Integrated Impact Analysis of Environmental and Socioeconomic Factors on Pollution Status of Dal Lake using Geospatial Tools

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DOCTOR OF PHILOSOPHY

IN

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In the name of ALLAH,

The Most Merciful, the Most Compassionate

Dedicated

To

My

Beloved Parents

Sher-e-Kashmir
University of Agricultural Sciences & Technology of Kashmir
Division of Environmental Sciences,
Shalimar Campus, Srinagar-191121

Certificate –I

This is to certify that the thesis entitled, **"Integrated Impact Analysis of Environmental and Socioeconomic Factors on Pollution Status of Dal Lake using Geospatial Tools"** submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy in Environmental Sciences**, to the **Faculty of Post Graduate Studies, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir** is a record of bonafide research work carried out by **Bazigha Badar (Regd. No. 2007-201-D)** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

It is further certified that information received during the course of investigation has duly been acknowledged.

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We, the members of the Advisory Committee of **Bazigha Badar (Regd. No. 2007-201-D)**, a candidate for the degree of **Doctor of Philosophy in Environmental Sciences** have gone through the manuscript of the thesis entitled **"Integrated Impact Analysis of Environmental and Socioeconomic Factors on Pollution Status of Dal Lake using Geospatial Tools"** and recommend that it may be submitted by the student in partial fulfilment of the requirements for the award of the degree.

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ABSTRACT

Dal Lake, a cradle of Kashmiri civilization has strong linkage with socio-economics of the state of Jammu and Kashmir. Since ages the lake has been a source of livelihood to a large number of people through various activities ranging from tourism, farming and fisheries. Over the years, various anthropogenic pressures in Dal Lake Catchment have caused environmental deterioration impairing, inter-alia, sustained biotic communities and water quality; the main contributors being land-use changes in the catchment, increased sedimentation, flow of fertilizers and pesticides from the catchment, unplanned urbanization and encroachment. Most of the Dal Lake research conducted earlier has been mostly of conventional/routine nature without any serious attempt to integrate the impact of the environmental and socioeconomic factors on the health of the Dal Lake Ecosystem. The present study is a

comprehensive research analysis of various processes at the watershed level and their integrated impact on the current status of Dal Lake ecology using multi-sensor and multi-temporal satellite data, Geographical Information System (GIS) simulation models (GWLF, PredICT) together with field data verification. 13 Dal watersheds (designated 'DW1-DW13') of the Dal Lake Catchment were identified and delineated on the basis of water divides using LISS (III) satellite image and 90 m Shuttle Radar Topographic Mission (SRTM) digital elevation model. All the 13 watersheds have been covered during the present research work and various aspects investigated include land use/ land cover change detection analysis, topographical analysis, hydro-meteorological data analysis, soil analysis, quantification of erosion, sediment and nutrient loadings and socioeconomic analysis. Data generation on such vital aspects is useful in understanding the complex lake ecosystem interactions, besides identifying the critically impaired watersheds leading to their prioritization. The land use/land cover change detection from 1992-2005 revealed significant changes in the Dal Lake Catchment. Built up showed a change of +12.08 Km^2, Agriculture (-1.84 Km^2), Fallow (-0.076 Km^2), Horticulture (-7.57 Km^2), Coniferous forest (-5.67 Km^2), Deciduous forest (-1.8 Km^2), Sparse forest (-0.96 Km^2), Grasslands (-7.89 Km^2), Scrublands (+11.97 Km^2), Plantation (-12.9 Km^2), Aquatic vegetation (+3.47 Km^2), Bare land (+4.44 Km^2), Bare exposed rocks (+1.61 Km^2), Water bodies (-0.91 Km^2), Water channel area (+0.06 Km^2), Snow (+5.45 Km^2) and Golf course/Turf (+0.51 Km^2) in the catchment. Maximum increase in the erosion yield was recorded for DW5 with 236.93 tons/yr followed by DW6 (76.49 tons/yr), DW8 (56.16 tons/yr) and DW11 (54.55 tons/yr). DW9 (12.82 tons/yr), DW10 (10.04 tons/yr) and DW13 (7.96 tons/yr) recorded the least increase. Similarly, the highest increase in sediment loadings was recorded for DW5 (36.7 tons/yr) followed by DW8 (15.2 tons/yr) and DW3 (12.3 tons/yr). DW4 (4.06 tons/yr), DW12 (2.82 tons/yr) and DW10 (0.94 tons/yr) showed least increase in the sediment loadings. The source area contribution for the erosion and sediment yields was highest for stream banks followed by bare lands, agriculture, hay/pasture and forests, whereas, the least loads were recorded for horticulture, turf/golf course, high intensity and low intensity developed areas. Overall nutrient (dissolved and total forms of nitrogen and phosphorus) loadings for 1992 and 2005 land use/land cover were recorded for the watershed DW5 followed by DW2, DW1, DW8 and DW3 with an upward trend from their 1992 values. The watersheds DW9 and DW10 were found to contribute least even though the nutrient

loadings were showing an increasing trend. Agriculture, ground water, high intensity urbanised areas, and bare lands were the major sources of the nitrogen and phosphorus loadings. The least loadings were recorded form forests, golf course and low intensity developed areas. The socioeconomic analysis of the watersheds in the Dal Lake Catchment revealed that the watershed DW2 has the highest population and the highest number of households followed by DW1, DW4, DW6, DW5 and DW3. The lowest population/ households were recorded for DW8 whilst no human habitation was observed in other watersheds (DW7, DW9 – DW13). The prioritization analysis revealed that DW5>DW2>DW6>DW8>DW1 rank highest in the cumulative weightage of environmental and socioeconomic factors and considered high priority; five watersheds (DW13>DW3>DW4>DW11>DW7) fall under medium priority category whilst three watersheds (DW12>DW9>DW10), belong to low priority category. The integration of the biophysical and the socioeconomic environment at the watershed level attempted using modern geospatial tools is of vital importance for the conservation and management strategies of Dal Lake Ecosystem.

Key words: Dal Lake, Catchment, Watershed, Remote Sensing, GIS, Model, GWLF, PredICT, Erosion, Sediment, Nutrients

Signature of Major Advisor **Signature of Co-Advisor**

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Signature of the Student

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"Allah alone is besought for help, and, on Him alone we depend."

Bazigha Badar

Dated:

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LIST OF ACRONYMS

%	Percent
°C	Degree Centigrade
Avg.	Average
BMPS	Best Management Practices
CN	Curve Number
C	Cover Factor
DW	Dal Watershed
DEM	Digital Elevation Model
DN	Dissolved Nitrogen
DP	Dissolved Phosphorus
Eq.	Equation
Fig.	Figure
GIS	Geographic Information System
GPS	Global Positioning System
GWLF	Generalized Watershed Loading Function
IRS -LISS	Indian Remote Sensing-Linear Imaging Self Scanning System
Km^2	Square Kilometre
LC	Land Cover
LS	Slope Length
LU	Land Use
Mg/l	Milligram per litre
mm	Millimetre
$M\ m^3$	Million Cubic Meter
MoEF	Ministry of Environment and Forests

MSS	Multi Spectral Scanner
NASA	National Aeronautics and Space Administration
NPS	Non Point Source
P	Support Practice
PredICT	Pollution Reduction Impact Comparison Tool
RUSLE	Revised Universal Soil Loss Equation
TM	Thematic Mapper
TN	Total Nitrogen
Tons/yr	Tonnes Per Year
TP	Total Phosphorus
UNEP	United Nations Environment Programme
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation

CHAPTER-1

INTRODUCTION

Life on earth depends on water, which maintains and links the planet's ecosystems. Two-thirds of the earth is surrounded by water, with lakes and rivers being the most important freshwater resources, accounting for 2.53% of the total water found on earth (UNEP, 1994). Wetlands in India (including lakes and excluding rivers), account for 18.4% of the country’s geographic area. India has 67,429 wetlands, covering an area of about 4.1 million hectares (MoEF, 1990). Jammu and Kashmir abounds in rich wetland diversity with a total of 3,684 wetlands which include both natural (1405) and manmade (39) wetlands. The total area covered by these wetlands is 3, 89,261 hectares, including 2240 such wetlands that have area less than 2.25 hectares (Panigrahy *et al*., 2010).

Lakes are one of the best defined natural ecosystems on Earth that host rich aquatic biodiversity. Since lakes are highly productive biological systems, they are considered to be one of the humanity's most important resources. Containing over 90% of the world’s liquid surface freshwater, natural and artificial lakes provide many uses for sustainable human livelihoods and economic development, while at the same time, serving as essential habitats for a great variety of flora and fauna. Resource development, wise use and judicious conservation of lakes have been major challenges across the continents, particularly with regard to satisfying human needs within, and sometimes beyond, the lake basin. In spite of the fact that freshwater bodies are very limited and sensitive resources that need proper care and management, they are probably the most neglected and mismanaged natural resources.

The valley of Kashmir, one of the most celestial lands on earth is represented by a picturesque mosaic of lakes, mountain tarns, snow and spring-fed streams, beautiful moraines, finest meadows and alpine forests. This serene beauty is still maintained largely due to high altitude bio-geographical nature of the Valley with the mountain chains of Himalayas acting as natural barriers for entry / incursions of several factors that would otherwise bring about a faster ecological deterioration. One of the striking features of the Valley is the chain of lakes gifted with enticing natural beauty. The lakes of Kashmir are categorized into Glacial, Pine-forest and Valley lakes based on their origin, altitudinal situation and nature of biota they contain (Zutshi *et al.*, 1972; Kaul, 1977; Zutshi and Khan, 1978; Pandit, 1996, 99). The glacial lakes are situated on the inner Himalayas between 3,000-4,000 m altitudes. These lakes are not larger in size (area<10 km^2) and include Alipathar, Nundkol, Gangabal and Kounsarnag. The second series of lakes (e.g., Nilnag) are present in the lower fringes of the Pir Panjal ranges and have come into existence due to tectonic activity. These occupy the upper and outer Karewa at altitudes of 2,000-2,500m. The valley lakes are spread throughout the expanse of the Valley proper at altitudes of 1,510-1600m. These lakes are considered to be of fluvial origin, having been formed from the oxbow of river Jhelum which flows across the Valley, meandering the alluvial deposits. The valley lakes (Dal, Wular, Anchar, Manasbal, Naranbagh, Khanpur, Waskur, Trigam, Tilwan and Pashkauri) are further subdivided into drainage, semi-drainage and non-drainage lakes on the presence and absence of inflow/ outflow channels (Zutshi and Khan, 1978).

The Kashmir Himalaya lakes vary from the oligotrophic conditions of Kounsarnag to eutrophic lakes of Anchar, while others are in process of continuous change towards eutrophication. While these changes result in part from the biotic, climatic and other environmental factors but in the recent past many of the changes are brought about under the influence of biotic impact, mostly in the name of development including eco-tourism. These inland waters, lakes in particular, provide an excellent opportunity for studying the structure and functional process of an aquatic ecosystem system.

1.1 Lake Degradation

Lake ecosystems are extremely sensitive to environmental changes in their catchments. The exponential growth of human populations and the attendant agricultural development (which demands more clearing of forests, need of irrigation facilities, fertilizers, and pesticides) and industrialization are the main causes of water quality deterioration on all scales. Lake basins are easily impacted by complex land and water relationships; they receive water, sediments, contaminants, nutrients and biota from rivers, surface runoff, groundwater, and the atmosphere. Because of their unique characteristics, lake systems are much more vulnerable to stresses, and more difficult to manage, compared to river systems.

All lakes, natural or artificial, undergo various transformations through time due to natural processes of aging caused by climatic, hydrologic and ecosystem changes. However, the greatest degradation impacts to lakes and reservoirs are caused by human interventions. The growing population and industrialization in a lake basin can lead to mounting pressures for development of lake resources. However, inside a lake, the progression of degradation often takes place on a wider and deeper scale than is apparent. Often, the symptoms of degradation remain unnoticed for a long period of time because of their incremental nature. The level of ecological and water quality degradation may have already reached crisis proportions, suddenly leading to instant loss of ecosystem sustainability.

In Kashmir valley, eutrophication and dwindling of lake ecosystems is a very recent event of the past 10-30 years, coinciding with a marked civilization evolution in the lake drainage basins (Pandit, 2002). Since, there has not been much development as regards the industrialization in the Kashmir valley, the main contributors towards the eutrophication of the water bodies are land-use changes in the catchment, unplanned urbanization, increased sedimentation, flow of fertilizers and pesticides from the catchment. Socio-economic activities and encroachment of the lake area by the lake dwellers has also contributed to the deterioration of these once pristine lakes. Since the valley lakes are situated in low lying areas (1583-1600m altitude) and in floodplains of river Jhelum, soil material that flowing water picks up is dropped when the water reaches a depression. Deposition of sediments is a continuous process, as seen in the Dal, Anchar, Wular, Hokarsar and Nilnag lakes, and can fill a lake basin completely. The rate at which the forest lakes e.g., Nilnag lake and the valley lakes are filled with silt also depends on nearby farming practices such as contour ploughing and strip cropping, the type of crop that is grown and the intensity of rainfall (Pandit and Fotedar, 1982). Even some high mountain lakes are facing the problem of natural siltation where glacial silt has been rapidly filling up the lake basins (Pandit, 2002), thereby, making the lakes shallow and affecting the summer stratification. Almost all the valley lakes are showing the signs of eutrophication, as is evident from the research conducted by various workers. It has been conclusively shown by Pandit and Qadri (1990) that altered land use patterns, opening of the catchment area and inflow of silt impregnated flood waters have greatly reduced the biological diversity and production, especially of submerged macrophytes. Temporal changes in eco-climate and vegetation patterns have affected the migratory waterfowl (ducks and geese) which no longer breed in the water bodies of Kashmir. The shallowing of lakes over long periods, together with other ecological changes and eutrophication, has been the main cause for the decline in the populations of snow trout (*Shizothorax sp*.) in the lakes of Kashmir. At present, *Cyprinus carpio* forms almost 60-75% of the fish catch in Dal and Wular lakes, having ousted the finer endemic fishes *Shizothorax* and *Shizothoraichthyes* by ecological competition, the juveniles and adults being adapted to less oxygenated and polluted water (Das, 1991). Thereby, confirming the degradation and eutrophication of such lakes.

1.2 Dal Lake Pollution

Dal Lake has historically been the centre of Kashmiri civilization and has played a major role in the economy of the state of Jammu and Kashmir. It is one of the most beautiful lakes of India and has been described as Lake Par-Excellence by Sir Walter Lawrence (Lawrence, 1967). This lake with its multi-faceted ecosystem and grandeur has been attracting the attention of national and international tourists for centuries. Other than the tourist trade, the Lake is considered to be a goldmine for inhabitants as it provides livelihood to thousands of people who draw benefits from it through a series of trade activities ranging from farming to fish production.

Of late, there has been great concern felt about the deterioration of Dal Lake ecosystem. The gradual reclamation of the lake to provide building and vegetable growing land and the increase in the area of floating gardens have combined with natural processes to reduce the area of open water within the lake area. The lake covered an area of 22 Km^2 in 1856 (Anonymous, 1971), a fact also corroborated by the studies of DANIDA (1990). As per DANIDA (1990), till 1940, the Dal Lake spread over an area of 2200 ha (22 Km^2). A sizeable (20%) portion of the lake is covered by floating gardens reducing the open water area to (59%) of the total Dal Lake area (Khan, 2000). The present open lake area is but a vestige of what was there even in the 18th century, and is little over half of the area existing at the turn of this century. Contaminants enter the lake through direct point sources, diffuse agricultural sources and diffuse urban sources. With the increase in the tourist influx, a large number of residential buildings, restaurants and hotels have come up along the lake front at an alarming rate. The number of house boats has also been increasing. As a result of rapid and unplanned urbanization, it is sewage of the one million residents of the nearby city of Srinagar, compounded by the human waste created by the lake dwellers, which is suffocating the lake and contaminating its water mass. Increase in nutrients, besides promoting rapid growth of algae, causes luxuriant growth of weeds to critical and unmanageable levels.

Since the last three decades, land use/ land cover in the Dal lake catchment has undergone significant changes. An increase in impervious surfaces like barren, built-up and deforested areas of the Dal Lake Catchment has caused the peak flow to swell over the period of time (Amin and Romshoo, 2007). As per the authors, this increase of about 23% in the total annual surface runoff from 1992-2001 under changed land use and land cover conditions at one of the stream main reaches of the Dal Lake Catchment is responsible for deteriorating lake ecological conditions due to excessive sedimentation and eutrophication. Increase in agricultural activity and the reduction of plant cover on the hillsides surrounding the lake with the consequential increase in surface erosion and leaching of soil nutrients have added increasing quantities of nutrient-rich runoff. As a result of these landscape modifications, it has been observed that the lake is fast losing its status as a beautiful and ecologically significant water body. Further, interruptions to the internal flow of lake water caused by weirs, islands, bunds, land between houseboats, etc, has reduced the capacity of the lake to respond to the stresses placed on it. The Dal Lake drainage is characterised by a myriad of channels which are both inflow as well as outflow in nature, chief among these being the Meerakshah, Nallah Amir Khan, Brari Nambal and Chuntkul. But during the last two decades, filling up of most of these channels due to excessive siltation, sewage inflow and garbage dumping has reduced their water holding capacity, thereby, disrupting the ecological balance of the lake.

1.3 Rationale of the Study

Keeping in view the multifaceted importance of the Dal Lake Ecosystem, the integrated use of the cutting edge technologies such as remote sensing together with Geographic Information System (GIS) simulation modelling and field observations can prove to be quite effective in understanding the nature and mechanisms of its degradation, besides identifying the critical source areas at the watershed scale. The results of this research are expected to go a long way in devising the pollution and management control programmes by government agencies for the restoration of the Dal Lake Ecosystem.

1.4 Scope and Approach of this Research

With rapid socio-economic changes and various environmental perturbations during the last few decades, Dal Lake Ecosystem has degraded significantly, resulting in increased ecological vulnerability and hydrological disruption. Water quality in Dal Lake is a major concern, and improving the ecological status of this large water body is now a regional and national priority.

Most of the studies conducted on the Dal Lake have been of routine nature, mainly conducted to determine the deteriorating water quality conditions of the lake, i.e. hydrochemistry and hydrobiology. Very few studies have been conducted to model and understand the land surface processes at the catchment scale that have a direct bearing on the health of the Dal Lake. No significant research work has been conducted till date to assess the impacts of the socio-economic factors on the health of the Dal Lake System. Many of the problems facing lakes are deeply rooted in socioeconomic issues. The socioeconomic importance of lakes for the civil society has now a days become a major factor for their degradation. These factors have both direct and indirect impacts on the lake which include outstretching of carrying capacity of the lake in terms of fish, water, tourism, livelihood issues, insufficient governance and accountability systems; limited public awareness, poor land management with cultivation in and around the lake. Therefore, there is a dire need to assess the human (socio-economic) factors that have a direct bearing on the health of the lake. The socioeconomic data can be given spatial sense when integrated in a Geographic Information System (GIS) environment. The collaboration between social science and Geographic Information System (GIS) becomes all the more imperative to tackle new problems which are related to understanding and controlling human impacts on the biophysical environment, as well as anticipating and responding to environmental impacts on humanity. Such understanding depends on better knowledge of biophysical systems, of human activity, and above all, of the relations between the two. Linking up GIS data with traditional field methods in the social and biological sciences has permitted more thoughtful sampling over a larger region, addressing questions of decadal change that could not be examined through traditional methods alone. Once, that is accomplished, then, the socioeconomic and ecological data can be integrated to understand and model the impact of their interactions on the lake system. Such an approach for studying Dal Lake Ecosystem has not been attempted so far.

In case of water pollution studies, watershed emphasis is essential due to the fact that the quality of water at any point in a water body depends on all processes taking place upstream in the watershed of that point. Since degradation of lakes is closely related to their watersheds, it is, therefore, essential that a watershed approach be used to understand the lake processes and responses. Hence, in this study, a watershed level approach has been undertaken in order to study different components and characteristics of the watersheds and identify different spatial, hydrological, vegetation and geomorphologic processes within these watersheds that influence the phenomenon of Dal Lake degradation. This research makes use of an integrated approach based on the use of multi-sensor and multi-temporal satellite data, simulation models used for different watersheds of the Dal Lake Catchment. While remote sensing data was used to generate up to date information about different parameters, simulation models and geospatial techniques were used to simulate the hydrological, sediment, erosion, pollution processes as well as management scenarios. This research provides useful and advanced information to understand the causative factors responsible for the degradation of the Dal Lake and accordingly, the research findings can be of tremendous practical use to develop a robust strategy for planning the conservation and management measures.

In case of Kashmir Valley lakes, extremely deficient information is available (Amin and Romshoo, 2007; Badar and Romshoo, 2007) in the application of advanced satellite based technologies such as remote sensing and Geographic Information System (GIS). In view of the multifaceted environmental importance of such technologies, the Dal Lake was chosen for application to study the "Integrated Impact Analysis of Environmental and Socioeconomic Factors on Pollution Status of Dal Lake using Geospatial Tools".

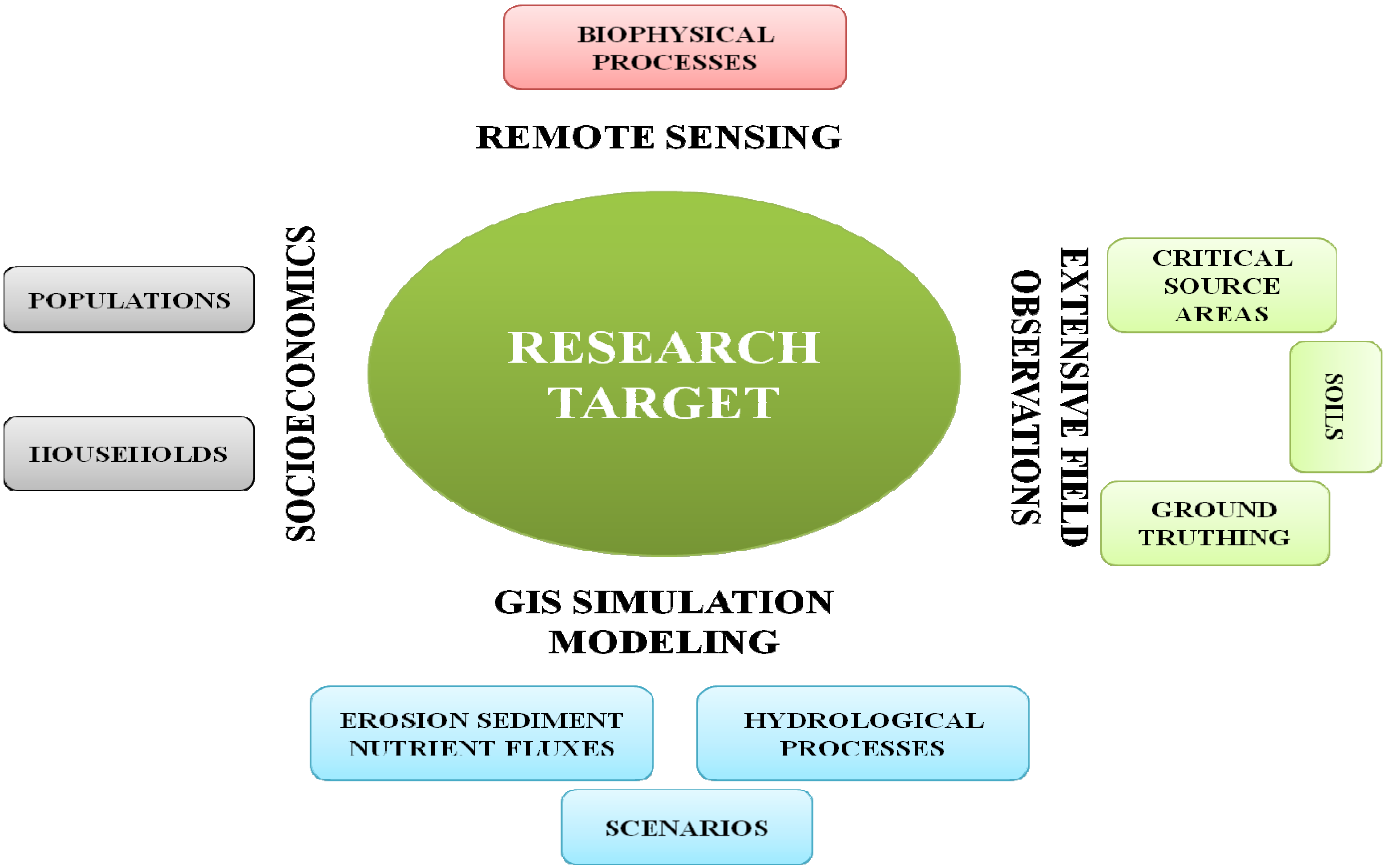


Fig. 1: Research strategy showing means and methods employed to achieve the research objectives

1.5 Objectives

The present research deals with understanding the nature and extent of environmental and socioeconomic factors that have been, and are impacting the health of Dal Lake Ecosystem. In this research, an integrated impact analysis of such factors prevalent in the lake catchment facilitates a better understanding of the pattern of degradation and its allied processes. The motivation for this study stems from the need for simple and reliable information that could facilitate the participation of stakeholders and decision makers in the implementation of water quality programs, thereby, improving the chances of the Dal Lake restoration. The specific objectives of the research are as follows:

1. Environmental Characterization of Dal Lake Catchment
2. Socioeconomic Characterization of Dal Lake Catchment
3. Assessing the Pollution Load of Dal Lake.
4. Integrated Impact Analysis of the Environmental and Socioeconomic factors responsible for Lake Degradation

1.6 Organization of the Thesis

This thesis is organized into eight chapters:

Chapter 1: This chapter gives an overview of the research. It is made up of brief highlighting of the topic, problem description, research objectives, rationale and specific approach used in the study.

Chapter 2: A review of the previous work that has been carried out on the different aspects like land use/ land cover mapping, water quality and erosion modelling, watershed prioritization has been given in this chapter. Furthermore, a review of the conventional studies that have been undertaken regarding different aspects of Dal Lake is also enlisted.

Chapter 3: This chapter provides a detailed account of the study area including different characteristics such as location, physiography, climate, drainage, geology and vegetation.

Chapter 4: A description of the types and characteristic features of the various datasets that were used to achieve the objectives has been given in this chapter.

Chapter 5: This chapter conclusively gives a thorough description of the various types of methods that were used to achieve the set objectives, ranging from remote sensing methods, simulations modeling to the conventional laboratory testing for physicochemical analysis of soil samples.

Chapter 6: A comprehensive analysis of the results that were obtained has been provided in this chapter.

Chapter 7: In this chapter, complete discussions in support of the results that were obtained are given. Besides, a list of conservation and management strategies recommended keeping in view the study area, nature of the problems/threats and the results obtained from this research are given in this chapter

Chapter 8: This chapter presents the summary, key findings and conclusions that were formulated on the basis of the results obtained.

CHAPTER -2

REVIEW OF LITERATURE

The dynamic nature of lakes and their surrounding landscape necessitates the widespread and consistent use of satellite-based remote sensors and low-cost, affordable Geographic Information System (GIS) tools for effective management and monitoring. The prime advantages of using remote sensing helps in vital and effective information collection due to synoptic, repetitive and real time coverage and cost-effective complement to ground-based monitoring programs. While at the same time, Geographic Information System (GIS) helps in effective storage and analysis for spatial and temporal databases, spatial analysis on depicting the source-pollutant relationship, graphical presentations, visual impacts and spatial distribution of graphical outputs on water quality changes, pollution load and relationship with sources and management of lake basins. As a result, remote sensing and GIS based systems have been found to be quite effective in identifying the nature and types of pressures in the lake catchments threatening their existence, besides, facilitating their conservation and management.

The research of remote sensing technique in water clarity monitoring can be traced back to 1977, while tremendous research began from 1990s. Pilot projects employing Multi Spectral Scanner (MSS) data for this purpose in Minnesota were conducted by Lillesand *et al.* (1983). Similarly, MSS data were central to the early trophic state assessment work of Chipman *et al.* (2004). Water quality assessment of ocean and inland waters using satellite data has been carried out since the first remote sensing satellite Landsat-MSS has been operational (Thiemann and Kaufmann, 2000) and holds significant potential for enhancing regional monitoring and assessment of lake water quality and trophic conditions. The potential benefits of satellite-based remote sensing and GIS have been recognized by lake managers (Chipman *et al.,* 2004). Imagery from satellite and aircraft remote sensing has been widely used in the assessment of water quality for lakes and reservoirs (Lillesand *et al.,* 1983; Lathrop and Lillesand, 1989; Ritchie and Cooper, 1991). Satellites based estimates of water quality have been derived from statistical relationships between spectral reflectance by the pollutants (suspended sediment) near the surface of water and corresponding ground truth data (water samples). According to the factors influencing water clarity, there are mainly two research directions using satellite system to monitor lake water clarity. One is to assess suspended sediment concentration; another is to estimate trophic state of the lake. Trophic state indices of Carlson (Carlson, 1997) are one of the key lake water management indicators. The three water quality variables that have been most commonly used to indicate trophic state are total phosphorous (TP), chlorophyll a (chl a), and Seechi Disk Transparency (SDT). Lake management agencies and organizations use these variables for measurements, along with various transformations (Sawaya *et al.,* 2003). Phosphorous which is the limiting nutrient of most lakes but not directly measured by optical instruments, is generally correlated with chlorophyll in multi-lake analysis. For lakes whose clarity is dominated by phytoplankton abundance chlorophyll is also highly correlated with satellite observations. Because lakes have increased water clarity, their chlorophyll levels are decreased (Budd *et al.,* 2001). Then spectral signatures of satellite imagery, water clarity, and trophic state indices can be related.

2.1 Watershed Modelling

During the past several years, a vast literature reports the development of computational tools to support decisions in water resources management (Loucks, 1995; Andreu *et al.,* 1996; Bouraoui and Dillaha, 1996; Jamieson and Fedra, 1996; Dai and Labadie, 2001). The packages differ in spatial and temporal scales and in the way they represent the physical, chemical and biological processes taking place in the watershed. The integration of land and water processes became crucial for the correct evaluation of water quality levels. Watershed simulation models, in fact, are commonly considered to be essential tools for evaluating the sources and controls of sediment and nutrient loading to surface waters. Such models provide a framework for integrating the data that describe the processes and land-surface characteristics that determine pollutant loads transported to nearby water bodies. Excellent historical overviews on the utility of computer models for quantifying and analyzing pollution problems within watersheds over the past three decades are provided (Moore *et al.,* 1991; Wilson, 1996; Deliman *et al.,* 1999; Arnold *et al.,* 2000). Due to the many inherent benefits, GIS software has been used to support literally hundreds of watershed modelling efforts over the last 10-15 years. Many states, regional, and federal environmental agencies, are in fact, using this technology routinely to support ongoing watershed modelling and assessment programs (Samuels, 1998).

The need for the development of reliable watershed information has increased as a response for an accelerated implementation of water quality programs. Since the simulations from watershed models will support watershed management decisions, confidence in them is extremely important for the implementation of any water quality program. Water quality models of volume, sediment loads, water quality and flow are, therefore, heavily dependent on geographic data sources which are provided in Geographic Information Systems (GIS) (Usery *et al.,* 2004). Such models simulate the fate of pollutants and the state of selected water quality variables in water bodies. They incorporate a variety of physical, chemical, and biological processes that control the transport and transformation of these variables. Models themselves can be simple or complex depending on the number of input parameters required, the extent of analysis required to generate output parameters and other model details such as calibration. A more complex approach couples GIS with models for point and non-point source pollution runoff. The models provide insight into sources and impacts of non-point and point sources of pollution, simulate water quality conditions of alternative scenarios for future land-use practices and effluent loading to the system, and help in designing and assessing alternate management practices to reduce such impacts. Various mathematical models have been developed and applied on streams, lakes and estuaries (Lung, 1986; Thomann and Mueller, 1987; Kuo and Wu, 1991).

2.1.1 Water Quality Modelling

Water quality models quantify physical, chemical and biological responses of aquatic systems to the load of waste imposed into the environment, mostly resulted from human activities. Despite this broad definition, water quality models differ in level of complexity according to the details incorporated to represent the aquatic system and the contaminants being simulated. Research papers have summarized the evolution of water quality models, from the earliest equation for oxygen balance in streams to more refined water quality models embedded in watershed information systems and decision support systems (Orlob, 1992; Rauch *et al.,* 1998; Chapra, 2003). The development of remote sensing and Geographic Information Systems (GIS) technologies has facilitated quantitative assessment of landscape influences on aquatic ecosystems and watershed-scale approaches to the study of water quality. GIS also has enjoyed a long history of use within the water resources field partially due to the early availability of remotely sensed data suited for this purpose (Sample *et al.,* 2001) and has found applications in ground water hydrology (Hinaman, 1993; Raterman *et al.,* 2001); nonpoint source pollution tracking (Liao and Tim, 1997; Wong *et al.,* 1997) surface runoff modeling (Shamsi, 1996; Zollweg *et al.,* 1996) and general hydrology applications (Frankenberger *et al.,* 1999; Olivera and Maidment, 1999). One common objective of water quality modelling studies is to be able to predict the impact of different point and non-point source loading scenarios on surface water bodies.

During the last two decades, efforts to incorporate the effects of non-point sources of pollution in the assessment and control of water quality have increased. Non-point source pollution is defined as the diffuse pollution carried by storm water and runoff from lands into receiving waters. Beginning in late 70s, the emphasis of water quality programs switched from the control of point sources of pollution to a more holistic evaluation of the watershed processes. NPS models are used to predict the pollutant load to a water body mainly as a result of land use patterns, slopes, soils and management practices. Many of the modelling experiments show that few critical areas in a watershed are responsible for the greater amount of pollutant yield. Identifying and targeting these areas optimizes water quality improvement programs. Precipitation, infiltration, evapotranspiration, snow melting and surface runoff are the governing processes for the computation of non-point source pollution. While the most common simulated waste constituents are sediment, nutrients (nitrogen and phosphorus) and pesticides. Since 1980s, the development of non-point source models has been intensified. Singh and Woolhiser (2002) presented an extensive list of available NPS models. SHE (Abbot *et al.,* 1986), AGNPS (Young *et al.,* 1987), ANSWER (Bouraoui and Dillaha, 1996) and SWAT (Neitsch *et al.,* 2001) are examples of distributed NPS models.

Early research efforts used GIS in parallel tracks of development by either employing GIS to estimate model input parameters or interfacing simulation models with GIS. Smith (1993) constructed a GIS model of total phosphorus concentrations in New Jersey streams. The core of this model was a regression equation that related transformed (natural logarithm) total phosphorus concentration measured at a given point to transformed concentrations resulting from exponentially decayed phosphorous loads in the upstream watershed. In this study, the classical approach of modelling first-order reaction was modified. Instead of using the time of travel and time decay coefficient, the travel distance and a distance decay coefficient for phosphorus were applied in the model respectively. The data from 104 long term sampling stations, collected in the period from 1982 to 1987 was utilized to estimate regression coefficients. The sources of phosphorous were represented by such variables as area of agricultural land, total human population, and total municipal effluent flow.

White and Hofschen (1993) developed a spatial model for assessing nutrient loads in New Jersey Rivers using Arc/Info. They used 3 arc-sec digital elevation models (DEM) to partition the study area (15,385 Km^2) into 2,893 drainage basins (polygons) with a network of 10,916 stream segments (arcs). Time of travel was assumed as the basis for calculating predictors of water quality. A first-order decay reaction was assumed to calculate the non-conservative downstream transport. The authors attempted to improve the model by representing the decay constant as a function of stream slope, and the non point source yields as a function of sub basin gradient. It was found that the time of travel, which was calculated from the exponential velocity formula, underestimated by a factor of 0.57 the time of travel of dye-tracer, i.e. the dye took approximately twice as long to traverse the stream as the formula suggested. This travel time underestimation was accommodated by assignment of higher values of pollutant decay than those reported in the literature.

Cressie and Majure (1994) used Arc/Info to determine explanatory variables for a statistical model of the variation in pollutant concentration from dairies in streams of the Upper North Bosque watershed located principally in Erath County, Texas. The Arc/Info GRID and the Digital Elevation Models (DEM) were used to determine drainage basins and the lengths along flow paths. Seventeen explanatory variables including a number of dairies per acre, a number of heads per acre, lagoons per acre, waste application method, soil hydrologic code, average slope, distance to basin outlet, and precipitation were considered. All variables, except one (seasonal variation), were determined using the GIS. The authors concluded that the GIS is an important tool in observational studies due to its ability to construct explanatory variables at the appropriate scale.

Mattikalli and Richards (1996) estimated surface water quality in response to changes in land use using export coefficient model in eastern England. The authors estimated the water quality, as indexed by the nitrogen loading using export coefficient model. The model calculates solute loading at the outlet of a watershed using land use data, fertilizer application rates and export coefficients. They derived land use data from a variety of sources including maps, aerial photographs and remotely-sensed Landsat and SPOT satellite images and compiled export coefficients for various land use classes from literature. They concluded that the export coefficient model operating in a GIS has significant potential for the rapid estimation of surface water quality using land use data derived from remotely sensed satellite images.

Yang *et al.* (1996) studied adaptive short term water quality forecast using remote sensing and GIS. The author used the water quality model (QUAL2E) and an image processing and GIS package (ERDAS IMAGINE) in a case study of the Te-chi reservoir in Taiwan. All water quality variables from simulations were displayed on a geographic registered map and in colour to correspond with varying water quality levels. They concluded that the visualization technique is helpful for rapid understanding of water quality conditions.

Dayawunsa (1997) studied critical non-point source pollution risk location in the watershed of Nilame River, Sri Lanka using remote sensing technique and through the application of Agriculture Non-point source Pollution Model (ANGPS). The author developed land use/ land cover map using digital analysis of Indian Remote Sensing Linear Imaging Self Scanning System (IRS -LISS II) data which has ground resolution of 37.5 meters to identify five model parameters related to Land cover. The AGNPS provided detailed output of runoff, upland erosion, sediment yield, nitrogen, phosphorus and Chemical Oxygen Demand (COD) concentration in sediment and runoff at any point of the catchment as well as the outlet. Accordingly, the author identified the critical locations in the study area in terms of sediment and nutrient production.

Yang (1999) studied the integration of the water quality modelling, remote sensing and GIS. The author used remotely sensed data in a water quality model – QUAL2E. He concluded that the resultant maps can predict water quality variables, which can be used as an input to initialize and update water quality conditions.

Basnyat *et al.* (2000) studied the use of remote sensing and GIS in watershed level analyses of non-point source pollution problems. The authors worked on different basin characteristics such as land use/land cover, slope, and soil attributes, which affect water quality by regulating sediment and chemical concentration. They developed a land use/land cover-nutrient-linkage-model for this purpose. Wang *et al.* (2000) studied the linkage of ArcIMS to ROUT, a river model developed by the United States Environmental Protection Agency (USEPA) to create a Web-GIS based river simulation model – GIS-ROUT. The authors concluded that the integration of spatial data, GIS and analytical models in GIS-ROUT makes it possible to examine and share the results of dynamic linkages between water quality and human activities to support environmental risk assessment by scientists.

Dayaker (2001) studied the impact of land use / land cover changes on water quality using remote sensing and GIS in Katedhan industrial area, Andhra Pradesh, India. The specific objective was to study the correlation between impact of land use and water quality. He found different land use classes affecting the water quality differently.

Evans *et al.* (2002) applied the GWLF model to estimate nutrient loads in some selected watersheds in the state of Pennsylvania, GWLF model was used to estimate sediment loads generated by stream bank erosion in some selected watershed. They concluded that the model provided reasonably good estimates of mean annual nutrient loadings in watersheds with variable landscape characteristics and that for phosphorus loadings, the modeling accuracy improved as one moved from evaluating shorter to longer time periods.

Fisher *et al.* (2002) studied the effect of land-use, soils, and human populations on export of water, C, N, and P from the Mid-Atlantic Coastal Plain. The authors studied the history of land use changes in Choptank River basin on the Delmarva Peninsula. The environmental impacts of these changes were assessed using the hydro chemical model GWLF to estimate fluxes of water, N, and P from sub basins of the watershed using the local land use, soil characteristics, and human population. The results showed that well-drained soils with large amounts of agriculture or large human populations had the greatest N fluxes due to the efficient passage of highly soluble nitrate via groundwater. In contrast, more poorly drained soils combined with large proportions of anthropogenic land uses promoted greater losses of P due to greater overland flow routing and erosion.

Bergamasco *et al.* (2003) studied the relationships between phytobenthos, hydrodynamics, nutrient cycling and sediment transport via identification, evaluation and modeling of feedback mechanisms using GIS in the Lagoon of Venice, Italy in the northern Adriatic Sea. The authors used GIS to generate the models of hydrodynamics, material transport and ecology, as well as a combined reaction model to understand the short-term transport and biology.

Ek *et al.* (2003) studied the ecological modelling of nitrate pollution in small river basins using spreadsheets and GIS. The modelling system was used to simulate amounts of nitrates in each compartment of the stream and the simulation of the dynamic model was carried out with the TabSim. The authors concluded that the modeling approach extended by the remote sensing and GIS can support decision-making process for better management practices in the basins. Endreny *et al.* (2003) studied the sensitivity of PLOAD and WinHSPF hydrographic to change in land use map units in the New York Croton River area. The author concluded that the PLOAD and Win HSPF land-cover swapping had peak flow sensitivity hydrographs between 33% underestimation and 20% overestimation.

Evans *et al.* (2003) conducted a study in the state of Pennsylvania using the modified GWLF model called AVGWLF to assess the TMDL for sediment loads, with stream bank erosion included. They compared simulated and observed loadings for 28 watersheds and concluded that the model performed well because the estimated erosion rates were within rates reported by others in literature. Jha and Gupta (2003) studied the application of a basin-scale simulation model (Mike Basin) and showed its usefulness in analyzing the basin performance and thus establishing the best management approaches for the efficient use and allocation of water resources in the Mun River Basin in northeast Thailand. Liu *et al.* (2003) reviewed four shallow water quality parameters – inorganic sediment particles, phytoplankton pigments, coloured dissolved organic material and Secchi disks using remote sensing. The authors concluded that the remote sensors such as Coastal Zone Colour Scanner and Sea-viewing Wide-Field-of-View (SeaWiFS) help expand the value of chlorophyll-a and Secchi disk measurements.

Hartnett and Nash (2004) modelled the nutrient and chlorophyll-a dynamics in the Wexford Harbour Estuary of southern Ireland. The authors used GIS to model Chlorophyll-a and dependency on light attenuation in shallow, well-mixed coastal and estuarine waters. Depth Integrated Velocity and Solute Transport (DIVAST) model was used for the purpose. They concluded that the key factor for plankton growth is light availability. Kelsey *et al.* (2004) studied the relationship between land use and faecal coliform bacteria pollution in Murrells Inlet Estuary, South Carolina using GIS. The authors calculated the variance inflation factors (temperature, salinity, rainfall and weighted distances to the nearest urban and rural land uses) and a regression model was run. The authors concluded that the rainfall and pet waste were contributing to the faecal coliform levels in the estuary.

Kirilenko (2004) developed an integrated GIS-based model for complex analysis of regional environmental changes driven by land use change in the Upper Wabash river basin. The model was designed to eventually become the core of a decision support system with the goal to assist in making informed decisions on urban development. They concluded that the varied spatial scales of model components produced additional challenges. Li and Li (2004) studied the relationship between

Secchi Disk Transparency (SDT) and the multi and hyper-spectral images. They concluded that the satellite remote sensing can be a timely and economical method of monitoring water clarity.

Reginato and Piechota (2004) used a simple model with GIS to determine the contribution of non-point sources to total nutrient loads from the Las Vegas Valley. Monthly and annual loads of total nitrogen (TN), total phosphorus (TP) and total suspended solids (TSS) were estimated with an appropriate GIS based model. The model was also able to track contributions of different land use to the total annual nutrient loads. They concluded that approximately 25% of the TN load and 18% of the TP load was from roads and highways and approximately half of the TN and TP loads originate from undeveloped areas. White *et al.* (2004) studied the water quality and phytoplankton biomass in two estuaries in South Carolina using GIS. The authors measured and analyzed the water quality parameters (NO_3^-, NH_4^+, PO_4^{3-} and chlorophyll-a concentrations) using GIS.

Ahearn *et al.* (2005) studied that influence of land use and land cover on water quality in a river in Western Sierra Nevada, California. The authors correlated the land use/ land cover with nitrate-N and total suspended solids (TSS) loading between water years 1999 and 2001. They concluded that the impact of human development on stream water quality was evident as both agricultural area and population density predicted TSS loading in a linear mixed effects model. In contrast to the TSS model, the nitrate-N loading model was more complex with agriculture, grassland, and the presence or absence of waste water treatment plants (WWTPs) all contributing.

Ershadi *et al.* (2005) studied the applications of remote sensing, GIS and river basin modelling in integrated water resources management of Kabul River Basin. The authors used remote sensing techniques for preparing fundamental rainfall, snow cover, land-use and topography information and all the prepared information on water demands and observed discharge was then organised in the Mike Basin model. Lopez and Jacob (2005) studied the impacts of urban sprawl on the water quality in League City, Texas using PLOAD model.

Munafo *et al.* (2005) developed an innovative and simplified index called the Potential Non-Point Pollution Index (PNPI), a multi-criteria technique to pollutant dynamics and water quality, which was used to assess the pressure exerted on rivers and other surface water bodies by different land uses. Tandac and Coskun (2005) used remote sensing and GIS techniques for water quality investigation in the Istinye Inlet on the Bosporus side in Turkey. The authors investigated the Istinye Inlet using satellite digital data (IRS-1D, LISS-III) with water quality measurements that were collected. They concluded that the reflectance showed a strong relationship with water turbidity levels.

Yin *et al.* (2005) studied the impact of the urban development in Shanghai, China on the water quality. The authors obtained the built-up surface area from the classification of the Landsat 7 ETM^+ image and the proportion of built-up surface and population density were extracted from buffer zones with radii ranging from 100 to 2000 m, and used in regression analysis against various water quality parameters obtained from 44 water quality monitoring stations across metropolitan Shanghai. They concluded that in most cases, the pattern of urban land use as represented by the built-up surface was a stronger predictor than population density in explaining spatial patterns of water quality parameters.

Coskun *et al.* (2006) used with computer-based geographic information systems (GIS) techniques as a tool for monitoring the water basin area and water quality in Istanbul's relatively less polluted and comparatively less destroyed catchment of the metropolis drinking water dam reservoir, Terkos. The authors used SPOT-PAN, XS and IRS-1C/D PAN and satellite data of 1993 and 2000 for urban analysis and Landsat-TM and LISS-III satellite data of 1992 and 2000 for water quality. As a result of monitoring land use and water quality changes, they made recommendations for planning and management of the Terkos catchment protected area. In another study, Kang *et al.* (2006) applied the soil and water assessment tool (SWAT) to develop total maximum daily load (TMDL) programs for a small watershed containing rice paddy fields in the Republic of Korea. The authors incorporated the Total Maximum Daily Load System (TOLOS), based on Arc View SWAT (AVSWAT) using Geographic Information System (GIS) and remote sensing, with the SWAT model to water balance and water quality from irrigated paddy fields. They concluded that the simulated runoff and water quality values were acceptably close to the observed data.

Ning *et al.* (2006) conducted research on soil erosion and non-point source pollution impacts assessment using multi temporal imageries in the Kao-Ping River Basin, South Taiwan. The authors started with a series of supervised land use classifications, using SPOT satellite imagery as a means. The accuracy was confirmed based on interpretation of available aerial photographs and global positioning system (GPS) measurements. Finally, a numerical simulation model, General Watershed Loading Function (GWLF) was used to relate soil erosion to non-point source pollution impacts in the coupled land and river water systems. The research findings indicated that while the decadal increase in orchards posed a significant threat to water quality, the continual decrease in forested land exhibits a potential impact on water quality management. The authors concluded that non-point source pollution, contributing to part of the downstream water quality deterioration of the Kao-Ping River system in the last decade, has resulted in an irreversible impact on land integrity from a long-term perspective.

Markel *et al.* (2006) evaluated pollution loads in the Lake Kinneret watershed, Israel using a GIS based AVGWLF model. The model was used to simulate daily stream flows and monthly sediment, nitrogen, and phosphorus loads discharged to the lake from the surrounding watershed. Results from simulations yield a satisfactory correspondence between simulated and measured daily water volume. Partition by source of total phosphorus delivered to the lake in the period of 2000–04 confirms the reduction in point source nutrient contribution due to improvement of wastewater treatment facilities in the area. Results from simulations will enable watershed managers to prioritize effective management alternatives for protecting the water quality in the lake. They concluded that future management should focus on reduction of nutrients originating from septic systems (point sources) and pasture and cropland areas (diffuse sources).

Wu *et al.* (2006) investigated the influence of recent and future land cover changes on stream flow of a watershed in North Eastern Puerto Rico using hydrologic modelling and simulation analysis. The authors compared monthly and average annual stream flows between an agricultural period and an urbanized/reforested period using a revised Generalized Watershed Loading Function (GWLF) model. The results showed that evapotranspiration, precipitation, and curve number were the most significant factors influencing stream flow. The authors suggested that managing local land cover changes can have important consequences for water management.

Sheeder and Evans (2007) employed a simple nonlinear statistical approach to establish nitrogen, phosphorus, and sediment concentration and unit area load thresholds to aid in the evaluation of aquatic biological health of watersheds within the state of Pennsylvania. For each watershed, rating curves depicting flow versus load relationships were developed using the U.S. Environmental Protection Agency's (USEPA's) storage and retrieval database (STORET) flow and concentration data, then applied to daily flow data obtained from U.S. Geological Survey (USGS) daily flow gauging stations to estimate daily load between 1989 and 1999. Results of Mann-Whitney tests conducted on each of the six datasets indicated that there is a statistically significant difference between the concentrations and unit area loads of nitrogen, phosphorus, and sediment in impaired and unimpaired watersheds. Annual unit area load thresholds were estimated to be equal to 8.64 kg/ha, 0.30 kg/ha, and 785.29 kg/ha, respectively, for nitrogen, phosphorus, and sediment species.

2.1.2 Soil Erosion Modelling

Soil erosion is one of the most serious ecological processes threatening the existence of freshwater ecosystems throughout the world. Soil losses (and erosion) is one of main causes of reduced fertility, increased sedimentation in canals, rivers and lakes, decreased storage capacity in dams, increased floods frequency, degradation of water quality etc. Soil erosion in the catchment areas and its subsequent deposition has greatly affected the water quality in numerous fresh water lakes throughout the world. Sediments are cited as the third leading cause of stress for lakes, reservoirs, and ponds, behind nutrients and metals (U.S. EPA, 2000). To estimate soil erosion and to develop optimal soil erosion management plans, many erosion models, such as Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978), Water Erosion Prediction Project (WEPP) (Flanagan and Nearing, 1995), Soil and Water Assessment

Tool (SWAT) (Arnold *et al.,* 2000), and European Soil Erosion Model (EUROSEM) (Morgan *et al.,* 1998), have been developed and used over the years. Among these models, the USLE has remained the most practical method of estimating soil erosion potential in fields and to estimate the effects of different control management practices on soil erosion for nearly 40 years (Dennis and Rorke, 1999; Kinnell, 2000), while other process-based erosion models have intensive data and computation requirements. The USLE has been used/ integrated with Geographic Information Systems (GIS) to estimate soil erosion because GIS helps users manipulate and analyze the spatial data easily, and it also helps users identify the spatial locations vulnerable to soil erosion (Yitayew *et al.,* 1999; Ouyang and Bartholic, 2001; Lufafa *et al.,* 2002).

Zing (1940) analyzed the degree of soil loss to slope length and slope steepness. The results suggested that the calculation of LS-value (slope length and slope steepness) has been affected by the average size of plots, which may have an impact on erosion risk estimation from water erosion. It was also found that dynamics of water erosion rate were controlled by an integrated interaction of determinant factors including changes in land use types, plot area, and position of field boundary. Examples of model input parameter estimation include the work carried out by Moore *et al.* (1988) in which GIS was used to provide topographic attributes for modeling hydrology and water quality within a watershed.

Samad and Abdul Patah (1997) conducted study on soil erosion and hydrological regime in the Bakun Dam Catchment Area, Sarawak using remote sensing and Geographic Information System (GIS). During this study, Universal Soil Loss equation (USLE) was applied to predict annual soil loss in the study area, using the integration of satellite remote sensing and geographic information system (GIS) technologies. The analysis was done in MICSIS (Micro-computer spatial Information system), an image processing and GIS software package developed specifically for erosion modelling. The current and potential erosion risk maps of the study area were generated useful for planning the land clearing activities at Bakun and estimating the severity of soil sedimentation in the dam area. The extents of inundation and the types of land cover affected were located. The corresponding water storage volume in the Bakun catchment at the three flood levels was also estimated.

Dwivedi *et al.* (1997) conducted studies on the nature, extent and magnitude of soil erosion in India using Landsat MSS, TM and IRS-1A LISS II data. Three categories of eroded lands, namely nil to slight, moderate, and severe to very severe were identified. The authors suggested that the Landsat MSS, TM and IRS-1A (LISS-II) data are useful in assessing and monitoring eroded lands in a rugged terrain. It was concluded that regular repetivity provided by the Earth resources satellite may provide a sound database for change detection in the soil erosion status and the extent and spatial distribution of shifting cultivation areas that could help soil conservationists evaluating the progress of soil conservation programme.

Viney and Sivapalan (1999) developed a conceptual model of sediment transport to be incorporated to an existing conceptual model of water and salt fluxes, LASCAM. In the model, the sediment transport processes are governed by a stream sediment capacity defined as a function of stream power. It is assumed that a stream flow of a given volume is able to carry a mass of sediment in suspension, provided sufficient material is available from any source (hill slope erosion, upstream sediment inflow, deposited channel sediment). The balance between deposition, re-entrainment and bank/bed degradation was determined by this stream sediment capacity.

Liu *et al.* (2000) evaluated the relationship between soil loss and slope length at three locations on the Loess Plateau in China using USLE and RUSLE. The results indicated that the exponent, m, for the relationship between soil loss and the slope length for the combined data from the three stations in the Loess Plateau was 0.44 ($r^2 = 0.95$). For the data as a whole, the exponent did not increase as slope and steepness increased from 20 to 60%. The authors concluded that the USLE exponent, $m = 0.5$, is more appropriate for steep slopes than is the RUSLE exponent, and that the slope length exponent varies as a function of rainfall intensity.

Jain *et al.* (2001) used GIS technique for estimation of soil erosion in a Himalayan Watershed. In the study, two different soil erosion models, i.e. the Morgan model and Universal Soil Loss Equation (USLE) model, were used to estimate soil erosion. Parameters required for both models were generated using remote sensing and ancillary data in GIS mode. The soil erosion estimated by Morgan model was in the order of 2200 t km^{-2} yr^{-1} and was within the limits reported for this region. The soil erosion estimated by USLE gave a higher rate. The authors concluded that GIS platform provides a faster and better method for spatial modelling and gives output maps that can be understood better and hence can be used as an ideal tool for developing land use management strategies to reduce soil loss.

Fu *et al.* (2002a, 2004) examined the effects of land use type on soil erosion in a hill and gully area of the Loess Plateau of China. Results suggested that under the same slope angle, slope length, slope aspect, slope type, slope position and plot area, sediment yield and runoff showed significant differences with the variation of land use types, and conversion of farmland to forest or pasture could greatly reduce sediment yield and runoff. The authors concluded that the land use changes decreased annual soil erosion by 24%.

Jain and Goel (2002*)* carried out an index-based approach based on surface factors such as soil type, vegetation, slope and various other catchment properties responsible for soil erosion in Ukai Reservoir located on the River Tapi in Gujarat, India. The authors used satellite data to evaluate the soil and vegetation indices, while as a G1S system was used to evaluate the topography and morphology-related indices. An integrated effect of all the parameters was evaluated to find different areas vulnerable to soil erosion. Based on the integrated index, the authors gave a priority rating of the watersheds for soil conservation planning.

Fu *et al.* (2003) applied the LISEM model to study the impact of five land use patterns on soil loss in Danangou catchment in the loess plateau in China. The results indicated that the soil loss rate showed a declining trend with the conversion of land use pattern from their actual condition to simulate scenarios due to the inter-annual and seasonal variation of catchment sediment yield. Yang *et al.* (2003) used a GIS-based RUSLE model to study the global soil erosion potential for viewing the present situation, analyzing changes over the past century, and projecting future trends with reference to global changes in land use and climate. The authors considered in the study several scenarios including historical, present and future conditions of cropland

and climate. The current soil erosion potential was estimated to be about 0.38 mm / year for the globe, with Southeast Asia found to be the most seriously affected region in the world. The authors concluded that nearly 60% of present soil erosions are induced by human activity, with developments of cropland further increasing the percentage by about 17%.

Evans *et al.* (2003) used GIS-based GWLF model for estimating stream bank erosion rates for predicting total sediment loads for watersheds in Pennsylvania. The technique was based on statistical relationships between lateral erosion rates and known watershed characteristics. An algorithm for estimating stream bank erosion was incorporated into a GIS-based watershed model. The results for simulated and observed sediment loads were compared, and values obtained using four different statistical measures suggested that the model performed very well. The authors concluded that estimated lateral erosion rates seemed to be reasonable giving similar results as those of other researchers in the study period.

Bayramun *et al.* (2003) studied the applicability of Geographic Information System (GIS) and remote sensing (RS) techniques to assess soil erosion risk with the ICONA erosion model in the Ankara-BeypazarY area. The erosion risk assessment was conducted using slope, geology, land use and land cover information in the model which resulted in a potential erosion risk map. It was found that land use, vegetation cover, parent material, topographic conditions, rainfall and soil properties are the major factors that affect soil erosion. The authors concluded that the ICONA model and GIS and RS techniques are very effective and useful to assess erosion risk.

In another study, Bayramun *et al.* (2006) used CORINE model to assess the risk of soil erosion in Semi-Arid Area of BeypazarY, Ankara. In this study, daily rainfall amounts were recorded from 1958 to 2003 from 11 climate stations by the Turkish Meteorological Service. The authors used 5 different procedures for calculating the Modified Fournier Index (MFI) to obtain the effect of rainfall variability and incidence of extreme storms on Soil Erosion Risk. These results suggested that to have dependable MFI surfaces and accordingly ASER surfaces, there is also a need for true accounting for the incidence of extreme storms together with the total variation expressed by within-year and year-to-year variations in the rainfall data. The authors concluded that ASER surfaces produced by the monthly return frequencies of rainfall events showed significant improvements and agreements with the erosion classes of the conventional soil survey of the study area.

Yuskel *et al.* (2008) used remote sensing and GIS Technology for erosion risk mapping of Kartalkaya Dam Watershed in Kahramanmaras, Turkey based on the methodology implemented in COoRdination of INformation on the Environment (CORINE) model. The results indicated that 33.82%, 35.44%, and 30.74% of the study area were under low, moderate, and high actual erosion risks, respectively. It was concluded that the CORINE model integrated with RS and GIS technologies has great potential for producing accurate and inexpensive erosion risk maps in Turkey.

Solaimani *et al.* (2009) conducted studies on prediction of soil erosion based on the change in land use land cover in Neka watershed to find the relationships between land use pattern, erosion and the sediment yield in the study area. The land use coefficient (Xa) was applied in the model of Erosion Potential Method (EPM) to forecast the effect of the land type to reduce the erosion. Land cover and land use change was projected for the next decade using topography, geology, land use maps and remote sensing data of the study area. The results revealed that the total sediment yield of the study area had notably decreased to 89.24% after an appropriate land use/cover alteration. The estimated special erosion for the Southern Neka Basin was observed to be about 144465.1 m^3 km^{-2} where after management policy it is predicted 15542.9 m^3 km^{-2} $year^{-1}$. The authors concluded that relationship between land-use changes and agricultural growth offered a more robust prediction of soil erosion.

2.2 Land Use/ Land Cover Mapping

Land use /land cover analysis is the core programme of International Geosphere and Biosphere programme (IGBP) and International Human Dimensions Programme on global environmental change (IHDP) (Turner and Butzer, 1992). Since it is an important factor in global change and imbalance in environment, it became the heart of global change studies. Before 1970s, most of the land cover mapping activities at local level depended on field surveys and remote sensing through interpretation of aerial photographs. Field studies allow the observation and description of processes of land cover change in a detailed and spatially disaggregated way. Thus, they are generally not sufficient to qualify and analyze spatial-temporal patterns of land cover/ land use changes at an aggregated level (Liverman *et al.,* 1998). Since the 1970s, numerous satellite systems have been launched to obtain information on earth's resources, and thus remote sensing has emerged as the most useful data source for qualitatively measuring land cover changes at the landscape scale (Rogan and Chen, 2004). Global scale mapping of land cover debuted in 1990 with the work of Lloyd (1990) who advocated for global land cover products based on phonological as well as floristic and physiognomic characteristics. Since then the dynamics of change process have been investigated through temporal series of remote sensing data (Singh, 1989; Kwarteng and Chavez, Jr. 1998; Mas, 1999; Munyati, 2000; Petit and Lambin 2001; Apan *et al.,* 2002). Over the last decades, numerous advances have been made in the development of remote sensors and Geographic Information Systems (GIS) and their linkage with land-use change models to assess the influence of land cover on biophysical processes and conditions, e.g. land degradation, ecosystem vulnerability, watershed condition, and biodiversity (Guisan and Zimmermann, 2000; Kepner *et al.,* 2005; Petrosillo *et al.,* 2008). Today, remotely sensed data in the form of classified land cover are used to derive input variables for a wide variety of environmental models, e.g. hydrologic-response and habitat models (Scott *et al.,* 1993; Edwards *et al.,* 1996; Miller *et al.,* 2007).

Anderson *et al.* (1972 and 2001) presented the framework of a national land use and land cover classification system for use with remote sensor data. The classification system was developed to meet the needs of Federal and State agencies for an up-to-date overview of land use and land cover throughout the country on a basis that is uniform in categorization at the more generalized first and second levels and that will be receptive to data from satellite and aircraft remote sensors. Revision of the land use classification system as presented in U.S. Geological Survey Circular 671 was undertaken in order to incorporate the results of extensive testing and review of the categorization and definitions.

Shedha and Pratap (1983) mapped various land use and forest types using remote sensing in Dehradun Tehsil and southern slopes of the Shiwaliks forming a part of Saharanpur district, Uttar Pradesh. Singh and Mathur (1988) undertook the study of SSP to understand the consequences of dam construction on forest cover and land use and subsequent impact on people and concluded that although the process of SSP construction cannot be reversed as it has reached irreversible stage, the maximum that can be done is to reduce the height of the dam so as to minimize the inundations being caused by the reservoir and also ensure that affected tribal's socio-economic conditions are in conformity to their earlier way of life.

According to Sangavongse (1995), the rapid growth of Chiang Mai city in Northern Thailand the rapid growth has led adverse effects on environment; therefore, multi-temporal Landsat TM imagery for monitoring land cover change has proven to be the best tool in this study. Suitable change detection techniques for the Chiang Mai area were developed by taking into account its physical and cultural conditions, thereby, optimizing use of information in the land cover maps. Results showed that forested areas decreased by about 29% during 1988 to 1991 while agricultural lands and built-up areas increased by about 5% and 26% respectively. Vadlapudi (1995) used the IRS-IB, LISS II Imagery of March, 1995 for the preparation of land use / land cover maps on 1:50,000 scales corresponding to Survey of India toposheets. The land use/land cover maps were interpreted visually by following the legend prescribed by Department of Space under National Mission Programme. Chutiratanaphan *et al.* (1995) carried out studies on land use/land cover changes in Phuket Island, Southern Thailand using remote sensing. During the research, SPOT and Landsat-TM data was used. It was found that rapid expansion of urban area has occurred both in town and along the seashore and abandoned tin mines have been changed to be golf course and luxurious resort. The changes in agricultural land are mainly the reduction of par rubber area and paddy field and the increasing of shrimp farm in the mangrove forest. The authors concluded that by using the advanced techniques of remote sensing, all of these changes can be detected and identified.

Mendis and Wadigamangawa (1996) used an integrated approach of remote sensing and GIS to find out changes of land use/land cover patterns due to implementation of the Nilwala Ganga Flood Protection Scheme in Nil Wala Basin in Sri Lanka. Both air borne and space borne remote sensing was used, both of which offer efficient and timely data for monitoring spatial changes of patterns over a period of time. A comparative study was also carried out in order to find the level of information obtainable from the two remote sensing techniques. The results from this study showed that the integration of remote sensing and GIS appears to have a potential for providing necessary information for updating land use maps.

Lopez *et al.* (1998) studied the effect of land use on Soil Erosion in the Guadiana Watershed in Puerto Rico. The Revised Universal Soil Loss Equation (RUSLE) was used in conjunction with a Geographic Information System (GIS) to determine the influence of land use and other environmental factors on soil erosion. The results showed that mean annual erosion, suspended sediment discharge, and the rainfall-erosion factor of the RUSLE increased with annual rainfall. Simulations of different land use configurations indicated that reforestation of 5% of the watershed with the highest erosion rates would decrease basin wide erosion by 20%. If the entire watershed was reforested, soil erosion would be reduced by 37%.

Fred *et al.* (1999) carried out studies on the hydrological and ecological impacts of land use change in the Salinas Valley. The authors used computer models to study the complex patterns of the land ecosystems and the physical processes within them. At the end of the study, it was concluded that the prediction is made easier through the use of computer models as they allow expressing different past and future scenarios of the land use with ease. Makino (1999) conducted studies on the land cover change and its effect on runoff in the Doki River Catchment. During this study, land cover change and discharge fluctuation for the past 12 years in the Doki River catchment were examined using multi-temporal satellite data. Using the multi-temporal satellite data, Landsat TM, in 1986 and 1990, approximately 3% of the total area had changed from forest to the agricultural fields during this period. From the water budget from 1981 to 1992 in the catchment, evapotranspiration decreased and runoff ratio increased. Moreover, statistical tests for hydrological data before and after 1986 showed that runoff ratio increased significantly with 0.05 of significant level. The author concluded that one of the factors that caused the increase of runoff ratio in the catchment should be the land cover change from forest to agricultural fields.

Jackson- Pringle and Wilson (2000) used remote sensing to analyze and study land-use/land-cover change impact on the environment of a section of Baltimore County and City in the state of Maryland. Accordingly, a study was scoped to determine the magnitude of land-use/land-cover change, with special emphasis on transportation, and assess its impact on the local environment over the past ten years. The study utilized data such as remotely sensed imagery, land-use/land-cover maps, hydrology, and roads. The remote sensing data comprised mostly Landsat Thematic Mapper (TM) images acquired from the early 1990 to 1999 with varying temporal internals. Initial analysis of the TM images for 1990 and 1999 showed increase in the urban category and a decrease in the cultivated land. The authors concluded that the final results from this study are expected to be beneficial to scientists, resource planners, managers, and policy makers.

