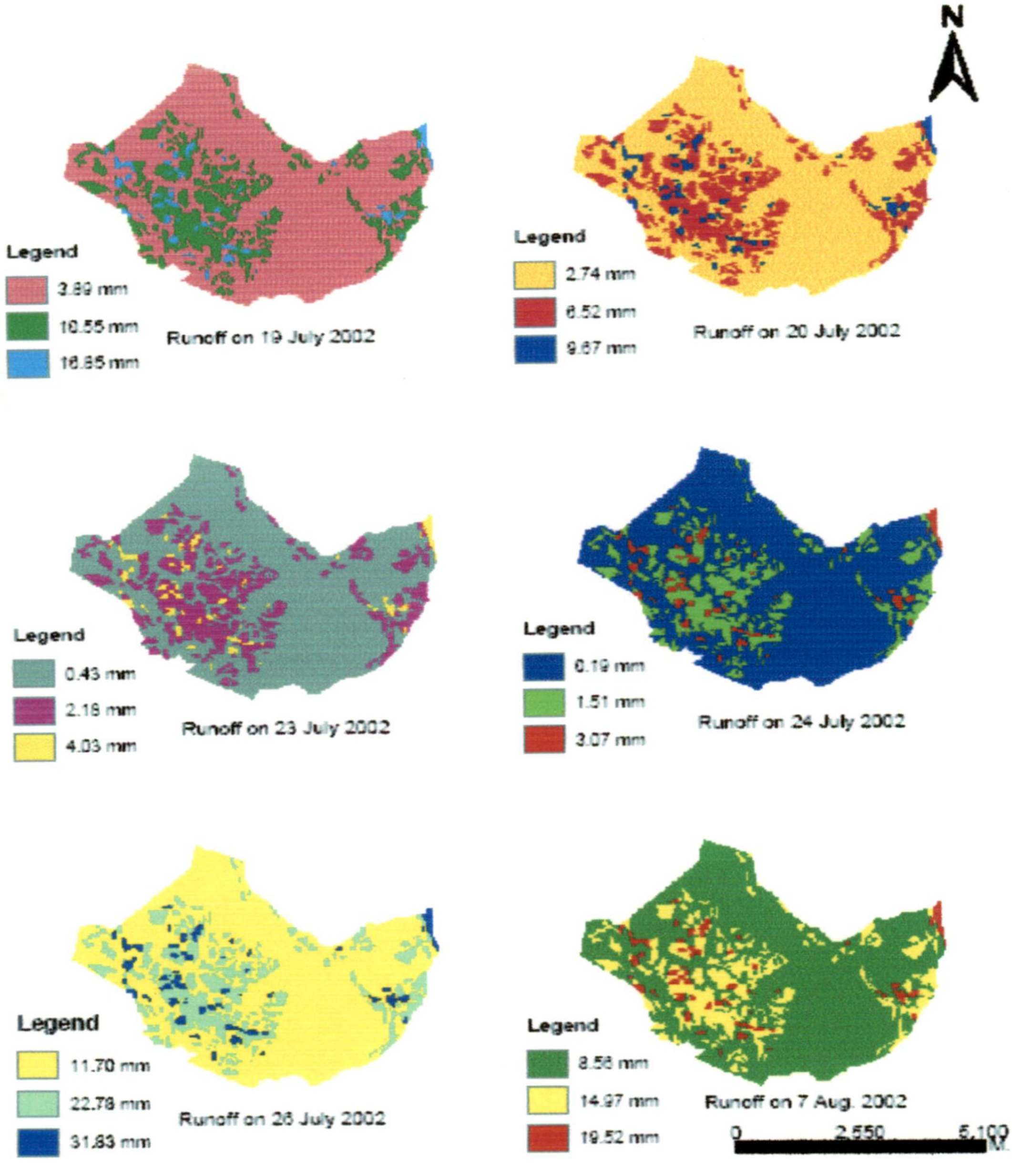


Fig. 7.4 Runoff Maps of Ozarkhed Watershed (Year 2002)

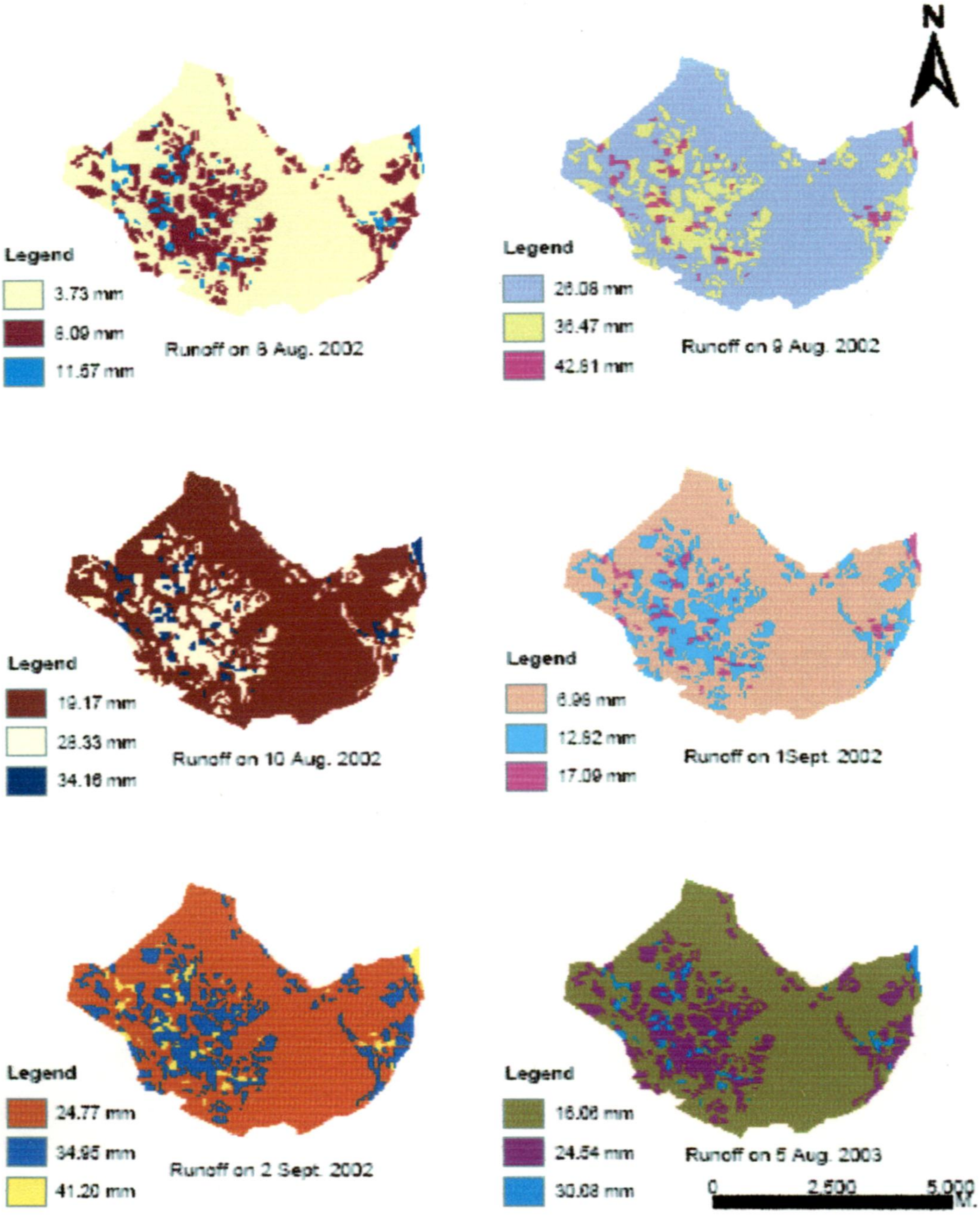


Fig. 7.5 Runoff Maps of Ozarkhed Watershed (Year 2002)

