LAND RESOURCE MANAGEMENT: A CASE STUDY OF SONG BASIN, UTTARANCHAL

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MASTER OF PHILOSOPHY

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DECLARATION

I, **PAYAL SRIVASTAVA**, declare that the dissertation entitled "**LAND RESOURCE MANAGEMENT: A CASE STUDY OF SONG BASIN, UTTARANCHAL**" for the degree of **MASTER OF PHILOSOPHY** is my bonafide work and may be placed before the examiners for evaluation.

PAYAL SRIVASTAVA

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PAYAL SRIVASTAVA

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Dedicated

in the loving memory of

my mother, Late Mrs. Santosh Srivastava,

and my forever friend,

Late Ms. Anshu Srivastava.

1. AN INTRODUCTION TO THE THEME

1.1 INTRODUCTION

According to Zimmermann (1972) "Resources are the bases of both opulence and security; these are the foundations of power and wealth". Without land, water and air resources, one cannot dream of agriculture. And without minerals we cannot think of any industry.

The word 'resource' may be defined as the "means of attaining given ends". These ends may be the satisfaction of individual wants, or the attainment of social objectives. Thus, anything useful or anything having the attribute of utility may be termed as 'resource' including many more things. They include not only material things such as land, forests, coal, machinery etc. but also intangible things like good health, knowledge, freedom, social harmony etc. All these things have the attribute of utility. Similarly, water, air, sunshine, etc. are all resources. The sum total of all the material components of the environment, both biotic and abiotic, constitutes natural resources. Resources can thus be defined as that portion of natural stock which is conceived by human as resource and for which he/she may develop know-how for purposive utilization. Resource is dynamic and increases in response to increased knowledge, improved arts, expanding science and changing individual wants and social objectives.

Initially, humans were the collectors of resources because of abundance and their needs too were limited. As people increased in number over the years and armed themselves with new tools and techniques, their resource base also increased. Thus they became the exploiters of nature. Resources are often identified with tangible natural substances. These are the elements of the biophysical environment but become resource only when these are preserved e.g., coal was always there but became a resource only when realized as a source of energy. Man knew nothing about these and their usefulness until recently, and therefore these were mere neutral stuff. Changing human needs and social objectives give rise to resources. Thus, resource creation is a continuous process and the requirement changes with change in human civilizations.

People have been using biophysical environment to satisfy their needs. This process is called 'resource utilization'. As cultural evolution proceeds, new resources and better methods of utilization are invented. Resource utilization thus means the actual use of the natural resources by transforming the 'neutral stuff' into a commodity or service to serve human needs. Resources help us in two ways: a) these provide material, energy and favourable condition for development; b) these constitute the natural environment in which man and other life forms live that consist of air, water, forests and various life forms which are essential for human survival and development. Resources are of different kinds – some are **exhaustible** while others are **inexhaustible**, or in other words, some are **renewable** while others are **nonrenewable**.

Available resources are the base for economic prosperity of any nation. Different countries are at different levels of economic development primarily because of their resources and resource utilization level. Wherever man has gained consciousness about planned and rational exploitation of resources, he has achieved high levels of economic prosperity. On the other hand, where he still lacks resource consciousness and thus exploits them recklessly, he has not been able to rise above the status of an animal. Reckless exploitation of resources to gain temporary personal advantage, may deny the society long term benefits of the resources provided to him by the nature. Thus the society has to take care of basic resources like land, water, oil, forests etc., and to plan accordingly that these resources provide a lasting benefit at large. Hence there is a need for resource management. Resource management emphasises on the wise use aimed at meeting current human needs without destroying any ecological balance, thus not jeopardising the needs of the future generations. It thus involves policies or practices regarding how resources are allocated under given conditions for development over space and time, based on needs, aspirations and desires within the framework of his or her legal and administrative arrangements. Resource management thus involves strategic action in evolving computation of tactics, methods and variety of objectives. In recent years, it is becoming increasingly concerned with the protection and enhancement of environmental quality and the establishment of new guidelines for the public use of common property such as air, water and landscape.

1.1.1 Land resource and its management

The FAO (1995) defined **Land** as:

> "A delineable area of the earth's terrestrial surface, encompassing all attributes of the biosphere immediately above or below this surface, including those of the near surface climate, the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes, and swamps), near-surface sedimentary layers and associated groundwater reserve, the plant and animal populations, the human settlement pattern and physical results of past and present human activity (terracing, water storage or drainage structures, roads, buildings, etc.)".

This definition encompasses at least eight functions of land that go beyond the production of food:

- It is the basis of a variety of life support systems, through the production of food, fodder, fibre, fuel, timber and other biotic materials for human use, either directly or through animal husbandry including aquaculture and inland and coastal fishery.
- Land is the basis of terrestrial bio-diversity by providing habitats and gene reserves for plants, animals and micro-organisms, above and below ground.
- Land acts as a source and sink of greenhouse gases and is a co-determinant of the global energy balance (reflection, absorption and transformation of radiated energy of the sun).
- Land regulates the storage and flow of surface- and groundwater resources, and influences their quality.
- Land is a storehouse of raw materials and minerals.
- Land retains, filters, buffers and transforms hazardous compounds.
- Land provides the space for human settlements, industrial plants and social activities such as sports and recreation, and connective space for transport of people, inputs and produce, and for the movement of plants and animals between natural ecosystems.
- Land stores and protects the evidence of the cultural history of mankind, and is a source of information on past climatic conditions and past land uses.

Land is a vital finite natural resource in any region, and an essential base necessary for production of basic needs such as food, fibre and fuel etc. The land resource holds potential for many different uses. Forest and woodlands are important regulators of hydrological cycle. These lands also provide habitat for wildlife and recreation opportunities. Much of the meat production comes from cattle and livestock reared on pastures and rangeland. Land requirement for cities, industries, highways, solid waste disposal and many other non-agricultural land uses for expanding urban societies are at large extent satisfied at the expense of forest, pasture and woodland. But the land shifting to non-agricultural uses includes often much of the cropland which is the fourth general landuse category. Each of the land uses is subject to change in terms of both quality (e.g. cropland changes in response to irrigation, fertilization and new agronomic technology) and quantity (increasing or diminishing areas).

The word "land resource" implies not only the soils, vegetation and other attributes of land surface, but also the water (other than that stored in deep aquifers and large reservoirs). The land resource has come under mounting pressure throughout the world for an increased demand of food and water on the one hand and their accelerated degradation on the other. The ability of land to produce is limited. The limits to production are set by climate, soil and landform conditions and the use and management applied to the land. Accordingly, knowledge on land resource endowment and its potential is an essential prerequisite for optimum land uses and subsequent long term development.

Land is an extremely crucial input in a populous agrarian economy; it is the basic foundation for the supply of fodder, fuel, fruit and fiber. Production of food is the most important basic activity for any country. It requires nutrient rich soil, assured water at various stages of production, conservation of soil and water and moisture retention capacity of soil. Other aspects that enhance the process include more infiltration of water in the ground raising water table, increase in soil moisture level etc. Moreover it helps in maintaining healthier and richer ecological balance.

Land has badly suffered in the post-independence period. The quest for economic development in order to provide necessities of life like food, fuel, clothing, education, healthcare etc. to the growing population has led to the reckless exploitation of resources. As more land is required for agriculture and other uses for the growing population, marginal lands which were earlier used for growing village forest, reserved and protected forests adjacent to village are being diverted to housing, producing food, building irrigation and multipurpose dams and mining. Consequently, a major proportion of reserved and protected forest is being lost. This has implication both for climate and ecology sustenance. Another adverse consequence of neglecting land conservation is that more sediment flows into our water reservoirs, therefore reducing life substantially.

1.1.2 Watershed approach in resource management

"The watershed is a natural unit of land which collects precipitation and delivers runoff to a common outlet. It may be represented by an electrical analogy which consists of elements which may be containers of or storage of resistance to movement of waters; storage runoff components of which there are four primary types: modules which consist of at least one of each type of storage which represents the smallest complete watershed and an array of modules which describes watershed complexity and permits extensive evaluation of the principles of watershed characteristics, behaviour and management.

The watershed is a system in dynamic equilibrium and is more easily influenced by man in later stages of its evolution. The watershed is more easily influenced by man through manipulation of factors which dominate the local scene and which mask broad regional patterns of watershed reaction and stream behaviour.

The watershed is most efficiently managed through careful manipulation of key elements of its environment which have effects beyond their apparent limits. The watershed is intricate natural resources which demands varied practices, complex management, decisions and manifold research effort in order to ensure its efficient utilization." Black (1970)

A watershed is a drainage area, of which the runoff leads to a single water body. 'It is an 'eco-system' or bio-geo-physical unit in which interdependences of renewable and non-renewable resources from environment are closeted' (Deshpande & Rajasekaran, 1997; 375).

It appears that current approach to land resource management is unsustainable. There is enough evidence to show the decline in living beings and increase in carbon dioxide proportions leading to global warming. These problems can be scientifically tackled if the land resources are managed on the basis of hydrological units i.e., watersheds and river basins. Since these are independent of territorial and administrative boundaries, warranting a holistic approach to resource management is a must. Singh (1992) emphasized the need of watershed approach at a local level, because complex interaction among the land resources leads to development of a typical environment within a watershed which differs from the others even under similar precipitation conditions.

Rain-fed areas differ in terms of resource endowments and agro-economic characteristics. Nonetheless, there are certain common constraints to development of agriculture in such areas. Rain-fed agriculture is at risk due to variability, drought or flood conditions. In rain-fed areas that receive heavy rainfall, poor drainage systems lead to the problems of floods, soil erosion and water logging. Further rain-fed areas are generally associated with higher incidence of poverty, which combined with unfavourable physical conditions, deter infrastructural growth and market orientation (Government of India, 1997).

Given these constraints associated with rain-fed areas, as also the growth potential of such regions, the Government of India is, at present, according a very high priority to the sustainable development of rain-fed areas based on the watershed approach. The interaction between land and water resources within a watershed makes it ideal as a planning unit for optimum utilization of the production potential of the area, while ensuring conservation of soil and water resources (Government of India, 2000b).

The ultimate goal of watershed management is to achieve and maintain a balance between resource development to increase the welfare of the population and resource conservation to safeguard resources for future exploitation; and to maintain ecological diversity – both for ethical reason and as an assumed prerequisite for the survival of mankind

1.1.3 Remote Sensing & GIS as a tool

Remote sensing affords us the capability to literally see the 'invisible'. From aerial or space vantage point we can obtain a synoptic (even global) view of earth resources. We can begin to see components of the environment on an "ecosystem basis", in that remote sensing data can transcend the cultural boundaries within which much of our current resource data are collected. Remote sensing also transcends disciplinary boundaries. It is so broad in its application that nobody 'owns' the field.

Remote sensing techniques cover large areas within the reasonable time with reliable accuracy. These surveys utilize materials collected from aerial vantage point, in particular aerial photographs (black & white, colour and infrared), radar and multispectral scanning from aerial platforms. Satellite imaging system has its own characteristic properties and has added new dimensions into the techniques of modern survey. In particular it permits (1) the production of regular sequence of images from approximately the same area at fixed periods in different time and (2) the simultaneous production of different kinds of high altitude images in different bands. For land use surveys as well as soil, water and vegetation, use of multitemporal images have been advocated. To get sequential images from normal aerial photographic system becomes difficult due to technical and financial reasons. Satellite imaging is multipurpose, multi-disciplinary and multinational. 'Sequential' is an essential element of satellite imagery. Satellite image does not always produce same kind of image definition as produced by conventional photography.

A GIS (Geographical Information System) is an information system that is designed to work with the data referenced by geographic coordinates. It is that chain of operations that takes us from planning the observation and collection of data to storage and analysis of data, to the use of derived information in some decision making process. It processes two or three-dimensional information and maps with ease.

Remote sensing data can be readily merged with other sources of geocoded information in a GIS environment. This permits the overlapping of several layers of information with the remotely sensed data, and the application of a virtually unlimited number of forms of data analysis. On one hand, the data in GIS might be used to aid in image classification. On the other, the land cover data generated by a classification might be used in subsequent queries and manipulation of the GIS data base.

Maps help to present the information in easy to perceive form. These are powerful tools to see various sets of data combined for the same location. The watershed approach has so much to do with the location and its details, the mapped data make the process of interpretation and analysis easy.

The mapped data calls for several changes – enlargement/reduction, superimposition etc. Some of these manual operations are very complex. The assistance of GIS is very much needed right from the level of data illustration to maneuvering mapped data, processing to generate final maps as per the requirement etc. GIS comes very handy for performing several map merging exercises which are extremely difficult manually and at the same time the automation has sufficient capacity for human control and intervention. The data in GIS are varied and complex. The GIS data includes digital description of map features, logical geographical relationship among features and non-geographical data that describe characteristics of the features and phenomena that occur at geographical locations (Lal et. al).

GIS analyses and queries both spatial and non-spatial data related to the database it holds. Since an intelligent GIS can combine almost infinite number of parameters (as layers of data), queries are designed to match all the specified parameters and find areas which fit the requirements. GIS has played an extremely important role in resource management, environment monitoring, and landuse and planning activities. GIS is found to be a reliable tool for creating, managing and making forecast under given scenarios on landuse issues (Rao & Ghosh).

1.2 STUDY AREA

The study area constitutes the watershed of the Song River falling in the administrative districts of Dehradun and Tehri-Garhwal (Uttaranchal). The Song River is a right bank tributary of the Ganga. It originates near Dhanolti, the eastern Duns, and inlets into the Ganga near Raiwala not far from Haridwar. It drains the Dun valley towards the south which is very fertile, well-irrigated and densely populated. It extends from 30° 04' 16.89" N to 30° 27' 31.02" N latitudes and from 78° 03' 54.44" E to 78° 19' 25.63" E longitudes. The watershed covers an area of about 933.5 km^2. The main tributaries of the Song River are Badan, Baldi and Jakhan. The basin consists of 23 sub-watersheds. The river is perennial in the upper mountainous region where as it dries up in the lower part because of base flow. The region is more or less an alluvial tract marked with tropical climate.

1.3 OBJECTIVES

This study mainly focuses on the appraisal of land use of the area for two time periods i.e. 1961 and 2001, in order to understand the degree of efficiency with which the land is being utilized from the locational point of view. Current land use will also be evaluated in terms of land suitability/capability of the area as presented by the land capability map prepared by National Atlas and Thematic Mapping Organisation (NATMO). Special emphasis will be placed on the forest cover assessment and areas subject to soil erosion. It will also involve morphometric analysis of the basin to evolve a basic understanding of terrain and landforms. Remedial measures for sustainable management of land will be suggested on the basis of the problem of the area. The objectives for present analysis are as follows:

- Morphometric analysis of the watershed under study to evolve a mathematical expression of landforms and drainage and the nature of the terrain characteristics.

- To determine the status of watershed in terms of landuse/landcover; and to evaluate in relation to land suitability/capability of the area.
- Assessment of landuse/landcover of the study area to analyse temporal change.
- Evolving suitable conservation methods to check soil erosion, particularly gully erosion, in the upper reaches of the basin.
- Suggesting remedial methods for sustainable management of land resource of the area.

1.4 METHODOLOGY

Data analysis through GIS is a necessary step for deriving required information from the data set. Terrain analysis will be done for the watershed by using morphometric techniques that will be applied digitally for linear, areal and relief aspects of the basin using Survey of India topographical sheets (scale 1:50000). Base map will be prepared from toposheets. Thematic maps for location, elevation, slope, geology, geomorphology, soil distribution, forest distribution, climate etc. will be prepared using District Planning Map of Dehradun and Tehri-Garhwal prepared by NATMO. Land use maps will be prepared using topographical sheets (1963) and IRS – 1D, LISS - III Satellite imagery (2001) in GIS environment by defining classes using supervised classification. Land capability map of the area will be prepared using Land Capability map of northern India prepared by NATMO.

1.5 DATABASE

The study is based solely on secondary data which will be obtained from map base and other published and unpublished sources. Map base will be provided by the SoI topographical sheets and LISS-III Satellite imagery. Thematic maps prepared by NATMO will also be used. It includes:

- Topographical sheets no. 53 J/3, 53 J/4, 53 J/7 and 53 J/8 published by Survey of India on the scale 1:50000.
- Digital satellite imagery obtained by IRS-1D, LISS-III dated 1st April 2001 in RGB bands and processed at NRSA, Hyderabad.

- Thematic maps prepared by NATMO (National Atlas and Thematic Mapping Organisation).
- Various unpublished (from libraries) and published research works (including thesis, dissertations and articles) from different journals, magazines and newspapers related to study area, research theme and methodology.
- Statistical Abstracts and Census Handbooks to provide socio-economic and demographic base concerning the area.

1.6 REVIEW OF THE LITERATURE

Literature survey reveals that wide-ranging studies have been conducted on the land resources evaluation and management using RS/GIS. But very few studies are directly related to land resource management particularly temporal study of land use and its analysis, forest cover evaluation and monitoring of soil erosion of the watershed of the Song River (Uttaranchal). Some relevant literature collected from books and articles (from journals and newspapers) have been summarized keeping in mind the theme of the study. They are as follows:

Sharma et. al, (1984) in their article, "Monitoring land use and land cover changes using LANDSAT images", have dealt with the preparation of a land use/land cover map and monitoring changes, if any, over a period of five years from Landsat image using visual interpretation techniques. The study was carried out on the partly mountainous terrain of Dehradun-Roorke region. Since changes in land use & land cover e.g. vegetation, soil and water quality etc. have a great impact on the economic and social development of a region, adequate knowledge of the existing land use/cover and its pattern of change, which is a continuous process, is essential for any planning activity. Conventional methods are time consuming and expensive and hence multi-spectral and multi-temporal landsat imagery, being more accurate, have advantage. The methodology adopted for the study used landsat images for two time periods fusing visual interpretation techniques. Based on textural and tonal differences, land use and land cover classes were identified. Conclusion that were drawn include recession of forest cover, increase in cultivated area on the cost of forest area, increase in urban areas etc. the visual analysis technique was adopted but due to lack of sequential availability of landsat images detail analysis was not possible for annual changes or monitoring if these changes.

Natrajan et. al, (1986) have attempted to provide information for better land use planning in the Mewat and adjacent areas of Haryana. They have presented land use with the help of aerial photographs. Soil and land use were studied in details and suggestive field checks were also made. Three levels of land use legends were formed during pre-visit interpretations i.e. symbols, physiography and landuse. Next level, dominant crops and area was confirmed during the field visits. Thus the accuracy of the data was ensured. The major categories identified were hills, piedmont plain with aeolin cover, intermontane basin, Yamuna alluvial plain and settlement.

Dhinwa, P.S. et. al, (1992), analysed information on existing land use, its spatial distribution and changes that are essential for planning, policy making and for better utilization of land is well established. The prime objective was to form an information base at the district level oriented towards regional planning through GIS package. Remote sensing data along with topographical sheets was used. ARC/INFO was used for the formation of files, digitization, editing, creation of polygon topology and union process. A spatial database was thus created. Discrepancies floated regarding short time period (1986-89), higher spatial resolution of database leading to differences with statistical data etc. though right interpretation was done for imageries using GIS techniques to identify major land use changes, it fails to bring forth the linking up of the analysis with that of actual process development plan.

Jaiswal et. al, (1999) in their article compared land use/cover data of two time periods (1967 & 1996), former based on SoI topographical sheet and latter on IRS-1C LISS-III image, for a part of Gohparu block (M.P.). Maps prepared by visual interpretation were digitized and incorporated into GIS domain for change analysis through Intergraph MGE software (using MGE – Area Loader Module). Land use/cover was classified into forest cover (including dense forest, open forest, degraded forest etc. depending upon density), woodland (vegetation cover outside notified forest cover), agricultural land, waste land settlement area etc. post-classification comparison technique was adopted. Results came out to be decrease in forest land and increase in waste land. Accuracy of data was ensured by comparing it with ground data.

Dewidhar (2004) has monitored land use/cover changes along the north part of the Nile delta, Egypt in order to assess the nature of future change following construction of the international coastal road which crosses the study area. It is essential for planning and implementing policies to optimize the use of natural resources and accommodate development whilst minimizing the impact on the environment. To study these changes along the study area, two sets of Landsat Thematic Mapper data (1984 & 1997) were used which is useful due to its high spatial resolution, spectral resolution and low repetitive acquisition (16 days). A post classification technique is used in this study based on hybrid classification (unsupervised and supervised) using the IDRISI program (WINIDRISI 1997). Each method used was assessed and checked in field. Nine land use/cover classes are produced. The overall accuracy for 1984 image is 78% and for 1997 image is 80% calculated by performing RMSE (root mean square error).

Bisht & Kothyari (2001) analysed the land cover change for Garur Ganga watershed (Bageswar, UT) during the period 1963-1996 and 1986-1996 using SoI toposheets and visual interpretation of Landsat 5 TM image band 2, 3 and 4 with the help of GIS (SML program of Arc/Info). Ground verifications were made for confirming the land use units.

Rao & Ghosh (1996) emphasized on GIS as a reliable tool for land use planning and management. They studied the watershed of Pranamti (Chamoli) for two data sets – one from SoI toposheet (1963) and other IRS satellite (1993). Apart from classifying land use classes, to find the GIS package analytical capabilities, land suitable for agriculture was assessed using the elevation, slope aspect and soil (depth and texture) parameters for defining suitability classes for agricultural land. A road under construction was also assessed on the basis of geology and current land use and it was found that most of its part was on unsuitable land.

Singh et. al, (1983) present a critical appraisal of the need and use of remote sensing techniques for land use mapping with particular reference to Indian conditions have been made. Land use classification system based on physiography, utility, management and identification have been suggested using remote sensing techniques at different levels of mapping.

Kumar et. al, (2004) carried out digital map processing on IRS-1C-LISS-III data acquired in 1998 to map the land use classes in part of the Kandi belt of Jammu region.

Supervised classification has been combined with rule based classification to delineate various land use classes including forest, agriculture, riverbed, urban fallow, wasteland and water. Rule based classifier using DN (digital numbers) was used to solve the problem of mixed pixel of water and boulder (river bed). 'Water rule' was created stating that if DN of a pixel is less than or equal to 50 in band 3 and land use class is riverbed in the earlier classified image then that particular pixel is water. The image was again classified using the knowledge classifier.

Dwivedi R.S. et. al, (2005) analyzed land use/cover change in part of Ethiopia using Landsat Thematic Mapper data for 1994 & 1997 involving radiometric normalization, geo-referencing, digital analysis and accuracy estimation. For deriving information on land use/cover, spectrally homogenous classes were made using an unsupervised classification algorithm. The class separability analysis was then carried out by computing the transformed divergence (TD) values.

Li. Z. et. al, (2004) aim at determining land use transition rates among land use types in Yulin prefecture, northwestern China over 14 years from 1986-2000 and to quantify the changes of various landscape metrics using FRAGSTATS, the spatial pattern analysis program for categorical maps. Using 30 m resolution Landsat Thematic Mapper (TM) data, images were classified into six land use classes – cropland, forestland, grassland, water, urban and/or built-up land and barren land. A land use ground reconnaissance was carried out. Two land use maps were overlaid to create a composite map and a transition matrix was produced to detect land use change. The study demonstrates that the integration of satellite remote sensing and GIS was an effective approach for analyzing the direction, rate and spatial pattern of land use change.

Gautam and Narayana (1983) dealt with the technique of remote sensing and how far it helps in the rapid study of geographical phenomena especially landuse within a very short time and accurate manner. They evaluate how well data from the Landsat Multispectral Scanner (MSS) could be used to detect, identify and delineate land use features within the Andhra Pradesh state. Multi-data Analysis System (M-DAS) was used to carry out digital analysis. The main objective was to prepare a small scale land use map from satellite imagery showing the broad distribution of land use patterns to serve as a base for monitoring land use change.

Shaik, R. et. al, (1998) have monitored and evaluated the watershed of kk4 (Mahboob Nagar) which faced problems like low soil fertility, wasteland, shortage of fuel wood and fodder, frequent droughts, improper management of marginal lands and community lands, denudation of forest etc. Land use/cover data through satellite was analyzed using GIS. It was done for the realistic assessment of the impact of DPAP/EAS by using satellite images available for pre and post treatment period.

Khan et. al, (2000) applied GIS for land use/cover management in the context of wasteland for Ferozepur Jhirka block (Haryana). ARC INFO GIS package was used to carry out the entire process and integrated land system analysis approach was employed to determine the capability of land. Secondary data on land use and population attributes were compiled from *patwari* records and census volume related to the study area.

Lal et. al, (1999), using GIS, studied two watersheds in Garhwal Himalayas viz. Ir Gad and Machhlad for optimizing the present utilization of natural resource, forest distribution, land use, slope stability, infrastructure distribution and socio-economic status. Remotely sensed data is used to make decisions and cross-examine the watersheds that have contrastingly different setup, currently undergoing deforestation due to unstable human activities. ARC/INFO package was used for generating thematic maps and these were superimposed on different combinations for delineating the final output. The thematic maps are used for decision support and planning of the watershed. One of such remedial measure for the target area, where currently soil erosion and consequent slope instability vulnerability exists, soil conserving plant species have been recommended. The high rate of gully erosion and active river network was attributed to local geological conditions that host highly fractured and weak lithology type. The morphometric analysis has also been done to determine the role of external forces on the landform. The maximum drainage density was observed near streams actively engaged in gully erosion and underground drainage movement. Appropriate remedial measures have been proposed to ensure sustainable development of the area without altering the present agricultural and irrigation pattern.

1.7 ORGANISATION OF THE WORK

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2. STUDY AREA: AN OVERVIEW

2.1 INTRODUCTION

The study area constitutes the watershed of the Song River falling in the administrative districts of Dehradun and Tehri-Garhwal (Uttaranchal) (figure 2.1). The Song River is a right bank tributary of the Ganga which drains some parts of very fertile, well-irrigtaed, and densely populated Dun valley. It originates near the Dhanolti, the eastern Duns, and inlets into the Ganga near Raiwala not far from Haridwar. It extends from 30° 04' 16.89" N to 30° 27' 31.02" N latitudes and from 78° 03' 54.44" E to 78° 19' 25.63" E longitudes. The watershed covers an area of about 933.5 km^2. The main tributaries of Song River are Badan, Baldi and Jakhan. Numerous small rivers also join the Song, which are locally known as "rao" like Palni Rao, Lambi Rao, Bidhalna Rao etc.

2.2 HISTORICAL PERSPECTIVE

According to the Skand Purana, Dun formed part of the region called Kedar Khand. It was included in the kingdom of Ashoka by the end of 3^{rd} century B.C. It is revealed by history that for centuries the region formed part of the Garhwal kingdom with some interruptions created by Rohillas. For about two decades, till 1815, it was under the occupation of the Gorkhas. In April 1815, Gorkhas were ousted from Garhwal and annexed by the British. In that year the area, comprising tehsil Dehradun, was added to district Saharanpur. In 1825, however, it was transferred to the Kumaon Divison. In 1828, Dehradun and Jaunsar *bhabar* were placed under the charge of a separate Deputy Commissioner. In 1892, the Dehradun district was transferred from the Kumaon to the Meerut division. In 1842, Dun was attached to Saharanpur district and placed under an officer subordinate to the Collector of the district. Since 1871, it is being administered as a separate district. In 1968, the district was taken out from Meerut division and included in Garhwal division. After the separation of Uttaranchal state from Uttar Pradesh, Dun was made the capital of the state (Gazetteer of Dehradun, 1979).

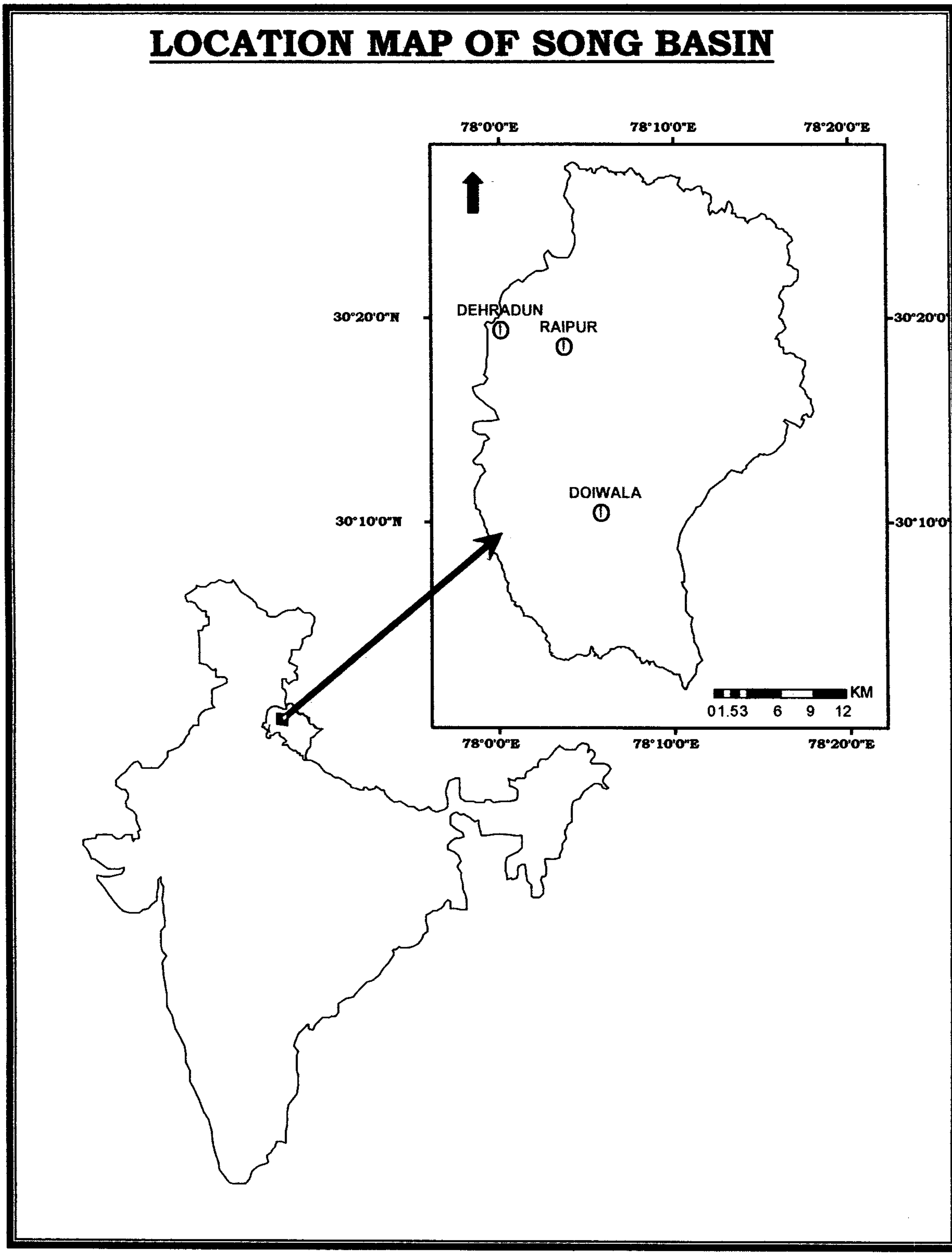

LOCATION MAP OF SONG BASIN
78°0'0"E
78°10'0"E
78°20'0"E
30°20'0"N
30°10'0"N
DEHRADUN
RAIPUR
DOIWALA
KM
0 1.5 3 6 9 12

Figure 2.1

2.3 GEOGRAPHICAL LANDSCAPE

2.3.1 Physiography

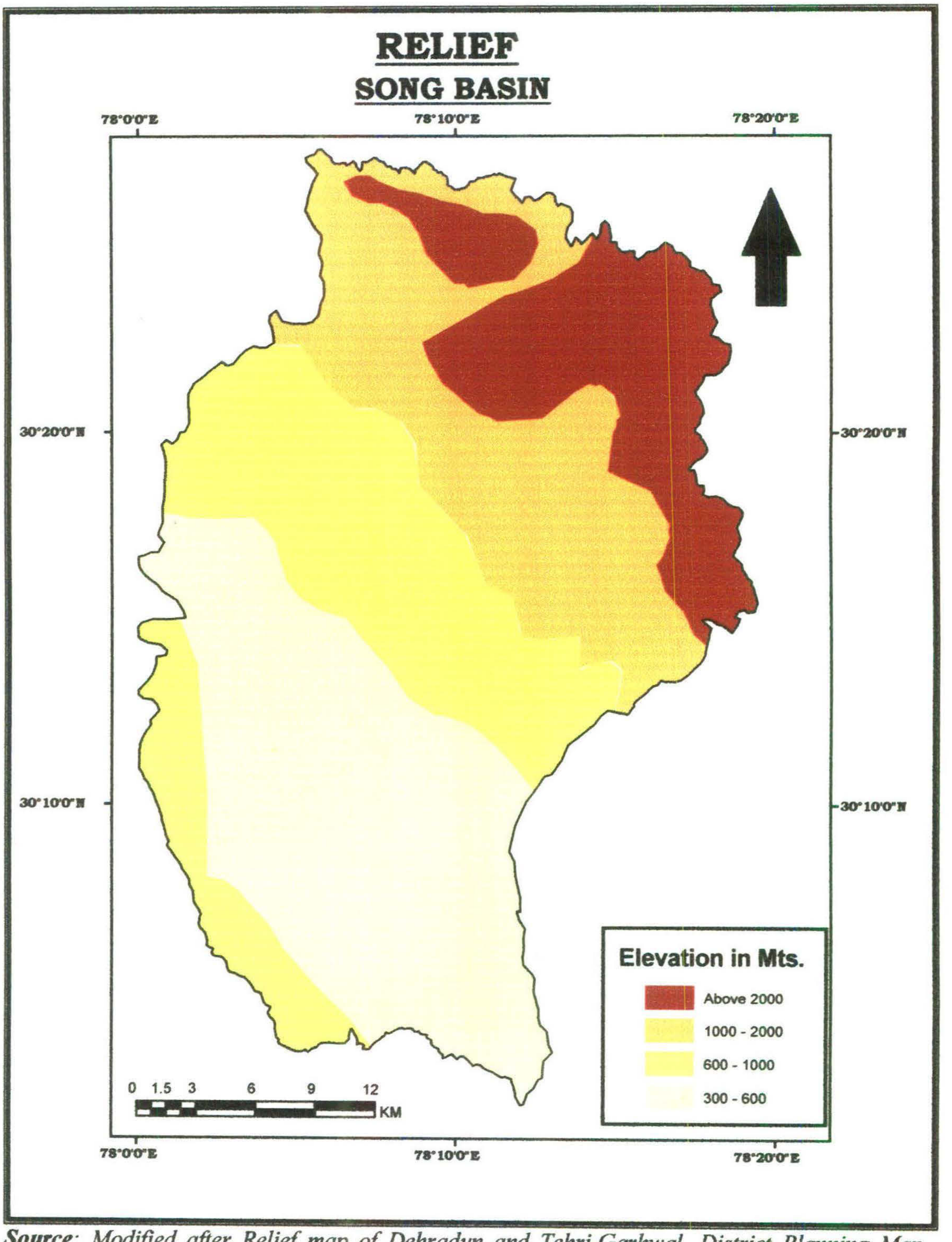
The area depicts a rugged terrain consisting of structural hills, denudational hills, piedmont zone, valleys, recent floodplains and river terraces. This region is tectonically active, bounded by the Lesser Himalayas in the north and the Siwalik range in the south. Within the study area the mountains of Lesser Himalaya in the north rise to an average elevation of 1200 m above mean sea level. Piedmont zone rises up to an elevation ranging from 300 to 500 m.s.l. On an average the area can be divided into three broad physiographic divisions viz. mountain, piedmont plain and Siwaliks hills:

- The northern mountainous terrain constituting the highly rugged dissected and denuded parts of the outer Himalayas,
- The gently sloping piedmont plains in the middle, and
- The southern part forming the northern dip slopes of the Siwalik hills.

The three sections, namely upper, middle and lower basin, represent marked differences in the nature of deposition on the river bed, channel form, characteristics of the valley slopes and the general nature of the terraces, fans etc.