Sangchan (2000) after studying the land use/ land cover changes in eastern region of Thailand concluded that remote sensing technology in combination with Geographic Information System (GIS) renders reliable information on land use/land cover change. During the study, LANDSAT TM images were acquired for 10-year period between 1987, 1990, 1994 and 1997 and were classified into 6 significant land use/land cover types, namely, forest, agriculture, water bodies, industrial area, urban/building, and other/bare land. The change of forest land to agriculture land and the change of agriculture land to water bodies and industrial area were the main type of significant changes observed in Rayong province of eastern Thailand. The author concluded that the underlying causes of the changes were the pressures of economic growth and economic development, as well as pressure of intense population that appeared to play a fair role as an important driving force during the study time.

Sukchan and Yamamoto (2000) studied the integrative use of satellite imagery and map data with GIS for improvement of classification methods to detect salt affected areas in Northeast Thailand. They concluded that the operation of dividing area according to soil type and landform information derived from map data lead to a good result of classification, with the authors recording an accuracy of 85.26%.

Andrea *et al.* (2001) conducted study in central Germany using three models namely Proland, ELLA and SWAT to examine the effects of land use changes on eco-hydrological process in the Aar watershed. Results revealed that the percentage of forested areas declined significantly, the area of grassland increased from 20 to 41 % and stream flow and surface runoff increased due to these changes in land use. Another study carried out by Bellot *et al.* (2001) indicated that the increase in vegetation cover significantly showed reduction in annual runoff and the erosion risk in the Vento's catchments, a semiarid landscape in Spain.

Campana and Tucci (2001) applied a hydrological model IPHIV with GIS to predict the hydrological graph corresponding to alternative urbanization scenarios in Diluvio Creek, located in Porto Alegre, Brazil. The simulation results suggested that when 50% of the free space was turned into an impermeable underlying surface in the city, urbanization increased the peak flow by 20-50 % compared with the urban conditions of the Diluvio basin in 1979.

Tadesse *et al.* (2001) commented that the information about changes in land use/ land covers provide valuable insights while devising future natural resource management strategies and remotely sensed data, serve as an effective tool for deriving this kind of information. During this study, Landsat Thematic Mapper images of 1987 and 1999 were used to extract land use/ land cover change of the city of Addis Ababa and the surrounding area. Analysis of the multi-temporal Landsat images clearly revealed the loss of forest to urban and residential sprawl within the city limit and the surrounding area.

Ransom *et al.* (2001) studied the land-use management of Finney County, Kansas using a Soil Survey Geographic Database (SSGD) within a Geographic Information System (GIS) coupled with remote sensing. The study demonstrated the effective use of SSGD with remote sensing and GIS in planning and management for natural resources. According to King and O'Hara (2001), the calculation of Normalized Difference Vegetation Indices (NDVI) can be very useful in the generation of a land use/ land cover classification. The authors suggested that NDVI's can provide useful information about the health and amount of vegetation cover across the landscape and their comparison can show seasonal variations within vegetation cover, helping to distinguish between deciduous and evergreen forest types. They concluded that comparisons can also be used to show variations of vegetative cover over longer temporal periods.

Thamm *et al.* (2001) investigated the land use changes in the Upper Oueme Catchment (Benin) between 1975 and 2000. Two temporal scales, one the seasonal vegetation dynamics and the other longer term decennial changes appeared to matter in this study. For this purpose, different satellite systems were utilized. The description of the seasonal vegetation dynamics within a period of 18 months was done on the basis of NOAA-AVHRR images. Additional LANDSAT-7 ETM, ENVISAT and MODIS scenes provided information about the land use / land cover in a higher resolution. This analysis of the vegetation dynamics was confirmed by intensive ground truth campaigns during which data about the leaf area index, the biomass and the spectral signatures were collected in the test area.

Land use is a dominant factor that affects the occurrence of the soil erosion processes. Soil conservation practices and management levels could have an impact on soil loss by changing micro-terrain and soil loss ratio. Fu *et al.* (2002a, 2004) examined the effects of land use type on soil erosion in a hill and gully area of the Loess Plateau of China. Results suggested that under the same slope angle, slope length, slope aspect, slope type, slope position and plot area, sediment yield and runoff showed significant differences with the variation of land use types, and conversion of farmland to forest or pasture could greatly reduce sediment yield and runoff.

Rautela *et al.* (2002) conducted GIS and remote sensing-based study of the reservoir-induced land use/ land cover changes in the catchment of Tehri dam in Garhwal Himalaya, Uttaranchal. During the study, it was found that the reservoir would affect the land around it by disturbing the delicate balance between soil, water and plants through rise in groundwater table (water-logging), and disturbing the natural salt distribution in the soil, thereby, affecting the biomass productivity in coming years; and the agricultural fields around the reservoir rim would be rendered unfit for cultivation.

Costa *et al.* (2003) examined the impact of land use in the Tocantins River Basin (175,000 Km^2) in South-eastern Amazonia, where substantial land cover changes occurred following intensification of agriculture. The land cleared for pastures and crops increased from 30% in 1960 to 49% in 1995. Analyzing rainfall and stream flow data statistically over two periods of 1949–1968 and 1979–1998, they found that mean annual discharge in the latter period is 24% greater than the previous period although the rainfall is not statistically different between the two periods. They concluded that the reduced infiltration after the changes in land cover causes an increase in surface flow during the rainy season.

Katheleen (2005) conducted studies to monitor and assess desertification using integrated geospatial technologies. The author found that runoff decreased consistently and substantially with afforestation across the entire catchment. More than one-fifth of the catchments experienced reductions of 75% or more during at least 1 year and 13% of the catchments experienced 100% runoff reductions for at least 1 year. Both the original vegetation type at a site and plantation species significantly influenced proportional changes in stream flow. When averaged across ages, annual runoff reductions were greater in grasslands (44 - 3%) than shrub lands (31 - 2%). Shrub lands showed a distinct recovery in runoff after approximately 35 years of afforestation, both in proportional and absolute amounts.

While examining the land use/land cover changes that had taken place in Lagos during the last two decades due to the rapid urbanization, Adepoju *et al.* (2006) adopted a post-classification approach with a maximum likelihood classifier algorithm. During the study, Landsat (TM 1984) and Landsat (ETM^{+} 2002) were merged with SPOT-(PAN) (2002) to improve classification accuracies and provided more accurate maps for the modeling and analysis. It also made possible to overcome the problem of spectral confusion between some urban land use classes. The land cover change map revealed that recreational and agricultural land uses were the most threatened. Also, the land use change spatial pattern analysis showed conversion of land use classes as well as transition from one class to another. The authors concluded that the use of GIS and RS can be effectively used to monitor and manage land use and land cover change in Lagos.

Shanzhong and Luo (2006) studied the land-use change and its environmental impact in the Heihe River Basin, arid north western China by the combined use of satellite remote sensing and Geographical Information Systems (GIS) and explored the interaction between these changes and the environment over 15 years from 1987 to 2002. Images were classified into six land-use types: cropland, forestland, grassland, water, urban or built-up land, and barren land. The results show that cropland, urban or built-up land and barren land increase greatly but water area decreased rapidly. The authors concluded that significant changes in land-use occur within the whole basin over the study period and cause severe environmental degradation, such as water environmental changes (including surface water runoff change, decline of groundwater table and degeneration of surface water and groundwater quality), land desertification and salinization, and vegetation degeneracy.

Kiage *et al.* (2007) assessed the recent land-cover/use change associated with land degradation in the Lake Baringo catchment, Kenya, using evidences from Landsat TM and ETM^+ data. During the study, both the NDVI differencing and post-classification comparison effectively depicted the hotspots of land degradation and land cover/use change in the Lake catchment. Change-detection analysis showed that the forest cover was the most affected, in some sections, recording reductions of over 40% in a 14-year period. The results also revealed that deforestation and subsequent land degradation have increased the sediment yield in the lake resulting in reduction in its surface area by over 10% and increased turbidity confirmed by the statistically significant increase ($t = -84.699$, $p<0.001$) in the albedo between 1986 and 2000.

Quilbe *et al.* (2008) conducted studies on the hydrological responses of a watershed to historical land use evolution and future land use scenarios in the Chaudière river watershed, Quebec, Canada using an integrated modeling system GIBSI. For this purpose past land evolution was constructed using satellite images that were integrated into GIBSI. The simulation results showed strong correlations between land use evolution and water discharge at the watershed outlet.

Tong *et al.* (2008) assessed the water quality impacts of future land-use changes in an urbanizing watershed. An integrated watershed hydrologic model, the Soil and Water Assessment Tool (SWAT) was adopted in this study to simulate the water quality conditions under the current and the future land-use configurations. The findings were compared to determine the hydrologic consequences of future land-use changes. Results indicate that as the land use in the watershed shifts from predominantly agricultural to mixed rural and residential lands, a reduction in flow, sediments, and nutrients is detected. The authors concluded that SWAT is a reliable water quality model, capable of producing accurate information for environmental decision-making.

2.3 Watershed Prioritization

Changes, man induced or natural in a watershed are critical to the ecosystem of any lake. Remote sensing and GIS play a very important role in assessing watershed health, prioritization and management. Murty *et al.* (1991) used remote sensing for selection of priority areas in watersheds in Sri Lanka. For this purpose, they used the SPOT HRV data. The procedure uses the information on soil erodibility, land use and land use cover, and prepares an erosion hazard maps. This could be useful when planning soil conservation measures in relatively large watersheds. Prasad *et al.* (1991) carried out studies in Tinau watershed of Nepal by using remotely sensed data, together with socio economic data and other data in a GIS environment to assess the watershed conditions for a watershed in western Nepal. The authors concluded that remote sensing and GIS, with the integration of socio-economic data is very useful for watershed planning and management.

Prasad *et al.* (1997) conducted research on the sub watershed prioritization in Trijuga river watershed in eastern Nepal using remote sensing and GIS. The prioritization was carried out by considering their degradation condition and land sensitivity. Universal Soil Loss Equation (USLE) in conjunction with Remote Sensing and GIS was utilized for estimating soil loss and land cover change using two time series data. Aerial photographs of year 1978 and Landsat TM data that of year 1991 were used to make the analysis of soil loss and land cover change. Based on conservation prioritization, the authors proposed sub-watershed conservation activities.

Basnyat *et al.* (2000) studied the use of remote sensing and GIS in watershed level analyses of non-point source pollution problems. The authors worked on different basin characteristics such as land use/land cover, slope, and soil attributes, which affect water quality by regulating sediment and chemical concentration. Saxena *et al.* (2000) used IRS-1C data in characterization and management of Gondkhairi watershed of Nagpur district. For a precise inventory of a watershed, components like drainage density and pattern, slope percentage and direction, physiography, soils, land use and land cover, were visually interpreted using the geo-coded false color composites (FCCs) of IRS-1B LISS II and IRS-1C LISS III at 1:50,000 scale. Based on results of soil types, percentage slope, drainage density, bifurcation ratio and constant channel maintenance ratio, the soil conservation modules like field bunding, contour bunding, Nala lining and Nala plug/cement check dams were erected. The authors concluded that it is possible to suggest the kind of conservation and engineering structures required their proper location and proposed cropping systems based on above studies.

Randhir *et al.* (2001) worked on watershed based land prioritization model for water supply protection in Ware River watershed in Massachusetts, USA. In this study, the authors used the criteria like geographic information, relationship between land criteria and effects, and travel-time of runoff water. The authors observed that the time of travel of surface runoff followed a complex spatial distribution. The distribution of the prioritization index showed that sensitive areas do not clearly fall within the boundaries of any single land characteristic (e.g. riparian buffer, steep slopes, sensitive soils, etc.). The authors concluded that by adjusting criteria and weights, this approach can be adapted to prioritize a wide variety of land-protection and land-use decisions such as preserving prime forestland, protecting critical wildlife habitats, recreational and open space planning, and ecological–economic planning.

Bahadur and Doppler (2004) worked on a methodological concept of integrating socioeconomic assessment and biophysical environment with a GIS. The authors concluded that integration of socio-economic data into the GIS system is an appropriate tool for zone delineation to formulate long-term problem solving strategies achieving both sustainable natural resource management and better livelihood simultaneously

Pandey *et al.* (2006) carried out the watershed prioritization of Karso watershed of Hazaribagh, Jharkhand State on the basis of average sediment yield data. Arc Info GIS and RS (ERDAS Imagine 8.4) were used for providing spatial input data to the model, while the USLE was used to predict the spatial distribution of the sediment yield on grid basis The authors estimated average sediment yields and then critical erosion prone areas of watersheds were arranged in the descending order of their sediment yields for prioritization purpose.

Vittala *et al.* (2008) conducted research on sub-watershed prioritization using an integrated approach of remote sensing, GIS and socio-economic data for sustainable development and management of natural resources in North Pennar basin of Tumkur District, Karnataka. The authors carried out prioritization on the basis of available natural resources derived from satellite images and socio-economic conditions, including drainage density, slope, water yield capacity, groundwater prospects, soil, wasteland, irrigated area, forest cover and data on agricultural labourers, SC/ST population and rainfall. On the basis of priority and weightage assigned to each thematic map, the sub-watersheds were grouped into high, medium and low priority categories. The authors concluded that the high priority sub-watersheds may be taken up with development and management plans to conserve natural resources on sustainable basis with immediate effect, which will ultimately lead to soil and water conservation.

Despite the use of remote sensing and GIS technology in India and abroad for ecological characterization of lacustrine ecosystems as well as their watersheds, there are hardly any detailed studies except for the preliminary reports of Amin and Romshoo (2007) and Badar and Romshoo (2007) involving the application of such recent and advanced technology for Kashmir lake ecosystems. It is possible that lack of adequate research facilities and necessary experts required for such sophisticated technology has hampered progress in the field.

2.4 Conventional Studies on Dal Lake

Most of the studies conducted on the Dal Lake have been of routine nature, mainly conducted to determine the deteriorating water quality conditions of the lake, i.e. hydrochemistry and hydro-biology. A brief review of these studies is given below:

2.4.1 Ecology and Macrophytic Vegetation

Till 1970 very few studies related to the ecological aspects of Dal Lake were carried out. Kaul and Zutshi (1966) investigated some aspects of ecology, genesis and development of floating islands in the Dal Lake. The authors reported that most of the islands are man-made and created primarily for vegetation cultivation. A survey of aquatic flora of the lake was also conducted by Kaul and Zutshi (1967).

Zutshi and Vass (1971) conducted a study on ecology and production of *Salvinia natans*. As per the authors one of the major causes for the spread of *Salvinia* was cultural eutrophication as a result of human and agricultural wastes going into the lake waters.

Zutshi and Khan (1978) worked on Lake Typology of Kashmir and classified the lakes into valley lakes, forest lakes and mountain lakes. The authors compared the lakes with respect to origin, topography, drainage, water depth as well as qualitative and quantitative analysis of macrophytes, plankton and fish population.

Kaul *et al.* (1980) while working on macrophytes reported that these are more efficient in removal of N, Ca and K compared with P and Na from the nutrient pool. The authors also reported the use of *Sparganium sp.* as a possible way of reducing nutrient pollution. Zutshi and Vass (1982) during their limnological investigations on Dal Lake found that *Typha angustata and Phragmites australis* achieve maximum development and colonize successfully in silted regions and at a depth of 0.5 m. Vass and Zutshi (1983) while evaluating the trophic evolution and energy flow of Dal Lake also dealt with the management of the lake ecosystem.

Handoo *et al.* (1988) worked on the energy content and ecological efficiency of macrophytes in the Dal Lake. As per the authors, the total energy present within the macrophytic beds for utilization for various purposes, despite removal of the biomass is destined to accumulate and decay on the lake bed.

Zutshi and Ticku (1990) assessed the impact of mechanical deweeding on Dal lake ecosystem. Significant changes were observed in water chemistry, plankton, macrophytic vegetation and fish. The authors inferred that it was deleterious to the lake ecosystem in general. Trisal (1987) and later Pandit (1993) gave a review of Dal lake ecology and listed some management options for the lake ecosystem.

Of late, there has been witnessed much interest in Kashmir lake studies, and several publications have been well focused on specific themes. For example, Khan and Shah (2004) worked on the land use pattern in the catchment and its impact on the ecology of Kashmir wetland ecosystem (Hokarsar) and reported that wetland environment, under varied anthropogenic perturbations, are influenced by adjoining hamlets. The assessment of land use practices in the catchment showed 2430 ha under various agro horticultural activities involving annual use of 403 metric tons of fertilizers and 7.8 metric tons of pesticides. The paddy cultivation accounts for more than 75%. The combined effects of intensive agricultural practices, expanding urbanization together with unsustainable exploitation of wetland resources have drastically altered the environmental status of wetlands.

In a more recent publication, Khan *et al.* (2008) dealt with biotechnological intervention in combating lake pollution and evaluated the performance of carrier-based inoculants in some vegetable crops grown on floating gardens of Dal Lake. The study stresses the need for using eco-friendly inoculants as biological tools for checking the menace of pollution due to agrochemicals.

2.4.2 Sediment Chemistry

Trisal and Kaul (1983) carried out studies on the exchange of nutrients taking place between the sediments and waters of Dal Lake, and observed the dominant role of macrophytes in regulating mineral nutrient exchange. In another study, Kango *et al.* (1987) while using X-ray diffraction (XRD) and differential thermal analysis (DTA) to investigate clay mineral content of lake sediments reported that illite and chlorite being the main clay mineral types in Dal Lake.

Bhat and Khan (2006) studied phosphorus adsorption by Dal lake sediments and assessed the impact of seasonality on the phenomenon. The authors while studying various fractions of phosphorus in sediments revealed that total phosphorus in Hazratbal basin was one and a half fold more than in Gagribal sediments. The authors suggested that dredging would lead to increased desorption of phosphorus.

Jeelani and Shah (2006) carried out studies on geochemical characteristics of water and sediment from the Dal Lake. The scatter diagrams [(Ca^{+} Mg)/total cations (TZ^{+}), (Ca^{+} Mg)/HCO_3, (Ca^{+} Mg)/ ($HCO_3{}^{+}SO_4$), (Na^{+} K)/TZ^{+}; (Ca^{+} Mg)/ (Na^{+} K)] and the geological map of the study area suggested predominance of carbonate and silicate weathering. The results also showed that Dal Lake is characterized by high chemical index of alteration (CIA: 87–95), reflecting extreme weathering of the catchment area. Geo-accumulation index (I Geo) and the US Environmental Protection Agency sediment quality standards indicated that the Gagribal basin and some patches of the Nagin basin are polluted with respect to Zn, Cu and Pb. These data suggest that the Dal Lake is characterized by differential natural and anthropogenic influences.

2.4.3 Nutrient and Chemical Environment

Zutshi and Vass (1973) demonstrated the changing eutrophic status of some lakes and found that some basins of the Dal show higher levels of eutrophication. This study stressed the importance of long term data in determining the extent of lake pollution. In another study, the same authors in 1978 while studying the chemical features of the Dal reported low enrichment of the lake as indicated by the low values of chlorides, silicates and sulphates.

ENEX (1978) gave a detailed account of nutrient balance in the Dal Lake based on assumptions like segments of populations living in the catchment and their living standards. As per the results, 46.3 tons of phosphorus and 634 tons of nitrogen are drained into the lake every year from the catchment that include human settlements, open fields, mountain slopes, agriculture land and apple orchards.

Trisal (1987) reviewed physicochemical characteristics of water and sediments, biological features and nutrient dynamics of Dal Lake, which indicated that the direct discharge from houseboats, reduction of plant cover in the catchment, interception to the flow of water and increase in population within the catchment have resulted in deterioration of water quality, prolific growth of aquatic macrophytes and siltation.

Ishaq and Kaul (1988) worked out the water budget of the Dal Lake for the year 1981-1982. The results showed an input of 68% through surface inflow and 2% through precipitation of the total surface output, evaporation from the lake surface accounted for about 3%. In another study, Ishaq and Kaul (1988) worked out on the monthly inputs, outputs and relations of Ca and Mg in Dal Lake. The lake showed on an overall basis the retention of calcium but not of magnesium. The authors related it to the variable flushing rates of water. Furthermore, the authors attributed the high concentration of both Ca and Mg in summer runoff to their leaching from agricultural soils during the season followed by over wash.

Ishaq and Kaul (1990) worked out the P-budget of Dal Lake and reported that the lake is characterized by high P-loading (7.5/g/m^2/yr) and had a high P- retention (retention coefficient 0.32). The authors attributed the high retention of P in the lake to its marl character. Ishaq and Kaul (1992) also carried out studies on the influence of hydrology on the dynamics of minerals in some streams, draining in and out of the Dal Lake and found that ortho and total P in runoff peaked during high water discharge periods which was attributed to the presence of their unbuffered and non-point sources in the catchment.

Sarwar *et al.* (1996) while studying the impact of floating gardens on the limnological features of Dal Lake observed high nutrient levels near the floating gardens as compared to the open water of the lake. Routine progress reports of J&K Lakes and Waterways Development Authority (Anonymous, 1998, 1999, 2000) indicate a progressive increase in nutrients and biomass (chlorophyll, algal matter) in all Dal Lake basins in time and space.

Khan (1993a, b; 2000) worked on the red-tide phenomenon which occurred first time (July - Aug. of 1991) in Dal Lake waters. The bloom was caused by a rare flagellate (*Euglena pedunculata Gojdics).* The origin of red tide occurred along the shores of boulevard embankments (near Convention Complex) experiencing nutrient influx as untreated sewage from adjacent hotels and residential huts in the catchment of Dal lake.

Khan (2008) provided information on chemical environment and nutrient fluxes in a nearby flood plain wetland ecosystem (Hokarsar) and reported nutrient pools in principal components (water, sediments and macrophytes) with sediments acting as long term major sinks. The author reports that notwithstanding the nutrient removal potential of macrophytes and their bioremediation role in combating water pollution, sediments act as a major sink and hold a key for sequestration and removal mechanism.

Solim and Wanganeo (2008) carried out studies on phosphorous loadings to Dal Lake, Kashmir. The authors calculated external and internal TP loads which were of the order of 5 and 1 gm^{-2} yr^{-1}, respectively for the lake. These loading rates were high in relation to the lake's critical tolerance range of 0.1-0.2 gm^{-2} yr^{-1}, and, over time, have resulted in severe eutrophication in view of extremely high macrophytic biomass (average = 3.2 kgm^{-2}-fresh weight) and bottom sediment enrichment (79 tons of TP reserves which contribute 88% of the annual TP budget). This study emphasized the importance of external TP load reduction as a primary management objective to counteract internal TP loading and P storage within bottom sediments resulting from historic anthropogenic loads.

It is obvious from the review that the research conducted on Dal Lake till date has been of routine nature mostly related to the hydrobiology and hydrochemistry.

CHAPTER - 3

STUDY AREA

3.1 Location

The Dal Lake and its catchment is situated between the geographical coordinates of 34°02´ – 34°13´ N latitude and 74°50´ – 75°09´ E longitude. The location of the study area is shown in Fig. 2.

Dal Lake commonly called as Heart of the Valley is surrounded on all sides by mountain ranges and occupies the central part of the Valley. City ward from the lake stands the Shankaracharya hill to the left and the Hariparbat fort hill to the right. Towards the west are the snow clad mountains of the Pir Panjal range (remaining covered with snow from December to March or April); while on the eastern side are the extensions of Kailash Parbat. Dal Lake functions as the central part of a large interconnected aquatic ecosystem in Kashmir valley and is the major surface water body of the Valley. Dal Lake is a shallow, multi-basin lake with an area of about 18 km^2, out of which open water area is not more than 12 Km^2. It has both, the inflow and the outflow water channels and is classified as a drainage lake (Zutshi and Khan, 1978) resembling more to a flow through system rather than a quiescent water body. The catchment of the Dal Lake is not only highly diverse but also covers a huge area of 337 Km^2 which is nearly 18 times more than the lake area. It exhibits a varied topography with altitudinal range of 1580-4360 m. This area is surrounded by Sindh basin in the north and Jhelum basin in the south.

The catchment area of Dal Lake can be broadly divided into five

3.1.1 Telbal- Dachigam Sub-catchment

Telbal- Dachigam is Dal Lake’s largest catchment, which is further divided into the Telbal- Dara (89 Km^2) and the Dachigam National Park (145 Km^2) sub-catchments. The mountain range in the east is a part of the Panjal trap, at many places agglomerate slates are also present. It is believed that the agglomerate slates are a joint product of glaciating and limestone. There is ample evidence of glaciating along

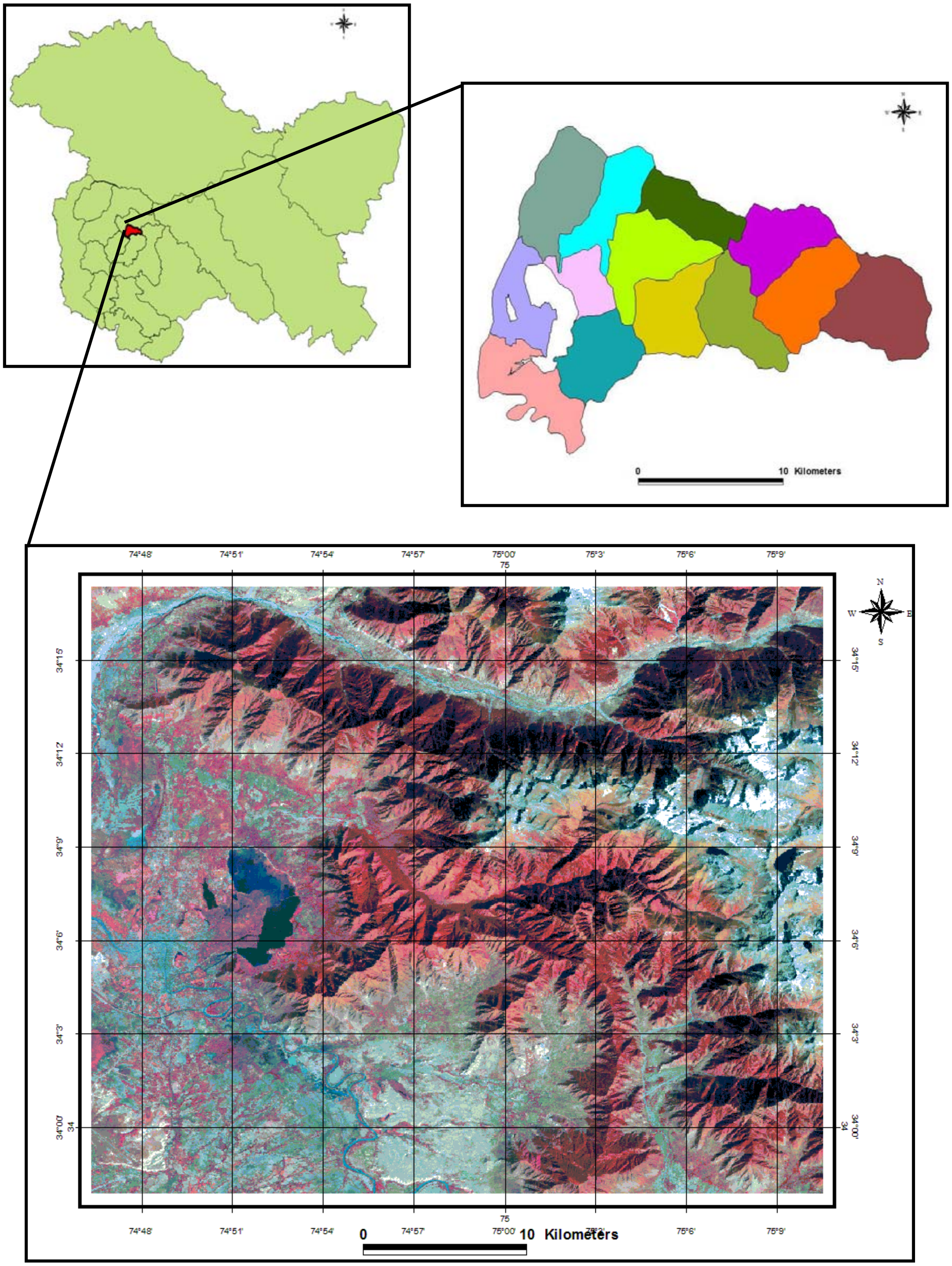


Fig. 2: Location of the study area

with the presence of glacial moraines in different parts of the catchment. But freshly deposited alluvium is mostly observed in the northern part of the surrounding area. Dachigam is the largest in area and comprises mainly the Dachigam Game Reserve and south-facing slopes. The Dachigam Game Reserve is a restricted area and has good forest and ground cover but the south-facing slopes have been denuded of forest cover due to overgrazing of cattle and in the past by burning off. It is evident that denudation of this area is resulting in significant contribution of silt to the Dachigam Nalla which drains this catchment area. Soils of the Dachigam National Park sub-catchment are dominated by undifferentiated brown soils, lacustrine sediment, moraine tongues, and parcels of recent alluvium (AHEC, 2000). While most of the Dachigam National Park is forested, some gentle slopes at lower elevations have been deforested for the agricultural purposes. Grassland areas in the areas are overgrazed by nomadic livestock. The reserve is drained primarily by Dachigam Creek (perennial flow), which splits into four smaller streams in its lower reaches namely Boutkul Creek, Telbal Creek, Pishpuw Creek and Meerakshah Creek. These streams enter the Hazratbal basin of the Dal Lake from the north-northeast. The Telbal- Dara sub-catchments consists of the south facing slope of the lake and is mostly treeless barren landscape) with soil characteristics being undifferentiated yellow podsolic to distinct podsolic.

3.1.2 Lake Hillside Sub-catchment

Lake Hillside catchment (47) Km^2 rises from 1582 m to 2924 m above mean sea level. It is composed of weathered rocks with underlying brown /yellow –grey soils (AHEC, 2000). High elevations in this catchment are mostly barren, except for the sparse stands of Pinus, Deodar and Kail located on the ridges and along southern slopes. Its lower slopes are being rapidly developed for residential use, and hotels, restaurants, and shopping malls with associated parking lots have been constructed in riparian areas adjacent to the lake. Both the dwellings and commercial establishments lack septic system facilities and any other treatment, thus this catchment is a major source of both municipal sewage and diffuse urban runoff. The Lake Hill side catchment drains into Dal Lake via a number of small streams around the east and south sides of the lake. Around the lake shore, the lower land slopes of this catchment have been utilized for rice cultivation, orchards and gardens. Beyond this, the land rises very steeply to 1000 m above the lake. The steep exposed slopes do not support any vegetation, and in some areas overgrazing has contributed to denudation.

3.1.3 Srinagar North Sub-catchment

The Srinagar North catchment comprises mainly outer suburbs of Srinagar City and is extensively used for paddy cultivation. Residential development in this area is relatively recent and yet only a small percentage of dwellings have septic systems. The topography is very flat and drainage is via slow flowing canals and open drains which in parts are badly contaminated with sewage and rubbish. This catchment covering an area of 24 Km^2 drains into the Dal Lake and directly into the Nallah Amir Khan which is an outlet of Dal Lake via Nigeen Lake. The catchment contains suburbs of Srinagar city and comprises of gardens and paddy fields. The sprawl of population in the catchment has expanded the city towards the peripheral areas.

3.1.4 Srinagar Centre Sub-catchment

Srinagar centre (14 Km^2) drains into the southeast corner of Dal Lake via a number of canals. The topography is very flat. This catchment is fully urbanized as it is situated in core city area. The area is densely populated by the city dwellers. Major sections of downtown Srinagar city are in Srinagar centre catchment, in which there are negligible areas of undeveloped land. High density residential areas within the catchment are without septic systems, and roads and lanes constructed from tar-macadam. The Srinagar City catchment is fully urbanized and densely populated and in most parts it drains via the Brari Nambal (a large swampy area which is grossly polluted with sewage and rubbish) that in turn drains into Dal Lake via a canal.

3.1.5 Lake Interior

This is comprised of the Dal Lake itself and includes open water, floating gardens, marsh and land masses within the lake. About 40, 000 people live directly on the surface of Dal Lake, mostly in what can be described as the floating hamlets and permanently anchored boats. These dwellings are mostly concentrated in the Bod-Dal basin. Except for night soil, which is used as a source of organic manure on floating gardens, most of the kitchen and laundry wastes are being directly disposed into the lake (Solim and Wanganeo, 2008).

Table 1: Area distribution of sub-catchments of Dal Lake (AHEC, 2000)

S. No	Sub-catchment	Area (Km^2)	Area (%)
1	Telbal including Dachigam	234.00	69.43
2	Lake Hillside	47.00	13.94
3	Srinagar North	24.00	7.12
4	Srinagar Centre	14.00	4.15
5	Lake Interior	18.00	5.34
	TOTAL	**337.00**	**100.00**

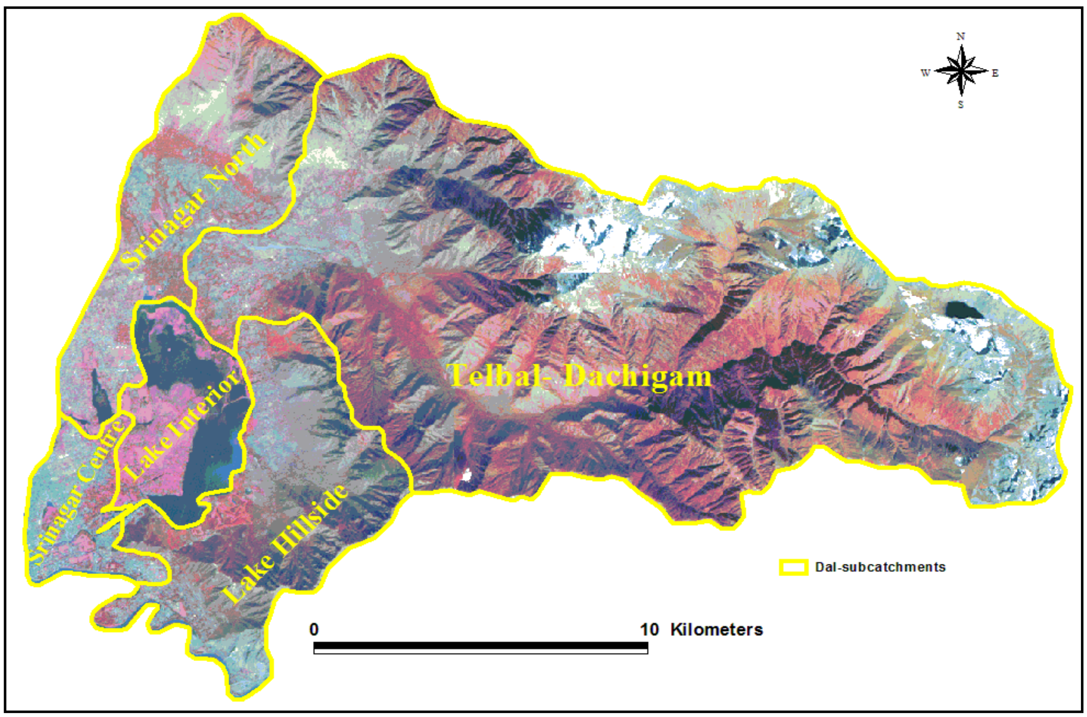


Fig. 3: Sub-catchments in Dal Lake Catchment

3.2 Physiography

Physiography entailing physical characteristics and morphological conditions of a catchment plays an important role in hydrological characteristics, water regime and vegetation covers. The physiographic characteristics of a catchment and its location, give a good quantitative and qualitative assessment of the hydrological system of the catchment. These factors have direct effects not only on the hydrologic regime, annual water production, flood volumes and soil erosion, but also affect the climate, ecological conditions and vegetation cover. Fig. 4 shows the landform elements in the study area.

The Dal lake catchment is fan shaped and broadens in the westward direction. Topographically, the catchment has evolved out of outwash apron of the Dachigam creek and has assumed the shape of a triangle. The stretch of the catchment is a diagonal extension from north-east to south-west. The western watershed limit is, by and large, a flatter area except for 4.5 km. length along which the average elevation is 2000 m. The watershed limits rise high towards the north and east of the catchment. On the whole, the Dal lake catchment represents varied topographic features. The general relief of the catchment is a basin which comprises the Dal Lake situated at an altitude of 1580 m approximately and a steep escarpment at an elevation of 4390 m located along northern watershed.

Dal Lake is a shallow, open drainage type water body subdivided into five basins (including Brainambal basin). These basins differ markedly in their area, volume, maximum depth, mean depth, index of shoreline development and other characteristics (Kaul, 1977) (Table 2). The largest is the Bod Dal and the smallest being the Brari Nambal. The basin walls are essentially convex towards the water and index figures are less than unity (Vass, 1973). The ratio between the mean and maximum depths ranges between 0.29 and 0.25, indicating a gentle slope of the lake bed.

3.2.1 Hazratbal Basin

This part is flanked by three Mughal Gardens – the Nishat, Shalimar and the Harwan on its eastern side and Hazratbal Mosque, University campus and Naseem

Table 2: Morphometric features of Dal Lake Basins (Kaul, 1977)

Basin Characteristics	Nigeen	Gagribal	Hazratbal	Bod Dal
Max. length (Km)	2.5	1.5	3.2	4.6
Max. width (Km)	0.5	0.8	1.6	2.1
Max. depth (m)	6.0	2.5	3.5	3.0
Mean depth	1.37	0.7	0.76	0.86
Surface area (Km^2)	0.89	1.30	3.54	5.72
Total volume ($M\ m^3$)	1.22	0.93	2.76	4.92

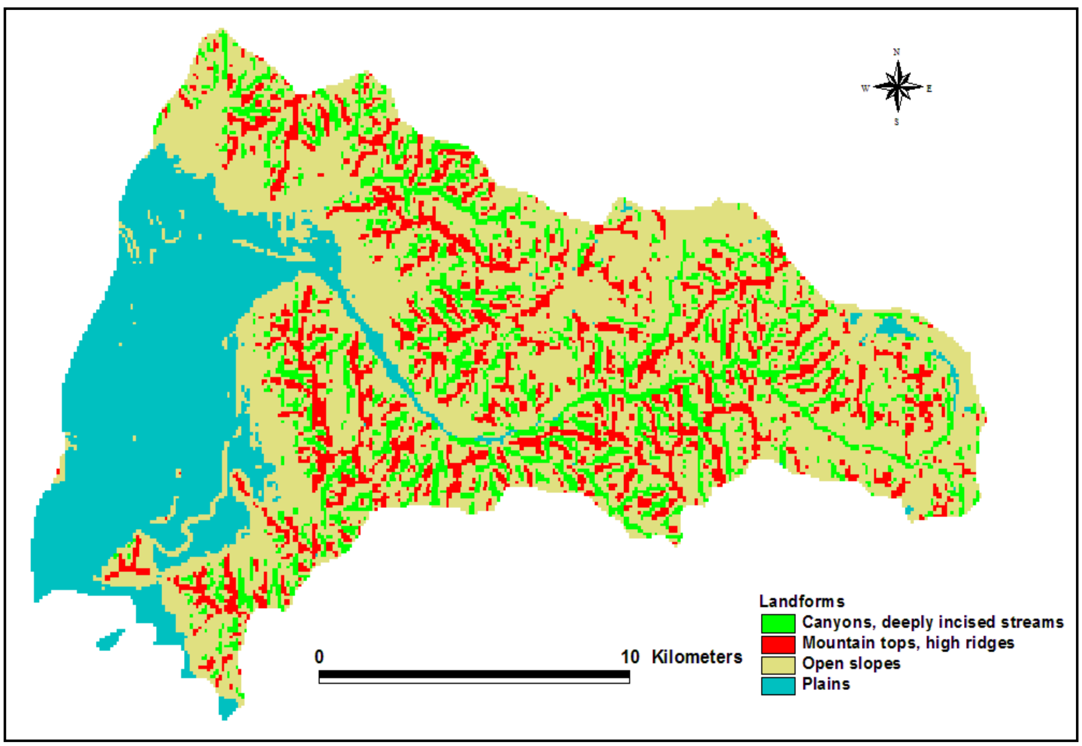


Fig. 4: Landforms in Dal Lake Catchment

Bagh on its western side. The Sona-lank, a small island, lies in this part of the lake. The maximum depth in this basin is 3.5 m.

3.2.2 Bod Dal Basin

It starts from Kotarkhana and Rupa-lank, a small island is situated on it. On its eastern side lies Chashmashahi Bagh. It is 3m in depth.

3.2.3 Gagribal Basin

This part of the lake extends from Nehru Park to Kotarkhana. The Boulevard road constructed in 1930 has cut off a sizeable portion of the basin along the Shankaracharya hill. A number of hotels have been constructed along the roadside of the basin (maximum depth 2.5 m).

3.2.4 Nigeen Basin

This is the deepest of all the lake basins with a depth of 6m and is mostly used for aquatic sports.

3.3 Geology

The valley of Kashmir was formed by folding and faulting as the Himalayan mountain chain was thrust up between the Indian sub-continent and Asia. It runs northwest –southwest along the strike of the mountain chain and is drained by the Jhelum River which cuts through the Pir Panjal range at the Baramullah Gap (ENEX, 1978). The origin and the age of Dal Lake is still a controversial matter. The evolution of Dal Lake since the 6^{th} century is illustrated in Fig. 5.

As per some workers a large lake occupied the northwestern half of the Kashmir valley until recent times when river down cutting, sedimentation and progressively warmer climatic conditions reduced the lake to the present relic lakes of Dal, Wular, Manasbal and Nageen. According to Dianelle (1922), the Dal Lake resulted from the progressive shrinkage of the ancient glacier which existed during Pleistocene period. Whereas, de Terra and Paterson (1939) state that the lake lies in the floodplain of the river Jhelum whose broad meanders have cut swampy low lands out of Karewa terraces and has been formed as inundated part of the river.

On the floor of the Valley, Dal Lake is situated on the alluvium cover of the Karewa group (Plip-Pleistocene). The sediments which form the base of the lake bed comprise non-stratified loamy clays interspersed with carbonaceous bands. These overlie pale yellow laminated marls and silts, and bands of inter-bedded medium to coarse grained greenish sands, marlstones, calcareous grits and varied clays of lacustrine origin. Below this, glacio-fluvial sediments of gravel sands and beds of resorted glacial moraines occur over basal boulder conglomerate. The geological formations of the catchment area are dominated by alluvium, Panjal traps and agglomerate slates. Agglomerate slates are pyroclastic slates, conglomerates and pyroclastic product. Panjal traps are Permian volcanic consisting of thick series of andesitic and basalts. Triassic limestones consist of limestone, shale and sandstones. The karewa deposits are quaternary fluvio-lacustrine deposits which contain unconsolidated materials such as light grey sand, dark grey clays, coarse to fine grained sands, gravels, marls, silts, varved clays, brown loams, lignite etc. (Wadia, 1971; Varadan, 1977; Data, 1983; Bhat, 1989).

3.4 Drainage

The Dal Lake is believed to be fed by a number of underground springs and steams but the main source is the Dachigam Creek (Nallah) that enters into the lake on the northern side after originating from the Marsar Lake, high up in the mountains and draining the Dachigam Reserve enroute. The Creek having a flow length of 39 km approximately is perennial in nature and enters the Hazratbal basin from the northern end. Boutkol Creek drains the water mainly from the northern and north-western catchment including the waters from the Sind Extension Canal, irrigation overflows and oozings in the lower green belt. Besides, a number of other small streams e.g., Meerakshah and Pishpav streamlets etc. carry water entering the Hazratbal basin of the lake. In addition, innumerable springs arise from the lake bed. Fig. 6 shows drainage network in Dal Lake Catchment.

The following drainage basins may be identified for the Dal Lake catchment (Amin and Romshoo, 2007):

3.4.1 Northern Drainage Basins

These include the Bran Nar, Dagwan Nar, Mayun Nar, Drog Nar, Mahadeo Nar, Mal Nar, and Waghat Nallah basins.

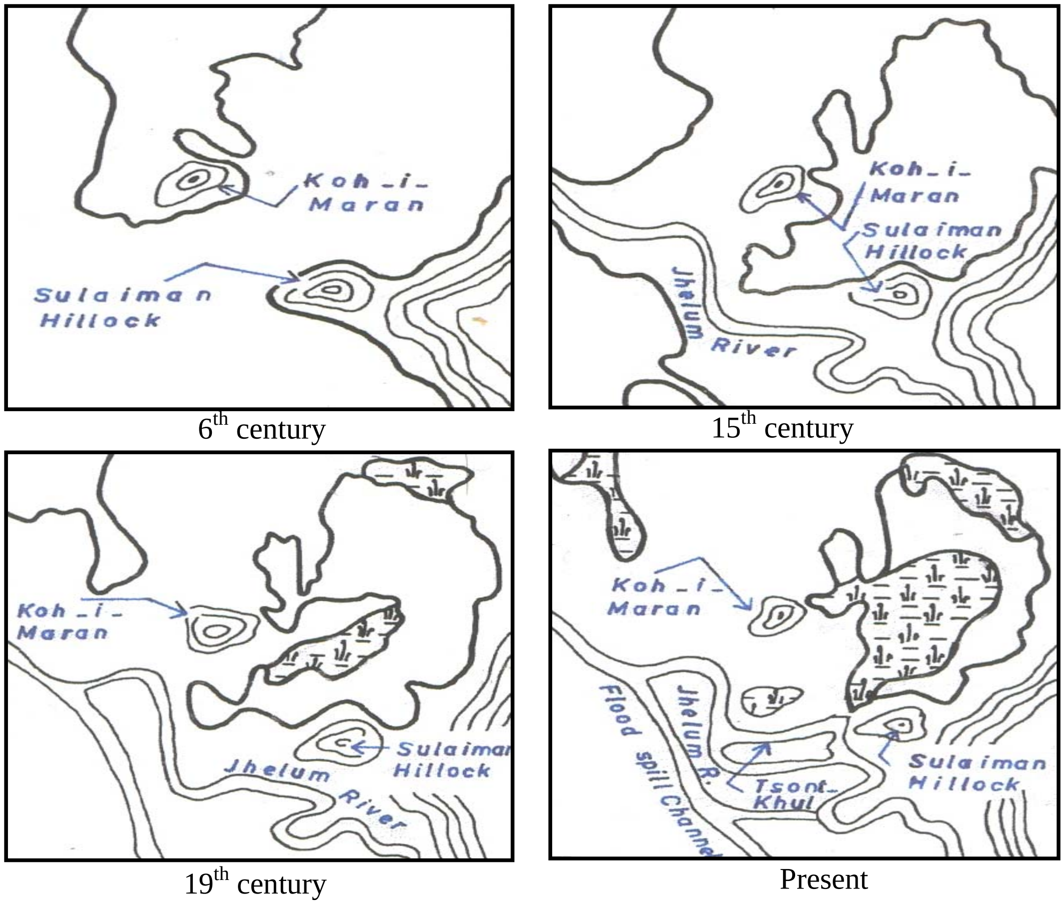


Fig. 5: Evolution of Dal Lake (Source: Master Plan Srinagar City, 1971)

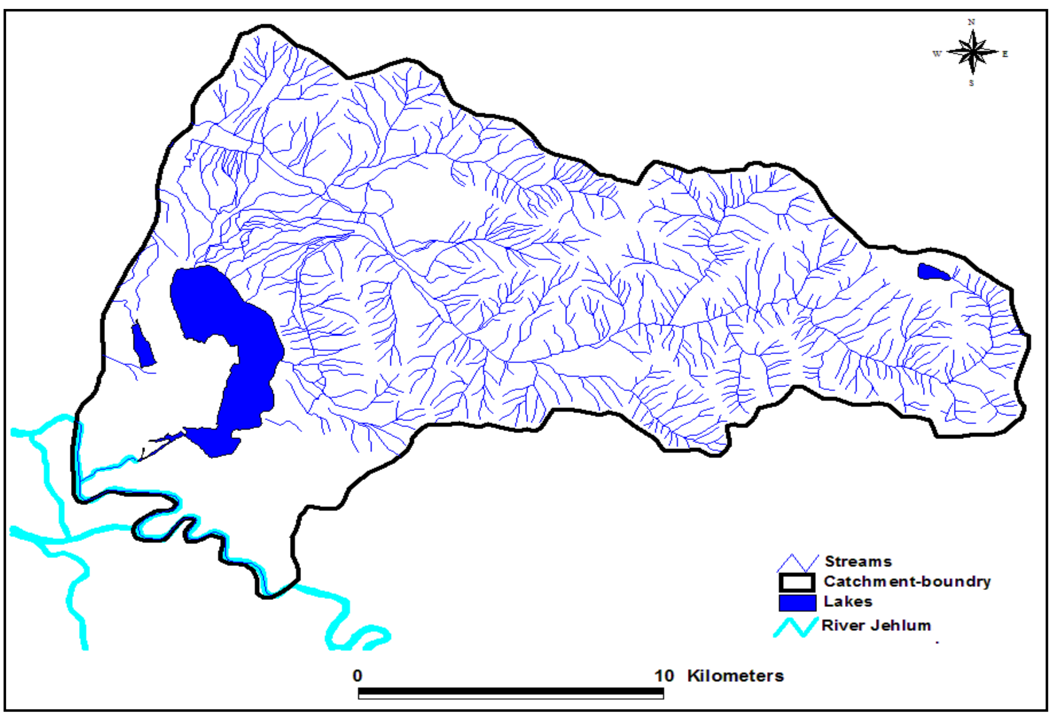


Fig. 6: Drainage network in Dal Lake Catchment

3.4.2 Southern Drainage Basins

These include the Nagberan, Gunas Nar, Gret Nar, Namblan Nar, Kau Nar, Bidan Nar and Heder Nar basins.

Water flows out of the lake through a weir and lock system on the southwest side, via Dalgate into Tsunthkul - a tributary to the river Jhelum. There is also another exit i.e., Nallah Amir Khan connecting the Nagin basin with Anchar lake via Khushalsar Lake. The drainage pattern in the study area is a combination of "Trellis" and "Dendrite" patterns with the general flow direction being from east to south west as shown in Fig. 6. Besides Dal Lake, the other water bodies of the catchment are the Marsar (glacial/snow fed Lake) and the Nagin Lake. Harwan reservoir is artificially created mini water body situated near Harwan and is meant for domestic water supplies. Marsar lies in the extreme east and Nagin to the west of the Dal Lake catchment.

3.5 Climate

Due to the large variations in altitude from 300m in the south to 8500m in the north, the climate of the state of Jammu and Kashmir varies from tropical to arctic (ENEX, 1978). According to Bagnoulus and Meher- Homji, (1959) the climate of Kashmir falls under Sub-Mediterranean type with four seasons based on mean temperature and precipitation. However, Kaul and Qadri (1979) maintained that the climate of Kashmir is highly variable and does not conform to any definite type, and presented a fresh classification the seasons of Kashmir based on Hadlow's world scale for mean monthly temperature. However, in the Vale of Kashmir in which Srinagar and Dal Lake are located, it can be described as temperate for most of the year.

The entire Dal Lake catchment remains covered with snow during winter months of December through March with minimum temperatures reeling below zero. The top crust of the lake has also been observed to freeze during winters. Early spring and summer are the wet periods when maximum rainfall occurs. The average annual rainfall is 650 mm at Srinagar and 870 mm at Dachigam. It is in this season that the snow thaw in the higher reaches of the catchment results in the maximum discharge in Dachigam and Dara Nallah. An average of 600 mm of snow falls in Srinagar during the winter but the snowfall on the higher slopes is much heavier. The temperature varies between a monthly mean maximum of 31 °C in July and a minimum of -4 °C in

January with an average of 11 °C. The maximum daily humidity ranges from 80% to 90% throughout the year and drops to approximately 70% at night during the winter and 40% during the summer. The sheltered and inland nature of the Kashmir valley means that strong winds are very uncommon and at Srinagar the wind strength seldom exceeds 5 km/hr.

3.6 Natural Vegetation

Of the entire five sub catchments of the Dal Lake, the Dachigam National Park represents an area of rich biodiversity. The Park constitutes more than half of catchment, besides forming the major hydrologic and precipitational catchment to the lake. It provides a home to the remnant biological diversity and threatened and endangered species of Kashmir forming part of north western Himalayas. The general vegetation of the area has been dealt with in detail by Singh and Kachroo (1976). They have recognized a number of vegetation types based on habitat, form and density of dominant species, though the vegetation patterns are controlled by such factors as habitat, slope, exposure to sunlight and altitude, besides biotic factors. Whereas, the mountain slopes sustain mostly natural vegetation, the plain valley with ravines supports both natural and planted vegetation. The authors further divided the vegetation complex of the area into thirteen types, each in turn being subdivided into two or more communities of their own. As per the studies of Bhat *et al.* (2002), the prominent vegetation types comprised evergreen scherophyll forests (*Pinus wallichiana* and *Abies pindrow*), deciduous forests communities of *Robinia pseudoacacia*, *Salix, spp*., *Quercus rober*, *Fraxinus hookeri*, *Ulmus villosa*, *Morus alba*, *Juglans regia*, *Ailanthus altissima* and stands or isolated patches of *Betula utilis* at higher elevations), deciduous scrub (*Parroptiopsis jacquemontiana, Corylus colurna*, *Isodon plectranthoides, Rosa webbiana*, *Berberis spp*., *Vibernum foetens, Lonicera spp.*), evergreen scrub (*Dephne olesides*, *Contaneaster namuullaria* and *Rhododendro*n *spp.,* and *Juniperus recurva* at higher elevations), Savanna (mid grasses like *Themeda anathera*, *Stipa siberica, Dactylis glometrata*, *Phragmitis communis* with scattered trees or scrub plants), grasslands (*Chrysopogon echinulatus, Cynodon dactylon, Themeda anathera, Bothriocloa pertusa, Pennisetum spp.etc) and broad-leaved herbs (Anemone biflora, Germanium spp. Fritillaria imperialis, Sambucus wightiana, Ferula jaeschkaina etc).* The conspicuous absence of such higher sub alpines and alpines as *Betula utilis*, *Rhododendron, spp.,* and *Juniperus* *recurve* is attributable to the difference in altitude and climate which is a noteworthy feature of the park.

In another study (Anonymous, 1985), six major biotypes have been identified in the park as:

- Riverine forests (confined in the plain valley)
- Grasslands (2000-3000)
- Broad-leaved woodland (2000-2800m)
- Coniferous forests (2000-3000)
- Rock faces and alpine pastures(hill tops)
- Scrub (3300-3600)

CHAPTER- 4

DATASETS USED

During the present study, a multitude of datasets were used in order to fulfill the objectives outlined in Chapter 1. These include:

4.1 Satellite Data

4.2 Field Study/ Lab Investigation Data

4.3 Ancillary Data

4.4 Field Equipments

4.1 Satellite Data

4.1.1 Landsat 7 TM Image

In 1967, the National Aeronautics and Space Administration (NASA), encouraged by the U.S. Department of the Interior, initiated the Earth Resource Technology Satellite (ERTS) program. This program resulted in the deployment of many satellites carrying a variety of remote sensing systems designed primarily to acquire Earth resource information. The Landsat program is the United States' oldest land-surface observation satellite system, having obtained data since 1972 (Jensen, 2000). The sensor characteristics of the Landsat series are shown in the Table 3 and Table 4.

The TM (Fig. 7) is a highly advanced sensor incorporating a number of spectral radiometric and geometric design improvements relative to the MSS. Spectra improvements include the acquisition of data in seven bands instead of four with new bands in the visible (blue), mid-IR, and thermal portions of the spectrum. Radiometrically, the TM performs its onboard A-D conversion over a quantization range of 256 digital numbers (8 bits). This corresponds to a fourfold increase in the gray scale range relative to the 64 digital number (6 bits) used by MSS. Fig. 8 (a-g) shows the data distribution in different bands of Landsat TM. The bands 1-3 represent the visible electromagnetic radiations with wavelengths of 0.45-0.52 µm, 0.52-0.60 µm and 0.63-0.69 µm respectively.

Table 3: Sensor-system characteristics of first, second and third Landsat Series

S. No.	Sensor-System Characteristics	First Series Landsat 1, 2 & 3	Second Series Landsat 4 & 5	Third Series Landsat 6 & 7
1	Swath Width	185 km	185 km	185 km
2	Data Rate	15 Mb/s	85 Mb/s	250 images per day
3	Revisit	18 days	16 days	16 days
4	Orbit	919 km, sun-synchronous	705 km, sun-synchronous	705 km, sun-synchronous
5	Inclination	99º	98.2º	98.2º
6	Quantization Levels	6 bit	8 bit	8 bit

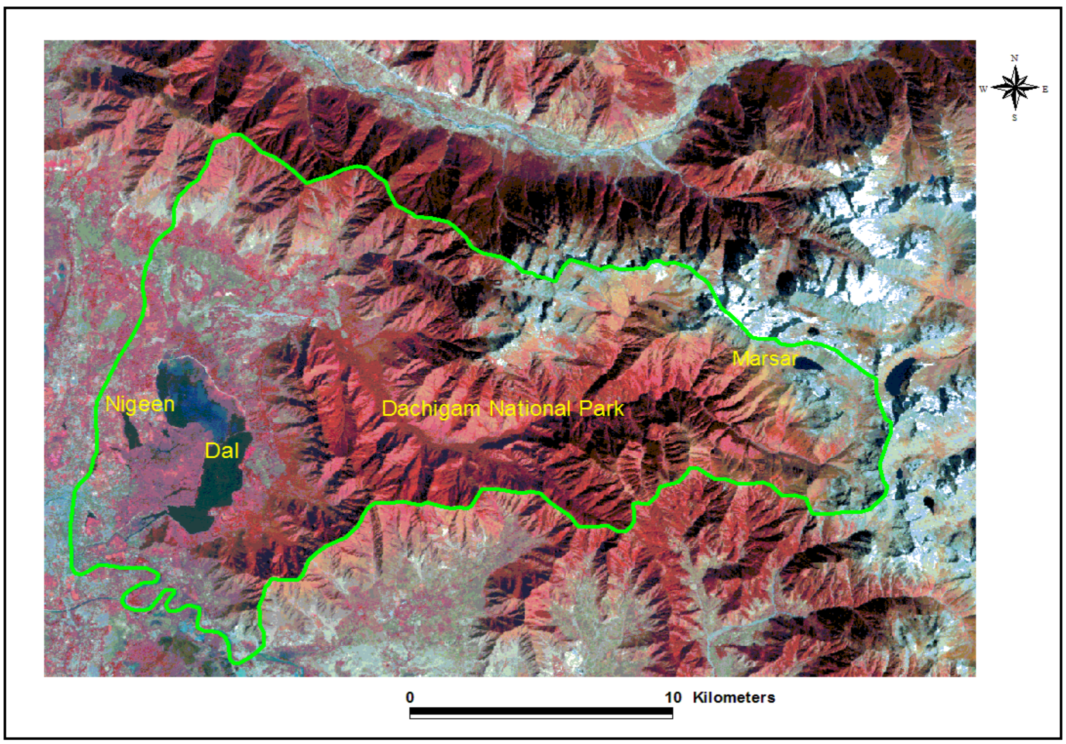


Fig. 7: Landsat TM Image of the study area

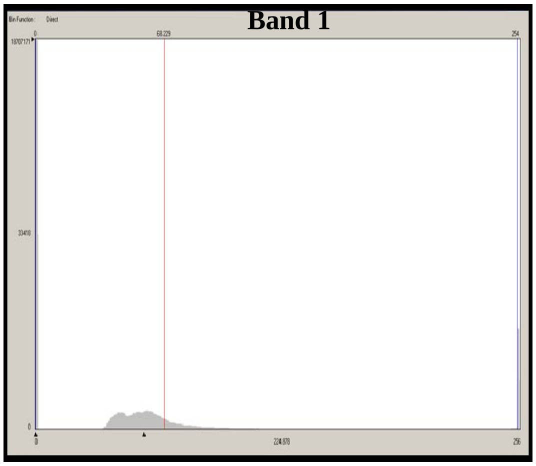
The band 4 represents the near IR with wavelengths of 0.76-0.90 µm and band 5 represents the mid IR with wavelengths of 1.55-1.75 µm. Band 6 represents the thermal IR with wavelengths ranging from 10.4-12.5, whereas, the band 7 falls in the mid-IR with wavelength ranges from 2.08-2.35 as shown in the Table 4.

All the bands were analyzed and finally a 3-band image with near infrared 0.76-0.90 µm, green 0.52-0.60 µm and the red bands 0.63-6-0.69 µm, with the band combination 4:3:2 (IR:R:G) was used in the research. During the current research programme, a 7-band Landsat TM image (Fig. 7) acquired on 30th September 1992 was used as a remotely sensed image data source for generating land use/ land cover map for the same year. The spatial resolution of the TM is 30 meter with the thermal band (6) having a resolution of 120 meters. This data formed the basis for performing the change detection.

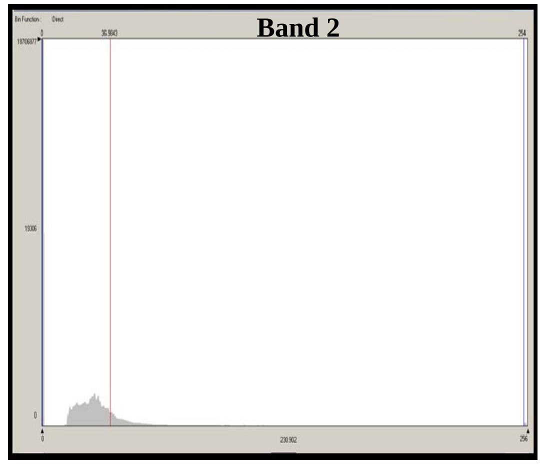
The histogram of each band of the 7 band Landsat TM image shows 256 gray levels [Fig. 8(a-g)], which helps to understand the distribution of data in the entire seven bands. As regards the statistics of different bands, Band 1 has the Minimum value of 0, Maximum of 254, Mean of 68.229 and standard deviation of 75.910. Band 2 also shows the Minimum of 0, Maximum of 254, Mean of 39.984 and a standard deviation of 50.98. Band 3 has a Minimum value of 0 and maximum of 254, mean of 42.506 and standard deviation of 58.723. The minimum, maximum, mean and standard deviation values for band 4 are 0, 254, 41.970 and 46.107 respectively. Similarly for Band 5 a minimum value of 0, maximum of 228, mean of 36.029 and standard deviation of 36.029 were observed. Band 6 has a minimum value of 0, maximum of 171, mean of 72.606 and a standard deviation of 52.260. Similarly, band 7 has a minimum of 0 and a maximum of 153 with a mean of 18.555 and standard deviation of 19.650.