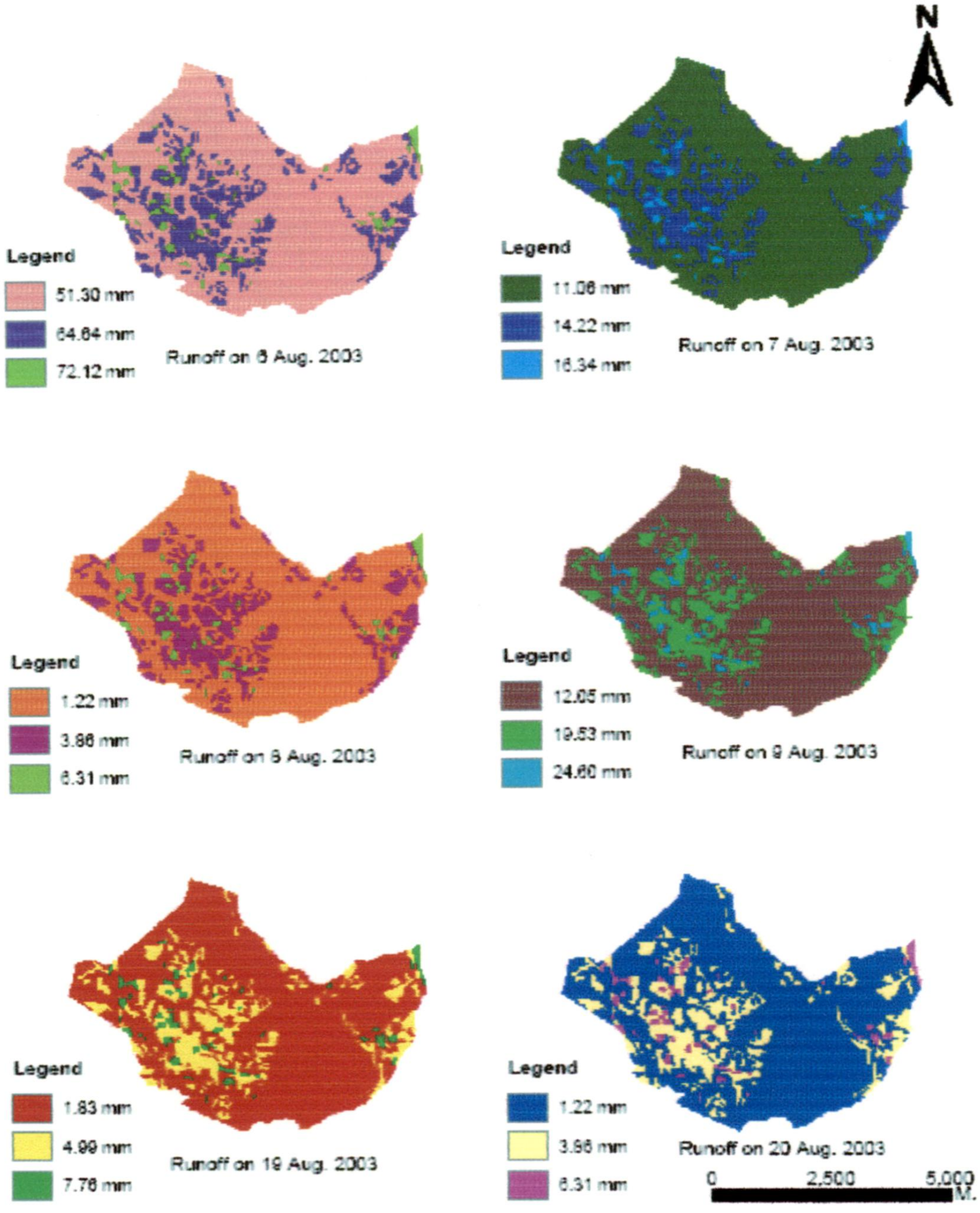


Fig. 7.6 Runoff Maps of Ozarkhed Watershed (Year 2003)

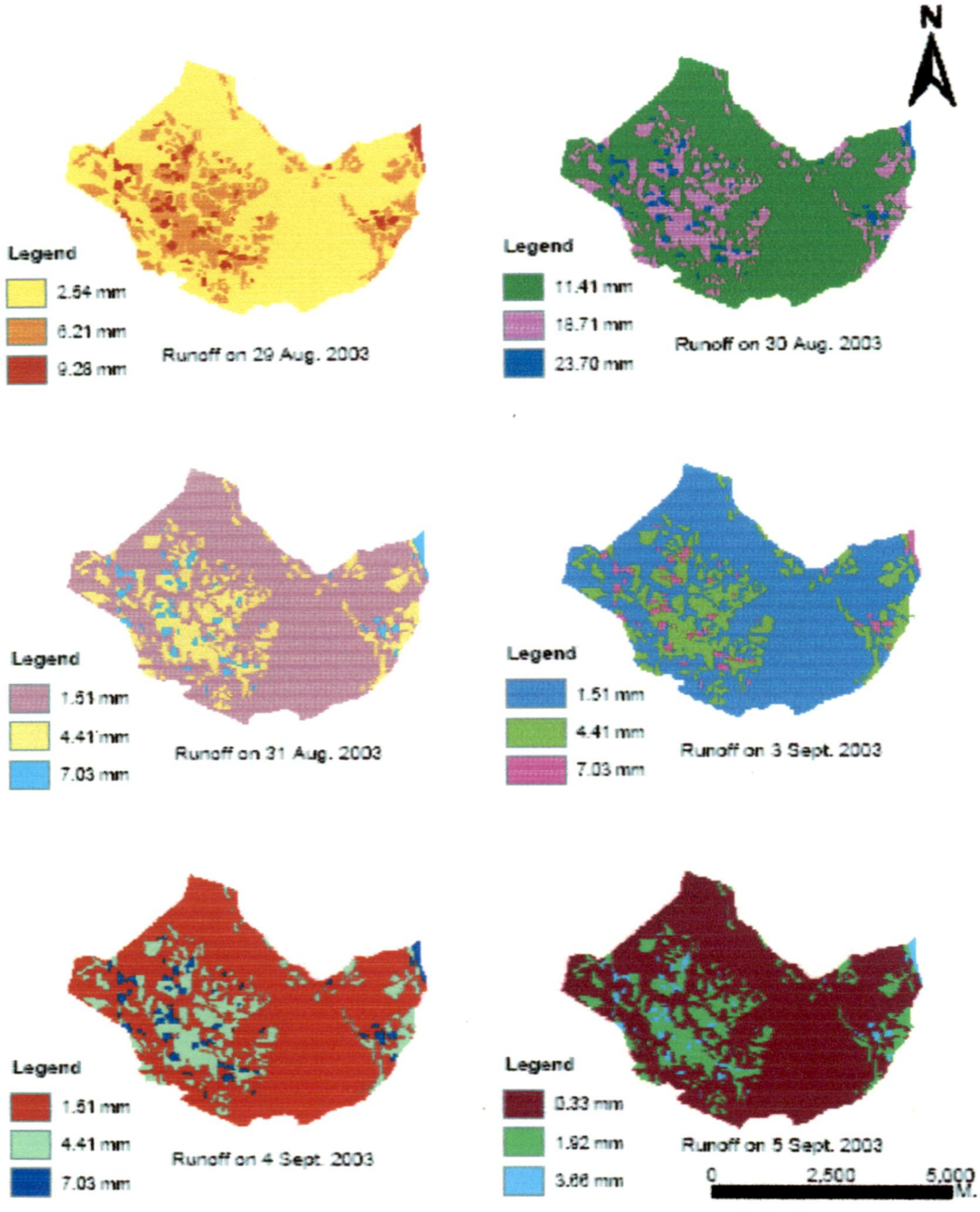


Fig. 7.7 Runoff Maps of Ozarkhed Watershed (Year 2003)

Table 7.31 Runoff generated on 19th July 2002 in Ozarkhed Watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Forest	1731	0.004	6.924	6.924
Agriculture	509	0.010	5.090	12.014
Waste Land	88	0.017	1.496	13.51
Total	2328		13.51	

Table 7.32 Runoff generated on 20th July 2002 in Ozarkhed Watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Forest	1731	0.003	5.193	5.193
Agriculture	509	0.006	3.054	8.247
Waste Land	88	0.010	0.88	9.127
Total	2328		9.127	

Table 7.33 Runoff generated on 23rd July 2002 in Ozarkhed Watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Forest	1731	0.0004	0.6924	0.6924
Agriculture	509	0.0021	1.0689	1.7613
Waste Land	88	0.0040	0.352	2.1133
Total	2328		2.1133	

Table 7.34 Runoff generated on 24th July 2002 in Ozarkhed Watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Forest	1731	0.0002	0.3462	0.3462
Agriculture	509	0.0015	0.7635	1.1097
Waste Land	88	0.0030	0.264	1.3737
Total	2328		1.3737	

Table 7.35 Runoff generated on 26th July 2002 in Ozarkhed Watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Forest	1731	0.0117	20.2527	20.2527
Agriculture	509	0.0227	11.5543	31.807
Waste Land	88	0.0318	2.7984	34.6054
Total	2328		34.6054	

Table 7.36 Runoff generated on 7th August 2002 in Ozarkhed Watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Forest	1731	0.0085	14.7135	14.7135
Agriculture	509	0.0149	7.5841	22.2976
Waste Land	88	0.0195	1.716	24.0136
Total	2328		24.0136	

Table 7.37 Runoff generated on 8th August 2002 in Ozarkhed Watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Forest	1731	0.0037	6.4047	6.4047
Agriculture	509	0.0081	4.1229	10.5276
Waste Land	88	0.0115	1.012	11.5396
Total	2328		11.5396	

Table 7.38 Runoff generated on 9th August 2002 in Ozarkhed Watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Forest	1731	0.0261	45.1791	45.1791
Agriculture	509	0.0364	18.5276	63.7067
Waste Land	88	0.0428	3.7664	67.4731
Total	2328		67.4731	

Table 7.39 Runoff generated on 10th August 2002 in Ozarkhed Watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Forest	1731	0.0191	33.0621	33.0621
Agriculture	509	0.0283	14.4047	47.4668
Waste Land	88	0.0341	3.0008	50.4676
Total	2328		50.4676	

Table 7.40 Runoff generated on 1st September 2002 in Ozarkhed Watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Forest	1731	0.0069	11.9439	11.9439
Agriculture	509	0.0128	6.5152	18.4591
Waste Land	88	0.0171	1.5048	19.9639
Total	2328		19.9639	

Table 7.41 Runoff generated on 2nd September 2002 in Ozarkhed Watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Forest	1731	0.0247	42.7557	42.7557
Agriculture	509	0.0349	17.7641	60.5198
Waste Land	88	0.0412	3.6256	64.1454
Total	2328		64.1454	

Table 7.42 Runoff generated on 5th August 2003 in Ozarkhed Watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Forest	1731	0.0160	27.696	27.696
Agriculture	509	0.0245	12.4705	40.1665
Waste Land	88	0.0300	2.64	42.8065
Total	2328		42.8065	

Table 7.43 Runoff generated on 6th August 2003 in Ozarkhed Watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Forest	1731	0.0513	88.8003	88.8003
Agriculture	509	0.0646	32.8814	121.6817
Waste Land	88	0.0721	6.3448	128.026
Total	2328		128.026	

Table 7.44 Runoff generated on 7th August 2003 in Ozarkhed Watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Forest	1731	0.0110	19.041	19.041
Agriculture	509	0.0142	7.227	26.2688
Waste Land	88	0.0163	1.434	27.70
Total	2328		27.70	