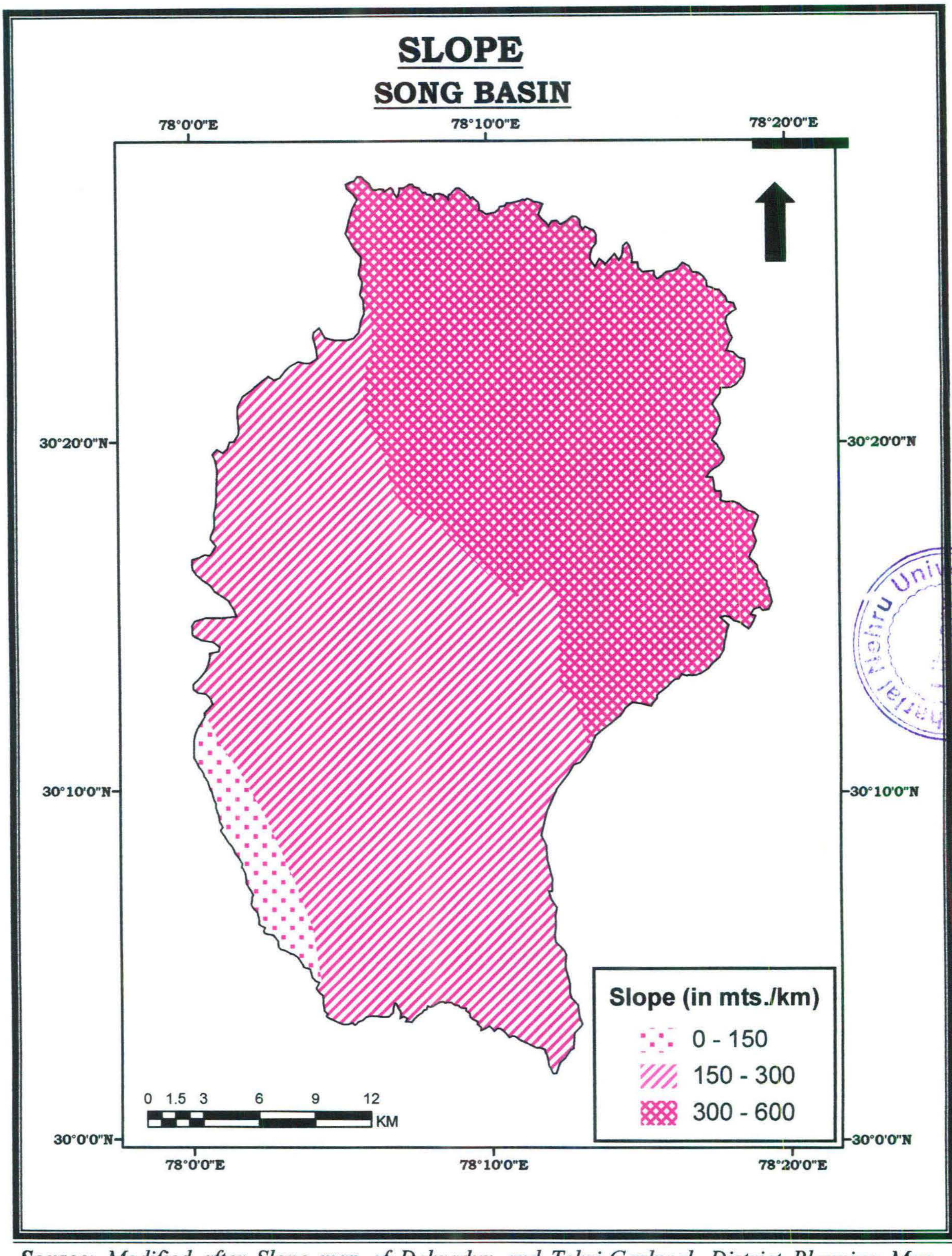
In the upper zone numerous channel dissect the southern slopes of the Lesser Himalaya with narrow V-shaped valleys cut into the rocks of calcareous constitution. In the middle, alluvial cones, river terraces, occasional escarpments of tectonic origin, etc., predominate the landscape. The middle and lower courses represent very prominent braided characteristic which is observed elsewhere also in the foothills of the Himalayas. In the lower course river flows through the Dun gravel which forms a flattish country with gentle undulations caused by the dissection of the terrain due to development of the smaller tributaries and gullies.

Micro-geomorphological study indicates that the channels and the interfluves at various elevations are composed of differential materials with an assortment of size-grains and diverse vegetation cover which indicate their relative age of



Source: *Modified after Relief map of Dehradun and Tehri-Garhwal, District Planning Map, NATMO.*

Figure 2.2



Source: *Modified after Slope map of Dehradun and Tehri-Garhwal, District Planning Map, NATMO.*

Figure 2.3

formation. Evidences of faulting are also observed on the two sides of the valley. The central part appears to be a downthrown block (Bandhopadhyay & Bandhopadhyay).

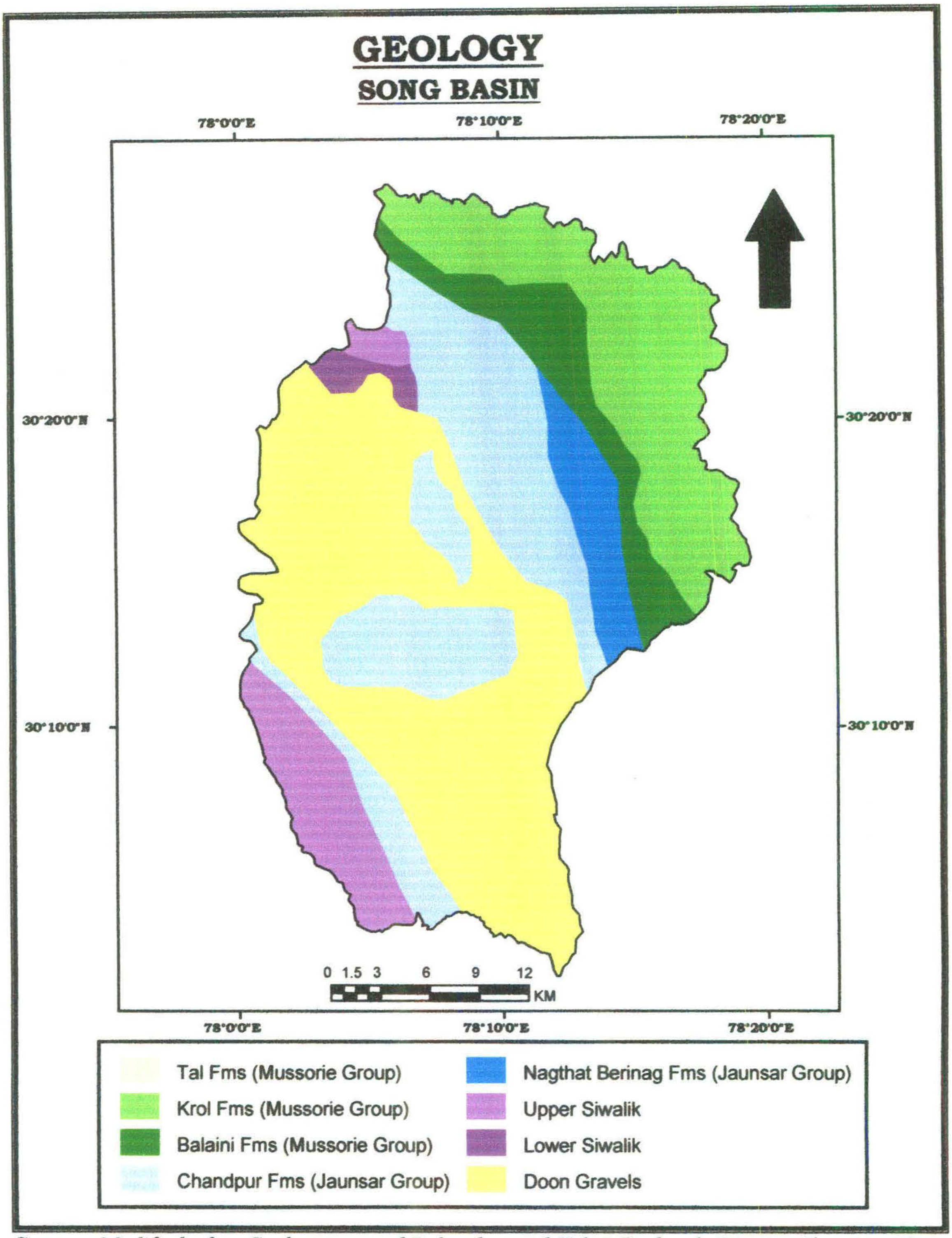
2.3.2 Geology

Geology is considered to be an important natural resource since it regulates genesis, formation and type of soil, occurance, distribution and flow of groundwater, and determines presence of minerals. Geology deals with different rock types that constitute the earth's crust, their origin, composition, chronology and tectonic settings.

Geologically, the area has complex lithology, though structures are discernible, especially in the Siwaliks (Fig. 2.4). The northern part mainly has Pre-Tertiary formation of the lesser Himalayas. Old Dun gravel occurs unconformably over the upper Siwalik, as an isolated hillock probably deposited during upper most Pliestocene age, comprising of boulders, pebbles, sand, and silt embedded in clay matrix giving resemblance to a boulder bed. Dun gravel is present in the form of piedmont deposits originating from Pre-Tertiary. Slopes of the Siwalik range are composed of gravel, sand, silt and clay resting unconformably over old Dun gravel and upper Siwalik. Other deposits comprise of fluvial origin, old and recent floodplains and paleochannels. Material is sometimes stratified and composed of boulders, pebbles, sand, silt and clay. The youngest deposits are of late Holocene. Minerals commonly found include limestone, gypsum, tufa, phosphorite, marble etc. (Gazetteer of Dehradun, 1979).

2.3.3 Climate

The area has within its limits the lofty peaks of the Outer Himalayas as well as the Dun with climatic conditions nearly similar to those in the plains. Temperature of any given locality in the area depends very largely on the elevation. In general, the climate of the area is **Humid Sub-Tropical Monsoon Climate**. A year may be divided into four seasons. The period from about middle of November to February is cold season. Hot season, which follows, continues up to about the end of June.



***Source**: Modified after Geology map of Dehradun and Tehri-Garhwal, District Planning Map, NATMO.*

Figure 2.4

The monsoon season is from July to about third week of September. The following period till mid of November is the post monsoon period. The average annual rainfall of the area is 250 cm. Almost 87% of it, is received during the months from June to September, July and August being the rainiest (Fig. 2.5 & 2.6).

The area, being hilly, has considerable temperature variations due to difference in elevation. After February, both day and night temperatures begin to increase rapidly. Generally May and early part of June constitute the hottest part of the year. In the hilly regions, the summer is pleasant, but in the Dun the heat is often intense. Afternoon thundershowers occur on some days bringing welcome relief from heat. Maximum and minimum temperature ranges between 41° C to 6° C (Fig. 2.7). Temperature class is defined as “Hyperthermic”. With the onset of southwest monsoon over the region, by about the last week of June, there is an appreciable drop in the day temperature, but the nights are nearly as warm as during summers. With the withdrawal of the monsoon by about the third week of September, temperature begins to decrease. During the cold season, cold waves affect the area in the rear of passing western disturbances, the minimum temperature falling down even below the freezing point of water (Gazetteer of Dehradun, 1979).

During cold season, passing western disturbances affect the weather over the area causing occasional thunderstorms, some of which are accompanied with hail (Fig. 2.8 (a)). Thunderstorms occur during the summer and monsoon season also. Fog occurs occasionally during the cold season. The frequency for special weather phenomena for hilly and plain area is:

	Mean No. of days with									
	Thunder		**Hail**		**Dust storm**		**Squall**		**Fog**	
	Plains	**Hills**	**Plains**	**Hills**	**Plains**	**Hills**	**Plains**	**Hills**	**Plains**	**Hills**
January	3.0	1.6	0.2	2.0	0.0	0.0	0.0	0.3	0.2	3.0
February	2.0	1.6	0.1	1.7	0.0	0.0	0.1	0.3	0.3	1.6
March	5.0	4.0	0.3	1.8	0.0	0.0	0.4	0.5	0.0	0.7
April	4.0	5.0	0.2	1.2	0.0	0.0	0.3	0.5	0.0	0.4
May	8.0	8.0	0.2	0.8	0.2	0.2	0.1	0.8	0.0	0.5

June	10.0	9.0	0.5	0.2	0.1	0.1	0.1	0.3	0.2	6.0
July	12.0	9.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	19.0
August	12.0	9.0	0.0	0.1	0.0	0.0	0.0	0.0	0.8	17.0
September	10.0	9.0	0.0	0.1	0.0	0.0	0.0	0.3	0.6	13.0
October	3.0	2.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	3.0
November	0.5	0.5	0.0	0.1	0.0	0.0	0.0	0.0	0.1	1.0
December	0.7	1.4	0.0	0.7	0.0	0.0	0.0	0.1	0.1	2.0
	70	60	1.6	9.0	0.3	0.3	1.0	3.0	3.0	67.0

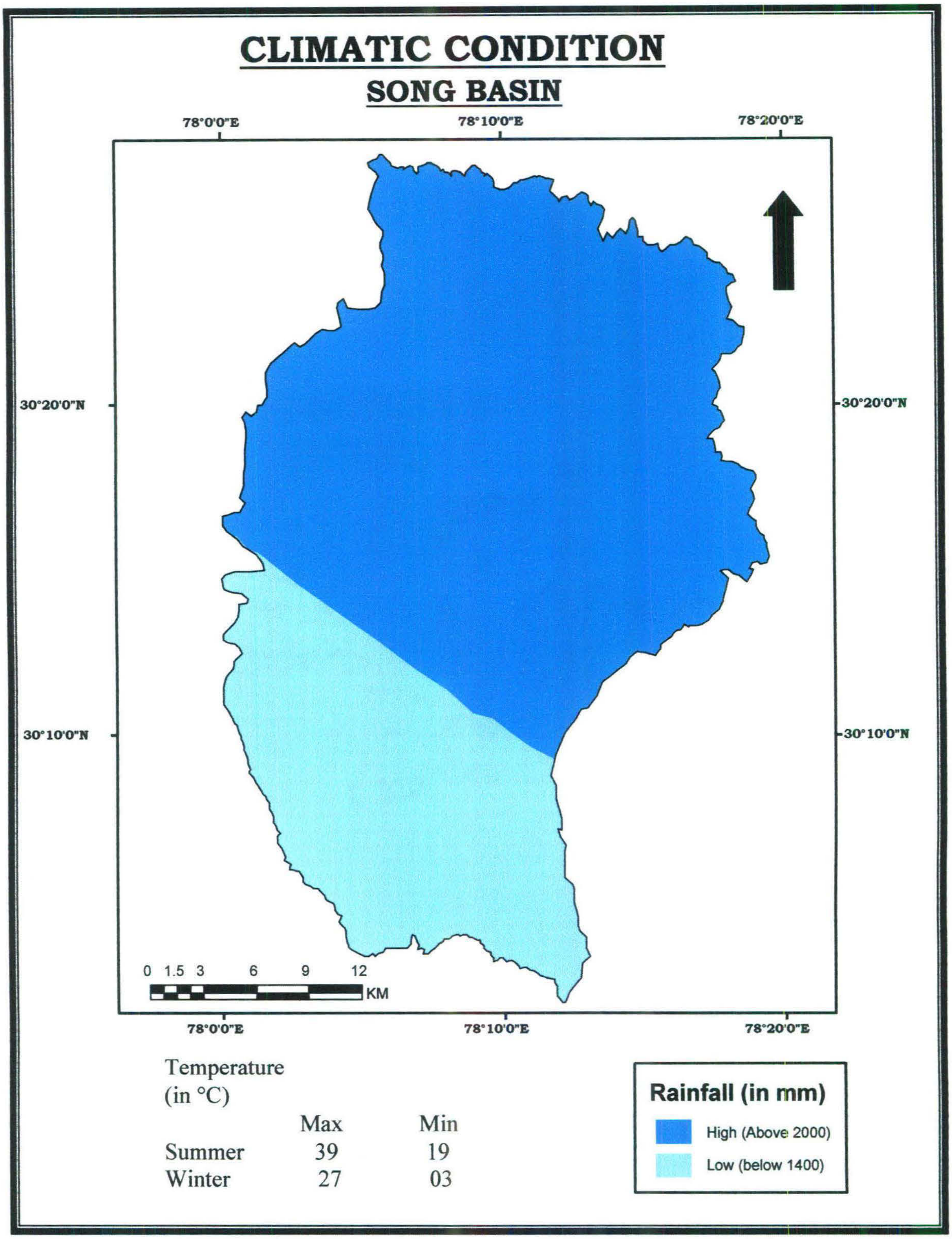
Source: Uttar Pradesh District Gazetteers, Dehrdun, Govt. of U.P., 1979.

Table 2.1

Most of the thunder storm phenomena are experienced during the months of June, July, August and September in both hilly and plain area (Fig. 2.8(b)). These happen to be monsoonal months. The occurrence is more in plains due to valley floor location. Minimum thunder storms take place during the month of November probably due to subsiding wind causing calm weather conditions. Hail usually occurs in hilly parts in the winter months mainly because of high altitude (Fig. 2.8(c)). While plains experience the phenomena in the extreme dry summers probably due to uprising convectional current resulting out of intense heating. Dust storms are very less in number and occur mainly in summer season both in hills and plains (Fig. 2.8 (d)). Plains have squalls during the pre-monsoon months while hills have both pre and post monsoon squalls (Fig. 2.8(e)). Fog is more experienced in hilly areas, perhaps owing to high altitude and windward location of the area while plains have fog during monsoons because of presence of clouds (Fig. 2.8(f)).

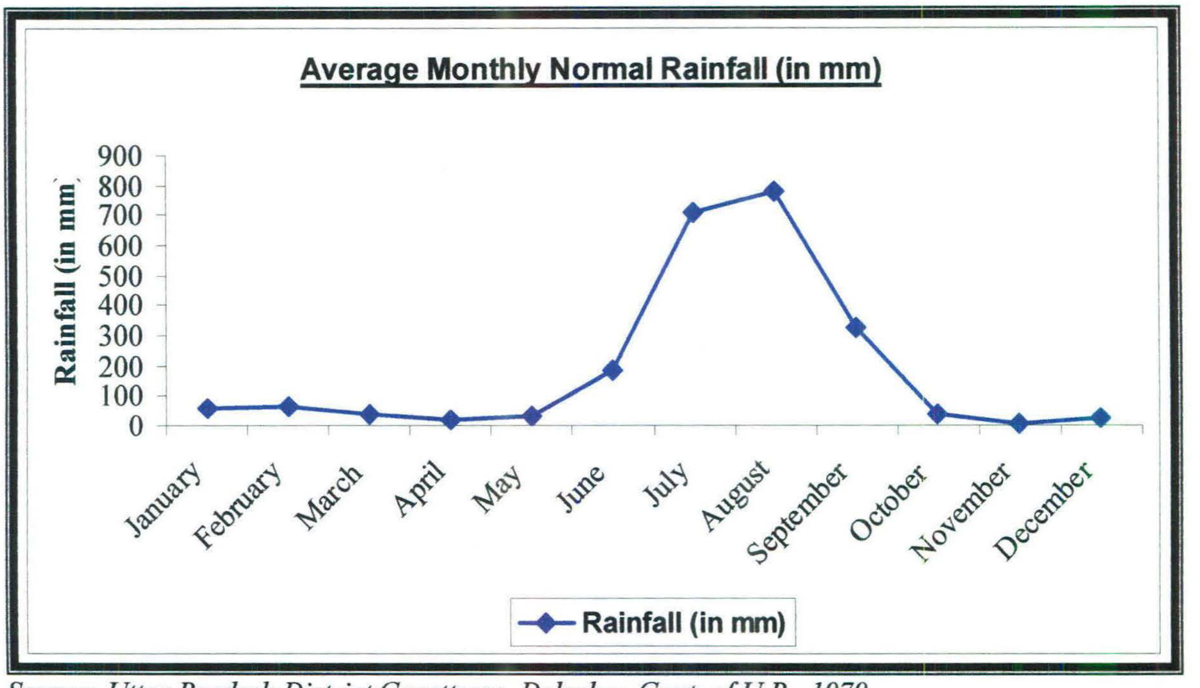
The relative humidity is high during the southwest monsoon season, generally exceeding 70% on an average. The mornings are comparatively more humid than the afternoons. It is less during the rest of the year, the driest part of the year being the summer season with the relative humidity in the afternoons becoming less than 45% (Fig. 2.9).

During the southwest monsoon season and the short spells of a day or two in the cold season, in association with passing western disturbances, skies are generally



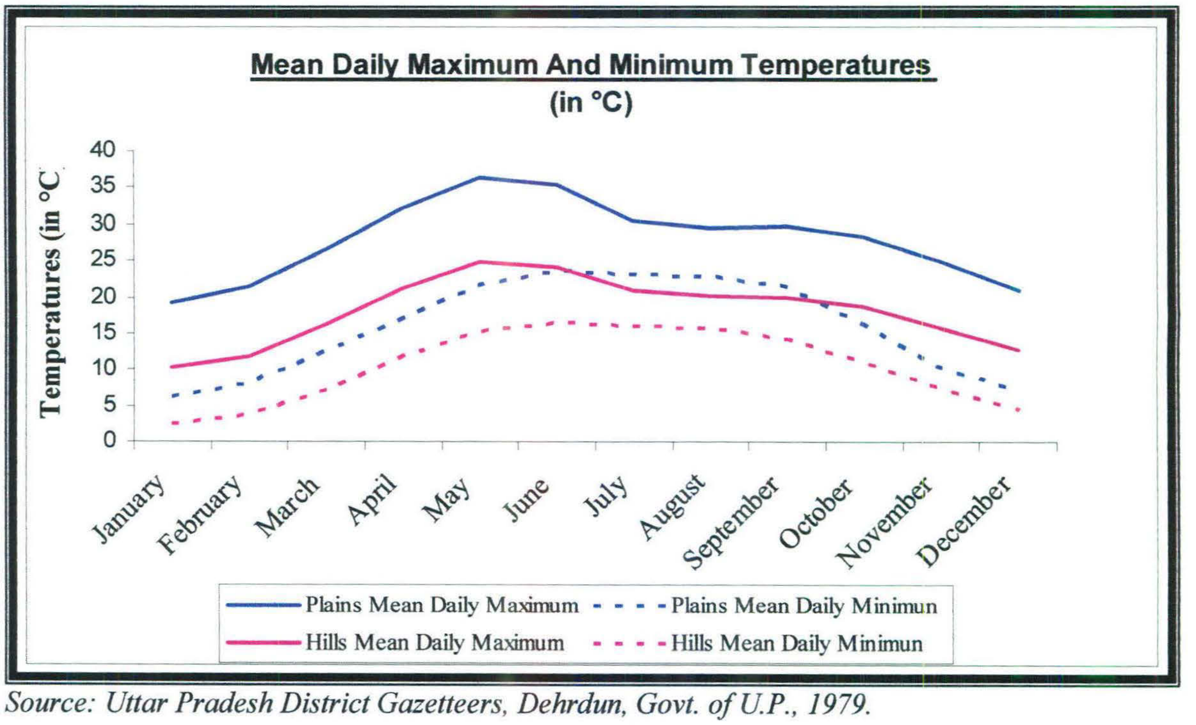
Source: *Modified after Climate map of Dehradun and Tehri-Garhwal, District Planning Map, NATMO.*

Figure 2.5



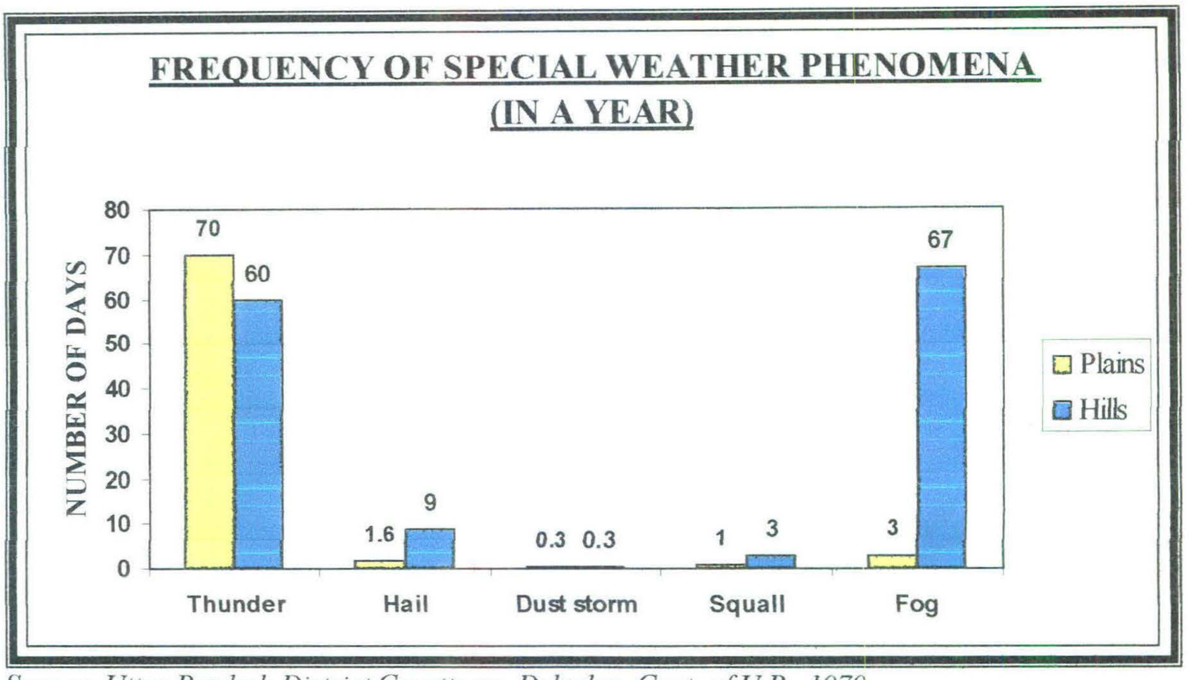
Source: Uttar Pradesh District Gazetteers, Dehrdun, Govt. of U.P., 1979.

Figure 2.6



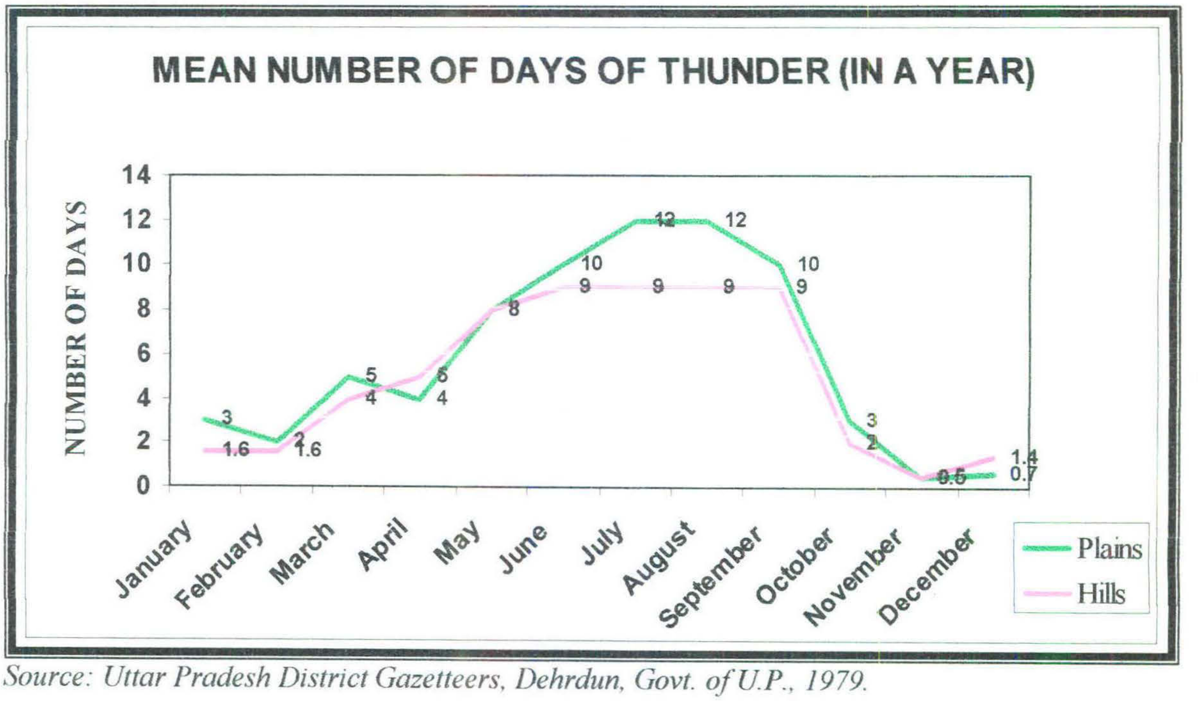
Source: Uttar Pradesh District Gazetteers, Dehrdun, Govt. of U.P., 1979.

Figure 2.7



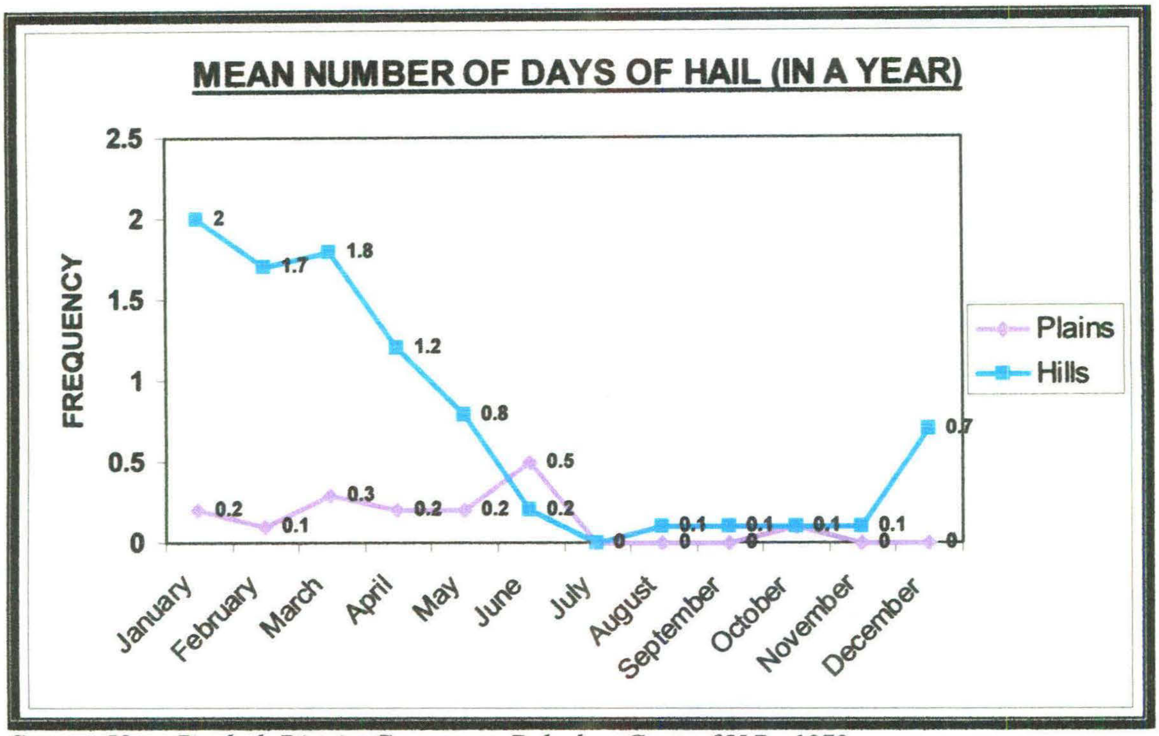
Source: Uttar Pradesh District Gazetteers, Dehrdun, Govt. of U.P., 1979.

Figure 2.8 (a)



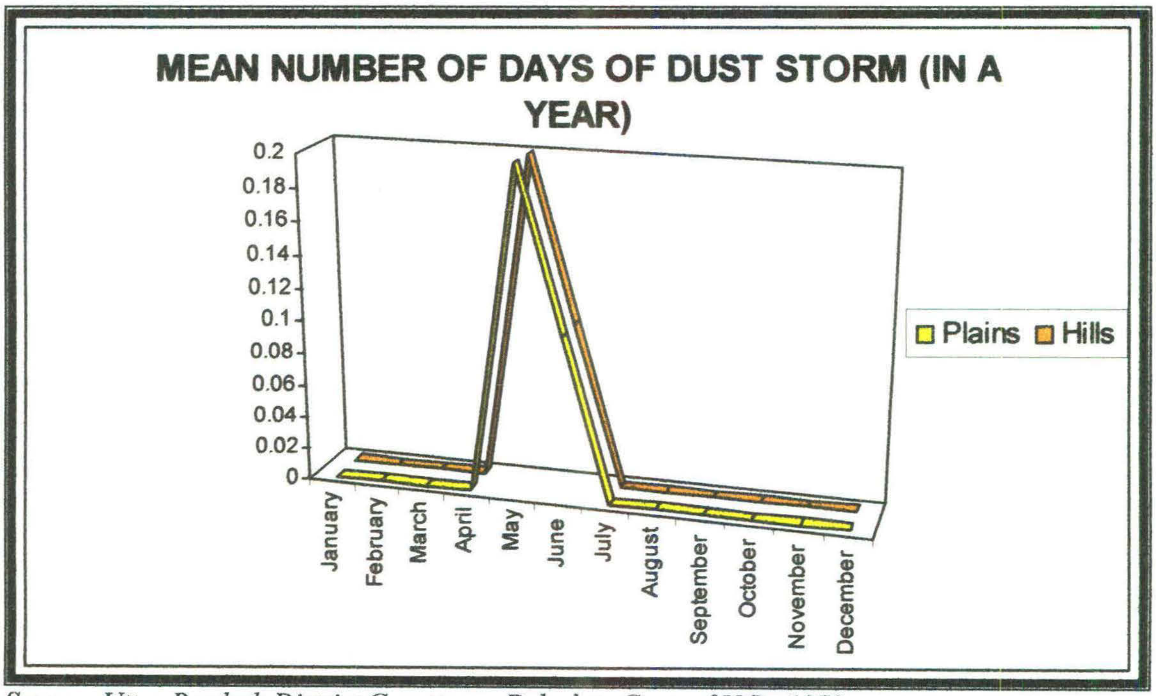
Source: Uttar Pradesh District Gazetteers, Dehrdun, Govt. of U.P., 1979.

Figure 2.8 (b)



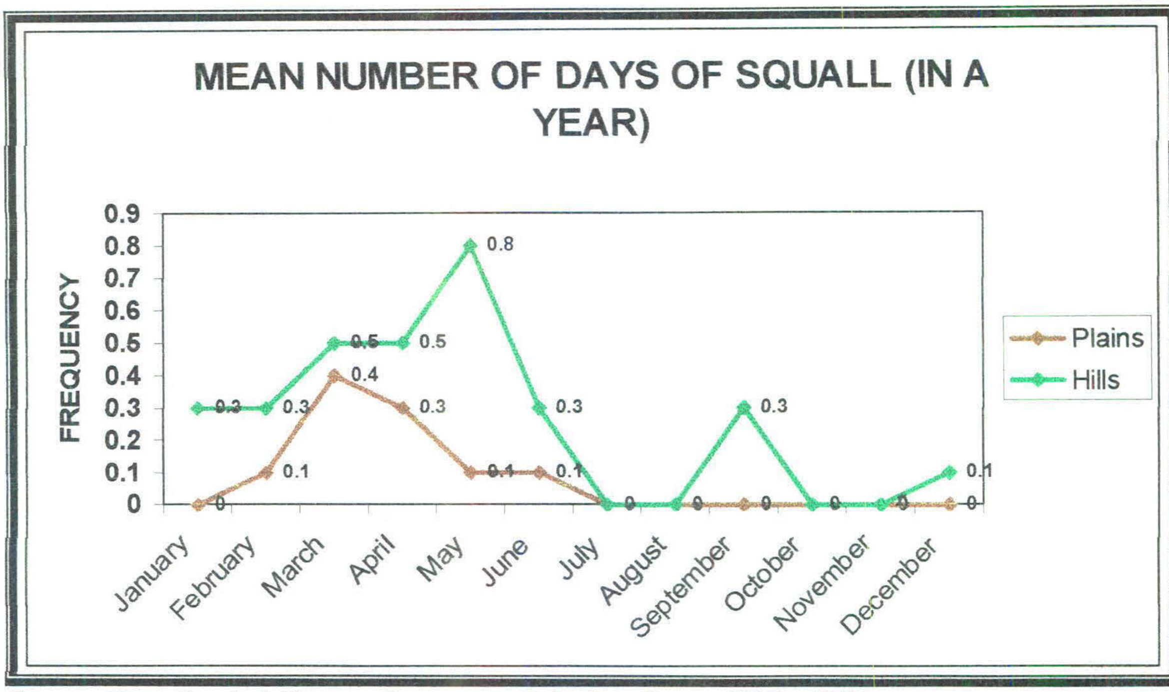
Source: Uttar Pradesh District Gazetteers, Dehrdun, Govt. of U.P., 1979

Figure 2.8 (c)



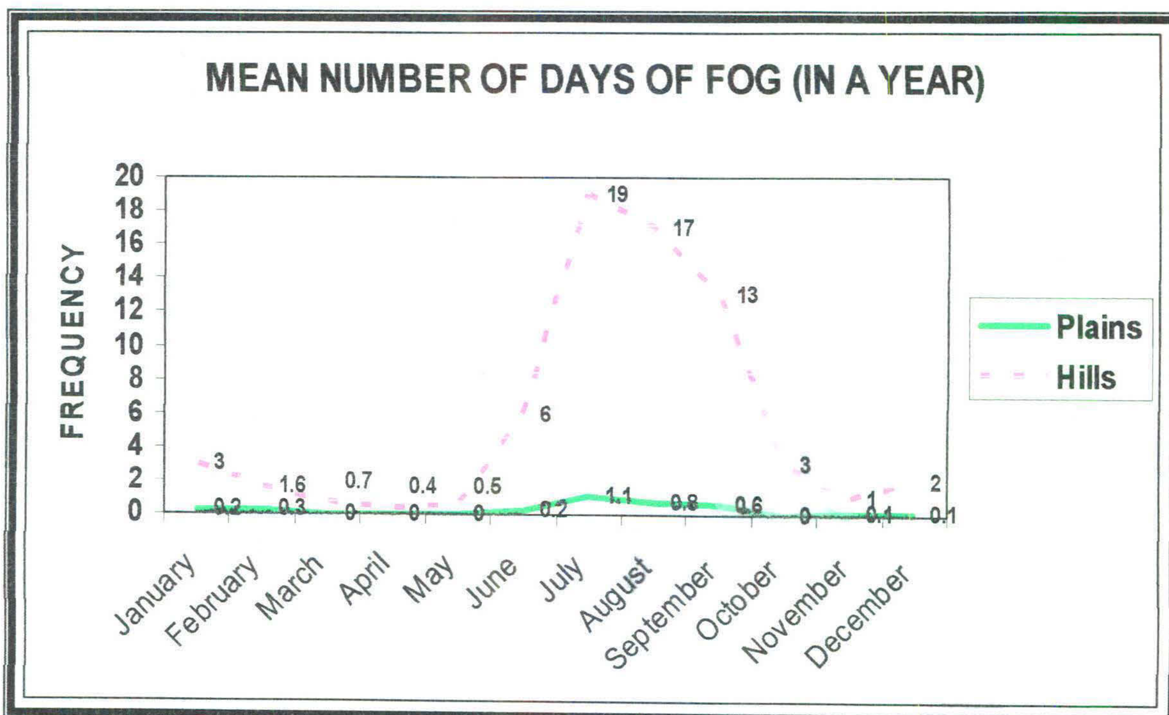
Source: Uttar Pradesh District Gazetteers, Dehrdun, Govt. of U.P., 1979.