Table 4: Sensor characteristics of Landsat Series

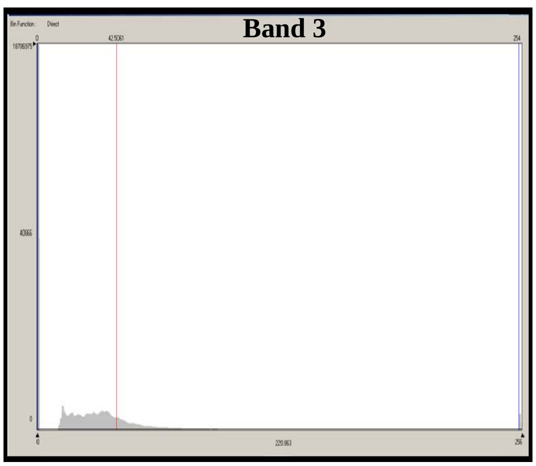
SENSOR	Band	Spectral Resolution (μm)	Spatial Resolution (m)	Use
MSS	4	0.5 – 0.6	79 x 79	Coastal zones, marine sediments
	5	0.6 – 0.7	79 x 79	Roads and Urban areas.
	6	0.7 – 0.8	79 x 79	Plant studies and mapping of earth/water boundaries.
	7	0.8 – 1.1	79 x 79	Plant studies and mapping of earth/water boundaries.
	8	10.4 – 12.6	240 x 240	
TM	**Band**	**Spectral Resolution (μm)**	**Spatial Resolution (m)**	**Use**
	1	0.45 – 0.52	30 x 30	Coastal mapping, soil vegetation discrimination, forest type mapping
	2	0.52 – 0.60	30 x 30	Vegetation discrimination, culture feature identification
	3	0.63 – 0.69	30 x 30	Plant species identification
	4	0.76 – 0.90	30 x 30	Vegetation type, biomass estimation, soil moisture determination, water body delineation
	5	1.55 – 1.75	30 x 30	Vegetation& soil moisture discrimination, differentiating snow from clouds
	6	10.4 – 12.5	120x120	Vegetation stress analysis, thermal mapping applications
	7	2.08 – 2.35	30 x 30	Mineral and rock type discrimination
ETM +	**Band**	**Spectral Resolution (μm)**	**Spatial Resolution (m)**	**Use**
	1	0.45 – 0.51	30 x 30	Ground/plant differentiation coastal zone
	2	0.52 – 0.60	30 x 30	Vegetation
	3	0.63 – 0.69	30 x 30	Differentiate plant species
	4	0.75 – 0.90	30 x 30	Biomass
	5	1.55 – 1.75	30 x 30	Snow/cloud differentiation
	6	10.4 – 12.5	60x60	Thermal
	7	2.08 – 2.35	30 x 30	Lithology
	8 (PAN)	0.52 – 0.90	15x15	



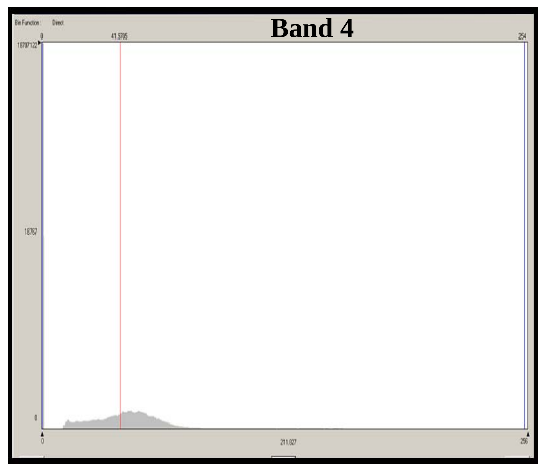
(a)



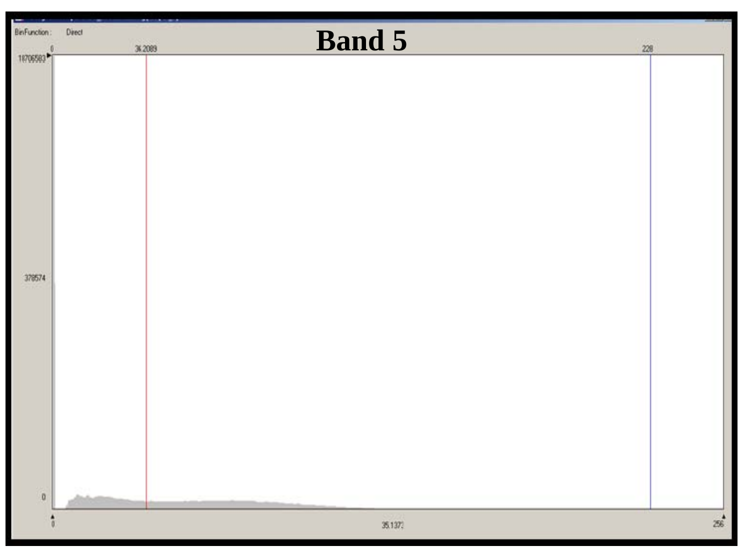
(b)



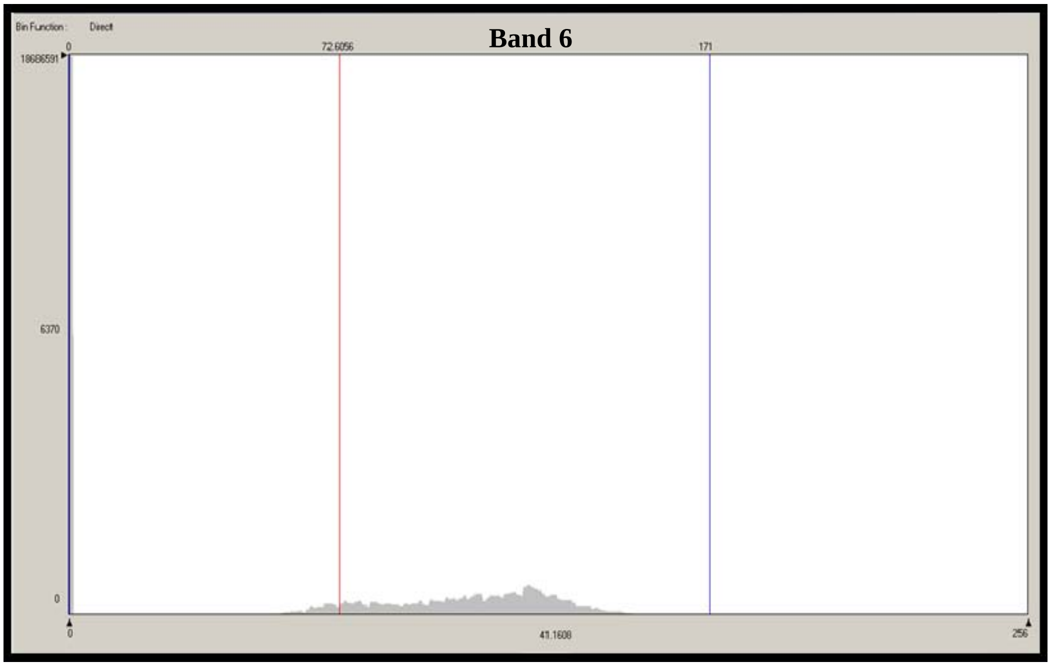
(c)



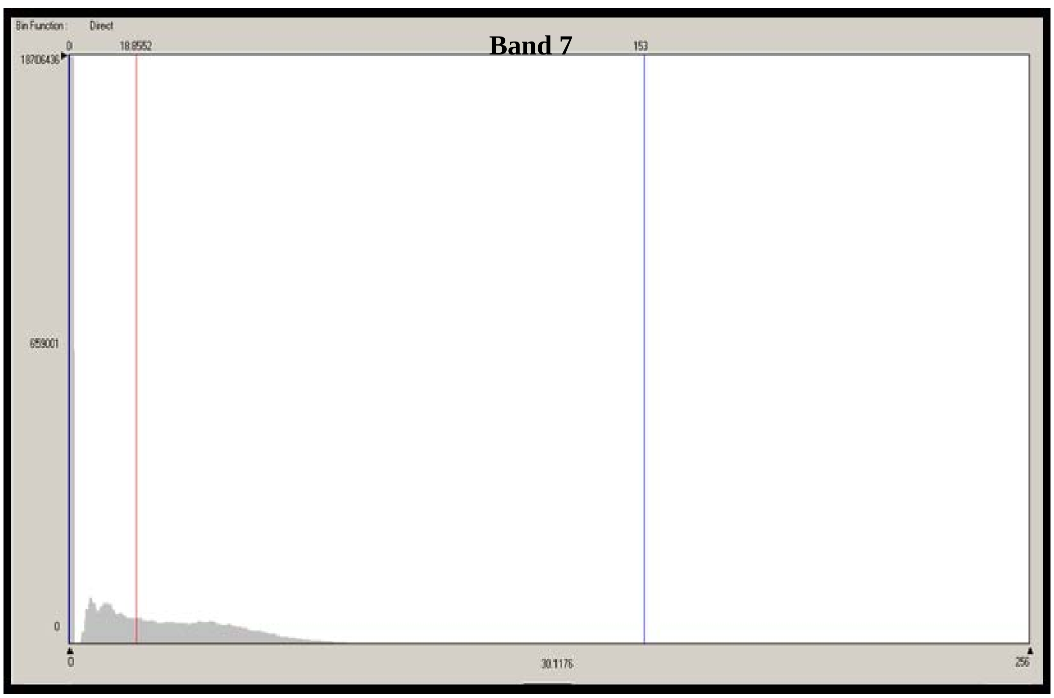
(d)



(e)



(f)



(g)

Fig. 8 (a-g): Distribution of data in 7 band Landsat TM Image

4.1.2 IRS LISS III Image

A 4-band IRS-P6, LISS-III image of 20th October 2005 (Fig. 9) represented the recent date satellite data for land use/ land cover classification in order to analyze the change that has occurred in the catchment area.

The IRS Satellite Systems are under the umbrella of National Natural Resource Management System (NNRMS), and coordinated at national level by the planning Committee of NNRMS (PC-NNRMS). The launch of IRS- IA on 17 March, 1988, which is the India's first civil remote sensing satellite, marked the beginning of successful journey in the international space programme. The two LISS (Linear Image Self Scanning) sensors on board IRS-IA, has aided its capabilities in large scale applications. Subsequently, the launch of IRS-IB on August 29, 1991 with same sensor provided better repetitive coverage. The introduction of PAN and WiFS (Wide Field Sensor) Sensors on IRS-IC Launched on December 28, 1995 and IRS-ID in September, 1997 further strengthened the scope of remote sensing applications in the areas like resource survey and management, urban planning, forestry studies, disaster monitoring and environmental studies (Chandra and Gosh, 2006). IRS-P6 was launched on 17th October 2003 and has four different sensors viz. LISS-III, AWIFS, LISS-IV (multispectral), and LISS-IV (PAN). IRS P6 LISS-III (Linear Imaging Self Scanner) sensor with four bands acquires the data of the Earth's surface in the short-wave-IR (SWIR) region besides visible band near-IR regions of the electromagnetic spectrum. The band-width for Band 1is (0.52-0.59µm), Band 2 (0.62-0.68µm), Band 3 (0.77-0.86µm) and Band 4(1.55-1.70µm). The radiometric resolution is 8 bit. It has a spatial resolution of 23.5m. The swath in the visible and near IR bands in 141 km, while SWIR has CCDs. The electro-optic modules are maintained at 20 ± 3 deg C. Different sensor characteristics of the IRS Satellite Systems are given in Table 5 and Table 6.

Table 5: Details on sensors carried onboard of IRS Satellite Missions

Sensor	Band	IRS -IA & IB	IRS-IC	IRS-ID
		Spectral range (µm)	Spectral range (µm)	Spectral range (µm)
LISS	1	0.45 -0.52		
	2	0.52 -0.59	0.52– 0.59	0.520.59
	3	0.62-0.68	0.62–0.68	0.62 – 0.68
	4	0.77–0.86	0.77–0.86	0.77 – 0.86
	5		1.55–1.70	1.55 – 1.70
PAN			0.50–0.75	0.50 – 0.75
WiFS	1		0.62–0.68	0.62 – 0.68
	2		0.77–0.86	0.77 – 0.86
	3			1.55 – 1.75

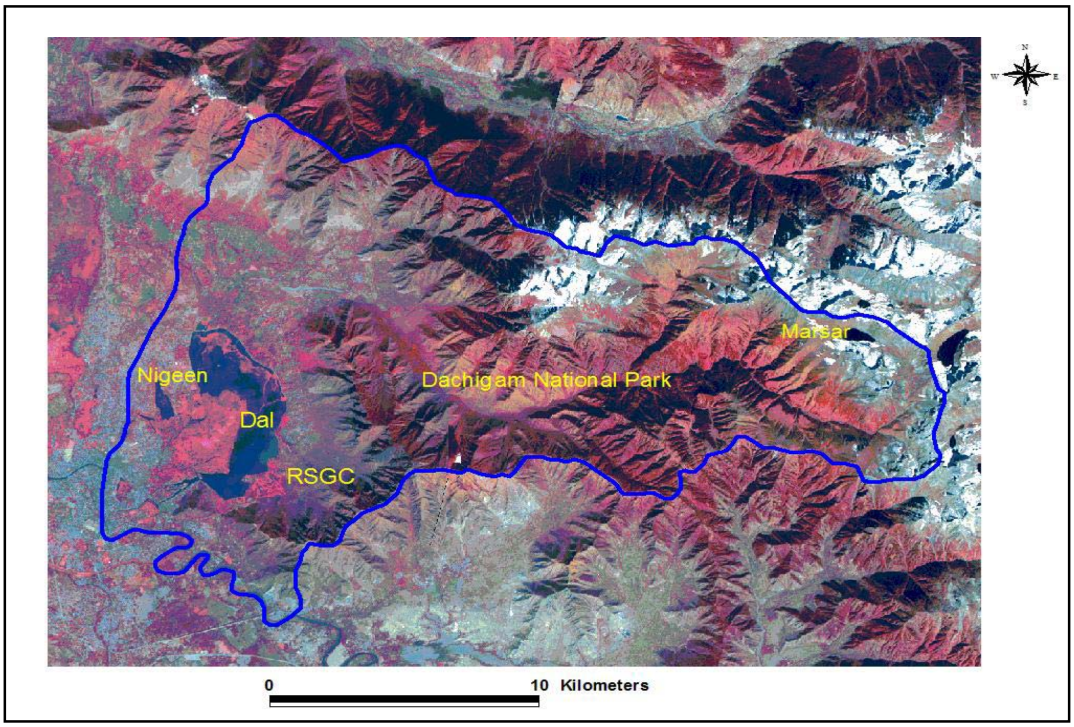


Fig. 9: IRS LISS III Image of the study area

Table 6: Details of the various IRS missions launched and their salient features

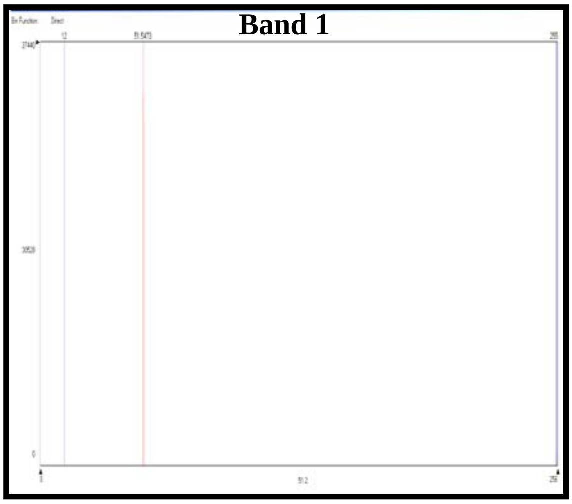
Characteristics	IRS IA & IB	IRS IC	IRS ID
Orbit	Near polar	Near polar	
	Sun-Synchronous	Sun-Synchronous	Sun-Synchronous
Altitude	914 km	817 km	821km
Inclination	99.028^0	98.69^0	98.62^0
Orbital period	103.192 minutes	101.35 minutes	100.56 minutes
Repeat cycle	26 days	24 days	24 days,5 days for PAN &WiFs
Swath width	148km(LISS I)	141km (LISSIIIVIS)	141m (LISS III VIS)
	74 km (LISS II)	148km(LISS SWIR)	148km(LISS SWIR)
		70km(PAN)	70km(PAN)
		810km (WiFS)	812km (WiFS)
Spatial resolution	72.50m(LISS I)	23.5m (LISS III V& NIR)	23.5m (LISS III V& NIR)
	36m(LISS II)	23.5m (LISS III V& NIR	23.5m (LISS III V& NIR)
		70.0m (LISS III SWIR)	70.0m (LISS III SWIR)
		5.8m (PAN)	5.8m (PAN)
		188.3m (WiFS)	188.3m (WiFS)

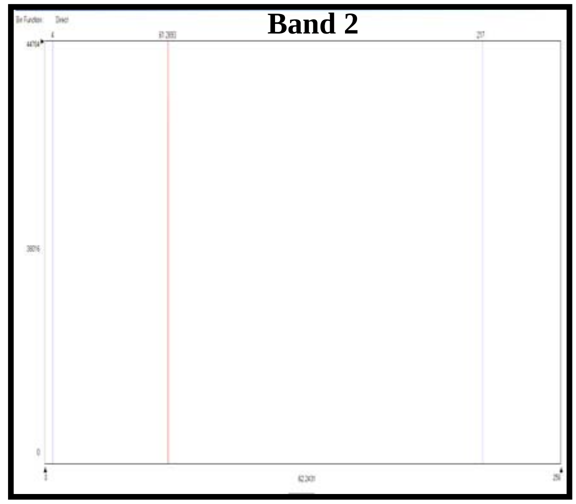
The band combination used in this study was 3:2:1(IR: R: G), with each band exhibiting a characteristic histogram [Fig.10 (a–d)]. The statistics of the bands reveal that band 1 has a minimum of 15, maximum of 255, mean of 82.006 and standard deviation of 30.198. Band 2 has a minimum of 12, maximum of 255, mean of 51.547 and a standard deviation of 26.113. Similarly, the statistics of band 3 show a minimum, maximum, mean and standard deviation of 4, 217, 61.289 and 22.003 respectively. Band 4 shows a minimum of 9, maximum of 182, mean of 58.582 and standard deviation of 25.183.

4.1.3 Shuttle Radar Topographic Mission (SRTM) DEM

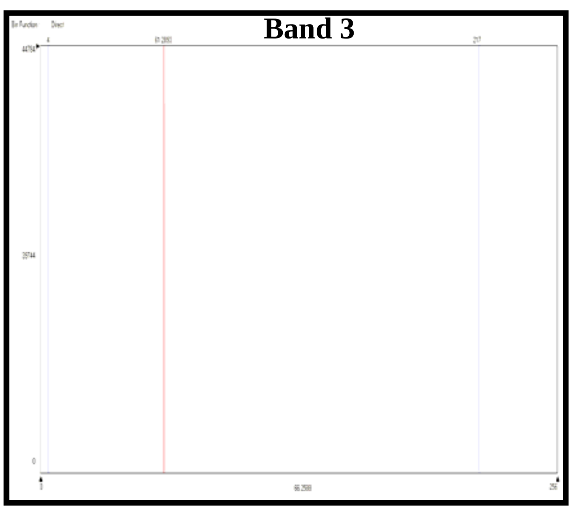
A digital elevation model (DEM) is a digital representation of ground surface topography or terrain. It is also widely known as a digital terrain model (DTM). A DEM can be represented as a raster (a grid of squares) or as a triangular irregular network. DEMs are commonly built using remote sensing techniques, but they may also be built from land surveying. DEMs are used often in geographic information systems, and are the most common basis for digitally-produced relief maps. Elevation is a numerical variable referring to the height above mean sea level of each cell and is directly available from the DEM. A number of products such as slope, aspect, slope gradient, drainage contributing area, etc. can be generated from the DEM.

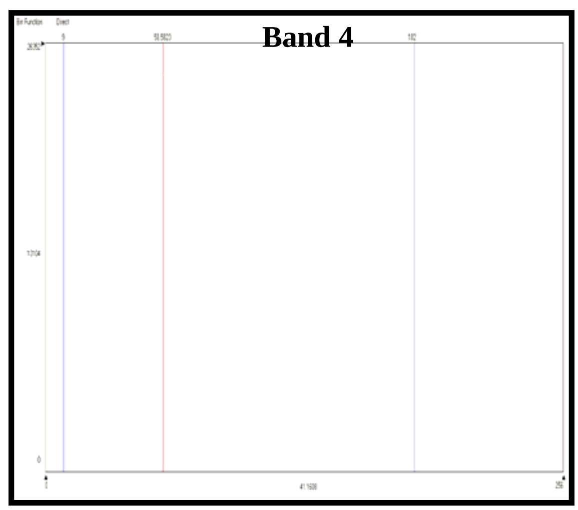
During the present study, the 90 m SRTM (Shuttle Radar Topography Mission) was used. SRTM is a joint project between NASA and NGA National Geospatial-Intelligence Agency (NGA), to map the Earth’s land surface in three dimensions at a level of unprecedented detail, flown aboard the NASA Space Shuttle Endeavour February 11-22, 2000. The mission objective is to obtain single-pass interferometric SAR imagery to be used for DEM (Digital Elevation Model, also referred to as DTM = Digital Terrain Model) generation, i.e. topographic maps. Coverage of the Earth's land surfaces is provided between the latitudes of -54º and +60º, representing nearly 80% of the land masses. The SRTM DEM data have been produced using radar images gathered from NASA’s shuttle. Two antennae receive the reflected radar pulses at the same time, one antenna located in the shuttle’s cargo bay, the other at the tip of a 60-m-long mast.





(a) (b)





(c) (d)

Fig. 10 (a-d): Distribution of data in 4 band LISS III Image

This configuration allows single -pass radar interferometry, and consequently the generation of a highly accurate global elevation model with a vertical accuracy of 6 m and a horizontal pixel spacing of 30 m. The data cover the entire globe (latitudes 60N – 60S), with downgraded resolution of 3 arc-seconds. The 1-second original data have been made available to the public only for North America. Whilst the data coverage is global, some regions are missing because of a lack of contrast in the radar image, presence of water, or excessive atmospheric interference. These data holes are especially concentrated along rivers, in lakes, and in steep regions (often on hillsides with a similar aspect due to shadowing, particularly in the Himalayas and the Andes). This non-random distribution of holes, ranging from 1 pixel to regions of 500 km^2, impedes the potential use of SRTM data, and has been the subject of a number of innovative algorithms for "filling-in" the holes through various spatial analysis techniques. These include spatial filters, iterative hole filling, and interpolation techniques.

Although the absolute accuracy specifications were stated as ±16 m vertical linear error and ±20 m horizontal circular error at the 90% confidence levels, many accuracy tests showed that the performance of SRTM data against with real data is better than expected. That the comparison results yield lower than the anticipated error characteristics has raised the demands of end-users from the SRTM The finished SRTM data were referenced to the WGS84 ellipsoid for horizontal datum, i.e. geographical coordinates, and to mean sea level defined by EGM 96 geoid for vertical datum. The elevations are arranged into tiles, each covering one-degree of latitude and one degree of longitude, named according to their south-western corners. The data are available in 1 arc second, 3 arc second and 30 arc second resolutions. The resolution of the source data is 1 arc second, but this data have only been released over United States territory; for the rest of the world, only 3 arc second and 30 arc second data are available. Each one arc second tile has 3601 rows, each consisting of 16 bit "big-endian" (Motorola byte-order standard) cells. The dimensions of the 3 arc second tiles are 1201 rows and 1201 columns. The tiles are prepared as DEM-grid that can also be converted into pixels (1200×1200). Although the native file format, which has the extension "hgt", is called SRTM, the data are also available in some other common formats. SRTM was an example of engineering at its best; it marked a milestone in the field of remote sensing. In the span of 7 years, the project evolved from concept to final data product, with 4 years of flight segment development, 10 days of observations, and one additional year of ground processor development. This was capped by 9 months of data production. Table 7 gives the data statistics of the SRTM DEM.

During the present study, the SRTM digital elevation model formed an important data set as it was used to generate a number of parameters such as topographic details of the Dal Lake catchment including slope, elevation, relief etc. The DEM also proved to be useful in understanding the different land use classes of the area, as the terrain determines the spatial variability of the land use classes. Different watershed characteristics including slope, slope length etc of study area were generated from the DEM. Besides, it also formed an integral component of the GIS based AVGWLF model used for generating erosion and pollution loads.

Fig. 11 shows the SRTM digital elevation model of the study area. The elevation of the Dal lake catchment varies between 1552 – 4342 meters. The north-eastern part of the study area shows maximum relief, whereas the western part shows a lower relief. In general, the regional slope of the area is towards the west. The maximum elevation shown by the SRTM digital elevation model in the study area is 4342 meters.

4.2 Field Study Data

Field survey formed an important aspect of the current study programme. The survey was conducted at different time periods during the research period for:

4.2.1 Soil Sample Data Collection

Soil samples pertaining to different land use land cover categories in the catchment area of the lake were collected to analyze different parameters related to soil viz. texture, organic carbon, NPK etc in order to generate the soil map.

Table 7: Data statistics of SRTM DEM

Launch date	11 February 2000	
Duration	11 days	
Altitude	275-km orbit (approx)	
Parameters	**C-Band**	**X-band**
Wave length	5.6cm	3.1cm
Frequency	5.3Ghz	9.6Ghz
Look angle	30º-60º	50º-60º
Swath width	225km	50km
Baseline separation	60m	30m

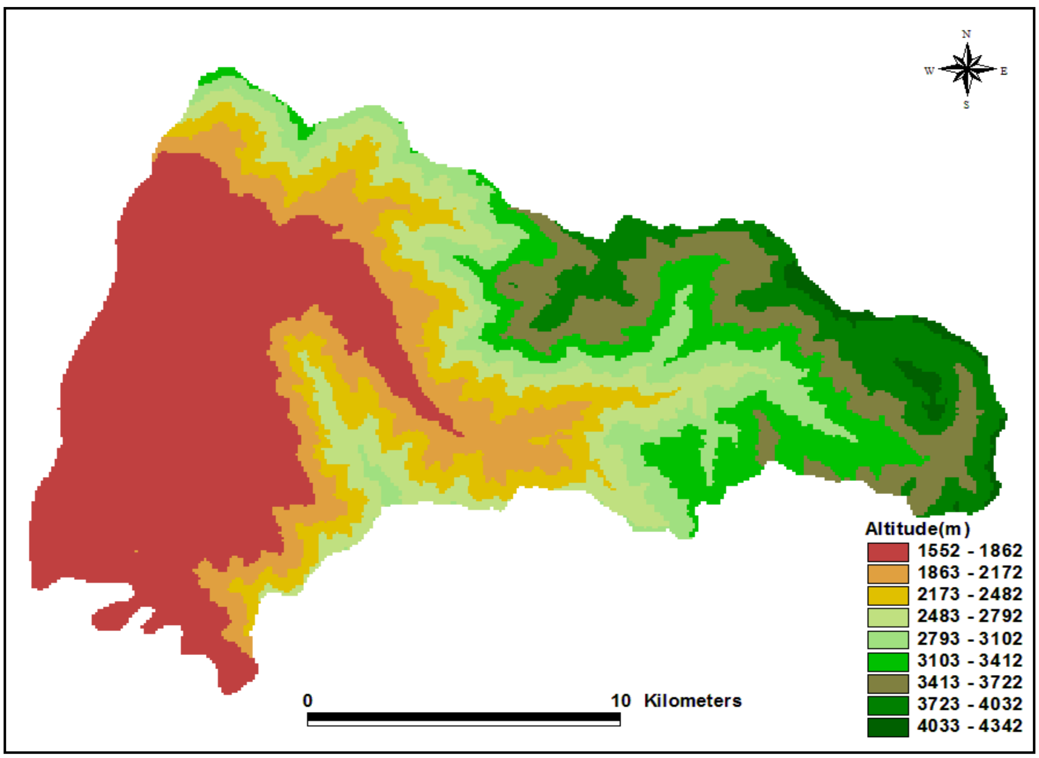


Fig. 11: SRTM Digital Elevation Model of the study area

4.2.2 Ground Truth Data Collection

The gathering of ground-truth information often referred to as reference data, involves collecting measurements or observations about objects, areas, or phenomena that are being remotely sensed (Lillesand and Kiefer, 1994). The land use /land cover maps generated through remote sensing were validated in the field through extensive field survey. Various management practices like the use of cover crops, terracing/ contour farming etc. carried out in the catchment were also identified. Besides, the identification of critical source areas in the lake as well as the in the catchment was carried out during the ground survey.

4.2.3 Hydro-metrological Data Collection

The hydro-metrological data was collected for the Dal Lake Catchment from the SKUAST-K, Shalimar station, Srinagar from 1981-2008. The data consisted of daily rainfall and daily temperature (minimum and maximum).

4.3 Ancillary Data

Ancillary data formed an important data source during the present study. A variety of secondary data sources were used during this study which comprised of:

4.3.1 Topographic Maps

A topographic map is a type of map characterized by large-scale detail and quantitative representation of relief, usually using contour lines in modern mapping, but historically using a variety of methods. Traditional definitions require a topographic map to show both natural and man-made features. During this study, SOI topo sheets dated 1969 were used, which served as the base maps to have a broad and general understanding of the study area.

4.3.2 Socioeconomic Data

The Census data (2001) was used as a source of socioeconomic data in the present research. Data produced by census is an important source of information needed for effective development, planning, and monitoring of population, services distribution, and socio economy. As Census data is relatively inexpensive and highly reliable, it represents one of the main sources of data and information. In the present study, the main objective of socioeconomic assessment was to identify various socioeconomic positive and negative impacts that can be implicated by different socioeconomic variables on the health of the Dal Lake.

4.3.3 Reports

During the present study, available statistics, government reports and scientific articles formed an important component of the secondary data. Data was collected from the Jammu and Kashmir Lakes and Waterways Development Authority (LAWDA) related to the sediment and nutrient concentrations for the validation of model simulation results. The Jammu and Kashmir Department of Tourism provided the data pertaining to the hotels and guest houses located in the Dal Lake Catchment. Moreover, data related to the number and capacity of houseboats in Dal Lake was provided by the House Boat Owners Association, Kashmir.

4.4 Field Equipments

Equipments in the form of GPS receiver, trowel, polythene sheets, 1 kg capacity polythene bags, 1 liter capacity plastic bottles and digital camera were used during the field survey. The GPS was used for the validation of land use/ land cover map of the study area. The location and identification of open drains entering into the lake at different points were also marked with the help of GPS. Trowel and polythene sheets were used for the collection of soil samples which were then stored in 1 kg capacity polythene bags.

CHAPTER - 5

METHODOLOGY

For understanding the process of lake degradation, that is quite complex in nature, a multidisciplinary approach is required with inputs from landscape, hydrology, climate and even socioeconomics of the catchment as these characteristics are the main determinants of the level of lake degradation (Puijenbroek and Knoop, 2004). In order to accomplish the research objectives outlined in the first chapter of the thesis, it is important to use a host of methods that includes the use of satellite remote sensing data, field observations, hydrological data, digital elevation data, secondary/ ancillary data, geospatial tools, simulation modeling and socioeconomic data analyses. Fig. 12 shows the schematic flow chart of the methods which were employed to accomplish the research objectives. The sequential details of the methodology adopted for carrying out the various tasks related to the research objectives are discussed in the following paragraphs.

5.1 Geospatial Modelling

The advancement in the field of geospatial modelling, data acquisition and computer technology has facilitated the use of geoinformatic tools in pollution control programs (Olivieri *et al.,* 1991; Prakash *et al.,* 2000; Evans *et al.,* 2002; Melesse *et al.,* 2007). Models are simulations of the real environment that allow us to interpolate between temporal sampling and extrapolate spatially to other areas that are not sampled. When suitably parameterized, calibrated, and verified, models can predict (with accuracy and precision) concentrations in space and time where and when empirical sampling data are not adequate for locally determined needs (Tim *et al.,* 1992; Hinaman, 1993; Liao and Tim, 1997; Wong *et al.,* 1997; Hartkamp *et al.,* 1999; Raterman *et al.,* 2001; Sample *et al.,* 2001; Evans and Corradini, 2007). Geospatial models are excellent tools that allow us to predict the hydrological and other land surface processes and phenomena at different spatial and time scales (Young *et al.,* 1989; Shamsi, 1996; Zollweg *et al.,* 1996; Frankenberger *et al.,* 1999; Olivera and Maidment, 1999; Romshoo, 2003; Yuksel *et al.,* 2008).

In order to simulate the erosion, sediment and pollution loads in the Dal Lake Catchment, the GWLF (Generalized Watershed Loading Function) Model was used.

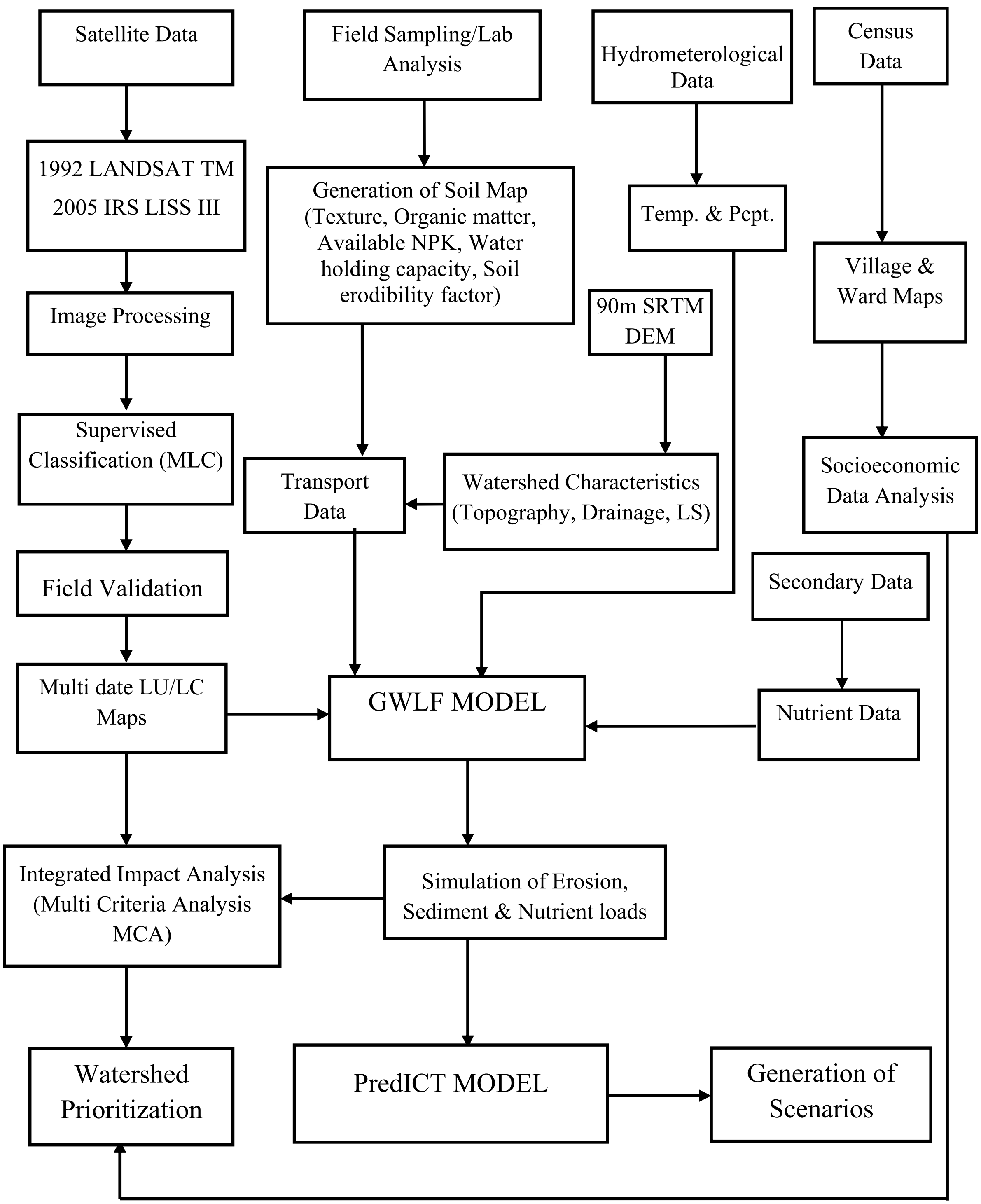


Fig. 12: General methodology adopted during the study

5.1.1 Overview of the GWLF Model

The GWLF (Generalized Watershed Loading Function) model was developed by Haith and Shoemaker (1987). The model provides the ability to simulate runoff, sediment, and nutrient (N and P) loads from a watershed given variable-size source areas (i.e., agricultural, forested, and developed land) on a continuous basis and uses daily time steps for weather data and water balance calculations (Haith *et al.,* 1992; Lee *et al.,* 2001; Evans *et al.,* 2008). Other than the non point source simulations, it also has algorithms for calculating septic system loads, and allows for the inclusion of point discharge data. The model is particularly useful for application in regions where environmental data of all types is not available to assess the point and non-point source pollution from watershed (Evans *et al.,* 2002; Strobe, 2002). The advantage of this model is the ease of use and reliance on input datasets less complex than those required by other watershed-oriented water quality models such as SWAT, SWMM and HSPF (Deliman *et al.,* 1999). The model has also been endorsed by the U.S. EPA as a good "mid-level" model that contains algorithms for simulating most of the key mechanisms controlling nutrient fluxes within a watershed (U.S. EPA, 1999).

The GWLF model is considered to be a combined distributed/lumped parameter watershed model in nature. For surface loading, it is distributed in the sense that it allows multiple land use/cover scenarios, but each area is assumed to be homogenous in regard to various attributes considered by the model. Additionally, the model does not spatially distribute the source areas, but simply aggregates the loads from each source area into a watershed total; in other words there is no spatial routing. The model acts as a lumped parameter model for sub-surface loading, using a water balance approach. Daily water balances are computed for an unsaturated zone as well as a saturated sub-surface zone, where infiltration is simply computed as the difference between precipitation and snowmelt minus surface runoff plus evapo-transpiration. For execution, the model requires three separate input files containing transport, nutrient, and weather related data. The transport file defines the necessary parameters for each source area to be considered (e.g., area size, curve number, etc.) as well as global parameters (e.g., initial storage, sediment delivery ratio, etc.) that apply to all source areas. The nutrient file specifies the various loading parameters for the different source areas identified (e.g., number of septic systems, urban source area accumulation rates, manure concentrations, etc.). The weather file contains daily average temperature and total precipitation values for each year simulated.

5.1.2 Model Structure and Mechanism

The GWLF model includes dissolved and solid phase nitrogen and phosphorous in stream flow from different sources. Dissolved loads from each source area are transported in runoff water and eroded soil from numerous source areas, each of which is considered uniform with respect to soil and cover.

The GWLF model estimates dissolved liquid and solid phase Nitrogen and Phosphorous in stream flow from the various sources as given in equation 1 and equation 2 below (Haith and Shoemaker, 1987.). Dissolved nutrient loads are transported in runoff water and eroded soil from numerous source areas, each of which is considered uniform with respect to soil and land cover.

$$LD_m = DP_m + DR_m + DG_m + DS_m \qquad \textbf{(1)}$$

$$LS_m = SP_m + SR_m + SU_m \qquad \textbf{(2)}$$

Where, LD_m & LS_m are the dissolved and solid phase nutrient load respectively (kg), DP_m & SP_m are the point source dissolved and solid phase nutrient load respectively (kg), DR_m & SR_m are the rural runoff dissolved and solid phase nutrient load respectively (kg), DG_m is the Ground water dissolved nutrient load (kg), DS_m is the Septic system dissolved nutrient load (kg), SU_m is the Urban runoff nutrient load (kg).

Dissolved loads from each source area are obtained by multiplying runoff by dissolved concentration as given in Eq. 3.

$$LD_m = 0.1\sum_{t=1}^{d_m} Cd_k * Q_{kt} * AR_k \qquad \textbf{(3)}$$

Where, LD_m is monthly load from each source area, Cd_k, the nutrient concentration in runoff from source area k (mg/l), Q_{kt} is the runoff from source area k on day t (cm),

AR_k is area of source area k (ha), d_m is number of days in month m.

The direct runoff is estimated from daily weather data using Soil Conservation Services (SCS) curve number equation given by Eq. 4

$$Q_{kt} = \frac{(R_t + M_t - 0.2DS_{kt})^2}{R_t + M_t + 0.8DS_{kt}} \quad \textbf{(4)}$$

Rainfall R_t (cm) and snowmelt M_t (cm of water) on the day t (cm), are estimated from daily precipitation and temperature data. DS_{kt} is the catchment's storage. Catchment storage is estimated for each source area using CN values with the Eq. 5 given below

$$DS_{kt} = \frac{2540}{CN_{kt}} - 25.4 \quad \textbf{(5)}$$

Where, CN_{kt} is the CN value for source area k, at time t.

Stream flow consists of runoff and discharge from groundwater. The latter is obtained from a lumped parameter watershed water balance (Haan, 1972). Daily water balances are calculated for unsaturated and shallow saturated zones. Infiltration to the unsaturated and shallow saturated zones equals the excess, if any, of rainfall and snowmelt runoff. Percolation occurs when unsaturated zone water exceeds field capacity. The shallow saturated zone is modelled as linear ground water reservoir. Daily evapotranspiration is given by the product of a cover factor and potential evapotranspiration (Hamon, 1961). The latter is estimated as a function of daily light hours, saturated water vapour pressure and daily temperature.

Monthly solid phase nutrient load are estimated using equation 6 given below. The solid phase rural nutrient loads are given by the product of the monthly sediment yield and average sediment nutrient concentration.

$$SR_m = 0.001 * C_s * Y_m \quad \textbf{(6)}$$

Where, SR_m is the solid phase rural nutrient load, C_s is the average sediment nutrient concentration (mg/l), Y_m watershed sediment yield (mg). Erosion is computed using the Universal Soil Loss Equation (USLE) and the sediment yield is the product of erosion and sediment delivery ratio. The yield in any month is proportional to the total capacity of daily runoff during the month.

Erosion from source area (k) at time t, X_{kt} is estimated using the following equation:

$$X_{kt} = 0.132 * RE_t * K_k * (LS)_k * C_k * P_k * AR_k \qquad \textbf{(7)}$$

Where, $K_k, (LS)_k, C_k$ & P_k are the soil erodibility, topographic, cover and management and Supporting practice factor as specified by the USLE (Wischmeier and Smith, 1978). RE_t is the rainfall erosivity on day t (MJ – mm/ha-h).

Soil loss from stream bank erosion is based upon the familiar sediment transport function having the form

$$LER = aQ^{0.6} \qquad \textbf{(8)}$$

Where *LER* is the lateral erosion rate in m/month which refers to the total distance that soil is eroded away from both banks along the entire length of a stream during a specified period of time, *a* is an empirically-derived erosion potential factor, and *Q* is mean monthly stream flow in m^3/sec. In this case, the value of 0.6 used based on a global review of stream bank erosion studies (Van Sickle and Beschta, 1983; Lemke, 1991; Rutherford, 2000)

Nutrient load from ground water source DG_m are estimated with the equation given below;

$$DG_m = 0.1 * C_g * AT * \sum_{t=1}^{d_m} G_t \qquad \textbf{(9)}$$

Where, C_g is the nutrient concentration in ground water (mg/l), AT is the Watershed area (ha) and G_t is the Ground water discharge to the stream on day t (cm).

Septic systems are classified according to four types: normal systems, ponding systems, short circulating systems and direct discharge systems. Nutrient loads from septic systems are calculated by estimating the per capita daily loads from each type of system and the number of people in the watershed served by each type. Monthly nutrient load from on-site septic system are estimated with equation given below;

$$DS_m = NS_m * SS_m * PS_m + DDS_m \qquad \textbf{(10)}$$

Where, DS_m is the total septic loads per month (m), NS_m is the monthly (m) loads from normal septic system, SS_m is the monthly (m) loads from short-circuited septic system, PS_m is the monthly (m) loads from ponded septic system, DDS_m is the monthly (m) loads from direct discharge system

The Urban nutrient loads, SU_m assumed to be entirely solid phase, are modelled by exponential accumulation and wash off function proposed by Amy *et al.* (1974) and Sartor and Boyd (1972). Nutrients accumulate on urban surfaces over time and are washed off by runoff events.

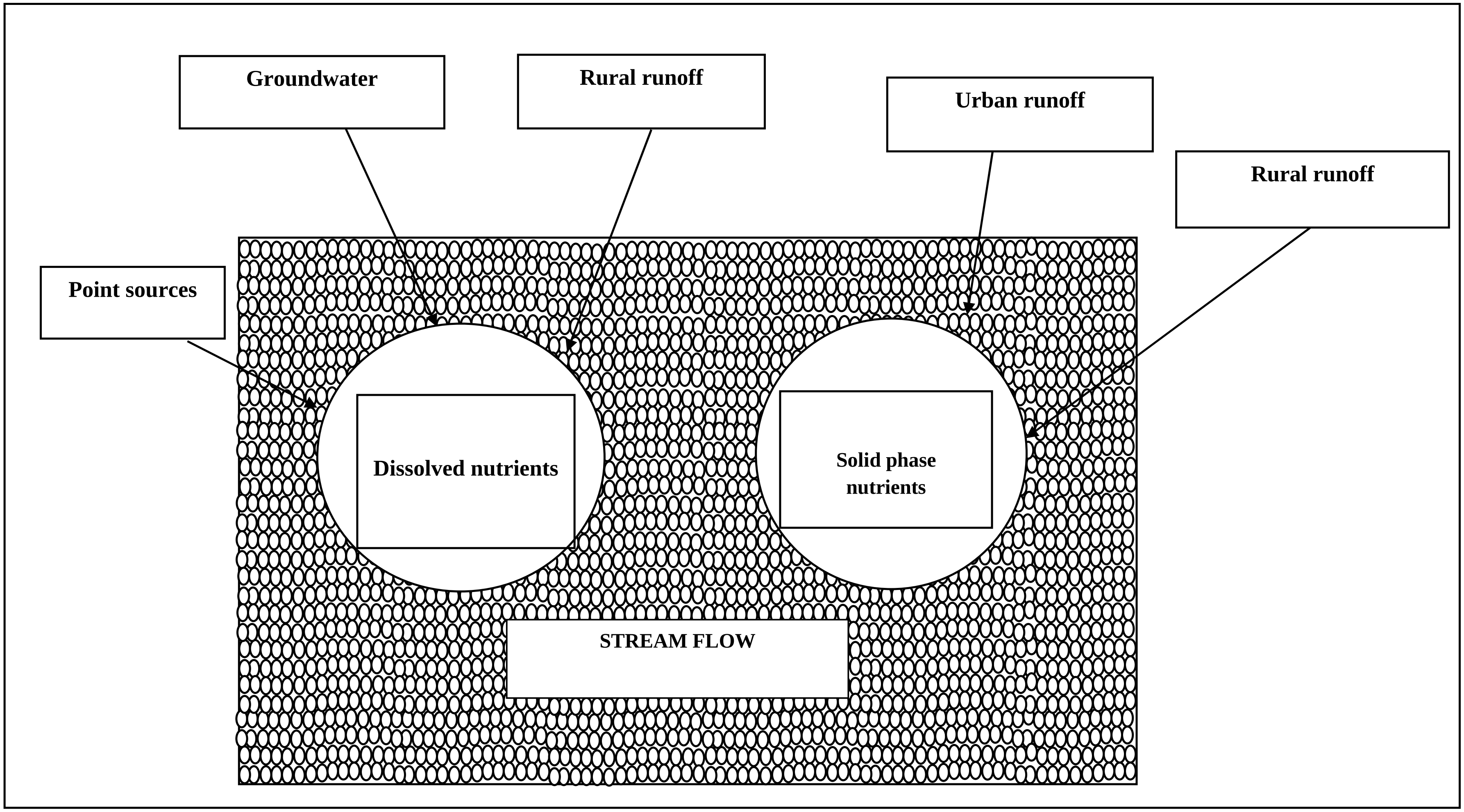


Fig. 13: Model structure for nutrient source in GWLF (adapted from Haith *et al.*, 1992)

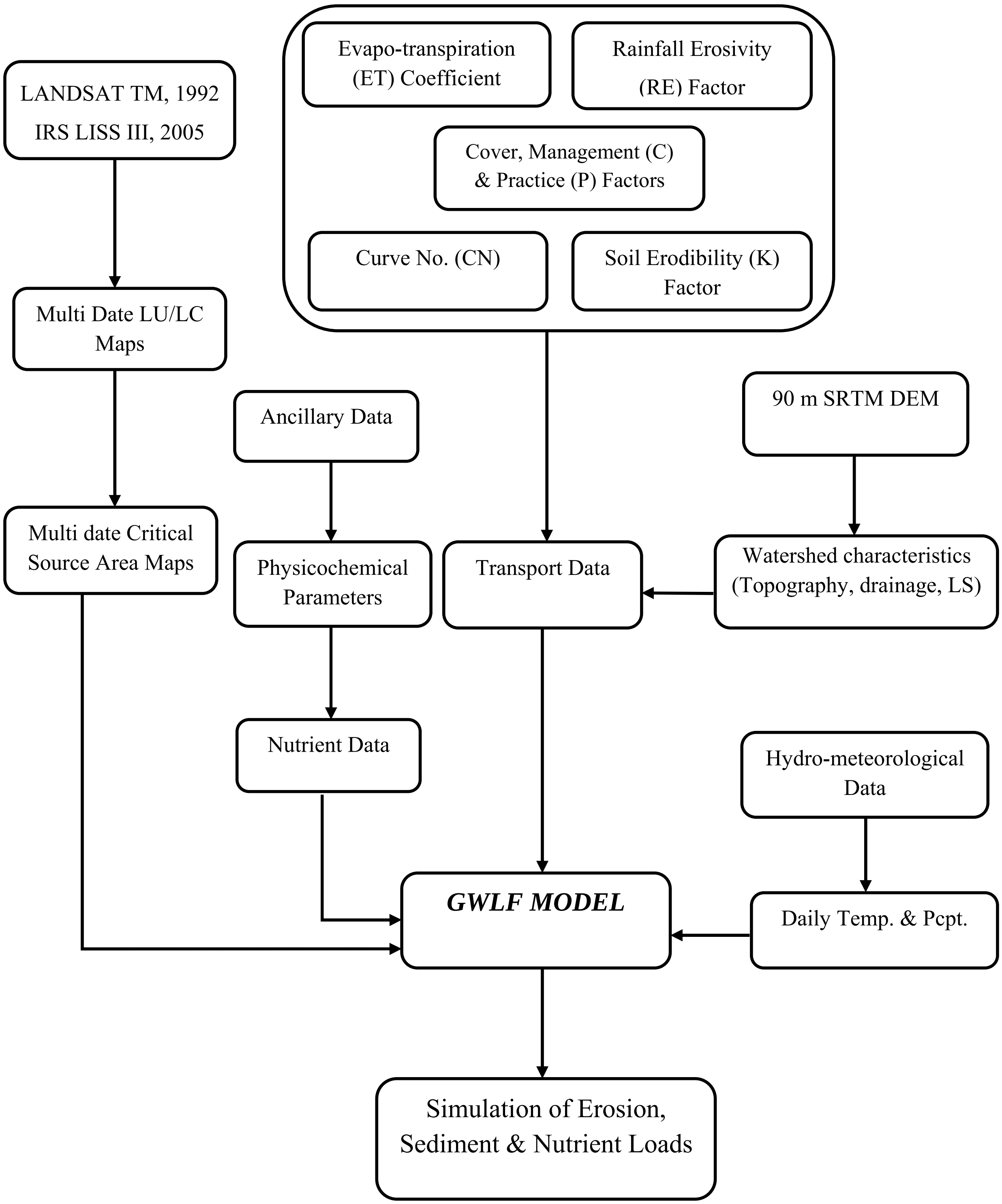


Fig. 14: Methodology adopted for the GWLF Model

5.1.3 Generation of Model Input Files

For simulation of erosion, sediment and nutrient yields, the GIS based GWLF model requires various types of input data at the watershed level such as land use/land cover data, digital topographic data, hydro-meteorological data, transport parameter data (hydrologic and sediment) and nutrient parameter (nitrogen and phosphorus) data. The procedure for the generation of the input data and their use in simulating the catchment level erosion, sediment and nutrient loads is given in the following paragraphs:

5.1.3.1 Land use/ Land cover Data

Land use/ Land cover (LU/LC) data forms an integral component of all the hydrological based models. This information is very critical for assessing a number of land surface processes and has been identified as one of the most important direct drivers of terrestrial ecosystem change that affects the biogeochemical cycles, climate, and hydrology of an ecosystem. The land use/ land cover layer is one of the most critical layers used within GWLF model, since pollutant loads emanating from a watershed are largely dictated by land surface conditions (Evans and Corradini, 2008). In case of the GWLF model, the land use/ land cover data forms an important input that helps us in identifying the various critical source areas or the runoff sources (Haith and Tubbs, 1981; Delwiche and Haith, 1983). During the present study, two different dated satellite imageries i.e., 1992 and 2005 were used. The main purpose of using the multi date data was to carry out the change detection in land use/land cover of the Dal Lake Catchment from 1992-2005 i.e., 15 years and also to assess how this change has impacted upon the erosion, sediment and nutrient fluxes in the catchment.

In order to generate the LU/LC data set, multi date satellite data in form of LANDSAT TM (1992) and IRS LISS III (2005) was used. Remote sensing has a long and successful history of application in generating LU/LC information on operational basis (Hausen *et al.,* 1996; Foody, 2002). Fig. 15 shows the methodology that was adopted for the land use/ land cover characterization of the study area. The methodology for image processing of the satellite data is described as under:

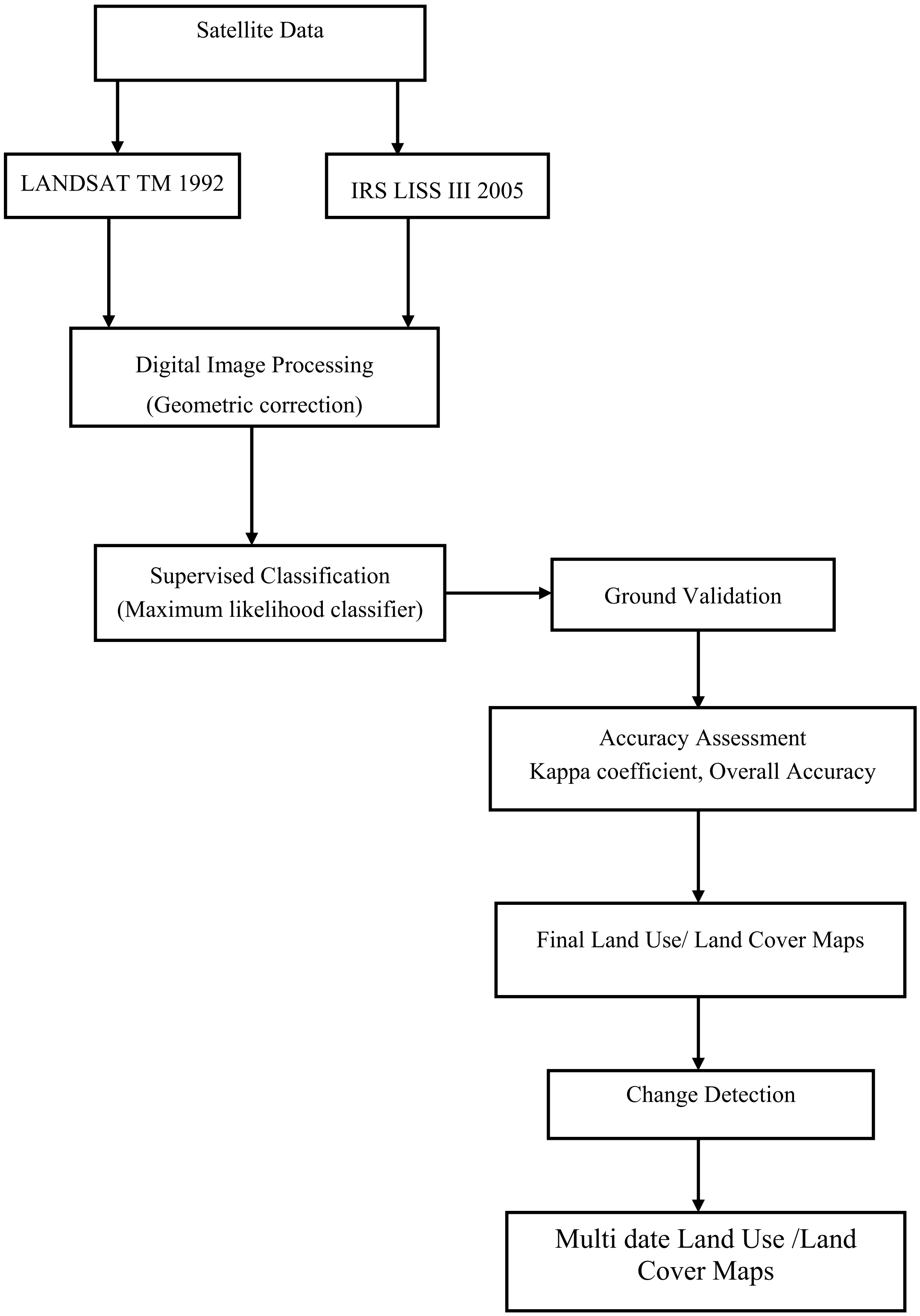


Fig. 15: Methodology adopted for Land use/ Land cover characterization of Dal Lake Catchment

5.1.3.1a Satellite Data Processing

Before using the satellite data for classification, the data was preprocessed using the image processing technique which involves the manipulation and interpretation of digital images so that the results become more interpretable and reproducible. The main aim of preprocessing is to improve the quality of data by rectification and restoration of the distortions and degradations that stem from the image acquisition process. This technique typically involves the correction for geometric distortions, radiometric calibrations and elimination of noise (Lillesand and Kiefer, 2000). The step wise procedure adopted for image processing technique is given as under:

Geometric Correction

When image data is recorded by sensors on satellites and aircrafts, it contains errors in geometry which are so significant that the data cannot be directly used as a map base. These errors can arise from a variety of sources ranging from variations in altitude, attitude, and velocity of the sensor platform to factors such as panoramic distortion, earth curvature, atmospheric refraction, relief displacement. The purpose of geometric correction is to compensate for the distortions introduced by these factors so that the corrected image will have the geometric integrity of a map (Lillesand and Kiefer, 1987). Rectification is the process of projecting the data onto a plane, and making it conform to a map projection system. A georeference uses a coordinate system, which contains projection information. The image was geometrically corrected in ERDAS Imagine and referenced to Universal Transverse Mercator (UTM) coordinate system with WGS 84 datum.

In the geometric correction process, 80 Ground Control Points (GCPs) were taken from different part of the study area and were located both in terms of their two image coordinates on the distorted image and on the high accuracy image in UTM coordinate system with WGS 84 datum. These values were submitted to least square regression analysis to determine two coordinate transformation equation that was used to inter-relate the geometrically corrected image coordinates with distorted image coordinates. The next step was to find the corners of the rectified image to the distorted image. This was done using the nearest neighbouring resampling which has the advantage that pixel values are real as they are directly copied from the image and no interpolation algorithms are used. The final rectified image was obtained with Root Mean square error (RMSE) of 1.146.

Radiometric Correction

When the emitted or reflected electromagnetic energy is observed by a sensor on board an aircraft or spacecraft, the observed energy does not coincide with the energy emitted or reflected from the same observed from a short distance. This is due to the sun's azimuth and elevation, atmospheric conditions such as fog or aerosols, sensor's response etc. which influence the observed energy. Therefore, in order to obtain the real irradiance or reflectance, those radiometric distortions must be corrected. Radiometric correction is a pre-processing technique to reconstruct physically calibrated values by correcting the spectral distortions caused by sensors, sun angle, topography and the atmosphere. Radiometric correction is generally done by absolute correction and relative correction. Absolute correction involves the measurement or conversion of correct radiance or reflectance by using the sensor calibration data, the sun angle and view angle, atmospheric models and ground truth data. However, this method cannot be applied in most applications because of the complicacy of atmospheric models and exact measurement of atmospheric conditions. The relative correction involves the normalization of multi-temporal data taken on different dates to a selected reference data at specific time.

If we consider a homogeneous land surface and similar atmospheric condition, the amount of received energy is a function of bandwidth of the spectral channel. In case of satellite sensing in the visible and near infrared portion of the spectrum, it is often desirable to generate mosaics of images taken at different times or to study the changes in the reflectance of ground features at different times and location. In such applications, it is usually necessary to apply a sun elevation correction and an earth-sun distance correction, the sun elevation correction accounts for seasonal position of sun relative to the earth. Through this process, image data acquired under different solar illumination angles are normalized by calculating the brightness values assuming that the sun was at the zenith on each day of sensing. The earth-sun distance correction is applied to normalize for the seasonal changes in the distance between the earth and the sun. The other radiometric corrections applied are the noise removal. The noise is any unwanted disturbances in the image data that are due to limitation in the sensing or data recording process. However, the data used in this study was already radiometrically corrected prior to acquisition.

5.1.3.1b Satellite data Classification for Land use/ Land cover

Among digital techniques, image classification is a common and powerful information extraction method (machine or automated interpretation) that involves sorting pixels into a finite number of individual classes, or categories of data, based on their data file values. Also known as image segmentation, classification involves the application of pattern recognition theory to multispectral images. The overall objective of classification procedures is to categorize all the pixels of an image into different land use/ land cover classes. The processes of classification involve conversion of satellite data (DN values) into different classes or themes of interest. The output of classification is a classified image usually called as thematic map of image (Lillesand *et al.,* 2004). The two basic approaches employed for digital image classification include unsupervised and supervised classification. Several variations of these methods exist. Each process uses multiband images to isolate unique spectral classes.

There are various classification algorithms that may be used to assign an unknown pixel to one of a number of classes. The choice of an approach assumes that the observed measurement vectors X_c obtained for each spectral band during the training phase of the supervised classification particular classifier or decision rule depends on the nature of input data and desired output. These classification algorithms are broadly classified into Parametric (statistical) and Non-parametric (feature space). Parametric approach follows some statistical distribution such as Gaussian distribution (Lillesand and Kiefer, 1987). In this study, only the parametric algorithms were used.

Supervised Classification Using Maximum Likelihood Classifier

Supervised classification is the procedure most often used for the quantitative analysis of remote sensing data. This method requires the knowledge of ground truth on land use/ land cover that can be obtained from field work or from large scale aerial photographs. Unlike some of the unsupervised methods, supervised classification allows the analyst to take charge of the pixel categorization process by specifying to the computer algorithm, the brightness values that will represent one category of land use/land cover in each band of the digital image. During this study, classification of Landsat TM and LISS III images was performed by the following procedure

Training Samples

During supervised classification, a prior knowledge is required about the number and the statistical nature of the information classes with which the pixels making up an image are to be identified. For this purpose, representative sample site of known thematic classes, known as 'training sets' are to be computed which are required for compiling the discriminant function or the interpretation key which describes the spectral attributes for each thematic class of interest. Any known pixel in the data sets is then compared numerically to each category in the interpretation key and is assigned to a specific class (Andrews, 1972; Lillesand and Kiefer, 1987; Swain and Davis, 1978). Different training sets were developed after analysis of various visual (colour, tone, texture, shape, shape, size, association, convergence of evidence, etc.) and statistical (mean, standard deviation, etc.) characteristics of the data. Selection of the training areas is very important step as it affects the accuracy of the final classification. The training sets were taken from homogeneous cover types as the validity estimate of sample depends upon size and the representativeness of the sample. Sample size is related to the number of spectral bands whose statistical properties are to be estimated. It was found that the increase in the sample size provided better results when the samples were taken from homogeneous classes of water and bare soil. However, at the same time, the accuracy decreased, if the same number of pixels were taken from heterogeneous areas like agriculture and built up. So the training set size was taken proportional to class size and variability of the class. Also, it was found that the variance co-variance matrix was considerably greater when computed from random samples within a class rather than from contiguous block of samples from the same block. So the samples were taken to ensure that they have minimum possible standard deviation.

Statistical classifier

Numerous statistical approaches are used in the classification strategies to spectral pattern recognition. These statistical parameters determine the property of any measurement vector (i.e. DN values of different bands of a pixel) that decides the class to which it belongs. These classification strategies use the "training set descriptions" of the categories of spectral response patterns as interpretation keys by which pixels of unidentified cover type are categorized into their appropriate classes. The discriminant function corresponding to any class (say i^{th}) has a value larger or smaller than any other class in the set at every point in that of the feature space corresponding to the i^{th} pattern class (Duda and Hart, 1973; Swain and Davis, 1978). These classifiers include the probability density (maximum likelihood), Euclidean distance, Mahalanobis distance, etc. In this study, the maximum likelihood classifier provided the best results.

Maximum Likelihood Classifier

The maximum likelihood (ML) procedure is a statistical approach to pattern recognition that quantitatively evaluates both the variance and covariance of the spectral response pattern. The probability density functions are used to classify an unidentified pixel by computing the probability of a pixel belonging to each of a predefined set of classes and then the pixel is assigned to the class for which the probability is the highest. This is defined by the following equation as suggested by Fu (1976):

$$g\ (x)\ =\ \log \rho\ (w_i)\ .\rho\ (x\ /\ w_i) \qquad \textbf{(11)}$$

Where g (x) = probability density

$\rho\ (w_i)$ = a priority probability

$\rho\ (x\ /\ w_i)$ = probability of 'x' for falling in class i.

i = 1, 2, 3……… n.

For equal priority probability with Gaussian distribution, we have:

$$g_i\ (x)\ =\ \log \rho\ (w_i) - N \log 2\pi / 2 - \log |\Sigma_i| - 1/2\ [(x-\mu_i)^{t} . \Sigma_i^{-1}\ (x-\mu_i)] \qquad \textbf{(12)}$$

or simply,

$$g_i\ (x)\ = - \log |\Sigma_i| - 1/2 \log\ [(x-\mu_i)^{t} . \Sigma_i^{-1}\ (x-\mu_i)] \qquad \textbf{(13)}$$

Where

$|\Sigma_i|$ = determinant of variance-covariance matrix of class i

Σ_i^{-1} = inverse of variance of variance-covariance matrix

x = measurement vector, i.e. DN values of any pixel for all the channels

μ_i = mean vector for the i^{th} class

t = transpose

Any measurement vector 'x' i.e. any pixel may be classified into i^{th} class if $g_i(x) \geq g_j(x)$ for all $i \neq j$.

Statistics of training samples

The statistics of training samples that were used to train the Maximum Likelihood Classifier are shown in the Table 8 (a-p).

Table 8a: Coniferous Forest (Count 200)

Layer 1	Minimum	Maximum	Mean	St. dev
1	13.00	20.00	15.69	1.34
2	11.00	19.00	14.04	1.43
3	17.00	39.00	26.07	4.10

Covariance

Layer 1	1	2	3
1	1.80	1.46	4.02
2	1.46	2.05	3.95
3	4.02	3.95	14.83

Table 8b: Deciduous Forest (Count 90)

Layer 1	Minimum	Maximum	Mean	St. dev
1	13.00	20.00	15.69	1.34
2	11.00	19.00	14.04	1.43
3	17.00	39.00	26.07	4.10

Covariance

Layer 1	1	2	3
1	0.35	0.31	0.55
2	0.31	1.36	0.86
3	0.55	0.86	5.01

Table 8c: Sparse Forest (Count 39)

Layer 1	Minimum	Maximum	Mean	St. dev
1	27.00	32.00	28.87	1.38
2	31.00	39.00	33.92	2.05
3	48.00	60.00	56.02	2.76

Covariance

Layer 1	1	2	3
1	1.81	2.18	4.68
2	2.18	3.49	6.20
3	4.68	6.20	15.56

Table 8d: Grasslands (Count 93)

Layer 1	Minimum	Maximum	Mean	St. dev
1	21.00	29.00	25.79	2.21
2	20.00	32.00	27.08	3.58
3	67.00	93.00	78.55	5.83

Covariance

Layer 1	1	2	3
1	1.90	2.41	-1.89
2	2.41	4.23	-2.55
3	-1.89	-2.55	7.65

Table 8e: Scrubland (Count 56)

Layer 1	Minimum	Maximum	Mean	St. dev
1	26.00	32.00	28.41	1.34
2	37.00	43.00	40.00	1.86
3	57.00	71.00	64.53	3.94

Covariance

Layer 1	1	2	3
1	1.11	1.04	1.43
2	1.04	2.36	3.31
3	1.43	3.31	6.53

Table 8f: Plantation (Count 96)

Layer 1	Minimum	Maximum	Mean	St. dev
1	21.00	25.00	23.12	1.00
2	19.00	26.00	22.47	1.40
3	31.00	50.00	38.81	3.41

Covariance

Layer 1	1	2	3
1	1.01	1.03	-0.62
2	1.03	1.97	-1.03
3	-0.62	-1.03	11.64

Table 8g: Agriculture (Count 120)

Layer 1	Minimum	Maximum	Mean	St. dev
1	28.00	33.00	30.20	1.05
2	31.00	41.00	35.82	1.53
3	31.00	45.00	36.68	2.55

Covariance

Layer 1	1	2	3
1	3.42	3.45	4.62
2	3.45	4.58	4.54
3	4.62	4.54	15.97

Table 8h: Horticulture (Count 87)

Layer 1	Minimum	Maximum	Mean	St. dev
1	21.00	24.00	22.42	0.74
2	20.00	24.00	21.57	0.85
3	48.00	56.00	51.49	2.19

Covariance

Layer 1	1	2	3
1	0.55	0.27	0.34
2	0.27	0.73	-0.008
3	0.34	-0.008	4.83

Table 8i: Fallow (Count 100)

Layer 1	Minimum	Maximum	Mean	St. dev
1	29.00	34.00	31.84	1.20
2	36.00	44.00	41.72	1.50
3	40.00	48.00	44.97	1.65

Covariance

Layer 1	1	2	3
1	3.42	3.45	4.62
2	3.45	4.58	4.54
3	4.62	4.54	15.97

Table 8j: Bare land (Count 72)

Layer 1	Minimum	Maximum	Mean	St. dev
1	32.00	35.00	33.77	0.71
2	39.00	45.00	41.94	1.34
3	50.00	59.00	53.70	1.93

Covariance

Layer 1	1	2	3
1	0.51	0.46	-0.10
2	0.46	1.80	0.44
3	-0.10	0.44	3.75

Table 8k: Exposed rocks (Count 44)

Layer 1	Minimum	Maximum	Mean	St. dev
1	30.00	38.00	33.84	1.98
2	36.00	44.00	40.15	2.77
3	32.00	46.00	38.65	3.46

Covariance

Layer 1	1	2	3
1	3.95	4.95	4.96
2	4.95	7.71	7.49
3	4.96	7.49	11.99

Table 8l: Built up (Count 96)

Layer 1	Minimum	Maximum	Mean	St. dev
1	28.00	36.00	32.10	1.84
2	30.00	43.00	36.04	2.14
3	26.00	49.00	33.65	3.99

Covariance

Layer 1	1	2	3
1	4.97	6.02	2.72
2	6.02	8.35	4.05
3	2.72	4.05	2.64

Table 8m: Water (Count 167)

Layer 1	Minimum	Maximum	Mean	St. dev
1	16.00	24.00	20.46	2.23
2	11.00	21.00	17.82	2.89
3	7.00	13.00	11.25	1.627

Covariance

Layer 1	1	2	3
1	17.992	17.422	1.452
2	17.422	24.705	2.338
3	1.452	2.338	1.422

Table 8n: Water Channel Area (Count 56)

Layer 1	Minimum	Maximum	Mean	St. dev
1	89.00	116.00	107.32	5.63
2	60.00	77.00	77.00	3.20
3	51.00	67.00	56.48	3.53

Covariance

Layer 1	1	2	3
1	3.42	3.45	4.62
2	3.45	4.58	4.54
3	4.62	4.54	15.97

Table 8o: Snow (Count 150)

Layer 1	Minimum	Maximum	Mean	St. dev
1	255.000	255.000	255.000	0.000
2	255.000	255.000	255.000	0.000
3	200.000	226.000	214.375	7.526

Covariance

Layer 1	1	2	3
1	0.000	0.000	0.000
2	0.000	0.000	0.000
3	0.000	0.000	56.911

Table 8p: Aquatic Vegetation (Count 73)

Layer 1	Minimum	Maximum	Mean	St. dev
1	85.00	105.00	93.76	5.63
2	42.00	54.00	47.52	3.67
3	102.00	152.00	131.84	12.54

Covariance

Layer 1	1	2	3
1	4.083	-0.917	5.606
2	-0.917	4.629	-5.030
3	5.606	-5.030	23.697

5.1.3.1c Ground Truth Survey for Accuracy Assessment of Supervised Classification

No classification is complete until its accuracy has been assessed (Lillesand *et al.,* 2004). After a classification is performed, its accuracy is to be evaluated, so as to check the authenticity and reliability of the classified data. In this context, the "accuracy" means the level of agreement between labels assigned by the classifier and the class allocations on the ground collected information by the user. For testing the accuracy of the classification, generally two methods are used. These include the thresholding, where a probability image file is used to screen out misclassified pixels. The second and the more commonly used method is the Accuracy Assessment which involves comparing the classification to ground truth or other data. In this study, the accuracy assessment method was used to for checking the validity of the data. Accuracy assessment is a general term for comparing the classification to the geographical data that are assumed to be true, in order to determine the accuracy of the classification process. Usually the assumed true data are derived from ground truth data. When performing accuracy assessment for the whole classified image, the known reference data should be another set of data, different from the set that is used for training the classifier.