Table 7.45 Runoff generated on 8th August 2003 in Ozarkhed Watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Forest	1731	0.0012	2.0772	2.0772
Agriculture	509	0.0038	1.9342	4.0114
Waste Land	88	0.0063	0.5544	4.5658
Total	2328		4.5658	

Table 7.46 Runoff generated on 9th August 2003 in Ozarkhed Watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Forest	1731	0.0120	20.772	20.772
Agriculture	509	0.0195	9.9255	30.6975
Waste Land	88	0.0246	2.1648	32.8623
Total	2328		32.8623	

Table 7.47 Runoff generated on 19th August 2003 in Ozarkhed Watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Forest	1731	0.0018	3.1158	3.1158
Agriculture	509	0.0050	2.545	5.6608
Waste Land	88	0.0077	0.6776	6.3384
Total	2328		6.3384	

Table 7.48 Runoff generated on 20th August 2003 in Ozarkhed Watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Forest	1731	0.0012	2.0772	2.0772
Agriculture	509	0.0038	1.9342	4.0114
Waste Land	88	0.0063	0.5544	4.5658
Total	2328		4.5658	

Table 7.49 Runoff generated on 29th August 2003 in Ozarkhed Watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Forest	1731	0.0025	4.3275	4.3275
Agriculture	509	0.0062	3.1558	7.4833
Waste Land	88	0.0092	0.8096	8.2929
Total	2328		8.2929	

Table 7.50 Runoff generated on 30th August 2003 in Ozarkhed Watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Forest	1731	0.011	19.041	19.041
Agriculture	509	0.018	9.162	28.203
Waste Land	88	0.023	2.024	30.227
Total	2328		30.227	

Table 7.51 Runoff generated on 31st August 2003 in Ozarkhed Watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Forest	1731	0.0015	2.5965	2.5965
Agriculture	509	0.0044	2.2396	4.8361
Waste Land	88	0.0070	0.616	5.4521
Total	2328		5.4521	

Table 7.52 Runoff generated on 3rd September 2003 in Ozarkhed Watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Forest	1731	0.0015	2.5965	2.5965
Agriculture	509	0.0044	2.2396	4.8361
Waste Land	88	0.0070	0.616	5.4521
Total	2328		5.4521	

Table 7.53 Runoff generated on 4th September 2003 in Ozarkhed Watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Forest	1731	0.0015	2.5965	2.5965
Agriculture	509	0.0044	2.2396	4.8361
Waste Land	88	0.0070	0.616	5.4521
Total	2328		5.4521	

Table 7.54 Runoff generated on 5th September 2003 in Ozarkhed Watershed

Class	Area (in ha.)	Runoff Depth (in M.)	Runoff (ha-m.)	Cumulative Runoff (ha-m.)
Forest	1731	0.0003	0.5193	0.5193
Agriculture	509	0.0019	0.9671	1.4864
Waste Land	88	0.0036	0.3168	1.8032
Total	2328		1.8032	

It was found that the runoff produced in the watershed was 13.51 ha-m, 9.127 ha-m, 2.11 ha-m, 1.37ha-m, 34.60 ha-m, for 19th, 20th, 23rd, 24th and 26th, July 2002 respectively. Similarly the runoff produced for other days has been estimated and given in the Table 7.31 to 7.54.

7.3.1 Runoff without using GIS

Runoff for Ozarkhed Watershed is also calculated analytically using SCS model. In this case average catchment values (parameters) are used. Considering the AMC of the watershed the weighted average CN is calculated and given in Table 7.55. The estimated values of the runoff for the year 2002 and 2003 are given in Tables 7.56 and 7.57 respectively.

Table 7.55 Weighted Average Curve Number

Land Use	Area (A)	Hydrological Condition	CN (C)	A * C
Agriculture	658	Poor	80	52640
Forest	1478	Fair	70	103460
Waste land	34	Fair	86	2924
Total	2170			159024

Wt. Av. Curve Number = $\frac{159024}{2170}$ = 73.28 ≈ 73

Therefore, weighted average CN = 73 (For AMC II)

Modified CN for AMC I = 54

Modified CN for AMC III = 87

7.3.2 Comparison of Runoff with and without using GIS

Comparison is made between the estimated runoff using GIS and without using GIS and it is found that percentage variation is within acceptable range. Comparison is shown in the Table 7.58 & 7.59 and in the Fig. 7.9 for the Year 2002 and 2003 respectively.

Table 7.56 Runoff calculation for Ozarkhed watershed without using GIS (YEAR 2002)

Date	Rainfall (mm)	Last 5 days Rainfall	AMC	CN	Modified CN	S	0.2*S	0.8*S	Runoff** (mm)
19-7-2002	44.4	39.0	II	73	73	93.94	18.78	75.15	5.48
20-7-2002	21.5	76.7	III	73	87	37.95	7.59	30.36	3.73
23-7-2002	13.6	79.8	III	73	87	37.95	7.59	30.36	0.82
24-7-2002	12.0	88.6	III	73	87	37.95	7.59	30.36	0.46
26-7-2002	63.8	39.7	II	73	73	93.94	18.78	75.15	14.58
7-8-2002	33.3	79.9	III	73	87	37.95	7.59	30.36	10.38
8-8-2002	23.9	113.1	III	73	87	37.95	7.59	30.36	4.90
9-8-2002	58.6	122.6	III	73	87	37.95	7.59	30.36	29.24
10-8-2002	49.4	174.6	III	73	87	37.95	7.59	30.36	21.91
1-9-2002	30.5	60.3	III	73	87	37.95	7.59	30.36	8.62
2-9-2002	56.9	89.0	III	73	87	37.95	7.59	30.36	27.86

** Runoff is calculated by using formula Q = $\frac{(P - 0.2 * S)^2}{(P + 0.8 * S)}$ subject to P > 0.2*S

Table 7.57 Runoff calculation for Ozarkhed watershed without using GIS (YEAR 2003)

Date	Rainfall (mm)	Last 5 days Rainfall	AMC	CN	Modified CN	S	0.2*S	0.8*S	Runoff** (mm)
5-8-2003	45.0	84	III	73	87	37.95	7.59	30.36	18.56
6-8-2003	89.0	129	III	73	87	37.95	7.59	30.36	55.52
7-8-2003	35.0	214	III	73	87	37.95	7.59	30.36	11.49
8-8-2003	17.0	240	III	73	87	37.95	7.59	30.36	1.87
9-8-2003	39.0	243	III	73	87	37.95	7.59	30.36	14.22
19-8-2003	19.0	77.0	III	73	87	37.95	7.59	30.36	2.36
20-8-2003	17.0	79.0	III	73	87	37.95	7.59	30.36	1.86
29-8-2003	21.0	85.0	III	73	87	37.95	7.59	30.36	3.50
30-8-2003	38.0	91.0	III	73	87	37.95	7.59	30.36	13.52
31-8-2003	18.0	82.0	III	73	87	37.95	7.59	30.36	2.24
3-9-2003	18.0	95.0	III	73	87	37.95	7.59	30.36	2.24
4-9-2003	18.0	92.0	III	73	87	37.95	7.59	30.36	2.24
5-9-2003	13.0	72.0	III	73	87	37.95	7.59	30.36	0.67

Table 7.58 Comparison of Runoff with and without GIS for the events of the year 2002

Date	Runoff Using GIS (mm.)	Runoff without using GIS (mm.)	Percentage Variation
19-7-2002	5.80	5.48	5.83
20-7-2002	3.92	3.73	5.09
23-7-2002	0.91	0.82	10.97
24-7-2002	0.59	0.46	28.26
26-7-202	14.86	14.58	1.92
7-8-2002	10.31	10.38	0.67
8-8-2002	4.96	4.90	1.22
9-8-2002	28.98	29.24	0.88
10-8-2002	21.68	21.91	1.04
1-9-2002	8.57	8.62	0.58
2-9-2002	27.55	27.86	1.11

Table7.59 Comparison of Runoff with and without GIS for the events of the year 2003

Date	Runoff Using GIS (mm.)	Runoff without using GIS (mm.)	Percentage Variation
5-8-2003	18.38	18.56	0.96
6-8-2003	54.99	55.52	0.95
7-8-2003	11.89	11.49	3.48
8-8-2003	1.96	1.87	4.81
9-8-2003	14.11	14.22	0.77
19-8-2003	2.72	2.36	15.25
20-8-2003	1.96	1.86	5.37
29-8-2003	3.56	3.50	1.71
30-8-2003	12.98	13.52	3.99
31-8-2003	2.34	2.24	4.46
3-9-2003	2.34	2.24	4.46
4-9-2003	2.34	2.24	4.46
5-9-2003	0.77	0.67	14.92