Figure 2.8 (d)



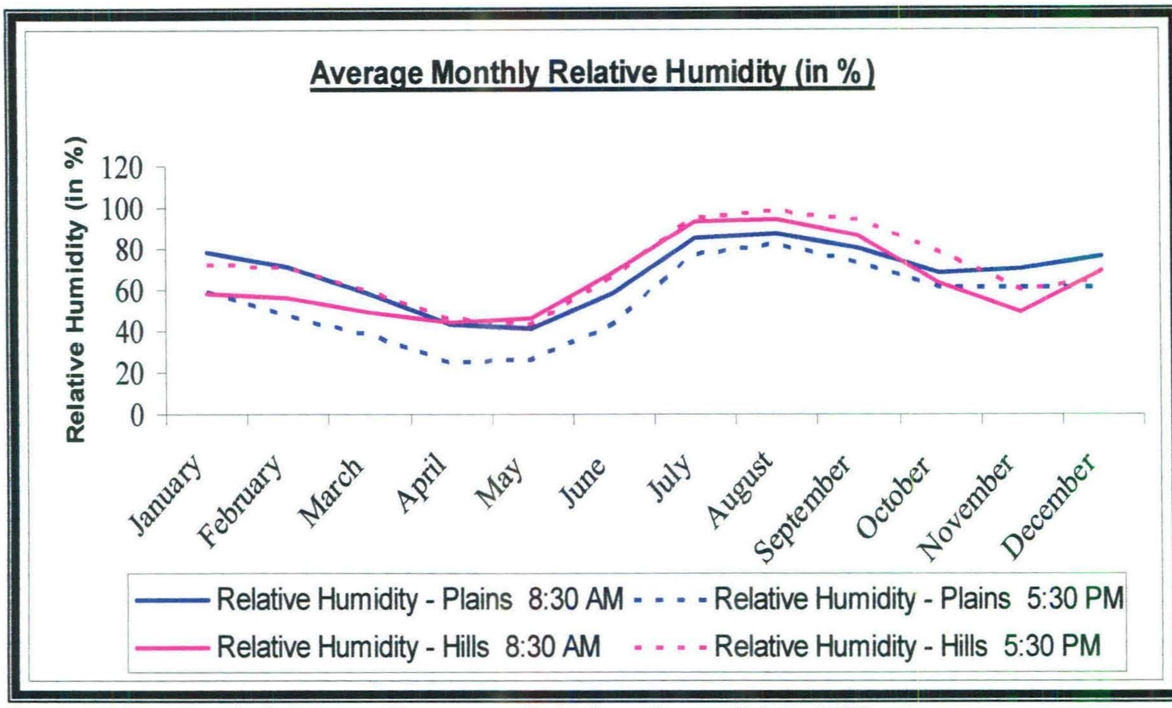
Source: Uttar Pradesh District Gazetteers, Dehrdun, Govt. of U.P., 1979.

Figure 2.8 (e)



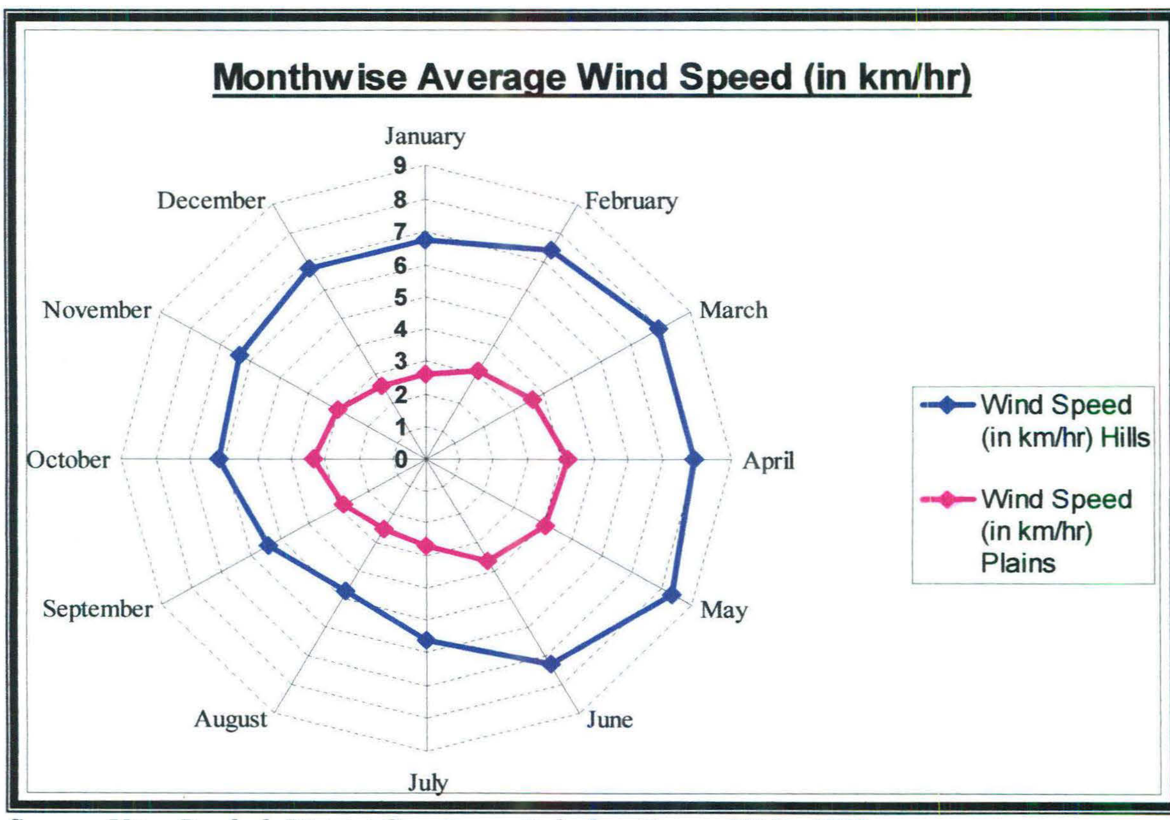
Source: Uttar Pradesh District Gazetteers, Dehrdun, Govt. of U.P., 1979.

Figure 2.8 (f)



Source: Uttar Pradesh District Gazetteers, Dehrdun, Govt. of U.P., 1979

Figure 2.9



Source: Uttar Pradesh District Gazetteers, Dehrdun, Govt. of U.P., 1979.

Figure 2.10

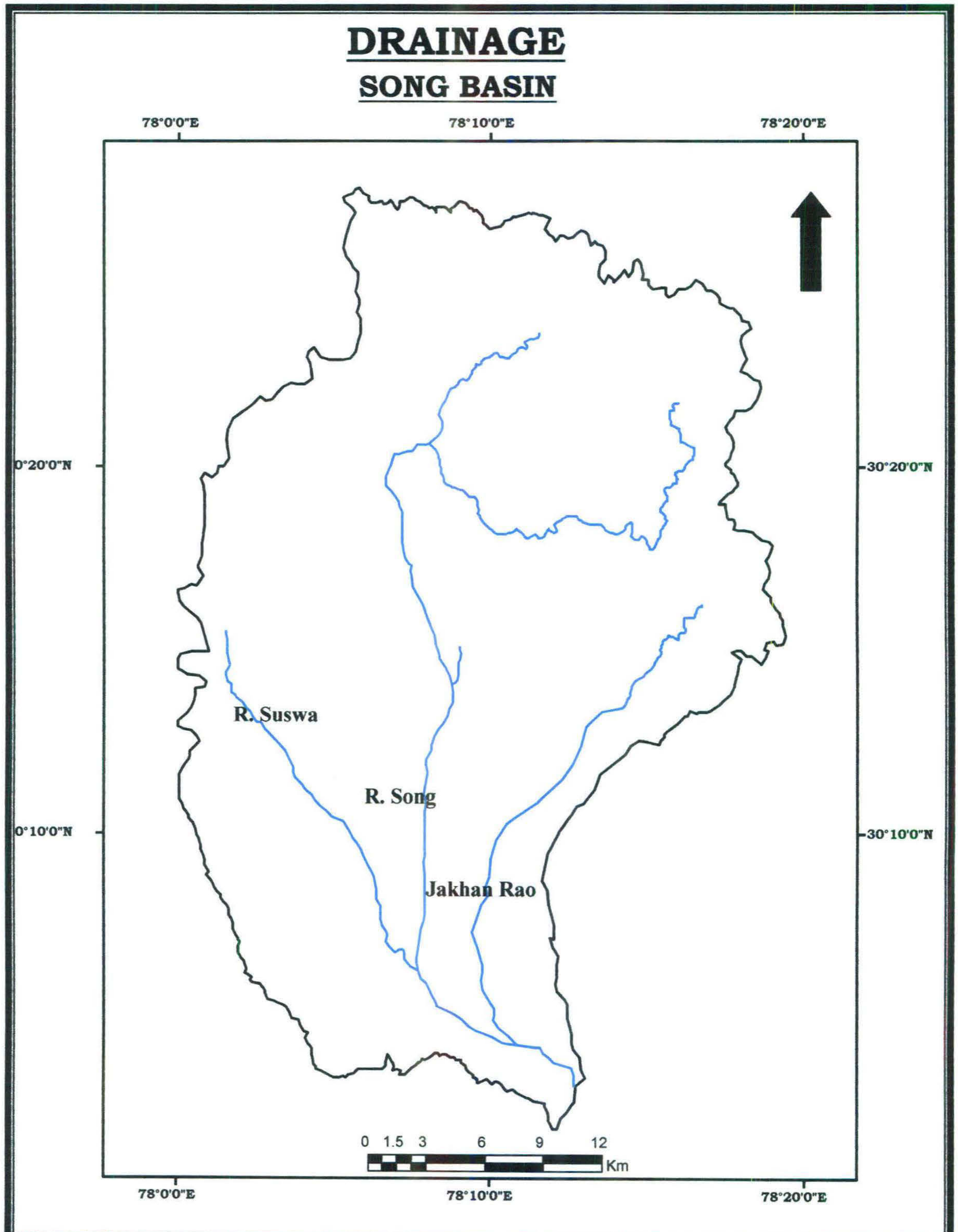
heavily clouded or overcast. The hills are often seen enveloped in clouds. During rest of the year, it is usually lightly clouded or clear.

Winds are generally light and are variable in direction. During post monsoon and winter mornings, northerly to northeasterly winds are experienced. In the afternoon, winds are mostly from directions between southwest and northwest throughout the year, except in October and November (Fig. 2.10).

2.3.4 Drainage

The Song River, one of the tributaries of the Ganga river system is the principal drainage system of the study area. The basin consists of 23 sub-watersheds. The river rises in Tehri-Garhwal and after running parallel to the Dun for some kilometers in a north-west direction unites with the Bindal. There it breaks, in a wide gorge, through the last line of the outer scrap of the Himalayas and receives the Baldi River near village Dwara. Then the combined waters flow in a south-easterly direction until they meet the Suswa. About two or three kilometer below the junction of the Song and the Suswa, a third torrent of the importance, the Jakhan Rao, is received. The Suswa maintains a parallel course for short distance. The portions of the Eastern Dun, north of the rivers to the east of the Tirsal forest, and the khadar of these rivers themselves present a network of streams and it is often difficult to distinguish the main rivers from their tributaries. In the middle section, adjacent to the Siwaliks, the river is much wider and the river takes a straight course from the north to the south. In the lower section, it takes a south-easterly turn and joins the Ganga near Haridwar.

The river is perennial in the upper mountainous region where as it dries up in the lower part because of base flow. The channel remains dry for about nine months a year. Occasional rain causes sudden variation of discharge of water. Rainy season shows violent flow of water immediately after the rains. The zigzag course with interlocking spurs is common in the Lesser Himalayas. Landslides are numerous on the hill slopes. Tremendous amount of debris supplied to the river sometimes choke up the whole valley.



Source: *Based on SoI Topographical sheets*

Figure 2.11

2.3.5 Vegetation

Forest products play an important role in the economy. Besides supplying fuel, fodder, bamboos, and medicinal herbs, they also yield a variety of products like honey, lac, gum, resin, catechu, wax, horns, and hides. This area is distinguished from other areas by the existence of very large forests chiefly stocked with *sal* (Shorea robusta). Owing to the variation in altitudes and other aspects, the flora varies from tropical to alpine species (Gazetteer of Dehradun, 1979). Different types of forest and varying species of shrubs, climbers and grasses, depending upon the aspect, altitude and soil condition are found in the area. It can be classified as:

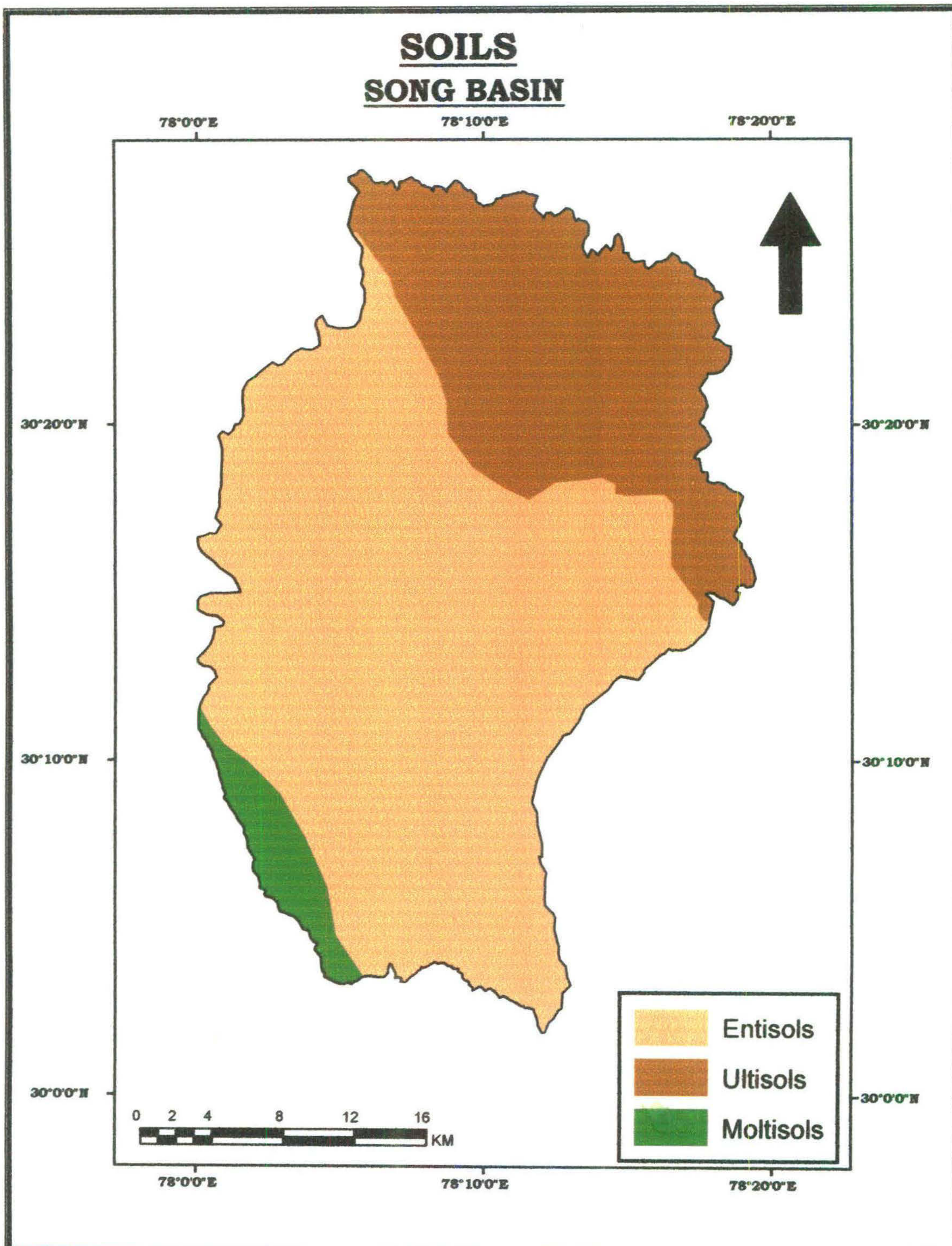
- ***Moist Siwalik Sal Forests*** – Low quality of *sal* is found in these forests. The main associates of *sal* are *bakli* and *sain*. The underwood is usually light consisting of *Amaltas, rial, aonla*; the undergrowth being *karaunda, gandhela, bindu* etc.
- ***Moist Bhabar Dun Sal Forests*** – *Sal* is pure in the overwood and its typical associates are *sain* and *dhauri*. The underwood growth includes *karaunda* and *chameli.*
- ***West Gangetic Moist Deciduous Forests*** – These are closed forest from medium to good height. The main associates of sal are *safed siris*, *jhingan, bohera* and *dhauri.* The grass found here are *kans, gorla* and *munj*.
- ***Sub-Montane Hill Valley forests*** – It consists of evergreen species which withstand wetness of the sites such as *gular, jamun, safed siris* etc. The underwood consists of *kala tendu* and *Salix tetrusperme*; the undergrowth comprising cane and *Ardesia solanacea.*
- ***Dry Siwalik Sal Forests*** – Sal is the predominant specie mixed with other associates viz. *bakli, sain, haldu, jhingan* etc. The underwood consists of *sandan, dheman, harsingar* etc. and the undergrowth comprising the *dhaula* and *indigofera pulchela.* The common grass is *baib* and *gorla* and bamboo also occurs frequently.
- ***Low Alluvial Savanna Woodland Forest*** – These are usually found on the higher and more stable alluvial terraces. The tree growth is generally poor and scattered consisting of *ambara*, semal, *saijana*, *siris* etc. The undergrowth is sparse and consists of *vasica, jharberi* and *karaunda.*

- ***Northern Dry Mixed Deciduous Forest*** – In the plains, these forests consist of semal, *khair*, *kanju*, *Amaltas* and *bel*. The *gutel* occurs near the river banks and water. The undergrowth consists of *gandhela*, *jharberi* and *bindu*. In the hills, the common species found are *bakli*, *semal*, *jhingan* etc. Grasses like *gorla*, *kumaria* and *baib* are fairly common vegetation.
- ***Dry Deciduous Scrub Forest*** – These forests represent a degraded stage of dry deciduous forest. The main species found are *jhingan, khhinni, mandana* and *amaltas*. Common shrubs are *harsingar, karaunda, mainphal* etc. The Euphorbia shrub generally occurs on higher elevation with very dry, rocky and bouldery soil.
- ***Khair Sissoo Forest*** – These forests occur on gravelly alluvium of streams and rivers. *Khair* and *sissoo* occur mixed but *sissoo* generally predominates. The undergrowth there, in general, consists of *basingha, gandhela and ber*.
- ***Sub Tropical Siwalik Chir Forest*** – These forest occur mixed with deciduous and sal forests. The pine stands singly or in groups.
- ***Sub Tropical Himalayan Chir Forest*** – These forests are found between the altitudes of 1200m – 2200m. The occurrence is however local and in small patches.
- ***Himalayan Sub Tropical Scrub Forest*** – These forests occur on shallow and excessively dry soil in the outer Himalayan chir forest zone. The tree species mostly occur along moist ravines and nullahs and consist of *Ficus roxburghii, burans, ban*, and *Pyrus pashia*.
- ***Banj Forest*** – These forest occur almost pure forming a somewhat open canopy of saplings and poles of coppice growth.
- ***Himalayan Temperate Secondary Scrub Forest*** – They represent a degraded stage of banj forests. The common shrubs are *kilmera, Rubus ellipticus* and *surai*.

2.3.6 Agriculture

Agriculture is the main source of income for the people in the area and is also a prominent sector of economy involving about 61% of the population. It is carried in the same way as in the plains but in the hilly areas, it requires hard labour and skill. The facilities for irrigation from canals and rivers are abundant but there is great deficiency of manure. Soil moisture regime is classified as "udic" (Fig. 2.11). Where there is irrigation, there are fine crops, but where there is no irrigation, it is a perfect matter of chance what the yield is, or whether there will be any yield at all. The surface soil is shallow and below this is gravel subsoil; this dries off all the moisture from the thin upper layers very soon, and if there isn't good rain, the yield of spring crops dwindles down to nothing. Cultivation in the hilly tract of Dehradun tehsil and throughout Jaunsar bhabar is of two descriptions – regular and intermittent. The hills, however, contain very little ground and terraced cultivation is, therefore, the rule. Intermittent cultivation consists of small patches of hill sides cleared off shrubs and grass usually by fire. These patches are cultivated for a year or so and then left fallow both to recuperate and also to allow the coarse grass to grow. In the area, there are two harvests. The *kharif* sown in June or a little earlier in the hills and reaped in September-October and *rabi* sown in October-November and reaped in March in the plains and in April-May in the hills. Paddy is one of the most important food crops. Basmati rice of the area is famous though both inferior and superior qualities of rice are sown. Wheat is the principal crop of *rabi* and is grown in almost all the parts of the area. Barley and mustard are other important *rabi* crops. Mustard, maize, *mandua*, *sonk*, *urd*, sugarcane etc. are other crops of importance. Fruits are also grown namely mango, guava, peach, grape, strawberry, pear, lemon etc. Potato is an important crop grown on Mussoorie hills.

Livestock play an important role in rural areas in raising the income of the small-scale farmers. Cows and buffaloes are the main source of milk, while male cattle are used for ploughing the fields. Sheep and goats are also reared in great numbers both for meat and wool. Wool is of immense importance and is used for making home spun woolen cloth and blankets. The production of milk per milch animal is very low. Action is being taken for the improvement of breed of the cattle.



***Source**: Modified after Geology map of Dehradun and Tehri-Garhwal, District Planning Map, NATMO.*

Figure 2.12

2.3.7 Industry, Trade and Commerce

The main industry of the area is tourism. Other activities can be classified in three main categories:

- Agro based industries such as sugarcane, fertilizer etc.
- Forest based such as railway sleeper from sal, furniture, plough shares and cartwheel.
- Additional industries are cement industry, lime stone quarrying, saw mill etc.

Large-scale industries include sugar mills, woolen textile mills, flour mills etc. Small-scale industries include dairy industry, canning & preservation, bakery products, chocolate, *khandsari*, tea, malt, silk textile, cardboard boxes, printing, timber goods, steel furniture, liquor, ayurvedic medicine, turpentine, tubes, leather goods, musical instruments, optical lenses, miniature bulbs, medical instrument, automobile industry, agricultural implements, utensils & hospital equipments, weigh bridges, sewing machines, metal goods, plaster of paris etc. Cottage industry includes wool industry, handloom cloth, power looms, *durries*, oil, jaggery, rice, apiary, walking sticks, baskets, cots & mats, brick-kiln etc.

Lime is the main export of the area. Other items of export include timber, rice, medicines etc. Items that are imported include gram, wheat, *arhar*, barley etc.

2.3.8 Social Structure

Most of the farmers have small holdings, inadequate and poor irrigation facilities, lack of knowledge of modern farming technology, use of local varieties of crops resulting in low production. Thus due to this reason the income status is not good. People supplement their income from employment and business. There is lack of production of commercial crops, cropping intensity, educational and infrastructural. Population of the area mainly comprise of Hindus followed by Muslims and Sikhs. Main languages spoken in the area are Hindi, Sindhi, Punjabi, Garhwali and Urdu.

The basin of the Song overall represents a fragile and complex ecosystem of both mountains and plains. It forms apart of the huge basin of the river Ganges and drains the eastern part of the Doon valley (District Dehradun). It is a tectonically active region and exhibits an array of features like structural hills, denudational hills, piedmont zone, valleys, recent floodplains, river terraces etc. The geology of the area dates back to Pre-Tertiary times. The climate is Humid Sub-Tropical Monsoon with occasional special weather phenomena like dust storm, hail, squall, fog etc. A wide variety of vegetation is found here including shrubs, climbers and grasses, *sal* being the dominant specie. Agriculture is the main stay of the economy. Livestock rearing is also important. Certain industries are also found in the area including fertilizer, sugarcane, limestone quarrying, tourism etc. Thus, the area in general has an economy that is developing.

3. MORPHOMETRIC ANALYSIS OF THE SONG BASIN

3.1 Introduction

"Measurement of the shape or geometry of any natural form – be it plant, animal or relief features – is termed as morphometry" (Strahler, 1964). But in geomorphology "morphometry may be defined as the measurement and mathematical analysis of the configuration of the earth's surface and of the shape and dimensions of its landforms" (Clarke, 1970). In fact, morphometry incorporates quantitative study of the area, altitude, volume, slope, profiles of the land and drainage basin characteristics of the area concerned.

Important factors governing the development of the land are resistance to erosion and geologic structure of the underlying rocks, climate and vegetative cover. Morphometry is gaining importance in evaluating hydrologic parameters of drainage basins. Quantitative measures of landforms have become the current thrust of geomorphology. Earlier it has been well-attempted by various geomorphologists like Horton, Schumm, Morisawa, Coates, King, Strahler and others. A detailed description of the methods of morphometric analysis of the basin characteristics is given by Horton (1932), Chow (1964), Doornkamp & King (1971), and Zavoianre (1985). In fact the vigorous application of the statistical methods for the analysis of drainage basin characteristics started after the publication in 1945. According to Gardiner (1982), 'morphometry is potentially an important approach to geomorphology, since it affords quantitative information on large scale fluvial landforms, which make up the vast majority of earth's configuration'.

Morphometric techniques are applied in character as well as integrated in approach. It provides a clear picture of the topography of a region. To divide a region into certain homogenous regions we need to necessarily deal with it. Spatial variations in socioeconomic condition are directly influenced by physiography and physiographic environment of particular region. Therefore, we have to take into account certain parameters which influence physiography. Terrain characteristics of particular region are important in their influence over one another, which are independent. With the help of morphometric parameters we will be able to evolve rationale for simulation or uniqueness occurring throughout the region.

Morphometric analysis generally deals with a drainage basin. River basins which are the most widely spread phenomena on the earth surface, cause the formation of distinctive shape of the earth's surface. The quantitative analysis of the drainage networks of a river basin stems from Horton's work (1945). It has been developed to enable a comparison to be made among different basin characteristics and channel properties of drainage basin. It also helps in establishing relationships between different aspects of the drainage pattern of the same basin, which can be formulated as general laws and to define certain useful properties of drainage basin in numerical terms.

Fluvial morphometry includes the consideration of linear, areal and relief aspects of a fluvially originated drainage basin. The *linear* aspect deals with the hierarchical orders of streams, numbers and lengths of stream segments and various relationships among them and related morphometric laws e.g. Law of Stream numbers and Law of Stream length. The *areal* aspect includes the analysis of basin perimeter, basin shape (both geometrical and topological), basin area and related morphometric laws viz. Law of Allometric growth, stream frequency, drainage density and drainage texture. The *relief* aspect incorporates besides hypsometric, clinographic and altimetric analysis, the study of absolute and relative and relative relief, relief ratios, average slope, dissection index, ruggedness index etc.

A quantitative approach is adopted here to show the morphometric characteristic of the region. Database for the purpose has been generated with the help of various sources such as satellite imagery and topographical sheet. Contour interval of 100 meters has been taken (Fig. 3.1). GIS techniques are used for making maps and doing calculations.

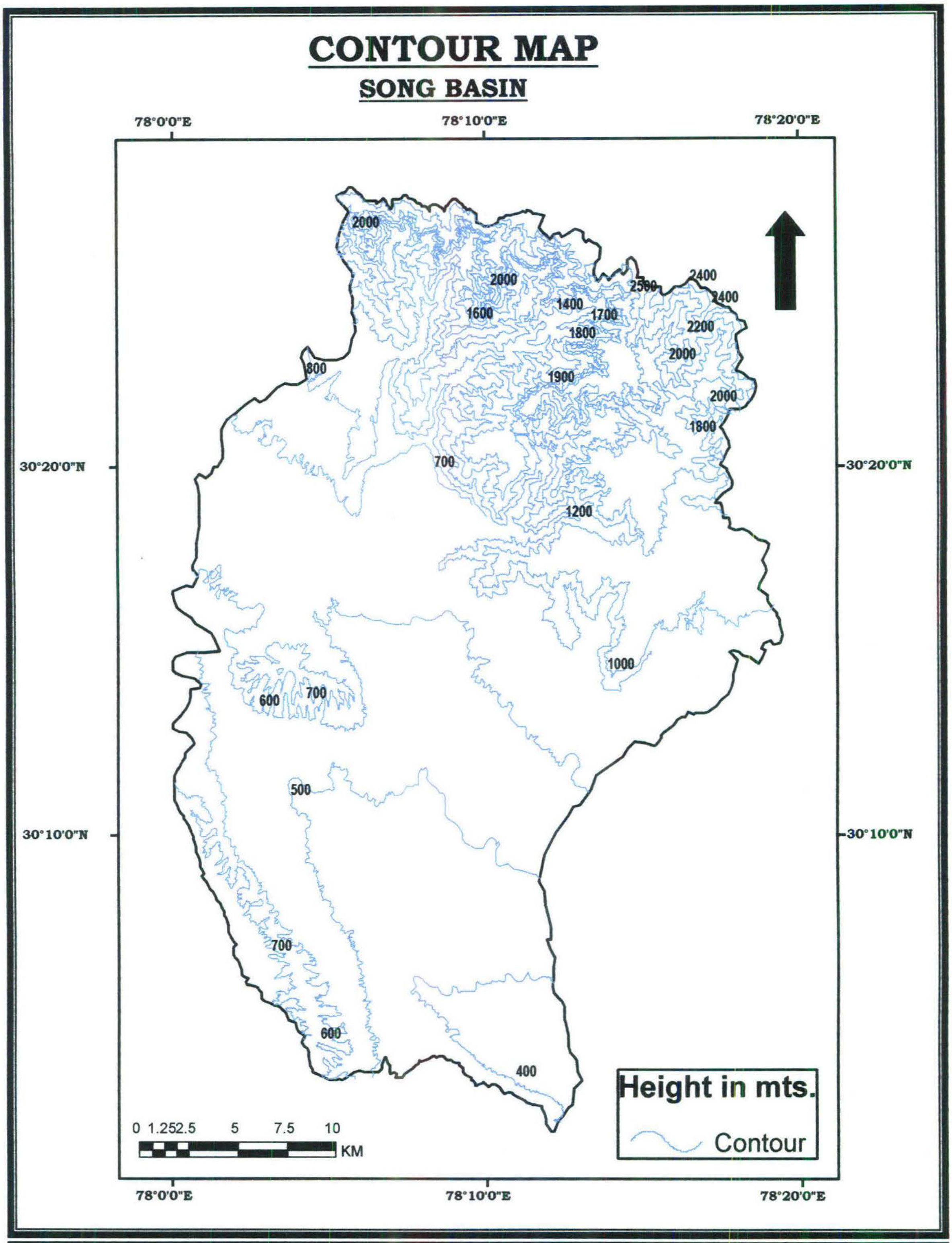

CONTOUR MAP
SONG BASIN
78°0'0"E
78°10'0"E
78°20'0"E
30°20'0"N
30°10'0"N
2000
2000
2500
2400
2400
1600
1400
1700
1800
2200
2000
1900
2000
1800
800
700
1200
1000
600
700
500
700
600
400
0 1.252.5 5 7.5 10
KM
Height in mts.
Contour

Figure 3.1

3.2 Morphometric Characteristics

Drainage patterns and their network are very important for the study of landform and environment. Drainage pattern means the 'form' (geometric forms) of the drainage systems and the spatial arrangement of streams in a particular locality or a region.

The drainage pattern of the Song river is more or less dendritic that is commonly found in which irregular branching of tributaries is in any direction and in almost any angle, although usually at considerably less than right angle characterizes it (Fig. 3.2). These develop the over rocks of uniform resistance and imply a notable lack of structural control. Dendritic patterns are most likely to be found upon nearly horizontal sedimentary rocks or in the areas of massive igneous rocks, but could be seen on the folded or complexly metamorphosed rocks, particularly when imposed upon them by super imposition (Thornbury, 1969). Though, towards the central and south-western part one can find a bit parallel pattern that denotes some structural control. In parallel pattern, numerous parallel rivers following the regional slope join the main river. In the higher reaches, the fingertip tributaries are quite closely packed and make the pattern very dense.

3.2.1 LINEAR PROPERTIES

Stream Ordering

It was first introduced by Horton in 1945 and later modified by Strahler (1952, 1964). This scheme is more universally accepted. The stream ordering is the process of identification of the links in a stream network in an unambiguous manner and also to provide an ordering system that could readily present an identification of the discharge from a network. In Horton's stream ordering, all unbranched streams are designated as first order; two first order streams combine to make a second order and so on. Subsequently, Strahler (1964) suggested slightly different method and according to him, the first order streams are those that have no tributaries. When two first order streams meet, the second order streams are formed, and two second order streams form the third stream and so on. The trunk stream through which all the water and discharge pass is the segment of the highest order. The basin is named after the highest order stream.

ORDER	NO. OF STREAMS	STREAM LENGTH (in km)
1^{st}	2032	1297.13
2^{nd}	471	434.80
3^{rd}	99	243.85
4^{th}	24	90.55
5^{th}	5	92.31
6^{th}	1	40.62
Total	2632	2199.26

Table 3.1

The basin of Song is a sixth order basin with a total number of 2632 perennial and non-perennial streams that spread over an area of 933.50 sq. km and stretch for a total length of 2199.26 km (Table 3.1).

The count of stream channels in each order is known as stream number. According to Horton's Law (1945) of stream numbers, "the numbers of streams of different orders in a given drainage basin tend closely to approximate as inverse geometric series of which the first term is unity and the ratio is the bifurcation ratio". According to this law the number of streams, counted for each order, are plotted on logarithmic scale on the y-axis against order number on arithmetic scale on x-axis. Horton noted that the number of streams of different orders in a watershed decreases with increasing order in a regular way. When the logarithms of the number of stream order are plotted against the order, the points lie on straight line.

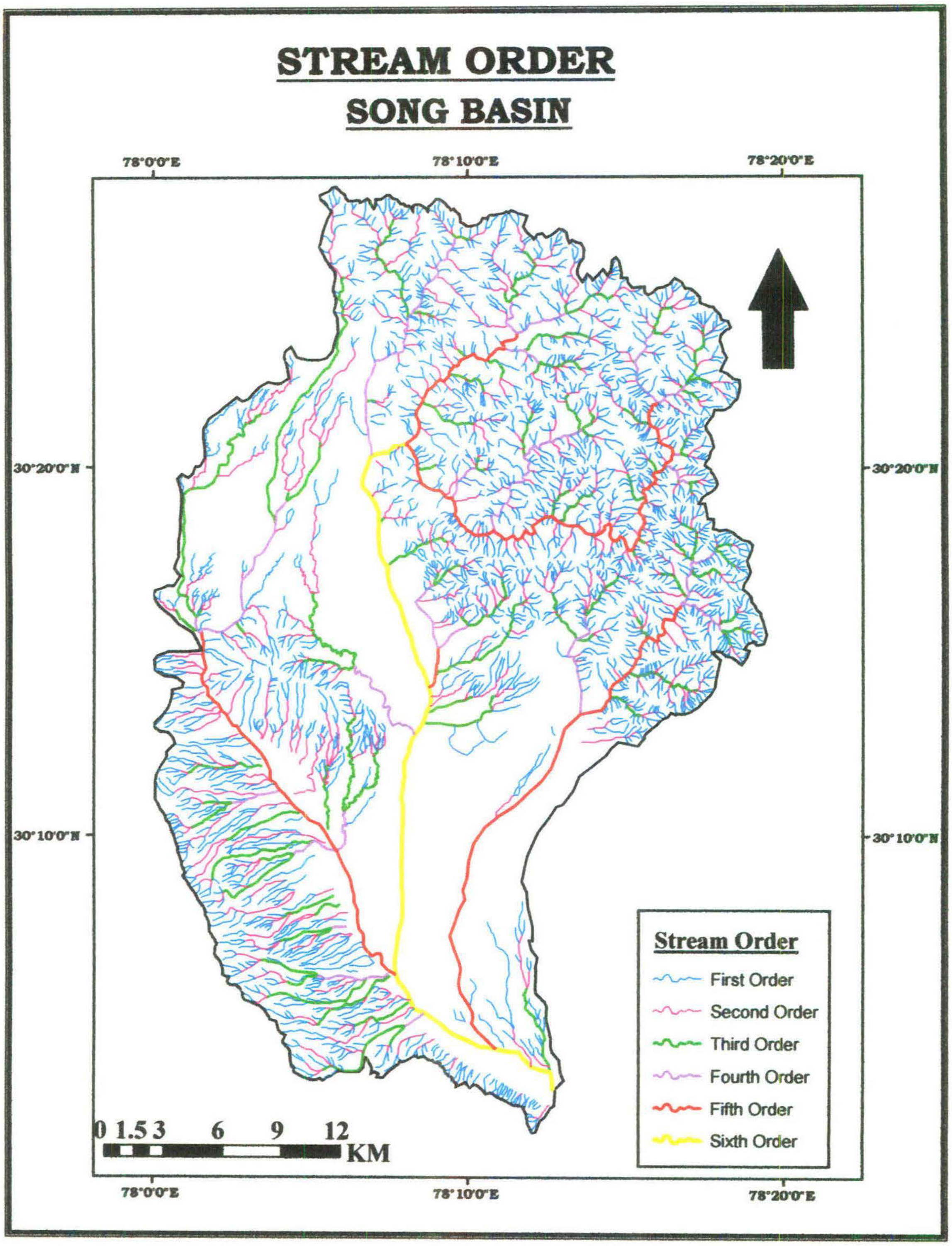

STREAM ORDER
SONG BASIN
78°0'0"E
78°10'0"E
78°20'0"E
30°20'0"N
30°10'0"N
Stream Order
First Order
Second Order
Third Order
Fourth Order
Fifth Order
Sixth Order
0 1.5 3 6 9 12
KM

Figure 3.2

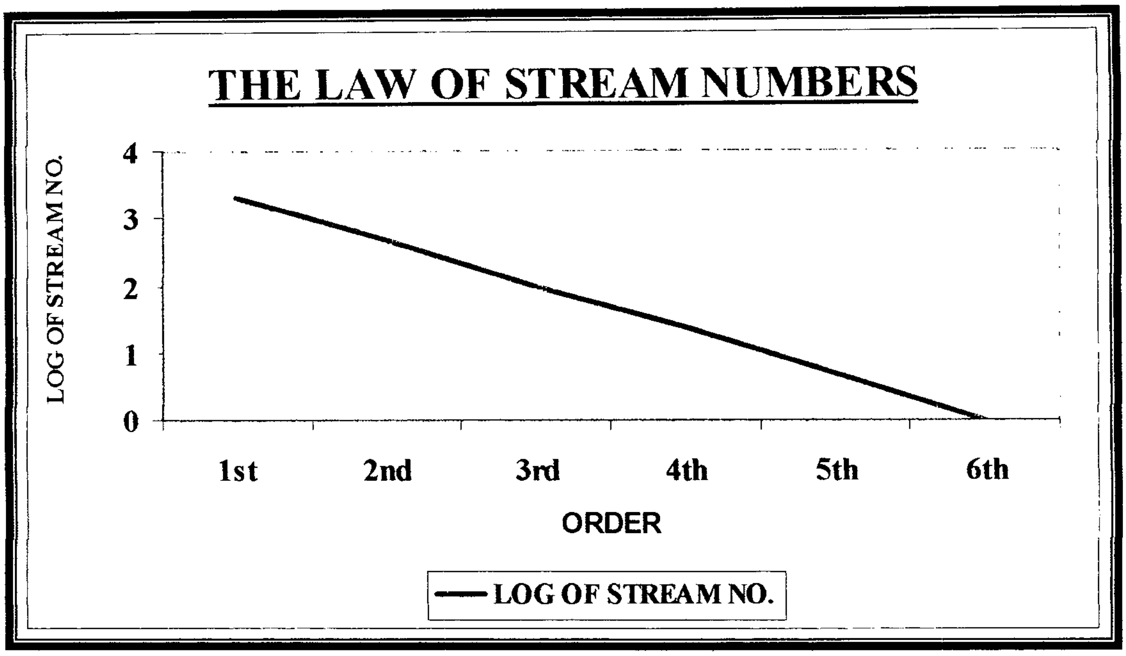


Figure 3.3

The figure 3.3 plotted between order and log of stream numbers for the Song basin almost validates the Horton's Law of Stream Numbers. Both the variables are found to have high negative correlation. As one moves from lower to higher order (i.e., 1, 2, 3 and so on), the number of stream segments decreases with highest order having just one stream that is the master consequent stream.