It is not usually practical to ground truth or otherwise test every pixel of a classified image. Therefore, a set of reference pixels is usually used. Reference pixels are points on the classified image for which actual data are (or will be) known. The reference pixels are randomly selected (Congalton, 1991). When reference pixels are selected by the analyst, it is often tempting to select the same pixels for testing the classification that were used in the training samples. This biases the test, since the training samples are the basis of the classification. By allowing the reference pixels to be selected at random, the possibility of bias is lessened or eliminated. The number of reference pixels is an important factor in determining the accuracy of the classification. It has been shown that more than 100 reference pixels are needed to estimate the mean accuracy of a class to within plus or minus five percent.

Well planned field surveys were organized at different stages during this research period. During the first phase of the field survey, the main thrust was to validate the generated land use/land cover map using the GPS and hard copies of actual satellite data. This trip spanned over a period of one week. The combination of all the above mentioned sources resulted in making the field survey a successful. The classified image was evaluated and the misclassified classes were identified. It was found that the main problems that were encountered in the classification processes arose as a result of the similarity in reflectance patterns found in classes like water channel areas, built up, exposed rock, agriculture, horticulture and degraded forest. As a result of this similarity, the accuracy of the classification decreased. The ground truthing helped to overcome the discrepancies in the classification results.

Accuracy assessment was carried out by using around 300 randomly selected points that were collected earlier during the field survey to determine the accuracy of the land use/ land cover classification and the error matrix. The error matrix has been widely used as a method for assessing the classification accuracy of remotely sensed images (Story and Congalton, 1986; Congalton, 1991; Congalton and Green, 1993). The error matrix also known as classification error matrix or confusion matrix simply compares the reference points to the classified points in a c x c matrix, where c is the no of classes (including class 0).

Error matrix (Appendix 1) is a square, with the same number of information classes that will be assessed as the row and column. Numbers in rows are the classification result and numbers in columns are reference data (ground truth). In this square, elements along the main diagonal are pixels that are correctly classified. Error matrix is a very effective way to represent map accuracy in that the individual accuracies of each category are plainly described along with both the errors of commission and omission. Error of commission is defined as including an area into a category when it does not belong to that category. Error of omission is defined as excluding that area from the category in which it truly does belong. Every error is an omission from the correct category and a commission to a wrong category. In addition to the interpretation of above said errors, the error matrix may also be used to compute a series of descriptive indices to quantify the attribute accuracy of the data which are given below:

Overall Accuracy

Overall accuracy is the proportion of all reference pixels, which are classified correctly. It is computed by dividing the total number of correctly classified pixels (the sum of the elements along the main diagonal) by the total number of reference pixels. According to the error matrix above, the overall accuracy can be calculated as the following:

$$OA = \frac{\sum_{K=1}^{N} a_{KK}}{\sum_{K=1}^{N} a_{KK}} = \frac{1}{n} \sum_{K=1}^{N} a_{kk} \qquad \textbf{(14)}$$

Overall accuracy is a very coarse measurement. It gives no information about what classes are classified with good accuracy. The accuracy assessment report was generated, after the field validation and correction of misclassified land use classes was carried out.

Producer's Accuracy

Producer's accuracy estimates the probability that a pixel, which is of class I in the reference classification, is correctly classified. It is estimated with the reference pixels of class I divided by the pixels where classification and reference classification agree in class I. Given the error matrix above, the producer's accuracy can be calculated using the following equation:

$$PA(class\ I) = \frac{a_{ii}}{\sum_{i=1}^{N} a_{ki}} \qquad \textbf{(15)}$$

User's Accuracy

User's accuracy is estimated by dividing the number of pixels of the classification result for class I with the number of pixels that agree with the reference data in class I. It can be calculated as: UA (class I) User's accuracy predicts the probability that a pixel classified as class I is actually belonging to class.

$$UA(class\ I) = \frac{a_{ii}}{\sum_{i=1}^{N} a_{ki}} \qquad \textbf{(16)}$$

Kappa Statistics

The Kappa analysis is a discrete multivariate technique used in accuracy assessment for statistically determining if one error matrix is significantly different than another (Lillesand, *et al.,* 2004). The result of performing a Kappa analysis is statistical estimate of Kappa, which is another measure of agreement or accuracy of classified images. Kappa coefficient or Kappa Index of Agreement (KIA) is an indicator of the extent to which the percentage correct values of an error matrix are due to true agreement versus the chance agreement (Rosenfield and Fitzpatrick-Lins, 1986; Congalton, 1991). Kappa accuracy is determined from the error matrix, which not only gives the number of correctly classified units but also the errors of commission and omission. This measure of agreement is based on the difference between the actual agreement in the error matrix (i.e., the agreement between the remotely sensed classification and the reference data as indicated by the major diagonal) and the chance agreement, which is indicated by the row and column totals (i.e., marginals). This statistic was introduced by Congalton and Mead (1983). Kappa statistic is defined as follows:

$$\boldsymbol{k = ((\theta 1 - \theta 2))/((1 - \theta 2))} \qquad \mathbf{(17)}$$

k gives an estimate of the overall accuracy.

$$\boldsymbol{\theta 1 = \sum xii/N} \qquad \mathbf{(18)}$$

Where i=1 to r

$$\boldsymbol{\theta 2 = \sum x_{i+} + x_{+i}/N^2} \qquad \mathbf{(19)}$$

Where i = 1 to r,

r is the number of rows in the error matrix

xii is the i^{th} diagonal element

xi is the marginal total of row

x_{+i} is the marginal total of column i

N is the total no. of observations

Large sample variance of the kappa estimate is given as

$$var\ (k) = (\theta 1(1-\theta))/(1-\theta 2)^2 + 2(1-\theta 1)(2\theta 1\theta 2-\theta 3)/(1-\theta 2)^3 + (1-\theta 1)^2\ (\theta 4-4\theta 2)^2) /(1-\theta 2)^4 \qquad \mathbf{(20)}$$

Where, $\theta 3 = \sum xii + xi) / N^2$ and i= 1 to r

$$\theta 4 = \sum x_{ij}(x_{j+} + x_{+i})^2 / N^3, i = r$$

Kappa coefficient of 0.90 means that the classification is 90% accurate. It is a coefficient of agreement as a measure of total map accuracy. A true agreement i.e., observed approaches 1 and chance agreement 0, k approaches 1 in an ideal case. In reality, k ranges between 0 and 1.

Proforma that was used for survey-cum-ground truthing is appended as Appendix 2.

5.1.3.2 Weather Data

Running the GWLF model involves preparation of daily data for the precipitation and temperature. The weather data with a time step of 29 years was thus prepared for the input into the model. In addition, mean daylight hours for the catchment with latitude 34^0N were obtained from Haith *et al.* (1992) and Evans *et al.* (2008).

5.1.3.3 Transport Parameters

Transport parameters can be considered to be those aspects of the catchment (hydrologic, erosion and sediment) that influence the movement of the runoff and sediments from any given cell in the catchment down to the lake. The complete procedures for generating each of these parameters are explained as under:

5.1.3.3a Hydrological Parameters

These parameters include the following:

Evapo-transpiration (ET) Cover coefficients

The Evapotranspiration (ET) cover coefficient is the ratio of the water lost by evapotranspiration from the ground and plants compared to what would be lost by evaporation from an equal area of standing water (Thuman *et al.,* 2003). The ET cover coefficients vary by land use type and time period within the growing season of a given field crop. The field assessment of the study area, therefore, also involved assessing the development stage of the entire crop for accurate allocation of the ET coefficients. Typical values range from 1.0 for wooded areas during the growing season to 0.3 for annual crops during the dormant season. The coefficients were derived from (FAO, 1980; Haith, 1987) (Appendix 3).

Runoff Curve Numbers

The Soil Conservation Service (SCS) Curve number is a parameter that determines the amount of precipitation that infiltrates into the ground or enters surface waters as runoff after adjusting it to accommodate the antecedent soil moisture conditions based on total precipitation for the preceding 5 days (EPA, 2003a). It is based on a combination of factors such as land use/ land cover, soil hydrological group, hydrological conditions, soil moisture conditions and management (Arhounditsis *et al.,* 2002) (Appendix 4 and 5). In GWLF, the CN value is used to determine for each land use, the amount of precipitation that is assigned to the unsaturated zone where it may be lost through evapotranspiration and/or percolation to the shallow saturated zone if storage in the unsaturated zone exceeds soil water capacity. In percolation, the shallow saturated zone is considered to be a linear reservoir that discharges to stream or losses to deep seepage, at a rate estimated by the product of zone's moisture storage and a constant rate coefficient (SCS, 1986).

Soil Data

Soil data forms an important and valuable input for the simulation of the hydrological responses at the watershed scale. The main parameters for use in the GWLF model are soil texture, soil organic carbon/organic matter and available water holding capacity. These parameters form the basis for determining other important soil properties such as soil hydrological group and erodibility factor. At the same time, analysis of some other parameters related to soil such as the pH, electrical conductivity, available nutrients (NPK), was also carried out in order to have a knowhow of the general soil characteristics of the study area. For this purpose, a field trip spanning over a period of one week was organized for collection of soil samples in the Dal Lake Catchment which were later analyzed in the laboratory. The standard methods by which each of these parameters was determined are given as follows:

i) **Organic Carbon**: was determined by Walkley and Black (1934) method.

ii) **Available Nitrogen:** Subbbiah and Asija (1956) method was used for the estimation of available nitrogen in soil**.**

iii) **Available phosphorus:** Olsen's method (1957) was used for determining the available phosphorus.

iv) **Available potassium:** was estimated by Jackson's Spectrophotometric method (1964).

v) **Soil texture:** was determined by International Pipetting Method.

vi) **Water holding capacity:** Keen-Raczkowski Box Method as described by Piper (1961) was used for determining the water holding capacity.

vii) **pH:** Digital pH meter

viii) **Electrical conductivity:** Digital conductivity meter

5.1.3.3b Erosion and Sediment Parameters

The GWLF model simulates erosion using the Universal Soil Loss Equation (USLE) model based on a number of soil and topographic parameters. In USLE, estimation of the rates of soil erosion is done using equation 21

$$A = RE * K * LS * C * P \tag{21}$$

Where,

A = rate of soil loss per unit area

RE =rainfall erosivity factor

K = soil erodibility factor

LS = slope length and slope steepness factor

C =Cover and management factor

P =support practice factor

The rate of soil loss (A) was determined for each source area for input into the GWLF model. However, estimation of (A) depends on accurate estimation of the **RE * K * LS * C * P** factors for each source area. The following subsections indicate how each of these factors was derived:

Rainfall Erosivity Factor (RE)

Rainfall erosivity factor (RE) accounts for the impact of rainfall on the ground surface, which can make soil more susceptible to erosion and subsequent transport. The precipitation-induced erosion varies with rainfall intensity as well as geographic region. RE for any given period is estimated from the product of the storm energy (E) and the maximum 30- minute rainfall intensity (I_{30}) data collected for that period (Montanarella *et al.,* 2000). However due to unavailability of this data from the local weather station, the RE factor (800MJ mm ha^{-1} h^{-1} y^{-1}) for the study area was estimated from erosivity factor map developed the joint research centre of the European Soil Bureau (Montanarella *et al.,* 2000). The factor is determined in the GWLF model as given in equation 22:

$$RE_t = 64.6 * a_t * Rt_t^{1.81} \qquad (22)$$

Where,

RE_t = Rainfall erosivity (in mega joules mm/ha-h),

a_t = Location- and season-specific factor, and

R_t = Rainfall on day t (in cm).

Determination of RE factor was of paramount importance because it made it possible to estimate the erosivity coefficient (a) for the wet and dry seasons. A coefficient of 0.28 for the wet season and 0.18 for the dry season was used for the input to the GWLF model.

Soil Erodibility Factor (K)

The soil erodibility factor (K) indicates the propensity of a given soil type on a given land unit to erode, and is a function of soil physical properties and slope. Estimation of the K factor requires the information about the soil organic carbon and the soil texture of the study area. For this purpose, an index by given by Steward *et al.* (1975) (Appendix 6) was used to determine the values for K factor.

Slope Length Factor (LS)

The LS factor is being made up of two parameters namely slope length (L) and slope steepness (S). The L and S factors are commonly combined as LS and referred to as the Slope factor (Troeh *et al.,* 1991). This factor accounts for the effect of topography on erosion. For use in model, the LS factor was estimated from the Digital Elevation Model of the study area (Arhounditsis *et al.,* 2002).

Cover and Management (C) and Practice (P) Factors

The mechanism by which soil is eroded from a land area and the amount of soil eroded depends on soil treatment resulting from a combination of land uses (e.g., forestry versus row-cropped agriculture) and the specific manner in which land uses are carried out (e.g., no-till agriculture versus non-contoured row cropping). Land use and management variations are represented by cover and management factors in the Universal Soil Loss Equation (USLE) and in the erosion model of GWLF. C is the crop management factor, whilst P is the conservation practice factor. Wischmeier and Smith (1978) define the C factor as the ratio of soil loss from land with a specific vegetation cover to the corresponding soil loss from continuous fallow ground. On the other hand, P is factor that reflects implementation of support practices such as terracing, buffer strips and/ or contour farming aimed at controlling erosion by reducing surface runoff (Pavanelli and Bigi, 2004). Both C and P have values ranging between 0 and 1 and in both factors, the higher the value, the higher the potential of soil erosion (EPA, 2003a).

Cover and management factors were drawn from Haith *et al.* (1992) and were determined from the tables given in Appendix 7. This was supported by land use characteristics of the study area and also by the facts collected during field work in the catchment.

Sediment Delivery Ratio (SDR)

The sediment delivery ratio (SDR) converts erosion to sediment yield, and indicates the portion of eroded soil that is carried to the watershed mouth from land draining to the watershed. Kinnell (2000) defines Sediment Delivery Ratio (SDR) as being “the ratio of the erosion of a point in the landscape to the sediment delivered from that point”. This means that erosion from a particular area is not equivalent to sediment yield since some soil may be impounded during overland flow. The SDR, therefore, accounts for soil losses due to sediment redeposition. In the GWLF model, the SDR is used to determine the sediment yield by multiplying it with the estimated erosion. Therefore, the SDR was determined through the use of the logarithmic graph (Appendix 8) based on the catchment area (Vanoni, 1975; Haith *et al.,* 1992; Evans *et al.,* 2008) using the following equation:

$$SDR = 0.451(b^{-0.298}) \quad \textbf{(23)}$$

Where,

SDR = Sediment delivery ratio

b = Size of the watershed in square kilometres.

5.1.3.3c Nutrient Parameters

This includes the dissolved nutrient concentration in the rural land use. GWLF requires a particulate concentration and a dissolved phase concentration for surface runoff from rural land uses. One of the greatest challenges of the study was the collection of runoff from various field crops for the assessment of nutrient concentrations and made use of the values estimated by Haith (1987) (Appendix 9) for different source areas which are more or less representative of rural catchments and are assumed to be same for the study area.

5.1.3.4 Topographic Analysis

Topography of an area provides the information about its physical and morphological conditions. Understanding of the physiographic characteristics of a catchment and its location can give a good quantitative and qualitative assessment of the hydrological, climatic and physiographical processes of the catchment. The topographic factors have direct effects not only on the hydrologic regime but also on annual water production, flood volumes and soil erosion (Singh, 1958).

Knowledge about various topographic features like slope, relief, elevation and drainage pattern is of paramount importance while assessing the processes like erosion. In order to characterize the Dal Lake Catchment on the basis of topography, the Shuttle Radar Topographic Mission (SRTM) digital elevation model (DEM) was used. The DEM was processed to generate watershed, slope, and drainage maps of the study area. The general methodology that was adopted for the topographic analysis is shown in the Fig. 16.

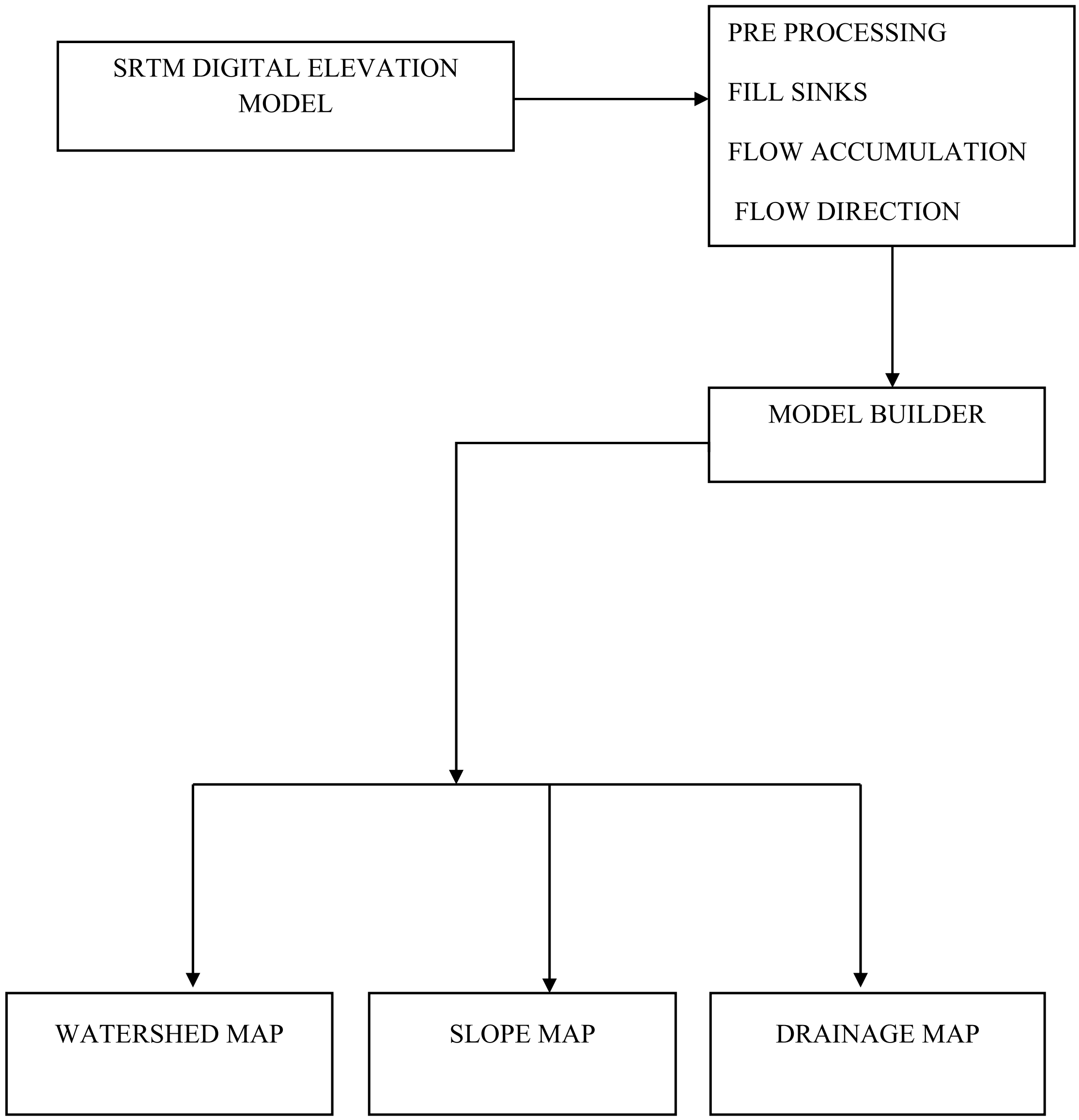


Fig. 16: Methodology for the generation of Watershed, Slope and Drainage

5.1.4 Implementation of the GWLF Model

Once all the input data was prepared, it was then incorporated in the GWLF model for implementation. The model was simulated for 28 years (1981-2008) as a function of changing land use/land cover using the data for 1992 and 2005.

5.2 Socioeconomic Analysis

Since the socioeconomic importance of lakes has now a days become a major factor for their degradation, therefore, social and economic aspects need to be considered to effectively mitigate lake degradation. There are various social factors that exert tremendous pressure on a water body and are responsible for making it more vulnerable to degradation such as total population, total households, illiteracy etc. The accomplishment of this objective was made by adopting the following approach as described in the Fig. 17.

The step wise approach for the execution of socioeconomic characterization is given below:

Socioeconomic Data: Socioeconomic data regarding the various parameters such as total population, total households, total literates etc. for all the villages falling in the Dal Lake catchment was collected from the Census Dept., Government of India. Besides, the above said data for the municipal wards was collected from the Srinagar Municipal Corporation. The data for both the villages as well as wards was then digitized and converted into GIS format for integration with other geospatial data.

Geo-referencing: The village and ward maps collected were geo-rectified by using an existing rectified image of same area.

Geospatial Database Generation: Once the geo-rectification and digitization processes for both the wards and villages maps were accomplished, a geospatial database in the GIS environment was generated for all the villages and wards using the socioeconomic and other spatial data collected from different sources.

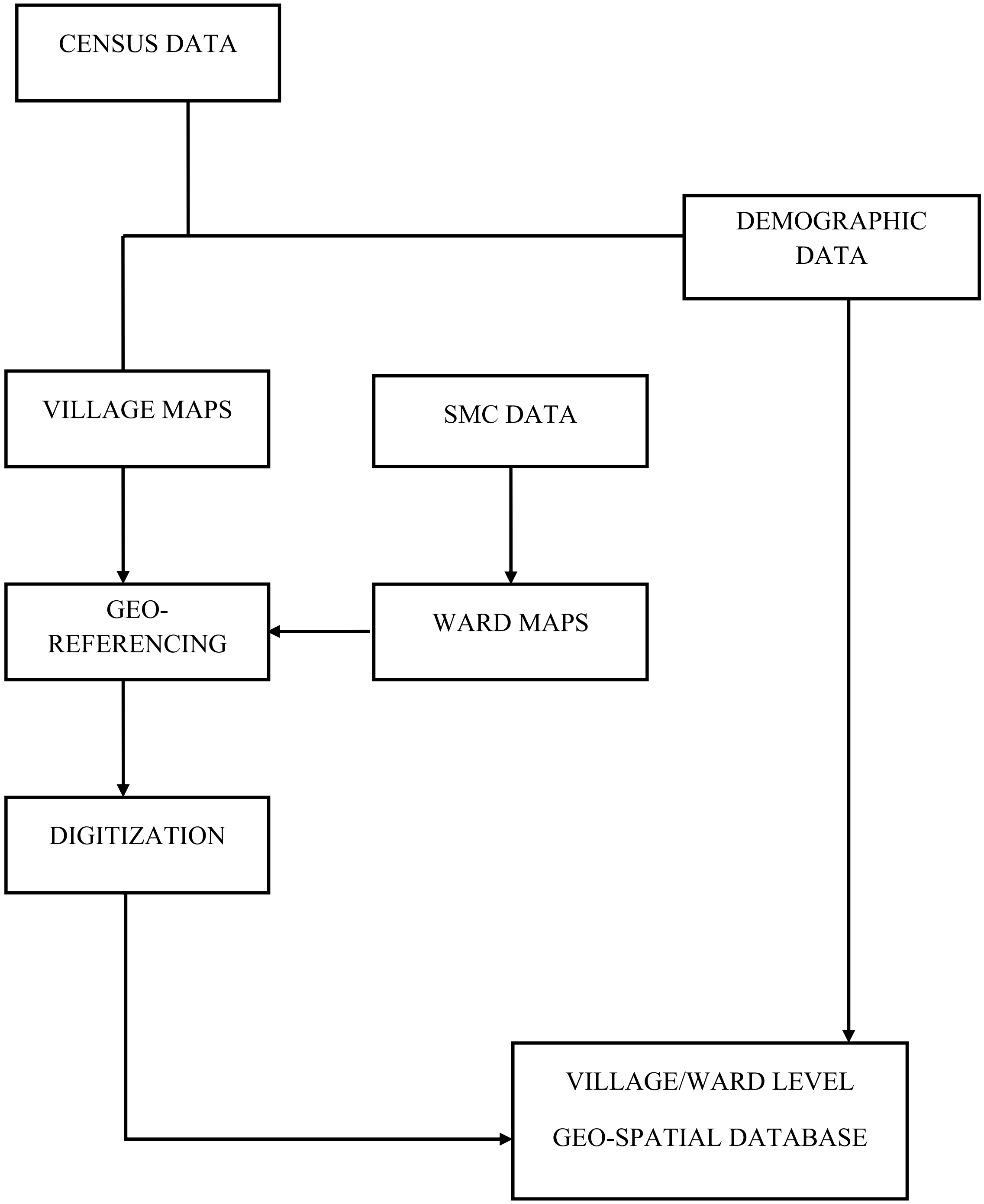


Fig. 17: Methodology for socioeconomic characterization of Dal Lake Catchment

Table 9: Formulae used for determining different socioeconomic variables

S. No.	SOCIOECONOMIC VARIABLE	FORMULA
1	**Population Density**	Total Population/Area
2	**Literacy Rate**	$\frac{\text{No. of literates}}{\text{Total population}} \times 100$
3	**Economic Development Status (E)**	E = Sqrt.[D.W (W-A)] Where E = Economic Development Status D = Population Density W = Proportion of employed population A = Proportion of unskilled workers (i.e. unemployed + Agri. Labourers + Marginal workers / Total Population)

5.3 Integrated Impact Analysis of Environmental and Socioeconomic Factors and Watershed Prioritization

Hydro-geological and biophysical environments in watersheds are directly affected by changes in land use and socioeconomic processes, which are largely controlled by human activities (Moldan *et al.,* 1997). Since assessing the process of lake degradation requires the collective understanding of different phenomena in its watersheds, the current study encompassed assessment of all such processes ranging from ecological to socioeconomic. Once all the data about the erosion, sediment, nutrients and population, household variables at landscape level was generated/ collected, it was then integrated into the GIS environment. The integration was based upon Multi Criteria Analysis. Multi-criteria evaluation is primarily concerned with how to combine the information from several criteria to form a single index of evaluation. As already discussed under previous headings the role of such processes in the deterioration of lakes, different weightages were given to each of these parameters depending upon their importance and relevance to assess their cumulative impacts in each of these watersheds. Since the different socioeconomic variables don't contribute equally towards the pollution/degradation of lakes, only those parameters were chosen for the final analyses which are more significant and relevant in their impacts vis-a-vis water pollution related phenomena. Hence, only total population and total households in each of these watersheds were considered. Equal weightage of 30% was given each to erosion and nutrient as these are the major threats to the Dal Lake Ecosystem. Weightage of 25% was given to land use/land cover of watersheds, whereas, 15% weightage was given to the socioeconomic variables. The integrated analysis in each of the watersheds gave an understanding of the nature and extent of the pressures exerted on the Dal Lake Ecosystem. The outcome of this analysis is the watershed prioritization map of the Dal Lake catchment that will prove to be quite helpful in devising the conservation and management strategies for the restoration of the lake ecosystem.

Table 10: Weightage assigned to different biophysical and socioeconomic parameters

S.No.	PARAMETER	WEIGHTAGE (%)	RESULT
1	**Erosion**	30	**Priority Watershed Ranks**
2	**Nutrients**	30	
3	**Land Use/ Land Cover**	25	
4	**Socioeconomic Variables**	15	
TOTAL		100	

5.4 Validation Study

For the validation of the GWLF model results, water quality data for the Dal Lake comprising of nutrient and sediments was compiled from the Lakes and Waterways Development Authority. Water quality data was collected from January, 2007 to December, 2007 and sediment data from September, 2005 to August, 2006, as data was available for the said period. Water quality and stream flow data were then used to derive the sediment, total nitrogen and phosphorus loads for the whole catchment which could be compared against simulated loads produced via the use of the GWLF model. The primary emphasis of this part of the research was to statistically evaluate the observed and predicted mean annual pollutant loads.

To assess the correlation, or "goodness-of-fit", between observed and predicted values for mean annual pollutant loads, the Nash-Sutcliffe statistical measure recommended by ASCE (1993) for hydrological studies was used. With the Nash-Sutcliffe measure, an R^2 coefficient is calculated using the equation

$$R2 = 1 - [\mathring{a}(Qo - Qp)2 \,/\, \mathring{a}(Qo - Qa)2] \qquad \textbf{(24)}$$

where Qo is the observed value, Qp is the predicted value, and Qa is the average of the observed values. Coefficient (R^2) values equal to 1 indicate a perfect fit between observed and predicted data, and R^2 values equal to 0 indicate that the model is predicting no better than using the average of the observed data.

5.5 Scenario Analysis through BMP Implementation and the PRedICT Model

Scenario analysis is gaining widespread acceptance among decision-makers as a practical tool for addressing uncertainty about the future and provides the ability to explore the potential impacts, risks, benefits, and management opportunities that stem from a variety of possible future conditions. Scenarios are plausible and often simplified descriptions of how the future may develop based on a coherent and internally consistent set of assumptions about driving forces and key relationships (IPCC, 2001). In natural sciences, this is, in general, accomplished by using a combination of land-use change and process models to develop an artificial representation of the physical manifestations of scenario characteristics, and to establish a multi-disciplinary framework within which scenario characteristics may be analyzed (Turner *et al.,* 1995; Clayton and Radcliffe, 1996; Millennium Ecosystem Assessment, 2005a). In case of water pollution studies, one of the effective ways of carrying out the scenario analysis is through the use of best management practices (BMPS).

World over, BMPS are considered to be valuable means of addressing water pollution problems at watershed levels and have been successfully used for devising water quality programmes and restoration of different aquatic systems (U.S. EPA, 1990, 1995; Susquehanna River Basin Commission, 1998). Novotny and Olem (1994) state that BMPs are methods and practices for preventing or reducing non-point source pollution in watersheds draining both urban and rural areas to a level compatible with water quality goals. The Soil and Water Conservation Society (SWCS, 1982) defines a BMP as a practice or combination of practices that are determined by a state or designated area-wide planning agency to be the most effective and practicable (including technological, economic, and institutional considerations) means of controlling point and nonpoint source pollutants at levels compatible with environmental quality goals.

In order to carry out the scenario analysis, the Pollution Reduction Impact Comparison Tool (PredICT) was used, that allows simple and quick analyses of load reductions for various BMP implementation strategies on a watershed scale.

5.5.1 Overview of the PRedICT Model

The Pollution Reduction Impact Comparison Tool (PRedICT) (Evans *et al.,* 2003) software application was developed for use in evaluating the implementation of both rural and urban pollution reduction strategies at the watershed level. This tool has the ability to create various scenarios in which current landscape conditions and pollutant loads (both point and non-point) can be compared against future conditions. This is achieved through the use of different pollution reduction strategies such as agricultural and urban best management practices (BMPs), stream protection activities, the conversion of septic systems to centralized wastewater treatment, and upgrading of treatment plants from primary to secondary and tertiary. While not necessarily identical, the BMP systems reflect the more generic and widely-used BMPs described in a variety of sources (Beegle and Lanyon 1994; Novotny and Olem, 1994; NRCS, 1998; Dillaha *et al.,* 2000).

While information for PRedICT can be compiled manually, the most efficient way to accomplish this task is to use the AVGWLF watershed modelling system (Evans *et al.,* 2001, 2002). This tool automatically creates a scenario file that can be used as input to the PRedICT. This input file contains information on watershed conditions and pollutant loads that can serve as the initial conditions from which future scenarios can be developed. While information on nutrient and sediment loads, as well as the presence of existing BMPs, can be developed and brought in via the use of AVGWLF, user's local knowledge of the watershed can also be considered. The analysis is based on user-provided watershed characteristics, such as land use distribution, loadings from various sources, existing BMP levels, and BMP pollution reduction efficiencies and costs. To mitigate on-farm loss of soil and nutrients, BMP systems rather than individual BMPs are used in the software.

Scenario analysis, although not part of the set objectives of the current study, was carried out to have a preliminary understanding of how the BMPS can help to check the pressures of excessive nutrient enrichment as well as the increased sedimentation in the Dal Lake ecosystem. The results from this analysis can go a long way in devising the strategies for management and restoration of the Dal Lake. Fig. 18 shows the methodology adopted for scenario analysis.

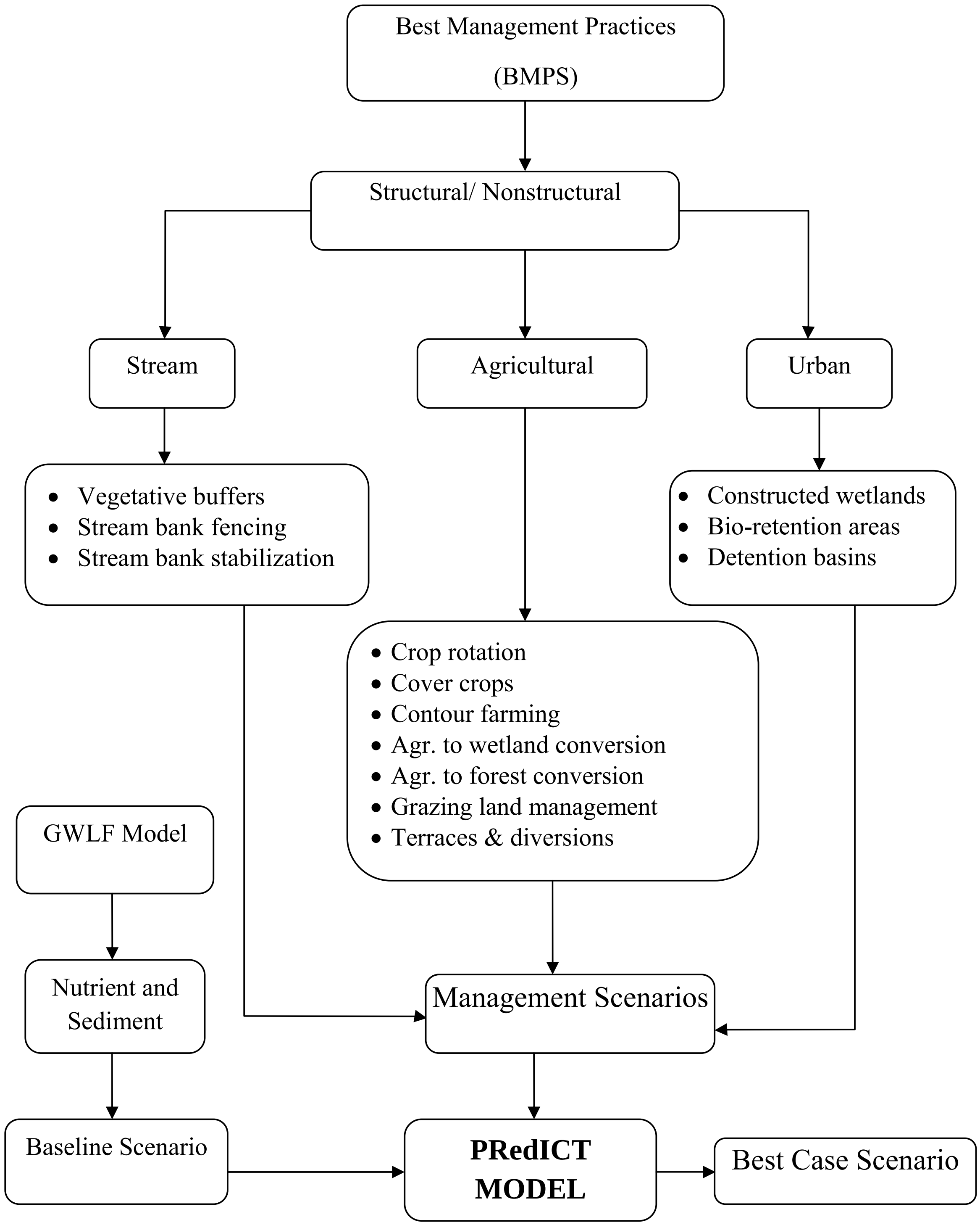


Fig. 18: Methodology adopted for Scenario Analysis

It is possible to incorporate the user's existing knowledge of a particular area into the PRedICT. For this purpose, a preliminary field trip was carried out to take cognizance of existing ground conditions about the management practices being carried out in the Dal Lake Catchment. Based on this existing information and other possible set of management practices that in future be practised, the scenario analysis was carried out.

For the scenario analysis, the catchment was analysed under three scenarios, the baseline scenario, and two management scenarios, namely MSCN1 and MSCN2. The detailed procedure is given below:

5.5.1.1 Baseline Scenario

Under the baseline scenario, the pollution was evaluated on the basis of existing conditions in absence of any management practice. In this scenario, no hypothetical management programmes for nutrient and sediment reduction have been introduced (Chisha, 2005). The main assumption underlying this scenario is that all the source areas are critical i.e., they are all contributing to the catchment nutrient and sediment pollution load to the lake. The justification for this is that during field work it was discovered that farmers in the Dal Lake Catchment as such do not engage in any erosion prevention activities which could be one of the main reasons for elevated sediment and nutrient loadings to the Lake. The input data to run this scenario is the one required for running the GWLF Model and is already explained in the previous headings.

5.5.1.2 Management Scenario

Under the management scenarios, two scenarios i.e., MSCN1 and MSCN2 were considered. For this purpose, all the three BMP systems viz. agricultural, urban and stream related management activities (Evans *et al.,* 2008) were employed to assess their effectiveness in reducing the nutrient and sediment loads coming from the Dal Lake Catchment and ultimately finding their way into the water body. These scenarios involve the use of existing land uses and explore the effect of best management practices on the nutrient and sediment loadings from the catchment. Examples of such management activities include planting crop types that are likely to reduce the C-factor, and implementation of support practices such as contouring, strip cropping and/or terracing on the existing land use types that are likely to reduce the P-factor (SARS, 2003). Besides, BMPs in form of detention basins, buffer strips have also been considered. Different possible combinations of the best management practices were assessed for each of the two scenarios in terms of % existing and % future conditions which are given in Appendix 10. The expected result is the reduction in both the sediment and nutrient levels. The description of these management practices is given as under:

5.5.1.2a Urban BMPs

For controlling the pollutants which find their way into the Dal Lake from the urban runoff, BMPs which are both structural and non-structural in nature were considered (CH2M-Hill, 1998). Typically, non-structural BMPs involve the preservation or enhancement of vegetative cover in selected areas (e.g., along streams) or the use of natural landscape features to act as filtration devices (e.g., as in the use of residential lawns to filter storm water runoff from rooftops). Whereas, structural BMPs include short-term construction activities (e.g., filter bags, silt curtains etc), infiltration trenches, filter strips, and constructed wetlands are intended to be in service for much longer time periods. Following three commonly-used urban BMPs were included in the PRedICT model:

Detention Basins: These generic structures are designed for the temporary capture and storage of surface runoff during storm events. The Telbal settling basin in the Dal Lake Catchment is included in this category. Detention basins dilute the initial runoff from storm events which typically has the highest concentrations of sediment and dissolved pollutants. Therefore, the concentration of pollutants in runoff released to downstream areas is reduced.

Constructed Wetlands: are essentially artificial shallow water-filled basins that have been planted with emergent plant vegetation. They are typically designed to achieve specific water quality objectives before the water is released, and can be an efficient method for removing a wide variety of pollutants including suspended solids, nutrients, heavy metals, toxic organic pollutants, and petroleum compounds. In certain cases naturally occurring ones can also serve the purpose. This is true in case of Dal Lake Catchment, where, along the Royal Springs Golf Course road, a large chunk of naturally occurring wetland with plantation can be used for checking the pollutant loads. These wetlands are also an effective means of reducing peak runoff rates and stabilizing flow to adjacent natural wetlands and streams.

Besides, the waste water treatment plants that are at present functional in the catchment area for controlling the nutrient pollution of the Dal Lake were also considered.

5.5.1.2b Agricultural BMPs

There are scores of possible BMPs that can be used to address problems in agricultural areas. Some of the most widely used and the ones that were considered for the Dal Lake Catchment are given below:

Crop Residue Management: involves the planned use of crop residue to protect the soil surface. This is one of the most commonly-used BMPs, and includes the use of residue from corn or soybean stalks, small grain straw, or the residue from vegetables and other crops. There are many forms of this management practice including no-till planting, mulch tillage, and other tillage techniques that leave at least 30% of the soil surface covered with crop residue after planting to reduce soil erosion by water (Ritter and Shirmohammadi, 2001).

Cover Crops: This BMP involves the use of annual or perennial crops (e.g., clover) to protect the soil from erosion during the time period between the harvesting and planting of the primary crop. The use of such crops can also improve soil health by storing needed nutrients over the winter, preventing their loss.

Crop Rotation: are primarily employed to reduce soil erosion, thereby reducing the quantities of sediment and sediment-bound pollutants such as nitrogen, phosphorus, and pesticides. It involves the use of different crops in a specified sequence on the same farm field. When addressing excess nutrients on agricultural land, cover crops are often included in the rotation sequence.

Contour Farming/ Terracing/ Strip cropping: involves conducting tillage, planting and harvesting operations perpendicular to the gradient of a hill or slope in order to reduce erosion mostly effective on moderate slopes of 3-8%. Also involves placing crops in strips or bands. Terraces help to control erosion on cropland. This BMP is seen being practised along the Dara and Faqir Gujri areas of the Dal Lake Catchment.

Grazing Land Management: utilises the practices that ensure adequate vegetation cover in order to prevent excessive soil erosion due to over-grazing and other forms of overuse. In this BMP, animals are periodically moved among fenced pastures or paddocks which prevent the overuse of any feeding area and allow forages to recover between periods of intensive feeding.

Nutrient Management: involves planned use of organic and inorganic sources of nutrients to sustain optimum crop production while at the same time protecting the quality of nearby water resources. An important objective of such a plan is to optimize forage and crop yields while minimizing nutrient loss to surface and ground water resources. This approach often involves using other BMPs such as providing adequate cover crops and devising appropriate crop rotations to reduce (or augment) overall nutrients loads on fields.

Agriculture to Forest Land and Wetland Conversion: provide a good prospectus for improving the water quality of lakes. Hereby, agricultural practices are shifted from cultivation of paddy to medicinal plants and other crops which emanate fewer pollutants and at the same time are commercially viable.

5.5.1.2c Stream Related BMPs

Stream-related activities are conducted along the streams for the purpose of reducing loads that might enter them from upland sources or to reduce the impacts associated with stream bank erosion. The types of mitigation activities included in PRedICT are vegetated buffer strips, stream bank fencing and stream bank stabilization. Such types of stream activities are to some extent being practised within the Dachigam National Park which forms the major portion of the Dal Lake Catchment. Following stream BMPS were introduced:

Vegetated Buffer Strips: also called conservation buffers, buffer zones, or filter strips are areas of land maintained in some type of permanent vegetation (i.e., grasses, shrubs, and/or trees) for the purpose of trapping pollutants contained in surface runoff from adjacent land areas. Buffer strips are commonly utilized to treat surface runoff from cropland or confined animal facilities. Pollutants are removed to varying degrees via the processes of filtration, infiltration, absorption, adsorption, uptake, volatilization, and deposition, with the predominant processes tending to be the infiltration of dissolved pollutants and deposition of sediment-attached pollutants.

Stream Bank Protection: collectively refers to practices that can be employed for the purpose of mitigating the effects that eroding or slumping stream banks have on adjacent streams. The most frequently used form of protection is fencing that prohibits cattle from trampling stream banks, destroying protective vegetation, and stirring up sediment in the streambed. In addition to reducing direct soil loss caused by stream bank degradation, fencing also reduces nutrient loads caused by defecation and urination of the animals in the stream. Stream bank protection also often involves the use of stable crossings and/or stream bank stabilization measures. With this approach, the banks are often covered with rocks, grass, trees, shrubs, and other protective surfaces to reduce erosion as well.

CHAPTER - 6

RESULTS

The results pertaining to the various aspects of the present research entitled "Integrated Impact Analysis of Environmental and Socioeconomic Factors on Pollution Status of Dal Lake using Geospatial Tools" are presented as follows:

6.1 Topographic Analysis

Topography has direct effects not only on the hydrologic regime but also on annual water production, flood volumes and soil erosion. The results of topographic analysis of Dal Lake Catchment are provided below:

6.1.1 Watersheds in Dal Lake Catchment

A watershed often referred to as a river basin, a river valley, or a drainage basin is the area of land for which water that flows across the land as streams, rivers as well as groundwater drains into a common body of water. Watersheds are the drainage area over which sediments, nutrients, pesticides and other chemical additions to the land are collected in a water body such as a lake, river, or ocean. Given the ecological importance of watersheds and the extent of human dependence on the services provided by them, watershed degradation has potentially enormous environmental and socio-economic costs.

A total of 13 watersheds were delineated in the study area on the basis of water divides identified on the LISS (III) image and with the help of DEM. The watersheds were labeled as DW i.e., Dal Watershed 1-13 (Fig. 19) and throughout this thesis these names would be used for them. These watersheds range from low altitude urban, semi urban, rural to the high altitude forest watersheds. The area under different watersheds is given in Table 11.

A perusal of the data in Table 11 reveals that DW13 is the largest in area covering 35 Km^2, followed by DW5 that covers 32 Km^2. DW4 is the smallest in size and covers 13.8 Km^2 of the total catchment area. The total area of watersheds is found to be 325 Km^2 of the total catchment area of 337 Km^2. This watershed area excludes the 12 Km^2 open water area of Dal Lake.

Table 11: Area wise distribution of different watersheds in Dal Lake Catchment

S. No.	ID	Area (Km^2)
1	DW1	18.4
2	DW2	26.8
3	DW3	24.7
4	DW4	13.8
5	DW5	32.0
6	DW6	21.1
7	DW7	19.7
8	DW8	28.3
9	DW9	24.9
10	DW10	25.5
11	DW11	24.7
12	DW12	29.3
13	DW13	35.84
Total	**325**	

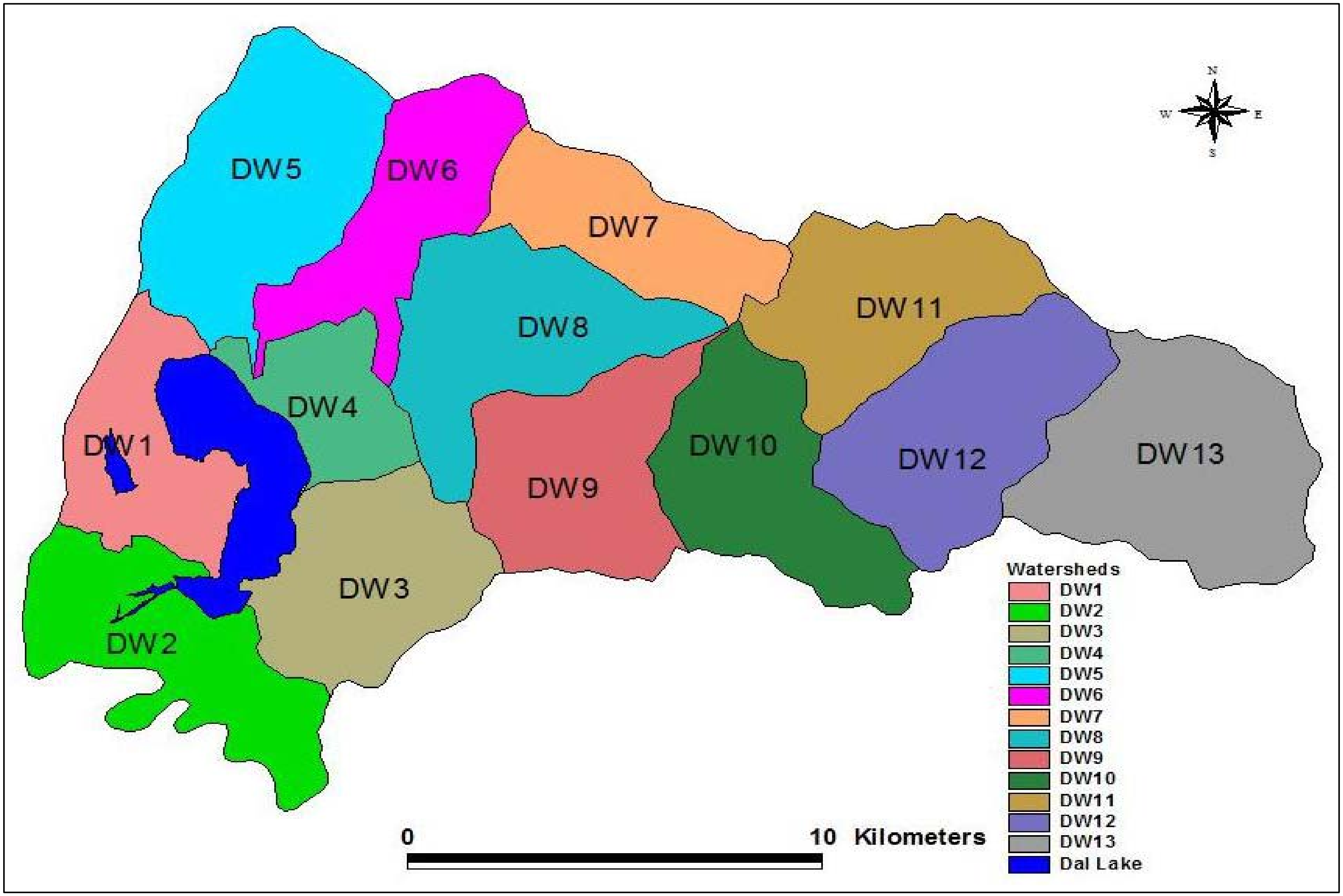


Fig. 19: Watershed Map of Dal Lake Catchment

6.1.2 Slope Analysis of Dal Lake Catchment

Slope analysis is an integral part of many environmental analyses, particularly erosion models. It is a very important characteristic for understanding the complexity of relief and associated features. The erosive capacity of runoff varies in direct proportion with the slope of the land as the speed and extent of runoff depends on the degree slope. The slope of the region also influences the drainage pattern and various structures. Thus, steep slopes have a tendency of increasing the erosion rates. Besides this, land use of a particular area is also determined by the slope. Therefore, while dealing with the problems of lake degradation caused by enhanced erosion and nutrient enrichment, slope analysis becomes all the more important. Fig. 20 and Table 12 show slope map of Dal Lake Catchment and the area under different classes respectively.

The Dal Lake Catchment been categorized into five slope classes ranging from 0° to more than 35° as shown in Table 20. From the Table 20, it is observed that flat regions cover 80 Km^2, constituting 23.7% of the study area. This slope class comprises of agricultural fields, horticulture, built up areas and also some deciduous forest patches. The Dal Lake also falls in this slope category. Gentle and gentle to moderate slope classes cover 72 and 92 Km^2 of the study area respectively. Almost 93 Km^2 of the study area falls under steep and very steep classes. These regions in the Dal Lake Catchment comprise of bare lands, bare exposed rocks, scrubland, grasslands and sparse forests.

Watershed wise slope analysis results are given in Table 13. Fig. 21(a-m) shows the watershed wise slope maps of Dal Lake Catchment.

Table 12: Area under different slope categories in Dal Lake Catchment

S. No.	Slope Classes (Degrees)	Area (Km^2)	Area (%)
1	Flat (0-5)	80	23.7
2	Gentle (5-15)	72	21.3
3	Gentle to moderate (15-25)	92	27.3
4	Steep (25-35)	48	14.2
5	Very steep (>35)	45	13.5
Total		**337**	**100**

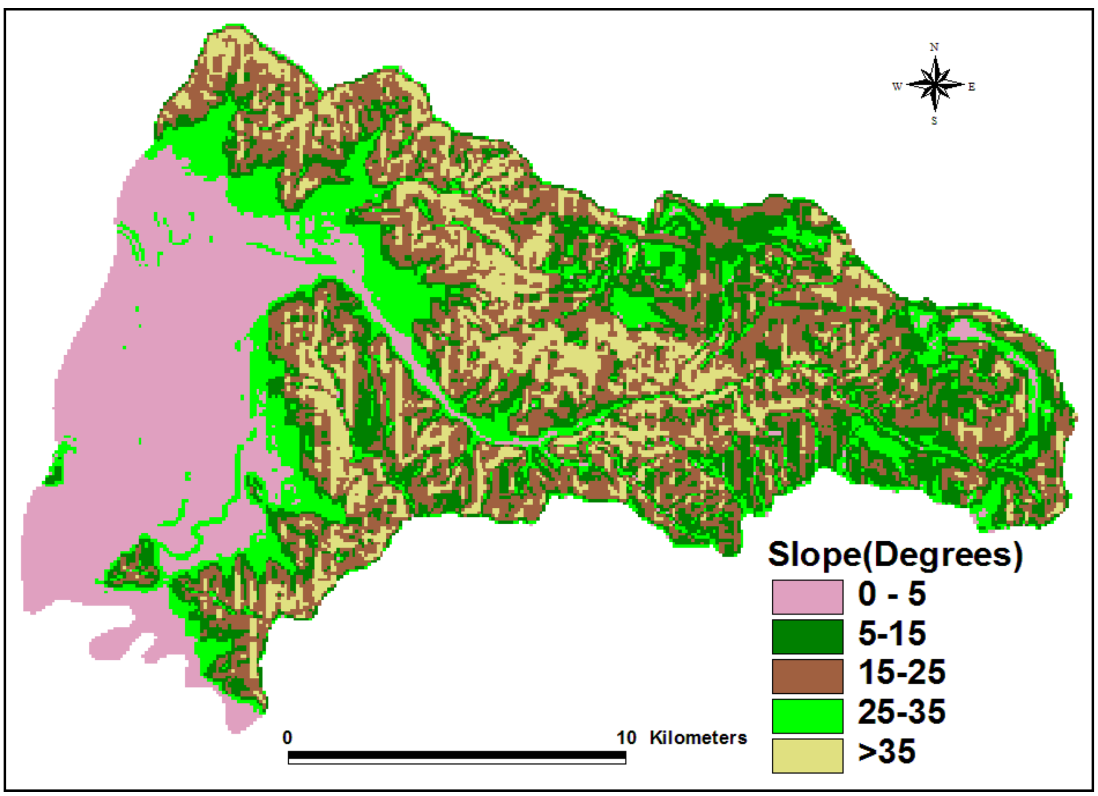
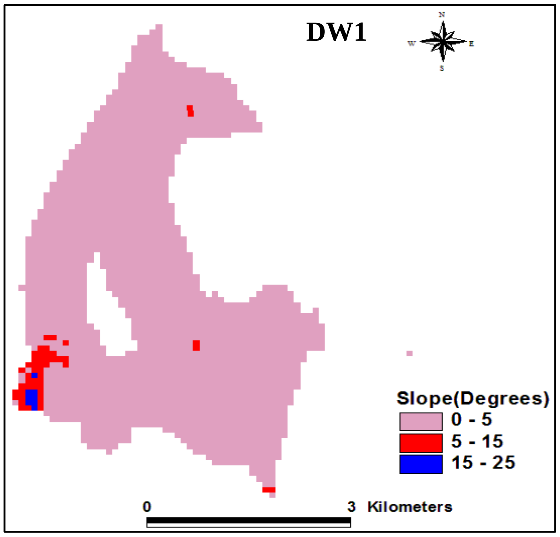


Fig. 20: Slope Map of Dal Lake Catchment

Table 13: Watershed wise area distribution of different slope classes in Dal Lake Catchment

S.No	Slope Classes (Degrees)	WATERSHEDS													Total Area
		DW1	DW2	DW3	DW4	DW5	DW6	DW7	DW8	DW9	DW10	DW11	DW12	DW13	
		Area(Km^2) Under Different Slope Classes													
1	Flat (0-5)	18.4	16	3	5.05	12	6	0	2	1.9	0	0	0	1	**65.35**
2	Gentle (5-15)	0	4.8	5	3	6	4	1.7	5	3	2	4	2	7	**47.5**
3	Gentle to moderate (15-25)	0	3	4.7	1.75	3	3.1	4	6.3	6	6	10	8	14	**112.85**
4	Steep (25-35)	0	3	8	3	6	5	8	10	9	10	8.7	14.3	11.84	**96.84**
5	Very Steep (>35)	0	0	4	1	5	3	6	5	5	7.5	2	5	2	**45.5**
	Total Area	**18.4**	**26.8**	**24.7**	**13.8**	**32**	**21.1**	**19.7**	**28.3**	**24.9**	**25.5**	**24.7**	**29.3**	**35.84**	**325**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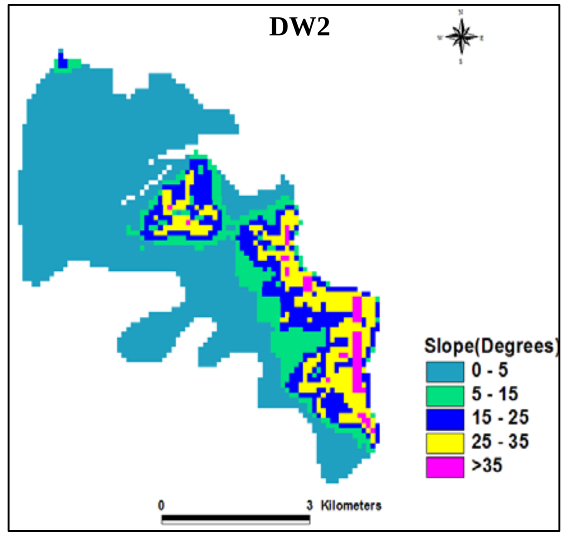
5 - 15
15 - 25
0
3 Kilometers

(a)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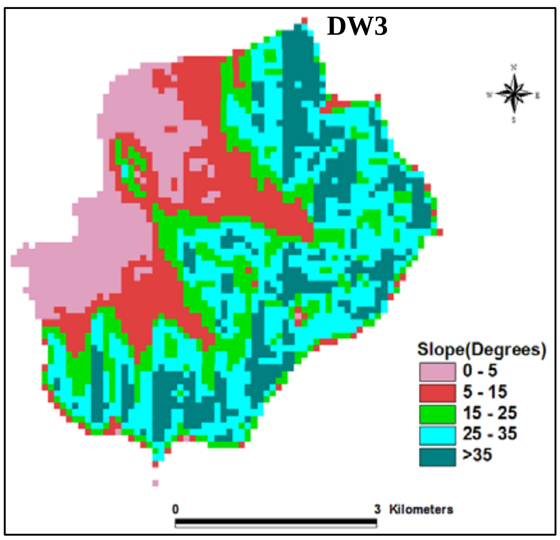
(b)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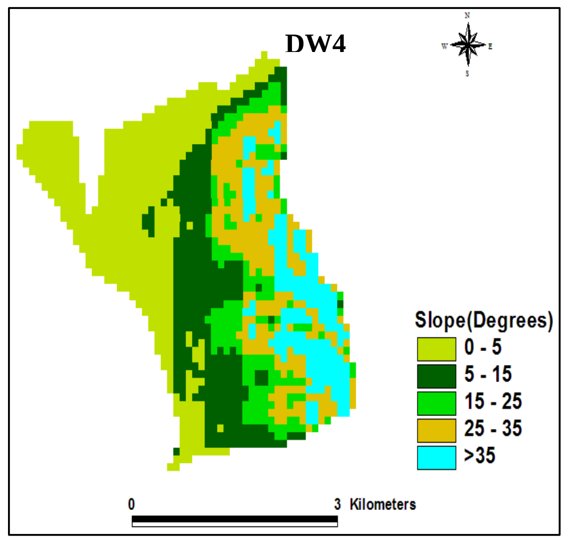
(c)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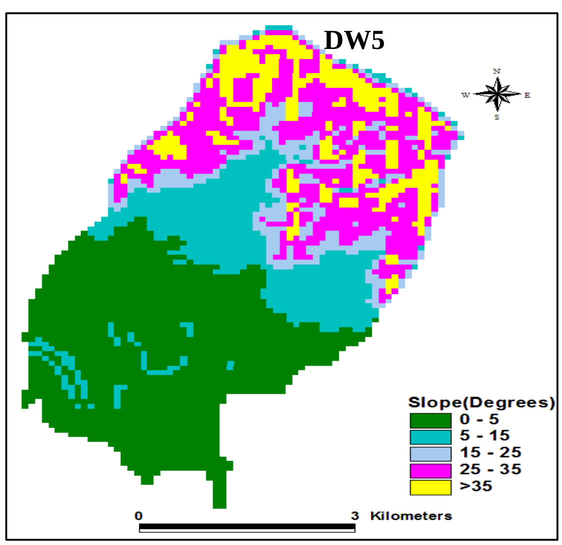
15 - 25
25 - 35
>35
0
3 Kilometers

(d)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25 - 35
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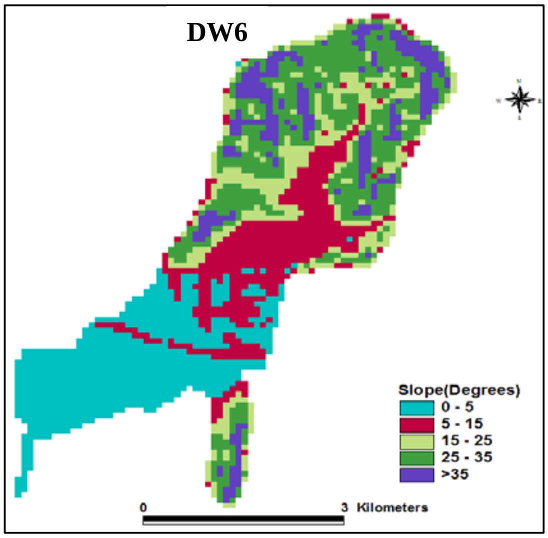
(e)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15 - 25
25 - 35
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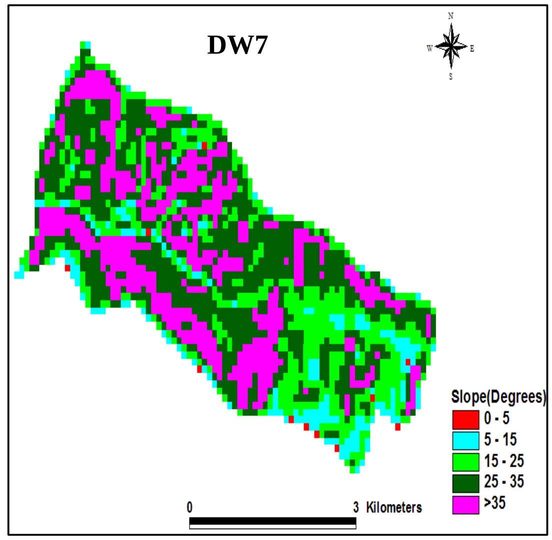
3 Kilometers

(f)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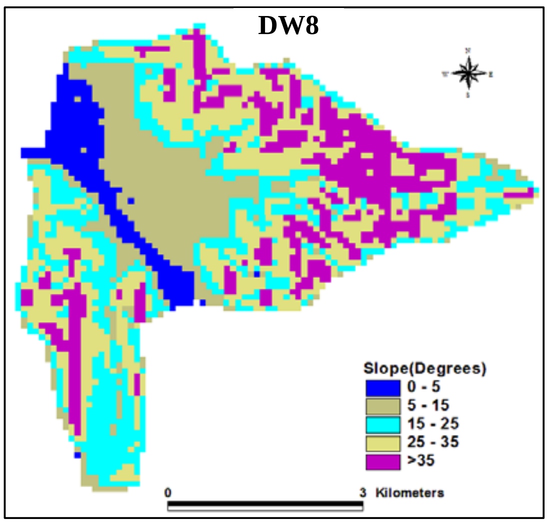
15 - 25
25 - 35
>35
0
3 Kilometers

(g)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25 - 35
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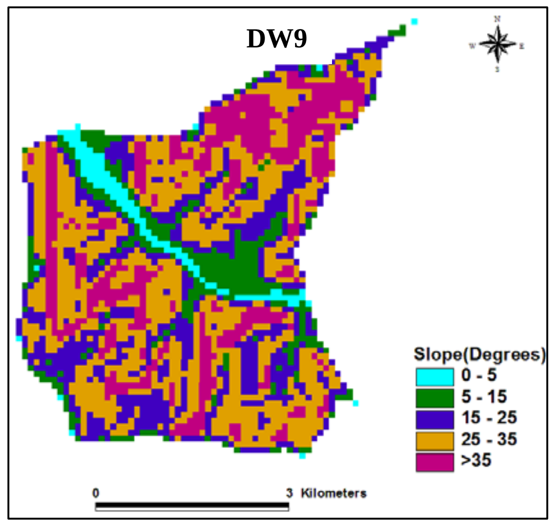
0
3 Kilometers

(h)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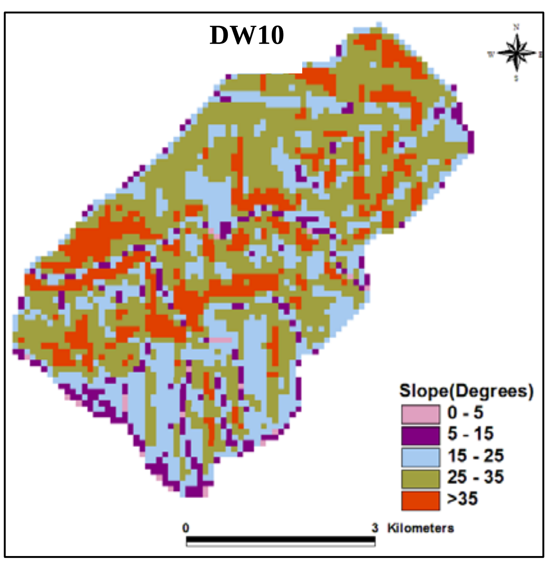
(i)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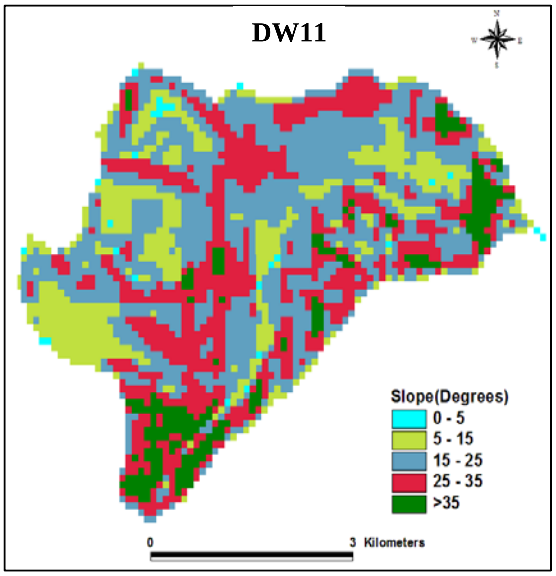
15 - 25
25 - 35
>35
0
3 Kilometers

(j)



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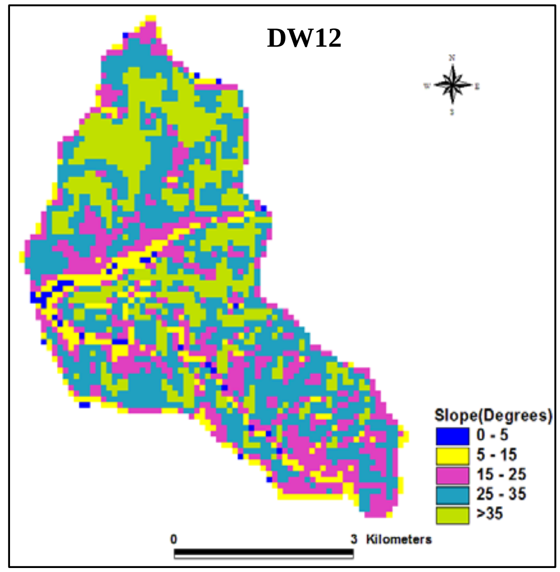
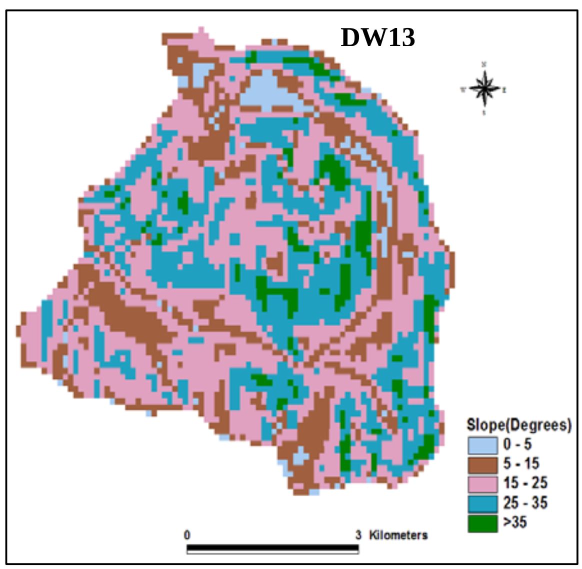


(l)



(m)

Fig. 21(a-m): Slope Maps of different Watersheds in Dal Lake Catchment

6.1.3 Drainage Analysis of Dal Lake Catchment

The Dachigam stream and a host of other streams draining the bordering mountain slopes constitute the drainage network of Dachigam Nallah and that of Dal Lake Catchment (Fig. 22). These include the fairy developed systems of Wagbat, Munyu, Drogwan, Burzakut, Mahadev, Sarbal and Nambalan streams in addition to many other tiny streamlets, evolved during the course of chequered history marked by stupendous changes. Generally, the stream network follows the denditic pattern.