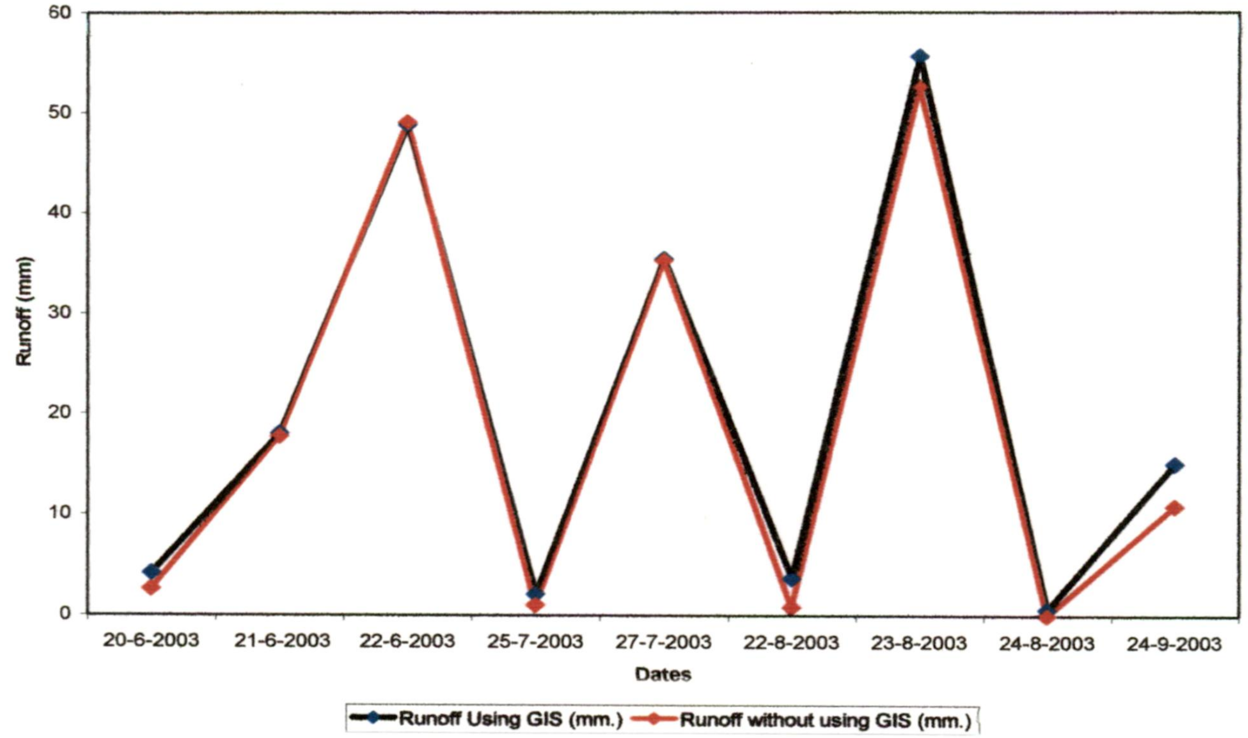
From the above comparison table it is inferred that the estimated runoff by the two methods is almost same when there is AMC III condition and rainfall in the watershed is more than 35 mm. Variation is more when rainfall is low and AMC I.

7.3.3 Validation of the SCS model

In order to validate the SCS model output, estimated runoff is compared with observed runoff measured by the Soil Conservation and Watershed Management Department, Pune and it is found that most of the estimated runoff matches with the observed runoff and the percent deviation ranges from 2.17 to 26.15 which are within the acceptable range, The details of which are given in Table 7.60 and in Fig. 7.10. A Correlation of 0.95 is obtained between estimated and observed runoff and the same is presented in the Fig. 7.11.

Table 7.60 Comparison of Estimated and Observed Runoff for Ozarkhed watershed for the year 2002

Storm Date	Rainfall (mm.)	AMC Condition	Runoff Observed(mm)	Estimated Runoff(mm)	Percent Deviation
19-7-2002	44.4	II	1.75	5.80	69.82
20-7-2002	21.5	III	1.89	3.92	51.78
23-7-2002	13.6	III	0.65	0.91	28.57
24-7-2002	12.0	III	0.73	0.59	23.72
26-7-2002	63.8	II	12.57	14.86	15.41
7-8-2002	33.3	III	11.51	10.31	11.63
8-8-2002	23.9	III	6.44	4.96	29.83
9-8-2002	58.6	III	26.00	28.98	10.28
10-8-2002	49.4	III	21.33	21.68	1.61
1-9-2002	30.5	III	8.92	8.57	4.08
2-9-2002	56.9	III	32.51	27.55	18.00



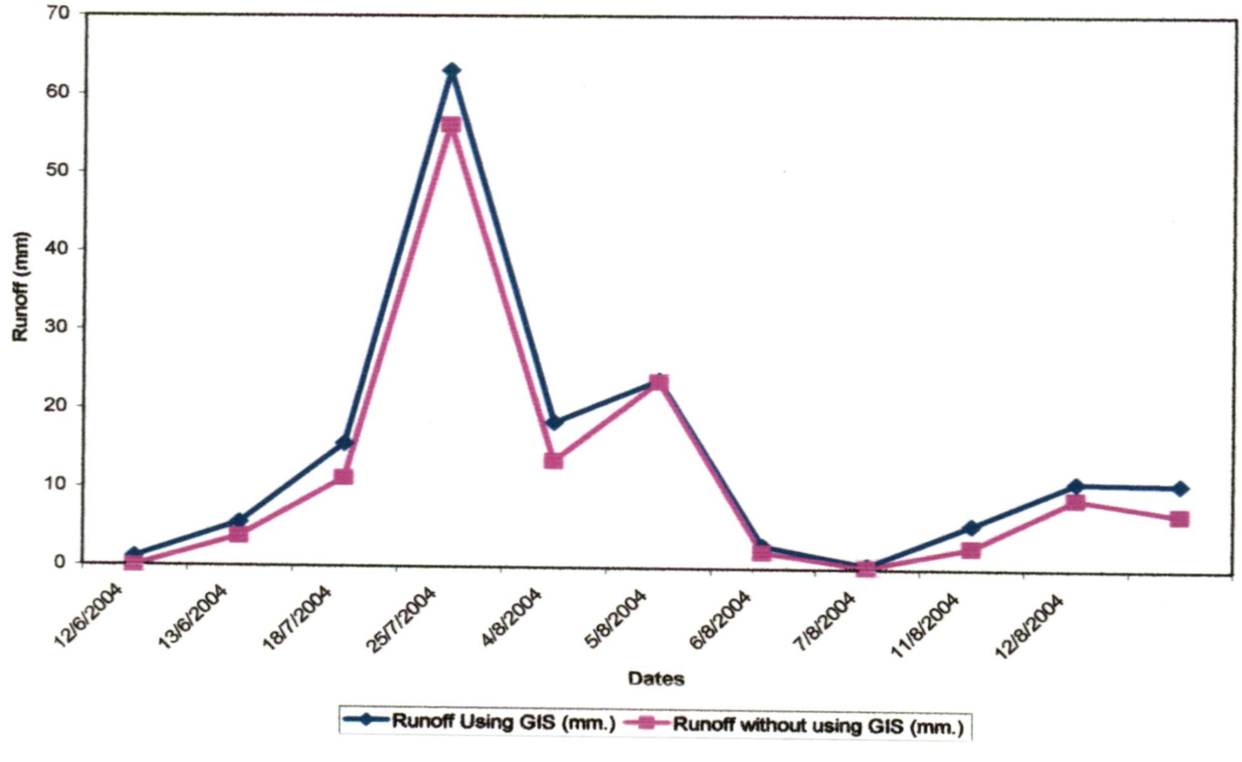
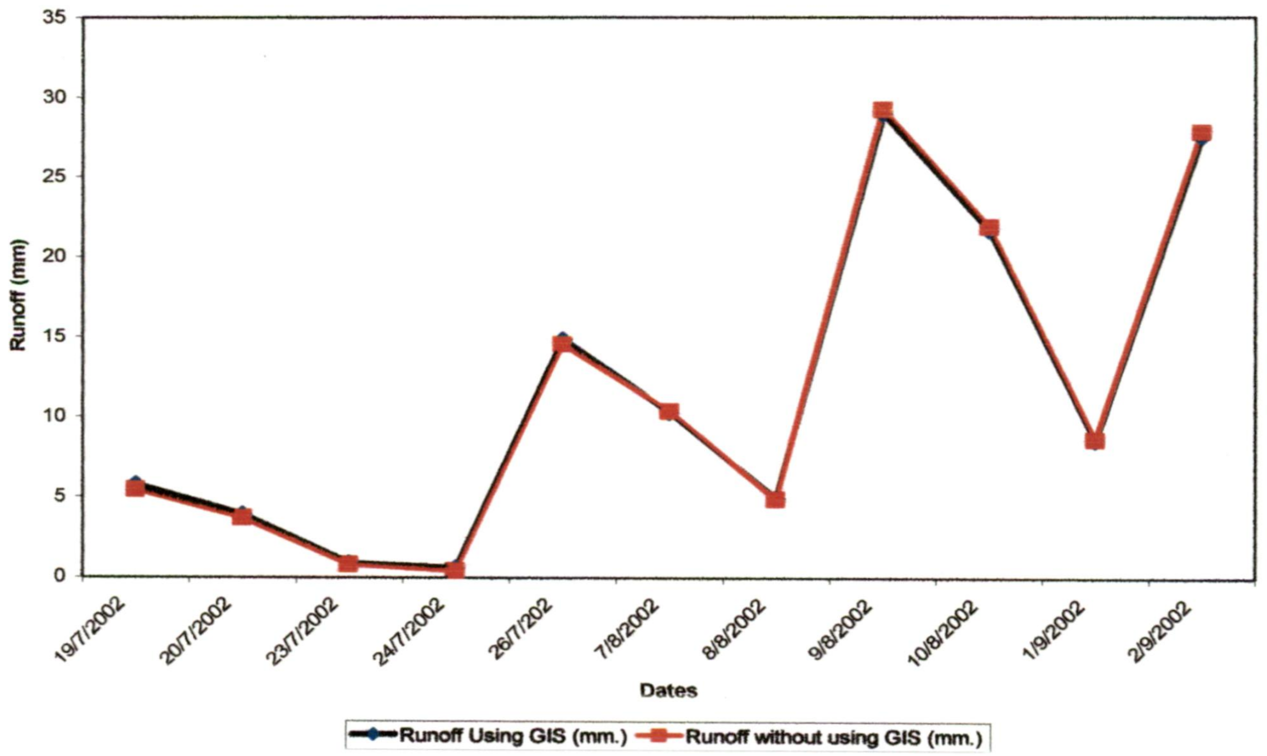


Fig. 7.8 Comparison of Runoff with and without GIS for the year 2003 and 2004 for Deshgaon Watershed