Bifurcation Ratio

The bifurcation ratio is the ratio between the numbers of stream segments of any given order to the number of stream segments of the next higher order (Schumm, 1956). Its irregular tendency is seen from one order to the next order.

The irregularity of the bifurcation ratio is dependent upon the lithological and geological development of the drainage basin (Strahler, 1971). It shows the degree of the integration prevailing between the streams of various orders in a drainage basin. The bifurcation ratio is calculated by using the following formula:

$$R_b = N / (N+1)$$

Where **N** is the number of streams in the given order,

And **N+1** is the number of steam in the next higher order.

Bifurcation ratio, a dimensionless property of the drainage basin is supposed to be controlled by drainage density, stream entrance angles (junction angles), lithological characteristics, basin shapes, and basin areas etc. which themselves are controlled by variation in physiographic and climatic conditions prevailing in the basin. It is an index of the degree of integration of streams of various orders in a drainage basin, and characteristically ranges from 3.0 to 5.0 for watersheds where the influence of geological structure on the drainage network is negligible. The theoretical minimum possible of 2.0 is rarely approached. High value of ratio indicates a lower degree of drainage integration and vice versa. Basin with similar rock composition, tectonic history, uniform climatic conditions and in similar age of development are characterized by more or less similar values bifurcation ratio. The relative constancy of R_b is due to the fact that drainage systems in homogenous materials tend to display geometrical similarity.

Abnormal bifurcation ratios usually have marked effect on maximum flood discharges. For example, basin with a high R_b, yields a low but extended peak flow. In areas of active gullies and ravines, the bifurcation ratio between first and second order streams may be considerably higher than R_b of higher order streams. This is indicative for a state of accelerated erosion. High bifurcation ratios are common where pronounced structural control encourages the development of elongate narrow drainage basins ($R_b >= 10$). If the groundwater is deep and infiltration is high, surface runoff will be relatively low with fewer channels and a lower bifurcation ratio can be expected.

ORDER	NO. OF STREAMS	BIFURCATION RATIO
1st	2032	4.31
2nd	471	4.76
3rd	99	4.13
4th	24	4.8
5th	5	5
6th	1	-

Table 3.2

The Song basin represents a more or less consistent bifurcation ratio (Table 3.2), ranging from 4 to 5, which explains the fact that the basin is characterized by similar rock structure, tectonic history and is in the same age of development. Moreover, uniform climatic conditions prevail over the area with slight differences in high altitude and plain areas. It also depicts geometrical similarity due to the presence of homogenous materials. Although comparatively higher bifurcation ratios towards lower orders indicate that higher reaches have areas of active gullies and ravines.

Stream Length

Horton's Law of Stream Length states that the average length of streams of each of the different order in a basin tends to approximate a direct geometric series in which the first term is the average length of the streams of the first order. The total stream length of various orders decrease as the order increases.

Mean stream length is a dimensionless property, characterizing the size aspect of drainage network and its associated surfaces (Strahler, 1964). It is calculated as:

$$AL_\mu = \Sigma L_\mu / N_\mu$$

Where, AL_μ = Mean stream length of given order
ΣL_μ = Total stream length of given order
N_μ = Number of streams of given order

The relationship between cumulative mean stream length and the stream order reveals more or less a straight line regression of positive exponential form as postulated by Strahler (1971).

Stream length ratio is the ratio between the mean length of streams of any two consecutive orders. Horton (1945) termed the length ratio as the ratio of the mean length of streams of one order to that of the next lower order. It tends to be constant throughout the successive orders of a watershed. It is obtained by:

$$\mathbf{R_L = AL_\mu / AL_{\mu-1}}$$

Where, $\mathbf{R_L}$ = Length Ratio

$\mathbf{AL_\mu}$ = *Mean stream length of given order*

$\mathbf{AL_{\mu-1}}$= Mean stream length of lower order

ORDER	MEAN STREAM LENGTH (in km)	LENGTH RATIO
1st	0.64	-
2nd	0.92	1.44
3rd	2.46	2.67
4th	3.77	1.53
5th	18.46	4.90
6th	40.62	2.20

Table 3.3

Table 3.3 clearly indicates that length ratio tend to deviate very much. As per Horton's Stream Length Ratio it should revolve around a constant in an ideal basin. Broadly, it tends to fluctuate around 2 with an exception of fifth order where it is quite high, being five. This shows structural control in the area.

The log of cumulative mean length (fig. 3.4) clearly shows a regression line of positive exponential function whereas total stream length (fig. 3.5) of given order is inversely related to stream order. Mean length of stream

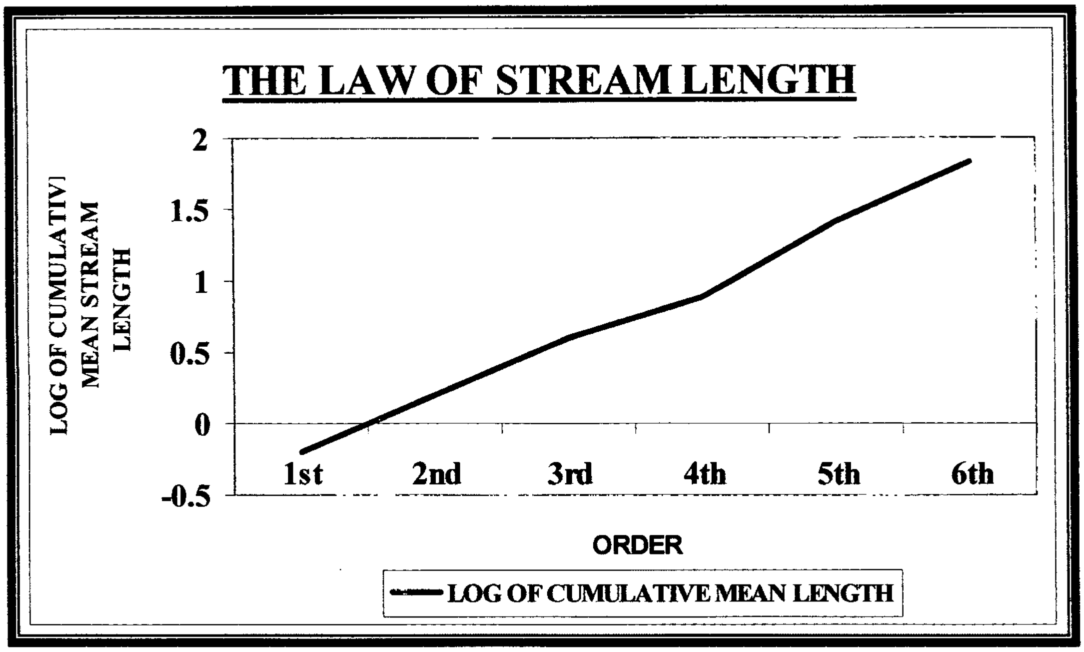

THE LAW OF STREAM LENGTH
LOG OF CUMULATIVE MEAN STREAM LENGTH
2
1.5
1
0.5
0
-0.5
1st
2nd
3rd
4th
5th
6th
ORDER
LOG OF CUMULATIVE MEAN LENGTH

Fig. 3.4

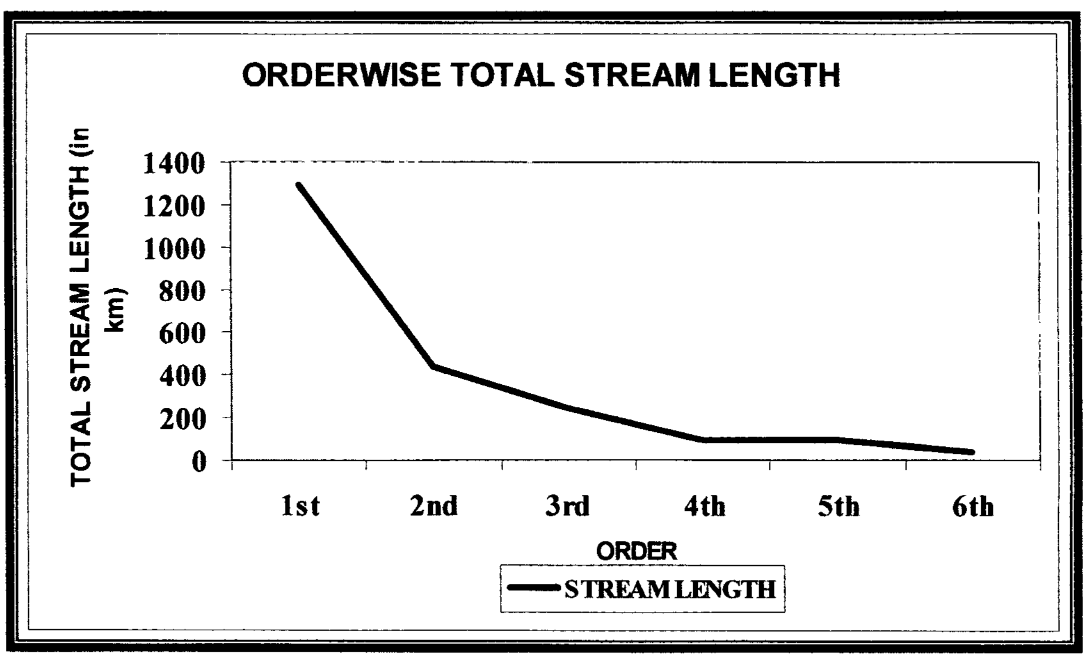

ORDERWISE TOTAL STREAM LENGTH
TOTAL STREAM LENGTH (in km)
1400
1200
1000
800
600
400
200
0
1st
2nd
3rd
4th
5th
6th
ORDER
STREAM LENGTH

Fig. 3.5

segments, having a positive relationship with order, increases with successive increasing order. The values of stream length for Song basin visibly confirm the Horton's Law of Stream length.

3.2.2 AREAL PROPERTIES

Basin Shape

The geometry of basin shape is of paramount significance as it helps in the description and comparison of different forms of the drainage basins. It is also related to the function of the units within basins and genesis. The ideal drainage basin is usually of pear shape. But since it is dependent on the size (of the basin) and length of the master stream of the basin and basin perimeter, which are themselves dependent on other variables such as absolute relief, slopes, geologic structure and lithological characteristics etc., a wide range of variations in basin shape is bound to evolve. On an average three sub-categories of basin shapes have been recognized viz. (i) circular, (ii) elongated, and (iii) indented. A compact shape may be elongated, non-elongated, or slightly indented where as a non-compact shape may be elongated, non-elongated, non-indented or highly indented.

The ratio of basin area to the square of basin length is called the **Form factor** (Horton, 1932). It is obtained by using the formula:

$$\mathbf{Rf = A / Lb^2}$$

Where, Rf = form Factor

A = Basin Area

Lb = Basin Length

The value of Rf varies from 0 (highly elongated shape) to the unity i.e. 1 (perfect circular shape). Thus higher the value of Rf, circular the shape of the basin and vice versa.

The **Elongation Ratio** is an indicative of the shape of the river basin. According to Schumm (1956), elongation ratio is defined as the ratio of the diameter of the circle having same area as the basin and the maximum basin length. The values of elongation ratio generally vary from 0.6 to 1.0 over a wide variety of climatic and geologic types. Values close to 1.0 are typical of regions of very low relief, where as values in the range 0.6 to 0.8 are commonly associated with high relief and steep ground slope (Strahler, 1964). These values can be grouped into four categories namely, (i) circular (above 0.9), (ii) oval (0.8-0.9), (iii) less elongated (0.7-0.8), and (iv) elongated (<0.7). It is very significant index in the analysis of basin shape which helps to give an idea about the hydrological character of a drainage basin. A circular basin is more efficient in the discharge of runoff than an elongated basin. This information is very efficient particularly in flood forecasting. It is attained by:

$$\mathbf{Re = d / Lb}$$

Where, Re = Elongation Ratio

d = diameter of the circle of the same area as the basin

Lb = maximum basin length

According to Miller (1953), the **Circularity Ratio** of a basin is the ratio of basin area to the area of a circle having the same perimeter as the basin. It is also a dimensionless index to indicate the form outline of drainage basins (Strahler, 1964). The value ranges from 0 (a line) to 1 (a circle). Higher the value, more circular the shape of basin and vice versa. The ratio is influenced by the length and frequency of streams, geological structure, vegetation cover, climate, relief and slope of the basin. It is obtained by:

Rc = Area of basin / Area of the circle with same perimeter as the basin

Where, Rc = Circularity Ratio

It is generally believed that all the factors controlling drainage basin development remain constant, the basin shape becomes more and more circular with the advancement of stages of cycle of erosion and the basin assumes pear shape in the penultimate stage of its development. But in most of the cases the shapes of the drainage basins do not appear to be the result of stages of basin development as topography and structure play important role in determining basin shape.

Areal Aspects	
PARAMETERS	**VALUE**
Basin area	933.50 sq. km
Basin length	48.36 km
Basin width	31.04 km
Basin perimeter	169.03 km
Form factor	0.40
Circularity ratio	0.41
Elongation ratio	0.36

Table 3.4

Song basin, as it is clear from Table 3.4, is neither perfectly circular nor perfectly elongated. Rather it is in the midway with a slight elongation. All the three ratios of basin shape broadly state the same. Low elongation ratio is because of the not high relief in the area. Structural control is significant in the south-western part of the basin where streams run parallel to each other. Discharge runoff is also less efficient as the basin shape is towards elongation.

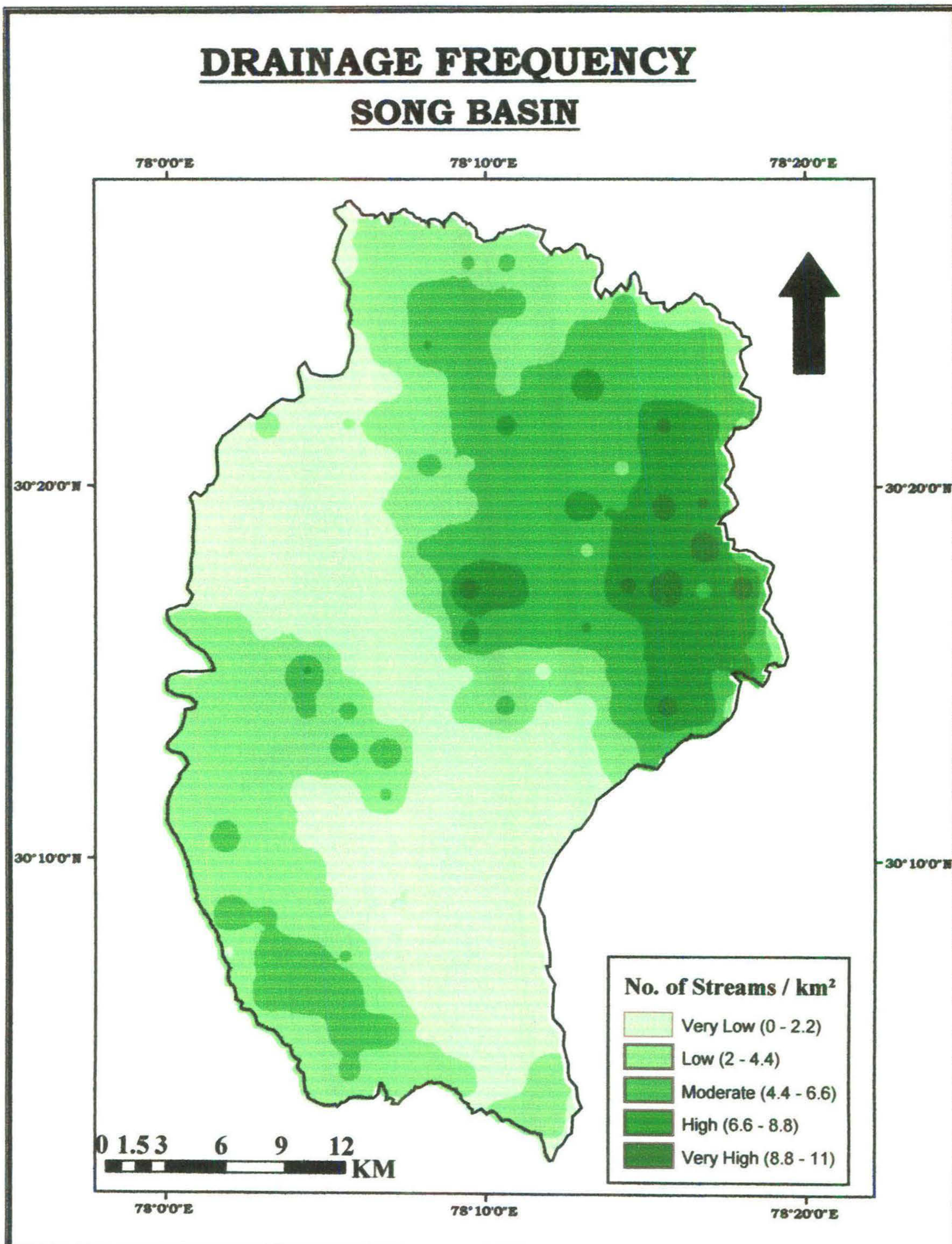
Drainage Frequency

Drainage frequency is defined as the total number of stream segments per unit area. The occurrence of stream segments depends upon the nature and structure of rock, nature and amount of rainfall, vegetation cover and infiltration capacity of soil. Stream frequency is obtained by following formula:

$$\textbf{Stream frequency} = \Sigma N / A$$

Where, ΣN is the total number of streams segments

And A is the area which is usually in Km^2.



DRAINAGE FREQUENCY
SONG BASIN
78°0'0"E
78°10'0"E
78°20'0"E
30°20'0"N
30°10'0"N
No. of Streams / km²
Very Low (0 - 2.2)
Low (2 - 4.4)
Moderate (4.4 - 6.6)
High (6.6 - 8.8)
Very High (8.8 - 11)
0 1.5 3 6 9 12
KM

Figure 3.6

Drainage Frequency		
Category	**Class**	**% of Area Occupied (Song Basin)**
Very Low	0 - 2.2	34.43
Low	2.2 - 4.4	31.98
Moderate	4.4 - 6.6	23.51
High	6.6 - 8.8	9.08
Very High	8.8 - 11	0.99
Very Low	0 - 2.2	34.43

Table 3.5

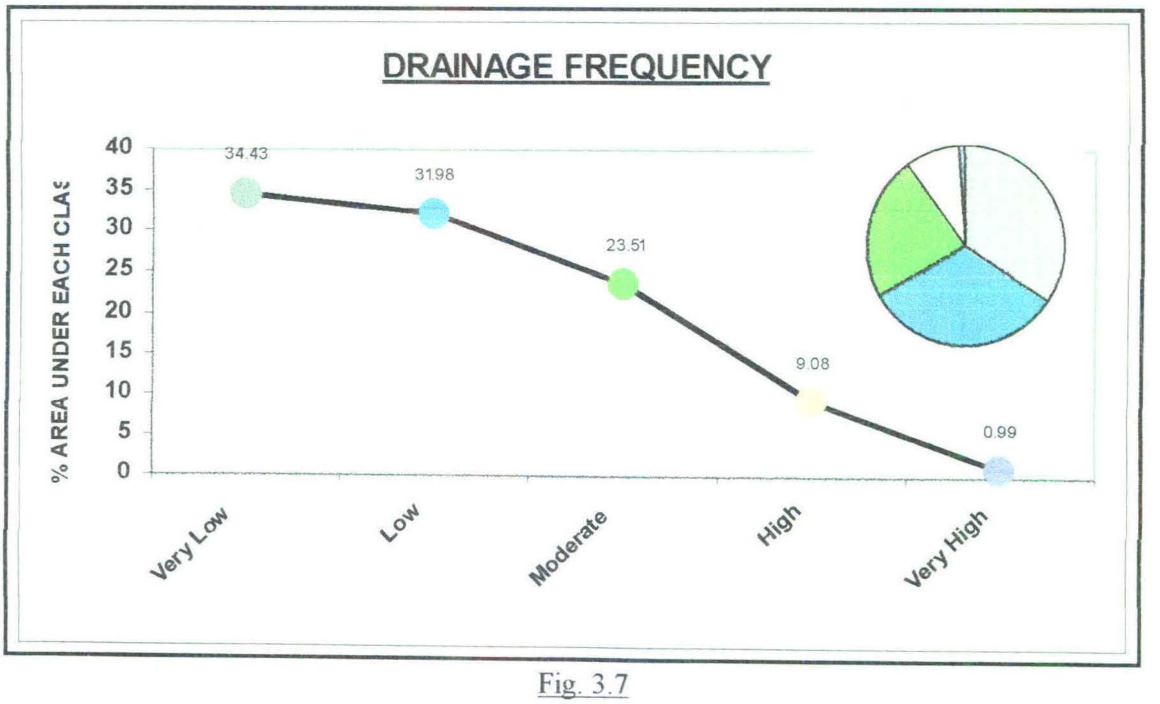


Fig. 3.7

On an average drainage frequency or stream frequency is high in the south-western and north-eastern part of the basin (Fig. 3.6 & 3.7) which is due to high relief that leads to more of gully and rill erosion and numerous ephermel streams originate. Very low to low drainage density covers maximum area of the basin, the area that is marked with low relief (Table 3.5).

Drainage Density

Drainage density is length of the stream channels per unit square area. Horton (1945) defined drainage density as a ratio of all stream segments in a given drainage basin to the total area of that basin. It is expressed in kilometers of channel length per sq. km. High drainage density represents the fine texture and low, the coarse structure. Drainage density is calculated by the following formula:

$$\textbf{Drainage density} = \Sigma L / A$$

Where, ΣL is total length of stream segments in Km.

And A is the area which is usually in Km^2.

It is measure for the degree of the dissection of the basin. It may vary from 0, for example, in dune areas to more than a thousand km/sq. km. in highly dissected badlands on impermeable shales. Heavy rainfall, annual or episodic and seasonal, seems to be largely responsible for high values of drainage densities. The drainage density in areas of comparable climatic conditions basically depends on geological factors (particularly lithology and the resistance of the rock to erosion) and on infiltration capacity (Moriasawa, 1968). The later is partly affected by the lithological factor of permeability, but relief and soil moisture are also factors. Low drainage densities and large basins with comparatively low-order main streams are common in resistant rocks, where as high drainage densities and higher order basins are common in soft rocks such as shales. Humid climates tend to have a lower drainage density than arid areas of comparable lithological composition resulting from the regulating effect of vegetation and stream flow and erosion. Areas of low relief and good infiltration capacity generally show lower drainage density values than zones of high relief or lower permeability.

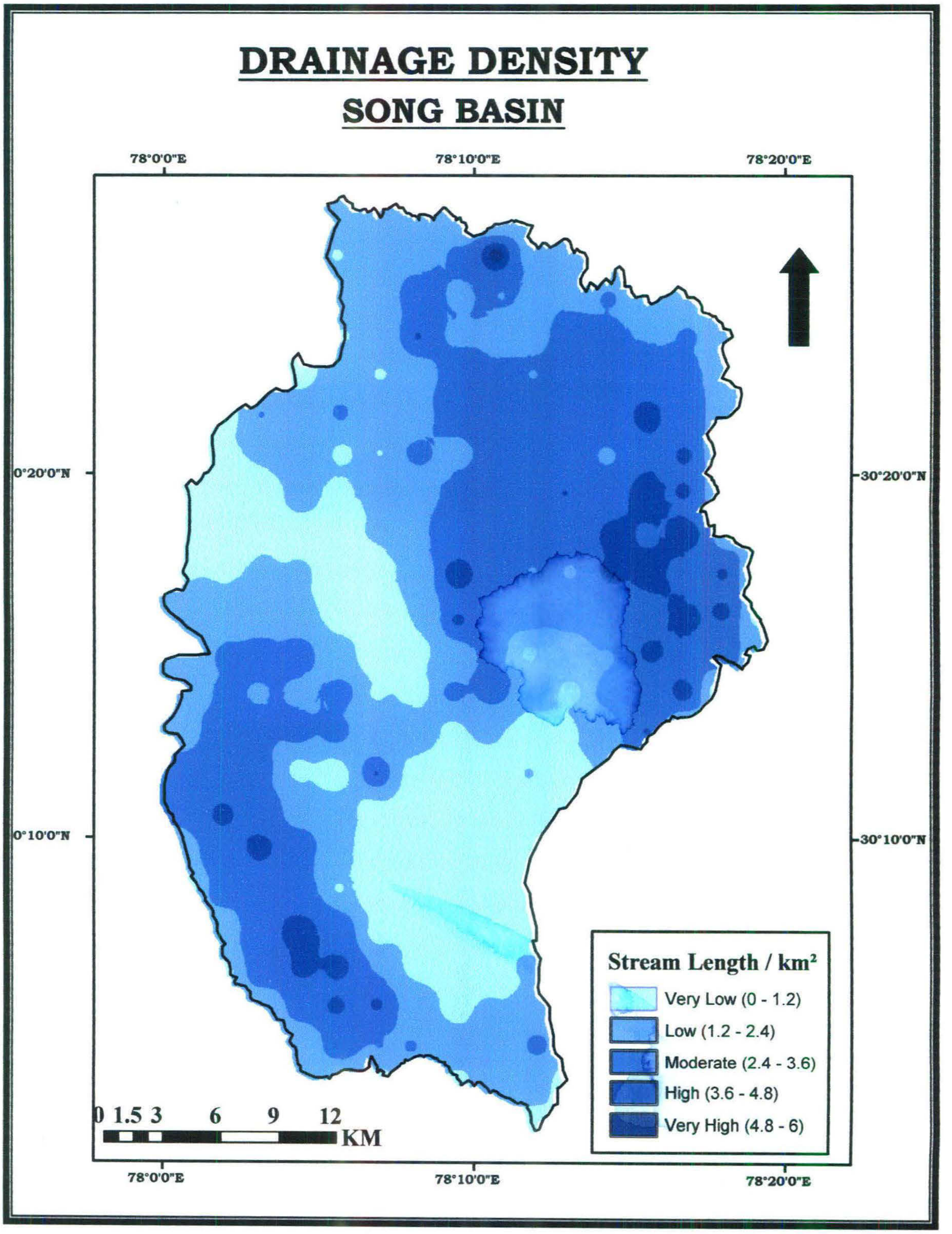

DRAINAGE DENSITY
SONG BASIN
78°0'0"E
78°10'0"E
78°20'0"E
0°20'0"N
0°10'0"N
30°20'0"N
30°10'0"N
Stream Length / km²
Very Low (0 - 1.2)
Low (1.2 - 2.4)
Moderate (2.4 - 3.6)
High (3.6 - 4.8)
Very High (4.8 - 6)
0 1.5 3 6 9 12
KM

Figure 3.8

Drainage Density		
Category	**Class**	**% of Area Occupied (Song Basin)**
Very Low	0 - 1.2	21.66
Low	1.2 - 2.4	36.52
Moderate	2.4 - 3.6	37.74
High	3.6 - 4.8	4.04
Very High	4.8 - 6.0	0.04

Table 3.6

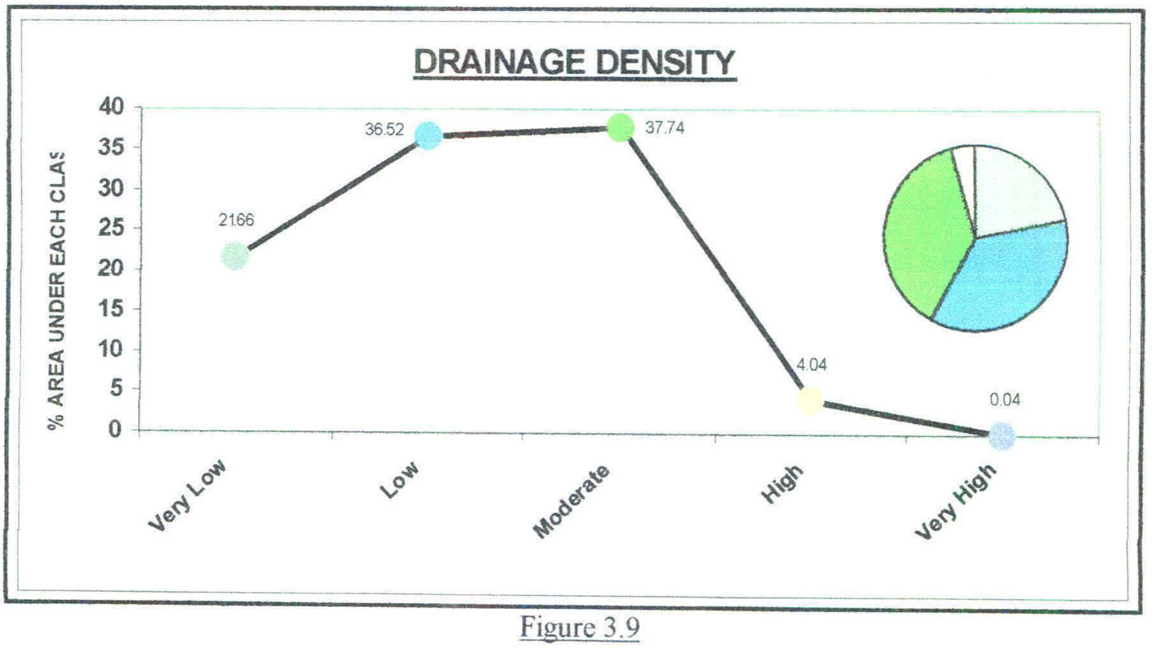


Figure 3.9

The areas of high density of streams more or less correspond to areas of high frequency, i.e., north-east and south-west part of the basin (Fig. 3.8 & 3.9). Maximum area of the basin approximately 50% has low to very low density which is the area of low relief (Table 3.6). Higher densities are found in very small patches in the areas of high relief.

Drainage Texture

'An important geomorphic concept is drainage texture by which we mean the relative spacing of drainage lines' (Smith, 1950). Horton (1945) defined drainage texture on the basis of stream frequency. The term drainage texture must be used to indicate relative spacing of streams in a unit area along a linear direction (Singh, 1976, 1978). It has advantage over stream frequency and drainage density, as it is combination of both. It is calculated by the following formula:

Drainage texture = stream frequency * drainage density

Drainage Texture		
Category	**Class**	**% of Area Occupied (Song Basin)**
Very Low	0 – 0.2	52.34
Low	0.2 – 0.4	31.83
Moderate	0.4 – 0.6	9.94
High	0.6 – 0.8	5.4
Very High	0.8 – 1.0	0.49

Table 3.7

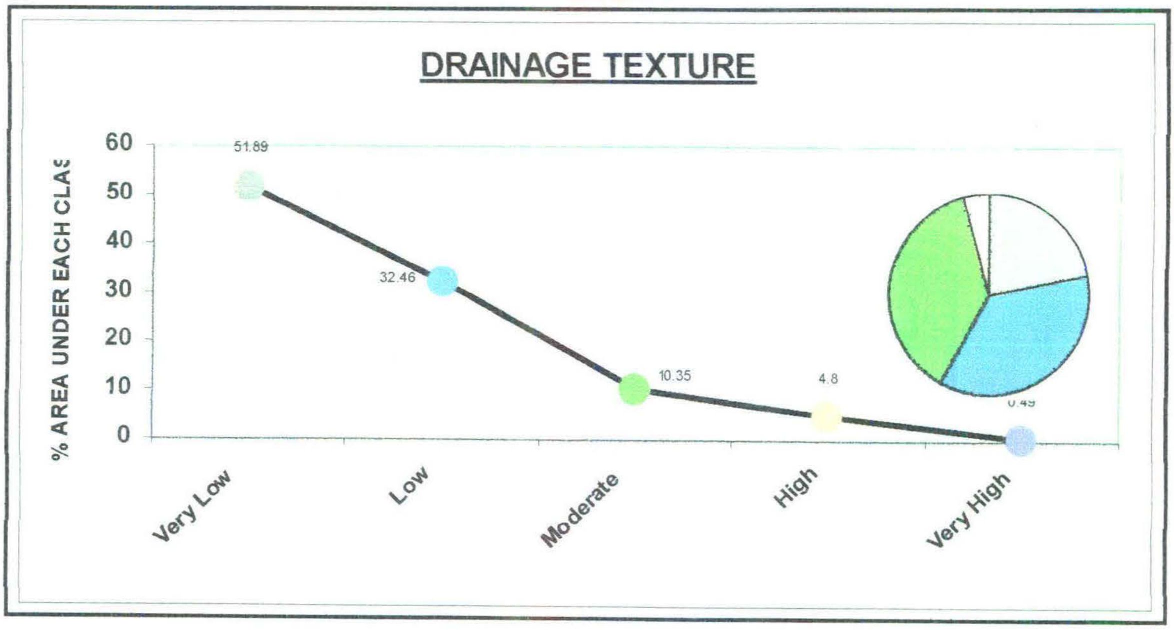


Figure 3.10

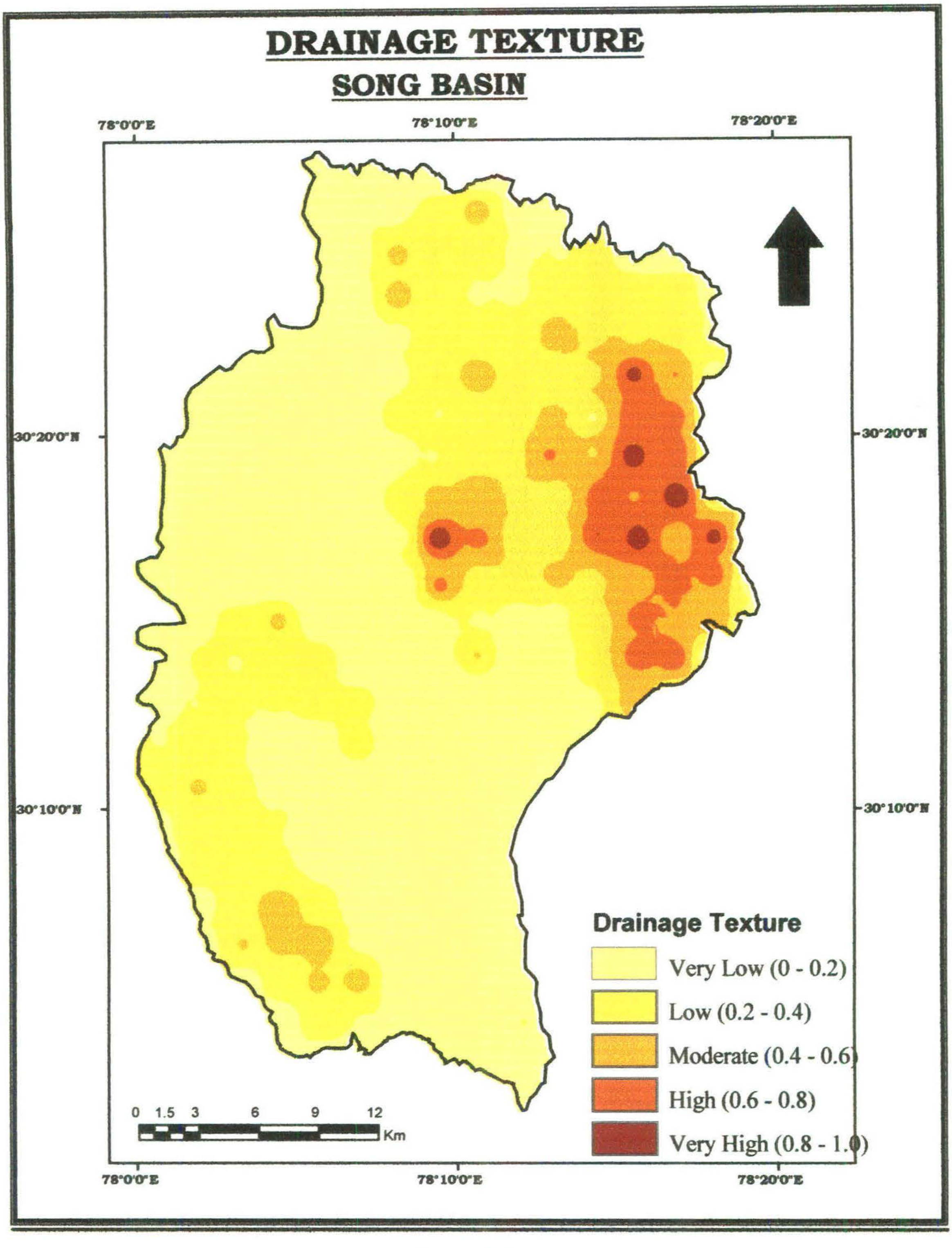

DRAINAGE TEXTURE
SONG BASIN
78°0'0"E
78°10'0"E
78°20'0"E
30°20'0"N
30°10'0"N
Drainage Texture
Very Low (0 - 0.2)
Low (0.2 - 0.4)
Moderate (0.4 - 0.6)
High (0.6 - 0.8)
Very High (0.8 - 1.0)
0 1.5 3 6 9 12
Km

Figure 3.11

Higher the drainage density, finer will be the drainage texture. Thus fine to very fine texture is found in fragments in the higher reaches in the areas that are marked with a dense network of streams (Fig 3.10 & 3.11). A major section (around 80%) of the basin has coarse texture due to very little number of streams found there (Table 3.7). South-eastern part that also possesses high density has a relatively moderate texture.