The stream takes its origin from the Lake Marsar (3849 m) and the surrounding snow bound mountains feed it during summer. All along its course, the stream is joined by a number of tributaries of a perennial- non-perennial origin. The stream leaves the Marsar Lake as Marsar Nar in Zajmarg Gali and Ramdach Gali. It traverses 1.4 km distance before being joined by a 2^{nd} order tributary giving it the status of a 2^{nd} order stream. During its course a number of stream segments of 0.12 km -1.5 km are added up. The Marsar Nar (3^{rd} order) traverses a distance of 6.1 km before it is joined by a 3^{rd} order, 2.5 km long stream segment arising at 4000m altitude. From this point onwards, the stream traverses as 4^{th} order stream. At 3146m, a 3^{rd} order stream (Mandalan Nar) is added up which is 2.35 km long.

The 4^{th} order stream i.e. Marsar Nar is joined by a three perennial streamlets of 1.5 km, 2.25km, and 0.5km distances respectively. Another tributary (Brari Nar) of 2.1 km long arising at 4275 m and joining it at 2800 m is added up to the Marsar Nar. From this point onwards the Marsar Nar traverses as the Dachigam stream. This stream travels a distance of 5.5 km before it is joined by Dachigam Nar (4^{th} order stream) at 2700 m, wherefrom, the stream order changes and flows as the 5^{th} order stream.

The Dagwan Nar is formed by a number of 1st, 2nd and 3rd order tributaries with length ranging from 0.7-4.5 km and the altitudinal situations between 4042-3635 m. The Dagwan stream after traversing a distance of 6.5 km is joined by another tributary (Nambalan Nar) at 2400m. Below it after traversing a distance of 2.5 km, the main stream splits itself into myriad of channels, which bifurcate and unite to create a maze of drainage channels.

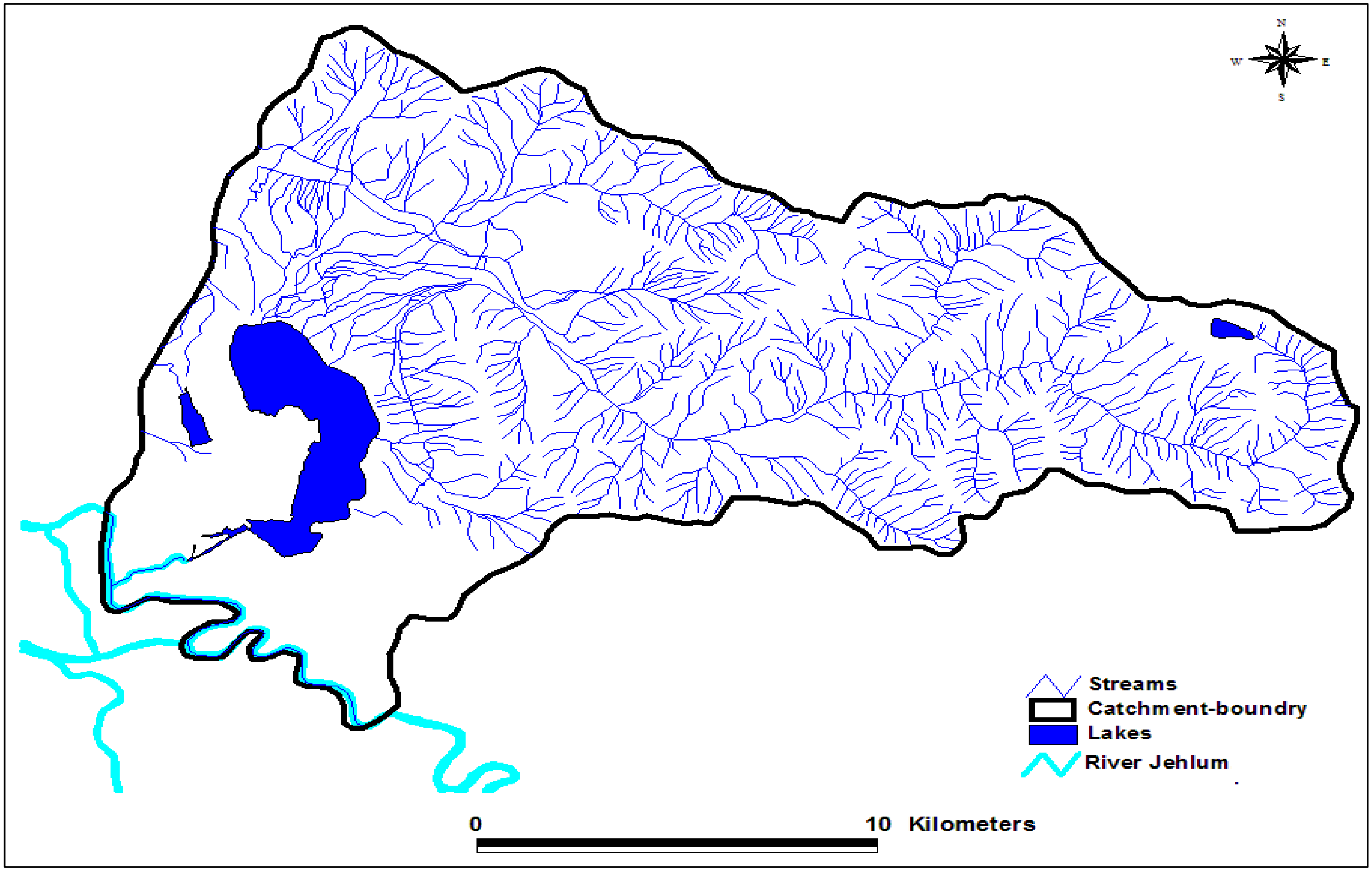


Fig. 22: Drainage network in Dal Lake Catchment

During this reunion, one of the channels traverses in the upward direction where it is joined by Mahadev Nallah coming down from the Mahadev range 2000 m (a part of the Dachigam stream and Mahadev Nallah) flows independently through the Dachigam National Park for some distance and leaves the latter as Mawas Kol which later flows through a few villages before joining the Dhara stream near Saidipur. Upper portion of the stream (Mahadev Nallah) drains its way through pines and disturbed pastures.

A part of a small stream segment of Dachigam stream leaves it as Sharab Kol which supplies water to agricultural fields and the floating gardens subject to vegetative cultivation while another stream segment is diverted to the Harwan reservoir with the remaining part flowing as Dachigam stream. During its course the Dachigam stream in the National Park flows through a variety of plant communities mainly comprising of pines, deciduous trees, shrubs and scrubs or open scrubs. After flowing through the National Park, it enters the Dal Lake on the Northern side at Hazratbal. At Wangund, it receives one of its major tributaries i.e., Dara stream. Dara catchment which is about 8 km is exposed to a lot of biotic interference and as such, the soil becomes loose and it is through this nallah that the Telbal stream receives large quantities of eroded soil throughout the year. Dachigam-Telbal catchment area is situated in the vicinity of the Srinagar city towards east of the Dal Lake.

6.2 Land Use/Land Cover Analysis

Land Use, the anthropogenic use of the land and Land Cover, the physical state of such land, are among the most evident impacts of human activities on natural resources. During the current study, multi-date Land use/ Land cover maps for the year 1992 and 2005 were prepared for the Dal Lake Catchment based on the National Natural Resources Management System (NNRMS) standards. For both the years, 16 classes were identified viz. coniferous forest, deciduous forest, sparse forest, grasslands, scrublands, plantation, agriculture, horticulture, agriculture fallow, aquatic vegetation, snow, water, water channel area, bare land, bare exposed rocks and built up. However, for the year 2005, an extra class in the form of golf course was identified, as it was not present for the earlier year of 1992. Land use / Land cover maps for 1992 and 2005 and their respective statistics are given under:

6.2.1 Land Use/Land Cover Map: 1992

Land use/ Land cover map of 1992 (Fig. 23) was represented by 16 classes viz. coniferous forest, deciduous forest, sparse forest, grasslands, scrublands, plantation, agriculture, horticulture, agriculture fallow, aquatic vegetation, snow, water, water channel area. Table 14 reveals that deciduous forest was the most dominant class in the study area covering 76.49 Km^2 (22.69%) followed by coniferous forest 51.87 Km^2 (15.39%), plantation 47.9 Km^2 (14.21%) and grasslands 33.31 Km^2 (9.88%). Snow 1.05 Km^2 (0.31%), aquatic vegetation 1.03 Km^2 (0.30%) and fallow 0.08 Km^2 (0.023%) were the least dominant classes.

6.2.2 Land Use/ Land Cover Map: 2005

Land use/ Land cover map of 2005 (Fig. 25) was represented by 17 categories. In addition to the classes that were identified for the year 1992, one more category i.e., golf course/turf was identified for 2005. From the statistics given in Table 15, it can be observed that the deciduous forest again dominated the land use/land cover area covering 74.69 Km^2 (22.16%) followed by coniferous forest 46.2 Km^2 (13.70%), plantation Km^2 (10.38%), grasslands 25.42 Km^2 (7.54%). The least representative of the classes was Golf course/turf 0.51 Km^2 (0.51%), water channel area 1.3 Km^2 (0.38%) and fallow 0.004 Km^2 (0.001%).

Table 14: Area under different Land use /Land cover classes in Dal Lake Catchment (Landsat TM, 1992)

S. No.	Class Name	Area (Km^2)	% age Area
1	Built up	9.31	2.76
2	Agriculture	14.71	4.36
3	Fallow	0.08	0.023
4	Horticulture	26.91	8.0
5	Coniferous Forest	51.87	15.39
6	Deciduous Forest	76.49	22.69
7	Sparse Forest	19.76	5.86
8	Grasslands	33.31	9.88
9	Scrubland	3.68	1.09
10	Plantation	47.9	14.21
11	Aquatic Vegetation	1.03	0.30
12	Bare Land	20.82	6.17
13	Bare Exposed Rocks	14.09	4.18
14	Water Bodies	14.8	4.39
15	Water Channel Area	1.24	0.36
16	Snow	1.05	0.31
Total		**337**	**100%**

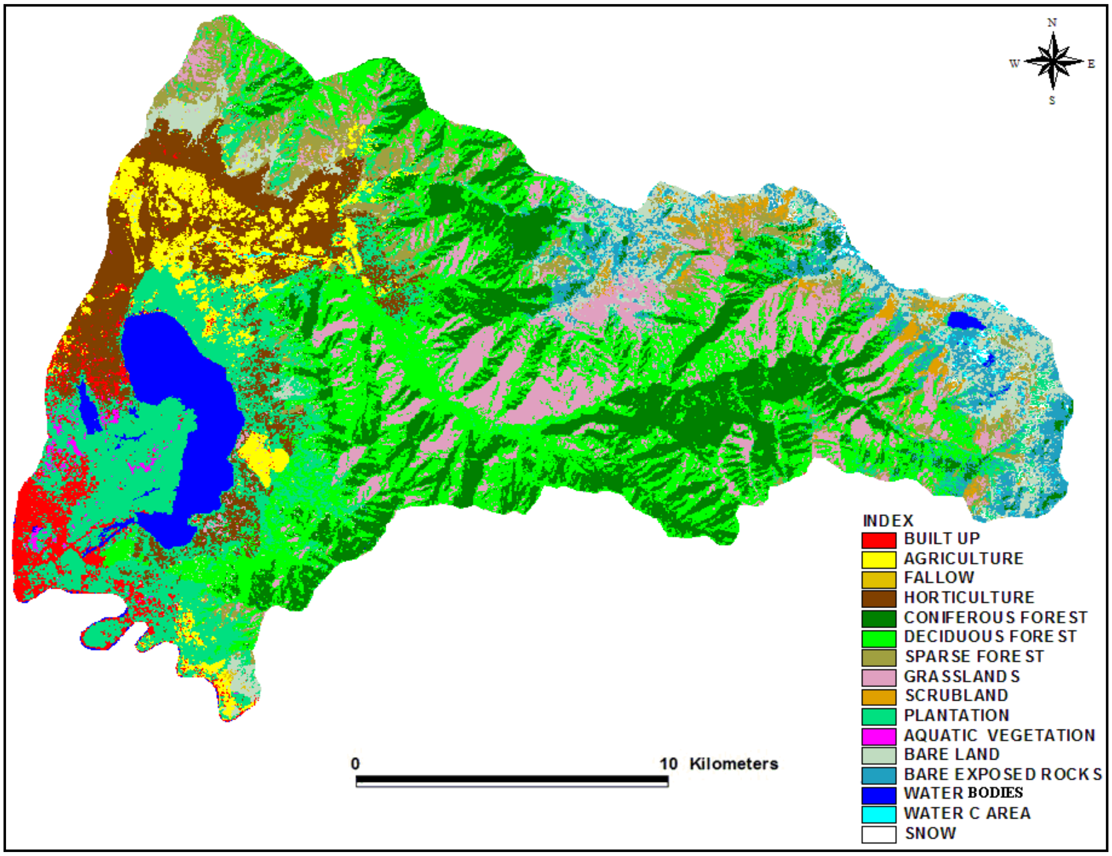


Fig. 23: Land use/ Land cover Map of Dal Lake Catchment (Landsat TM, 1992)

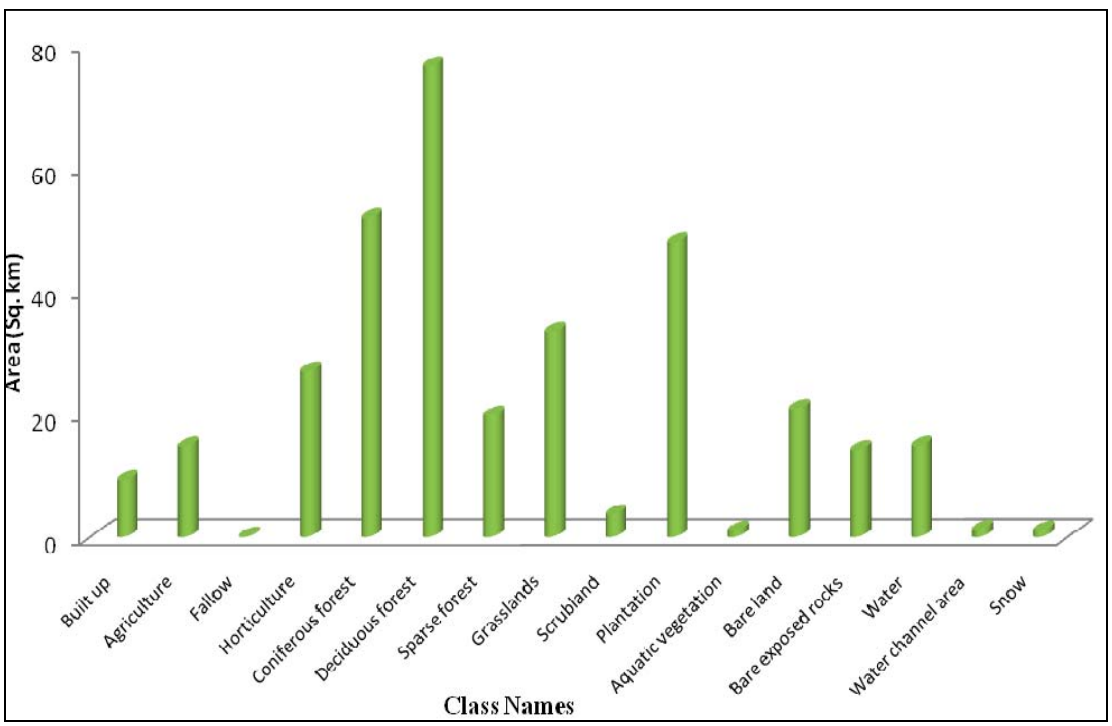


Fig. 24: Area under different Land use/ Land cover classes in Dal Lake Catchment (Landsat TM, 1992)

Table 15: Area under different Land use /Land cover classes in Dal Lake Catchment (IRS LISS III, 2005)

S. No.	Class Name	Area (Km^2)	% age Area
1	Built Up	21.39	6.34
2	Agriculture	12.87	3.81
3	Fallow	0.004	0.001
4	Horticulture	19.34	5.73
5	Coniferous Forest	46.2	13.70
6	Deciduous Forest	74.69	22.16
7	Sparse Forest	18.8	5.57
8	Grasslands	25.42	7.54
9	Scrubland	15.65	4.64
10	Plantation	35	10.38
11	Aquatic Vegetation	4.5	1.33
12	Bare Land	25.26	7.49
13	Bare Exposed Rocks	15.7	4.65
14	Water Bodies	13.89	4.12
15	Water Channel Area	1.3	0.38
16	Snow	6.5	1.92
17	Golf course/Turf	0.51	0.15
Total		**337**	**100%**

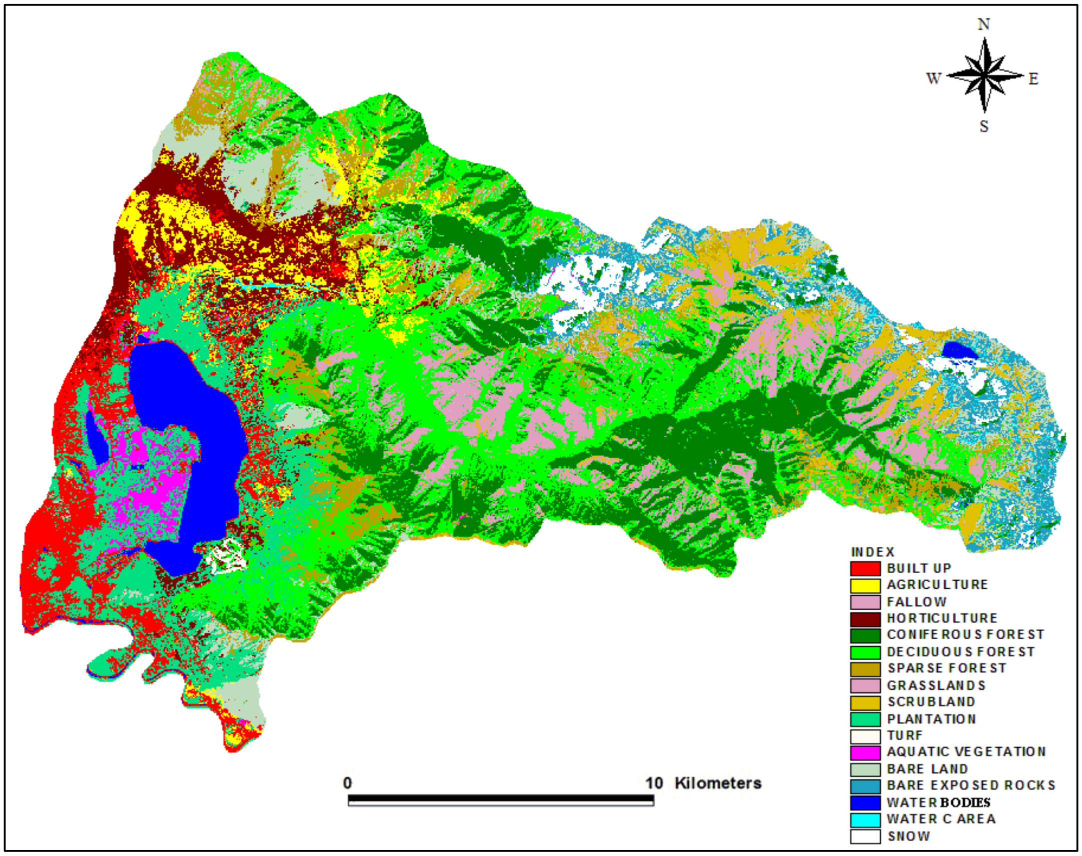


Fig. 25: Land use/ Land cover Map of Dal Lake Catchment (IRS LISS III, 2005)

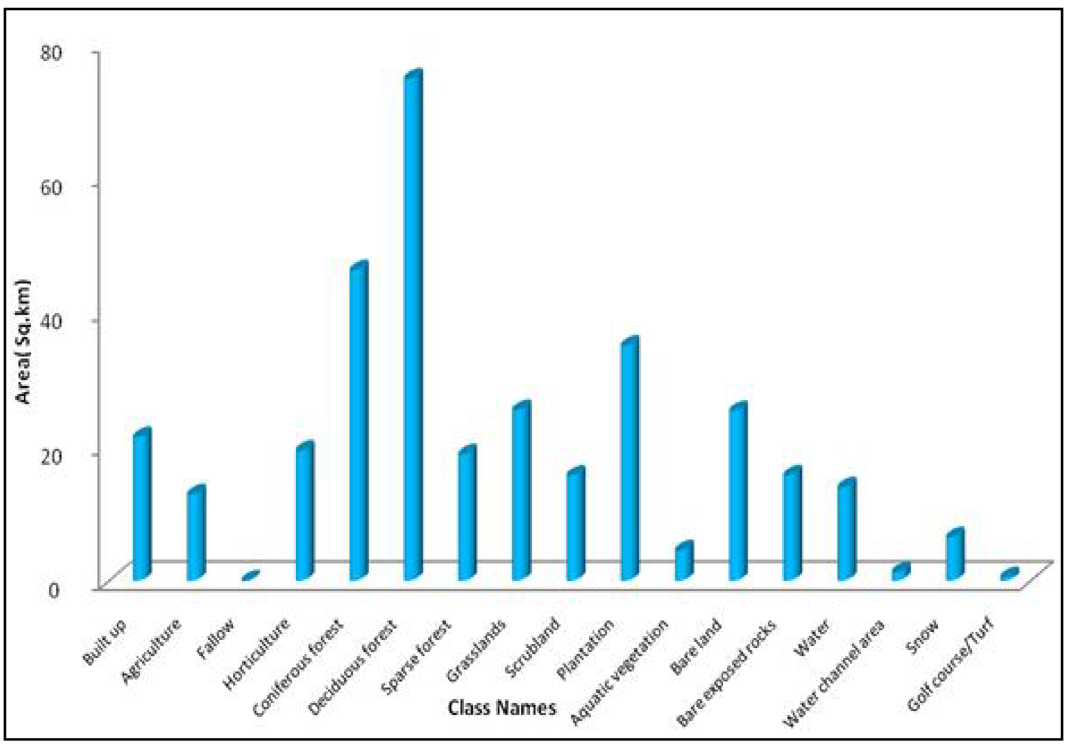


Fig. 26: Area under different Land use/Land cover classes in Dal Lake Catchment (IRS LISS III, 2005)

6.2.3 Change Detection

Remote sensing techniques offer benefits in the field of land use/ land cover mapping and their change analysis. One of the major advantages of remote sensing systems is their capability for repetitive coverage, which is necessary for change detection studies at global and regional scales. Land use/ land cover change is critically linked to natural and human influences on environment. Keeping the above in view, the change detection of Dal Lake catchment was done by using Post-classification change detection method. The land use/ land cover maps prepared from two data sets Landsat TM (1992) and IRS LISS (III) (2005) were used for change detection. By comparing the respective maps for two years, a general scenario of the major changes that have taken place in the catchment was derived.

From Table 16 and Fig. 27, it is quite evident that the land use/land cover pattern in the Dal Lake Catchment has undergone considerable changes from 1992 and 2005. The description of the land use/land cover classes for the two years vis-à-vis the change in their respective statistics is given as under:

Built up

The built-up class comprises of the areas of settlements, residential, commercial, industrial establishments. In Dal Lake Catchment, this class comprises of the urban areas of the Srinagar city as well as the rural areas. From the Table 16, it is observed that built up covered an area of 9.31 Km^2 in the year 1992 constituting 2.76% of the total area. However, the statistics for the year 2005 reveal an increase of 12.08 Km^2 i.e., 6.34% in the total built up area from 1992-2005.

Agriculture

This class includes cumulative land under different crops. Paddy *(Oryza sativa)* is the chief cultivated food crop. Besides, cultivation of Maize *(Zea mays)*, Mustard *(Brassica oleraceae)*, Oats *(Avena sativa*), fodder pulses and vegetables is also being practised. The statistics of the agriculture class reveal a decrease in the area by 1.84 Km^2 from 1992 to 2005.

Table 16: Change in the Land use/ Land cover pattern of Dal Lake Catchment (1992-2005)

S. No.	Class Name	Area (Km^2)		Area change	% change
		1992	2005		
1	Built up	9.31	21.39	+12.08	3.58
2	Agriculture	14.71	12.87	-1.84	0.54
3	Fallow	0.08	0.004	-0.076	0.02
4	Horticulture	26.91	19.34	-7.57	2.24
5	Coniferous Forest	51.87	46.2	-5.67	1.68
6	Deciduous Forest	76.49	74.69	-1.8	0.53
7	Sparse Forest	19.76	18.8	-0.96	0.28
8	Grasslands	33.31	25.42	-7.89	2.34
9	Scrubland	3.68	15.65	+11.97	3.55
10	Plantation	47.9	35.00	-12.9	3.82
11	Aquatic Vegetation	1.03	4.50	+3.47	1.02
12	Bare Land	20.82	25.26	+4.44	1.31
13	Bare Exposed Rocks	14.09	15.7	+1.61	0.47
14	Water Bodies	14.8	13.89	-0.91	0.27
15	Water Channel Area	1.24	1.30	+0.06	0.01
16	Snow	1.05	6.50	+5.45	1.61
17	Golf course/Turf	0.00	0.51	+0.51	15.37
Total		**337**	**337**		

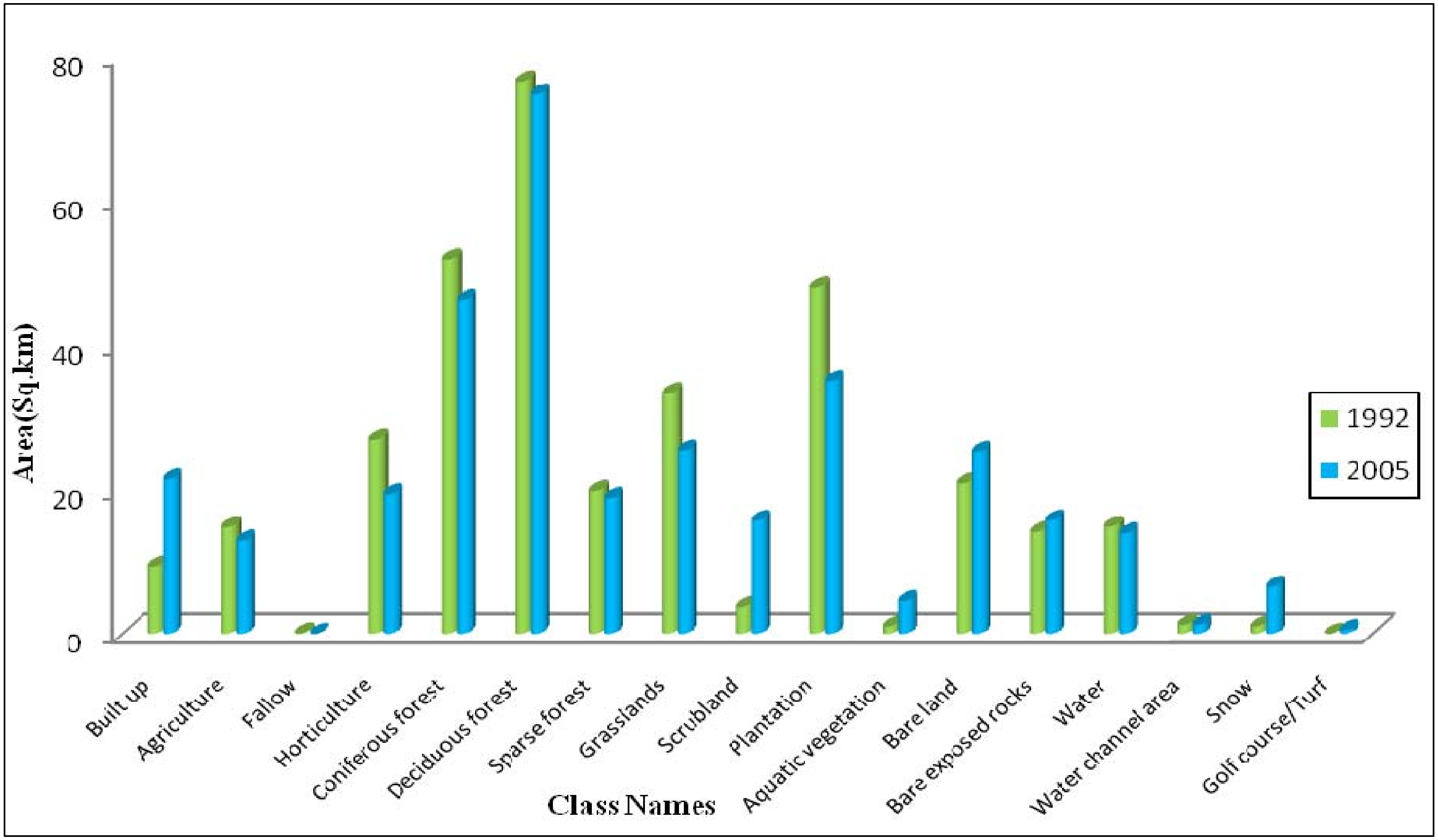


Fig. 27: Change in the Land use/ Land cover pattern of Dal Lake Catchment (1992-2005)

Fallow

Fallow land comprises of the unused agricultural land that is left vacant for some time. This class constitutes almost negligible area in the study area for both the years. The statistics of this class from Table 16 show a decrease in the area from 0.08 to 0.004 Km^2 from 1992-2005.

Horticulture

Horticulture is a type of agriculture in which generally fruit and nut crops are grown. These fields are mostly patterned and the major horticultural plantations in the catchment area include apple *(Pyrus malus)*, cherry *(Prunus avium)* and walnut *(Juglans regia)*. Minor horticultural crops include peach *(Prunus persica)*, almond *(Prunus amygdalus)*, plum (*Prunus domestica)*, apricot *(Prunus armenica)*, sweet chestnut *(Castaenia sativa)* etc. Table 16 shows that horticulture covered an area of 26.91 Km^2 in the year 1992, whereas, in 2005 it covered 19.34 Km^2 of the Dal Lake Catchment. Thus, a decrease of 7.57 Km^2 in the horticulture area was recorded from 1992-2005.

Coniferous Forest

The upper reaches of the Dal Lake Catchment are covered with thick dense forests which include a majority of conifers in the Dachigam sub-watershed viz. Deodar, Fir and Kail. Blue Pine Forest community consists of Kail (*Pinus griffithii*) and grows on the slopes along the north and north east aspect between Harwan Water Reservoir to Draphama in the elevation zone of 1700m. Mixed Blue Pine and Fir Forests (Budul) community is found along higher elevations (2700m to 3100m). The blue pine occurs on the open and exposed sides, whereas, *Abies pindrow* is confined to smaller shady places and nallahs. This community is found along the main Dachigam Nallah from Waskar to Namblan in the north and in the south up to Gugjiyar peak.

Table 16 shows that the total area covered by the coniferous forests in 1992 was 51.87 Km^2 which accounted for 15.39 % of total catchment area. In 2005, statistics for the same class show the total area as 46.2 Km^2 showing a decrease of 5.67 Km^2 from 1992-2005.

Deciduous Forest

This vegetation type is mainly confined along the main Dachigam Nallah from Harwan in the west up to Waskur in the east within an altitude limit of 2300m. It is basically a successional vegetation type which is mainly dictated by the local eudopho-climatic conditions. This vegetation type has association of broad leaved tree species like *Aescules indica* (Handoon), *Celtis caucasia* (Brun and Brimji), *Salix wallichiana* (Weer), *Roubinia pseudoacacia* (Kiker), *Morus alba* (Mulberry), *Quercus robur* (Chhoor), *Rhus spp.*(Arkhur), *Corylus spp.* (Hazle). The statistics revealed by Table 16 show that the total area under deciduous forests in 1992 was 76.49 Km^2 which decreased to 74.69 Km^2 in 2005, showing a decline of 1.8 $Km^{2.}$

Sparse Forest

This class of land use/ land cover includes the forests that over a period of time have been degraded due to the various environmental and anthropogenic pressures. Such forests can include either of the coniferous or deciduous trees or a mixture of both. These occur mainly along the lower reaches but have also been found along some higher altitude forests as well. Analysis of the statistics given in Table 16 shows that total area under sparse forest was 19.6 Km^2 in 1992 which decreased to 18.8 Km^2 in 2005, showing a decline of 0.96 $Km^{2.}$

Grasslands

The grasslands in the Dal Lake Catchment are specifically found in the Dachigam National Park and constitute an important ecological component of the Park. Locally known as Margs/ Bahaks, these grasslands are devoid of tree cover but have luxuriant herbaceous and grass cover. A number of grasses like *Chrysopoqon, Echinulatus, Themeda anathera, Muhilembergia hueqelii, slipa sibiria and Poa stewardiana* are present. In over grazed areas the commonest species are *Cynodon dactylon* and *Bothriochloae.* The alpine pastures fall in upper reaches of Upper Dachigam near Mahadeo, Wawirgul, Sarbal, Batagul, Hangulmarg, Marsar, Pansalmarg, Sangargul and Gugjiyari. These alpine pastures are generally dominated by *Fritillaria imperialis, Corydalis diphylla, Geranium lucidum, Sibbaldia cuneata, Sieversia elata, Anaphalis nepalensis, Sibbaldia cureata, Anemone obtusiloba* and *Sieversia spp.* These grasslands are of tremendous importance in checking the runoff and soil erosion besides serving as grazing lands for shepherds, Gujaras, and Bakerwals.

Analysis of the statistics in Table 16 shows that in 1992, the total area under grasslands was 33.31 $Km^{2.}$ By 2005, only 25.42 Km^2 of the total area was covered by grasslands, thereby, showing a decrease of 7.89 Km^2 during the 15 years.

Scrubland

These are vast stretches of open lands particularly on slopes facing south and south-west. These open stretches are sparsely covered by thickets of broad leaved deciduous scrub comprising, *Parrotiopsis jacquemontiana, Prunus armenica, Celtis caucasica, Ulmus spp.* This vegetation type has a large number of xerophytic species as its undergrowth that include *Indigofera heterantha*, *Rosa brunonii, R. mecrophylla, Rosa webbiania, lsodon plectranthoides, Berberis lycium, Lonicera quinqelocularis, Fragaria Vesca, Geranium nepalensis* etc. This vegetation type in found in its north-western areas of Lower Dachigam in Mulnar and Mahadeo Nar. Lower down along the Dachigam Nallah from Sheep Breeding Farm to Waghut Nallah and covers the entire Drog Nallah and Muyun Nallah. In the south-west Lower Dachigam, there are very small patches of open scrub at Barobal and Namblan.

A perusal of the statistics given in Table 16 reveals that the area under scrubland in the Dal Lake Catchment has increased by 11.97 Km^2 from 1992 to 2005.

Plantation

This class comprises of the land under natural plantation as well as other trees that are exotic in nature and over a period of time have adapted in the local ecosystem. The common plantation species that were observed in the study area include the Willows (*Salix spp)*, Poplars *(Populus spp)*, Oriental Plane *(Plantanus orientalis)*, Black Locust *(Robini pseudoacacia)*, White Mulberry *(Morus alba)*, Walnut *(Juglans regia).* This type of vegetation is normally found along the banks of streams, wetlands, lakes etc. As revealed by the Table 16, the area covered by this class in 1992 was 47.9 $Km^{2.}$ Whereas, in 2005 a total of 35 Km^2 were under plantation, thereby, showing a decline of 12.9 Km^2 during the 15 years.

Aquatic Vegetation

This class comprises of the vegetation found in the lake waters growing naturally as well as cultivated for commercial purposes. In the Dal Lake Catchment, this class is found in abundance in Dal Lake waters where large floating gardens are created by filling the waters with soil and then used for cultivation of vegetables which are later supplied to the entire Srinagar city. Besides, macrophytes such as *Potamageton sp.*, *Nelumbo nucifera*, *Nymphaea sp.* etc are found in the lake. Large thick mats of such vegetation are found floating on the lake waters. A comparison of the statistics in Table 16 shows that the area of aquatic vegetation has increased from 1.03 Km^2 to 4.5 Km^2, showing an increase of 3.47 Km^2 during the span of 15 years.

Bare Land

The land parcels that are devoid of any vegetation cover are placed in this category. This class has been found both at the higher and the lower elevations of the study area. The statistics of bare land as revealed by Table 16 show that in 1992, the area under the class was 20.82 Km^2 constituting 6.17% of the total study area. By 2005, the area covered by the bare lands was 25.26 Km^2 and constituted 7.49 % of the study area. Thus an increase of 4.44 Km^2 was recorded from 1992-2005.

Bare Exposed Rocks

The exposed rock surface that is devoid of any vegetation cover because of higher elevation and low temperature is included in this class. These consist of steep rocky cliffs which have little or no vegetation. A very sparse sprinkling of secondary succession of pines is found on these rocky cliffs. These are found at Batgul, Marsar, Navirgul and Mahadeo areas of the Dal Lake Catchment. Analysis of the statistics in Table 16 reveals that in 1992, 14.09 Km^2 of the total study area was covered by exposed rocks constituting 4.18 % of the total area. In 2005, the area covered by this class was 15.7 Km^2 i.e., 4.65 % of the study area, showing an increase of 1.61 Km^2 from 1992-2005.

Water Bodies

There are a number of small and large water bodies found in the Dal Lake Catchment. Besides the Dal Lake itself, the other water bodies include the Nigeen Lake, Marsar Lake, Dachigam stream and the Jehlum River. These are mostly open water bodies. Table 16 shows that the area covered by water bodies in 1992 was 14.8 Km^2 constituting 4.39% of the total catchment area. In 2005, the total area under this class was found to be 13.89 Km^2 i.e., 4.12% of the total area. Thus from 1992-2005, water bodies showed a decline of almost 1 $Km^{2.}$

Water channel area

This class includes the boulders and river beds in the study area. The major portion of these river beds remain under water in the summer seasons, while in the autumn and winter season they are exposed. The main water channel areas are the Dachigam Nallah in the Dachigam National Park and its tributaries like, Dagwan Nar, Bidan Nar, Namblan Nar, Gret Nar, and Mahadevo Nar. Analysis of the statistics in Table 16 show that in 1992, 1.24 Km^2 i.e., 0.36% of the total study area was covered by the water channel area. In 2005, 1.3 Km^2 i.e., 0.38 % of the study area was covered by this class, showing a slight increase of 0.06 Km^2.

Snow

Higher reaches of the Dal Lake Catchment remain snow covered even during summer. However, the spatial snow coverage varies with season/ and year. An increase or decrease in the areal extent is subject to the amount of snowfall received in a particular area as well as the temperature variations. Sarbal, Hokasar and Mahadeo are some of the places in the catchment that remain almost snow covered for a fairly long period of time. Table 16 reveals that the snow cover in 1992 was 1.05 Km^2 constituting 0.31 % of the study area. In 2005, however, 6.5 Km^2 i.e., 1.92 % of the study area was covered with snow.

Golf course/Turf

Highly-maintained, intensively-fertilized area that is similar to golf courses or sod farms may be included in this category. In the Dal Lake Catchment, Royal Springs Golf Course (RSGC) was created by clearing the city reserve forest near the SKICC, Srinagar. In 1992, this class was under the deciduous and sparse forest. Hence, the statistics were calculated for 2005 only which showed 0.51 Km^2 i.e., 0.15% of the total area covered by the golf course.

6.2.4 Land use/ Land cover Characteristics of Watersheds in Dal Lake Catchment

Since this study is based on a watershed level approach, understanding the biophysical characteristics of these watersheds becomes all the more imperative. Land use/ land cover is one of the important parameters that determine the erosion and the pollution potential of the watersheds. Thus analyzing its change over a period of time would be helpful in understanding the changing erosion, sediment and nutrient fluxes in Dal Lake Catchment. The land use/ land cover maps for the years 1992 (Fig. 28a-m) and 2005 (Fig. 29a-m) of all the watersheds in Dal Lake Catchment and their statistics for the respective years are given in Table 17.

Table 17: Change in the Land use/ Land cover pattern of different watersheds in Dal Lake Catchment (1992-2005)

S. No	Class Names	DW1		DW2		DW3		DW4		DW5		DW6		DW7	
		1992	**2005**	**1992**	**2005**	**1992**	**2005**	**1992**	**2005**	**1992**	**2005**	**1992**	**2005**	**1992**	**2005**
1	Turf	0.00	0.00	0.00	0.00	0.00	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	Snow	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.35
3	Water Bodies	0.38	0.59	0.59	0.43	0.05	0.04	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00
4	Water Channel Area	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.11	0.29	0.12	0.06
5	Bare Land	0.00	0.11	0.88	2.85	0.12	2.10	0.29	2.63	2.67	5.93	0.73	1.78	1.31	1.88
6	Bare Exposed Rocks	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.02	0.01	0.01	0.01	1.73	1.72
7	Built Up	2.15	5.80	6.07	9.30	0.08	2.07	0.11	1.52	0.12	1.65	0.07	0.98	0.00	0.00
8	Agriculture	0.41	0.16	1.31	0.55	1.01	0.23	0.99	0.47	6.05	4.77	3.62	3.77	0.09	0.57
9	Horticulture	5.28	1.38	0.74	0.76	3.00	0.79	1.57	1.08	9.54	8.82	5.37	5.06	0.00	0.05
10	Fallow	0.04	0.00	0.22	0.00	0.22	0.00	0.13	0.00	0.17	0.00	0.00	0.00	0.00	0.00
11	Grasslands	0.00	0.02	0.12	0.01	1.40	0.02	0.21	0.01	1.37	0.06	0.83	0.33	1.03	0.33
12	Coniferous Forest	0.00	0.00	0.10	0.03	5.05	3.23	0.86	0.50	1.08	0.82	1.97	1.98	6.93	6.39
13	Deciduous Forest	0.00	0.00	1.72	0.74	9.03	7.73	2.42	1.50	3.34	3.07	3.80	3.45	4.89	4.71
14	Sparse Forest	0.04	0.00	1.10	0.22	0.53	3.44	1.12	1.40	4.35	3.72	3.07	1.84	1.92	1.00
15	Scrubland	0.00	0.01	0.01	0.00	0.00	0.73	0.00	0.01	0.02	0.30	0.01	0.22	0.02	0.33
16	Aquatic Vegetation	0.71	3.62	0.31	0.65	0.00	0.00	0.00	0.10	0.00	0.01	0.00	0.00	0.00	0.00
17	Plantation	9.40	6.72	13.63	11.13	4.20	3.80	6.10	4.45	3.26	2.81	1.51	1.39	1.65	0.31
	Total	**18.41**	**18.41**	**26.80**	**26.80**	**24.70**	**24.70**	**13.80**	**13.80**	**32.00**	**32.00**	**21.10**	**21.10**	**19.70**	**19.70**

Table 17: Contd.

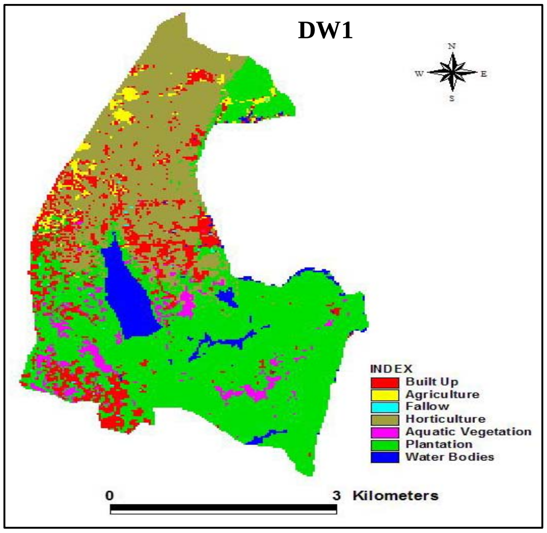
S. No	Class Names	DW8		DW9		DW10		DW11		DW12		DW13	
		1992	**2005**	**1992**	**2005**	**1992**	**2005**	**1992**	**2005**	**1992**	**2005**	**1992**	**2005**
1	Turf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	Snow	0.00	0.43	0.00	0.05	0.00	0.01	0.84	1.33	0.15	0.01	0.52	2.10
3	Water Bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.49	0.41
4	Water Channel Area	0.01	0.02	0.00	0.01	0.00	1.20	0.24	0.15	0.02	0.10	0.62	0.67
5	Bare Land	0.27	1.37	0.17	0.67	0.31	0.37	3.16	4.51	1.06	1.81	5.18	7.01
6	Bare Exposed Rocks	0.42	0.37	0.19	0.16	0.14	0.10	2.81	3.92	0.87	1.02	7.29	7.94
7	Built Up	0.02	0.19	0.00	0.01	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00
8	Agriculture	0.74	2.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.11
9	Horticulture	2.03	1.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Fallow	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Grasslands	2.24	2.37	5.04	5.84	4.70	4.08	2.67	1.89	5.44	5.37	4.44	3.87
12	Coniferous Forest	5.36	5.01	6.10	5.74	8.79	8.40	3.13	2.58	12.11	11.05	2.86	2.21
13	Deciduous Forest	12.41	11.49	12.00	11.38	10.50	9.46	4.48	4.07	7.81	6.60	5.85	5.20
14	Sparse Forest	2.20	1.68	0.60	0.57	1.04	0.81	3.94	1.22	1.19	0.67	3.98	2.12
15	Scrubland	0.01	0.57	0.00	0.46	0.01	0.92	1.63	4.96	0.44	2.65	1.37	4.09
16	Aquatic Vegetation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	Plantation	2.59	1.32	0.80	0.01	0.01	0.03	1.80	0.07	0.21	0.02	3.21	0.11
	Total	**28.30**	**28.30**	**24.90**	**24.90**	**25.50**	**25.50**	**24.70**	**24.70**	**29.30**	**29.30**	**35.84**	**35.84**

Analysis of the statistics from Table 17 reveals that the land use/land cover has changed from 1992- 2005 in each watershed of the Dal Lake Catchment, with the change being more prominent in certain watersheds. It can be observed from the Table 17 that Turf/ golf course is present in DW3 only and records an area of 0.51 Km^2 in 2005. Snow cover statistics do not show any particular trend as its increase or decrease is subject to a number of factors such as snow fall, altitude, temperature, topography etc. Snow cover was found to be absent in DW1, DW3, DW4, DW5 and DW6 for both the years. In the rest of watersheds, it recorded the maximum change in DW7 with an increase of 2.35 Km^2 followed by DW13 (+1.58 Km^2), DW11 (+0.49 Km^2), DW8 (+0.43 Km^2), DW2 (+ 0.12 Km^2), DW9 (+0.05 Km^2) and DW10 (+0.01 Km^2). Decrease in snow cover was observed for DW12 only, where a decline of -0.14 Km^2 was recorded against the 1992 values.

Water bodies showed an increase in their area in DW1 (+0.21 Km^2), DW2 (+0.16 Km^2) and DW4 (+0.13 Km^2). A decrease by 0.01 and 0.08 Km^2 was respectively recorded for DW3 and DW13. The rest of the watersheds i.e., DW4, DW5, DW6, DW7, DW8, DW9, DW10, DW11 and DW12 showed no change in the statistics for the said class.

Water channel areas were found to be absent for DW1, DW2, DW3 and DW4 for both 1992 and 2005. DW7 marked a decrease in the area by 0.06 Km^2. In the rest of the watersheds, water channels showed an increase with the maximum in DW10 (+ 1.2 Km^2) followed by DW6 (+ 0.18 Km^2), DW11 (+0.09 Km^2), DW12 (+0.08 Km^2), DW13 (+0.05 Km^2), DW5 (+0.02 Km^2) and DW8 (+ 0.01 Km^2). Depending upon the precipitation and snowmelt, the water channel areas are subject to changes in their spatial extent.

Bare lands showed an increasing trend in area for all the watersheds. The maximum increase was recorded for DW5 (+3.26 Km^2), followed by DW4 (+2.34 Km^2), DW3 (+1.98 Km^2), DW2 (+1.97 Km^2), DW13 (+1.83 Km^2), DW11 (+1.35 Km^2), DW8 (+1.1 Km^2), DW6 (+1.05 Km^2). The remaining watersheds i.e., DW7 (+0.57 Km^2), DW9 (+0.5 Km^2), DW1 (+0.11 Km^2) and DW10 (+0.06 Km^2) showed slight increase in the bare land area.


DW1
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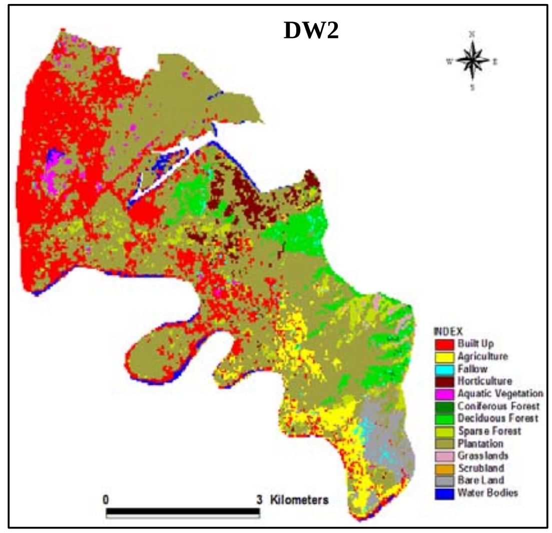
Built Up
Agriculture
Fallow
Horticulture
Aquatic Vegetation
Plantation
Water Bodies
0
3 Kilometers

(a)


DW2
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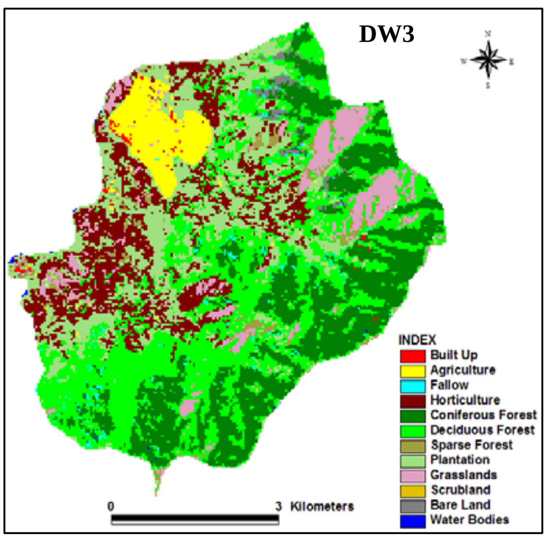
Horticulture
Aquatic Vegetation
Coniferous Forest
Deciduous Forest
Sparse Forest
Plantation
Grasslands
Scrubland
Bare Land
Water Bodies
0
3 Kilometers

(b)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Fallow
Horticulture
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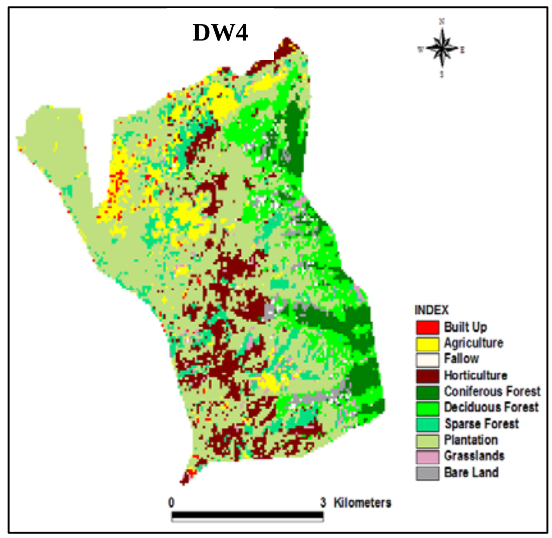
Deciduous Forest
Sparse Forest
Plantation
Grasslands
Scrubland
Bare Land
Water Bodies
0
3 Kilometers

(c)


DW4
INDEX
Built Up
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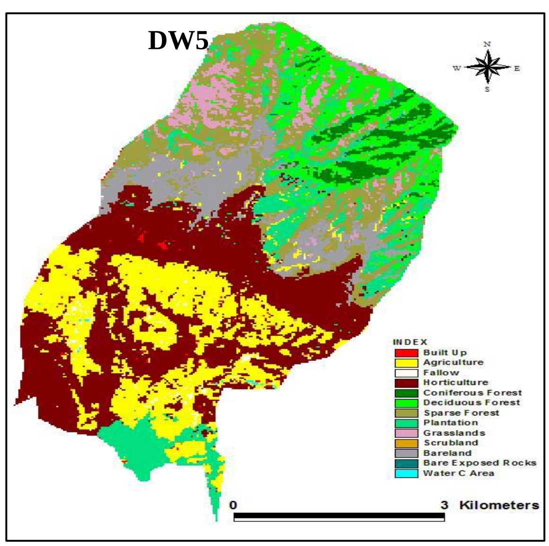
Deciduous Forest
Sparse Forest
Plantation
Grasslands
Bare Land
0
3 Kilometers

(d)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Built Up
Agriculture
Fallow
Horticulture
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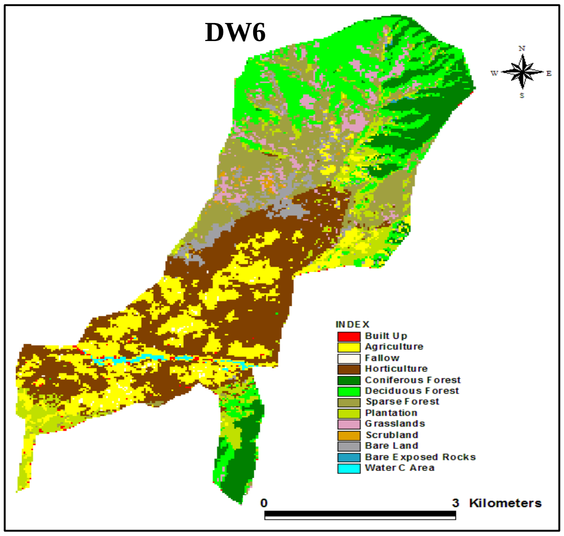
Deciduous Forest
Sparse Forest
Plantation
Grasslands
Scrubland
Bareland
Bare Exposed Rocks
Water C Area
0
3 Kilometers

(e)


DW6
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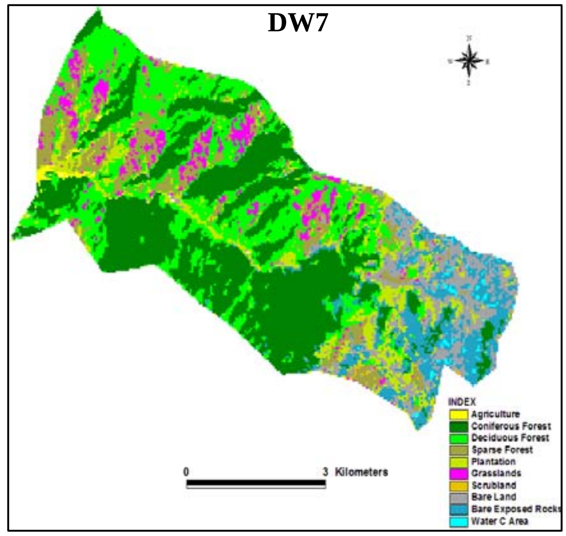
INDEX
Built Up
Agriculture
Fallow
Horticulture
Coniferous Forest
Deciduous Forest
Sparse Forest
Plantation
Grasslands
Scrubland
Bare Land
Bare Exposed Rocks
Water C Area
0
3 Kilometers

(f)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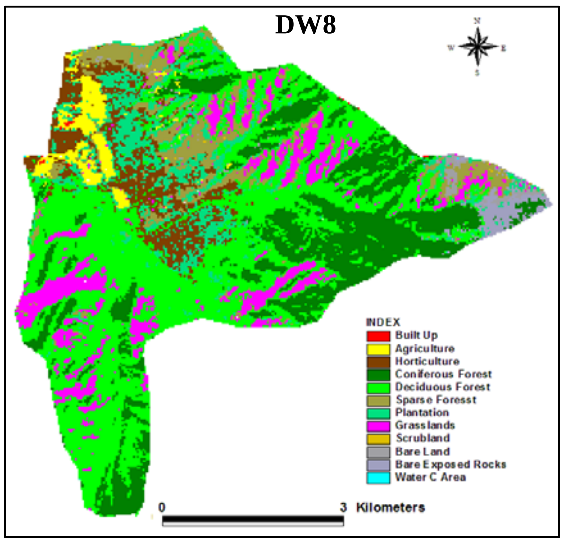
Deciduous Forest
Sparse Forest
Plantation
Grasslands
Scrubland
Bare Land
Bare Exposed Rocks
Water C Area
0
3 Kilometers

(g)


DW8
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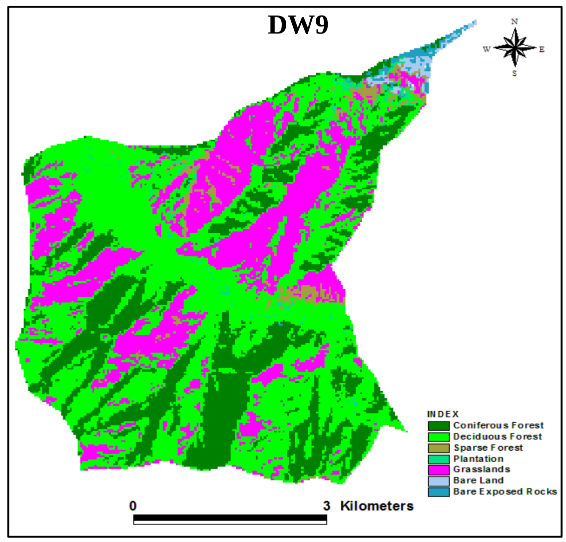
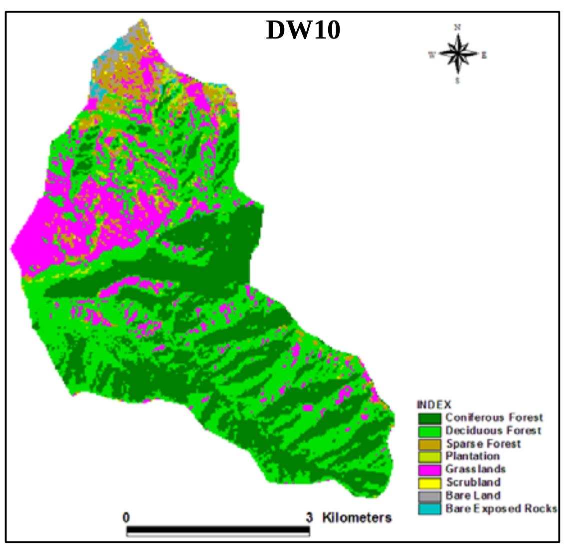
INDEX
Built Up
Agriculture
Horticulture
Coniferous Forest
Deciduous Forest
Sparse Foresst
Plantation
Grasslands
Scrubland
Bare Land
Bare Exposed Rocks
Water C Area
0
3 Kilometers

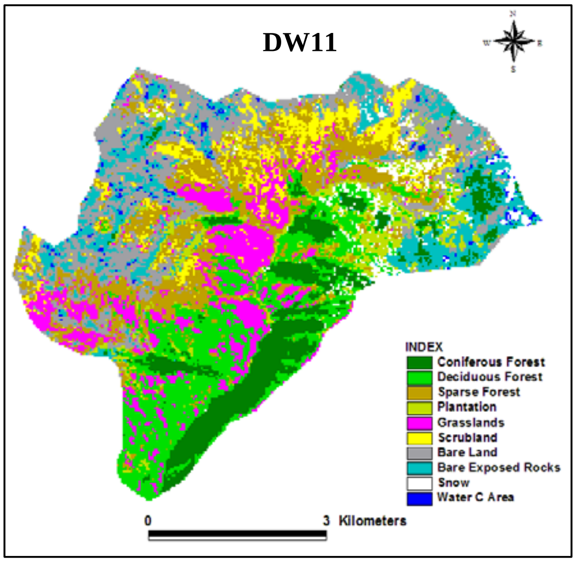
(h)


DW9
N
W
E
S
INDEX
Coniferous Forest
Deciduous Forest
Sparse Forest
Plantation
Grasslands
Bare Land
Bare Exposed Rocks
0
3 Kilometers

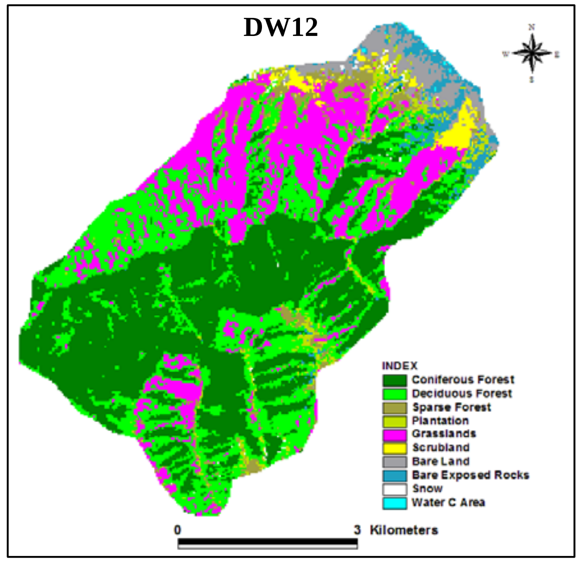
(i)


DW10
N
W
E
S
INDEX
Coniferous Forest
Deciduous Forest
Sparse Forest
Plantation
Grasslands
Scrubland
Bare Land
Bare Exposed Rocks
0
3 Kilometers

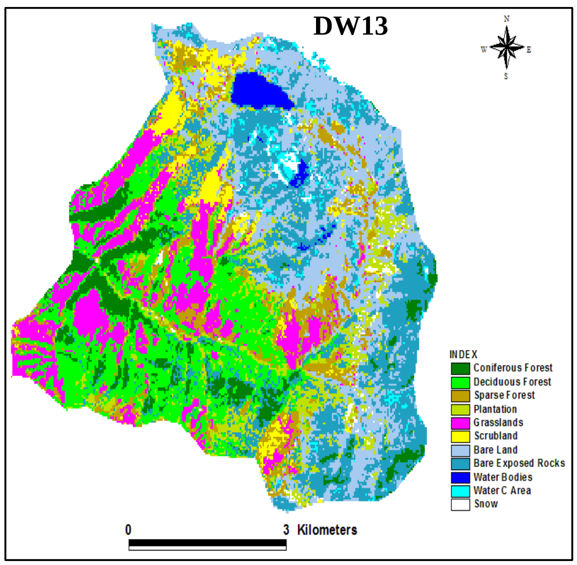
(j)



(k)



(l)



(m)

Fig. 28(a-m): Land use/ Land cover maps of different watersheds in Dal Lake Catchment (Landsat TM, 1992)

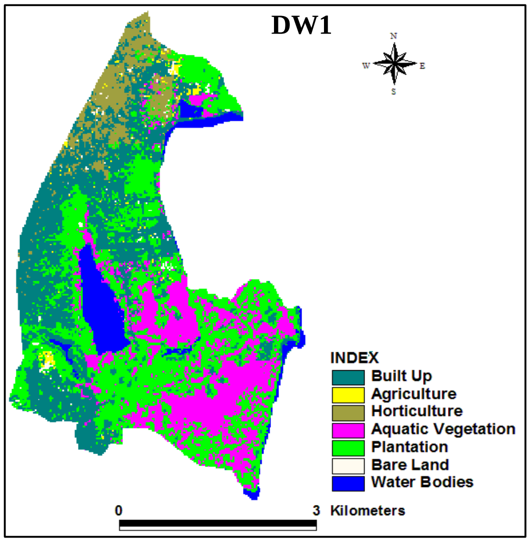
Bare exposed rocks are mostly confined to the upper watersheds and predominantly remain under snow cover, hence increase/ decrease in their area are largely dependent upon the amount of snow fall received and the temperature variations. However, these can also be found down the mountain reaches. The statistics for the said class from Table 17 reveal that DW1, DW3 and DW4 do not show any presence of bare rocks. Increase in area is observed for DW11 (+1.11 Km^2), followed by DW13 (+0.65 Km^2), DW11 (+ 0.15 Km^2), DW2 (+0.01 Km^2), and DW3 (+0.01 Km^2). Decline in the area of bare exposed rocks was recorded for DW8 (-0.05 Km^2), DW10 (-0.04 Km^2), DW9 (-0.03 Km^2), DW7 (- 0.01 Km^2), DW5 (- 0.01 Km^2).