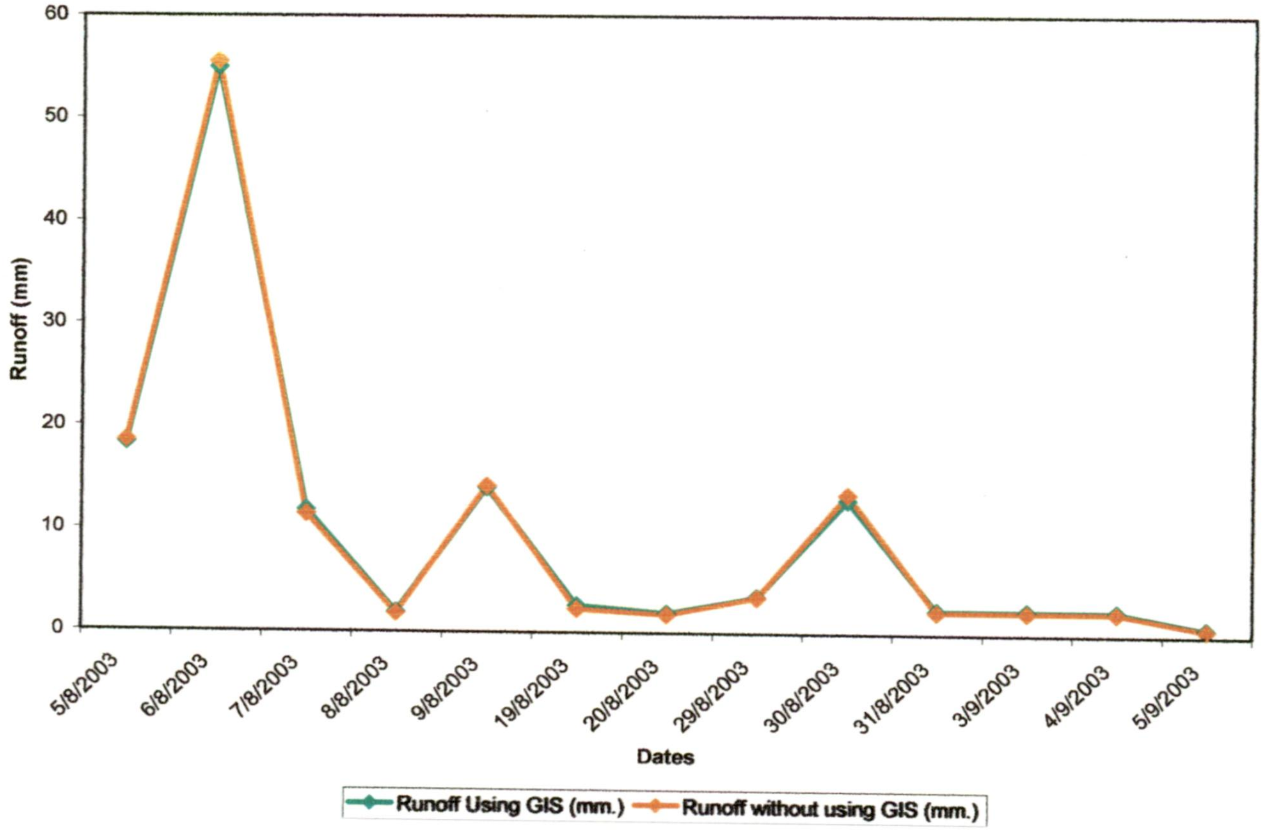


Fig. 7.9 Comparison of Runoff with and without GIS for the year 2002 and 2003 for Ozarjkhed Watershed

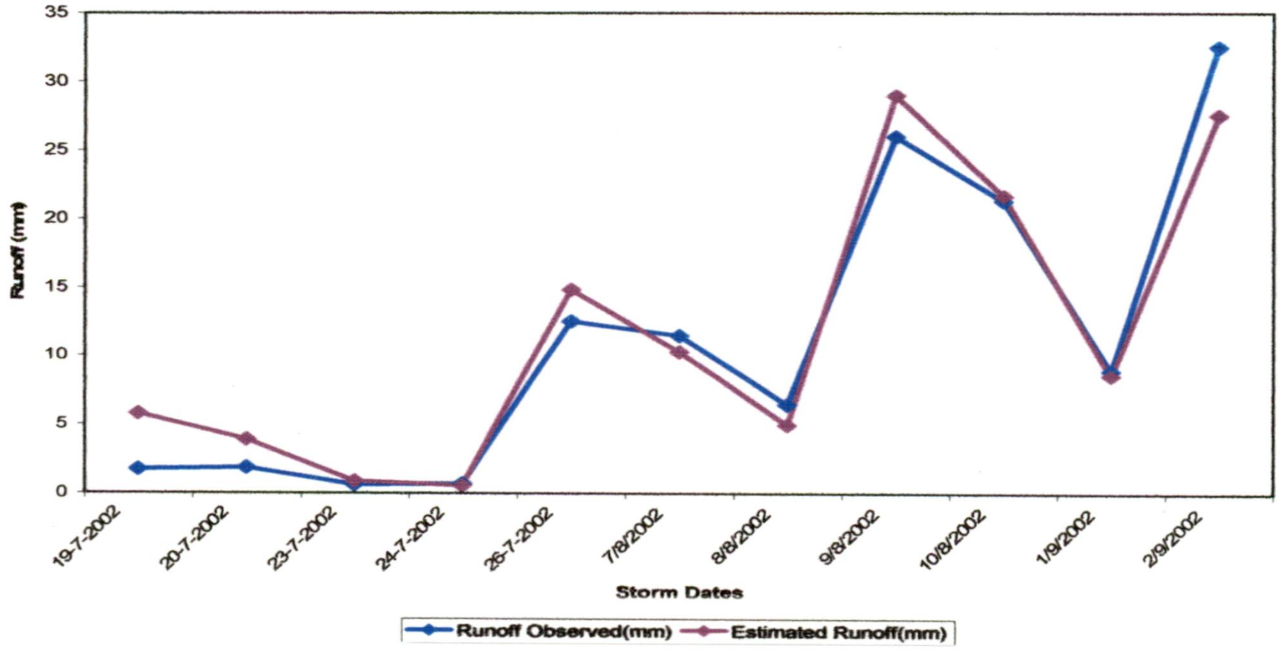


Fig. 7.10 Comparison of Estimated and Observed Runoff for Ozarkhed Watershed for year 2002.

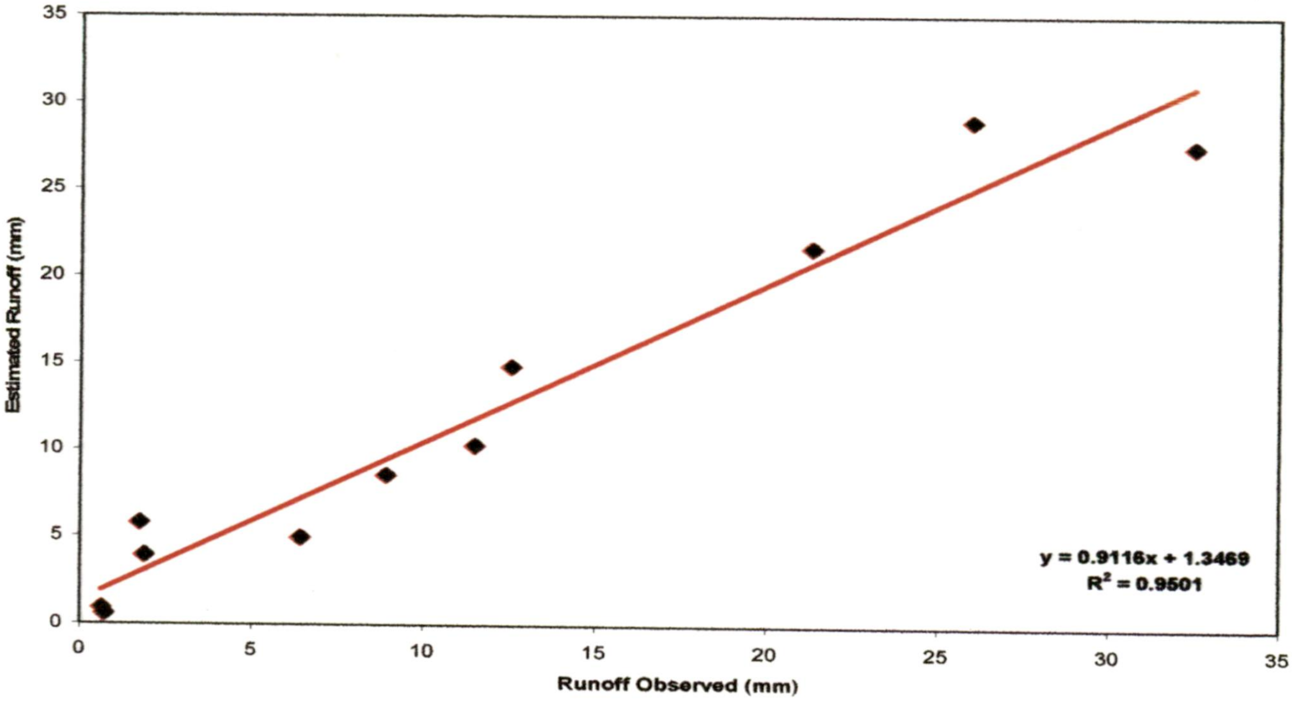


Fig 7.11 Correlation of Estimated Runoff with Observed Runoff

7.4 SENSITIVITY ANALYSIS

Sensitivity Analysis is done in the present study to know the importance of each parameter that affect the direct runoff. In the SCS method direct runoff depends mainly on Curve Number, AMC, λ (initial abstraction ratio) etc,. Out of these parameters Curve Number (CN) is the most important one and hence the same is chosen for the sensitivity analysis.