3.2.3 RELIEF PROPERTIES

Absolute Relief

The actual elevation of any point above the mean sea-level gives the absolute relief of that point. It provides a clear picture of the nature of terrain and undulations of the surface.

Absolute Relief	
Class	**% of Area Occupied (Song Basin)**
300-600	33.86
600-900	28.33
900-1200	11.06
1200-1500	11.64
1500-1800	9.03
1800-2100	5.73
2100-2400	0.35

Table 3.8

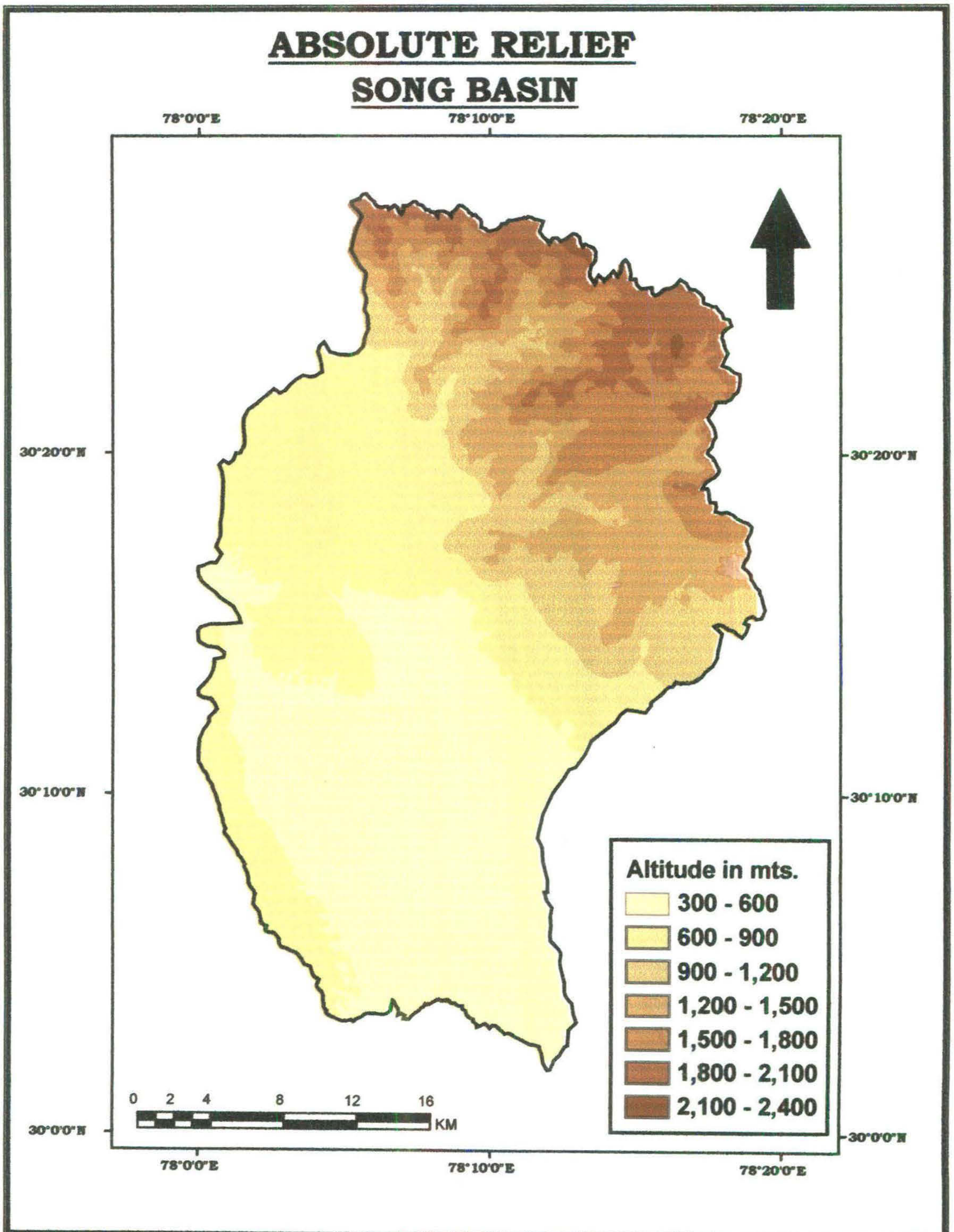

ABSOLUTE RELIEF
SONG BASIN
78°0'0"E
78°10'0"E
78°20'0"E
30°20'0"N
30°10'0"N
30°0'0"N
Altitude in mts.
300 - 600
600 - 900
900 - 1,200
1,200 - 1,500
1,500 - 1,800
1,800 - 2,100
2,100 - 2,400
0 2 4 8 12 16
KM

Figure 3.12

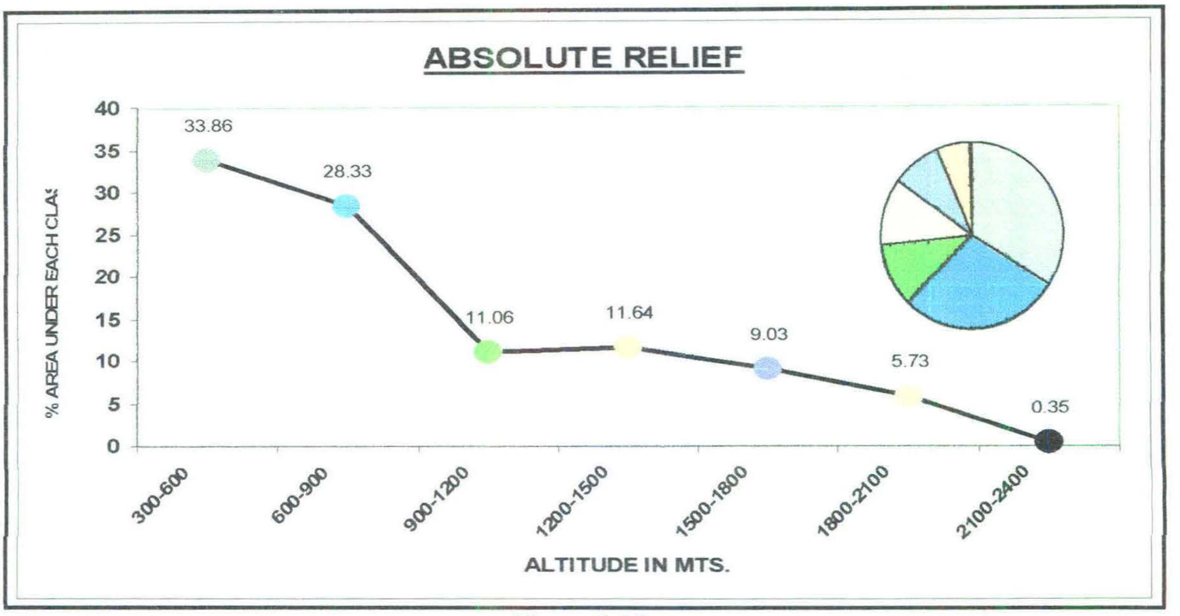


Figure 3.13

The absolute relief mapping for the Song basin is done by plotting contours on an interval of 100 meters (Fig. 3.12). Figure 3.13, area under various classes of absolute relief is decreasing with increasing altitude. On an average, absolute relief ranges from 300 meters to 2400 meters. Though most of the area under the basin is comparatively low lying, that is up to 500 meters (Table 3.8). Very high relief is found towards the northern part that forms a part of the Lesser Himalayas. Relatively high relief is also found in south-western part which is the Siwalik formation.

Relative Relief

Relative relief is defined as the differences in height between the highest and lowest point in a unit area. It is also termed as amplitude of 'available relief' or 'local relief'. It is a very important morphometric variable, used for overall assessment of morphological characteristics of terrain and degree of dissection. W.S. Glock (1932) used the term 'amplitude of relief' and defined it as 'the vertical distance from a horizontal fairly flat upland down to the initial grade of the streams'. Higher the degree of dissection, greater is the relative relief. It is calculated using the following formula:

Relative relief = Highest contour value/ Spot Ht. – Lowest contour value/ Spot Ht.

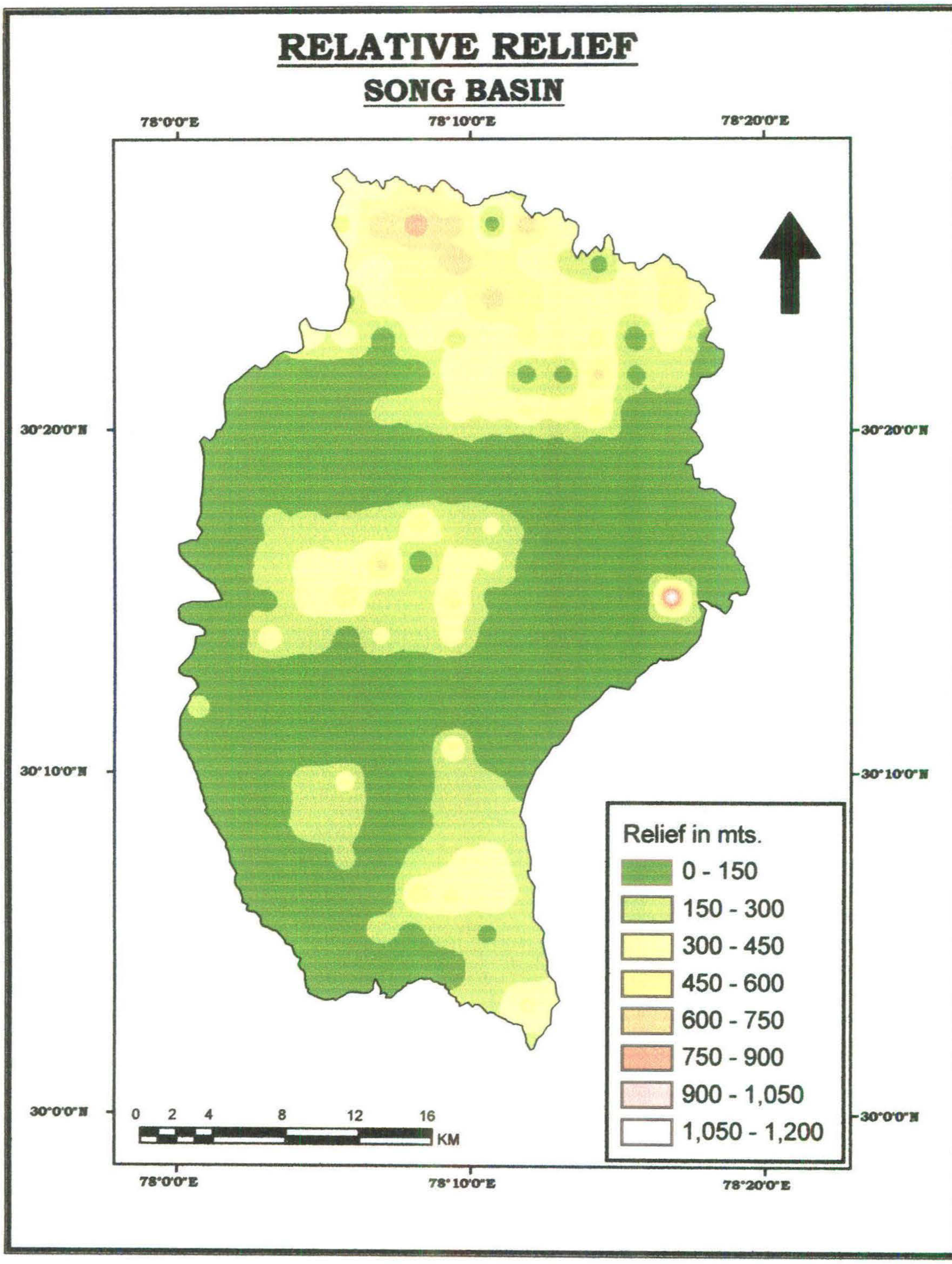

RELATIVE RELIEF
SONG BASIN
78°0'0"E
78°10'0"E
78°20'0"E
30°20'0"N
30°10'0"N
30°0'0"N
0 2 4 8 12 16
KM
Relief in mts.
0 - 150
150 - 300
300 - 450
450 - 600
600 - 750
750 - 900
900 - 1,050
1,050 - 1,200

Figure 3.14

Relative Relief	
Class	% of Area Occupied (Song Basin)
0-150	55.55
150-300	21.29
300-450	15.83
450-600	5.67
600-750	1.44
750-900	0.11
900-1050	0.07
1050-1200	0.03

Table 3.9

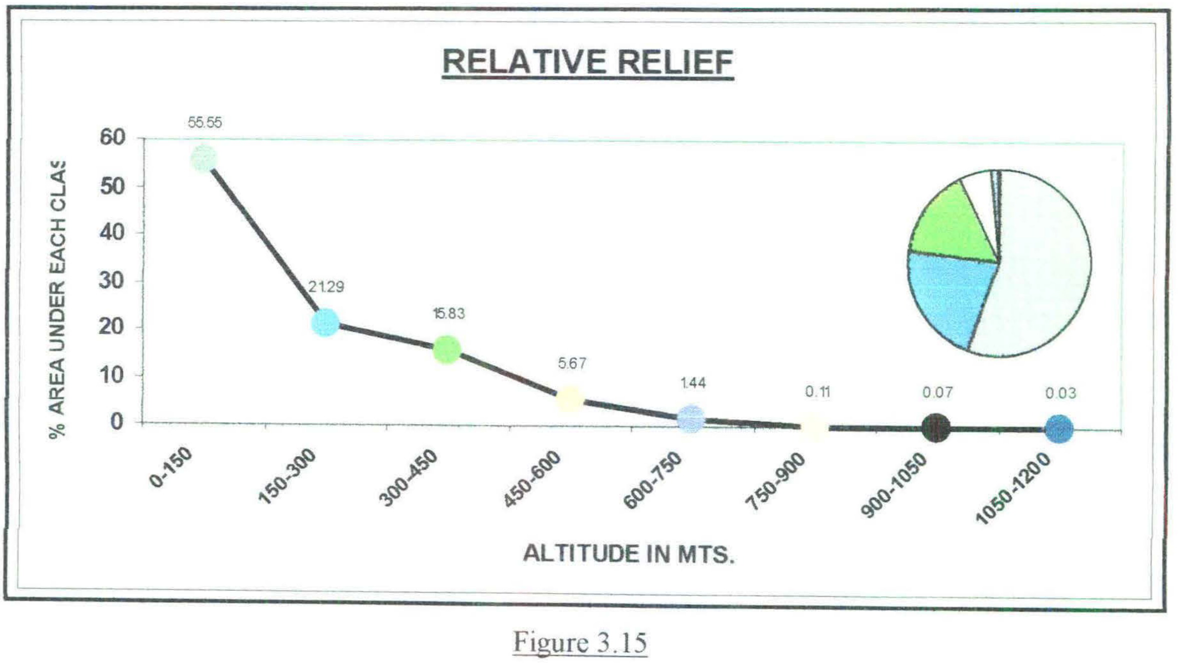


Figure 3.15

Moderate to high relative relief is found in very limited sections in the area towards the upper reaches where numerous closely packed first and second order tributaries are found that have highly dissected the surface (Fig. 3.14 & 3.15). Due to this, greater undulations have been created over the facade. Extreme northern part of the area has a higher relative relief i.e., 700 meters. More than half of the area possesses very low relief (Table 3.9). It depicts that the central and the southern parts of the basin are roughly flat.

Dissection Index

Dissection index, expressing a ratio of the maximum relative relief to the maximum relative relief, is an important indicator of the nature and magnitude of the dissection of terrain. Slaucitajas (1936) used real area to the projected area between successive contours to calculate dissection index. It clearly indicates the stages in the cycle of erosion. Dissection index is also used as morphometric determinant of the stage of cycle of erosion wherein old, mature and young stages are related to dissection indices of less than 0.1, 0.1 - 0.3, and more than 0.3 respectively. The value of dissection varies from zero (complete absence of dissection) to one (vertical cliff). It is calculated using following formula:

Dissection index = relative relief / absolute relief

Dissection Index	
Class	**% of Area Occupied (Song Basin)**
0 - 0.09	41.36
0.09 – 0.21	36.23
0.21 – 0.44	21.9
0.44 - 1	0.51

Table 3.10

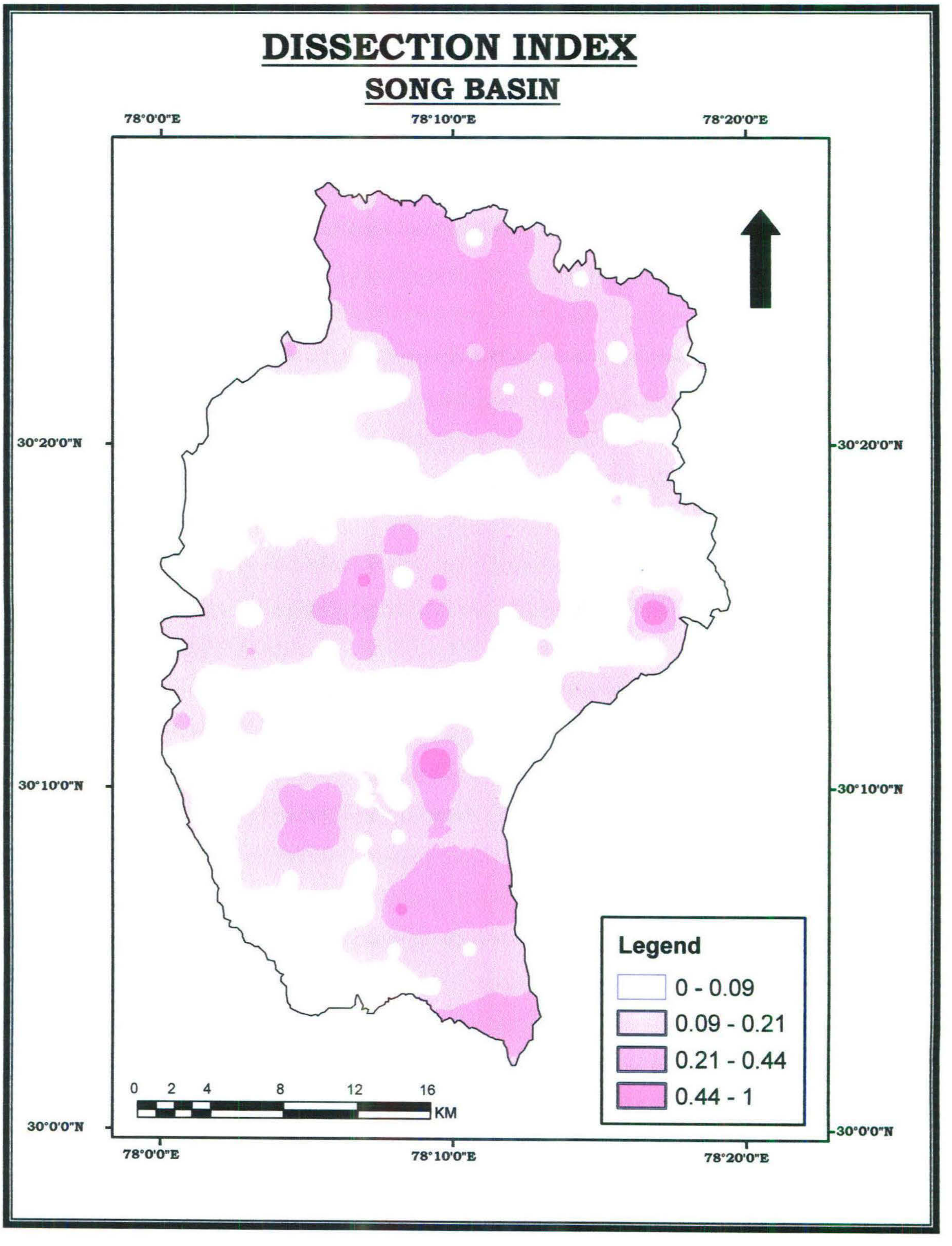

DISSECTION INDEX
SONG BASIN
78°0'0"E
78°10'0"E
78°20'0"E
30°20'0"N
30°10'0"N
30°0'0"N
0 2 4 8 12 16
KM
Legend
0 - 0.09
0.09 - 0.21
0.21 - 0.44
0.44 - 1

Figure 3.16

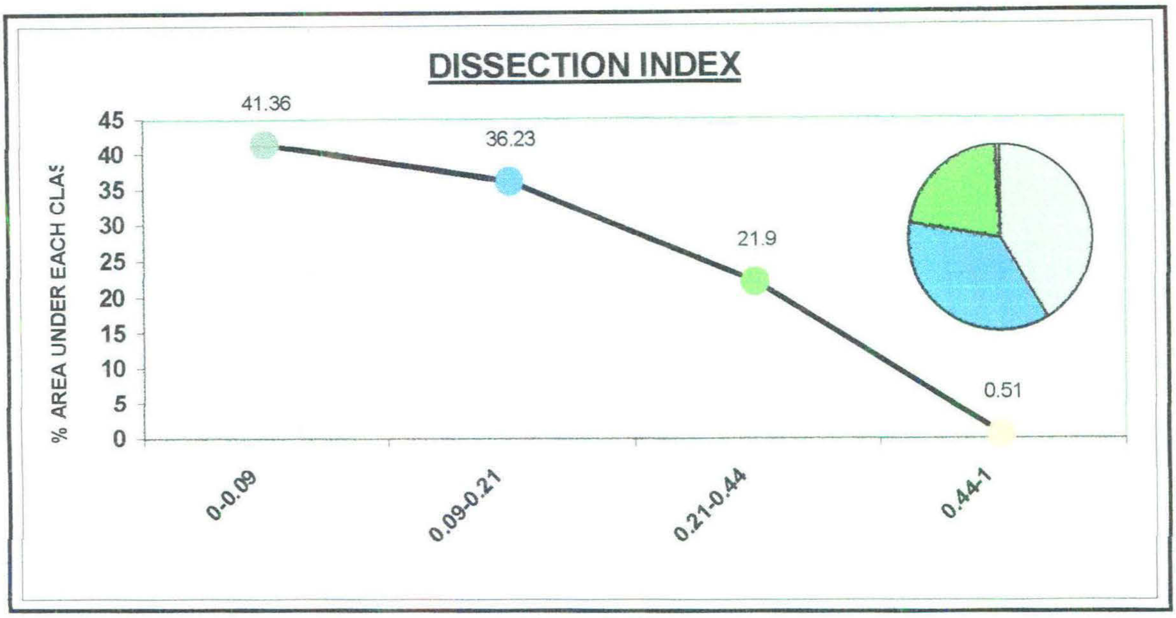


Figure 3.17

Highly dissected areas are those that lie in the zones that have a dense system of a number of streams actively involved in under-cutting. These are the regions of high altitude mainly extreme northern and southern sections of the basin that are parts of lofty mountain ranges. Around 20 percent area in the basin is highly dissected (Table 3.10). In addition to it some parts in the centre and south also possess slightly dissected terrain (Fig. 3.16 & 3.17). Most of the area (around 70%) of the basin is less dissected because of low relief and less number of streams flowing over the surface.

Ruggedness Index

Ruggedness is a derivative of long standing interaction between available sharpness of local relief and the amplitude of available drainage density and other environmental parameters such as slope, precipitation, weathering, soil texture, natural vegetation etc. It is a measure of surface unevenness. It is a function of relief and drainage density (Chorley, 1971). It is calculated by the following formula:

Ruggedness index = (relative relief * drainage density) / 1000

Ruggedness Index	
Class	**% of Area Occupied (Song Basin)**
0-0.16	43.84
0.16-0.45	28.3
0.45-0.81	13.05
0.81-1.22	11.31
1.22-2.20	3.5

Table 3.10

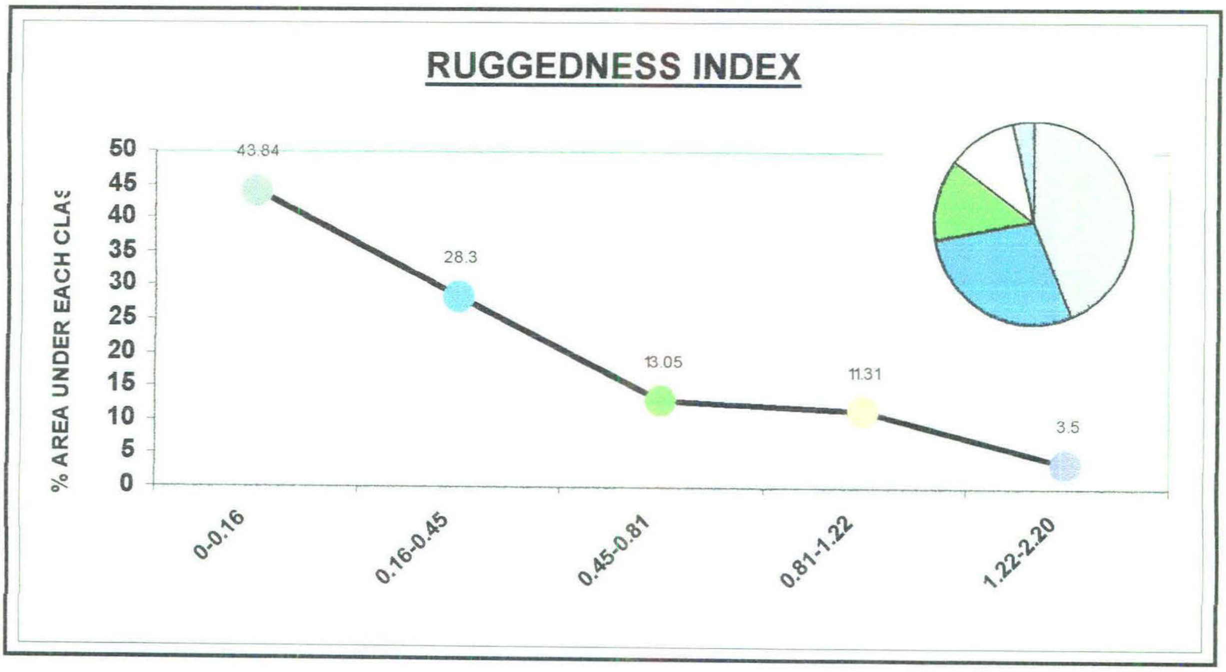
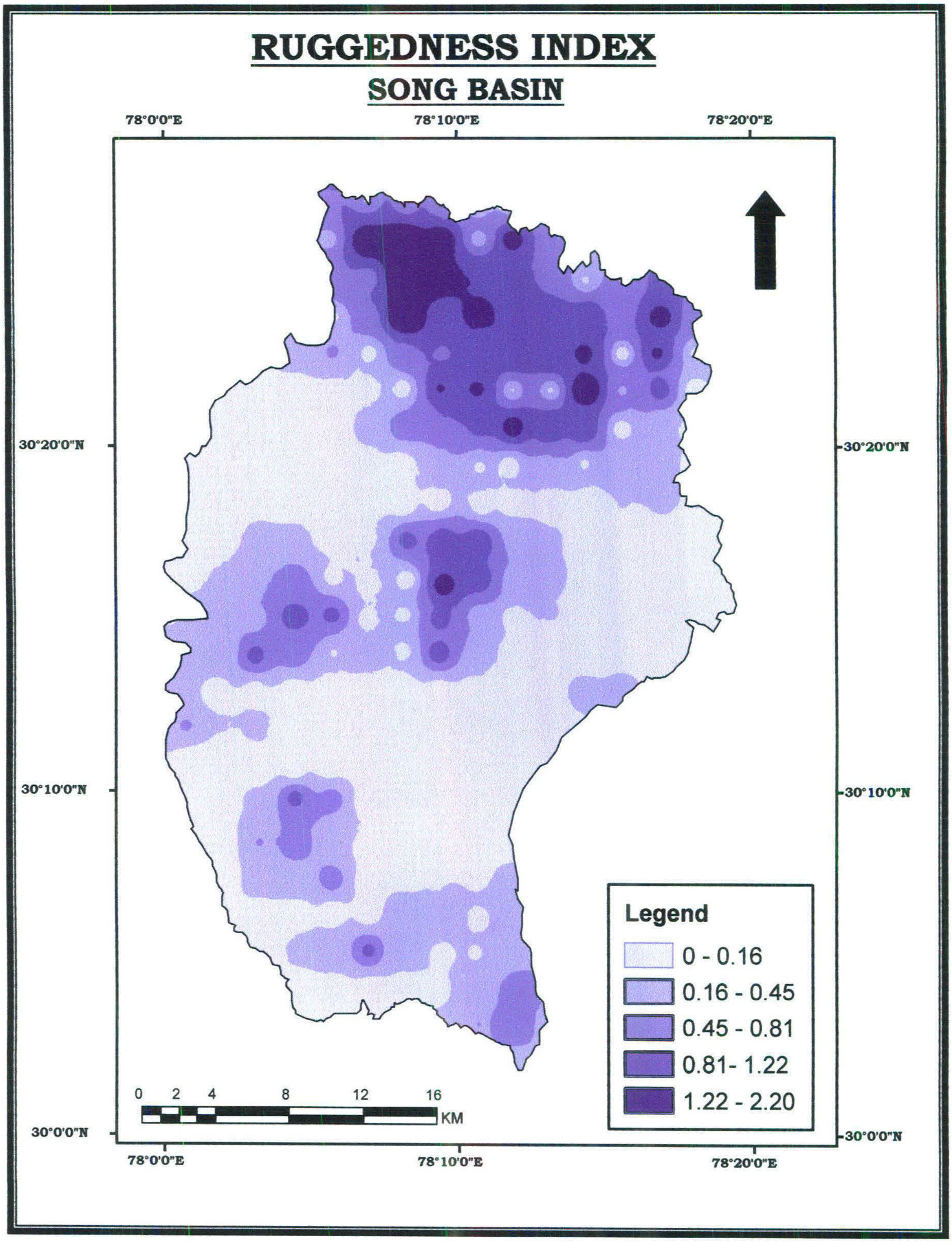


Fig. 3.18

High ruggedness is found in the upper reaches of the basin where relative relief is also high as ruggedness is directly influenced by the relative relief (Fig. 3.18 & Fig. 3.19). Thus the basin has rugged terrain in a contiguous unit in the northern most part lying in the Lesser Himalayas and certain non-contiguous unit in the central part where high relief is found. Most of the area in the basin is not as rugged in nature as the relief and density are low (Table 3.10).



RUGGEDNESS INDEX
SONG BASIN
78°0'0"E
78°10'0"E
78°20'0"E
30°20'0"N
30°10'0"N
30°0'0"N
0 2 4 8 12 16
KM
Legend
0 - 0.16
0.16 - 0.45
0.45 - 0.81
0.81- 1.22
1.22 - 2.20

Figure 3.19

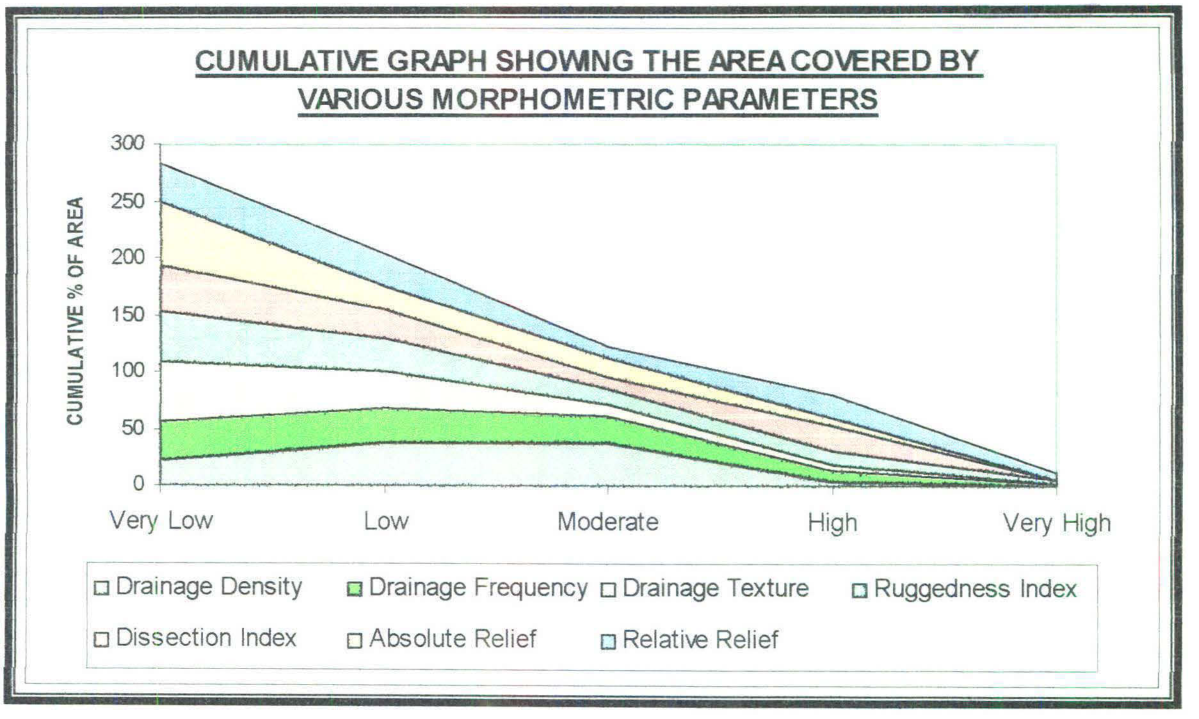


Figure 3.20

Figure 3.20 shows that the maximum cumulative area for various classes of morphometric parameters falls under very low to moderate category. Very less area comes under very high to high class and that too is found in the upper reaches of the region.

Thus morphometry proves its soundness in being significant for getting a basic understanding of the study area which happens to be a drainage basin. It is thus a fundamental step in any sort of regional planning which is done through watershed approach. With the application of morphometric techniques, the nature of terrain, slope, elevation, surface characteristics like texture, ruggedness, dissection etc. have been calculated for the study area. All these parameters would further help in the evolving conservation methods for the management of the land resource in the area as these are directly related to the geomorphic processes transforming the physiography of the region.

4. LAND USE/LAND COVER CHANGES

4.1 INTRODUCTION

Since the beginning of human civilization mankind has lived in a close relationship with nature. While mankind's interdependence on environment is greater than that of any other organism; his restless pursuit of progress, comfort and security has resulted in increased stress on the resources particularly land. Since land use and land cover are two important related aspects, these have also got altered vastly. While land cover refers to the physical state of land, land use refers to the human employment of land. The term land cover represents the types of feature present on the surface of the earth. Urban buildings, lakes, trees and glaciers are all example of land cover types. The term land use corresponds to the human activity associated with a specific piece of land. For example, a tract of land on the fringe of an urban area may be used for single family housing. Depending on the level of mapping detail, land use could be described as urban, residential or single family residential use. The same tract of land would have a land cover consisting of roofs, pavement grass and trees. For the study of the socio-economic aspects of land use planning (school requirements, municipal services, revenue, etc.), it would be important to know that the use of this land is for single family dwellings. For a hydrologic study of rainfall runoff characteristics, it would be important to know that the amount and distribution of roofs, pavement, grass, and trees in this tract. Thus, a knowledge of both land use and land cover is important for land planning and land management activities.

Land use is the result of a continuous field of tension created between available resources and human need acted upon by their efforts. Some resources like climate and relief are not readily responsive to human intervention and therefore induce a tendency towards stability. Other resources like level of urbanization leads to a distressing state of land use. Land can be used for the purpose of forestry, residence, commerce, recreation etc. Each piece of land has specific characteristic which determines its potential that can be optimized through suitable land use pattern. Not all types of land can be used for all types of activities.

Over the years, land use pattern has been developed in accordance with landscape ecology. The activities of primitive societies were in general harmony with nature. Thus, productivity was low and the impact of man's activity on land was least. But with the march of urbanization and industrialization along with the increasing pressure of population, the relationship once in harmony with nature is disrupting the ecological balance.