Further perusal of the Table 17 reveals that the built up class is absent in DW7, DW11, DW12 and DW13. Increase in the built up area is observed for DW1 (+3.65 Km^2), followed by DW2 (+3.23 Km^2), DW3 (+1.99 Km^2), DW5 (+ 1.53 Km^2), DW4 (+ 1.41 Km^2), DW6 (+0.91 Km^2), DW8, (+0.17 Km^2), DW10 (+0.12 Km^2) and DW9 (+0.01 Km^2).

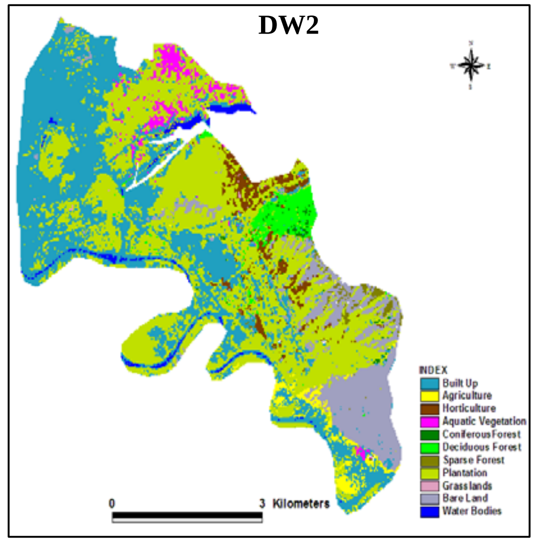
Agriculture class was recorded to be absent in DW9, DW10, DW11 and DW12. In the remaining watersheds, both increasing as well as a decreasing trend was observed for this land use class. DW8 followed by DW2, DW7, DW1, DW6 and DW13 showed an increase in agriculture area as shown in Table 17, whereas, a decline in area was observed for DW5 (-1.28 Km^2), DW3 (-0.98 Km^2) and DW4 (-0.52 Km^2).

Analysis of the statistics for horticulture class from Table 17 in different watersheds shows that this land use category has decreased in area in watersheds DW1 (-3.9 Km^2), followed by DW3 (-2.21 Km^2), DW8 (-0.74 Km^2), DW5(-0.72 Km^2) and DW4(-0.49 Km^2). DW2 and DW7 showed slight increase in the horticulture area. The remaining watersheds i.e., DW9, DW10, DW11, DW12, and DW13 recorded absence of horticulture class for both the years.

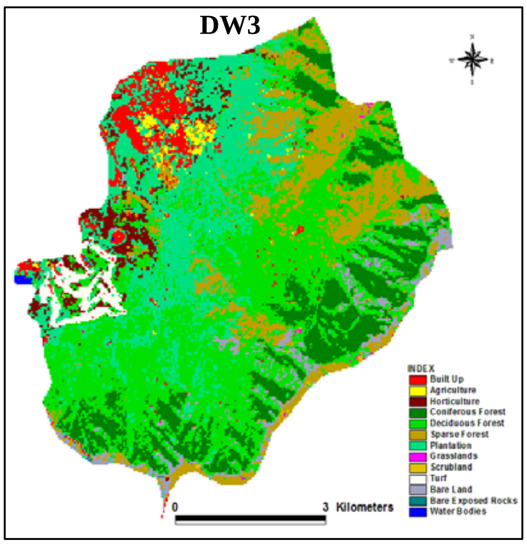
Table 17 further reveals that fallow land is predominantly absent in the watersheds of Dal Lake Catchment. It is found to cover very small area and at the same time shows a decreasing trend in area with DW2 (-0.22 Km^2), DW3 (-0.22 Km^2) followed by DW4 (-0.17 Km^2) and DW5 (-0.13 Km^2) being the only watersheds recording the presence of fallow land.


DW1
INDEX
Built Up
Agriculture
Horticulture
Aquatic Vegetation
Plantation
Bare Land
Water Bodies
0
3 Kilometers

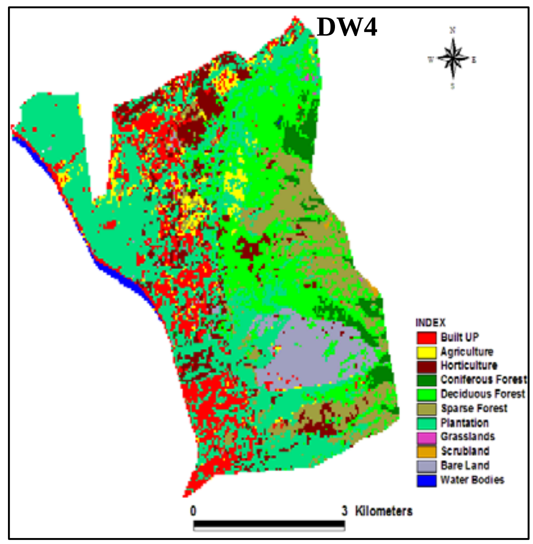
(a)


DW2
INDEX
Built Up
Agriculture
Horticulture
Aquatic Vegetation
Coniferous Forest
Deciduous Forest
Sparse Forest
Plantation
Grasslands
Bare Land
Water Bodies
0
3 Kilometers

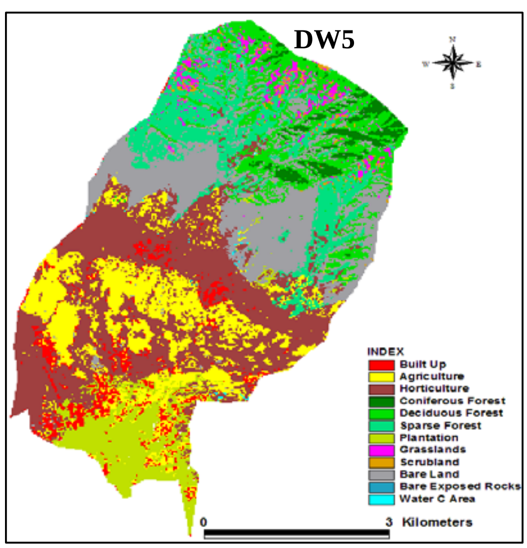
(b)


DW3
INDEX
Built Up
Agriculture
Horticulture
Coniferous Forest
Deciduous Forest
Sparse Forest
Plantation
Grasslands
Scrubland
Turf
Bare Land
Bare Exposed Rocks
Water Bodies
0
3 Kilometers

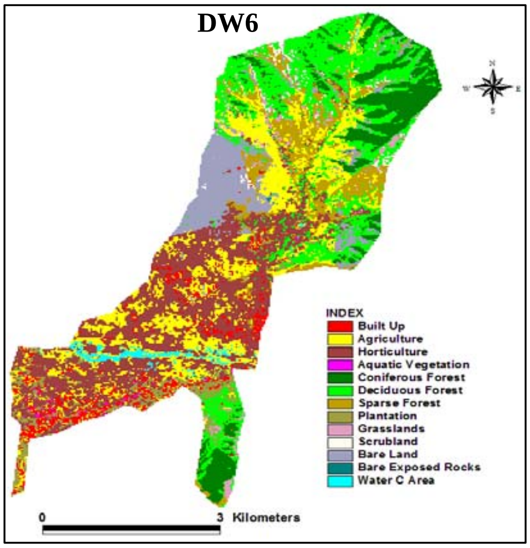
(c)


DW4
INDEX
Built UP
Agriculture
Horticulture
Coniferous Forest
Deciduous Forest
Sparse Forest
Plantation
Grasslands
Scrubland
Bare Land
Water Bodies
0
3 Kilometers

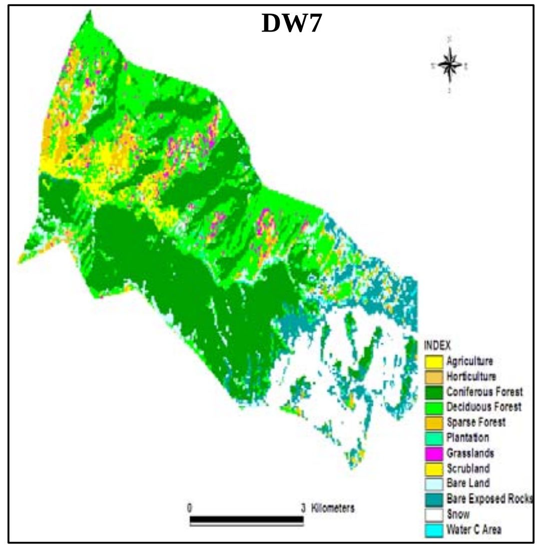
(d)


DW5
INDEX
Built Up
Agriculture
Horticulture
Coniferous Forest
Deciduous Forest
Sparse Forest
Plantation
Grasslands
Scrubland
Bare Land
Bare Exposed Rocks
Water C Area
0
3 Kilometers

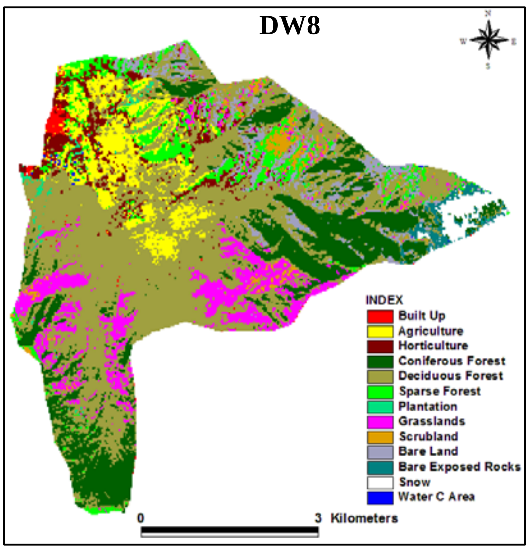
(e)


DW6
INDEX
Built Up
Agriculture
Horticulture
Aquatic Vegetation
Coniferous Forest
Deciduous Forest
Sparse Forest
Plantation
Grasslands
Scrubland
Bare Land
Bare Exposed Rocks
Water C Area
0
3 Kilometers

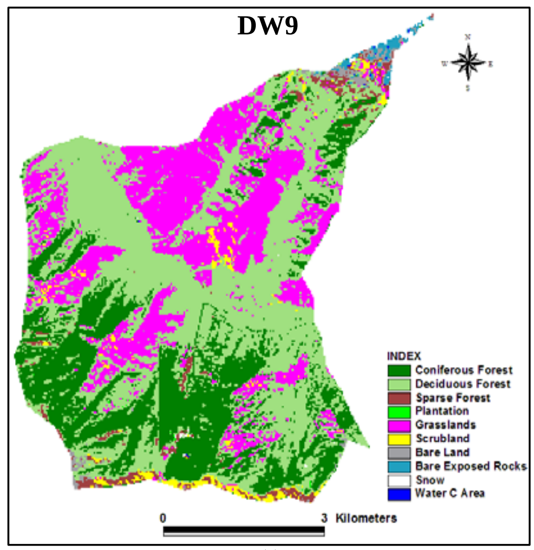
(f)


DW7
INDEX
Agriculture
Horticulture
Coniferous Forest
Deciduous Forest
Sparse Forest
Plantation
Grasslands
Scrubland
Bare Land
Bare Exposed Rocks
Snow
Water C Area
0
3 Kilometers

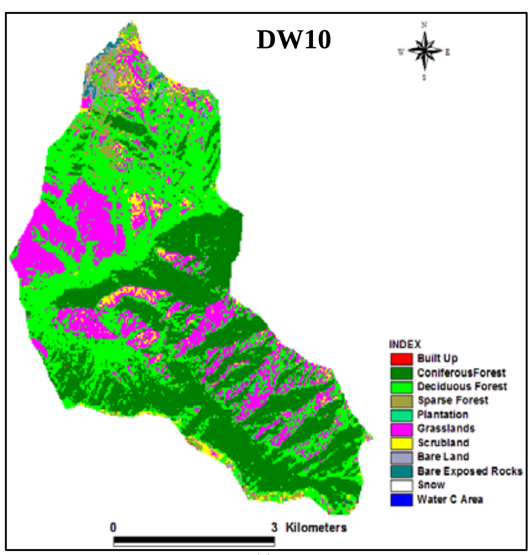
(g)


DW8
INDEX
Built Up
Agriculture
Horticulture
Coniferous Forest
Deciduous Forest
Sparse Forest
Plantation
Grasslands
Scrubland
Bare Land
Bare Exposed Rocks
Snow
Water C Area
0
3 Kilometers

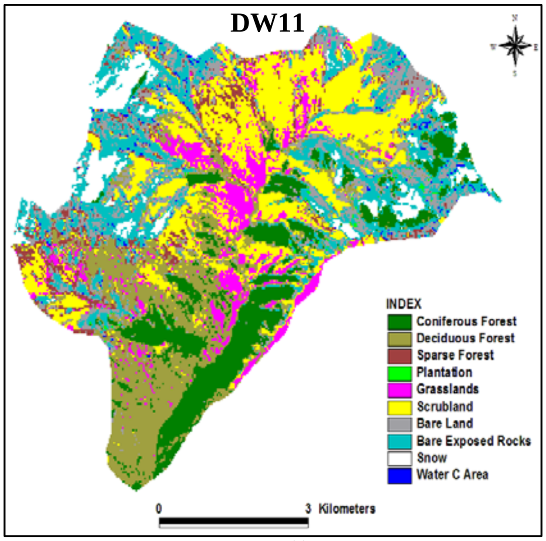
(h)


DW9
INDEX
Coniferous Forest
Deciduous Forest
Sparse Forest
Plantation
Grasslands
Scrubland
Bare Land
Bare Exposed Rocks
Snow
Water C Area
0
3 Kilometers

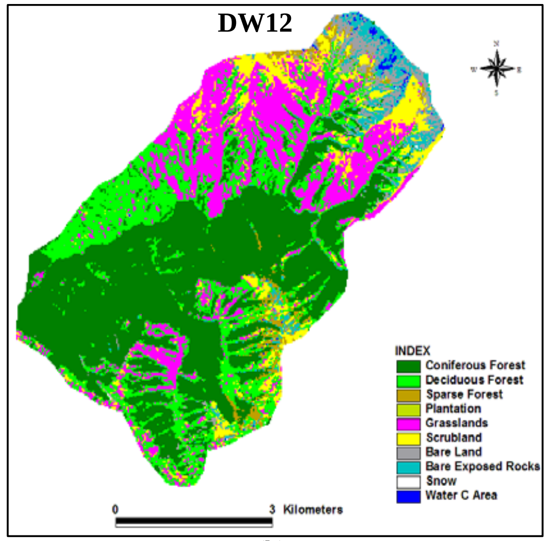
(i)


DW10
INDEX
Built Up
ConiferousForest
Deciduous Forest
Sparse Forest
Plantation
Grasslands
Scrubland
Bare Land
Bare Exposed Rocks
Snow
Water C Area
0
3 Kilometers

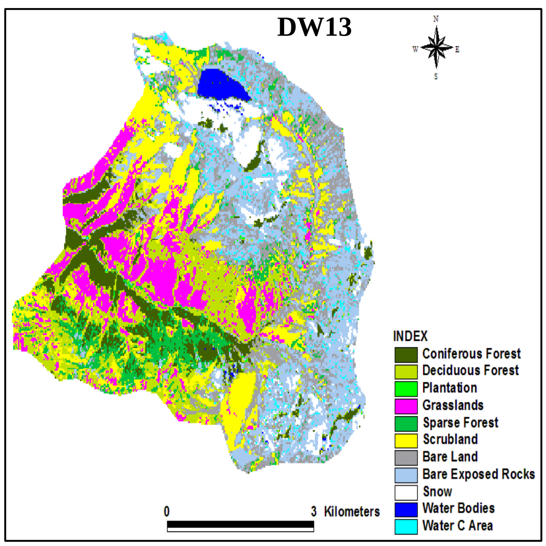
(j)



(j)



(k)



(m)

Fig. 29(a-m): Land use/ land cover maps of different watersheds in Dal Lake Catchment (IRS LISS III, 2005)

Grasslands/pasturelands as analysed from Table 17 show a declining trend in majority of the watersheds. The decrease in area was found to be highest in DW3 (-1.38 Km^2), followed by DW5 (-1.31 Km^2), DW11 (-0.78 Km^2), DW10 (-0.62 Km^2), DW7 (-0.70 Km^2), DW13 (-0.57 Km^2), DW6 (-0.50 Km^2), DW4 (-0.20 Km^2) and DW2 (-0.11 Km^2). DW9 (+0.8 Km^2) followed by DW8 (+ 0.13 Km^2) and DW1 (+0.02Km^2) are the only watersheds that showed an increase in the grassland/pastureland area from 1992-2005.

From the Table 17, coniferous forest class is found to be absent in DW1 for both 1992 and 2005. The results suggest this class registers a decline in its area in majority of the watersheds. It can be analysed that the highest decrease is recorded for the watershed DW3 (-1.82 Km^2) followed by DW12 (-1.06 Km^2), DW13 (-0.65 Km^2), DW11 (-0.55 Km^2), DW7 (-0.54 Km^2), DW10 (-0.39 Km^2), DW9 (-0.36 Km^2), DW8 (-0.35 Km^2), DW5 (-0.26 Km^2) and DW2 (-0.07 Km^2). Whereas, slight increase in area was observed for DW4 (+0.36 Km^2) and DW6 (+0.01 Km^2).

Table 17 revealed a similar trend for the deciduous forests with the class being absent in DW1. Like the coniferous forests, this class also showed a decreasing trend in majority of watersheds with the main decline being recorded for DW3 (-1.3 Km^2) followed by DW12 (-1.21 Km^2), DW10 (-1.04 Km^2), DW2 (-0.98 Km^2), DW8 (-0.92 Km^2), DW13 (-0.65 Km^2), DW9 (-0.60 Km^2), DW6 (-0.35 Km^2), DW5(-0.27 Km^2), DW11 (-0.41 Km^2) and DW7(-0.18 Km^2). The only increase was observed for DW4 where deciduous forest class showed an increase by 0.92 Km^2.

Sparse forest class was found to be present in all the watersheds for both 1992 and 2005 with the same decreasing trend as that of the other forest classes. It was observed from Table 17 that DW3 (+2.91 Km^2), DW11 (+2.72 Km^2) and DW4 (+0.28 Km^2) are the only watersheds where increase in area was recorded for the respective years. For the remaining watersheds, sparse forests decreased in area with the major decline in DW13 (-1.86 Km^2) followed by DW6 (-1.32 Km^2), DW7 (-0.92 Km^2), DW2 (-0.88 Km^2), DW5 (-0.63 Km^2), DW8 (-0.52 Km^2), DW12 (-0.52 Km^2), DW10 (-0.23 Km^2), DW1 (-0.04 Km^2) and DW9 (-0.03 Km^2).

Further analysis of the Table 17 reveals that scrubland area has increased in all the watersheds except for DW2 which showed a decline by 0.01 Km^2. The highest change was witnessed for DW11 (+3.33 Km^2) followed by DW13 (+2.72 Km^2), DW12 (+2.21 Km^2), DW10 (+0. 91 Km^2), DW3 (+0.73 Km^2), DW8 (+0.56 Km^2), DW9 (+0.46 Km^2), DW7 (+0.31 Km^2), DW5 (+0.28 Km^2), DW6 (+0.21 Km^2), DW4 (+0.01 Km^2) and DW1 (+0.01 Km^2).

The statistics for aquatic vegetation in Table 17 revealed that this class is restricted in its occurrence with an upward trend from 1992 values. DW1 (+2.91 Km^2) followed by DW2 (+0.34 Km^2), DW4 (+0.10 Km^2) and DW5 (+0.01 Km^2) were the only contributors to this land use class

Plantation statistics as revealed from Table 17 also show a declining trend in area from 1992-2005. The major changes were recorded in DW13 (-3.1 Km^2) followed by DW1 (-2.68 Km^2), DW2 (-2.5 Km^2), DW11 (-1.73 Km^2), DW4 (-1.65 Km^2), DW7 (-1.34 Km^2), DW8 (-1.27 Km^2), DW9 (-0.79 Km^2), DW5 (-0.45 Km^2), DW3 (-0.40 Km^2), DW12 (-0.19 Km^2), and DW6 (-0.12 Km^2). The only increase in the plantation area was observed for DW10 (+0.02 Km^2).

6.2.5 Accuracy Assessment

Land use/ Land cover maps derived from remote sensing data always contain some errors due to several factors which range from classification techniques to satellite data types and methods employed for satellite data processing. Hence to have an exact knowledge of the field, accuracy assessment of the land use/land cover maps was done before finalising them. As already explained in the previous chapter, well planned field trips were organised to collect the ground information for the Dal Lake Catchment (Plate 1a, 1b). Around 300 ground validation points were collected from the field. Table 18 and Table 19 give the results for accuracy assessment and Kappa coefficient for the 1992 classified data. The results reveal that the overall accuracy of the land use/ land cover data for the year 1992 is 89.67 % with a Kappa coefficient of 0.8541. The results for 2005 land use/ land cover data are given in Table 20 and Table 21. The results show that the overall accuracy is 93.67 % (Table 20) with a Kappa coefficient of 0.913 (Table 21).

Table 18: Accuracy Assessment of 1992 Land use/ Land cover data

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy (%)	Users Accuracy (%)
Built up	9	8	8	88.89	100.00
Agriculture	5	8	5	100.00	62.50
Agriculture Fallow	2	5	2	60.00	40.00
Horticulture	13	11	11	84.62	100.00
Coniferous Forest	21	24	20	95.24	83.33
Deciduous Forest	41	35	31	75.61	88.57
Sparse Forest	14	13	10	71.43	76.92
Grasslands	8	10	5	62.50	50.00
Scrubland	2	2	1	50.00	50.00
Plantation	15	18	14	93.33	77.78
Aquatic Vegetation	3	3	3	100.00	100.00
Barren	8	10	4	40.00	30.00
Bare Exposed Rocks	4	4	3	75.00	75.00
Water	4	4	4	100.00	100.00
Water Channel Area	2	5	2	40.00	20.00
Snow	2	2	2	100.00	100.00
Totals	308	308	283		
Overall Accuracy = 89.67% %					

Table 19: Overall Kappa Statistics of 1992 Land use/ Land cover data

KAPPA (K^) STATISTICS	
OVERALL KAPPA STATISTICS = 0.8541	
CONDITIONAL KAPPA FOR EACH CATEGORY	
Class Name	**Kappa**
Built up	1
Agriculture	0.6186
Agricultural Fallow	0.3213
Horticulture	1
Coniferous Forest	0.8208
Deciduous Forest	0.8676
Sparse Forest	0.7579
Grasslands	0.4863
Scrubland	0.4966
Plantation	0.7661
Aquatic Vegetation	0.463
Barren	0.3836
Bare Exposed Rocks	0.7466
Water	1
Water Channel Area	0.658
Snow	0.333

Table 20: Accuracy Assessment of 2005 Land use/ Land cover data

Class Name	Reference Totals	Classified Totals	Number Correct	Producer's Accuracy (%)	Users Accuracy (%)
Built up	10	9	8	80	88.90
Agriculture	5	6	5	100	83.33
Agriculture Fallow					
Horticulture	10	9	9	90	100.00
Coniferous Forest	24	24	22	91.67	91.67
Deciduous Forest	32	33	28	87.5	84.85
Sparse Forest	10	9	8	80.00	88.89
Grasslands	14	12	12	85.71	100.00
Scrubland	5	6	5	100	83.33
Plantation	14	15	12	85.71	80.0
Aquatic Vegetation	2	3	2	100	66.67
Barren	14	12	11	78.57	91.67
Bare Exposed Rocks	5	6	4	80.00	66.67
Water	6	6	6	100.00	100.00
Water Channel Area					
Snow	2	3	2	100.00	66.67
Totals	300	300	281		
Overall Accuracy = 93.67%					

Table 21: Overall Kappa Statistics of 2005 Land use/ Land cover data

KAPPA (K^) STATISTICS	
OVERALL KAPPA STATISTICS = 0.91314	
CONDITIONAL KAPPA FOR EACH CATEGORY	
Class Name	**Kappa**
Built up	0.8851
Agriculture	0.8305
Agricultural Fallow	0.3213
Horticulture	1
Coniferous Forest	0.9094
Deciduous Forest	0.8304
Sparse Forest	0.8851
Grasslands	1
Scrubland	0.8305
Plantation	0.7902
Aquatic Vegetation	0.6644
Barren	.9126
Bare Exposed Rocks	.6610
Water	1
Water Channel Area	0.658
Snow	.6644

Dense Forest

Sparse forest

Scrub Land

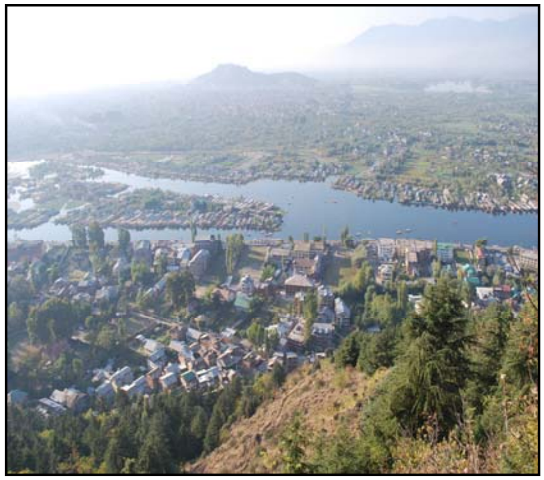
Plantation

Agriculture

Horticulture

Plate 1a: Land use/ Land cover in Dal Lake Catchment

Floating Gardens (Aquatic vegetation)



Built Up

Barren Mountains

Stream Bank Erosion

Dachigam Stream

Golf Course/Turf

Plate 1b: Land use/ Land cover in Dal Lake Catchment

6.3 Weather Data Analysis of Dal Lake Catchment

GWLF Model requires hydrometrological data in the form of daily precipitation and daily maximum and minimum temperatures for the simulation of the major processes viz. erosion, pollution load, runoff etc. For this purpose, hydrometrological data from 1981-2008 was analysed for the Dal Lake Catchment.

6.3.1 Precipitation Data Analysis

The analysis of 28 years of total annual precipitation data (Fig. 30; Appendix 11a) shows that from 1981-2008, the catchment received the highest annual precipitation in the year 1995 (1132 mm) and the lowest in the year 2000 (464.5mm). Fig. 30 also reveals that the catchment is witnessing a decreasing trend in the precipitation.

On a monthly average basis (Fig. 31, Appendix 11b), the maximum precipitation was received in the month of March (121.76mm) and the least in the months of November (27.87)

6.3.2 Temperature Data Analysis

The analysis of average monthly maximum and minimum temperatures for 28 years (1981-2008) is given in Fig. 32 (Appendix 12a). Analysis of the data reveals that the average daily maximum temperature was observed to be highest in the month of July (31.37°C) and lowest in the month of January (-0.6°C). Whereas, average daily minimum temperature from Fig. 32 (Appendix 12b) was observed to be highest in the month of January (-6.22°C) and lowest in the month of July (19.80°C).

In addition to the analysis of the long term hydrometrological data series from 1981-2008, the mean daylight hours for the catchment with latitude 34^0N for requirement into the GWLF model were obtained from Haith *et al.* (1992) and Evans *et al.* (2008). Table 22 shows the mean daylight hours for the Dal Lake Catchment. Analysis of Table 22 reveals that the mean daylight hours were highest in the month of June (14.3) and July (14.1), whereas, the lowest were seen to be in the months of December (9.7) and January (9.9).

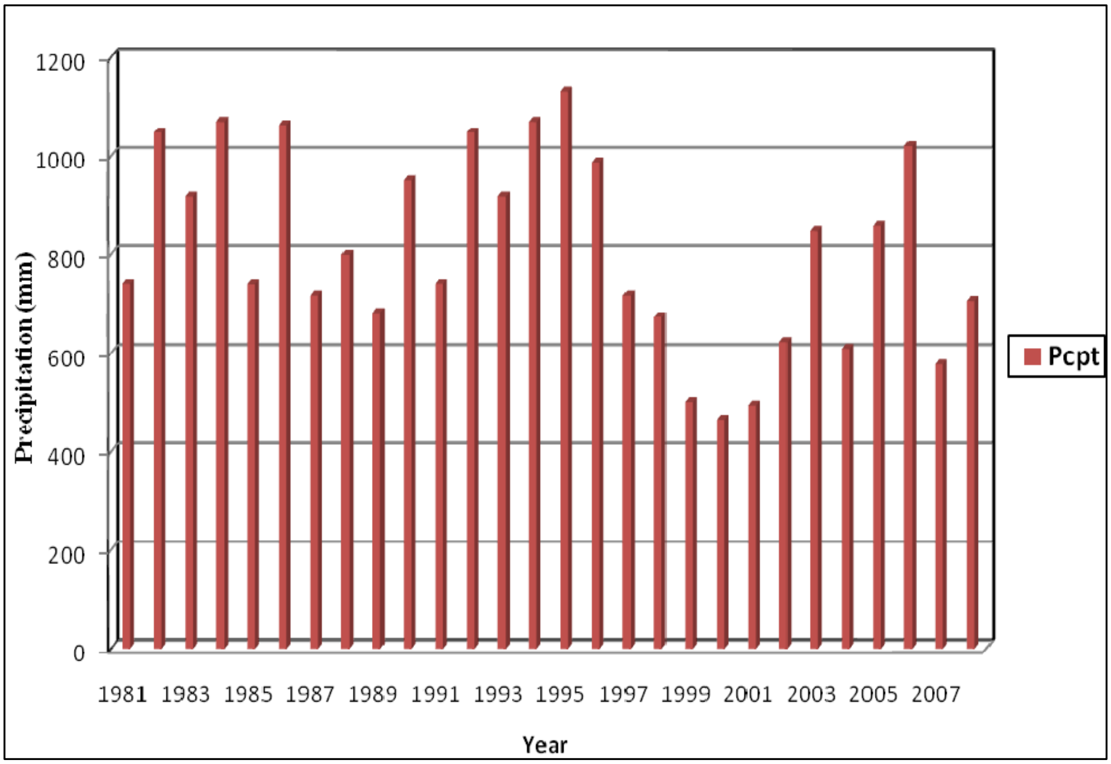


Fig. 30: Total annual precipitation in the Dal Lake Catchment (1981-2008)

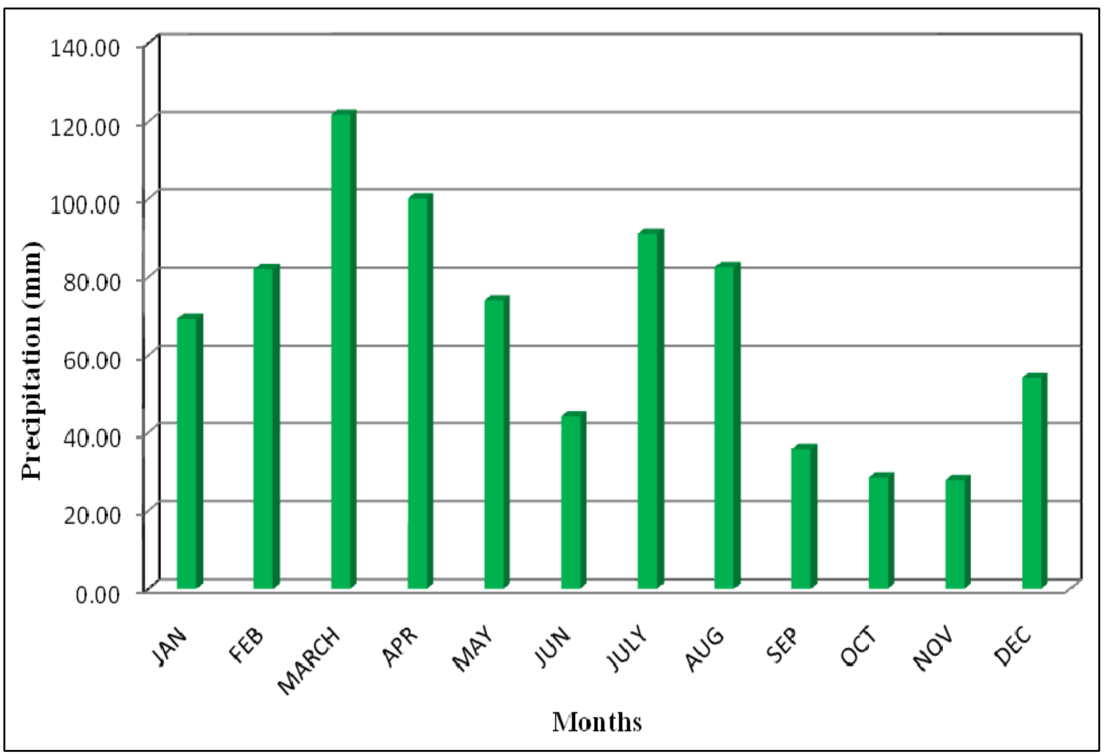


Fig. 31: Mean monthly precipitation in Dal Lake Catchment (1981-2008)

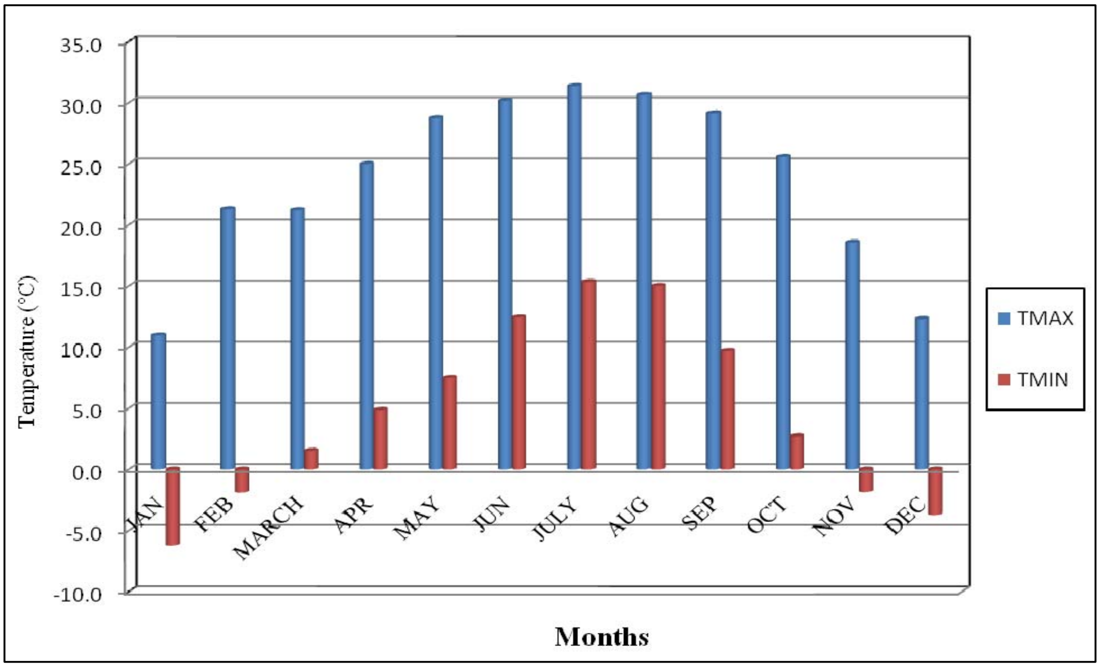


Fig. 32: Average monthly maximum & minimum temperature (°C) in Dal Lake Catchment (1981-2008)

Table 22: Mean daylight hours for Dal Lake Catchment

S. No.	Months	Day Light Hours
1	January	9.9
2	February	10.7
3	March	11.8
4	April	13
5	May	13.9
6	June	14.3
7	July	14.1
8	August	13.3
9	September	12.2
10	October	11
11	November	10.1
12	December	9.7

6.4 Soil Data Analysis of Dal Lake Catchment

Soil maps of different parameters for the Dal Lake Catchment were prepared as per the methodology described in Chapter 5 and the results are given in Fig. 33-38. The soil characteristics of different land use/land cover categories are given in Table 23.

Analysis of the data in the Table 23 reveals that the soil characteristics vary for each land use/ land cover class. Table 23 revealed that the organic matter content was observed to be highest for the forest soils with the maximum value being recorded for the deciduous forest soils (6.0%) followed by coniferous forest (5.91%) and hay/pasture (5.5%). The lowest values were recorded for agriculture (2.01%) and bare lands (1.01%).

The data presented in Table 23 reveals that the available nutrients in form of nitrogen, phosphorus and potassium were recorded highest for the forest soils with deciduous forest followed by the coniferous and sparse forests dominating the values. The lowest values were recorded for high intensity development and the bare lands.

Table 23 shows that the land use/land cover classes exhibited the pH ranging between 5.01 and 7.8 and are acidic to alkaline in nature. The pH was observed to be generally low for the forest soils i.e., deciduous forest (5.01), coniferous forest (5.57), hay/pasture (5.69), exhibiting their acidic nature. High pH was recorded for arable soils i.e., agriculture (7.8) and horticulture (7.5) and bare land (7.1).

The data presented in the Table 23 further shows that the electrical conductivity values ranged between 377 µS to 140 µS. The values were highest for golf course/ turf (377 µS) followed by sparse forest (358 µS) and horticulture (300 µS). The lowest values were recorded for agriculture (151.75 µS) and bare land (140 µS).

Table 23: Soil characteristics of major Land Use/Land Cover classes in Dal Lake Catchment

Class Name	% OM	Av. N (Kg/ha)	Av. P (Kg/ha)	Av. K (Kg/ha)	pH	EC (µS)
Agriculture	2.01	300.54	30.62	146.0	7.8	151.75
Horticulture	2.25	317.29	25.42	176.0	7.5	173
Aquatic Vegetation	3.1	212.3	34.11	195.0	5.95	300
Turf/Golf Course	3.9	385.4	30.2	212.0	6.64	377.0
Sparse Forest	4.75	654.5	48.1	322.93	5.9	358.00
Deciduous Forest	6.0	700.12	72.86	476.0	5.01	244.0
Coniferous Forest	5.91	654.5	64.26	442.0	5.57	176.66
Hay/ Pasture	5.5	601.2	60.12	323.0	5.69	170.00
Low Int. Development	3.06	295.6	21.45	255.0	6.4	251.0
High Int. Development	2.94	151.4	17.1	100.0	6.97	235.00
Bare Land	1.01	103.6	11.82	80.0	7.1	140.00

NOTE:- OM: Organic matter; Av.N: Available nitrogen; Av.P: Available phosphorus; Av. K: Available potassium

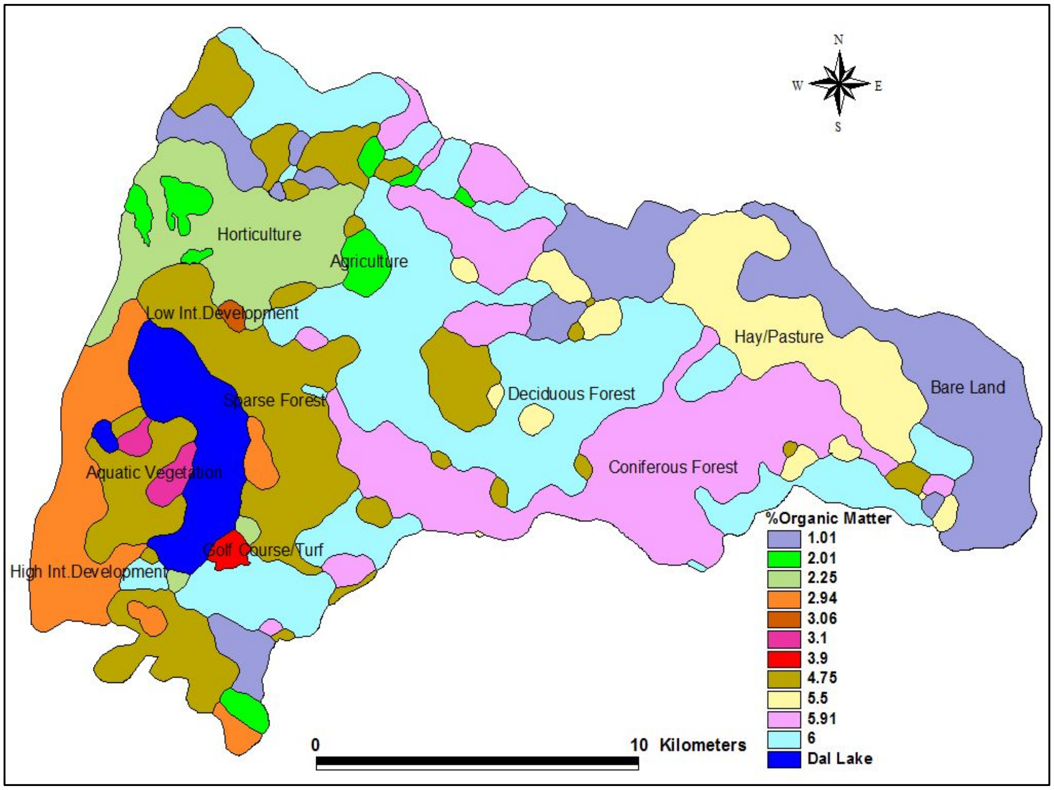


Fig. 33: % Organic matter in different Land use/Land cover classes of Dal Lake Catchment

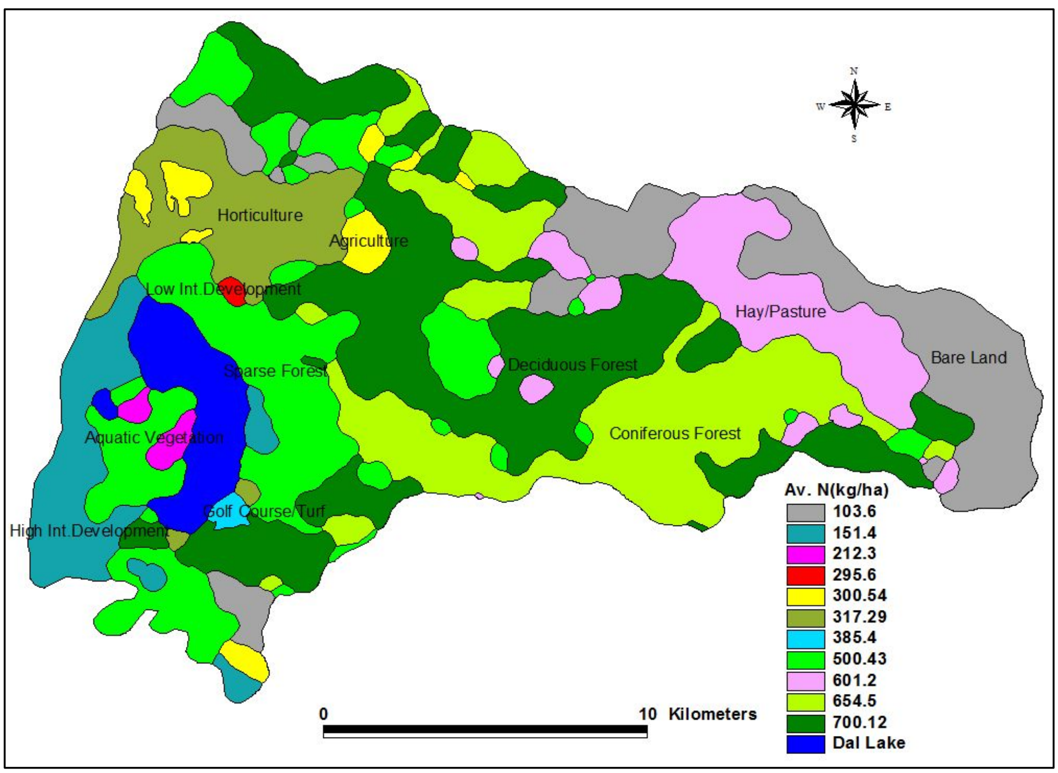


Fig. 34: Available Nitrogen in different Land use/Land cover classes of Dal Lake Catchment

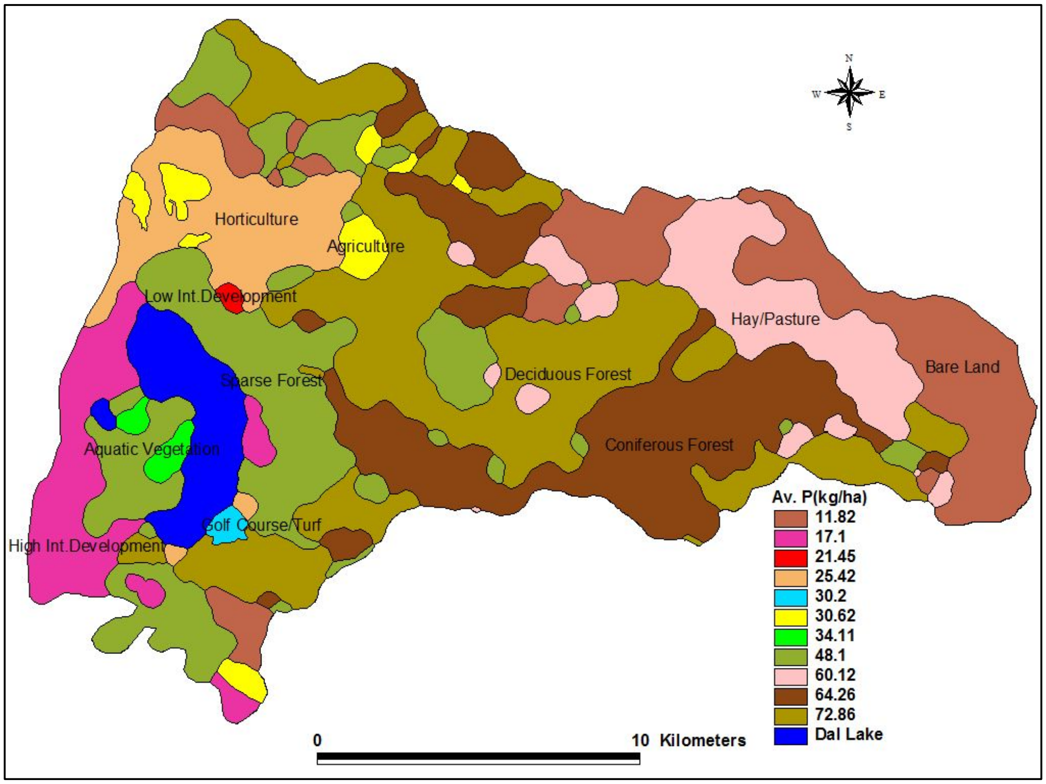


Fig. 35: Available Phosphorus in different Land use/Land cover classes of Dal Lake Catchment

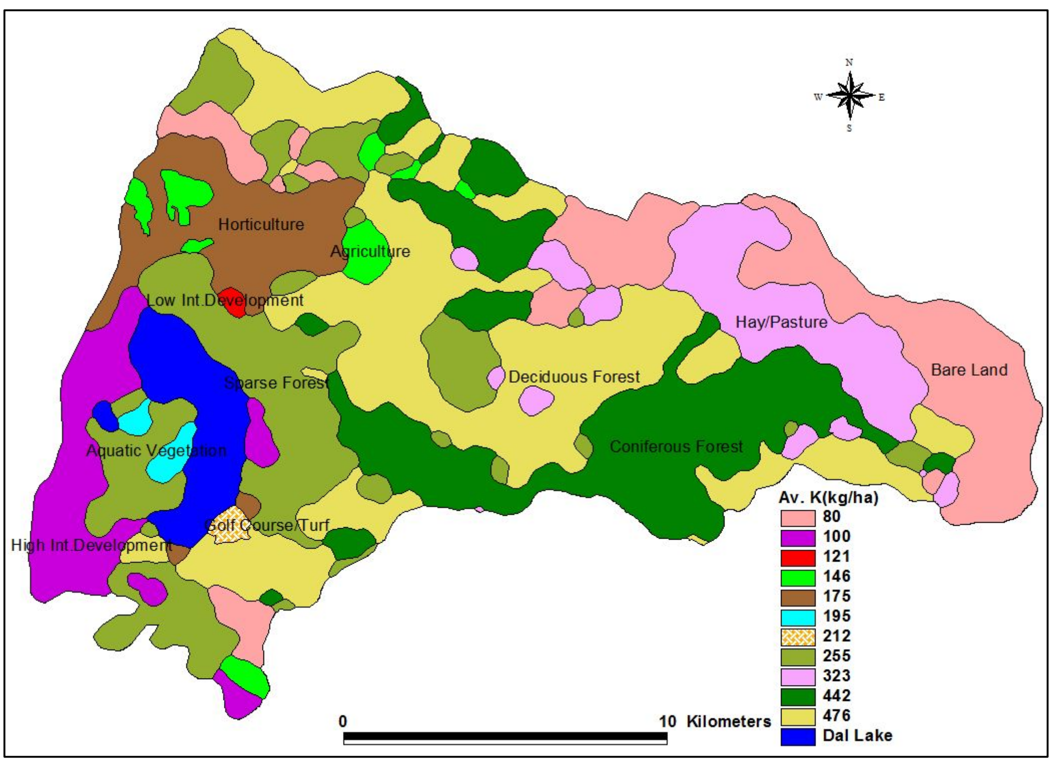


Fig. 36: Available Potassium in different Land use/Land cover classes of Dal Lake Catchment

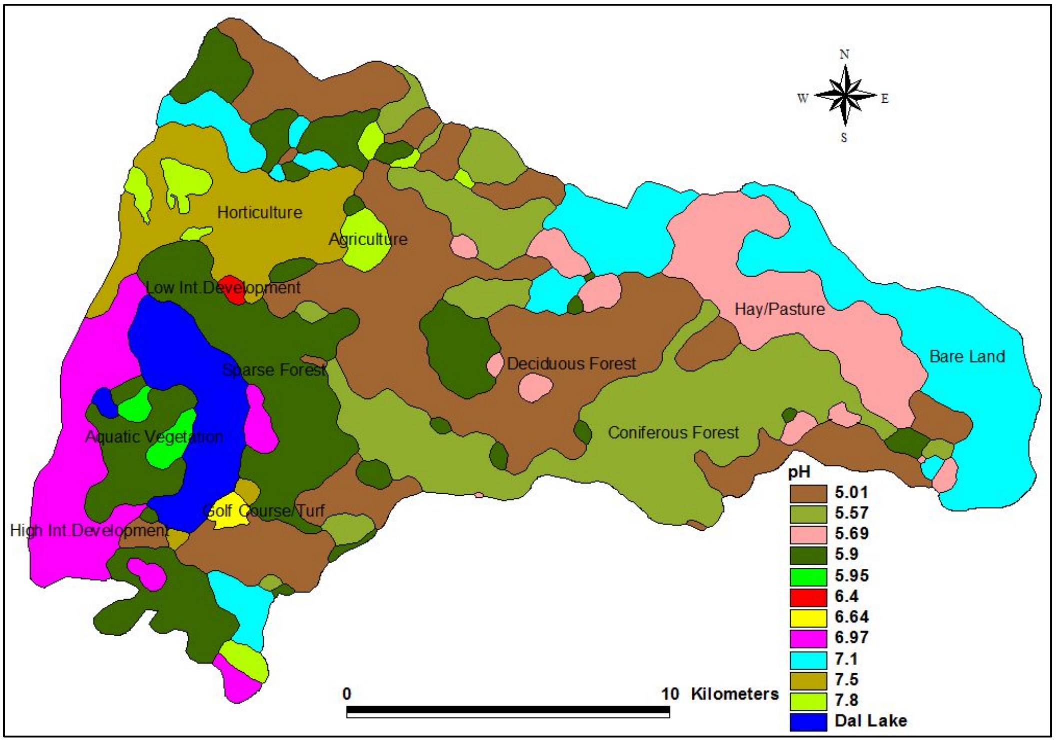


Fig. 37: pH of different Land use/Land cover classes in Dal Lake Catchment

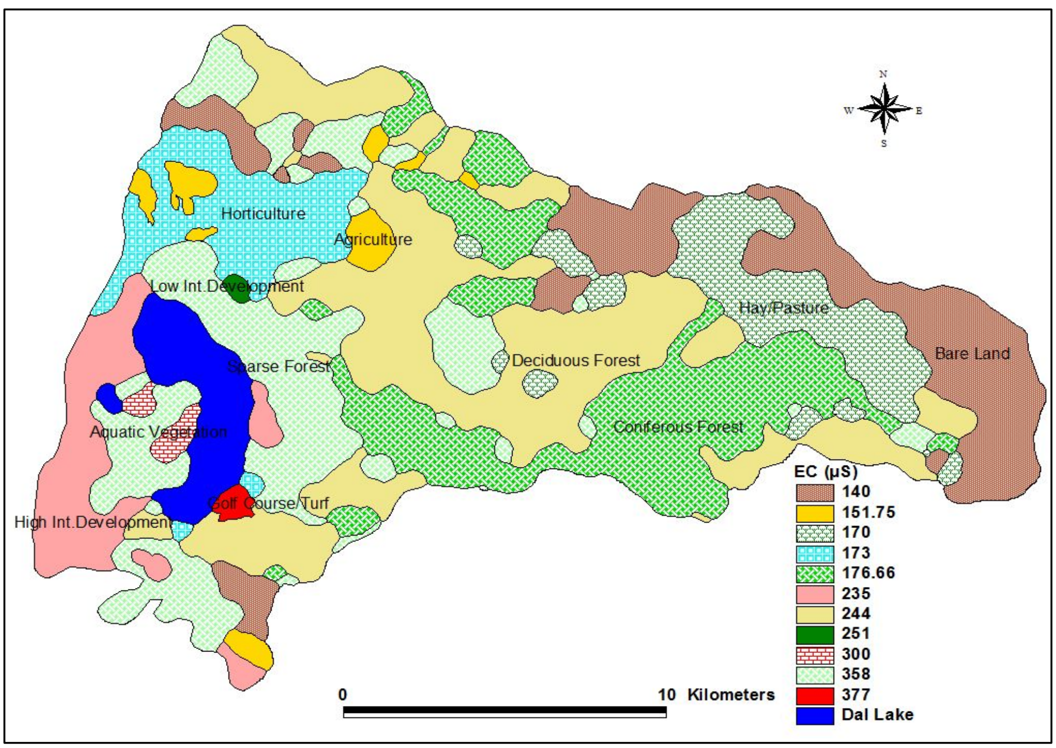


Fig. 38: EC of different Land cover/Land cover classes in Dal Lake Catchment

Soil texture analysis results of Dal Lake Catchment are given in Table 24 and Fig. 39. Analysis of the statistics in the Table 24 reveals that soils in the catchment mainly fall into nine textural classes viz. loam, loamy sand, sandy clay loam, sandy clay, silt loam, silt clay loam, clay, clay loam and sandy loam. It is observed that about 76.93 Km^2 (22.83%) of the catchment is covered by sandy clay loam soils. Sandy clay soils cover 65.41 Km^2 (19.41%), loam 62.91 Km^2 (18.67%), loamy sand 46.27 Km^2 (13.73%), silt loam 43.47 Km^2 (12.9%), clay 35.72 Km^2 (10.%16), silt clay loam 5.39 Km^2 (1.37%), clay loam 0.74 Km^2 (0.22%) and sandy loam 0.13 Km^2 (0.04%). Soil hydrological groups as determined from the soil texture classes reveal that most of the soils belong to the hydrological group D. Water holding capacity of different soils and soil erodibilty and slope length (LS) factor in Dal Lake Catchment are given in Fig. 40-43.

6.5 Model Simulations

The GWLF model was run using the above generated input parameters for the assessment of nutrient pollution as well as erosion in different watersheds of Dal Lake Catchment. The model was run on multi date land use/ land cover data (1992 and 2005) in order to assess the effects of its change on nutrient and sediment transport processes. The results thus obtained are discussed under the following sub-headings:

6.5.1 Catchment Hydrological Conditions

Knowledge about the hydrological conditions of a catchment is important because it provides the basis for understanding the behaviour of various processes such as erosion, nutrient fluxes, runoff etc. that eventually end up into the lake. The GWLF model provides estimation of the hydrological conditions of the catchment based on the daily precipitation and temperature input data. The model simulations were run for 28 years. Fig. 44 shows the mean monthly hydrological output of GWLF model for the 28 years (1981 - 2008) simulation period.

Table 24: Area under different textural classes in Dal Lake Catchment

S. No.	Texture Class	Soil Hydrological Group	Area(Km^2)	Area (%)
1	Loam	B	62.91	18.67
2	Loamy sand	A	46.27	13.73
3	Sandy Clay Loam	C	76.93	22.83
4	Sandy Clay	D	65.41	19.41
5	Silt Loam	B	43.47	12.9
6	Silt Clay Loam	D	5.39	1.37
7	Clay	D	35.72	10.16
8	Clay Loam	D	0.74	0.22
9	Sandy Loam	A	0.13	0.04
Total			**337**	**100**

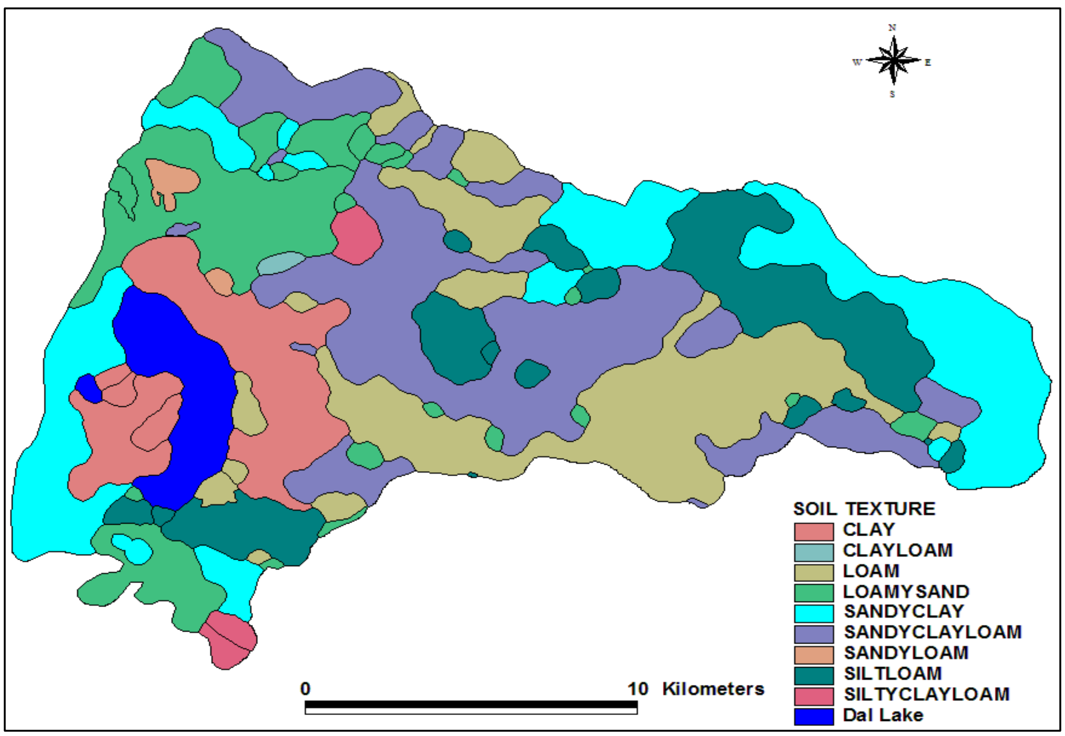


Fig. 39: Soil textural classes in Dal Lake Catchment

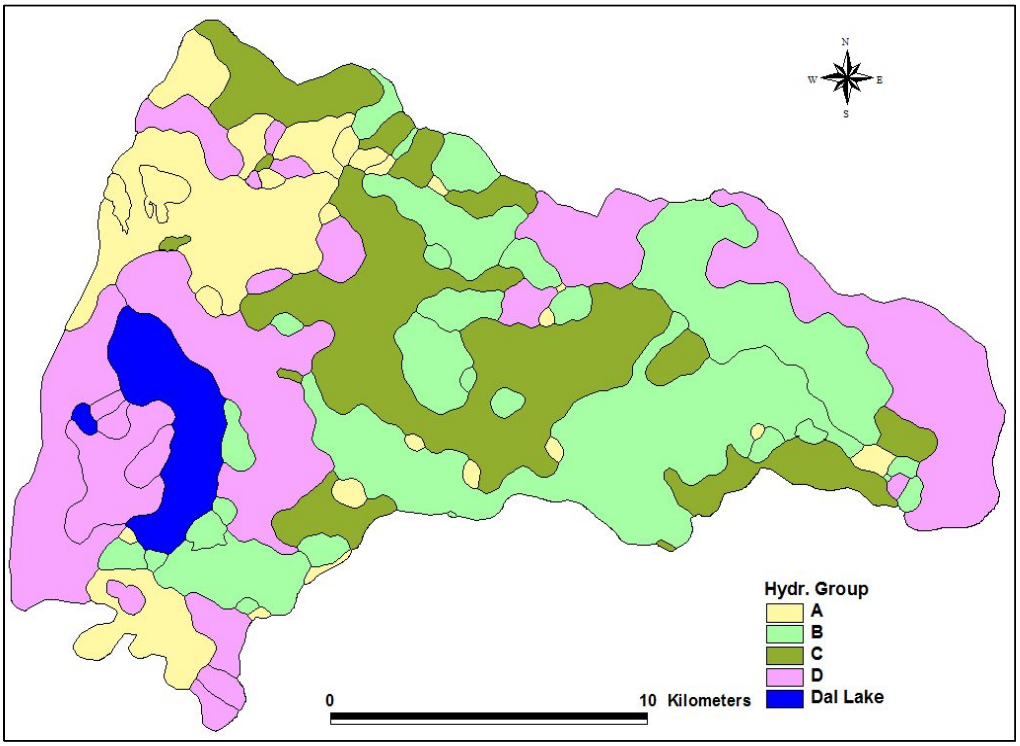


Fig. 40: Major soil hydrological groups in Dal Lake Catchment

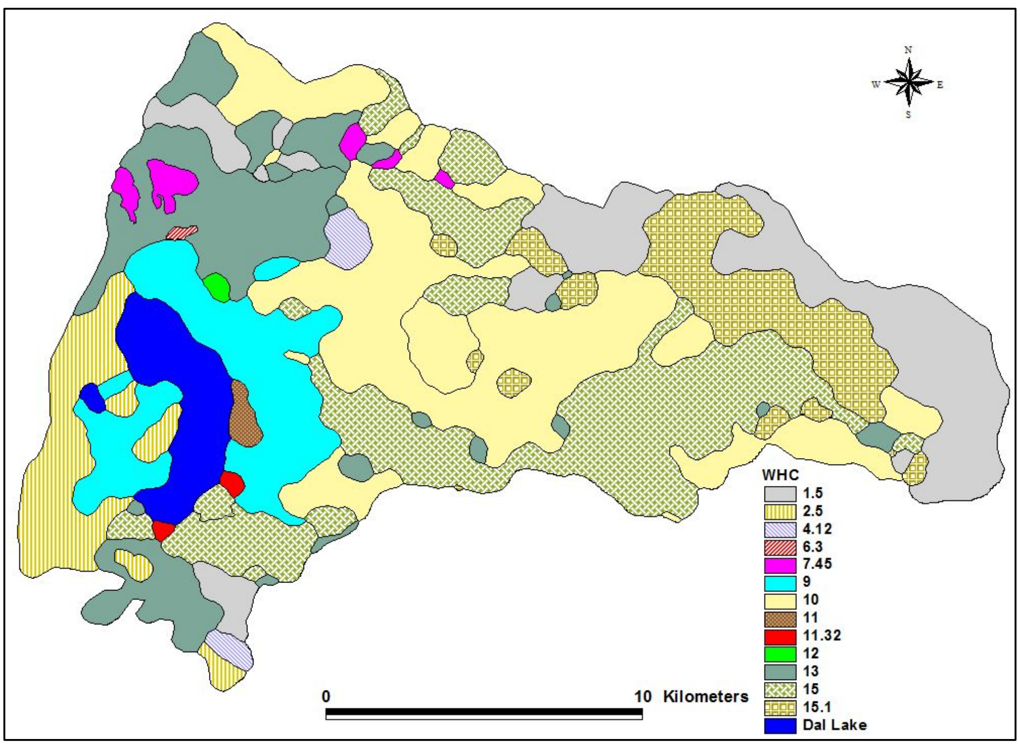


Fig. 41: Water holding capacity of soils in Dal Lake Catchment

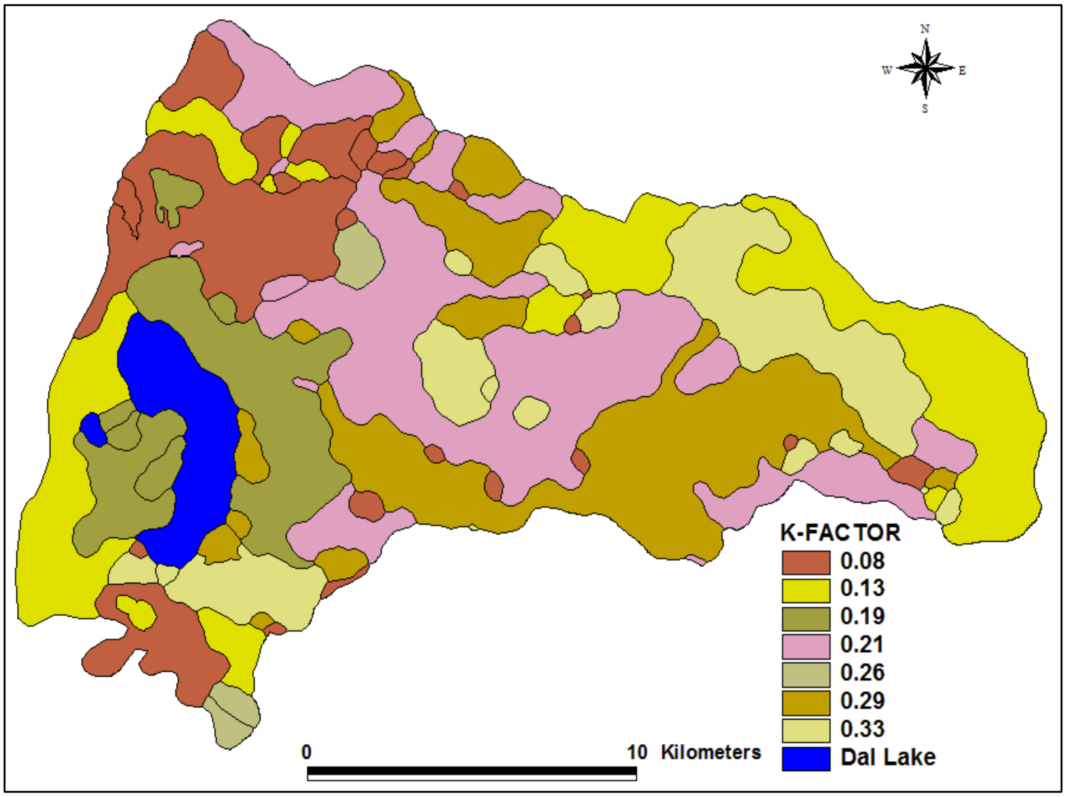


Fig. 42: Soil erodibility factor (k) in Dal Lake Catchment

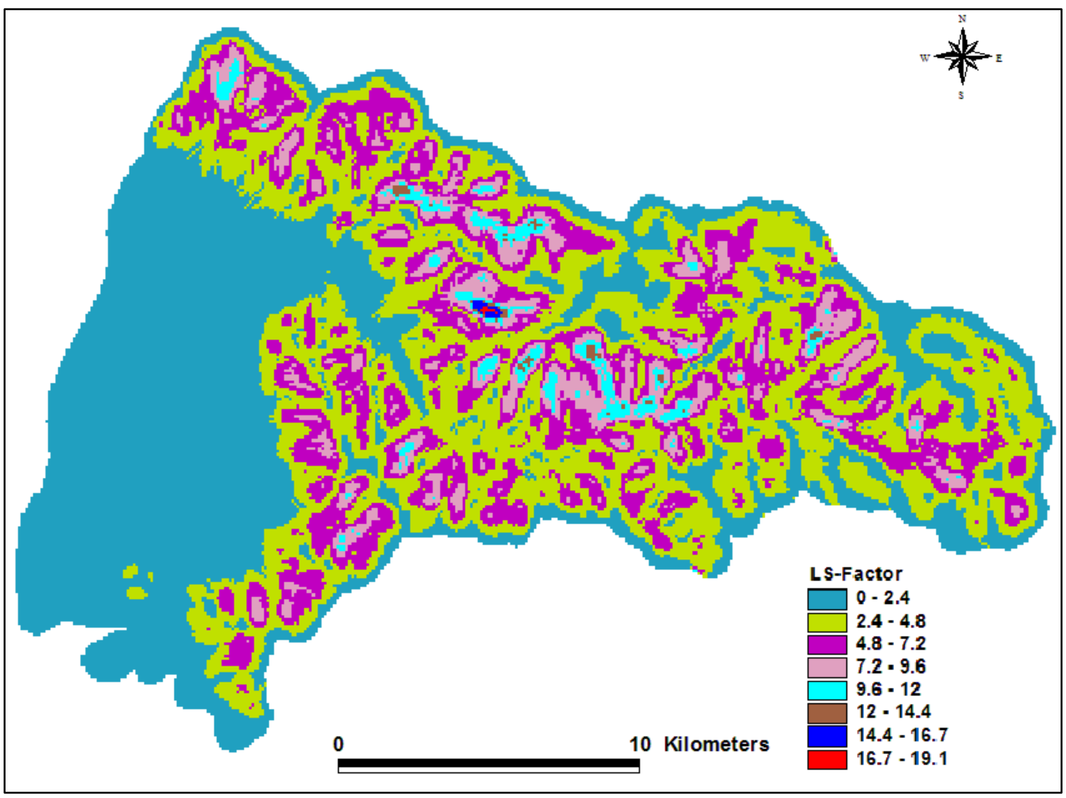


Fig. 43: Slope length (LS) factor in Dal Lake Catchment

Analysis of Fig. 44 reveals that October, November and December are the driest months with all the stream flow being made up of base flow. The scanty rain that the catchment receives is lost through evapotranspiration which reaches maximum around July. Since the runoff at this time of the year is very small, it can be concluded that most of the nutrients and sediment loading reaching the Dal Lake from its catchment are transported through stream flow and sub-surface flow. Further analysis of the Fig. 44 reveals that the catchment receives its maximum rainfall in the months of April, May and March of a particular year. During this period, surface runoff, stream flow and ground water flow are substantially high and the peak flows for all the parameters occur in the month of May. Since storm events are normally associated with the transport of matter through overland flow and/or percolation to ground water, it is expected that the nutrient and the sediment loadings to the lake will also reach maximum levels during this time of the year.