For the sensitivity analysis the value of curve number is changed by a defined percentage and percent change in the output (runoff) is studied for different value of storms. The results of the sensitivity analysis are presented in Table 7.61 to 7.66.

It is found from the study that;

i. For a given storm, the smaller the value of CN, the larger is the effect of the variation of CN on runoff and vice versa.
ii. For a given Curve Number, the variation in output (runoff) is small for rainfall greater than 100mm.
iii. Variation in output (runoff) is small for CN ranges from 70 to 100.

From the study it is inferred that Curve Number is very sensitive for SCS model. Therefore, for better calculation of runoff its value should be determined very accurately by considering the land use, soil group, AMC of the watershed. Because even misjudgment or drastic change in AMC or land use over a short period of time may cause a serious error in the calculation of CN value and hence estimated runoff (Q). Sensitivity of runoff to Runoff Curve Number (CN) is shown in Fig. 7.12.

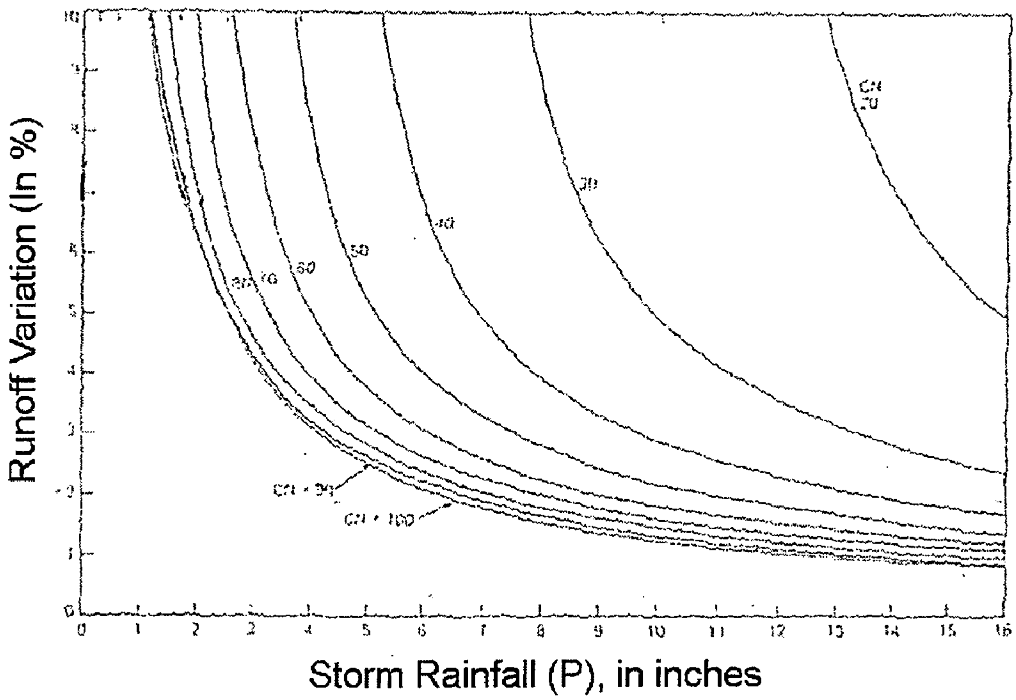


Fig. 7.12 Sensitivity of Runoff to Runoff Curve Number (CN)

Table 7.61 Sensitivity of CN (for CN=90) on Runoff Variation (in %)

Rainfall (mm.)	Variation in CN				
	1%	2%	3%	4%	5%
20	13.91	29.47	46.9	66.48	88.56
30	9.28	19.34	30.25	42.08	54.98
40	7.10	14.65	22.69	31.25	40.37
50	5.79	11.87	18.26	24.98	32.04
60	4.90	10.01	15.32	20.85	26.62
70	4.26	8.66	13.21	17.92	22.78
80	3.77	7.64	11.62	15.72	19.93
90	3.38	6.84	10.38	14.00	17.71
100	3.06	6.19	9.38	12.63	15.94
125	2.49	5.01	7.56	10.15	12.77
150	2.10	4.21	6.34	8.48	10.65
175	1.81	3.63	5.46	7.30	9.13
200	1.59	3.19	4.79	6.39	8.00
225	1.42	2.85	4.27	5.69	7.11
250	1.28	2.57	3.85	5.13	6.40
275	1.17	2.34	3.51	4.67	5.82
300	1.08	2.15	3.22	4.28	5.34

Table 7.62 Sensitivity of CN (for CN=80) on Runoff Variation (in %)

Rainfall (mm.)	Variation in CN 1%	2%	3%	4%	5%
20	22.31	47.38	75.42	106.61	141.2
30	11.23	25.32	40.23	58.67	76.56
40	7.64	15.67	24.12	33.0	42.34
50	6.04	12.33	18.88	25.70	32.80
60	4.06	10.29	15.69	21.28	27.06
70	4.38	8.88	13.51	18.27	23.16
80	3.87	7.84	11.90	16.06	20.31
90	3.48	7.03	10.65	14.35	18.12
100	3.16	6.38	9.66	13.00	16.38
125	2.59	5.21	7.85	10.53	13.25
150	2.20	4.41	6.64	8.88	11.14
175	1.91	3.83	5.75	7.69	9.63
200	1.69	3.38	5.08	6.78	8.48
225	1.51	3.03	4.55	6.07	7.58
250	1.37	2.75	4.12	5.49	6.86
275	1.26	2.51	3.77	5.01	6.26
300	1.16	2.32	3.47	4.62	5.76

Table 7.63 Sensitivity of CN (for CN=70) on Runoff Variation (in %)

Rainfall (mm.)	Variation in CN 1%	2%	3%	4%	5%
30	21.2	44.6	70.26	98.25	128.62
40	10.53	21.67	33.41	45.77	58.78
50	7.40	15.11	23.13	31.46	40.11
60	5.86	11.91	18.15	24.59	31.22
70	4.92	9.97	15.15	20.47	25.92
80	4.27	8.64	13.11	17.68	22.34
90	3.80	7.67	11.62	15.64	19.73
100	3.43	6.92	10.46	14.07	14.72
125	2.78	5.61	8.46	11.34	14.25
150	2.36	4.4	7.14	9.56	12.00
175	2.06	4.12	6.20	8.28	10.38
200	1.82	3.65	5.49	7.33	9.17
225	1.64	3.28	4.93	6.57	8.22
250	1.49	2.98	4.48	5.97	7.45
275	1.37	2.74	4.10	5.46	6.82
300	1.26	2.53	3.79	5.04	6.29

Table 7.64 Sensitivity of CN (for CN=60) on Runoff Variation (in %)

Rainfall (mm.)	Variation in CN 1%	2%	3%	4%	5%
30	No runoff as P < 0.2*S				
40	31.72	67.81	108.28	153.17	202.48
50	12.70	26.15	40.37	55.35	71.10
60	8.37	17.08	26.12	35.5	45.21
70	6.43	13.05	19.87	26.88	34.08
80	5.30	10.73	16.3	21.99	27.80
90	4.56	9.21	13.96	18.80	23.73
100	4.03	8.13	12.3	16.53	20.84
125	3.17	6.38	9.63	12.92	16.24
150	2.65	5.32	8.02	10.73	13.47
175	2.29	4.60	6.92	9.25	11.59
200	2.03	4.07	6.11	8.15	10.21
225	1.82	3.65	5.48	7.31	9.14
250	1.66	3.32	4.98	6.63	8.29
275	1.52	3.04	4.56	6.08	7.60
300	1.41	2.81	4.22	5.62	7.01

Table 7.65 Sensitivity of CN (for CN=50) on Runoff Variation (in %)

Rainfall (mm.)	Variation in CN 1%	2%	3%	4%	5%
50	No runoff as P < 0.2*S				
60	24.97	52.61	82.90	115.80	151.30
70	12.40	25.48	39.23	53.63	68.69
80	8.55	17.41	26.58	36.06	45.84
90	6.66	13.50	20.53	27.74	35.12
100	5.53	11.18	16.95	22.84	28.85
125	4.00	8.06	12.18	16.35	20.57
150	3.21	6.45	9.73	13.03	16.36
175	2.71	5.45	8.20	10.97	13.76
200	2.37	4.75	7.15	9.55	11.96
225	2.11	4.24	6.36	8.49	10.03
250	1.91	3.83	5.75	7.67	9.59
275	1.75	3.50	5.26	7.01	8.70
300	1.62	3.24	4.85	6.46	8.07

Table 7.66 Sensitivity of CN (for CN=40) on Runoff Variation (in %)

Rainfall (mm.)	Variation in CN 1%	2%	3%	4%	5%
75	No runoff as P < 0.2*S				
80	79.47	181.28	305.01	450.25	616.62
90	20.59	42.95	67.05	92.86	120.35
100	12.24	25.1	38.56	52.62	67.27
125	6.46	13.08	19.86	26.78	33.85
150	4.59	9.25	13.98	18.77	23.63
175	3.64	7.33	11.05	14.80	18.59
200	3.06	6.15	9.26	12.39	15.54
225	2.67	5.35	8.05	10.75	13.47
250	2.38	4.76	7.16	9.55	11.96
275	2.15	4.31	6.47	8.63	10.80
300	1.97	3.94	5.92	7.89	9.87

CHAPTER - 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

For designing any hydrological structure, knowledge of peak and total runoff is of utmost importance. Estimation of runoff for 'Ungauged Watershed' is a serious concern for the hydrologist in the developing countries where the cost and time to develop reliable networks of gauging station are too high. Conventional methods of runoff estimation are more costly, time consuming and difficult. Even if it is available, these data are inadequate for the purpose of design and operation of water resources systems. In such cases remote sensing data combined with GIS are of great use for the estimation of relevant hydrological data, because these data are in near real time, less time consuming and more cost effective.