The land use changes significantly due to various physical and socio-economic factors. The land use pattern of an area is directly related to the level of techno-economic advancement and the nature and degree of civilization of its inhabitants (Whyte, 1961). Land use is a dynamic phenomenon, and both its value and pattern changes from one particular point of time to another and also from one geographical unit to another, with varying efficiencies, abilities, priorities and needs (Bisht and Tiwari, 1996). The information on land use/ land cover patterns, their spatial distribution and changes over a time scale are the prerequisites for making development plans. In view of the pressure exerted by increasing population and need for mitigating increasing demand of land resources, appropriate scientific land use planning and land management strategies could provide the alternative for the sustainable development of any region.

Classification of Land use

For most purposes we need to arrange our detailed observation into groups using some criterion. Many land use classifications that exist should not surprise us especially when we consider the succinct summary by Anderson (1974)

> "There is no ideal classification of land use and is unlikely that one could ever be developed. There are different perspectives in the classification process and the process itself tends to be subjective, even when the objective numerical approach is used. There is, in fact, no logical reason to expect that one detailed inventory should be adequate for a short time since land use pattern changes with demand for natural resources. Each classification is made to suite the needs of the users."

Dudley Stamp (1930) gave the first elaborate classification of land which was primarily applied for studies in U.K. In India a nine-fold classification has been in vogue. Probably this classification has its root in the ancient revenue 'Classification of Land' which is being followed by the 'Ministry of Agriculture'. Under this, land use is classified as forest, cultivable wasteland, barren land, current fallow, other fallow, non-agricultural land, pastures, orchards and net sown area (Syed, 1994).

Land Use Mapping

A prerequisite for monitoring changes in overall use of the land or developing a plan for improved land use is the knowledge of current pattern. We presently have maps of land use in this country, and of course have had such maps for sometime. The older the maps, the more unsatisfactory they are, in ways not apparent to the casual viewer. If the cartographer has done his job well, a map has a professional appearance and the originating agency names provide official status. It is when we look at the data used by the cartographer that shortcomings begin to appear. Methods of data collection, the nature of a data (including its date), and sample size are examples of factors which often restrict the value of maps for many would-be users. Yet, it may truly represent the best obtainable at that time.

Assessment and monitoring of land use on a national scale is likely to be carried out with different goals in mind than in regional or local cases. For most long term planning purposes, an up to the minute national map is not necessary, if indeed, even possible. There are large areas in which the use of land changes very slowly or not at all. In some areas, however, change on a local or even regional basis is occurring with unprecedented speed. In such areas especially, the need for "a better way" is evident in the form of distressing ecological problems that appear to be at best the product of lack of foresight.

Total regional land use management has to contend with a basic problem: the increasing competition for space. The inexorable spread of land in many parts of the country will change whether we make an effort to order the change or not. If we could make a beginning by achieving a better assessment of present use and capability, the possibilities for more ordered use would be much improved.

4.2 LAND USE/COVER THROUGH REMOTE SENSING

Knowledge of land with land use/cover is important for many planning and management activities concerned with the surface of the earth. Land use mapping has always been a time consuming and expensive process. Often, when the study has limitation, the planner's and specialist in various disciplines are forced to use existing data on the land use which is usually outdated because of the pattern of available resources and demand for resources are constantly changing. Land use is a matter of continuous growth and change in pattern. For economic development of a region, planners need up to date information which can only be obtained quickly, economically and accurately through remote sensing techniques. The changes in land use/ land cover due to natural and human activities can be observed using current and archived remotely sensed data (Luong, 1993). Remote sensing data provides detailed and cost effective information with respect to spatial distribution of vegetation types and land use. Earlier land use studies used to be carried out by conventional ground method, old records, census etc. The use of panchromatic, medium scale aerial photographs to map land use has been an accepted practice since the 1940s. More recently small scale aerial photographs and satellite images have been utilized for land use/land cover mapping of large areas.

The USGS has devised a land use and land cover classification system for use with remotely sensed data. Ideally land use and land cover information should be presented on separate maps and not intermixed as in the USGS classification system. From a practical standpoint, however, it is most efficient to mix the two systems when remote sensing data form the principal data source for such mapping activities. While land cover information can be directly interpreted from appropriate remote sensing images, information about human activity on the land (land use) cannot always be inferred directly from land cover. For example, extensive recreational activities covering large tracts of land are not particularly amenable to interpretation from aerial photographs or satellite images. For instance, hunting is a common and pervasive recreational use occurring on land that would be classified as some type of forest, range, wetland or agricultural land during either a ground survey or image interpretation. Thus, additional information sources are needed to supplement the land cover data. Supplemental information is also necessary for determining the use of such lands as parks, game refuges or water conservation districts that may have land uses coincident with administrative boundaries not usually identifiable on remotely sensed images. Recognizing that some information could not be derived from remote sensing data, the USGS system is based on categories that can be reasonably interpreted from imagery.

The USGS land use and land cover classification system was designed according to the following criteria:

1. The minimum level of interpretation accuracy using remote sensed data should be at least 85%,
2. The accuracy of interpretation for the several categories should be about equal,
3. Repetitive or repeatable results should be obtainable from one interpreter to another and from one time of sensing to another,
4. The classification system should be applicable over extensive areas,
5. The categorization should permit land use to be inferred from the land cover types,
6. The classification system should be suitable for us with remotely sensed data obtained at different times of the year,
7. Categories should be devisable into more detailed subcategories that can be obtained from large scale imageries or ground surveys,
8. Aggregation of categories must be possible,
9. Comparison with future land use and land cover data should be possible, and
10. Multiple uses of land should be recognized when possible.

The resulting USGS land use and land cover classification system for use with remotely sensed data is shown in table 4.1.

S. No.	Level I	S. No.	Level II
1	Urban or built-up land	1.1	Residential
		1.2	Commercial and service
		1.3	Industrial
		1.4	Transportation, communications and utilities
		1.5	Industrial and commercial complexes
		1.6	Mixed urban or built-up land
		1.7	Other urban or built-up land
2	Agricultural land	2.1	Cropland and pasture
		2.2	Orchards, groves, vineyards, nurseries, and ornamental horticultural areas
		2.3	Confined feeding operations
		2.4	Other agricultural land
3	Rangeland	3.1	Herbaceous rangeland
		3.2	Shrub and brush rangeland
		3.3	Mixed rangeland
4	Forest land	4.1	Deciduous forest land
		4.2	Evergreen forest land
		4.3	Mixed forest land
5	Water	5.1	Streams and canals
		5.2	Lakes
		5.3	Reservoirs
		5.4	Bays and estuaries
6	Wetland	6.1	Forested wetland
		6.2	Non-forested wetland
7	Barren land	7.1	Dry salt flats
		7.2	Beaches
		7.3	Sandy areas and other than beaches

		7.4	Bare exposed rock
		7.5	Strip mines, quarries and gravel pits
		7.6	Transitional areas
		7.7	Mixed barren land
8	Tundra	8.1	Shrub and brush tundra
		8.2	Herbaceous tundra
		8.3	Bare ground tundra
		8.4	Wet tundra
		8.5	Mixed tundra
9	Perennial snow or ice	9.1	Perennial snowfields
		9.2	Glaciers

Table 4.1

The system is designed to use four "levels" information, two of which are detailed in the table. A multilevel system has been devised because different details can be obtained from different remote sensing products, depending on the sensing system and image resolution.

The USGS classification system also provides for the inclusion of more detailed land use/land cover categories in Levels III and IV. Levels I and II, with classification specified by the USGS (Table 4.1), are principally of interest to users who desire information on a nation wide, interstate or statewide basis. Levels III and IV can be utilized to provide information at a resolution appropriate for regional or local level planning and management activities. It is intended that Levels III and IV were designed keeping in mind that the categories at each level must aggregate into the categories in the next higher level. Fig 4.1 illustrates a sample aggregation of classification for Levels III, II and I.

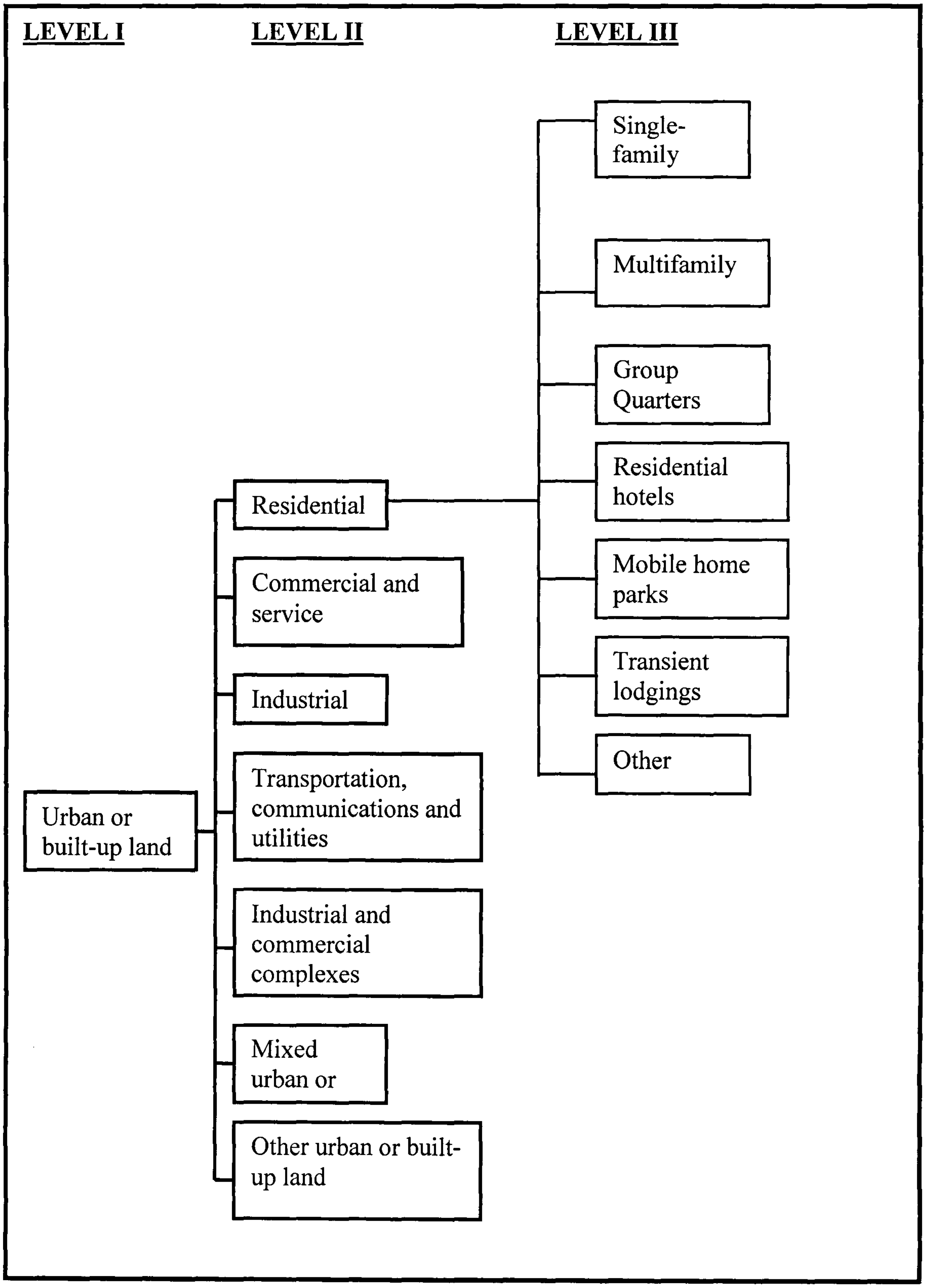

LEVEL I
LEVEL II
LEVEL III
Urban or built-up land
Residential
Commercial and service
Industrial
Transportation, communications and utilities
Industrial and commercial complexes
Mixed urban or
Other urban or built-up land
Single-family
Multifamily
Group Quarters
Residential hotels
Mobile home parks
Transient lodgings
Other

Fig. 4.1

Table 4.2 lists representative image interpretation formats for the four land use and land cover classification levels. Level I was designed for use with very small scale imagery such as Landsat Multispectral Scanner (MSS) images. Level II was designed for use with small scale aerial photographs. The most wide used image type for Level II mapping has been high altitude colour infrared photographs. However, small scale panchromatic aerial photographs, Landsat Thematic Mapper images, and SPOT satellite images are also appropriate data sources for many Level II mapping categories. The general relationships shown in table 4.2 are not intended to restrict users to particular scales, either in the original imagery or in the final map products. For example, Level I land use/land cover information, while efficiently and economically gathered over large areas by the Landsat satellites, could also be interpreted from conventional medium scale photography or compiled from a ground survey. Conversely, some of the Level II categories have been accurately interpreted from Landsat MSS data.

Land use / land cover classification level	**Representative format for image interpretation**
I	Landsat MSS
II	Small scale aerial photography, Landsat TM and SPOT images
III	Medium scale aerial photography
IV	Large scale aerial photography

Table 4.2: *Representative Image Interpretation for Various Land Use/Land Cover Classification Levels*

For mapping at Level III, substantial amount of supplemental information, in addition to that obtained from medium scale images, may have to be acquired. Similarly, mapping at Level IV would also require substantial amounts of supplemental information, in addition to that obtained from large scale images.

The size of the minimum area that can be mapped as any particular land use/ land cover class depends on the scale and resolution of the aerial photographs or satellite images. It also depends on the scale of the land use /land cover map. When land use/ land cover data are to be presented in the form of maps, it is difficult to represent any unit area smaller than 2.5 mm on a side. In addition, smaller areas cause legibility problems for the map reader. Table 4.3 lists the minimum size ground areas that can be mapped at the various classification levels.

Land use / land cover classification level	**Representative map compilation scale**	**Approximate minimum area mapped* (ha)**
I	1:500,000	150
II	1:62,500	2.50
III	1:24,000	0.35

Table 4.3

The USGS definitions for Level I classes are set forth in the following paragraph. Since this system should be able to account for 100 percent of the earth's land surface (including inland water bodies), each square meter of the earth's surface should fit into one of the nine Level I categories.

Urban or built-up land is composed of areas of intensive use with much of the land covered by structures. Included in this category are, cities, towns, villages, strip developments along highways, transportation, power and communication facilities and areas such as those occupied by mills, shopping centers, industrial and commercial complexes, and institutions that may, in some instances, be isolated from urban areas. This category takes precedence over others when the criteria for more than one category are met. For example, residential areas that have sufficient tree cover to meet forest land criteria should be placed in the urban or built-up land category.

Agricultural land may be broadly defined as land use primarily for production of food and fiber. The category includes the following uses: cropland and pastures, orchards, groves and vineyards, nurseries and ornamental horticultural and confined feeding operations. Where farming activities are limited by soil wetness, the exact boundary may be difficult to locate and agricultural land may grade into wetland. When wetlands are drained for agricultural purposes, they are included in the agricultural land category.

When such drainage enterprises fall into disuse and if wetland vegetation is reestablished, the land reverts to the wetland category.

Rangeland historically has been defined as land where the potential natural vegetation is predominantly grasses, grass like plants, forbs, or shrubs and where natural grazing was an important influence in its pre-civilization state. The historical connotation of rangeland is expanded in the USGS classification including those areas in the eastern states called brushlands.

Forest land represents areas that have a tree-crown areal density (crown closure percentage) of 10 percent or more, are stocked with trees capable of producing timber or other wood products, and exert an influence on the climate or water regime. Lands from which trees have been removed to less than 10 percent crown closure but which have not been developed for other uses are also included. For example, lands on which there are rotation cycles of clear cutting and block planting are part of the forest land category. Forest land that is extensively grazed would also be included in this category because the dominant cover is forest and the dominant activities are forest related. Areas that meet the criteria for forest land and also urban and built-up land are placed in the latter category. Forested areas that have wetland characteristics are placed in the wetland class.

The *water* category includes streams, canals, reservoirs, lakes bays and estuaries.

The *wetland* category designates those areas where the water table is at, near, or above the land surface for a significant part of most years. The hydrologic regime is such that aquatic or hydrophytic vegetation is usually established, although alluvial or tidal flats may be non-vegetated. Examples of wetlands include marshes, mudflats, and swamps situated on the shallow margins of bays, lakes, ponds, streams, and artificial impoundments such as reservoirs. Included are wet meadows or perched bogs in high mountain valleys and seasonally wet or flooded basins, playas, or potholes with no surface water outflow. Shallow water areas where aquatic vegetation is submerged are classified as water and are not included in the wetland category. Areas in which soil wetness or flooding is so short-lived that no typical wetland vegetation is developed belong to other categories. Cultivated wetlands such as the flooded fields associated with rice production and developed cranberry bogs are classified as agricultural land. Uncultivated wetlands from which wild rice, cattails, and so forth are harvested are retained in the wetland category, as are wetlands grazed by livestock. Wetland areas, drained for any purpose, belong to the other land use/land cover categories such as urban or built-up land, agricultural land, rangeland or forest land. If the drainage is discontinued and wetland conditions resume, the classification will revert to wetland. Wetlands managed for wildlife purposes are properly classified as wetland.

Barren land is land of limited ability to support life and in which less that one third of the area has vegetation or other cover. This category includes such areas as dry salt flats, beaches, bare exposed rock, strip mines, quarries and gravel pits. Wet non-vegetated barren lands are included in the wetland category. Agricultural land, temporarily without vegetative cover because of cropping season or tillage practices, is considered agricultural land. Areas of intensively managed forest land that have clear-cut blocks evident are classified as forest land.

Tundra is the term applied to the treeless regions beyond the geographic limit of the boreal forest and above the altitudinal limit of trees in high mountain ranges.

Perennial snow or ice areas occur because of a combination of environmental factors that cause these features to survive the summer melting season. In doing so, they persist as relatively permanent features on the landscape.

The detection and monitoring of land use/cover change using satellite multi-spectral image data has been a topic of interest in remote sensing. Several techniques for accomplishing change detection have been formulated, applied and evaluated. A common method for the detection of land use change is to compare two or more images covering the study area at different dates. Change detection generally employs one of two basic methods: pixel-to-pixel comparison and post classification comparison (Martin 1989, Green et al. 1994). The first method is a pixel by pixel combination of multi-date images without classifying the data. This pixel-to-pixel method has two major types of variations: image differencing (Toll et al. 1980) and image ratioing (Nelson 1983). The second method compares two or more separately classified images of different dates. Other types of change detection techniques have also reported like principal component analysis. Post-classification is considered to be one of the most appropriate and commonly used methods for change detection. This method involves comparing two independent classified land use/ land cover maps from images of two different dates.

4.3 LAND USE/LAND COVER DYNAMICS OF THE AREA

The basin of the river Song has undergone major land use/land cover changes in the past four decades (1963-2001). The change detection analysis is done on land use/ land cover mapping of two time periods. Survey of India topographical sheets are used to map the land use in the year 1963 where as digital satellite imagery is used for land use mapping of 2001 (fig. 4.2 & 4.3). Extreme northern part of the area could not be analysed due to the non-availability of satellite data. Supervised classification technique has been used for land use classification on satellite imagery. Only four major land uses of the area namely built-up area, cultivated area, forest cover and wasteland are considered for analysis and interpretation. Their change analysis is as follows:

4.3.1 Forest Cover

As it is evident from figure 4.4, forest cover of the area has declined considerably. The forest cover existing in the proximity of human settlements has suffered most where as the far off dense forest cover is still in a much better condition. Forest cover which is still maintained near the urban areas is the one that comes under the category of reserved forest. For example, Thano Reserved Forest to the southeast of Dehradun city is very less degraded. Forest cover has also degraded in the catchment of the streams. Deforestation has arisen due to four principal causes, often in relationship with each other; excessive felling of trees for timber, overgrazing, fire and clearance of land for cultivation/ settlement. Woodlands are mainly shifted towards agricultural land and wasteland. A major area of forest changed into agricultural land due to increase in population and far fulfilling rapid growing demand for food, fiber, fodder and shelter. The analysis of the data shows that the degraded forests now exist on the periphery of agricultural lands and settlements indicating human encroachment and other biotic interference. This is achieved by illegal felling of trees.

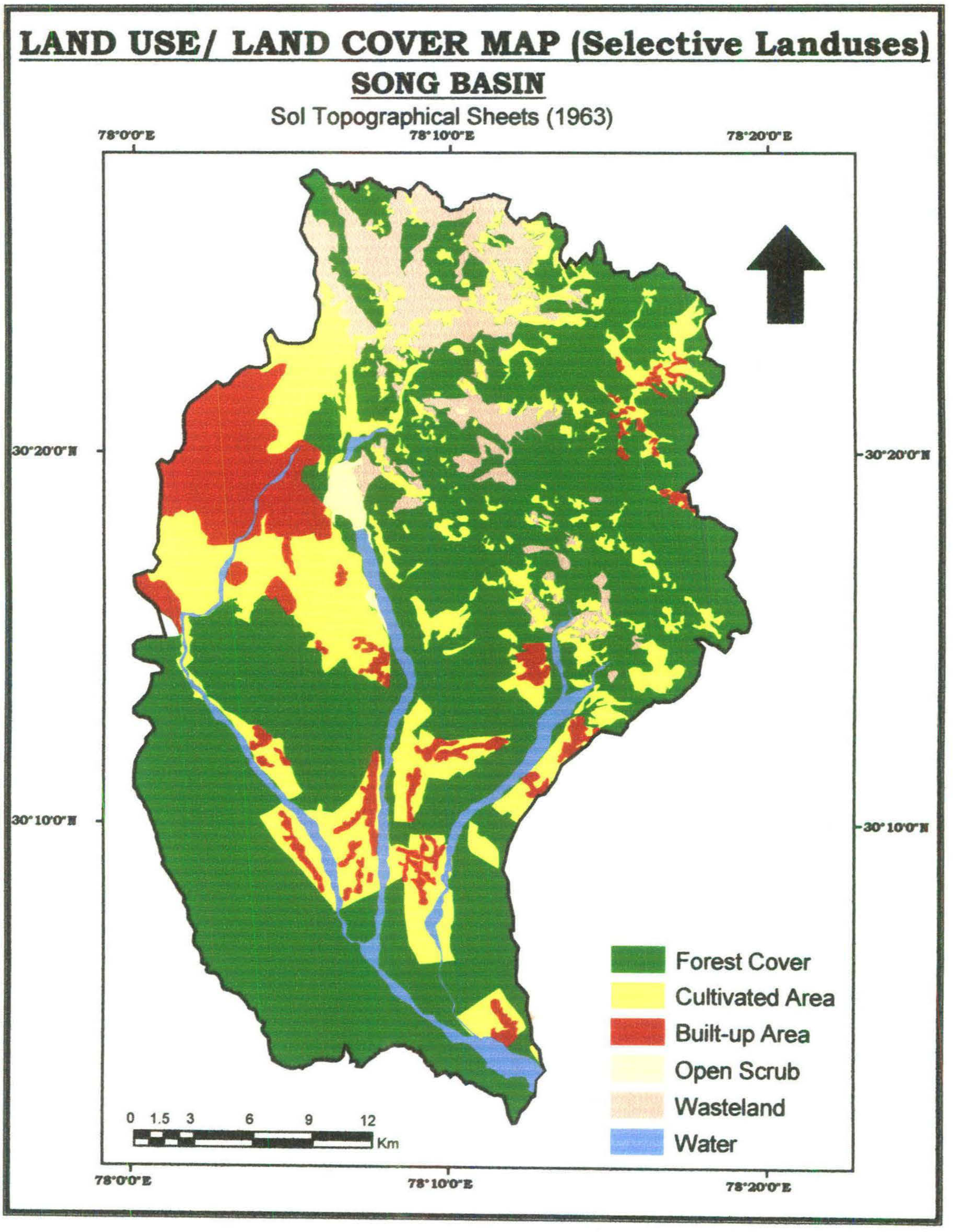

LAND USE/ LAND COVER MAP (Selective Landuses)
SONG BASIN
SoI Topographical Sheets (1963)
78°0'0"E
78°10'0"E
78°20'0"E
30°20'0"N
30°10'0"N
Forest Cover
Cultivated Area
Built-up Area
Open Scrub
Wasteland
Water
0 1.5 3 6 9 12
Km

Figure 4.2

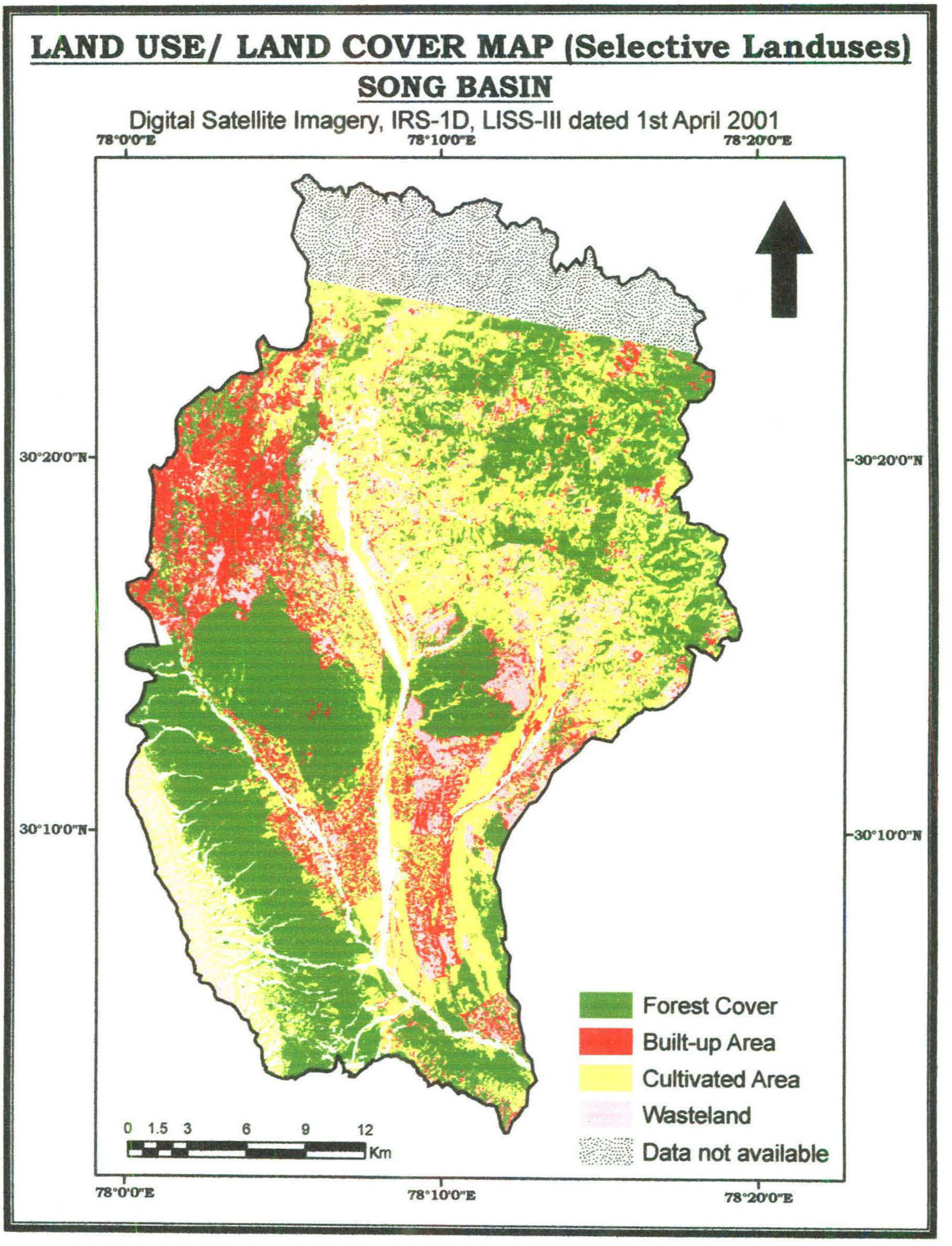

LAND USE/ LAND COVER MAP (Selective Landuses)
SONG BASIN
Digital Satellite Imagery, IRS-1D, LISS-III dated 1st April 2001
78°0'0"E
78°10'0"E
78°20'0"E
30°20'0"N
30°10'0"N
Forest Cover
Built-up Area
Cultivated Area
Wasteland
Data not available
0 1.5 3 6 9 12
Km

Figure 4.3

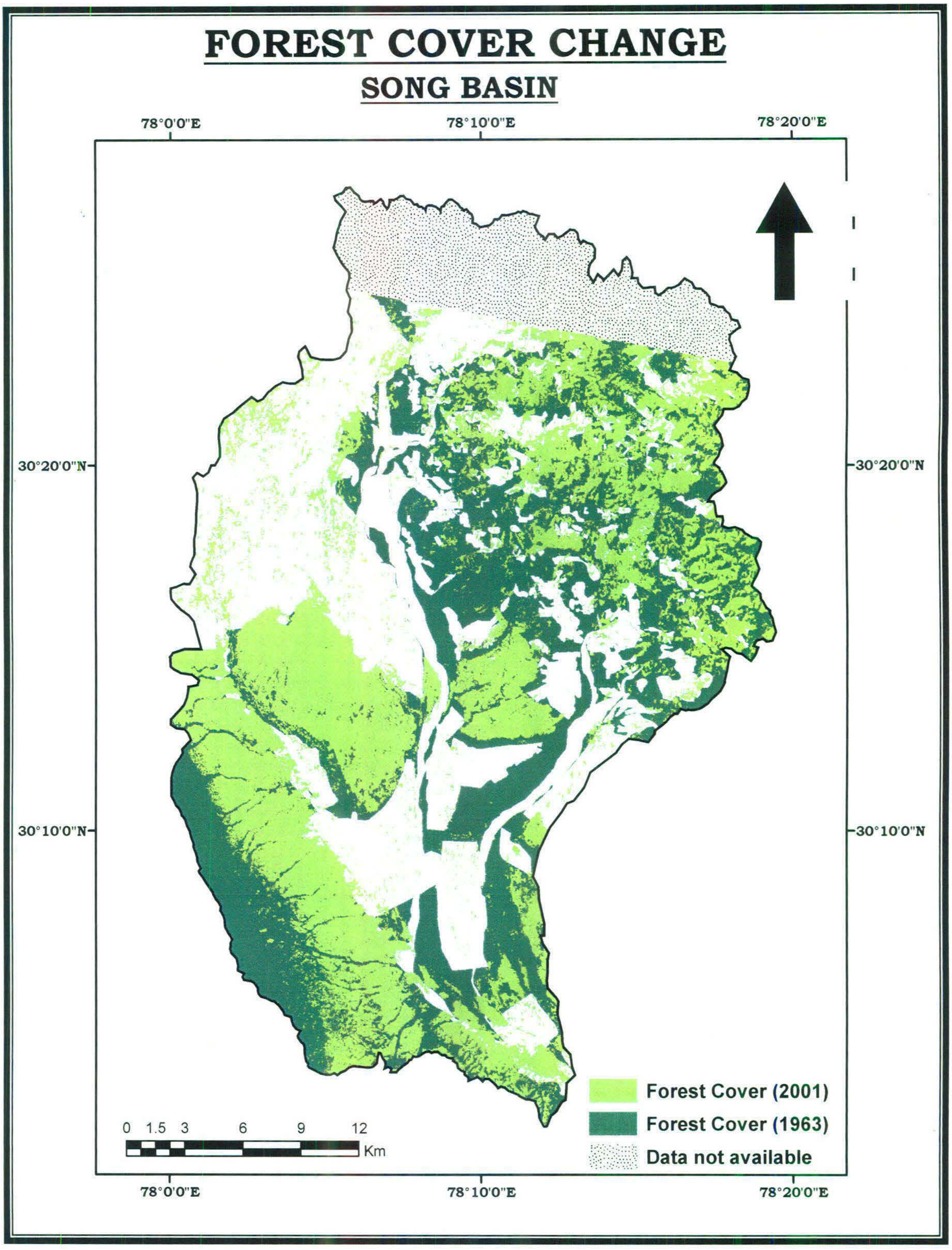


Figure 4.4

Forest cover change detection analysis (fig. 4.5) clearly indicates that most of the forest cover decline is mainly because of the conversion of forest into cultivated area. Much of this transformation has taken place on the marginal slopes and in the higher reaches particularly in the north-eastern part of the study area. Near the small settlements forests have been used up to expand the settlements. Also where new agricultural fields have developed, settlements also developed side by side. Appreciable amount of forest cover also got converted into wastelands. One important reason behind this is limestone quarrying by removing forest cover in the mountains.

4.3.2 Built-up area

Built-up area shows a rapid increase in a short span of time (fig 4.6). Increase in built-up area is usually associated with the expansion of settlement, particularly urban settlement. This occurs mainly because of the accommodation demand of the increasing population. Settlements grow intruding into the nearby forest and cultivated area.

Existing settlements in the region have expanded at a very fast rate. Expansion is concentrated mainly near the streams. Rural settlements like small villages and hamlets have evolved around the agricultural fields. Dehradun city has also expanded covering the nearby fields and forest. Major expansion is experienced towards the south and east of the existing city where the elevation is low. As one moves northwards, expansion gets reduced ands is scattered in small pockets due to high elevation. Towards plain areas, the expansion is more compact and found in contiguous units.

4.3.3 Cultivated Area

Apart from built-up area, cultivated area is the other land use that has increased very fast (Fig. 4.7). It has been found that encroachment on marginal lands for cultivation took place due to population pressure, decrease in per capita land holding size and fragmentation of land holdings. Substantial agricultural extension has been recorded in higher elevations probably because of unavailability of land at lower elevation. At the same time nearly all cultivable land at the lower elevation had already been brought under cultivation.