6.5.2 Erosion and Sediment Loadings

The results of the model simulations for erosion and sediment loadings against the changing land use/ land cover scenario are presented in the form of watershed and source area contributions. Table 25 and Fig. 45-49 present the results for the watersheds wise erosion and sediment contributions. The examination of the data in Table 25 shows that the changed land use/land cover conditions had a significant impact on the erosion and the sediment yield as is reflected by their increasing trend. A perusal of the data presented in Table 25 reveals that all the watersheds in the catchment show an increase in both the erosion and sediment yields. The increase although small in certain watersheds is by and large reflective of their changing biophysical charcteristics. It can be observed from the Table 25 that the erosion and sediment yields are in tandem for the multi dated land use/ land cover data and the watershed contribution follows the same order with the exception of DW5 that replaces DW13 for the 2005 land use/ land cover as the highest contributor. It is observed that DW5 followed by DW13, DW11, DW6 and DW8 are the highest contributors for both erosion and sediment loads. Further analysis of the Table 25 reveals that the watersheds DW12, DW7, DW3, DW2, DW4, DW1 are other contributors, though, not much increase in the erosion and sediment yields is observed. DW9 and DW10 are the least contributors to the loadings.

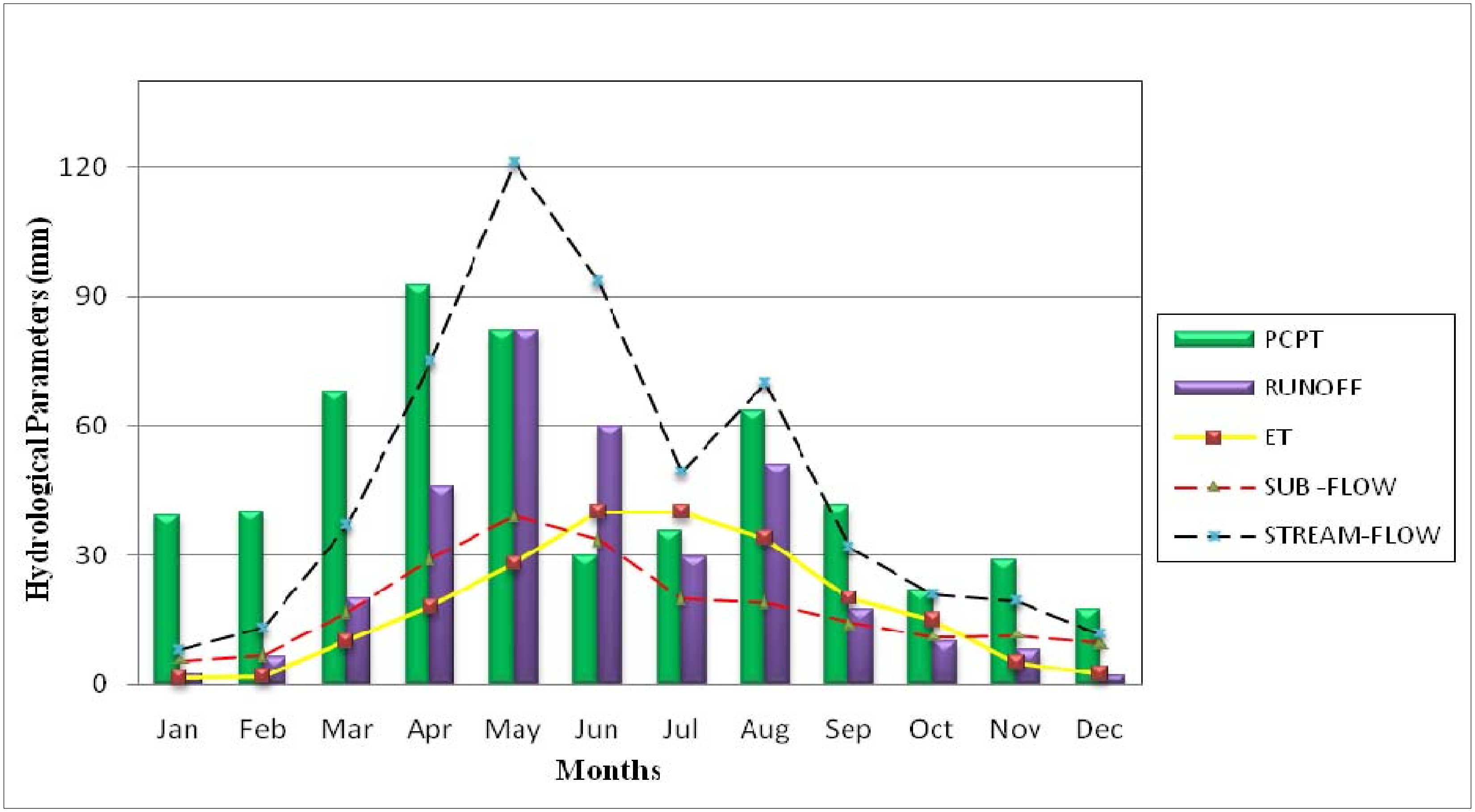


Fig. 44: Mean monthly hydrological output of GWLF model for Dal Lake Catchment (1981-2008)

Table 25: Contribution of different watersheds to avg. annual erosion and sediment yields in Dal Lake Catchment (1981-2008) as a function of changing Land use/Land cover

W ID	Erosion (Tons/yr)			Sediment (Tons/yr)		
	1992	2005	Change	1992	2005	Change
DW1	11.74	50.89	39.15	2.32	8.37	6.05
DW2	41.99	67.05	25.06	8.29	15.86	7.57
DW3	53.66	92.67	39.01	19.09	31.39	12.3
DW4	26.81	45.39	18.58	5.24	9.3	4.06
DW5	269.29	505.22	236.93	43.6	80.3	36.7
DW6	125.04	201.53	76.49	22.52	32.76	10.42
DW7	44.17	78.95	34.78	10.21	17.11	6.9
DW8	44.26	100.42	56.16	12.08	27.28	15.2
DW9	7.8	20.62	12.82	2.18	8.24	6.06
DW10	0.04	10.08	10.04	0.01	0.95	0.94
DW11	161.68	216.23	54.55	30.2	36.85	6.65
DW12	40.87	81.71	40.84	7.94	10.76	2.82
DW13	474.94	482.9	7.96	68.78	75.48	6.7
Totals	**1302.29**	**1953.66**	**651.37**	**232.45**	**354.65**	**122.2**

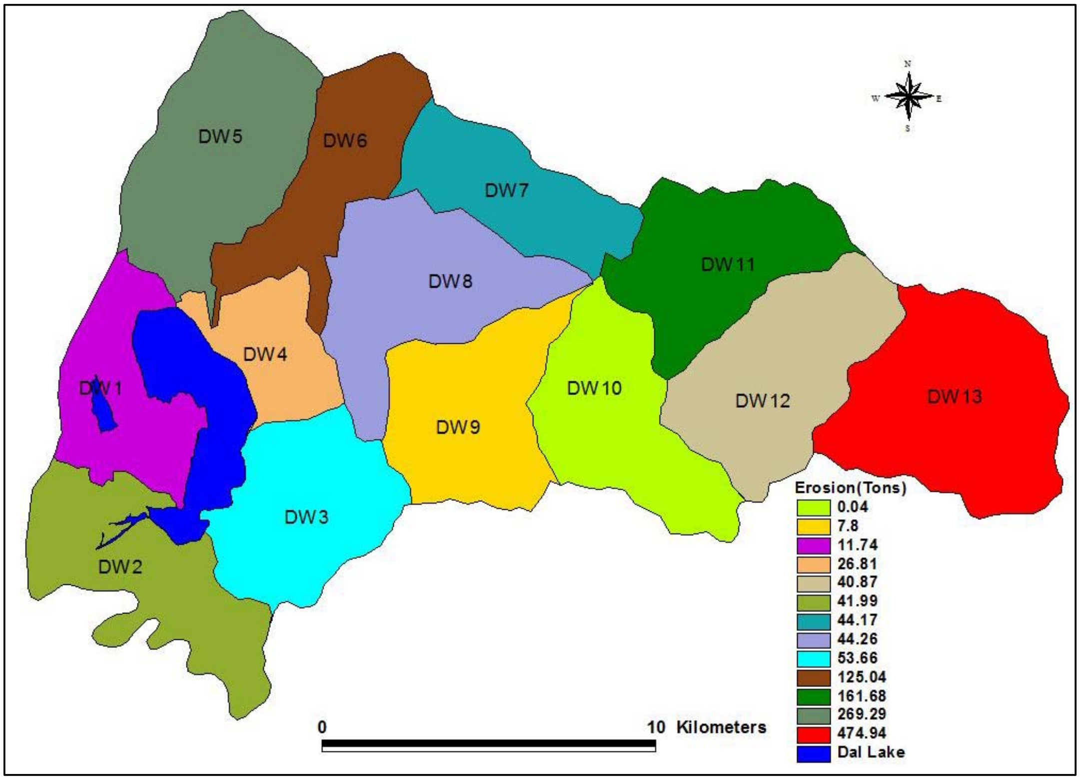


Fig. 45: Contribution of different watersheds to avg. annual erosion yields in Dal Lake Catchment (1981-2008) - 1992 Land use/ Land cover

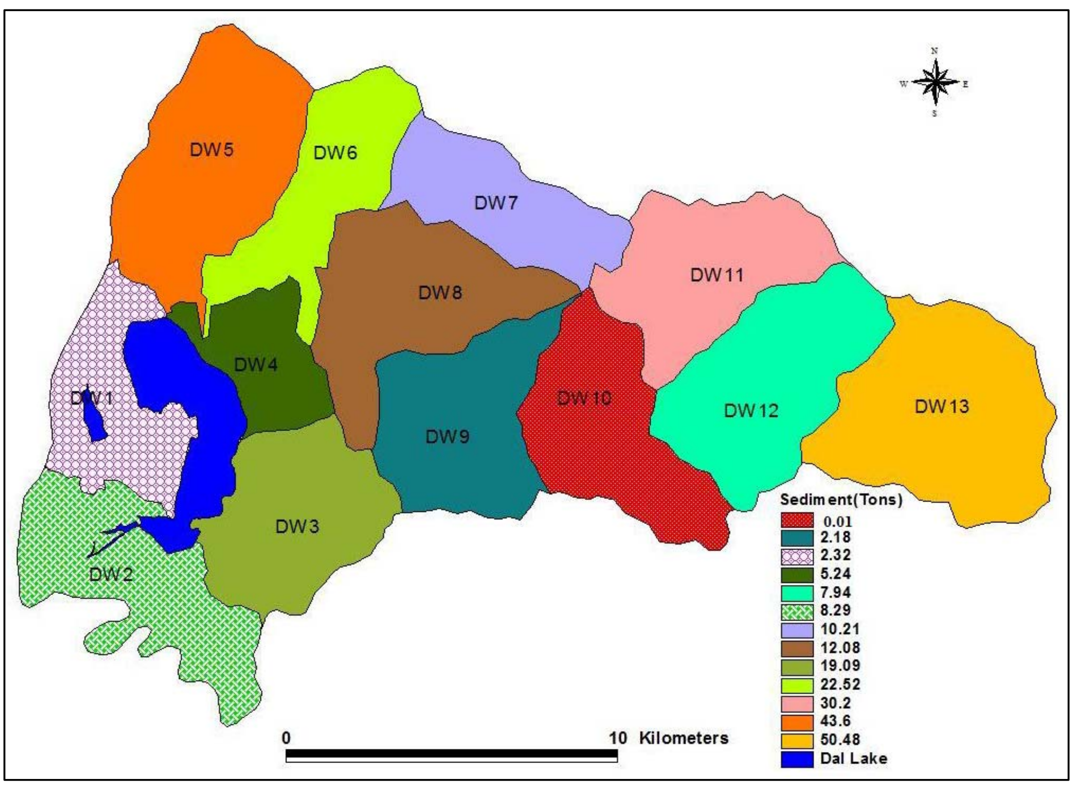


Fig. 46: Contribution of different watersheds to avg. annual sediment yields in Dal Lake Catchment (1981-2008) - 1992 Land use/ Land cover

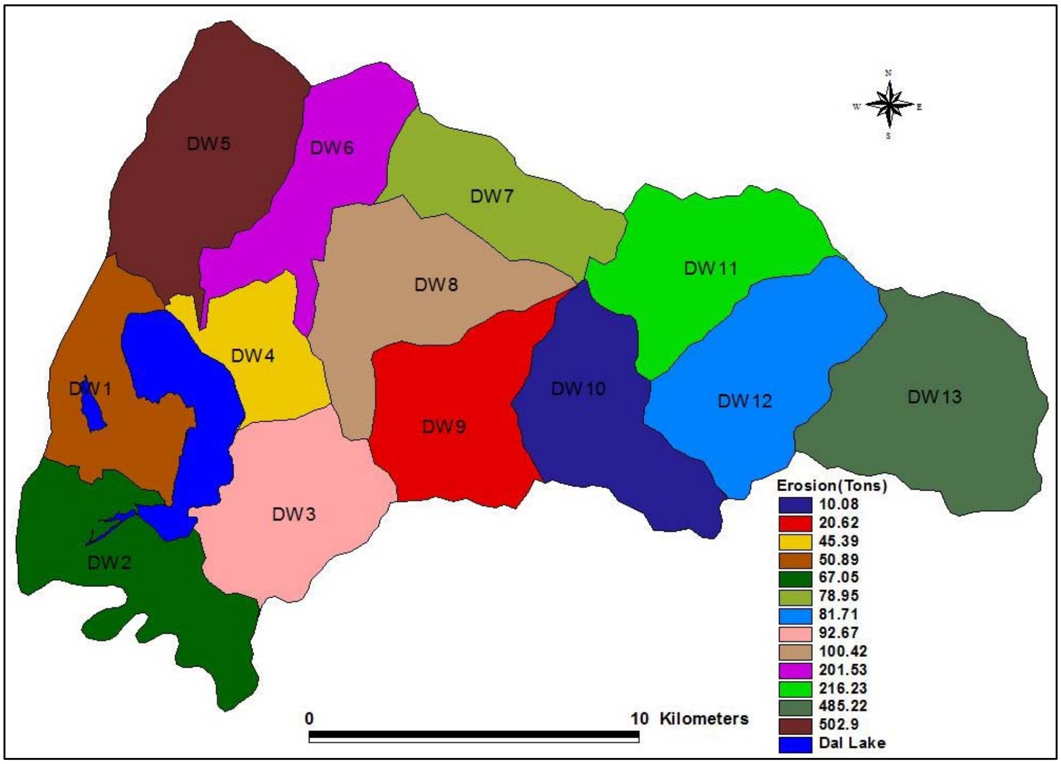


Fig. 47: Contribution of different watersheds to avg. annual erosion yields in Dal Lake Catchment (1981-2008) - 2005 Land use/ Land cover

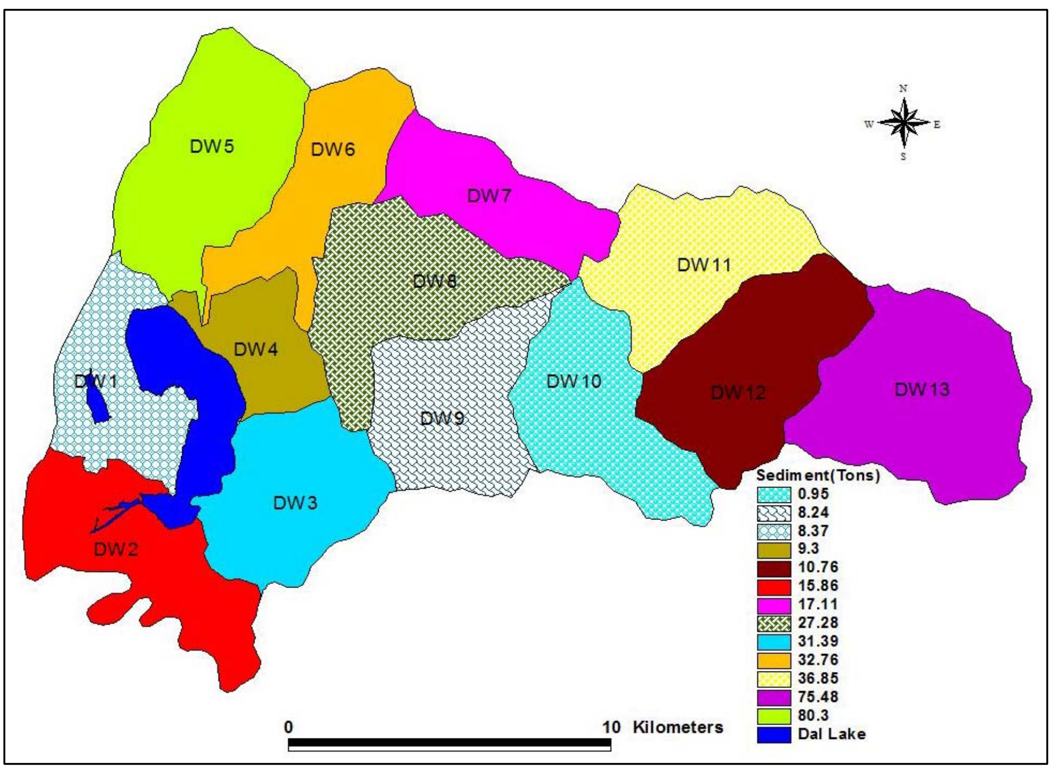


Fig. 48: Contribution of different watersheds to avg. annual sediment yields in Dal Lake Catchment (1981-2008) - 2005 Land use/ Land cover

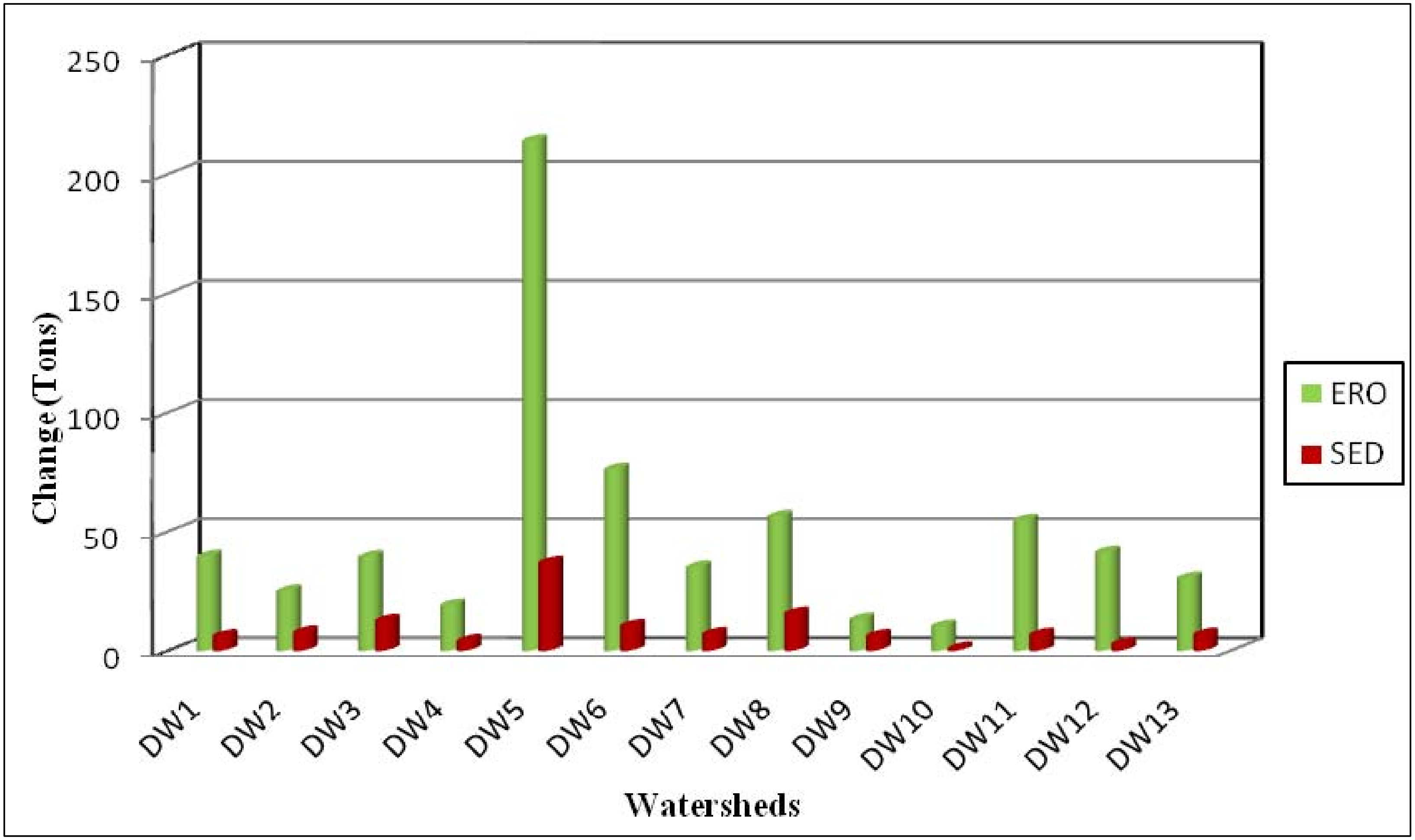


Fig. 49: Watershed wise change in avg. annual erosion and sediment yields in Dal Lake Catchment (1981-2008) as a function of changing Land use/Land cover

Further analysis of the data presented in Table 25 shows that the maximum increase in the erosion yield was recorded for DW5 with (236.93 tons/yr) followed by DW6 (76.49 tons/yr), DW8 (56.16 tons/yr) and DW11 (54.55 tons/yr). It is also observed that DW9 (12.82 tons/yr), DW10 (10.04 tons/yr) and DW13 (7.96 tons/yr) recorded least increase. Similarly, the highest increase in sediment loadings was recorded for DW5 (36.7 tons/yr) followed by DW8 (15.2 tons/yr), DW3 (12.3 tons/yr) and DW6 (10.42 tons/yr) and DW2 (7.57 tons/yr). DW4 (4.06 tons/yr), DW12 (2.82 tons/yr) and DW10 (0.94 tons/yr) showed less increase in the sediment loadings.

The results for the source area (land use/land cover) contributions towards erosion and sediment yields against the changing land use/land cover conditions are given in Table 26 and Fig. 50. Analysis of the data provided in Table 26 reveals that the an increasing trend is observed for the erosion and sediment loadings. The highest erosion is experienced by the bare lands followed by agriculture, forests and hay/pasture. Horticulture, high intensity and low intensity developed areas recorded negligible contributions. Further examination of the data given in Table 26 shows that the major increase in erosion loadings was recorded for bare lands (578.9 tons/yr) followed by hay/pastures (46.14 tons/yr), agriculture (23.3 tons/yr), and forests (2.72 tons/yr).

Results for the source area contributions to sediment loadings as revealed from Table 26 also show an increasing trend. The major loadings are recorded by stream banks, bare lands, agriculture and hay/pasture. Horticulture, high intensity and low intensity developed areas again recorded insignificant contributions. Increase in sediment loads is observed to be highest for the stream banks (42.6 tons/yr) followed by bare lands (30.61 tons/yr), pasture/grasslands (22.9 tons/yr) and agriculture (19.58 tons/yr). The rest of the classes i.e., horticulture, high intensity and low intensity developed areas record insignificant changes in the sediment loadings.

Table 26: Source area contribution to avg. annual erosion & sediment yields in Dal Lake Catchment (1981-2008) as a function of changing Land use/ Land cover

Source	Erosion (Tons/yr)			Sediment (Tons/yr)		
	1992	2005	Change	1992	2005	Change
Hay/Pasture	11.41	57.55	46.14	3.2	26.19	22.99
Agriculture	94.25	117.50	23.25	30.1	49.68	19.58
Forest	25.16	27.88	2.72	1.3	8.64	7.34
Horticulture	0.133	0.15	0.02	0.0	0.01	0.01
Turf/Golf course	-	0.02	0.02	-	0.00	0.00
Bare Land	1171.16	1750.06	578.9	90.7	121.31	30.61
Lo_Int_Dev	0.018	0.05	0.03	0.9	0.00	0.9
Hi_Int_Dev	0.164	0.44	0.27	0.0	0.02	0.02
Stream Bank				106.2	148.80	42.6
Totals	**1302.295**	**1953.66**	**651.37**	**232.4**	**354.65**	**122.25**

Note: Lo_Int_Dev: Low Intensity Development; Hi_Int_Dev: High Intensity Development

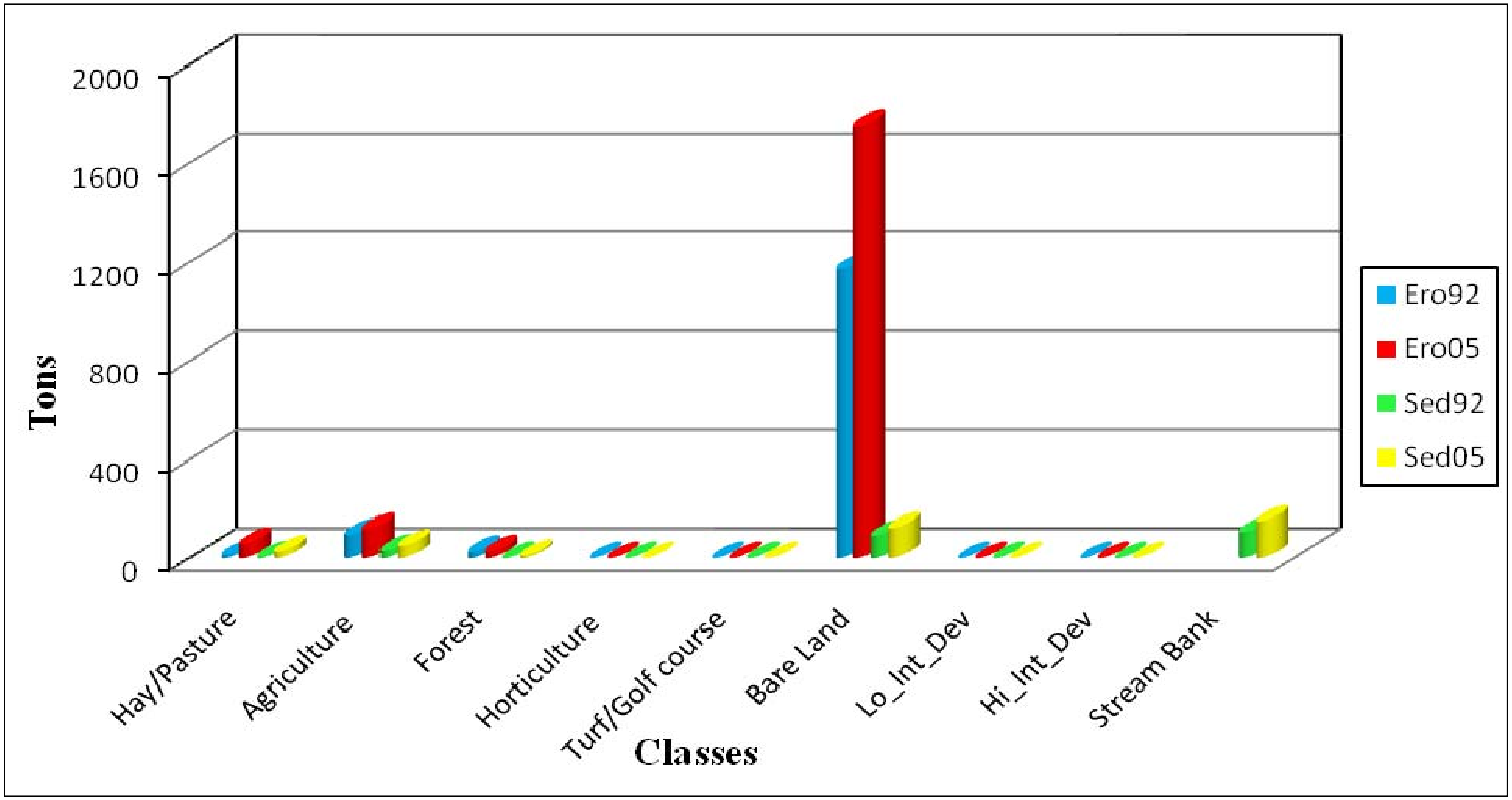


Fig. 50: Source area contribution to avg. annual erosion & sediment yields in Dal Lake Catchment (1981-2008) as a function of changing Land use/ Land cover

6.5.3 Nutrient Loadings

The results of the nutrient loadings to the Dal Lake for the 28 year simulation period (1981-2008) as a function of changing land use/land cover are presented in the form of watershed and source areas contributions given in Table 27, Table 28 and Fig. 51- 62.

Analysis of the data in Table 27 reveals an increasing trend for the nutrient loadings (nitrogen and phosphorus) as a function of changing land use/land cover scenario. It is observed from the Table 27 that maximum loads for both dissolved and total forms of nitrogen and phosphorus under 1992 and 2005 land use/land cover come from the watershed DW5 followed by DW2, DW1, DW8 and DW3 with an upward trend from their 1992 values. DW5 recorded an increase of 89.38 tons/yr in DN, 59.81 tons/yr in TN, 4.42 tons/yr in DP and 10.77 tons/yr in TP. This was followed by DW2 where an increase of 24.21 tons/yr in DN, 59.49 tons/yr in TN, 4.27 tons/yr in DP and 11.66 tons/yr in TP was observed. DW1 showed an increase of 13. 74 tons/yr in DN, 60.64 tons/yr in TN, 0.68 tons/yr in DP and 9.28 tons/yr in TP. DW8 recorded an increase of 6.93 tons/yr in DN, 16.23 tons/yr in TN, 0.12 tons/yr in DP and 6.13 tons/yr in TP. It was observed for DW3, DN recorded an increase of 13.84 tons/yr, TN increased by 34.09 tons/yr, DP by 0.94 tons/yr and TP increased by 9.79 tons/yr. The watersheds DW9 and DW10 were found to contribute in smaller quantities even though the nutrient loadings are showing an increasing trend. DW9 recorded an increase of 1.13 tons/yr in DN, 4.84 tons/yr in TN, 0.4 tons/yr in DP and 2.41 tons/yr in TP. For DW10 an increase of 1.18 tons/yr in DN, 1.9 tons/yr in TN, 0.37 tons/yr in DP and 2.12 tons/yr in TP was recorded.

The results of the source area (land use/land cover) contributions towards nutrient loadings against the changed land use/land cover conditions are given in Table 28. Analysis of the data reveals that agriculture, ground water, high intensity urbanised areas, and bare lands are the major sources of the nitrogen and phosphorus loadings. The least loadings are recorded form forests, golf courses and low intensity developed areas.

Table 27: Contribution of different watersheds to avg. annual nitrogen and phosphorus loads in Dal Lake Catchment (1981-2008) as a function of changing Land use/Land cover

W ID	DN-92	DN-05	TN-92	TN-05	DP-92	DP-05	TP-92	TP-05
DW1	177.63	191.37	201.81	262.45	6.63	7.31	18.3	27.58
DW2	187.72	211.93	300.92	360.41	10.27	14.54	38.13	49.79
DW3	135.37	149.21	161.51	195.6	4.19	5.13	9.57	19.36
DW4	110.48	121.01	129.74	148.95	3.23	4.01	8.41	13.02
DW5	301.48	390.86	420.95	480.76	16.14	20.56	40.63	51.4
DW6	127.28	146.76	157.42	195.31	4.02	5.04	8.49	13.78
DW7	85.01	90.63	47.54	67.98	1.72	1.84	3.5	5.6
DW8	158.61	165.54	187.27	203.5	4.83	5.26	15.47	21.6
DW9	39.19	40.32	43.45	48.29	1.13	1.53	2.94	5.35
DW10	35.66	36.84	40.1	42.1	0.64	1.01	2.2	4.32
DW11	102.2	106.8	115.99	127.8	2.74	3.04	6.09	8.89
DW12	88.21	91.14	90.93	98.39	2.02	2.91	4.5	6.71
DW13	113.15	123.46	139.5	150.16	3.33	4.01	7.79	10.9
Total	**1661.99**	**1865.87**	**2037.13**	**2381.7**	**60.89**	**76.19**	**166.02**	**238.3**

Note:- Values as tons/yr; 92:1992; 05:2005; DN: Dissolved nitrogen; DP: Dissolved phosphorus; TN: Total nitrogen; TP: Total phosphorus

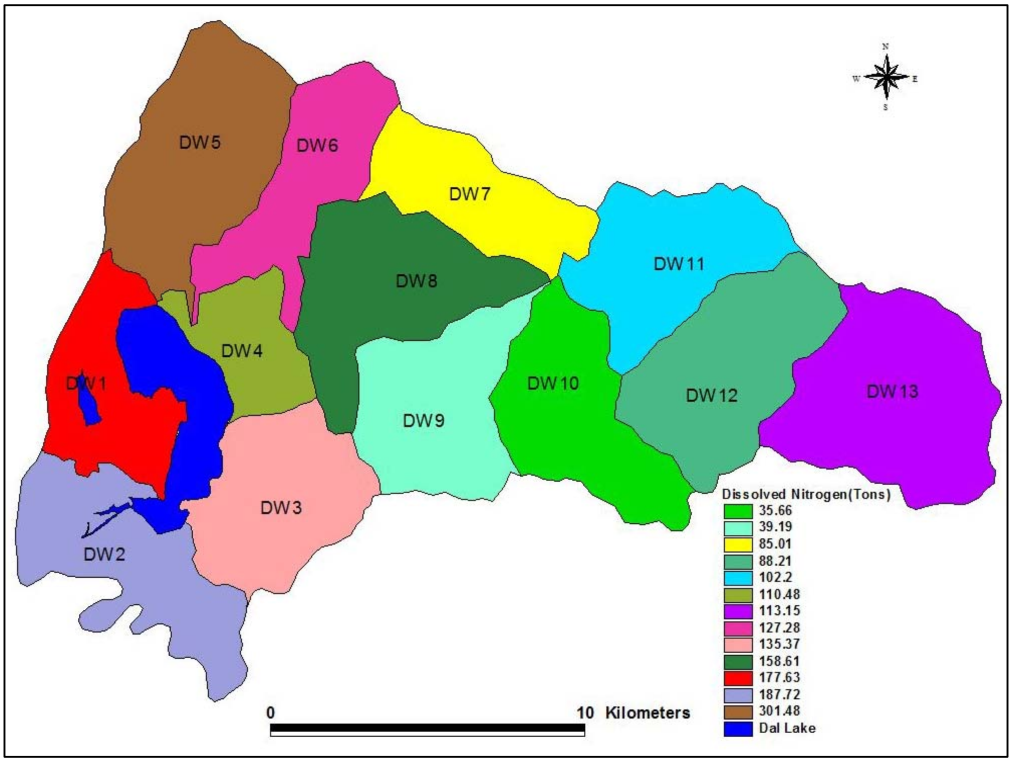


Fig. 51: Contribution of different watersheds to avg. annual dissolved nitrogen loads in Dal Lake Catchment (1981-2008) - 1992 Land use/Land cover

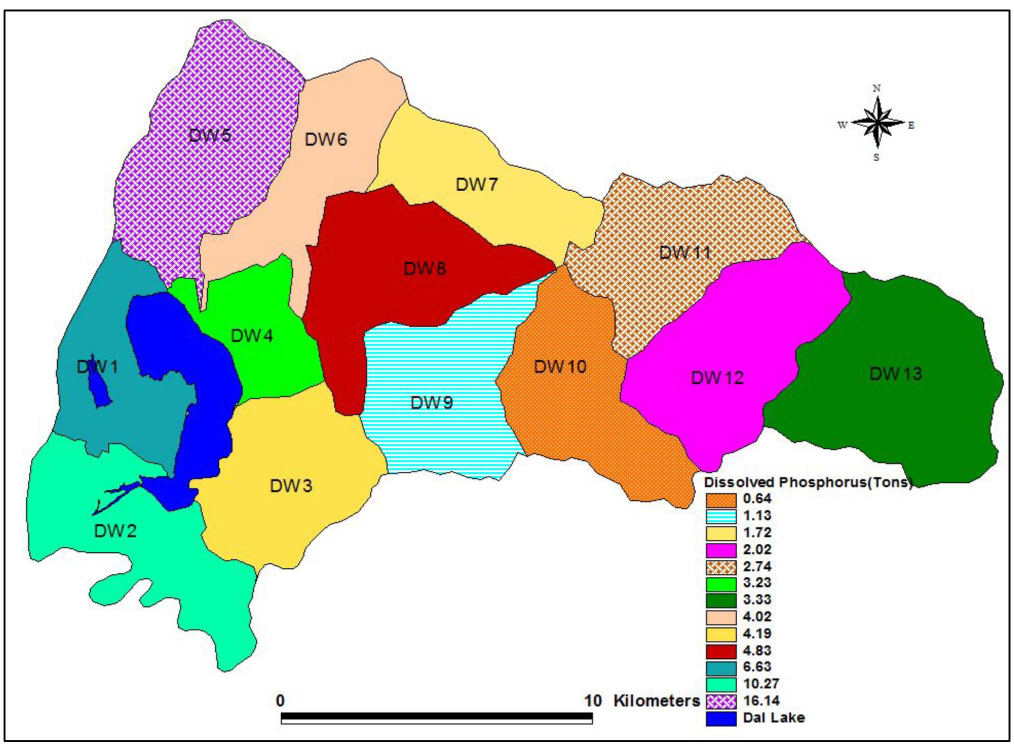


Fig. 52: Contribution of different watersheds to avg. annual dissolved phosphorus loads in Dal Lake Catchment (1981-2008) - 1992 Land use/Land cover

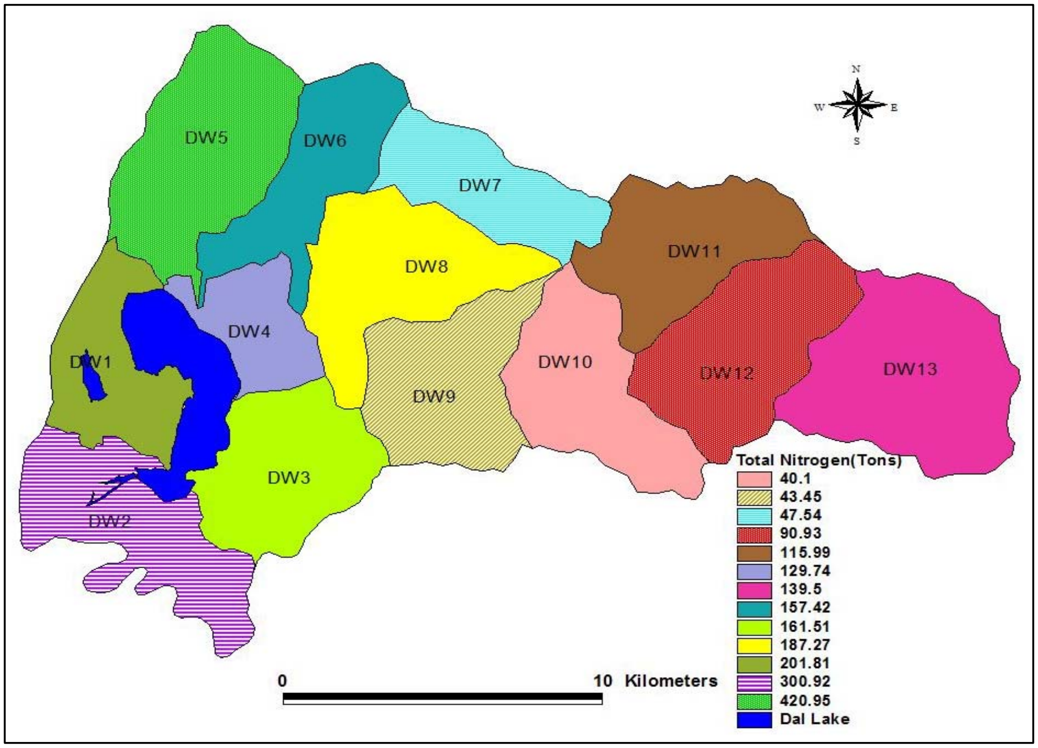


Fig. 53: Contribution of different watersheds to avg. annual total nitrogen loads in Dal Lake Catchment (1981-2008) - 1992 Land use/Land cover

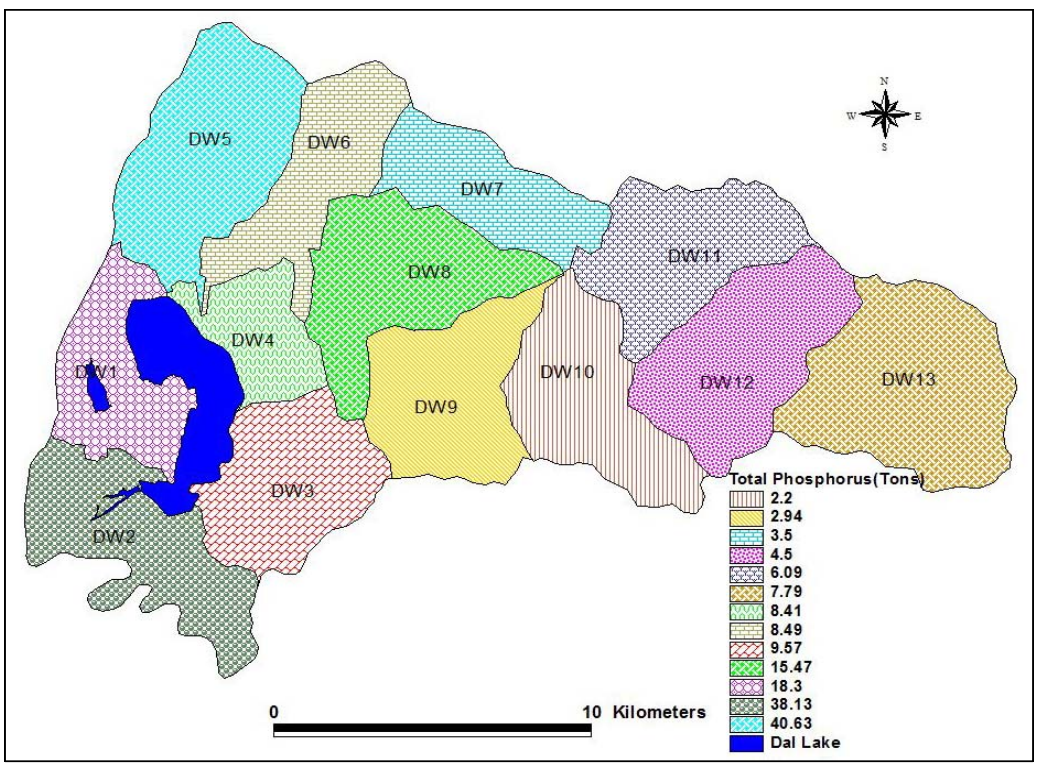


Fig. 54: Contribution of different watersheds to avg. annual total phosphorus loads in Dal Lake Catchment (1981-2008) - 1992 Land use/Land cover

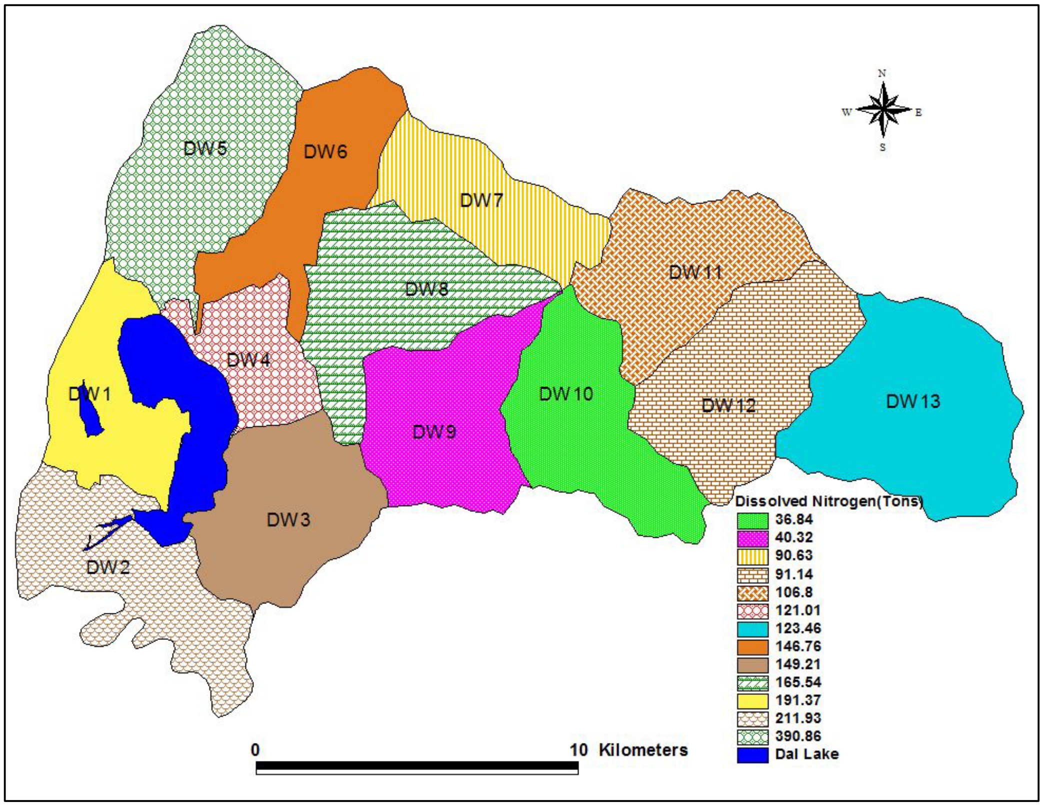


Fig. 55: Contribution of different watersheds to avg. annual dissolved nitrogen loads in Dal Lake Catchment (1981-2008) - 2005 Land use/Land cover

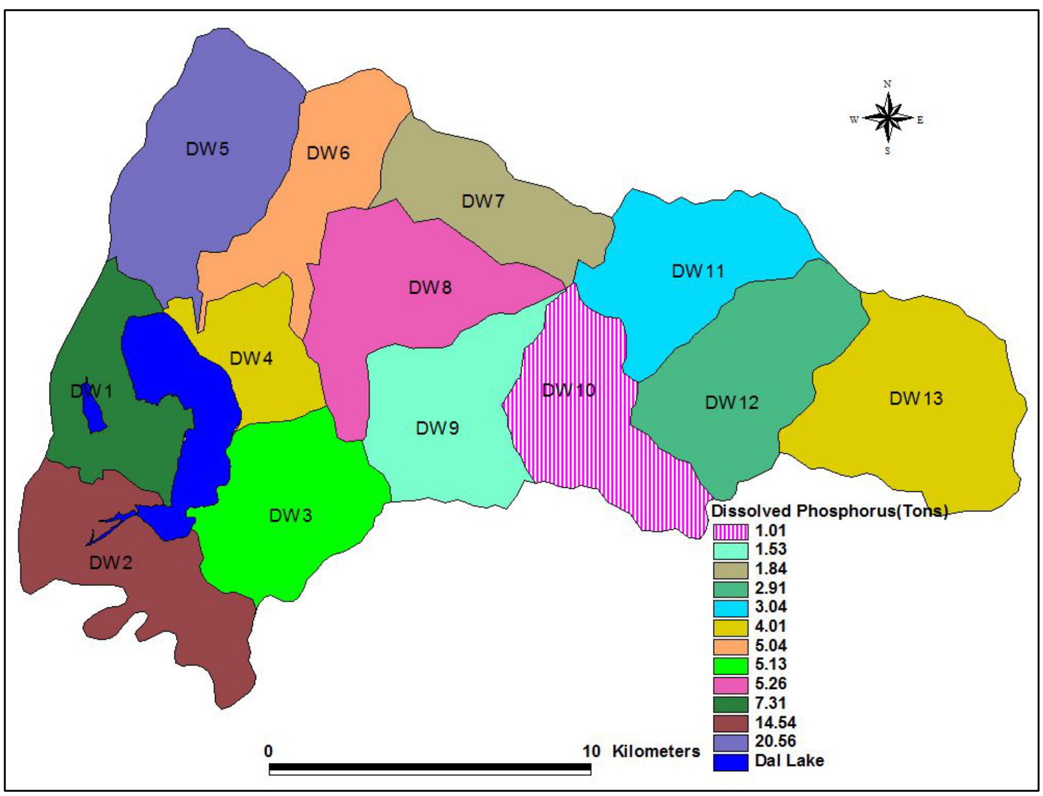


Fig. 56: Contribution of different watersheds to avg. annual dissolved phosphorus loads in Dal Lake Catchment (1981-2008) - 2005 Land use/Land cover

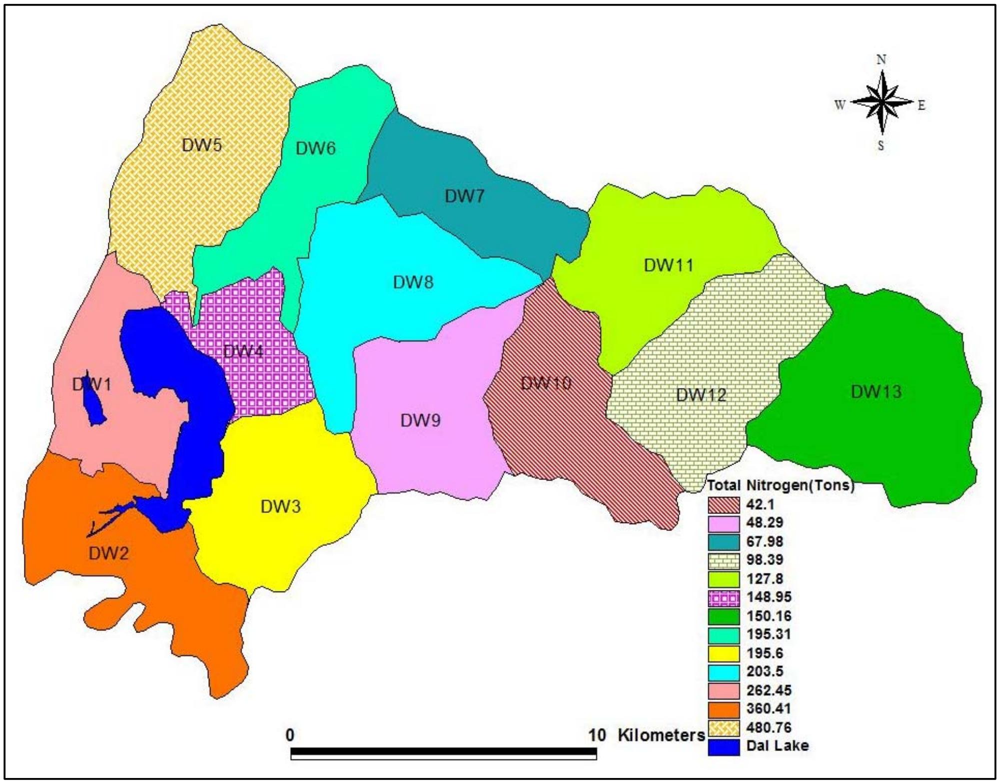


Fig. 57: Contribution of different watersheds to avg. annual total nitrogen loads in Dal Lake Catchment (1981-2008) - 2005 Land use/Land cover

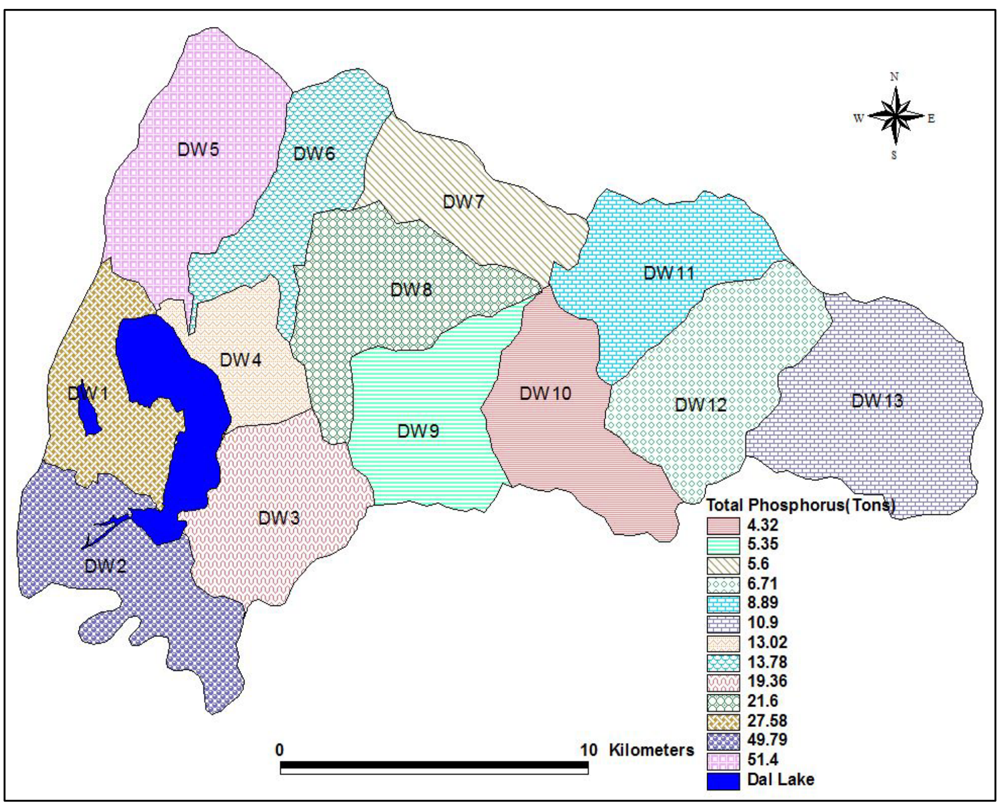


Fig. 58: Contribution of different watersheds to avg. annual total phosphorus loads in Dal Lake Catchment (1981-2008) - 2005 Land use/Land cover

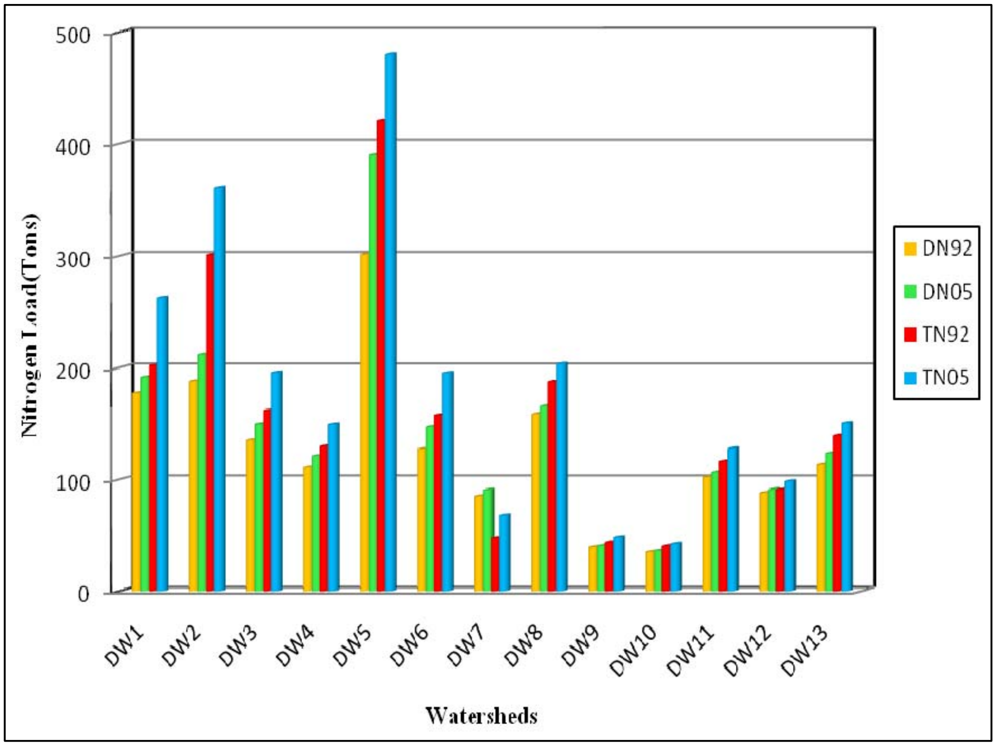


Fig. 59: Watershed wise change in avg. annual nitrogen loadings in Dal Lake Catchment (1981-2008) as a function of changing Land use/ Land cover

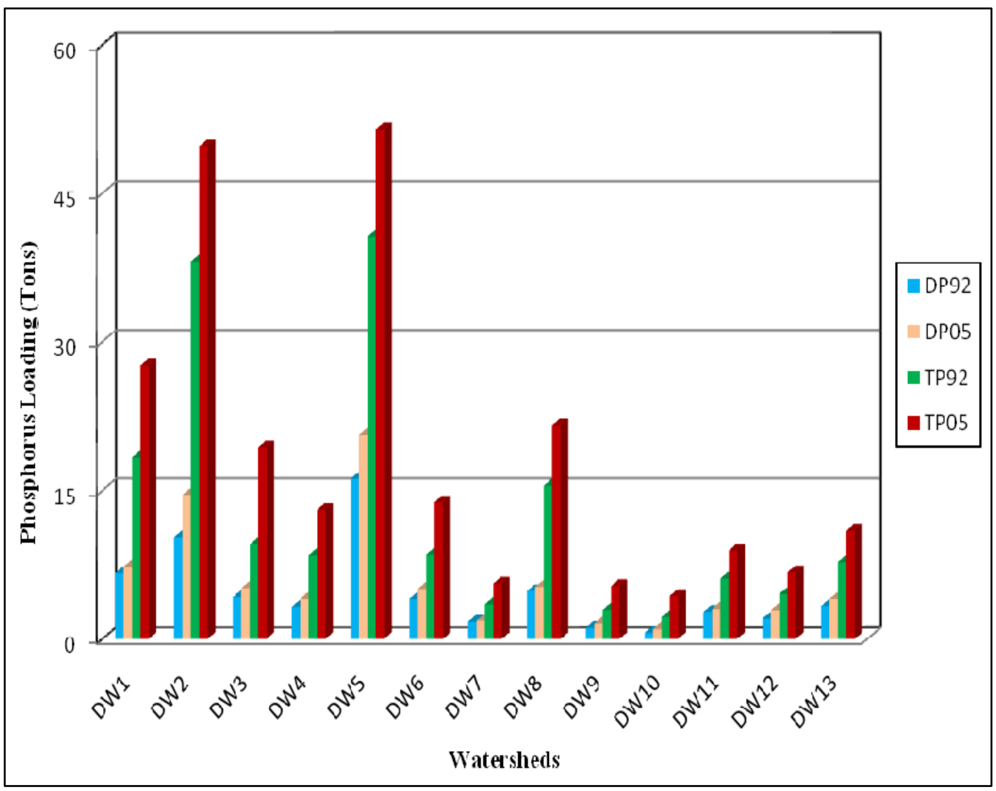


Fig. 60: Watershed wise change in avg. annual phosphorus loadings in Dal Lake Catchment (1981-2008) as a function of changing Land use/ Land cover

Table 28: Source area contribution to avg. annual nitrogen and phosphorus loads in Dal Lake Catchment (1981-2008) as a function of changing Land use/ Land cover

Source Name	1992				2005			
	DN	TN	DP	TP	DN	TN	DP	TP
Hay/Pasture	153.08	176.43	8.13	13.12	178.6	195.2	9.58	20.32
Agriculture	700.28	627.45	30.66	64.04	796.26	751.4	38.16	89.64
Forest	80.06	144.9	3.63	5.61	100.06	160.2	4.19	7.73
Horticulture	32.51	76.45	3.7	14.89	38.98	85.45	5	21.23
Turf /Golf course	-	-	-	-	2.82	4.82		
Bare Land	231.39	216.1	7.72	25.01	266.69	246	11.25	30.61
Lo_Int_Dev	0	0.052	0	1.21	0	10.32	0	2.04
Hi_Int_Dev	0	228.43	0	30.43	0	315.7	0	46.23
Stream Bank	0	6.73		1.67		7.51		6.09
Ground Water	464.67	560.59	7.05	10.04	482.46	605.2	8.01	14.45
TOTAL	**1661.99**	**2037.13**	**60.89**	**166.02**	**1865.87**	**2382**	**76.19**	**238.34**

Note: Values in tons/yr

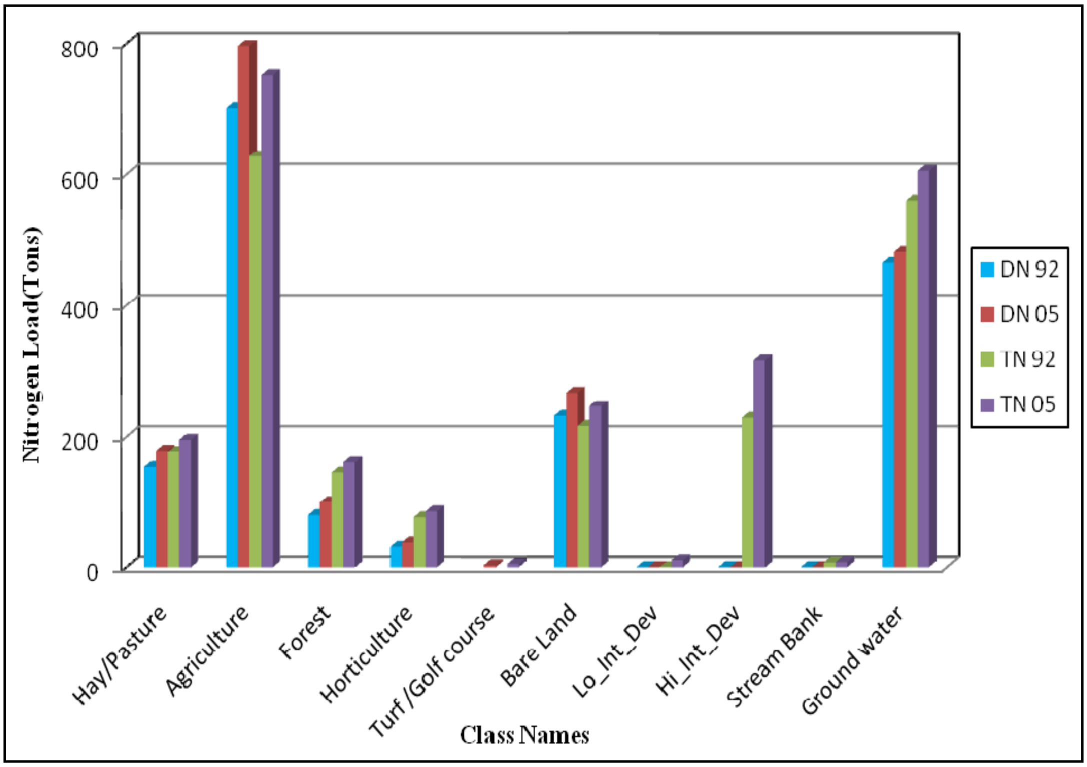


Fig. 61: Source area contribution to avg. annual nitrogen loads in Dal Lake Catchment (1981-2008) as a function of changing Land use/ Land cover

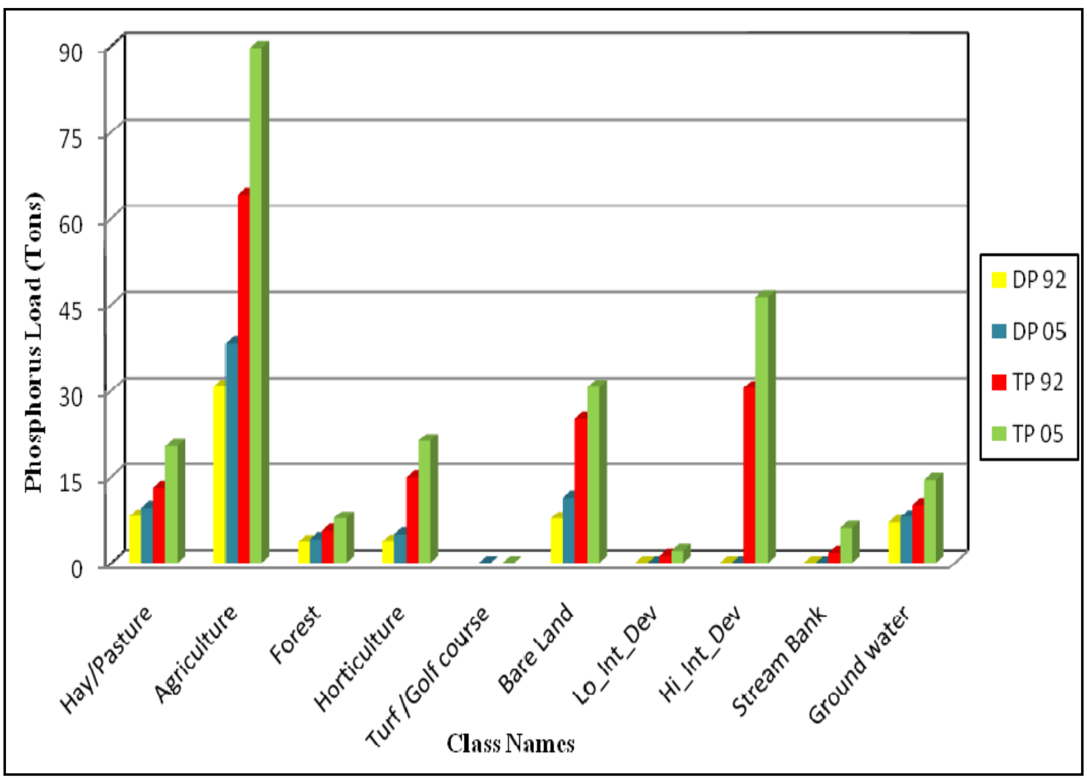


Fig. 62: Source area contribution to avg. annual phosphorus loads in Dal Lake Catchment (1981-2008) as a function of changing Land use/ Land cover

6.6 Socioeconomic Characterization

In order to assess the socioeconomic impacts on the degradation of Dal Lake, the village and ward level socioeconomic characterization of all the watersheds was carried out based on 2001 census data using geospatial techniques as explained in Chapter 5. Although the analysis was carried out for both the villages and the wards, the cumulative socioeconomic parameters were finally considered at the ward level. This was done because a large area of the Dal Lake Catchment is comprised of the Srinagar city.