Remote Sensing and GIS can serve as model input for the determination of river catchment characteristics, such as land use/ land cover, geomorphology, slope, drainage etc. Using remote sensing data both spatial and temporal patterns of the land-cover can be derived. GIS offers the potential to increase the degree of definition of spatial sub-units, in number and in descriptive detail. Once the base maps are stored in digital form in the computer, repetitive analysis for different rainfalls (daily, weekly, monthly etc.) can be done for obtaining runoff. It is also easy to update the base maps by incorporating changes. Effects on runoff generating potential due to change in land use plans can give an insight to the planners for future development activities in the basin.

On the basis of the study following conclusions can be drawn.

i. Remote Sensing combined with GIS and SCS model makes the runoff estimation more accurate, reliable, cost effective, in near real time, and fast with respect to the conventional method.

ii. GIS emerges as an efficient tool for the preparation of most of the input data required by the SCS Curve Number Model.

iii. The runoff estimates using SCS Curve Number model are comparable with the runoff measured by the conventional method.

iv. For Deshgaon watershed comparison of runoff with and without GIS ranges in general from 0.34% to 60.3% and 0.8% to 37.83% for the year 2003 and 2004 respectively.

v. Similarly for Ozarkhed watershed comparison of runoff with and without GIS ranges from 0.58% to 28.26% and 0.77% to 15.25% for the year 2002 and 2003 respectively.

vi. Estimated runoff is compared with observed runoff for Ozarkhed watershed for the year 2002 and it was found that most of the estimated runoff matches with the observed runoff and the percentage variation ranges from 2.71% to 26.15% which are within the acceptable range.

vii. Estimated and observed runoff were found to be in good correlation (R^2 = 0.95) which indicates that GIS can be a good substitute for analytical method for runoff estimation.

viii. This approach could be applied in other Indian watersheds for planning of various conservation measures.

8.2 RECOMMENDATIONS AND FUTURE SCOPE

SCS Curve Number equation is an empirical equation that transforms rainfall frequency to runoff frequency. In this study SCS model developed by the United States Department of Agriculture (USDA) is used because of its simple mathematical relationship and low data requirement.

Following are the Recommendations;

i. Soil and water is dynamic in nature. A number of parameters such as soil permeability, texture, structure, class, drainability, field capacity of soil, evapotranspiration, etc. need to be studied and should be incorporated in runoff model.

ii. Slope of the watershed is an important parameter affecting direct runoff volume. Lower the average slope of the watershed, lesser is the flow obtained at the outlet due to higher travel time through the watershed. Therefore, original SCS CN equation should be modified for the slope.

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LIST OF MODELS AND THEIR APPLICATION AREA

OPSET Model	: Continuous stream flow simulation model. It is a self-calibrating model (ESMA type)
TANK Model	: Rainfall-Runoff model (ISMA type)
HEC-1 Model	: Rainfall-Runoff model (Event based)
NETWORK Model	: Flow routing model for river network
DWOPER	: Dynamic Wave Operational Model
WEPP Model	: Soil erosion, Sediment yield model (process based).
QUAL2 Model	: Water quality, pollutant transport model
SCS Model	: Rainfall-Runoff model (Event based)
WYM	: Water Yield Model (Monthly basis)
KWM	: Kentucky Watershed Model: rainfall-runoff
SWM	: Stanford Watershed Model: rainfall-runoff
SWAT	: Soil and Water Assessment Tool: Distributed parameter Model (IIT Delhi)
SWMM	: Storm Water Management Model
MIKE II	: One dimensional model for River basin modelling
SHE	: System Hydrological European: Distributed parameter Model
RIBASIM	: River Basin Simulation Model
HYMOS	: Hydrological Modelling System
DAMBRK	: Hydraulic routing of a flood wave due to a breach in dam

APPENDIX II - A

Rainfall Data of Village Deshgaon (Year 2003)

Date	Rainfall(mm.)	Date	Rainfall(mm.)	Date	Rainfall(mm.)
1-Jun-03	0.0	18-Jul-03	0.8	3-Sep-03	1.5
2-Jun-03	0.0	19-Jul-03	0.0	4-Sep-03	0.0
3-Jun-03	0.0	20-Jul-03	0.0	5-Sep-03	0.0
4-Jun-03	0.0	21-Jul-03	22.0	6-Sep-03	0.0
5-Jun-03	0.0	22-Jul-03	3.2	7-Sep-03	0.0
6-Jun-03	0.0	23-Jul-03	1.5	8-Sep-03	0.0
7-Jun-03	0.0	24-Jul-03	2.3	9-Sep-03	0.0
8-Jun-03	0.0	25-Jul-03	6.3	10-Sep-03	0.0
9-Jun-03	0.0	26-Jul-03	5.2	11-Sep-03	0.0
10-Jun-03	0.0	27-Jul-03	55.2	12-Sep-03	0.0
11-Jun-03	0.0	28-Jul-03	2.1	13-Sep-03	0.0
12-Jun-03	0.0	29-Jul-03	1.2	14-Sep-03	0.0
13-Jun-03	0.0	30-Jul-03	0.0	15-Sep-03	3.4
14-Jun-03	5.4	31-Jul-03	1.0	16-Sep-03	0.0
15-Jun-03	0.0	1-Aug-03	0.0	17-Sep-03	1.5
16-Jun-03	22.2	2-Aug-03	0.0	18-Sep-03	14.2
17-Jun-03	0.0	3-Aug-03	6.0	19-Sep-03	8.2
18-Jun-03	0.0	4-Aug-03	2.2	20-Sep-03	0.0
19-Jun-03	0.0	5-Aug-03	0.0	21-Sep-03	0.0
20-Jun-03	24.1	6-Aug-03	0.0	22-Sep-03	3.5
21-Jun-03	20.2	7-Aug-03	0.0	23-Sep-03	1.2
22-Jun-03	96.3	8-Aug-03	0.0	24-Sep-03	100.5
23-Jun-03	3.1	9-Aug-03	18.0	25-Sep-03	0.0
24-Jun-03	1.2	10-Aug-03	0.0	26-Sep-03	10.2
25-Jun-03	0.5	11-Aug-03	2.1	27-Sep-03	12.1
26-Jun-03	0.0	12-Aug-03	0.0	28-Sep-03	25.2
27-Jun-03	0.0	13-Aug-03	0.0	29-Sep-03	7.1
28-Jun-03	0.0	14-Aug-03	0.0	30-Sep-03	0.0
29-Jun-03	0.0	15-Aug-03	0.0	1-Oct-03	0.0
30-Jun-03	0.0	16-Aug-03	0.0	2-Oct-03	0.0
1-Jul-03	6.8	17-Aug-03	0.0	3-Oct-03	0.0
2-Jul-03	0.0	18-Aug-03	0.0	4-Oct-03	0.0
3-Jul-03	0.0	19-Aug-03	1.0	5-Oct-03	0.0
4-Jul-03	0.0	20-Aug-03	0.0	6-Oct-03	0.0
5-Jul-03	0.5	21-Aug-03	0.0	7-Oct-03	0.0
6-Jul-03	0.0	22-Aug-03	45.2	8-Oct-03	0.0
7-Jul-03	0.0	23-Aug-03	105.3	9-Oct-03	0.0
8-Jul-03	17.5	24-Aug-03	3.1	10-Oct-03	0.0
9-Jul-03	0.0	25-Aug-03	1.2	11-Oct-03	0.0
10-Jul-03	0.0	26-Aug-03	0.0	12-Oct-03	0.0
11-Jul-03	10.2	27-Aug-03	1.0	13-Oct-03	0.0
12-Jul-03	8.1	28-Aug-03	5.2	14-Oct-03	0.0
13-Jul-03	0.0	29-Aug-03	0.0	15-Oct-03	0.0
14-Jul-03	0.0	30-Aug-03	0.0		
15-Jul-03	22.2	31-Aug-03	0.0		
16-Jul-03	0.0	1-Sep-03	0.0		
17-Jul-03	18.5	2-Sep-03	0.0		

Rainfall Data of Village Deshgaon (Year 2004)

Date	Rainfall(mm.)	Date	Rainfall(mm.)	Date	Rainfall(mm.)
1-Jun-04	0.0	18-Jul-04	74.8	3-Sep-04	0.0
2-Jun-04	0.0	19-Jul-04	0.2	4-Sep-04	0.0
3-Jun-04	0.0	20-Jul-04	0.0	5-Sep-04	0.0
4-Jun-04	0.0	21-Jul-04	0.0	6-Sep-04	0.0
5-Jun-04	0.0	22-Jul-04	0.0	7-Sep-04	0.0
6-Jun-04	0.7	23-Jul-04	0.0	8-Sep-04	0.0
7-Jun-04	10.4	24-Jul-04	18.0	9-Sep-04	0.0
8-Jun-04	5.1	25-Jul-04	150.6	10-Sep-04	0.0
9-Jun-04	25.2	26-Jul-04	0.0	11-Sep-04	0.0
10-Jun-04	8.8	27-Jul-04	0.0	12-Sep-04	0.0
11-Jun-04	0.0	28-Jul-04	13.0	13-Sep-04	0.0
12-Jun-04	12.7	29-Jul-04	0.0	14-Sep-04	0.0
13-Jun-04	29.1	30-Jul-04	30.0	15-Sep-04	0.0
14-Jun-04	0.0	31-Jul-04	0.0		
15-Jun-04	0.0	1-Aug-04	0.0		
16-Jun-04	0.0	2-Aug-04	0.0		
17-Jun-04	0.0	3-Aug-04	0.0		
18-Jun-04	0.0	4-Aug-04	80.0		
19-Jun-04	0.0	5-Aug-04	42.0		
20-Jun-04	0.0	6-Aug-04	12.5		
21-Jun-04	0.0	7-Aug-04	7.0		
22-Jun-04	0.0	8-Aug-04	5.0		
23-Jun-04	0.0	9-Aug-04	0.0		
24-Jun-04	0.0	10-Aug-04	0.0		
25-Jun-04	0.0	11-Aug-04	50.0		
26-Jun-04	0.0	12-Aug-04	40.0		
27-Jun-04	0.0	13-Aug-04	0.0		
28-Jun-04	0.0	14-Aug-04	0.0		
29-Jun-04	0.0	15-Aug-04	0.0		
30-Jun-04	0.0	16-Aug-04	0.0		
1-Jul-04	0.0	17-Aug-04	0.0		
2-Jul-04	10.2	18-Aug-04	0.0		
3-Jul-04	13.4	19-Aug-04	64.0		
4-Jul-04	0.0	20-Aug-04	0.0		
5-Jul-04	0.0	21-Aug-04	50.0		
6-Jul-04	0.0	22-Aug-04	0.0		
7-Jul-04	0.0	23-Aug-04	0.0		
8-Jul-04	0.0	24-Aug-04	0.0		
9-Jul-04	0.0	25-Aug-04	0.0		
10-Jul-04	30.2	26-Aug-04	0.0		
11-Jul-04	0.0	27-Aug-04	0.0		
12-Jul-04	0.0	28-Aug-04	0.0		
13-Jul-04	0.0	29-Aug-04	0.0		
14-Jul-04	0.0	30-Aug-04	0.0		
15-Jul-04	0.0	31-Aug-04	0.0		
16-Jul-04	0.0	1-Sep-04	0.0		
17-Jul-04	0.0	2-Sep-04	0.0		