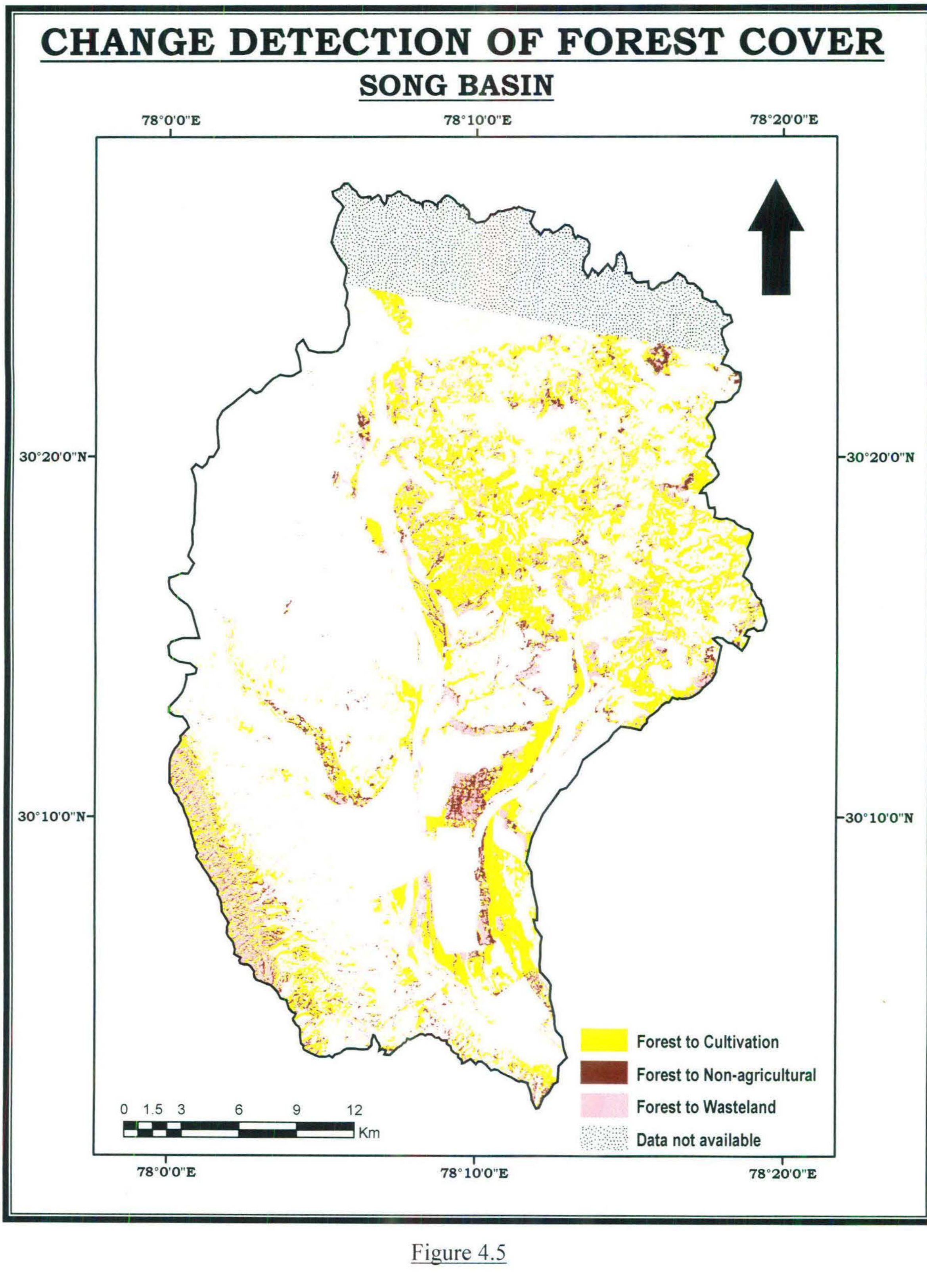

CHANGE DETECTION OF FOREST COVER
SONG BASIN
78°0'0"E
78°10'0"E
78°20'0"E
30°20'0"N
30°10'0"N
Forest to Cultivation
Forest to Non-agricultural
Forest to Wasteland
Data not available
0 1.5 3 6 9 12
Km

Figure 4.5

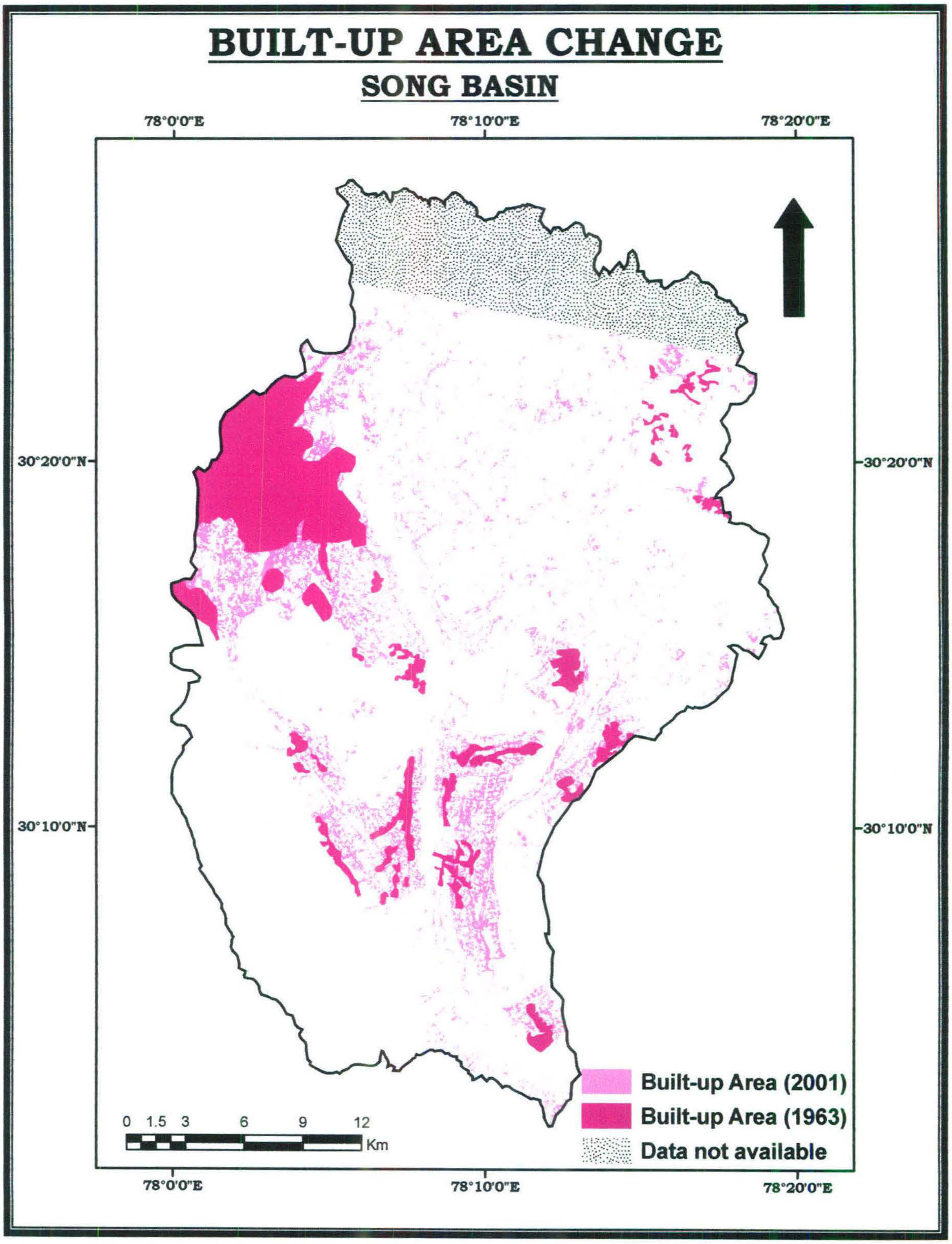

BUILT-UP AREA CHANGE
SONG BASIN
78°0'0"E
78°10'0"E
78°20'0"E
30°20'0"N
30°10'0"N
0 1.5 3 6 9 12
Km
Built-up Area (2001)
Built-up Area (1963)
Data not available

Figure 4.6

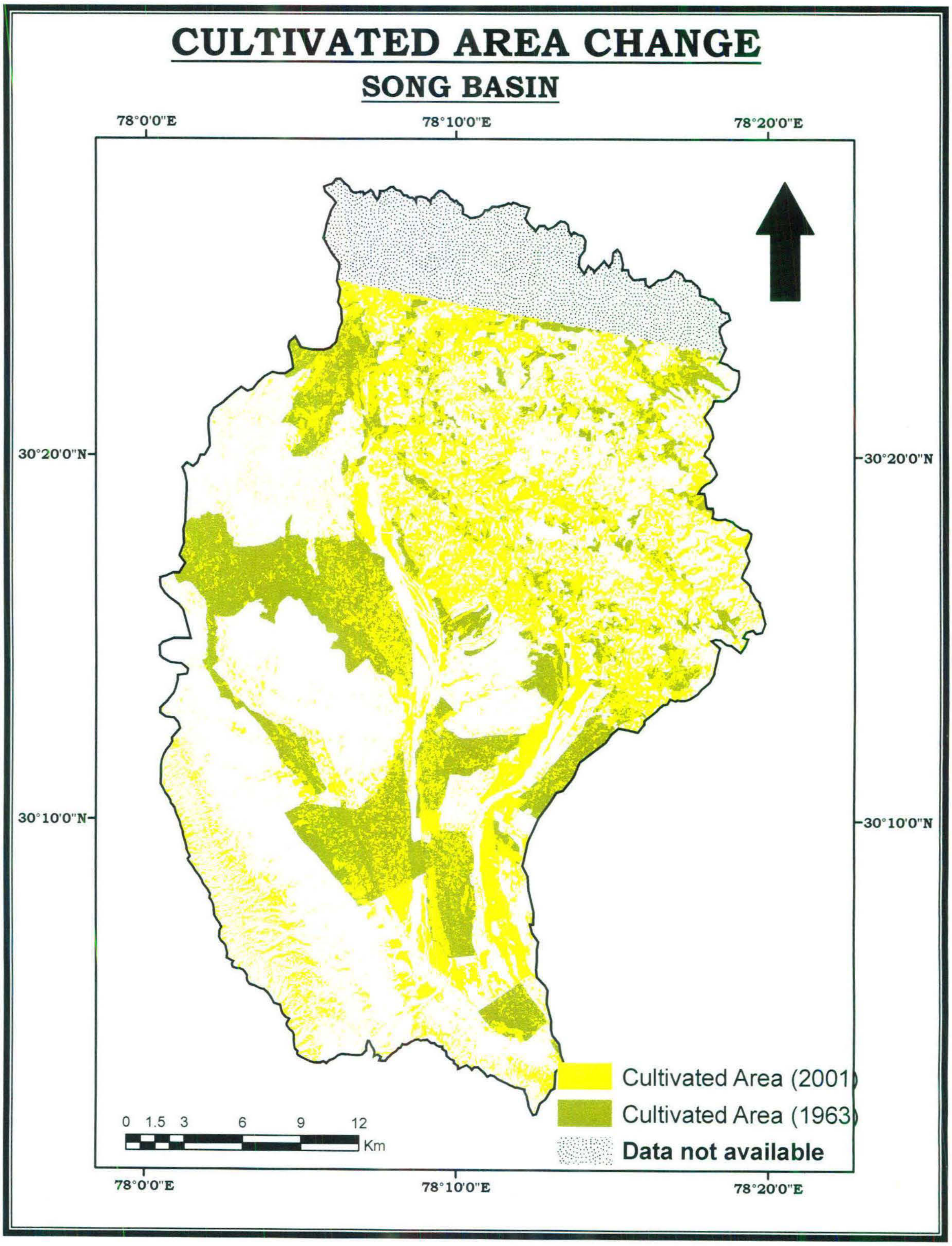

CULTIVATED AREA CHANGE
SONG BASIN
78°0'0"E
78°10'0"E
78°20'0"E
30°20'0"N
30°10'0"N
0 1.5 3 6 9 12
Km
Cultivated Area (2001)
Cultivated Area (1963)
Data not available

Figure 4.7

Cultivated areas that, once, existed near the settlements that time have usually disappeared as a result of city growth and encroachment. Most of the unreserved forests, lying in the plains, have been converted into agricultural fields. Cultivation that existed in small pockets in the hill slopes has now expanded at a large scale.

4.3.4 Wasteland

It is inclusive of fallow and cultivable wasteland (fig. 4.8). With increasing human and animal pressure on land, the intensive cultivation has extended even to areas under ecological stress, leading to accelerated soil erosion and excessive land degradation. Wastelands have increased significantly in the area. While its occurrence was broadly restricted to higher elevations till 1963, it spread rapidly in the plains in the following years. This mainly happened because of the stress on the land causing its degradation. Wastelands are usually the degraded lands. Towards the southeast of the area, wastelands occur in a contiguous strip. This area is marked with high gully erosion resulting in ravine like formation. Wastelands on higher reaches, at certain places, are the result of limestone quarrying. After limestone is taken out, the area is left as it is and it consequently turns into wasteland. Wastelands lying near the settlements or agricultural area are usually either fallow or cultivable wastelands. Those surrounding the forest are the degraded land due to deforestation. Land in the immediate catchment of the streams has also become degraded owing to erosion.

4.4 LAND CAPABILITY ANALYSIS OF THE AREA

Land capability refers to the potential of land to sustain a number of predefined land uses. It assesses the suitability of land for specified land use like cultivation, grazing and others. It is a broad grouping of soils based on their limitations. It is this risk of land degradation that stands at the root of land capability evaluation. If the capability of land decreases, the land becomes suited for fewer major land uses.

Concern about land degradation grew sharply in the past because of human and animal population explosions in the developing world. Increasing population pressure often causes over-exploitation of high potential land and/or misuse of marginal land. The rate of change of pressure on land in critical regions will increasingly violate

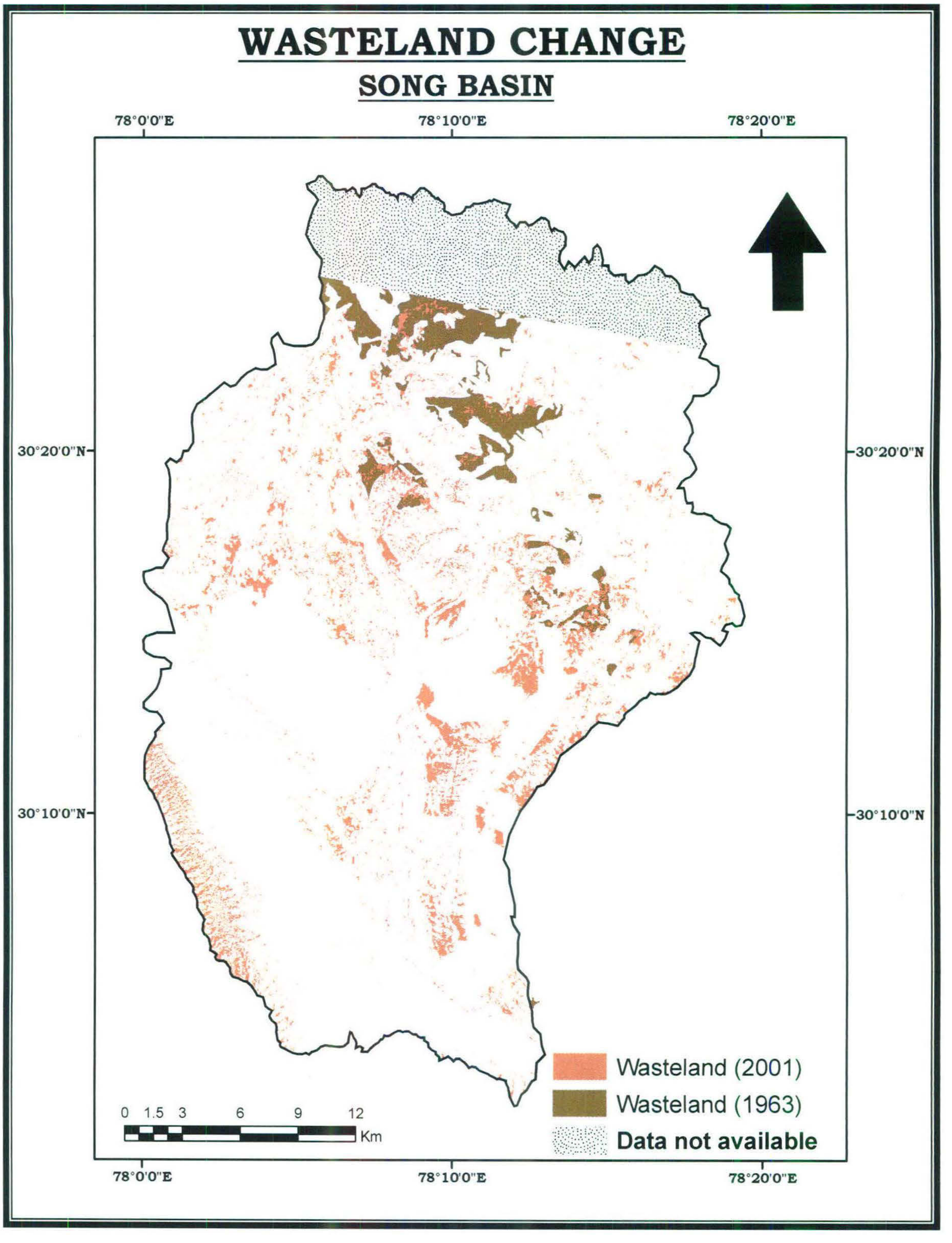

WASTELAND CHANGE
SONG BASIN
78°0'0"E
78°10'0"E
78°20'0"E
30°20'0"N
30°10'0"N
Wasteland (2001)
Wasteland (1963)
Data not available
0 1.5 3 6 9 12
Km

Figure 4.8

the limits of the carrying capacity, even if available technological packages for managing the land resources have become better.

A systematic way of doing this is set out in '*A framework for land evaluation*' (FAO, 1976). Detailed procedures are given in guidelines on evaluation for rain-fed agriculture, irrigated agriculture, forestry and extensive grazing. In simplified form, the procedure is:

- describe promising land-use types;
- for each land-use type, determine the requirements, e.g. for water, nutrients, avoidance of erosion;
- conduct the surveys necessary to map land units and to describe their physical properties, e.g. climate, slope, soils;
- compare the requirements of the land-use types with the properties of the land units to arrive at a land suitability classification.

Land cannot be graded from "best" to "worst" irrespective of the kind of use and management practiced because each kind of use has special requirements. Land capability evaluations are sometimes conducted directly in terms of land characteristics, e.g. by using rainfall instead of availability of water, slope angle instead of erosion hazard. The first and most important decision is to separate land that is suitable from the other. Important criteria for deciding on the suitability of land for a specific use are sustainability and ratio of benefits to costs. Land should be able to support the land use on a sustained basis and the use yields benefits that justify the inputs.

Land capability map of the area (fig. 4.9) is prepared after the Land Capability map of Northern India published by National Atlas and Thematic Mapping Organisation. The entire region has been divided into four major zones. The higher elevations are the lands with severe limitation. This represents the fragile mountain ecosystem which is very sensitive to human interference. The second division is the land suitable for forestry and grazing. In this case the existing ecosystem is least affected. The third division includes land that is not fit for cultivation owing to soil and moisture conditions. Last category is the land good for cultivation. The areas where soil, moisture, terrain etc. favour crop raising come under this category.

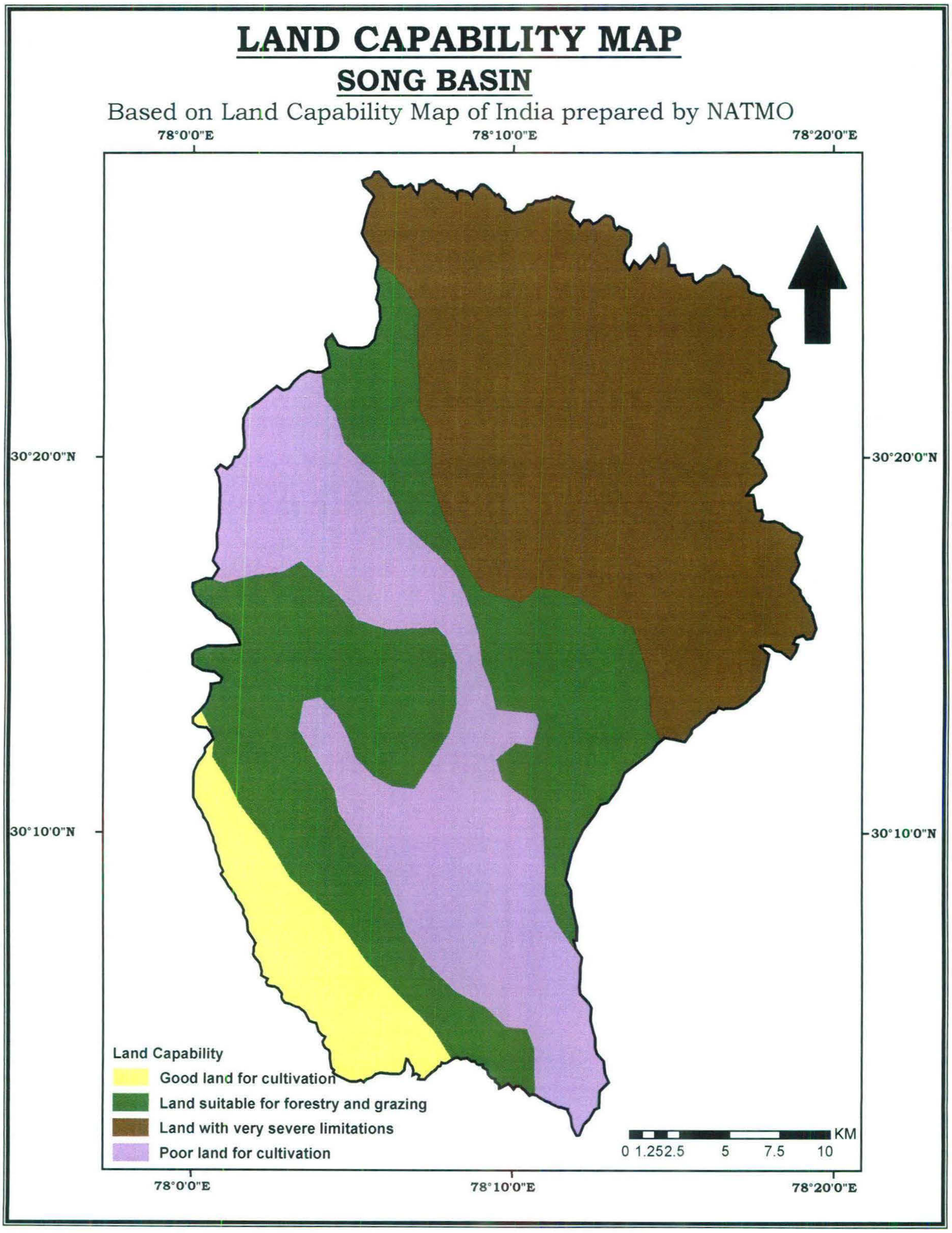

LAND CAPABILITY MAP
SONG BASIN
Based on Land Capability Map of India prepared by NATMO
78°0'0"E
78°10'0"E
78°20'0"E
30°20'0"N
30°10'0"N
Land Capability
Good land for cultivation
Land suitable for forestry and grazing
Land with very severe limitations
Poor land for cultivation
KM
0 1.252.5 5 7.5 10

Figure 4.9

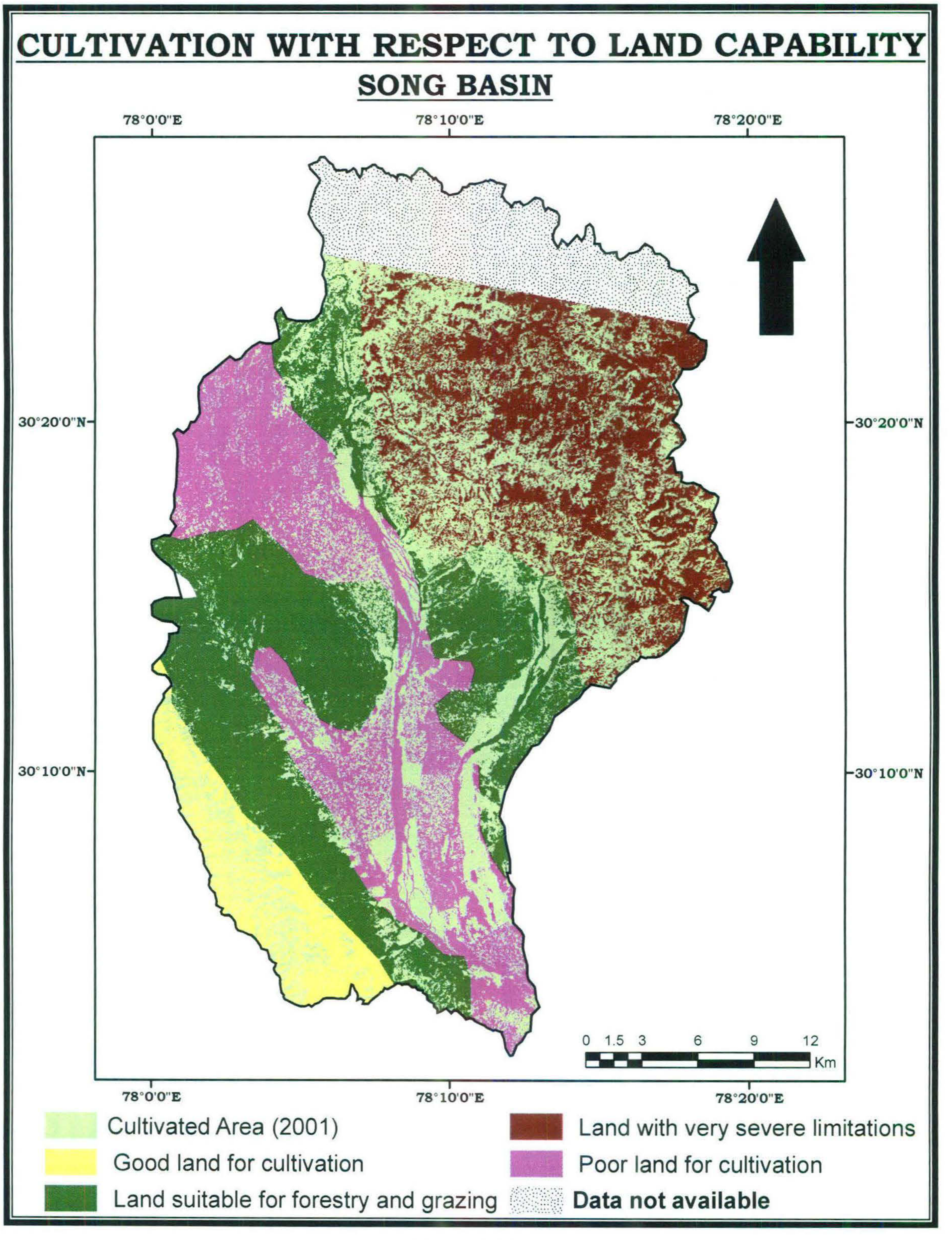

CULTIVATION WITH RESPECT TO LAND CAPABILITY
SONG BASIN
78°0'0"E
78°10'0"E
78°20'0"E
30°20'0"N
30°10'0"N
0 1.5 3 6 9 12
Km
Cultivated Area (2001)
Good land for cultivation
Land suitable for forestry and grazing
Land with very severe limitations
Poor land for cultivation
Data not available

Figure 4.10

Land capability map of the area with cultivated area (2001) map overlaid on it (fig. 4.10) clearly indicates that cultivation is being carrying out irrespective of the capabilities of the land. Most of the area that bears severe limitations has been brought under cultivation. This obviously has serious consequences. Moreover, cultivation is also being carried out in the land which otherwise is unsuitable for cultivation. The zone of land suitable for forestry and grazing in the north is also being intensively cultivated. The land unsuitable for agriculture exists in the lower elevations which is cultivated more intensively than the one on the higher elevation. The zone of land suitable for forestry and grazing in the south is the only tract where cultivation is very sparse, in accordance to the suitability factors. All these practices do have negative implications. One of its consequences is excessive erosion upstream due to removal of forest cover. This consequently causes increased sedimentation downstream.

The land use system is highly dynamic which undergoes significant changes according to the changing socio-economic and natural environment. The changes in any form of land use are largely related with the external forces and the pressure built-up within the system. This analysis explains how the technologies of satellite remote sensing and GIS analysis have been combined to address land use and land cover changes in the Song basin during the period 1963-2001. In the present investigation, land under agriculture and settlement has increased significantly at the cost of reduction of forest land. Wastelands have also increased considerably. Transformation of marginal lands from forests and barren areas into agricultural is basically to fulfill ever-increasing demand of food, fuel wood, fodder and timber. The process of rapid land transformation has not only brought about an ecological crisis in the region but has also threatened the agricultural economy of the watershed through accelerated soil erosion, deforestation and reduction in ground water recharge.

5. SUSTAINABLE LAND CONSERVATION AND MANAGEMENT

5.1 INTRODUCTION

Land degradation is a challenge to sustainable development. The latter has been defined as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" suggested by Brundtland Commission in 1987. This was accepted as a common goal at the UN Conference on Environment and Development (UNCED) in 1991. At the global scale, key problems threatening natural resources and the sustainability of life support systems are: (1) soil degradation, (2) the availability of water and (3) the loss of biodiversity. These occur in virtually all socio-cultural and economic contexts worldwide. However, there are great variations in the abilities of countries to cope with the problem of land degradation. For example, the following natural resources may be affected:

(1) Soils: about one third of the world's agricultural land has been damaged, mostly by loss caused by water erosion

(2) Water: problems of quality and quantity, as well as spatial and temporal interdependence (highland-lowland effects)

(3) Natural vegetation: problems of quality, quantity and biodiversity

(4) Wildlife: problems of protected areas, wildlife corridors, controlled hunting and poaching.

Natural resources can potentially be used in a sustainable way if appropriate land management technology, regional planning and the policy framework complement one another in a purposeful manner, in accordance with the principles and concepts of sustainable land management (SLM). At the center of this thinking is the concept of "ecosystem balance", and especially the questions of irreversibility of ecologic (and socio-economic) processes, resilience of ecosystems, and the spatial and temporal scales are to be considered at the landscape level (Hurni, 1997).

Smyth and Dumanski (1993) defined sustainable land management as:

"Sustainable land management combines technologies, policies and activities aimed at integrating socio-economic principles with environmental concerns so as to simultaneously:

- maintain or enhance production/services
- reduce the level of production risk
- protect the potential of natural resources and prevent degradation of soil and water quality
- be economically viable
- be socially acceptable."

Muchena and Bliek (1997), however, added the following:

- it may not always be possible to maintain or enhance production; in some cases there may be a need to choose options that have a lower productivity
- degradation of vegetation resources and biodiversity in flora and fauna should also be prevented.

The concept of sustainable land management (SLM) grew out of a workshop in Chiang Rai, Thailand, 1991(Dumanski, 1997). This workshop recommended that an international working group of the International Society of Soil Science (ISSS) be formed to refine the concept, develop a definition and recommend a procedure to monitor and evaluate our progress towards sustainable land use systems. A second workshop (Lethbridge, Canada, 1993) emphasized the development of indicators of sustainable land management as instruments for monitoring and evaluation (Dumanski, 1997). The results of these experiences were presented at the 15th Congress of Soil Science, Acapulco, 1994. Subsequent international workshops (Cali, Colombia, 1995; Nairobi, Kenya, 1995; Washington DC, 1996; Naurod, Germany, 1997) focused on indicators of land quality as part of the suite of required SLM indicators (Dumanski, 1997). The workshop held in Enschede in 1997 set the stage for the next step in the development and application of sustainable land management. The definition of sustainable land management calls for integrating technologies, policies and activities in the rural sector, particularly agriculture, in such a way so as to enhance economic performance while maintaining the quality and environmental functions of the natural resource base. Five criteria, called the pillars of SLM, were identified: productivity, security, protection, viability and acceptability. Definitions and pillars are the basic principles and the foundation on which sustainable land management is being developed, and these have been examined and debated by many over the past fifteen years. The concept of sustainable land management, like the concept of sustainable development on which it is founded, is gaining momentum in rural as well as in urban constituencies, and at local, national and international levels. The lack of a comprehensive, quantifiable definition for sustainable land management is sometimes considered to be a serious deficiency. Observations from various case studies show that the non-quantified definition adds flexibility to the approach, and this contributes directly to the resilience of the concept. Because of this, the concept of sustainable land management can be applied at different levels and different scales to resolve different issues, while still providing firm guidance on the scientific standards and protocols to be followed in the evaluation (Figure 5.1).

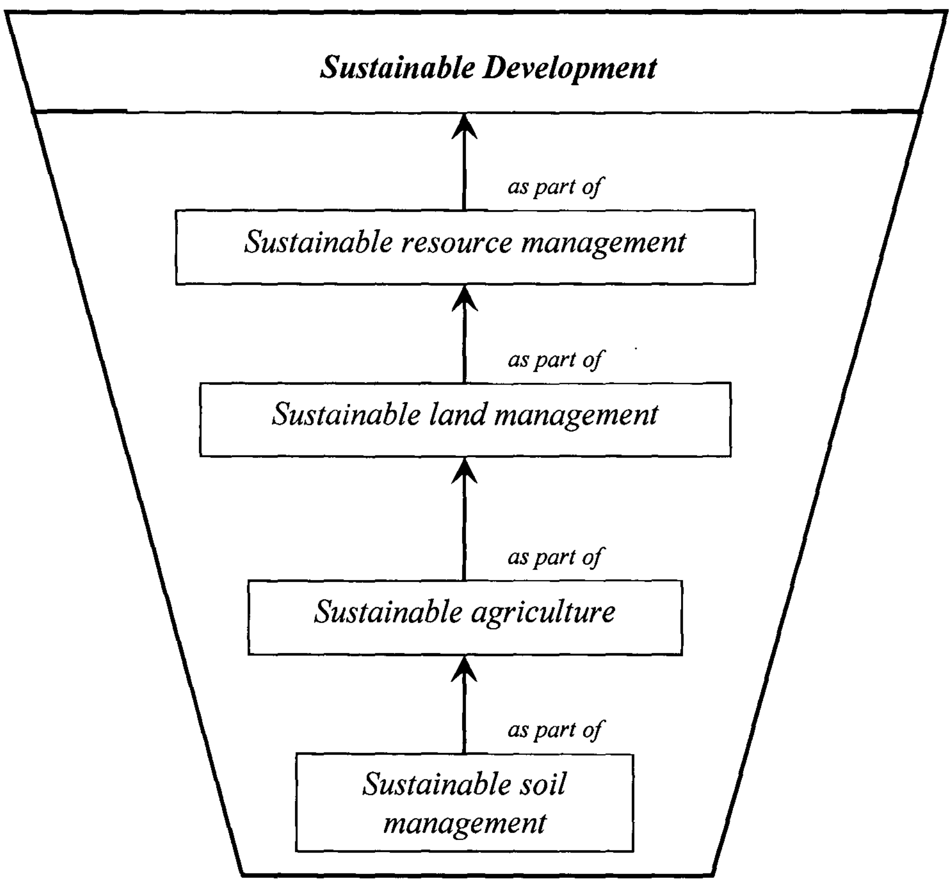


Figure 5.1

Relationships among sustainable development, sustainable agriculture and sustainable land management

The original concept of sustainable land management was related to technologies that contributed to sustainable agriculture, but Traeger *et al* (1997) interpreted this concept as part of the broader concept of natural resources management. These are two scales of interpretation and both are correct because each views the problem from a different perspective and with a different set of criteria. The concept of sustainable land management is being increasingly applied in land management decisions, and the flexibility in definition does not detract from the value or the quality of the evaluation. The necessary refinements, however, in the form of more practical guidelines and indicators for application at different scales, are being identified through field tests, evaluation and experimentation.

Objective of sustainable land management is to harmonize the complementary goals of providing environmental, economic and social opportunities for the benefit of present and future generations, while maintaining and enhancing the quality of the land (soil, water and air) resource. Land provides an environment for agricultural production, but it is also an essential condition for improved environmental management (source/sink functions for greenhouse gases, recycling nutrients, ameliorating and filtering pollutants, transmitting and purifying water as part of the hydrologic cycle, etc).

Sustainability can be achieved only through the collective efforts of those who are immediately responsible for managing resources. This requires a policy environment where farmers and other local decision makers are not only able to reap the benefits of good land use decisions, but are also held responsible for inappropriate land uses. However, environmental problems do not recognize land ownership boundaries or geopolitical spheres of influence. Land degradation affects the yields obtained by farmer, but the larger impacts are often indirect, *e.g.,* degradation of water quality, loss of habitat, loss of biodiversity, etc. Although the concerns for sustainability are global, the required actions must focus at local and national level. The comprehensive integration of economic and environmental interests is necessary to achieve the objectives of sustainable land management. There is urgent need to resolve the global challenge to produce more food to feed the rapidly rising population, while at the same time preserving the biologic production potential and the environmental maintenance systems of the land. Sustainable land management, improved technologies and improved economic performance are central to achieving the goals of sustainable agriculture. Sustainable agriculture demands that consideration be given to achieving both goals simultaneously. Hence, there is a need for planning for sustainable land management. If properly designed and implemented, it will ensure that agriculture becomes part of the environmental solution rather than remaining an environmental problem.

Planning is considered as an attempt, based on available knowledge and insight, to lead the course of events in some desired direction. In this process, data are systematically collected and analyzed, alternative proposals for action are discussed, and alternatives most likely to achieve the specified objectives are worked out. Planning is carried out at various levels and has both spatial and time aspects. Over the past several decades, different approaches have been used in an attempt to tackle the problems of increasing production needs, poverty and environmental degradation in developing countries. In the '60s, a "production-centered" approach was used, where advanced technologies were applied and farmers were used as agents of economic production. This was gradually replaced by the rural development strategies of the '70s, which aimed at meeting the basic needs of the rural population. This approach, however, neglected the institutional dimensions for development, and there was little or no participation by the people. This culminated in unsustainable programmes. The failures and successes of past development programmes have shown that the participation of beneficiaries in project design, implementation, operation, maintenance and monitoring is essential to reach the target group and respond appropriately to their needs. The split between "planners" and "users" had often led to theoretical planning exercises that bore no relationship to what was actually happening on the ground. As a result, during the '80s "people-centered" approaches to development were created, which called for people's initiatives based on the social, physical and economic resources under their control. In the '90s, approaches that create opportunities for the people to decide their own destiny and make their own choices have been, and are still being emphasized (Muchena & Bliek, 1997).

If we look at the planning of natural resource use in particular, several trends can be identified. From the beginning of this century, natural resource inventories (*e.g.,* soil surveys, forest inventories, vegetation mapping, wildlife resources, agro climatic mapping, present land use surveys etc.) have provided the basic information for land use planning. In the 1930s, land capability classification was introduced to classify land according to the degree of its limitations for sustained use and the soil conservation measures necessary. In the 1970s, FAO developed land evaluation as a method to evaluate land for a specific land use type (LUT) that was relevant to local conditions in terms of the physical environment and social acceptability. It is, however, important to bear in mind that land users have varied and personal reasons for choosing a particular land use. The land management and technology levels also vary widely among users, depending on their perceptions of what is profitable and most suitable for them. Physical suitability is usually just one of the many aspects taken into account. Another weakness is that land evaluation considers the land as a blank drawing sheet, whereas in almost all cases there is already "present land use". Land use planning places more emphasis on the process than on the outcome of a blueprint plan. Methodologies of land use planning have not yet been well developed, despite FAO's attempt to issue guidelines for land use planning. It is recognized that land users as well as policy makers need to be sufficiently motivated for change. As a result, the need for a more participatory approach to land use planning, based on the premise that the land users will be the final decision makers and implementers of land use changes, is now generally accepted. However, experiences with participatory approaches in land use planning and examples of successful land use planning are still very scarce.

Improved sustainable use and management of resources implies that those who use and manage the resources should take part in the planning process. Thus land use planning can only be relevant and successful when all crucial stakeholders are involved. This requires a thorough understanding of the land/resource users (stakeholders) and an understanding of the decision-making processes in resource use. This focus on users implies that user needs, user priorities, their constraints and possibilities need to be considered in planning. It is often possible to identify two distinctly different groups of stakeholders: insiders (the resource users) and outsiders (*e.g.,* governmental and non-governmental organizations and the private sector).

Resource users can include agriculturists, settlers, pastoralists, mixed farmers, pastoralists coming from elsewhere to graze their livestock, etc. These two groups have different roles, mandates and resources. In short, the resource users of the area manage, use and plan for the natural resources in the area. They are the main decision makers. The outside agencies advise, facilitate and assist the resource users, ideally resulting in improved use and management. It will also be their task to safeguard the needs of the wider community and future generations. Communication and negotiation between inside and outside stakeholders often takes place through representatives of resource users and other stakeholders. In identifying suitable discussion/negotiation partners, it will be important to consider the following:

- which institution is most likely to be able to represent the resource users, and does this institution represent all users or are certain groups excluded
- what kind of forum will be most suitable for decision-making in this particular area, and what are the local decision-making, control and management processes in respect to natural resources
- whether the same institution will be involved in planning, implementing and monitoring land use improvements
- what is the present situation with regard to control over and access to the different natural resources
- what are the present strengths and roles of traditional institutions

In summary, suitable discussion/negotiation partners (local institutions) should preferably have an adequate level of authority, and they need to represent and ensure commitment from different groups of resource users.

5.2 MAJOR PROBLEMS CAUSING LAND DEGRADATION

5.2.1 LAND-USE RELATED PROBLEMS

Declining Forest Cover

Decline in forest cover is interpreted as deforestation, forest degradation, or a combination of both. The Food and Agriculture Organization of the United Nations defines deforestation as the "sum of all transitions from natural forest classes (continuous and fragmented) to all other classes" (FAO 1997). The loss of forest cover attributed to these transitions must occur over less than 10% of the crown cover for the phenomenon to qualify as deforestation.