RAINFALL IN OZARKHED WATERSHED
(YEAR 2003)

Date	Rainfall (mm.)	Date	Rainfall (mm.)	Date	Rainfall (mm.)
1-Jun-03	0.0	15-Jul-03	3.1	28-Aug-03	6.0
2-Jun-03	0.0	16-Jul-03	0.9	29-Aug-03	21.0
3-Jun-03	0.0	17-Jul-03	69.0	30-Aug-03	38.0
4-Jun-03	0.0	18-Jul-03	13.0	31-Aug-03	18.0
5-Jun-03	0.0	19-Jul-03	3.0	1-Sep-03	17.0
6-Jun-03	0.0	20-Jul-03	0.5	2-Sep-03	1.0
7-Jun-03	0.0	21-Jul-03	48.0	3-Sep-03	18.0
8-Jun-03	0.0	22-Jul-03	11.0	4-Sep-03	18.0
9-Jun-03	0.0	23-Jul-03	0.0	5-Sep-03	13.0
10-Jun-03	0.0	24-Jul-03	47.0	6-Sep-03	2.0
11-Jun-03	0.0	25-Jul-03	27.0	7-Sep-03	18.0
12-Jun-03	0.0	26-Jul-03	46.0	8-Sep-03	1.0
13-Jun-03	0.0	27-Jul-03	99.0	9-Sep-03	1.0
14-Jun-03	0.0	28-Jul-03	175.0	10-Sep-03	7.0
15-Jun-03	0.1	29-Jul-03	5.0	11-Sep-03	95.0
16-Jun-03	8.2	30-Jul-03	1.0	12-Sep-03	5.0
17-Jun-03	0.6	31-Jul-03	0.0	13-Sep-03	24.0
18-Jun-03	17.9	1-Aug-03	4.0	14-Sep-03	15.0
19-Jun-03	34.1	2-Aug-03	9.0	15-Sep-03	1.0
20-Jun-03	22.2	3-Aug-03	14.0	16-Sep-03	0.0
21-Jun-03	90.5	4-Aug-03	57.0	17-Sep-03	0.0
22-Jun-03	63.5	5-Aug-03	45.0	18-Sep-03	0.0
23-Jun-03	53.9	6-Aug-03	89.0	19-Sep-03	0.0
24-Jun-03	6.6	7-Aug-03	35.0	20-Sep-03	7.0
25-Jun-03	0.7	8-Aug-03	17.0	21-Sep-03	0.5
26-Jun-03	17.8	9-Aug-03	39.0	22-Sep-03	9.0
27-Jun-03	3.4	10-Aug-03	3.0	23-Sep-03	17.0
28-Jun-03	53.2	11-Aug-03	2.0	24-Sep-03	5.0
29-Jun-03	31.2	12-Aug-03	12.0	25-Sep-03	22.0
30-Jun-03	75.1	13-Aug-03	2.0	26-Sep-03	21.0
1-Jul-03	4.6	14-Aug-03	17.0	27-Sep-03	79.0
2-Jul-03	2.7	15-Aug-03	32.0	28-Sep-03	27.0
3-Jul-03	0.9	16-Aug-03	2.0	29-Sep-03	26.0
4-Jul-03	2.3	17-Aug-03	23.0	30-Sep-03	0.0
5-Jul-03	1.5	18-Aug-03	3.0	1-Oct-03	0.0
6-Jul-03	0.0	19-Aug-03	19.0	2-Oct-03	0.0
7-Jul-03	2.7	20-Aug-03	17.0	3-Oct-03	0.0
8-Jul-03	9.1	21-Aug-03	5.0	4-Oct-03	0.0
9-Jul-03	30.9	22-Aug-03	4.0	5-Oct-03	0.0
10-Jul-03	14.5	23-Aug-03	10.0	6-Oct-03	0.0
11-Jul-03	0.2	24-Aug-03	15.0	7-Oct-03	0.0
12-Jul-03	6.7	25-Aug-03	47.0	8-Oct-03	23.0
13-Jul-03	3.4	26-Aug-03	12.0	9-Oct-03	0.0
14-Jul-03	1.6	27-Aug-03	5.0	10-Oct-03	8.3

RAINFALL IN OZARKHED WATERSHED
(YEAR 2002)

Date	Rainfall (mm.)	Date	Rainfall (mm.)	Date	Rainfall (mm.)
1-Jun-02	0.0	15-Jul-02	3.1	28-Aug-02	2.5
2-Jun-02	0.0	16-Jul-02	9.9	29-Aug-02	7.9
3-Jun-02	0.0	17-Jul-02	14.5	30-Aug-02	0.9
4-Jun-02	0.0	18-Jul-02	4.8	31-Aug-02	47.2
5-Jun-02	0.0	19-Jul-02	44.4	1-Sep-02	30.5
6-Jun-02	0.0	20-Jul-02	21.5	2-Sep-02	56.9
7-Jun-02	0.0	21-Jul-02	3.1	3-Sep-02	14.9
8-Jun-02	0.0	22-Jul-02	6.0	4-Sep-02	3.9
9-Jun-02	0.0	23-Jul-02	13.6	5-Sep-02	25.6
10-Jun-02	0.0	24-Jul-02	12.0	6-Sep-02	2.7
11-Jun-02	3.0	25-Jul-02	5.0	7-Sep-02	1.3
12-Jun-02	9.7	26-Jul-02	63.8	8-Sep-02	0.0
13-Jun-02	0.2	27-Jul-02	12.6	9-Sep-02	0.2
14-Jun-02	7.1	28-Jul-02	3.5	10-Sep-02	0.0
15-Jun-02	0.2	29-Jul-02	0.0	11-Sep-02	0.1
16-Jun-02	0.0	30-Jul-02	0.4	12-Sep-02	0.0
17-Jun-02	7.4	31-Jul-02	0.0	13-Sep-02	0.0
18-Jun-02	2.3	1-Aug-02	0.0	14-Sep-02	0.0
19-Jun-02	2.3	2-Aug-02	0.1	15-Sep-02	0.1
20-Jun-02	5.7	3-Aug-02	14.4	16-Sep-02	0.0
21-Jun-02	34.3	4-Aug-02	6.6	17-Sep-02	0.0
22-Jun-02	1.4	5-Aug-02	5.9	18-Sep-02	7.0
23-Jun-02	23.0	6-Aug-02	52.9	19-Sep-02	2.6
24-Jun-02	55.7	7-Aug-02	33.3	20-Sep-02	0.1
25-Jun-02	46.9	8-Aug-02	23.9	21-Sep-02	7.5
26-Jun-02	88.7	9-Aug-02	58.6	22-Sep-02	0.0
27-Jun-02	156.2	10-Aug-02	49.4	23-Sep-02	0.0
28-Jun-02	146.1	11-Aug-02	10.5	24-Sep-02	0.0
29-Jun-02	115.4	12-Aug-02	18.9	25-Sep-02	0.0
30-Jun-02	52.3	13-Aug-02	12.9	26-Sep-02	0.0
1-Jul-02	2.7	14-Aug-02	10.2	27-Sep-02	0.8
2-Jul-02	0.5	15-Aug-02	6.2	28-Sep-02	0.0
3-Jul-02	1.9	16-Aug-02	8.4	29-Sep-02	0.7
4-Jul-02	0.4	17-Aug-02	1.5	30-Sep-02	0.0
5-Jul-02	1.1	18-Aug-02	20.7	1-Oct-02	0.0
6-Jul-02	0.0	19-Aug-02	6.8	2-Oct-02	0.0
7-Jul-02	0.6	20-Aug-02	6.3	3-Oct-02	0.0
8-Jul-02	4.7	21-Aug-02	0.6	4-Oct-02	0.0
9-Jul-02	4.7	22-Aug-02	7.1	5-Oct-02	0.0
10-Jul-02	0.2	23-Aug-02	4.4	6-Oct-02	0.0
11-Jul-02	0.0	24-Aug-02	9.4	7-Oct-02	0.0
12-Jul-02	0.0	25-Aug-02	58.8	8-Oct-02	0.0
13-Jul-02	0.0	26-Aug-02	48.1	9-Oct-02	0.0
14-Jul-02	6.7	27-Aug-02	1.8	10-Oct-02	0.0