Forest degradation takes different forms, particularly in open forest formations, deriving mainly from human activities such as overgrazing, over-exploitation (for firewood or timber), repeated fires, or other natural causes such as cyclones. In most cases, degradation does not show as a decrease in the area of woody vegetation but rather as a gradual reduction of biomass, changes in species composition and soil degradation. Unsustainable logging practices can contribute to degradation if extraction of mature trees is not accompanied with their regeneration or if the use of heavy machinery causes soil compaction or loss of productive forest area. The growth of timber output is taken for granted and is not treated as a subject for analysis. Conventionally, the conversion of woodlands to other land uses has been seen as the only index of deforestation. It used to be expressed as land cleared of trees and put to other uses This approach finds the expansion of arable and residential land as being primarily responsible for deforestation and ignores the fact that extracting more wood than the regenerative capacity of forests leads to slow degradation, which consequently results in denudation in long run. The land under the forest department even when overexploited or clear felled is not considered as undergoing deforestation because it can always regenerate and thus re-forest itself. Here, forest is a legal category, and any land so defined is forest area, irrespective of tree cover. Hence, department lands face deforestation only when that land is transferred to others through disforestation, i.e. declared as non-forest land. In this definition of deforestation, there is no place for the fact that a dense forest can become sparsely forested and finally be reduced to scrub due to overexploitation and lack of regeneration.

Various pressures are put on the forests of the area: increased population both within and outside the region; and consequently the growing demand for timber and firewood; the demand for raw material and fuel by industries; and the demand for wood for sleepers and fuel by the railways. Development of Dehradun city as a prime educational centre and now as the capital of Uttaranchal has played an important role in the growth of population. Local consumption of firewood increased as the population grew. It included dead, fallen and refuge wood; trees were rarely felled for firewood. The local population, therefore, cannot be held alone responsible for degradation of the forests under the forest department. New emerging cantonments, hill stations, and administrative centers also created a remarkable pressure on the forests in their surroundings. Considerable amount of wood was required for the construction of barracks and firewood requirements of troops. Deforestation has lead to wider agro-ecological changes with serious consequences for the natural resource base of the communities.

Extending Cultivated and Built-up area

The present trend in land use studies, on an average, depicts rapid increase in the cultivated and built-up areas in any region. This is happening owing to the increasing population pressure, resulting in urbanization and industrialization. The net result of this is severe degradation of the land.

These two categories of land uses have shown a remarkable enhancement. Growing demands of the increasing population have resulted in the sudden boost in the expansion in the area under cultivated and built-up area. Built-up area has a marked increase around Dehradun city (Fig. 5.2). Rapid urbanization of the city and its suburbs is taking place at the expense of adjoining crop fields or forest land. The crop land that has been undertaken by the built-up area usually migrates towards the forest cover. This is causing rapid clearing of forests leading to degraded ecosystem. Forests are otherwise also cleared in order to meet the mounting requirements in various sectors

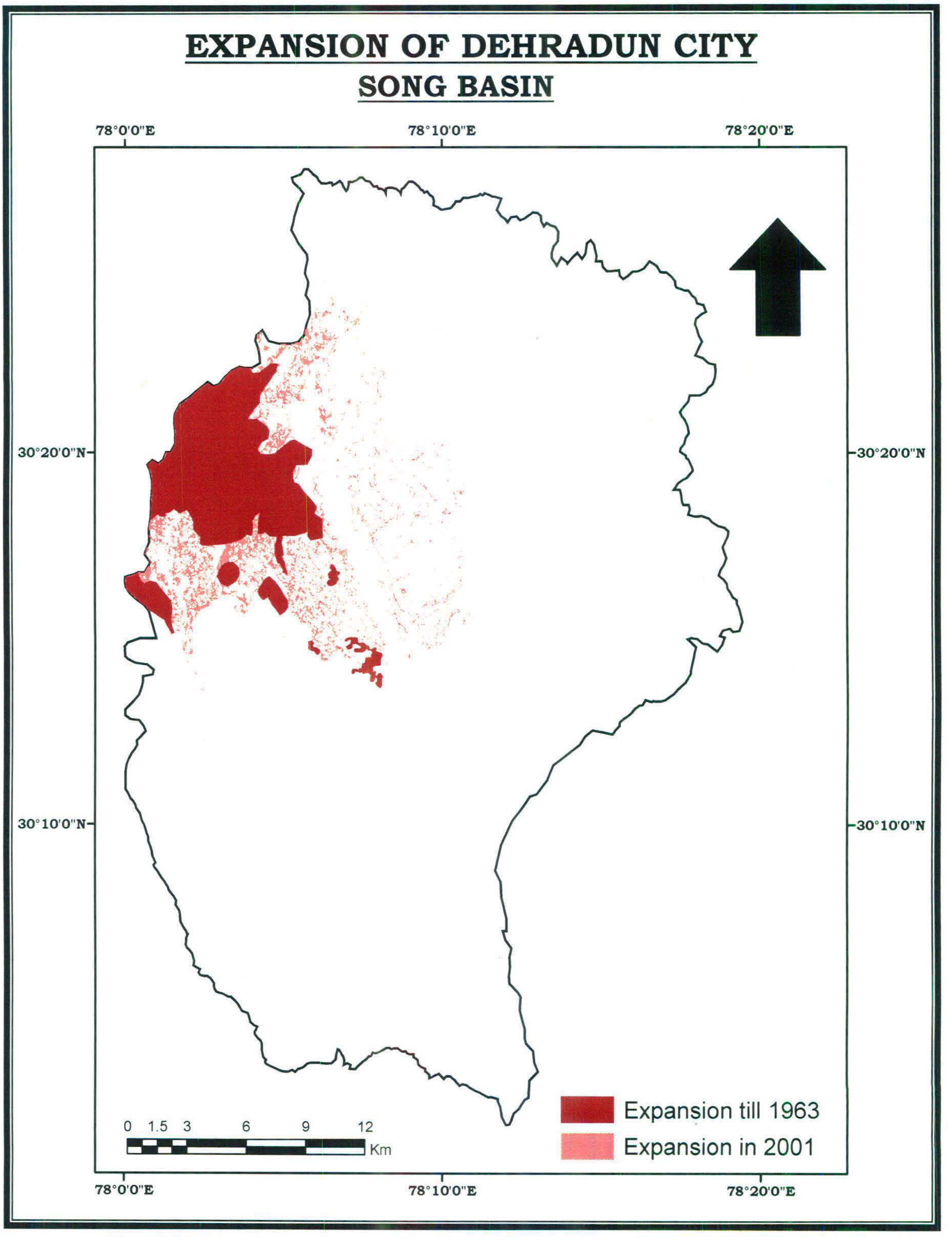

EXPANSION OF DEHRADUN CITY
SONG BASIN
78°0'0"E
78°10'0"E
78°20'0"E
30°20'0"N
30°10'0"N
0 1.5 3 6 9 12
Km
Expansion till 1963
Expansion in 2001

Figure 5.2

including domestic use. Newly planned colonies are being setup in the suburbs of cities. Small settlements have sprung up along the highways to cater the needs of the flowing traffic. Rural settlements have developed around the shifted fields. Smaller towns like Raipur, Doiwala etc. are expanding at even faster rates.

Since the fields around the cities are being swallowed up by the urbanization process, therefore, agriculture gets shifted outwards. Leveled land has already been taken up by one or the other use, thus, marginal slopes are being hunted for cultivation. Cultivated area has extended substantially on the hill slopes by practicing contour and terrace farming. This is causing severe deterioration of the ecosystem.

Extending Wasteland

Wastelands are the degraded and unutilized lands except current fallows due to different constraints (CSIR, 1990). Poor land practices have led to malnutrition and decline in production capacity of the soil. It is estimated that in wastelands the biomass production is less than 20% of its overall potential. It includes areas affected by water logging, ravine, sheet and gully erosion, riverine lands, shifting cultivation, salinity and alkalinity, shifting and sand dunes, wind erosion, extreme moisture deficiency, coastal sand dunes etc. These degraded lands are ecologically unstable with almost complete loss of topsoil and are unsuitable for cultivation due to decline in their quality and productivity. The reason which is quite obvious for this reduction in the production of the crops and trees is the degradation and destruction of the soils. The erosion and depletion of the fertile top layer of the soil are caused by a number of factors such as unscientific agricultural practices, construction of large dams, massive deforestation and number of human activities concerned with over cultivation, urbanization and industrialization etc.

The area has experienced a significant increase in the wasteland of late. This is mainly because of the degrading forest cover and over cultivation owing to primitive agricultural practices in the fragile slopes. Though contour bunding and terrace farming is practiced in many areas but replenishment of soil fertility is not taken care of. Certain areas, where shifting cultivation was once done, have now turned into wasteland.

Clearing of forest leads to bare surfaces exposed to erosion. Surface runoff over wastelands in upper reaches is high, causing siltation downstream. This creates flood conditions in the streams. Removal of brown earth from hill slopes for earth work is also exposing the hill slopes to wind and water erosion. Higher reaches in mountains are virtually wastelands as these are not in use. Thus, the overall impact of wasteland expansion is negative on the entire landscape resulting in loss of land.

5.2.2 <u>OTHER PROBLEMS</u>

<u>Gully Erosion</u>

A gully is an open incised erosion channel where water flows during or immediately after rain. It is the removal of soil along drainage lines by surface water runoff that evolves gullies. Once started, gullies will continue to move by headward erosion or by slumping of the sidewalls unless steps are taken to stabilise the disturbance. Gully erosion generally starts as small rills and gradually develops into deeper crevices. Ravines are a form of extensive gully erosion. Gully erosion not only damages the land resources but at the same time contributes larger amount of sediment load to river system. Under natural conditions, run-off is moderated by vegetation that generally holds the soil together, protecting from excessive run-off and direct rainfall.

The basin of the river Song is subject to immense gully erosion in the upper reaches particularly in the Siwaliks owing to its weak and easily erodable rock structure. It has given rise to numerous short-spell channels that make a closely packed drainage network in higher reaches. Morphometric analysis carried out in the area clearly indicates towards this fact. Excessive clearing, inappropriate land use and trampling of the soil caused by grazing have left the soil exposed and unable to absorb excess water. It has resulted in increase in surface run-off and its concentration in drainage lines, consequently allowing gully erosion to form in susceptible areas.

Gully erosion has thereby caused some severe problems that include:

- removal of more fertile topsoil layers

- sedimentation of streams
- discolouration and contamination of water caused by clay materials carried in suspension reduction in the area of arable and other agricultural land, dividing it into smaller parcels, thus increasing the costs of farming operations
- formation of pathways for the removal of sediments from adjacent areas
- lowering of the water table, which can adversely affect plants on adjacent areas
- dissection of the property causing access and management difficulties
- loss of productive land (gullies often occur in the most productive area of the catchment)

Limestone Quarrying

In recent times, widespread environmental degradation due to limestone quarrying in the area has caused concern amongst local inhabitants and conservationist. It has become the focus of a serious conflict over the mode of utilisation of the rich limestone deposits located here which occur in the northern part of the basin. For one interest group (including the operators of the limestone quarries and the scientific and technical agencies of the state government in charge of geology and mining), the most productive use of the limestone deposits in the region lies in their extraction for commercial and industrial use. For the other and much larger interest group (consisting of the local communities, both rural and urban), the most productive use of the same limestone deposits lies in their in situ function in conserving the large volumes of rain water that falls in the hilly area during the monsoon every year. During the last three decades the limestone industry, consisting of both quarrying of limestone and its processing, received a lot of encouragement which led to its accelerated growth. For the people residing in the area, this growth has threatened the material basis of survival through the destructive impact of the limestone industry on the hydrological balance of the basin. Damage to vital resources such as water, through the destruction of the essential ecological processes controlling the hydrological balance of the basin, has been perceived by the people as a violation of their political and economic right to a decent though often minimal share of the vital resources that are needed for their biological and economic sustenance.

Direct and major human interference in the limestone deposits began in 1900 when the railway line was brought to Dehradun and the forest department started selling quarrying rights to the limestone deposits at a royalty of Rs. 5 per 100 cubic feet. An attempt by the government to assume full control of all limestone deposits was challenged in the court by the local landlords. They argued that the boulders on the surface of the earth and river beds were not mines, and their objections were upheld. As a result, surface boulders were declared as not to be quarried, until the settlement of 1904 which declared all quarries as government property. The limestone of the area, being of high purity, had a ready market in the steel, chemicals, sugar, textile, and other industries.

Quarrying in the area has disturbed the ecosystem drastically. The limestone belt lies in a tectonically active zone. The extraction of minerals by open cast mining disturbs the land-soil-vegetation system by the removal of the vegetation and the top soil. It is, however, accentuated locally by the precipitous slopes and high rainfall, which add to the land's instability. The actual process of extraction of limestone thereafter casts ecological impact on land resources, which is unique to the fragile and sensitive ecosystems characterizing the region. The use of explosives to remove the rocks further weakens the already weak rock structure. The result is induced slope failure and landslides, which are increasing in the region since the mining operations began. The further impact of quarrying is also reflected in the flow characteristics of the springs and streams in the basin. As in the last few years, quarrying has led to the most drastic changes in the surface characteristics of the catchments-both in terms of extent and intensity-decline in the lean period base flow in the streams can be linked with it. Such disturbance of the hydrological cycle resulting from human intervention in the limestone belt in the processes of quarrying seems unavoidable and an expensive impact of quarrying. This disturbance has been further accentuated by the impact of the disposal of overburdens and 'finest' on the hill slopes, and by the landslides induced by mining related activities in this sensitive region. The resulting debris covers large areas of the hill slopes below the limestone belt. During heavy rainfall, debris is carried by the run-off to the river beds. This in turn raises the river beds, changes the course of rivers, leads to soil erosion in the adjoining agricultural land and forests, and blocks the vital canal systems of the Valley. The Baldi river's bed has been rising constantly, threatening roads and bridges in the area of Sahastradhara, which lies about 1 km upstream of its confluence with the Song river. Buildings near the only bridge over the Baldi river have already been washed away, and the cumulative piling up of '*bajri*' will, in the near future, pose a serious threat of floods in large parts of the Valley. Such floods have already begun to affect villages on the banks of Baldi and the Song.

Besides damaging land and property along the river beds, the debris loaded flow in rivers has started choking canal works, thus heavily increasing their maintenance costs and the vulnerability of the water distribution system. The Irrigation Department has to employ a large labour force to work around the clock throughout the monsoons, so that the canal head is not blocked by silt and other debris. The maintenance team is involved in such activities as not allowing the rivers to change their course in order to ensure that the water reaches the canal head, clearing out debris from the canal head and the canals. Through water, the impact of quarrying is carried on to the human settlements, which depend on these water resources for survival.

Limestone quarrying and the processing units which have been established to support it, have destroyed the resource base on which other activities, like agri-horticulture, tourism, education such as schools and research institutions and knowledge-intensive manufacturing, survive and prosper. The 'growth' recorded by the limestone industry has, thus, to be seen against the background of the decay of other economic activities and not independently of it. The entire area below the limestone belt can no longer be used for grazing, and large areas have practically no vegetation as they are covered by debris from the mines. The few pockets of shrubs and forest that remain are of no use for cattle, because of the perpetual danger of boulders rolling down the slopes as a result of blasting. An important economic activity based on animal husbandry is therefore being eroded, and the decline in cattle population in areas affected by mining is as much as 40 per cent. The decline in livestock population affects the production of milk, the production of energy for farm operations, and the production of animal dung that provides soil fertility for sustainable agriculture. As a consequence of these problems, villagers living near the quarries are becoming increasingly dependent on non-agricultural incomes. Quarrying affects agricultural activity not only in the villages in the vicinity of the quarries but also in the villages in the other parts of the basin served by canal network. The increasing difficulty in the distribution of water interferes with the timely availability of irrigation water, which leads to increased crop failure. The growing of Basmati rice, famous for its flavour, is on the decline, thus reflecting the failure of the region to utilise its relative advantages of climate and water resources. The lime rush which has been profitable for the quarry operators could be one of the most important factors behind the ecological, and hence economical, collapse of the Valley.

Primitive Cultivation Techniques

Agriculture practiced in any area is one of the major factors that decide the quality of land in that area. Intensive agriculture, without properly manuring and fertilizing the field, leads to deterioration of land resource. Most of the land in the study area is not suitable for cultivation and an appreciable amount of land bears severe limitations. Mostly in the hilly tracts where soil and land is highly vulnerable, unprecedented cultivation is being carried out. This is posing a serious threat to the fragile ecosystem.

Clearing of forest vegetation commences a cycle of rapid soil erosion and decline in land productivity. Soil erosion is found to be heavy on the regularly cultivated slopes that too without proper conservation methods. The rural farmers do not adopt soil-conservation measures, either mechanical or agronomic, at least partly due to lack of awareness and knowledge. Nearly always poorly designed measures do more harm than good. Adoption of mechanical conservation measures are labour-intensive and expensive to construct, therefore it is not readily acceptable to small farmers for controlling soil erosion. Majority of farmers have small farm holdings and they rarely produce enough to meet the subsistence requirements of the families. The farmers have no capacity to adopt conservation measures to sustain productivity. As a result there is rapid decline in productivity. Thus a vicious circle is set in motion.

Practice of shifting agriculture in the hilly areas is also one of the major causes that has accentuated the problem. Common to all shifting cultivation practices such as deforestation, burning of the biomass as a way of land preparation, non-adoption of conservation measures and low levels of crop management have serious degradation consequences. In shifting cultivation, the practices adopted are designed for low inputs and to minimize risks. The outputs are low; therefore, income generation is also very low and it is not sufficient for reinvestment on land improvement.

Population Pressure

Land degradation is a twofold process - deterioration of soil quality and loss of land. The functional capabilities of soil deteriorate from activities related to agriculture, forestry, and industry. On the other hand, urban sprawling and infrastructure development cause loss of available land. The linkage, however, between increasing population densities, declining yields and land degradation is not simple but involves the interaction of societal, institutional and environmental factors over both space and time.

Increasing population pressure is the main cause that has initiated other reasons causing land degradation. To meet the demands of the growing population, immense stress is laid upon land resources. Conventional forest areas are being converted into agricultural and residential areas. Cultivation is being done on vulnerable marginal hill slopes which otherwise portray a very fragile ecosystem. This causes deterioration of land and most of it becomes wasteland.

The basin of the river Song is also under great population pressure due to the urbanization and expansion of the Dehradun city which forms a part of the area. During the hundred-year period of the survey the population rose by about 425 percent in which the most dramatic growth has occurred since 1940 with a 185 percent increase. Population densities have increased from 47/ km^2 in 1880 to 246/ km^2 in 1980. Much of this growth has been driven by the rapid development of the Dehradun metropolitan area, with an urban population of 293,628 in 1981. Due to this unprecedented urban growth, land is being exploited recklessly for various products whether forests or agro products. This is subsequently causing degradation of quality and quantity of land.

5.3 CONSERVATION MEASURES

Declining Forest cover

Modern forestry has its basis in 18th-century Germany (Hermosilla, 2000). Like the Chinese and the Mayan forest practices, German forestry is essentially agricultural. Trees are managed as a crop. Two concepts are important: renewability and sustainability. Renewability means that trees can be replanted and seeded and harvested repeatedly on the same tract of land in what are known as crop "rotations." Sustainability means that forest harvest can be sustained over the long term. Today, however, sustainability is a vital issue in forestry and people must rely more and more on second-growth or managed forests. Forests are essential for survival and sustenance of life. They are source of many direct and indirect benefits and need to be managed in such a way that extraction of benefits does not deplete the resource. Their growth should be optimised so that greater benefits are derived from them.

When the forest department realised that the quality of forests was declining rapidly, canopy cover began to be treated as an important measure of the quality of the forests. This has also become possible due to the availability of satellite imagery of forests. The Forest Survey of India began analysing the satellite images of forest cover in the 1980s. Now, the forestland under the Forest Department is categorised as dense (crown density above 40 per cent), open (crown density between 10 and 40 percent) and degraded or scrub forests (crown density below 10 per cent). This recognises that forest degradation can result in denudation of the forestland due to overexploitation and lack of regeneration. Since this recognition was not there before 1980s, data on the quality of forest cover are not available for time prior to this period.

Forest fires constitute a major threat to the forests, as the forests in the plains and foothills are mostly dry and deciduous and prone to forest fires in the summer season from February to June. The forest fires can be managed through 'prevention' as well as 'fighting'. Fire prevention is done through a system of fire lines that criss-cross the forest. In addition to the specially cut fire lines, all roads passing through the forest are treated as fire lines.

Forest officers are deployed to check various offences and smuggling carried out from the forests. In addition to illegal felling, illegal possession and transport of most types of forest produce (timber and minor forest products), encroachments on forest land for any purpose, and setting forests to fire are offences under various laws. Forest Officers are vested with powers to enquire into offence cases, force attendance of witnesses, stop and search vehicles, arrest without warrant, issue search warrants, seize forest produce suspected to be illegally obtained, confiscate vehicles and other property used in the commission of forest offences, eviction of forest encroachers, and also, to compound cases under these laws.

Moreover, the local communities also need to play a key role in protecting and sustainably managing their forests. Based upon traditional knowledge and through a process of trial and error the tribal/indigenous communities have to devise certain 'best practices' for the use of the forests. Such practices should be inherited as a part of the traditions and customs of the communities.

Extending Built-up/ Cultivated area

Such extensions could not be completely arrested, but it can always be restricted. But while carrying it out, it is important to see that ecological balance does not get disturbed. The areas that are highly susceptible should be left out. Afforestation should be done on wastelands, on higher elevations, to counter balance this loss. Cultivation should be prohibited on fragile slopes and, if necessary, should be carried out in a proper manner. Terrace farming should be practiced with some obstacle on the edge of the terrace in order to prevent soil erosion. Cultivable and other wastelands in the lower elevation should be brought under cultivation in order to release stress from the areas in higher elevation.

Further extensions of built-up areas should be ecological in character. Unprecedented growth of urban settlements should be checked on the hill slopes. Growth should be restricted to the plains. Wastelands in the proximity of settlements, which can not be reclaimed, should be utilized for building purpose. Concept of town/city planning must be adopted for space management.

Extending Wasteland

Dry land degradation is brought about mainly by inappropriate land use practices. These different processes need different management approaches as the level and severity varies. These processes could be prevented and reversed by integrated ecosystem approaches involving land and water by considering watershed as planning unit. This means that the planner's attention has to be shifted from combating desertification towards improving natural resources management. Rehabilitation and sustainable management of land is essential to meet the gap between demand and supply.

Goals in this regard are to check further degradation; sustainable use of degraded lands; increase biomass availability along with nourishing soil; and restore ecological balance. This can be done by participatory approach with the help of local people in the planning and management of lands. Ecosystem approach in management considering watershed, would ensure integration of various ecological components (both biotic and abiotic). This would also help in enhancing the socio-economic status of a region. Broadly, it can be done through:

- Wasteland monitoring and preparedness.
- Assessing infrastructure available to meet the requirement.
- Checking soil erosion and malnutrition
- Reducing runoff by water and wind.
- Maintaining biological diversity and the nutrient storage in soil matrix.
- Exotic species should be avoided as far as possible and be considered only when the indigenous species are unable to thrive in a degraded ecosystem.
- Afforestation should involve a multi-species approach. This would be more advantageous from the point of resistance to pest and diseases, and more efficient

utilization of environmental resource. This can also serve as a better cover to the soil and regeneration of soil.

- Integrated village ecosystem planning with watershed approach needs to be espoused for sustainable development.
- Research and information access to understand the causes of land degradation and effective means to address them.
- Promoting conservation of natural resources through traditional knowledge.

The study highlights the need for an integrated ecosystem approach in watershed management considering all components to maintain sustainability in wasteland management. Rehabilitation of the degraded land through sustainable management of soil and vegetation would minimize siltation and enhance water yield in the catchments. Multi-species approach with native species for afforestation would be more advantageous due to its resistance to pest and diseases, meeting the local demand, providing perennial water source and more efficient utilization of environmental resources. This would serve as a better cover to the soil and aid in regeneration of soil.

Gully Erosion

For the purpose of gully control measures, gullies are classified on the bases on several factors. One method takes into consideration the gully depth and catchment area. Gullies are generally deeper than 30 cm. Any erosion channel less than this depth is classified as a rill and can usually be removed by tillage. Table 5.1 gives the classification of gullies:

Description	Gully depth	Catchment area
Small	1m or less	2 ha. Or less
Medium	1 to 5m	2 - 20 ha.
Large	Greater than 5m	Greater than 20 ha

Table 5.1

Repair work done in the early stages of newly formed gullies is easier to manage and more economical than letting the problem go unchecked for too long. Large gullies are difficult and costly to repair. Areas that have an extreme level of gully erosion can be best treated by changing the land use. If these are currently used for cropping, they should be converted to grazing or, in some cases, rested completely and allowed to revert to native forest. If these are currently used for grazing, it may have to be withdrawn completely from production and natural re-afforestation should be allowed to take place. The lands that are still under native forests, usually develop extreme gullies if forests are cleared. In this case, every effort should be made to retain the forest cover and to exclude grazing stock or allow only lightly grazing in the area. Gully plugs which are earthen embankments usually constructed for blocking the active and erosion prone gullies for their stabilization can also be made. Check dams involving stone work can be adopted where stones are available easily and in plenty. In this, a wire mesh can be used to hold the stone in place.

As with other forms of erosion, prevention is better than cure. In most cases gullies can be prevented by good land management practices aimed at maintaining even infiltration rates and a good plant cover. It can be prevented by:

- Maintaining remnant vegetation along drainage lines and eliminating open grazing from these areas.
- Increasing water usage by planting deep-rooted perennial pastures, trees, or an appropriate mixture of both thus maintaining healthy, vigorous levels of vegetation.
- Identifying drainage lines as a separate land class in which vegetation needs to be protected.
- Immediate stabilisation of sheet or rill erosion.
- Maintaining high levels of organic matter in the soil.
- Avoiding excessive cultivation.

Sound crop, pasture and soil management practices are essential to complement soil conservation. If such practices are not included in the erosion control program, the structural works will be always of little use.

Limestone Quarrying

The heavy negative externalities of limestone quarrying in the area have long aroused popular protests. . This contradiction came to a climax when a large number of leases were due for renewal at the end of 1982. In 1981, the Department of Industries of Uttar Pradesh had appointed a committee to decide the policy for renewal of the leases. According to the recommendations of this committee, total ban was recommended in the Song Valley because of the practice of dip slope mining, as the stability of the entire mountain was in danger. The decision was, however, challenged in the High Court by the quarry operators, who obtained 'stay' orders allowing them to continue quarrying even in those quarries which had been recommended for closure. The stay order led to confusion among the local monitoring agencies for the quarries. The quarry operators reportedly interpreted any control and monitoring by the official agencies as interference in their activity which had been approved of by the Court. The result was severe and reckless quarrying, as the operators tried to maximise their production in a period of uncertainty about future possibilities.

Resistance to extraction of limestone from this vulnerable ecosystem was in three phases. In the first phase, the local village organizations politically resisted the mining activities. Without the support of science or the state, the villagers lost their campaign. The second phase was characterized as a conflict between the state and the lessees. The Court called on technical experts to inform its decisions. The technical experts, who were partisan scientists, informed the Court that quarrying in the lease areas does not necessarily affect the environmental and ecological balance in regard to water, soil and other related factors'. Without counter arguments from ecology as public interest science, even the state could not control mining. In the third phase, citizen groups in Dehradun and Mussoorie fought a similar case in the Supreme Court, this time informed by public interest science. The Court acted as a public interest science laboratory where scientific ideas were tested, verified, and developed into a countervailing force challenging the power of partisan expertise. Public interest litigation backed by public interest science was successful in controlling mining. On 12 March 1985, a Supreme Court bench consisting of Justice P.N. Bhagwati, Justice A.N. Sen and Justice R. Misra, who had been hearing the public interest litigation against limestone quarrying in the Dehradun district, passed an order closing permanently or temporarily, fifty-three limestone quarries out of sixty within the geographical limits of the Dehradun district (http://www.unu.edu/).

This issue of violation, through ecological destruction of the people's rights, has been presented before the Supreme Court of India in an attempt to seek justice which is apt to be denied in the economic world when it is dominated by profit motives and market forces. This initiative to seek justice, which is rather exemplary, came from an NGO, the RLEK (Rural Litigation and Entitlement Kendra) in Dehradun, and was supported by interventions from citizens' pressure groups, such as the Save Mussoorie Society and the Friends of the Doon. The petition was also supported by those official agencies whose concern coincided with that of the citizens. These agencies included the Department of Environment of the Government of India and the City Board of Mussoorie. The litigation is in the course for decision in accordance with the due process of law of the Supreme Court of India.

All the negative externalities of limestone quarrying, be in the terms of resource degradation or ecological disturbance, can only be counter balanced if it is carried out in a restricted and sustainable manner. Since it bears a viable economic importance which can not be totally neglected, it can not be completely stopped. Moreover, it is a source of income for the people who reside in the villages near quarries. Thus, it is imperative to limit the activity to certain specific areas which are not engaged in other uses so that it does not interfere with other economic activities. And this should be conceded in an environmental backdrop.

Primitive Cultivation Techniques

Sustainable agriculture is the way that should be adopted in order to combat the degradation caused by ill-practice of agriculture. It is defined as the "successful management of resources for agriculture to satisfy changing human needs while managing or enhancing the quality of the environment and conserving natural resources".

Hilly areas should be protected from soil erosion through better agricultural practices and construction of terraces where it is cost effective. Steeply sloping and vulnerable areas should be put out of any agricultural use. A system should be established for monitoring surface runoff and transfer of sediments to the river, carrying fertilizers, in order to protect the channel from pollution. The probability of soil water availability should be considered for crop planning. Small-scale water harvesting (ponds, wells) must be practiced for life saving irrigation of crops. Earthen dykes should be constructed in the areas prone to acute soil erosion. Plantation should be done in the marginal slopes. Green pastures should be developed in the wasteland on slopes. Proper irrigation should be done in order to maintain acidity of the land. Thus with appropriate management techniques, land degradation can be controlled and degraded lands reclaimed.

Land is an important natural resource that has direct and indirect linkages with human being in every sense such as production system, economic activities, and social and cultural and more. A good number of policies to combat land degradation have been evolved, but these are not fully implemented. It needs to be emphasized that a plan to prevent land degradation must begin with strengthening of knowledge regarding the susceptible areas. There is a wide gap between awareness of land degradation problems and actions necessary to combat them. Land degradation in many areas goes unnoticed from generation to generation, and therefore the concept of land resource conservation fails to attract politicians and planners. Scientists are worried about and warn everyone on the sustainable management of land. However, they are often disregarded and the common attitude of the people is that they know about their own land better. It is clear that the quality of land has deteriorated, and its impacts visible. There are a number of policies to deal with land degradation, but with limited implementation. The existing polices must be implemented, and a number of new activities be undertaken in the immediate future to address land degradation.

Therefore, it is pertinent to arrest land degradations and launch conservation and rehabilitation programmes in the most critically affected and vulnerable areas. To attain sustainable land management and development, it is very necessary to build institutional capacity to conduct field level research and apply the results through extension programs along with enabling policy makers to take necessary decision and undertake appropriate mitigation measures.

6. SUMMARY & CONCLUSION

Resources are important for forming the base for the economic development of any nation. Every country possesses a different level of economic development primarily because of their resource base and utilization level. Land is an important natural resource. It is vital and essential for production of basic needs, such as food, fiber and fuel etc. The land resource holds potential for many different uses like providing habitat for wildlife, pastures for cattle and livestock, forest and woodland, regulating hydrological cycle, etc. Of late, it has come under growing pressure throughout the world for an increased demand of food and water on the one hand and its accelerated degradation on the other.

The ability of land to produce more is limited owing to climate, soil and landform conditions and the use and management applied to the land. There is enough evidence of the decline in living beings and increase in the carbon dioxide proportions leading to global warming. This visibly points toward the current approach to land resource management that is unsustainable. These problems can be scientifically tackled if the land resources are managed on the basis of hydrological units i.e., watersheds and river basins. Since these are independent of territorial and administrative boundaries, warranting a holistic approach to resource management is necessary.

Remote sensing and GIS techniques are gaining momentum for land related studies. Remote sensing techniques can cover large areas within the reasonable time with reliable accuracy. This also helps in providing up-to-the-minute data for analysis. GIS provides innovative tools to work efficiently on map data and its attributes. Land use studies have become very uncomplicated and advanced with the help of these tools. Therefore, these techniques have been incorporated in this study to make it more relevant and proficient.

To proceed with the study, it is important to have an overview of the area that is to be studied. This overview should integrate both historical and geographical aspects. The study area is a drainage basin of the Song River which is a tributary of the Ganges. It drains the eastern part of the Doon valley (District Dehradun). The tributaries of the Song include Jakhan Rao, Bindal, Baldi, Suswa, Rispana, etc. The basin comprises features like structural hills, denudational hills, piedmont zone, valleys, recent floodplains, river terraces etc., and is a tectonically active region. The physiography is divided into three sections – the northern mountains, the piedmont plains in the middle and Siwaliks in the south. The geology of the area dates back to the Pre-Tertiary times, youngest deposits being of the late Holocene. Climate on the whole is Humid Sub-Tropical Monsoon type with occasional special weather phenomena like dust storm, hail, squall, fog etc. A wide variety of vegetation is found here including shrubs, creepers and grasses, *sal* being the dominant specie. It is classified into fourteen classes on the basis of altitudinal occurrence. Agriculture is the main stay of the economy. Livestock rearing is also done adequately. Some industries are found in the area including fertilizer, sugarcane, limestone quarrying, tourism etc. Thus, the area in general has a developing economy. Lithology, climate, natural vegetation, soil, and several other elements including man's interference with nature have been responsible for the evolution of a complex form of topographic features in the area.

Morphometry, which is the mathematical analysis of the configuration of the earth's surface, helps in understanding the physiographic environment of the region. If the study area is a drainage basin, it is important to perform morphometric analysis to understand terrain evolution. It is a competent tool to analyse topography of any region which in turn affects the socio-economic conditions of that area. It includes all three dimensions of the surface – linear, areal and relief.

The quantitative analysis of the area suggests the pattern of the river to be dendritic with an exception to the south-western section. It resembles more a parallel pattern. The Song basin is a sixth order basin. Total number of streams in the basin decrease with increasing order and total length increases with increasing order. Bifurcation ratio suggests uniformity in rock structure, tectonic history, climatic conditions and stage of development. It also indicates towards gully erosion in higher reaches.

The basin is slightly elongated in shape, discharge being less efficient. Drainage frequency, density and texture are found to be high in northern, north-eastern and south-western part of the basin owing to high relative relief. Numerous rills and gullies have developed in these areas forming a close network of streams.

Relief analysis of the basin shows that a high absolute and relative relief is found in the upper part of the basin which covers almost half the area and also towards the south-western part which is the Siwalik formation. Rest of the area is plain in nature. Highly dissected and rugged terrain is also found in the same area due to high relative relief. This is because of a number of streams involved in under-cutting of the surface.

Land degradation, in most cases, is a result of human intervention. Since land use and land cover are the aspects directly modified by human beings, to a great extent, these are responsible for degradation of land. Faulty land use, which is not in accordance to the potentials of the land, causes major deterioration of land. Although there are other factors that accentuate the problem. Land use/ land cover analysis of the study area clearly shows a pattern that is highly modified due to human interference. Forest cover of the area has significantly decreased, and taken over by residential and cultivation purposes. This is mainly due to excessive felling of trees for timber, overgrazing, fire and clearance of land for cultivation and settlement. This phenomenon is more widespread in the proximity of settlements. Change detection analysis of forest cover shows that most of the forest has been converted into cultivable land or brought under settlement. Some forest cover has changed into wasteland. Rapid expansion of urban centers has also taken place. It is the cultivated area that has most widely expanded in the past forty years. Wasteland has also shown a significant increase due to reckless cultivation and quarrying.

This vulnerable ecosystem has been facing various problems. These include problems induced through ill land use practices. Forestland is declining at an alarming rate where as residential and cultivated areas have been unprecedentedly increasing. Gully erosion in the northern, north-eastern and south-western parts, due to high relative relief, is very high. It has resulted into highly dissected terrain in these parts. Human encroachment in these susceptible areas is also a prominent reason. Major problem due to limestone quarrying in the region has resulted into severe land deterioration. Blasting, manual extraction and other methods applied for removing limestone leave the land patches degraded. It is a source of income generation in the villages near the quarries. Cultivation practiced irrespective of the vulnerability of marginal slopes is also causing problems. Especially methods applied are too primitive to maintain the land. A common linkage to all these problems is the increasing population pressure. All the above mentioned problems are implicit to the latter. Increase in population has fuelled the hunt for land and put stress on available land. Land has been utilized intensively without even considering its capabilities.

Along with the identification of problems, their conservation measures have also seen suggested. "Sustainable Land Management" approach is the demand of today. This approach evolved in 1991. It incorporates technologies, policies and activities that aimed at integrating socio-economic principles with environmental concerns. Sustainable land management has soil and agriculture management implicit to it. It clearly suggests the involvement of the users in the planning and management process. It has become essential to adopt this approach for an overall integrated sustainable development.

In the basin, it is important that appropriate land use practices should be adopted in accordance with the capabilities of the land. Decline in forest cover can be arrested by controlling forest fires, deploying forest guards to check smuggling, and involving the local communities in conservation programmes. Gully erosion can be controlled by maintaining vegetation along drainage lines, crop management, constructing gully plugs, check dams etc. Quarrying has been banned in most areas, but is still being carried out illegally in the basin. It needs to be checked and restricted to specific areas. The lands that have already been degraded by the activity must be rehabilitated by developing forest and pastures. 'Sustainable agriculture' should be carried out keeping in view the capabilities of land to maintain land and soil quality. Reclamation of wastelands needs to be on priority.

It can be concluded that this basin is subjected to an immense environmental degradation due to increased population pressure and other factors.

Conversion of forest land to agricultural and residential land, unprecedented soil erosion resulting in various hazards, irrational human interference like unscientific quarrying and blasting for road and dam construction, overgrazing, over ploughing, over fallowing, deforestation etc. are giving rise to low fertility and low productivity. Thus there is an urgent need for conservation and management of land resource in the area in order to make it usable for the coming generations.

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