The results for the socioeconomic characterization of Dal lake catchment at the village and ward level are given in Table 29 and Table 30 respectively. The village and ward maps of Dal Lake Catchment are given in Fig. 63 and Fig. 64 respectively. Various socioeconomic parameters viz. total population, population density, total number of households, literacy rate etc. were assessed for all the villages and wards (Table 29, 30). Fig. 65a and 65b respectively show the spatial distribution of the total population of villages and wards in Dal Lake Catchment. It is found that village Dara (2,669 individuals) and Ward number 7 (68,103 individuals) have the highest population, whereas, village Mufti Bagh (186 individuals) and Ward number 14 (5,599 individuals) have the lowest population. The village and ward wise distribution of total households is given in Fig. 66a and Fig. 66b respectively. The maximum number of households are present in village Dara (398 households) and Ward number 08 (9107 households), whereas, the least number of households are found in village Takya Sangi Reshi (28 households) and Ward number 30 (372 households).

The spatial distribution of literacy rate at village and ward level is given in Fig. 67a and Fig. 67b respectively. It is observed that highest literacy rate is recorded for village Mufti Bagh (66) and Ward number 30 (95.8). Whereas, the lowest is observed for village Forest block (10.4) and Ward number 11(8.61). The economic development index for villages and wards in the Dal Catchment is respectively given in Fig. 68a and Fig. 68b. It is found that of all the villages, Chhatrahama and Takya Sangi Reshi are economically the best and least developed respectively. In case of the adminitrative wards, Ward number 06 and Ward number 03 show the highest and the lowest economic development respectively.

Table 29: Village level socioeconomic characteristics of Dal Lake Catchment

S. No.	Name	Total HH	Total Population	Population Density	Literacy Rate	E	Education Facility
1	Forest Block	155	1042	9.90	10.40	985.32	No
2	Faqir Gujri	209	1238	10.33	14.50	931.07	No
3	Wara Pahu	92	741	7.86	50.70	963.54	Yes
4	Hadorah	91	550	4.77	47.70	250.46	Yes
5	Takya Sangi Reshi	28	202	2.67	36.60	100.48	No
6	Bakra	238	1619	5.69	27.30	888.86	Yes
7	Said Pora Bala	192	1286	10.29	35.90	1946.36	Yes
8	Dara	398	2669	8.06	36.00	2213.00	Yes
9	Wani Hama Bala	36	238	3.90	13.50	153.47	Yes
10	Khimber	301	2046	5.75	34.70	1658.57	Yes
11	Chhatra Hama	373	2483	6.60	28.60	3765.52	Yes
12	Said Pora Hamchi	47	274	6.33	42.40	190.41	Yes
13	Inder Hama	108	581	35.86	27.80	1651.33	Yes
14	Ahal	30	186	4.30	30.20	107.09	No
15	Murandar Bagh	172	1071	12.84	44.00	1023.67	Yes
16	Wani Hama Pain	190	1174	30.57	38.90	1894.51	Yes
17	Mulanar	43	275	7.81	27.50	214.38	No
18	Mufti Bagh	125	673	39.13	66.00	1499.07	Yes
19	Dani Hama	64	447	1.96	41.90	174.57	Yes
20	Burza Hama	66	398	5.64	56.10	231.85	Yes
21	Gassu	186	1110	20.63	39.60	1302.19	Yes

Note: E- Economic Development Status; HH - Households

Table 30: Ward level socioeconomic characteristics of Dal Lake Catchment

Ward No.	Total Households	Total Population	Population Density	Literacy Rate	E
01	6008	40632	28.92	55.64	66, 042.20
02	3427	24067	34.85	65.50	53, 896.29
03	2027	17755	7.87	70.94	25, 645.94
04	6398	41715	360.73	69.12	2,56,113.30
05	7159	50293	655.97	65.12	3,48,646.80
06	4700	35507	346.38	70.82	21,44,414.90
07	7307	68103	554.95	63.51	5,28,950.30
08	9107	66586	280.41	51.62	3,09,802.10
09	6274	44905	296.42	59.43	2,34,953.50
10	2658	19505	66.42	62.73	50,518.20
11	4252	30107	49.09	8.61	63,889.00
12	5710	38432	38.21	59.02	64,569.10
13	4443	32020	17.33	57.11	38,260.10
14	7504	53295	68.99	50.49	1,25,303.20
15	6011	41928	45.63	57.86	86,360.50
22	5572	38369	108.64	52.64	1,17,591.70
30	372	5599	39.74	95.80	32,105.90
CB	3074	18923	58.36	75.66	67,805.00

Note: CB-Cantonment Bagh

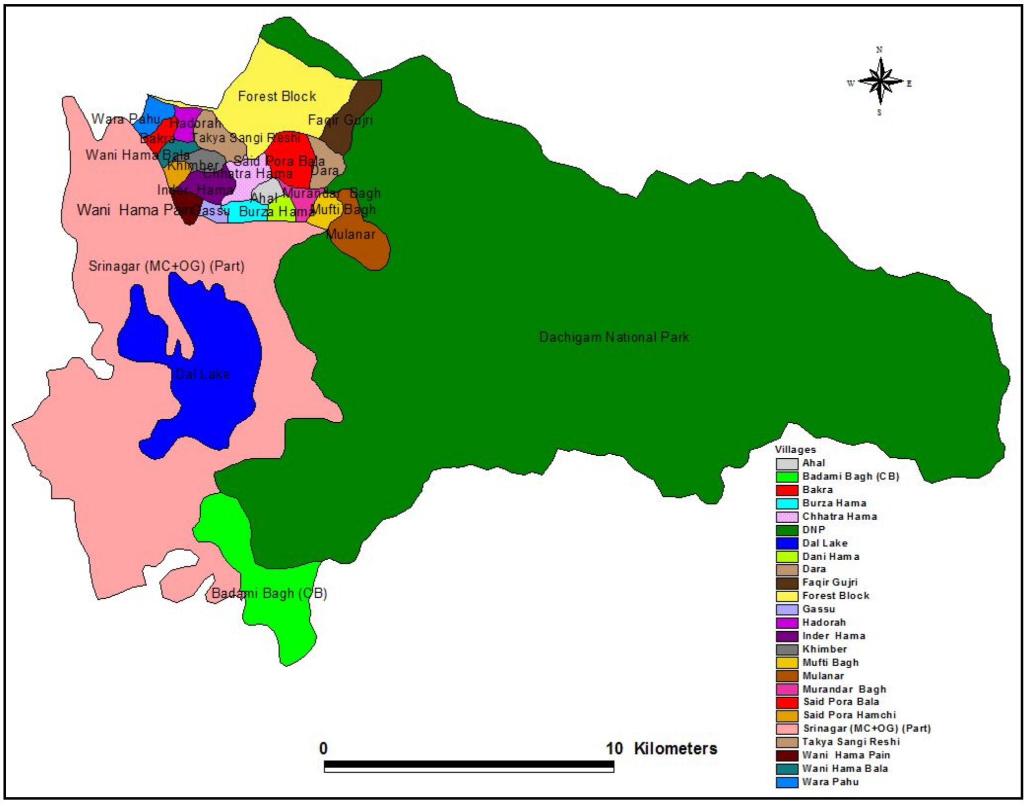


Fig. 63: Village Map of Dal Lake Catchment

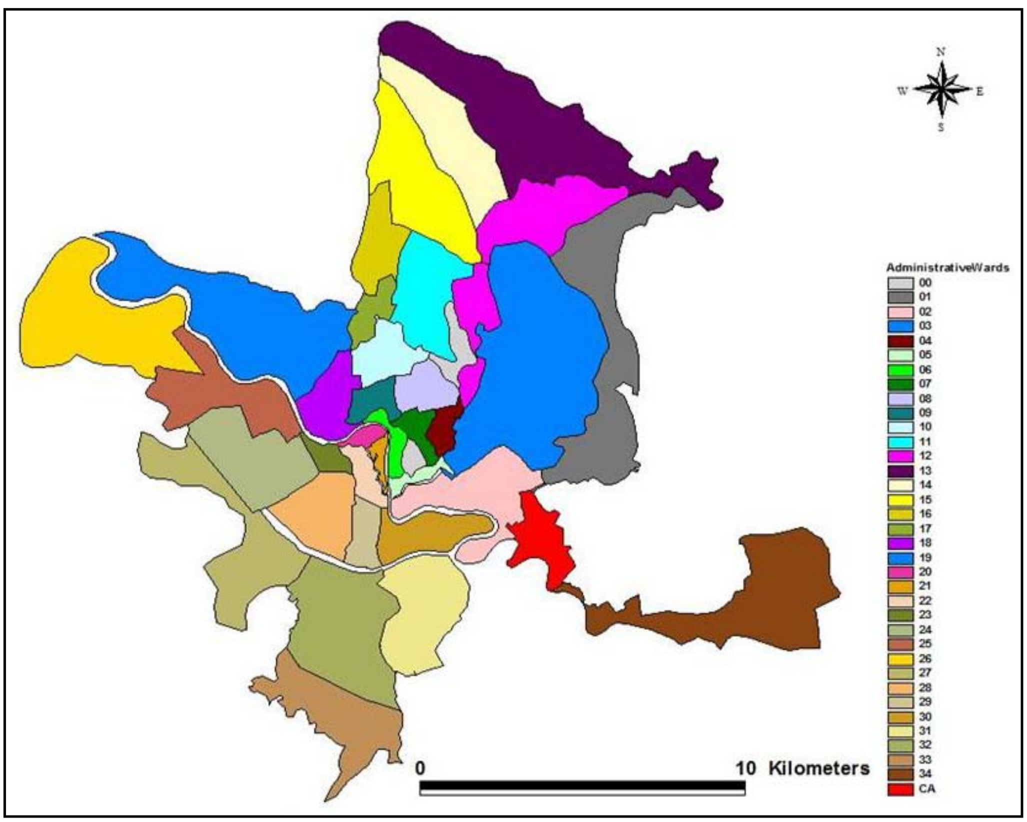
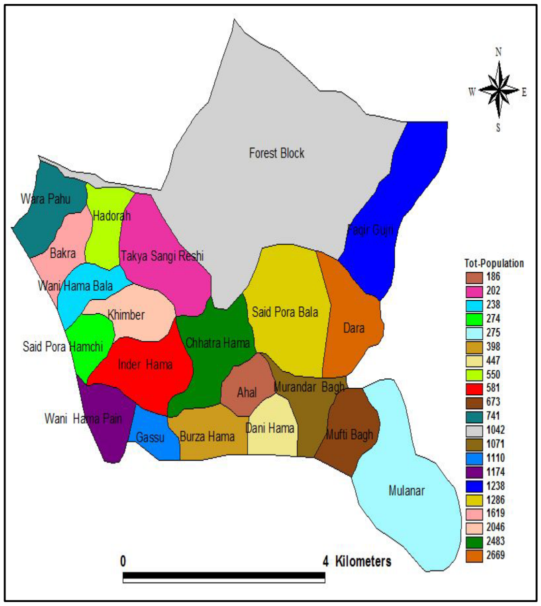
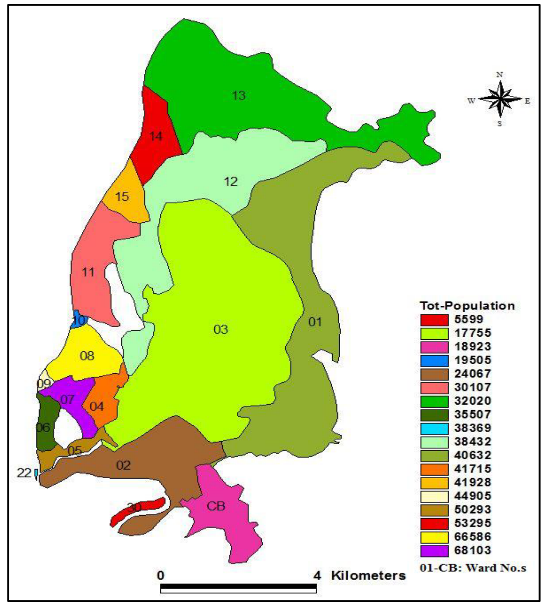


Fig. 64: Ward Map of Srinagar City



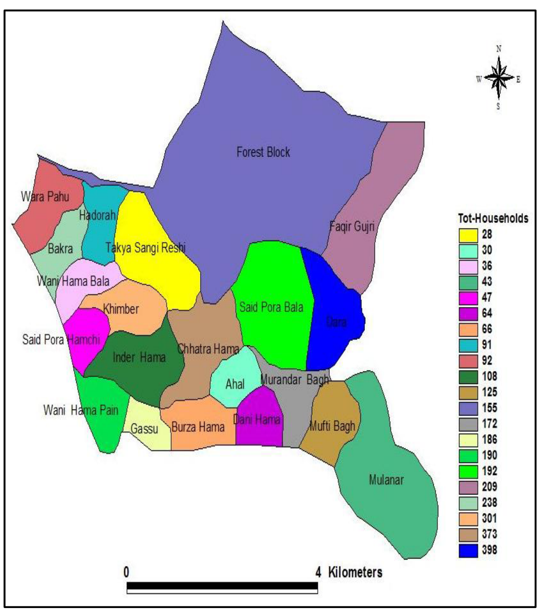
(a)

Fig. 65a: Village level total population in Dal Lake Catchment



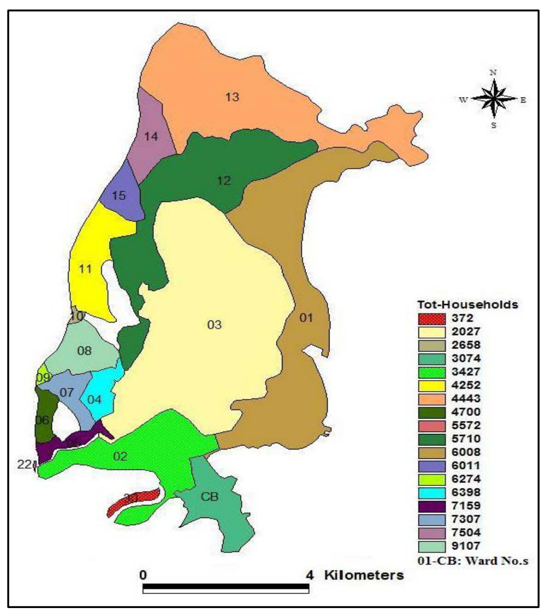
(b)

Fig. 65b: Ward level total population in Dal Lake Catchment



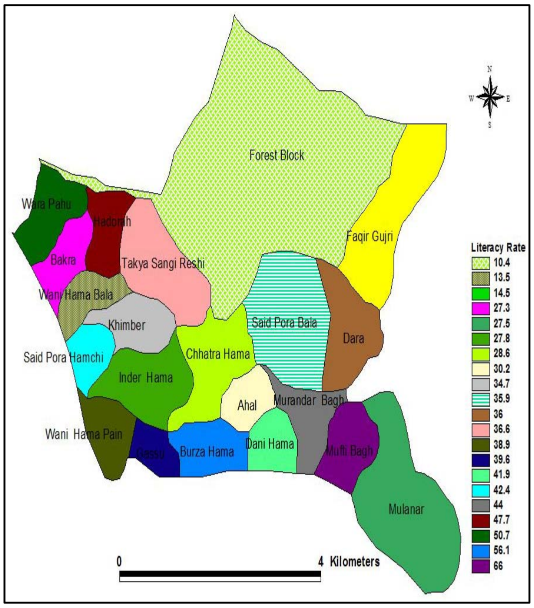
(a)

Fig. 66a: Village level total households in Dal Lake Catchment



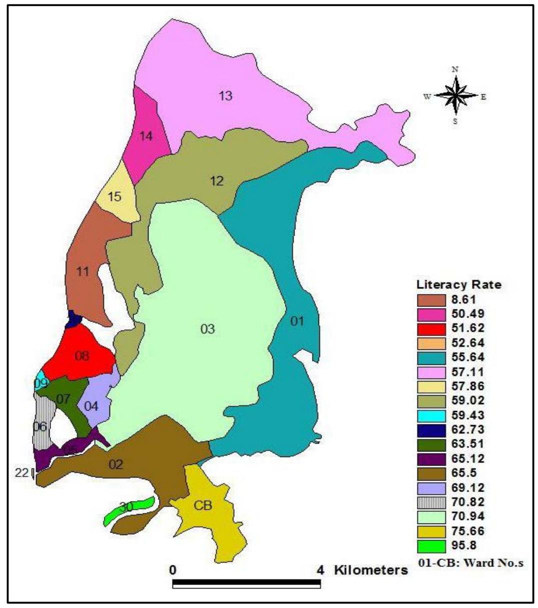
(b)

Fig. 66b: Ward level total households in Dal Lake Catchment



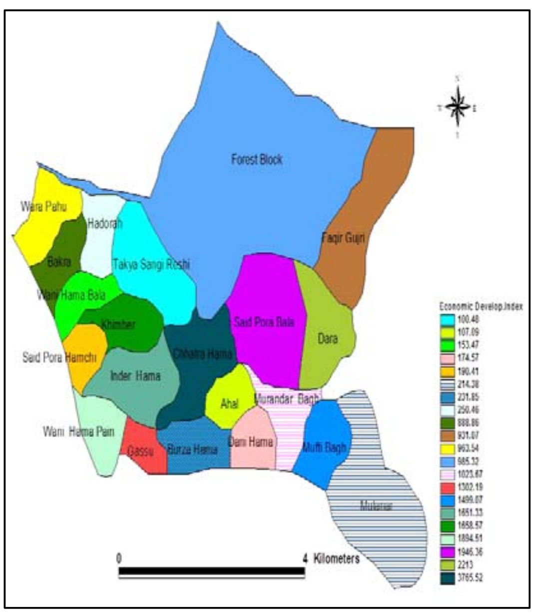
(a)

Fig. 67a: Village level literacy rate in Dal Lake Catchment



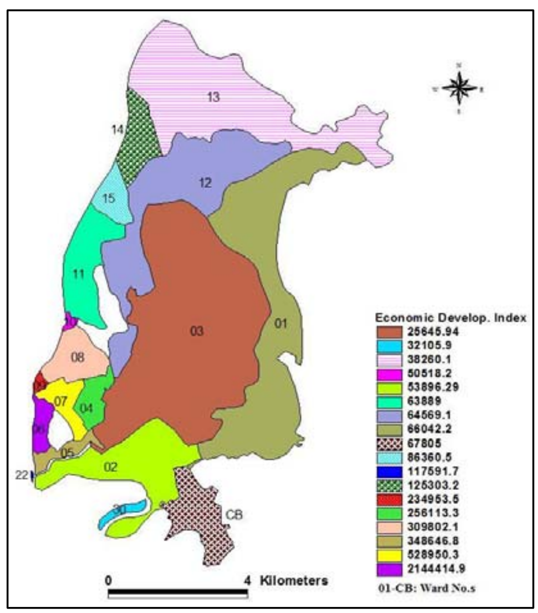
(b)

Fig. 67b: Ward level literacy rate in Dal Lake Catchment



(a)

Fig. 68a: Village level economic development status in Dal Lake Catchment



(b)

Fig. 68b: Ward level economic development status in Dal Lake Catchment

After evaluating the socioeconomic properties of both the villlages as well as the administrative wards in the Dal catchment, the final assessment was made at the ward level. This was done because all villages in the Dal Catchment are within the Srinagar municipal limits. Also, in order to incorporate the area of the Srinagar city outgrowth (MC+OG) that falls in the Dal Lake Catchment, the ward level analysis was chosen for the final assessment. Given that this study is based on the contribution of individual watersheds towards the deterioration of Dal Lake, the socioeconomic characterisation at watershed level was mandatory. Since all socioeconomic variables that were evaluated donot have direct water quality implications, only total population and total number of households were chosen to be integrated with the biophysical, topographic, erosion and pollutant variables for the integrated impact analysis as these have a profound effect on different watershed characteristics in general and water quality in particular. Table 31 and Fig. 69 and Fig. 70 show the socioeconomic characteristics of different watersheds in Dal Lake Catchment.

Analysis of the data provided in the Table 31 reveals that almost half the number of watersheds in the Dal Catchment are not inhabited mainly because of their high altitude, dense forested and remote nature. Although accessed by people for grazing cattle, firewood collection and other activities, these watersheds are still uninhabited. Among the populated watersheds, DW2 has the highest population (65, 228 individuals) and the highest number of households (9,562). This watershed mainly comprises of the congested Srinagar city west and the south. This is followed by DW1 (28,463 individuals and 3,921 households) again comprising of the Srinagar city west. DW4 follows at the third place (17,473 individuals and 2,578 households) including eastern parts of the catchment comprising of the areas of Nishat, Shalimar etc. DW6 (14,980 individuals and 2,169 households) and DW5 (14,672 individuals and 3,921 households) comprise of the northern parts of the city in Dal Lake Catchment. DW3 (10,519 individuals and 1,555 households) includes the City east side. DW8 (1,731 individuals and 243 households) has the lowest population and number of households. This watershed comprises of the eastern portion of the Dal Lake Catchment and partly falls in the Dachigam National Park.

Table 31: Watershed level total population and total households in Dal Lake Catchment

ID	Watershed Name	Total Population	Total Households
1	DW1	28,463	3,921
2	DW2	65,228	9,562
3	DW3	10,519	1,555
4	DW4	17,473	2,578
5	DW5	14,672	2,067
6	DW6	14,980	2,169
7	DW7	0	0
8	DW8	1,731	243
9	DW9	0	0
10	DW10	0	0
11	DW11	0	0
12	DW12	0	0
13	DW13	0	0

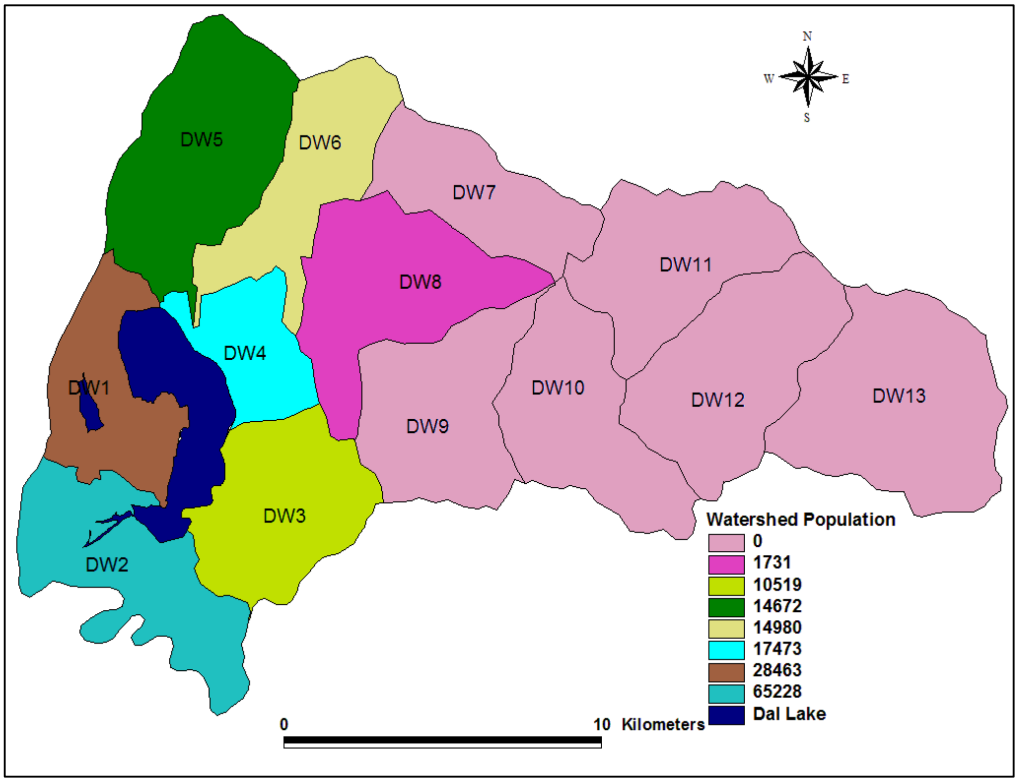


Fig. 69: Watershed level total population in Dal Lake Catchment

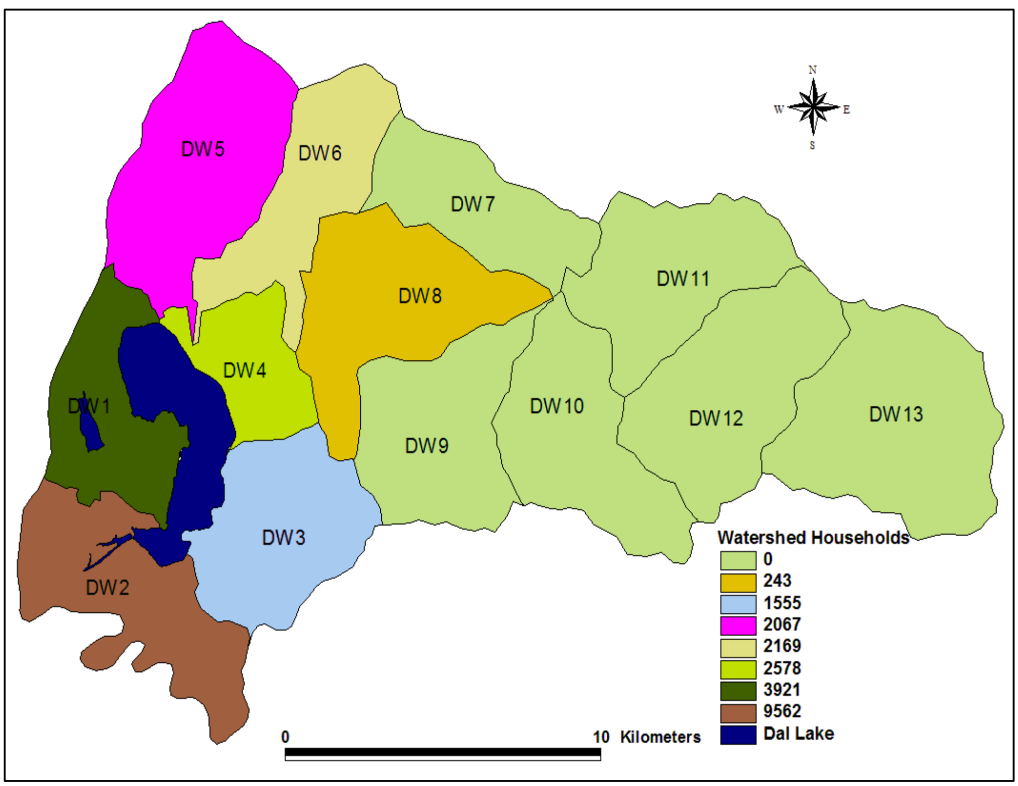


Fig. 70: Watershed level total households in Dal Lake Catchment

6.7 Integrated Impact Analysis and Watershed Prioritization of Dal Lake Catchment

Assessing the process of lake degradation requires the collective understanding of the different phenomena taking place in its watersheds. The current study encompassed assessment of all such processes ranging from biophysical to the socioeconomic ones. All the 13 watersheds in the Dal Lake Catchment were prioritized by considering the results of various thematic maps derived from satellite imagery, model simulations, socio-economic data and field visits as well as. The prioritization results for the study area were derived on the basis of the cumulative weightage given to different features of the thematic maps.

The prioritization analysis results are given in Table 32 and Fig. 71 and Fig. 72. A perusal of the Table 32 reveals that on the basis of priority and cumulative weightage assigned to each thematic map, the watersheds are grouped into three categories: high, medium and low priority. It is further observed from the Table 32 that of the total 13 watersheds of Dal Lake Catchment, five (5) watersheds namely DW5>DW2>DW6>DW8>DW1 rank highest in the overall weightage and are considered under high priority. Out of the remaining 8 watersheds, 5 watersheds viz. DW13>DW3>DW4>DW11>DW7 fall under the medium priority category. The remaining 3 watersheds i.e., DW12>DW9>DW10 fall under low priority category.

Table 32: Results of prioritization carried out for watersheds in Dal Lake Catchment

S. No	Watershed Name	Priority Result	Priority Rank
1	DW1	High	PZ5
2	DW2	High	PZ2
3	DW3	Medium	PZ7
4	DW4	Medium	PZ8
5	DW5	High	PZ1
6	DW6	High	PZ3
7	DW7	Medium	PZ10
8	DW8	High	PZ4
9	DW9	Low	PZ12
10	DW10	Low	PZ13
11	DW11	Medium	PZ9
12	DW12	Low	PZ11
13	DW13	Medium	PZ6

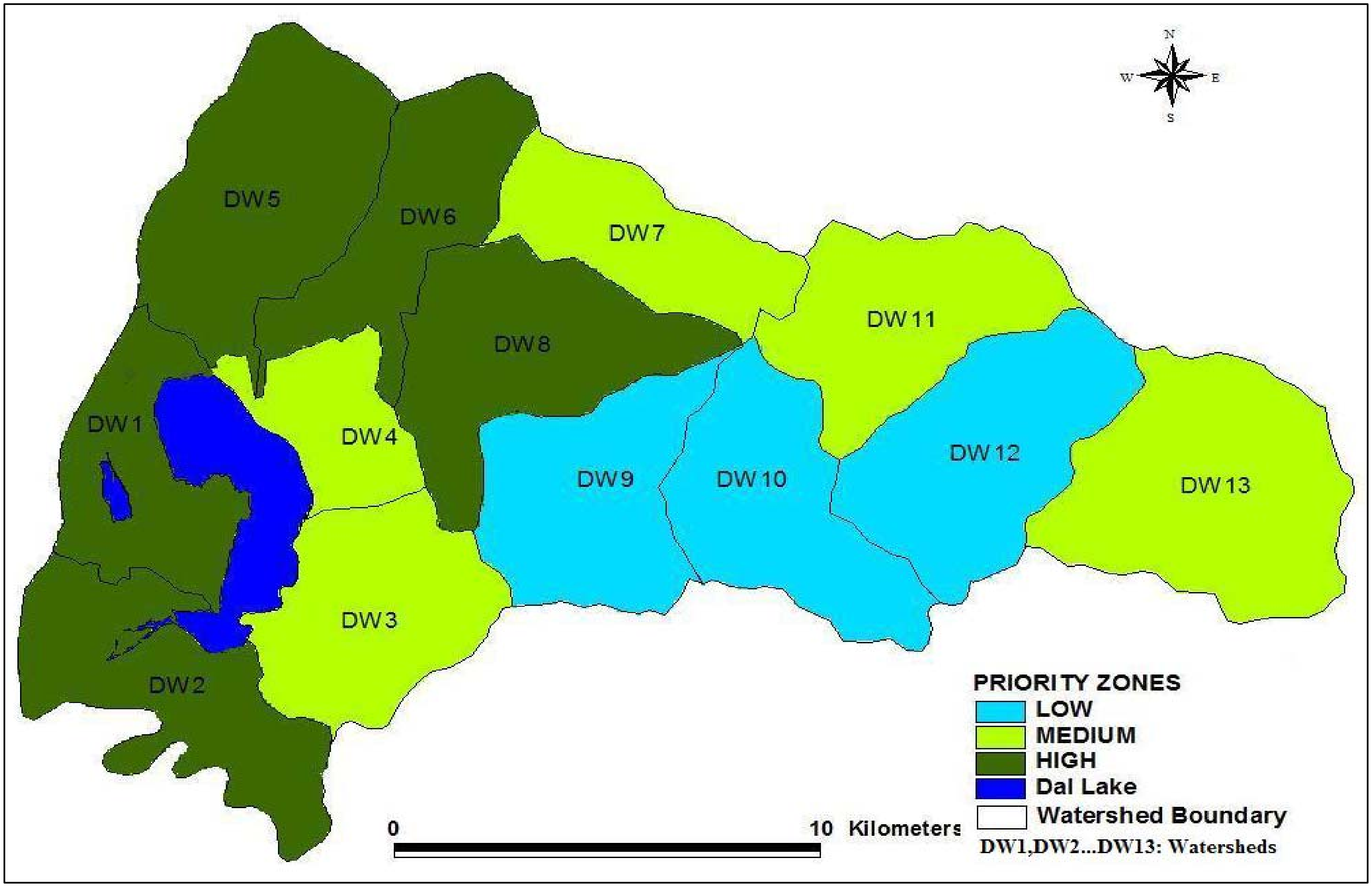


Fig. 71: Spatial distribution of priority results for watersheds in Dal Lake Catchment

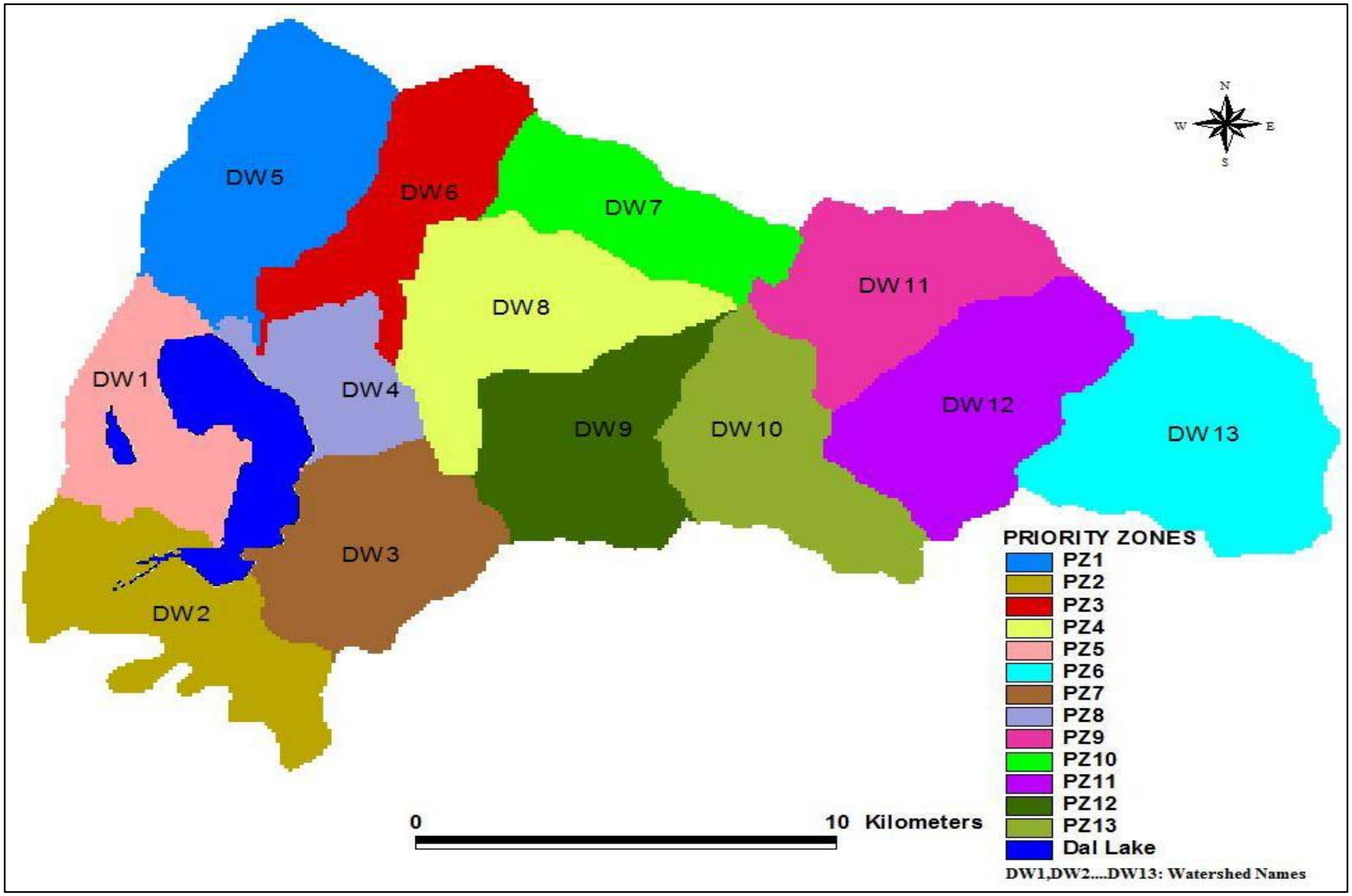


Fig. 72: Watershed Prioritization Map of Dal Lake Catchment

6.8 Validation Study

For the validation of the GWLF model results, water quality data for the Dal Lake Catchment comprising of nutrient and sediment data was compiled from the Lakes and Waterways Development Authority. Nutrient data was collected from January, 2007 to December, 2007 and sediment data from September, 2005 to August, 2006, as data was available for the said period. Water quality and stream flow data were then used to derive the sediment, total nitrogen and phosphorus concentrations for the whole catchment which could be compared against simulated loads produced via the use of the GWLF model. The GWLF model calculates nutrient loads on a daily basis, but provides output on a monthly and annual basis. The primary emphasis of this part of the research was to statistically evaluate the observed and predicted mean annual pollutant loads.

As illustrated by the model verification results (Table 33, Fig. 73, Fig. 74, Fig. 75), the AVGWLF approach, overall, appears to provide reasonably good estimates of mean annual pollutant loads in the Dal Lake Catchment exhibiting a wide range of landscape characteristics. Also, as shown in Table 33, the majority of the calculated N-S coefficients for the pollutants were consistently above 0, which means that AVGWLF almost always provided a better estimate than just the mean monthly, seasonal or annual load in the lake catchment. Since historical water quality measurements are not available for the Dal Lake Catchment in general, and watersheds in particular, the potential benefit of using AVGWLF in such situations cannot be undervalued.

Table 33: Predicted versus observed sediment and nutrient values in Dal Lake Catchment

Month/ Yr	Sediment (mg/l)		Month/ Yr	DN (µg/l)		TP (µg/l)	
	Predicted	Observed		Predicted	Observed	Predicted	Observed
Sep-05	130.4	127	**Jan-07**	1263.4	1387.5	1994.06	1919
Oct	102.3	106	**Feb**	2463	3661.5	1391.9	1206
Nov	132	125	**March**	2693	3804.13	1998.59	1336
Dec	85.7	72	**April**	NA	NA	NA	NA
Jan-06	90	**84**	**May**	4170	6049.48	2031.95	1415
Feb	133.5	127	**June**	1165	4078.94	2710	1526
March	276.3	242	**July**	4603	3036.01	1416.6	1522
Apr	280	245	**Aug**	8727	9825.42	2592.13	1690
May	341.8	333	**Sept**	2599	3709.21	1902.69	1555
June	245.7	233	**Oct**	5561	6964.96	4098.5	3833
July	199.1	192	**Nov**	1068	2076.76	2995.12	3061
Aug	179.3	177	**Dec-07**	1772	1935.41	2363.94	2874
Natsh-Sutcliffe (R^2) Coefficient : 0.91				0.87		0.81	

NA: Not Available

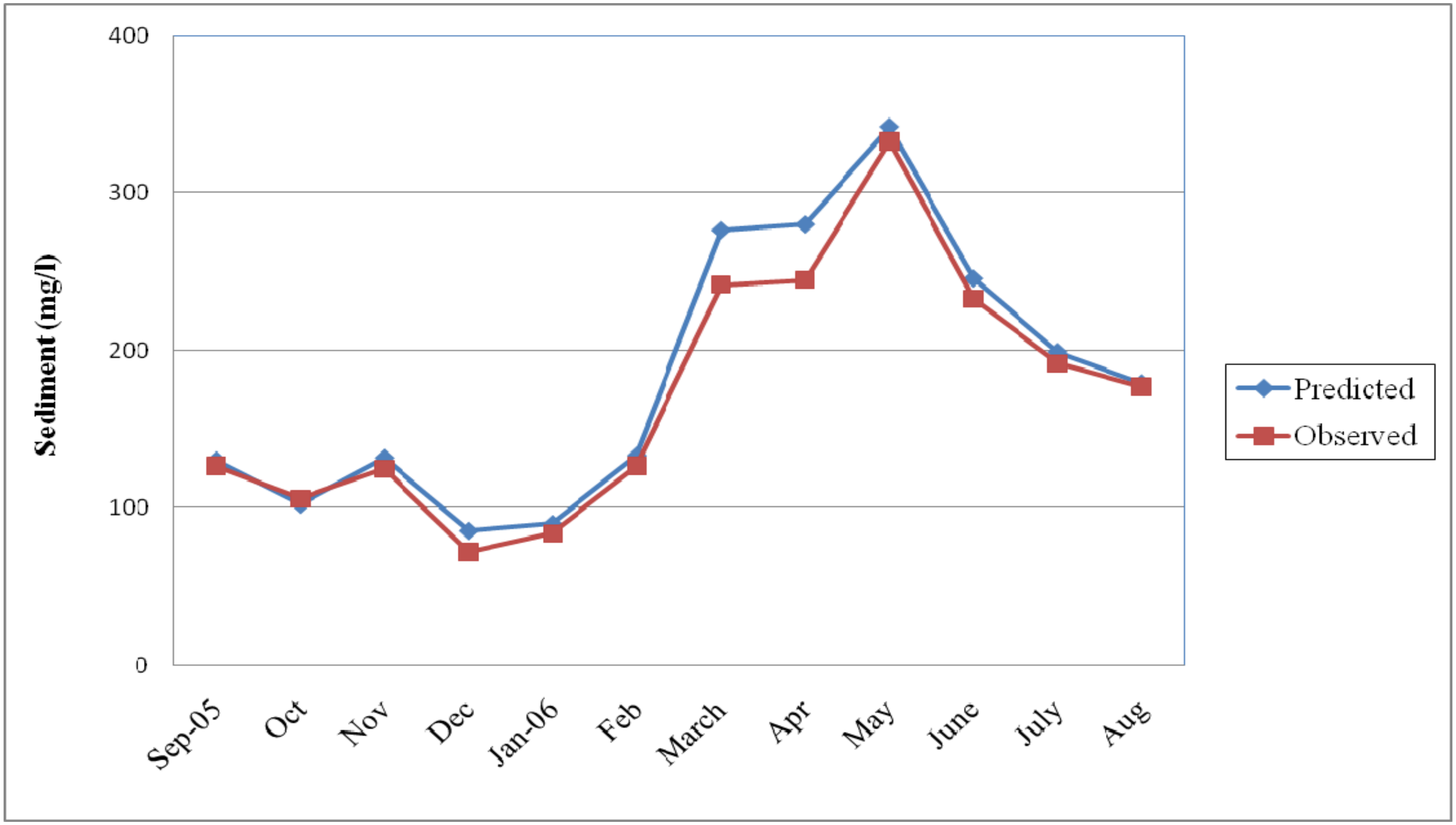


Fig. 73: Predicted vs. observed sediment concentrations in Dal Lake Catchment

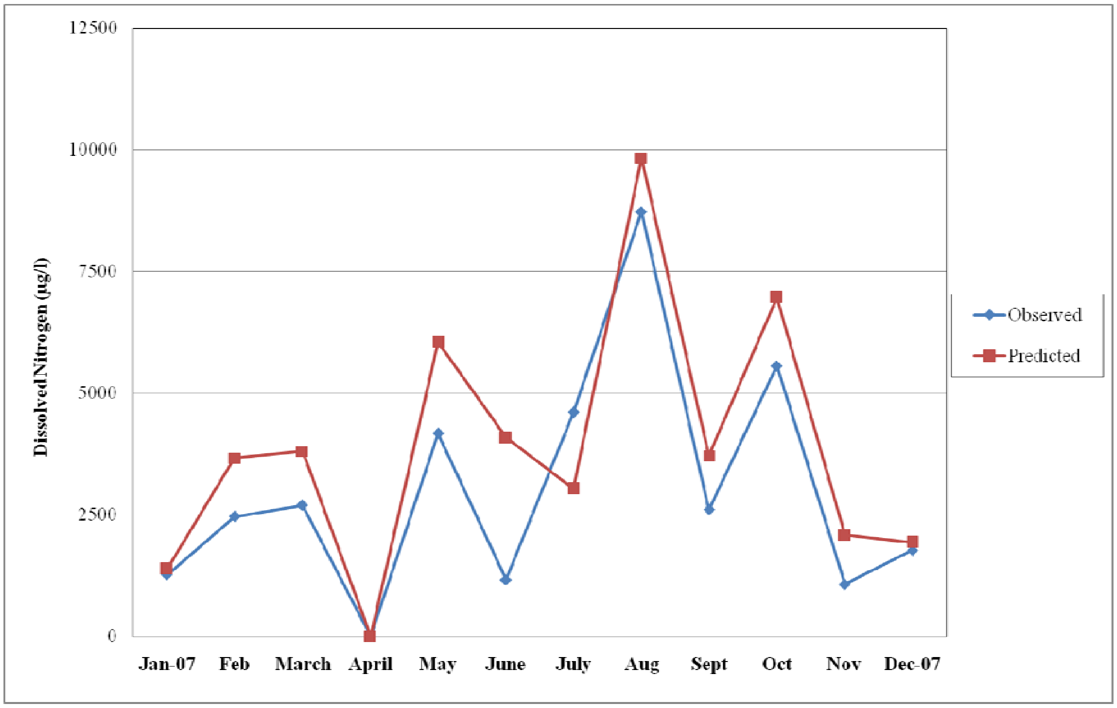


Fig. 74: Predicted vs. observed Dissolved Nitrogen concentrations in Dal Lake Catchment

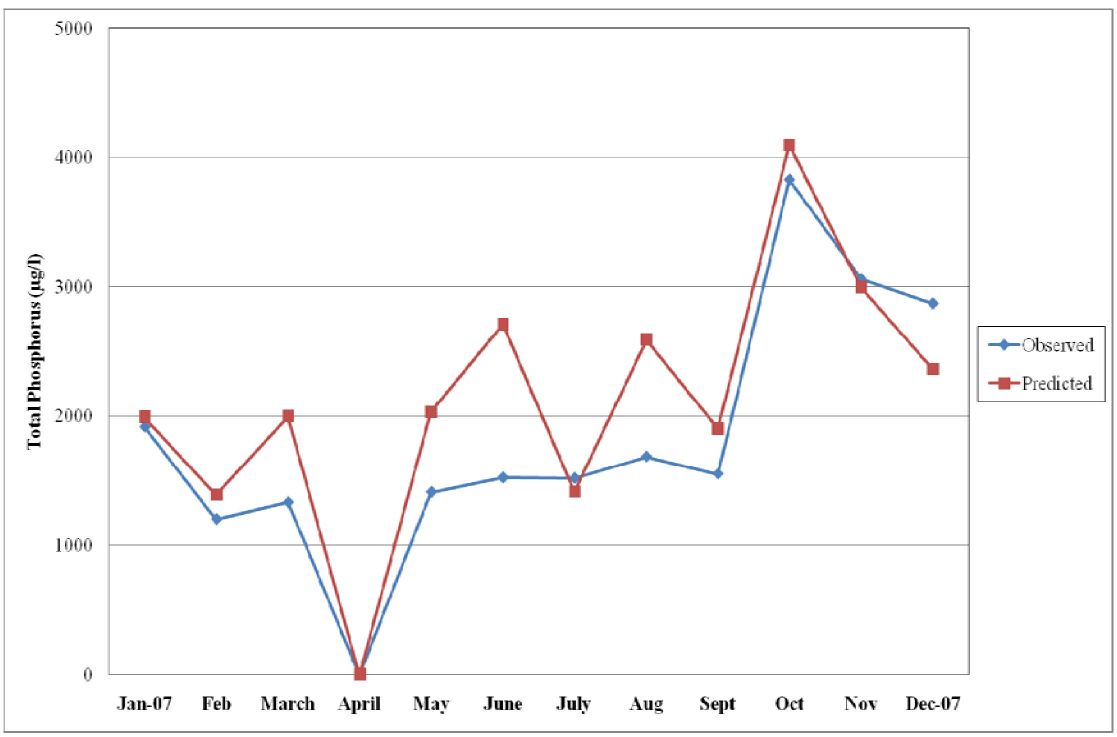


Fig. 75: Predicted vs. observed Total Phosphorus concentrations in Dal Lake Catchment

6.9 Scenario Analysis

It is evident from the observations of sediment and nutrient estimates recorded during the current study for the Dal Lake Catchment that the land use practices and the subsequent change in them over a period of time have increased erosion, sediment, organic enrichment, and noxious aquatic weeds in addition to numerous other problems of the Dal Lake. To address these issues, a variety of best management practices (BMPs) as explained in Chapter 5 were implemented using the PRedICT Model and their effectiveness in tackling increased catchment pressures on Dal Lake was assessed. The model was run on three scenarios, one the baseline scenario which did not involve any BMP, and two management scenarios MSCN1 and MSCN2, where a combination of different management practices was used.

The results of the scenario analysis are given in Table 34 and Table 35. Analysis of the results reveals that both the scenarios had a significant impact in reducing the pollutant levels in the catchment. Table 34 shows the impact of BMPS on the sediment load reductions. Analysis of the data presented in the Table 34 reveals that the sediment loads show a substantial reduction against both the management scenarios. It is observed that the MSCN1 resulted in 18.5% decrease of sediment loads whereas, MSCN2 reduced the sediment loads by 36.53%.

Table 35 presents the results for the efficiency of BMPS in reducing the nutrient loads. It is revealed from the statistics that 20% and 26.6% of nitrogen and phosphorus loads were respectively deduced from their baseline levels against the MSCN1. It is further observed from the Table 35 that MSCN2 decreased the nutrient and phosphorus loads respectively by 37% and 40%. On the whole, MSCN2 proved to be more effective as compared to MSCN1 in controlling the sediment and nutrient pollution. It is also observed that all the land use/ land cover categories show considerable reductions in both the sediment and nutrient loads from their baseline levels once the BMPS are implemented.

Table 34: Sediment load reduction in response to BMP implementation in Dal Lake catchment

SOURCE	Baseline Scenario	MSCN1	MSCN2
	Sediment (Tons/Yr)		
Hay/Pasture	26.19	21.43	16.71
Agriculture	49.68	34.92	18.56
Forest	8.64	6.54	5.1
Bare Land	121.31	95.31	78.76
Low Intensity Development	0.002	0.001	0.001
Hi Intensity Development	0.02	0.005	0.001
Stream Bank	148.80	130.84	105.93
Total Sediment	**354.65**	**289.04**	**225.07**
% Reduction		**18.5**	**36.53**

Table 35: Nutrient load reduction in response to BMP implementation in Dal Lake Catchment

SOURCE	Baseline Scenario	MSCN1	MSCN2	Baseline Scenario	MSCN1	MSCN2
	Nitrogen (Tons/Yr)			Phosphorus (Tons/Yr)		
Hay/Pasture	195.2	140.01	100.13	20.32	16.17	12.7
Agriculture	751.4	600.3	454.8	89.64	59.82	51.2
Forest	160.2	128.94	98.82	7.73	5.97	4.8
Horticulture	85.45	65.76	40.54	21.23	17.9	14.9
Turf /Golf course	4.82	3.9	2.27			
Bare Land	246	200.65	168.15	30.61	22.49	18.54
Low Int. Dev	10.32	7.45	3.27	2.04	1.5	0.7
High Int. Dev	315.7	250.9	141.9	46.23	35.05	28.27
Stream Bank	7.51	6.83	3.98	6.09	5.81	4.18
Ground water	605.2	500.9	486.8	14.45	10.04	7.71
Totals	**2382**	**1905.6**	**1500.66**	**238.34**	**174.75**	**143.0**
% Reductions		**20.0%**	**37.0%**		**26.6%**	**40.0%**

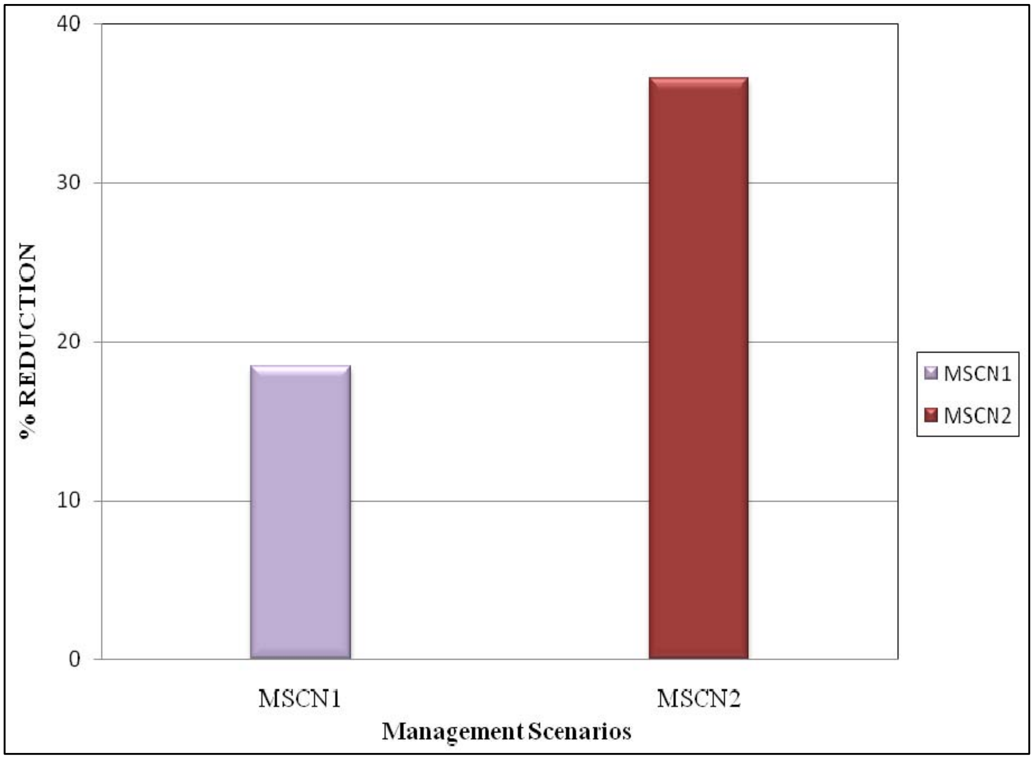


Fig. 76: Sediment load reduction in response to BMP implementation in Dal Lake Catchment

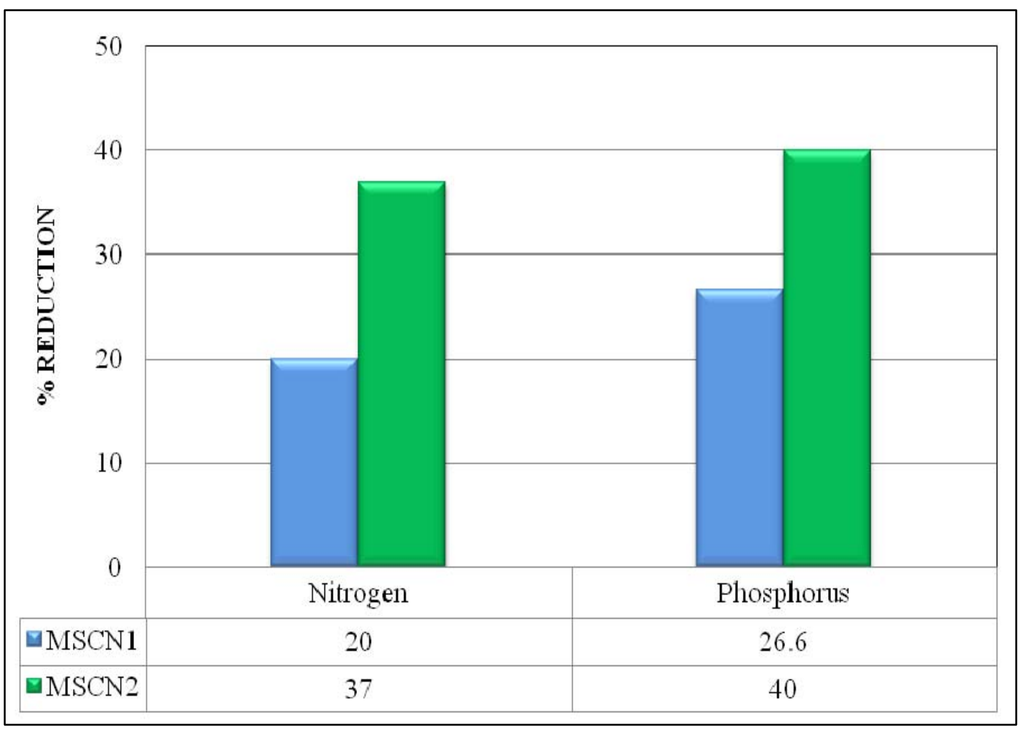


Fig. 77: Nutrient load reduction in response to BMP implementation in Dal Lake Catchment

Sewage Treatment Plant at Nishat

Settling Basin at Telbal

Terrace/ Contour Farming at Dara/ Faqir Gujri

Stream Bank Stabilization at Dara

Plate 2: Best Management Practices (BMPS) in Dal Lake Catchment

CHAPTER- 7

DISCUSSION

Lakes are extremely fragile and sensitive ecosystems, and are largely dependent on their catchments/watersheds for the energy and matter. The nature of actions in the catchments/watersheds drives the course of the reactions within these water bodies. Understanding the mechanism of the deterioration of these freshwater ecosystems requires the collective understanding of the different phenomena taking place in its watersheds. During the current study, an attempt was made to assess the integrated impact of different catchment scale processes including both the biophysical and socioeconomic ones on the pollution status of Dal Lake. The results obtained during the course of the research are discussed in this chapter under the following headings:

7.1 Land Use/Land Cover Change

7.2 Soil Characteristics

7.3 Model Simulations

7.4 Integrated Impact Analysis and Watershed Prioritization of Dal Lake Catchment

7.5 Conservation and Management Measures

7.1 Land Use/Land Cover Change

Land use/ Land cover is one of the most critical sources of information that needs to be assessed to better understand different catchment scale processes. The type and distribution of land use/ land cover substantially affects a number of hydrological processes that have a profound effect on lake ecosystems (Matheussen *et al.,* 2000; Fohrer *et al.,* 2001; Quilbe *et al.,* 2008). The present study on the land use/ land cover change analysis in the Dal Lake Catchment using satellite data for the 15 year time period (1992-2005) revealed significant changes both at the catchment and watershed scale. These changes are largely attributable to the activities of man as land use/land cover is among the most evident impacts of human activities on natural resources (Lundqvist, 1998), and can be observed using current and archived remotely sensed data (Tekle and Hedlund, 2000). This data has been observed to have potential scientific value for the study of human-environment interaction and aid in ascertaining the impact of land use on the amount of pollution (Tong and Chen, 2002; Tang *et al.,* 2005; Tong *et al.,* 2008).

During the study period, considerable changes were observed for almost all the land use/land cover classes particularly agriculture, horticulture, built up, bare lands, grasslands, scrublands and forests (Table 16). Agriculture and horticulture classes showed a decline by 1.84 Km^2 and 7.57 Km^2 respectively in the catchment area. One of the most significant changes observed from 1992-2005 was the increase of 12.08 Km^2 in the built up area. Increased population and congestion in the Old city have resulted in the conversion of large peripheral areas that were essentially used for agro-horticultural purposes into built up mostly residential areas. Accelerated nutrient enrichment of the Dal Lake due to incoming effluents from the catchment results in the proficient and luxuriant growth of macrophytes. As a result, 3.47 Km^2 increase in the area of aquatic vegetation was recorded during the span of 15 years. This causes the surface water to remain covered by the decomposed thick mats of such vegetation, disrupting the ecological balance of the lake.

Large scale decline in grassland area (7.89 Km^2) (Table 16) from 1992-2005 in Dal Lake Catchment reveals the tremendous pressures on this ecologically and socioeconomically important land cover. The main reason for this decline is the biotic interference in and around the Dachigam National Park including clearing of the grasslands at the low altitudes for cultivation, exploitation for medicinal plants etc. Several decades of grazing and that too beyond the carrying capacity has resulted in the creation of denuded and semi-denuded patches in these grasslands. This observation is similar to those made by Bhat *et al.* (2002) in relation to the human interfered temperate and alpine pasturelands of Dachigam National Park. Increase in scrubland area during the 15 year study period by 11.97 Km^2 is another significant change observed in the land use/land cover analysis. This increase in area may be attributed to the dwindling grasslands as well as the sparse forests in the catchment.

Decline in the overall forest cover of the study area was observed (Table 16) with 5.67 Km^2, 1.8 Km^2, 0.96 Km^2 loss in coniferous, deciduous and sparse forest respectively. This reduction is mostly attributed to the large scale deforestation, both within the Dachigam National Park as well as outside it particularly along the higher reaches. Increase in the area of bare lands by 4.44 Km^2 (Table 16) during study period at both the higher and lower elevations of the Dal Lake Catchment was observed. It has been found that the overgrazed grasslands have paved the way for creation of barren area (Shah and Bhat, 2004). Also deforested areas of the Dal Lake Catchment have resulted in the creation of bare lands. This land is very much vulnerable to increased erosion and sediment yields as well increased runoff.

Understanding the land use/ land cover characteristics at the watershed level is essential as such properties determine the erosion and the pollution potential of the watersheds (Vieux and Farajalla, 1994). Results of the watershed level land use/ land cover (Table 17) reveal that all the watersheds have undergone significant changes from 1992-2005. It is observed that for the vegetation cover, whether it is the coniferous, deciduous and sparse forest classes or the grasslands, significant decline in their area has taken place during the 15 years. The main reason for this is attributed to the increased anthropogenic pressures in form of clearing of forest areas for cultivation, unplanned urbanization, overgrazing of pasture/ grasslands etc. to name a few. Human influences have had a direct effect on the hydrologic cycle by altering the land in ways that change its physical, chemical, and biological characteristics (Hem, 1985; Meybeck and Helmer, 1989). Removal of forests or other vegetation can sharply reduce water retention and increase erosion, resulting in more siltation downstream. As the intensity of land use change increases, infiltration and the ability to recharge ground water decreases. As a consequence, increased runoff that results, leads to increased water pollution and physical damage to our aquatic systems (Miller and Mc Cormick, 2001). Decline in the vegetation cover and the corresponding increase in barren, scrub and other impervious surfaces in these watersheds greatly influence their response to different catchment level phenomena.

The results obtained for the accuracy assessment of the classified data (Table 18, Table 20) are encouraging and shall improve the quality of the hydrological simulations that use land use/ land cover information as an important data input (Foody, 2002). Remote sensing has emerged as a useful biophysical information gathering technique and brings about a better understanding of land use/cover dynamics and the factors that drive them (Dale *et al.*, 1993; Quattrochi and Goodchild, 1997).

7.2 Soil Characteristics

Soils play a vital role in the development and sustainability of ecosystems as a result of their ecohydrological influences on different land surface processes. As a result, almost all the hydrological models use soils as an important data input (Peschel *et al.*, 2003). From the Table 23, it can be observed that soil characteristics vary in all the land use/land cover categories. Forest soils record the highest amount of organic matter with the maximum value being recorded for the deciduous forest soils followed by hay/pasture and coniferous forest. Bare land, agriculture and horticulture recorded the minimum values. High content of organic matter in these high altititude soils could be generally attributed to the low rate of mineralization because of low temperatures, besides fall of leaf, twigs etc. Moreover, low temperatures and heavy rainfalls at the high altitudes restrict the microbial growth. Similar findings were reported by Verma *et al.* (1990) and Mushki (1994). Soils under arable land use are relatively low in organic matter due to relatively coarse fractions of soils, resultant lesser accumulation of organic matter due to the removal of finer soil particles being devoid of vegetation cover for longer periods of the year (England and Lessesne, 1962; Singh and Prakash, 1985; Castillo *et al.*, 1997).

Further analysis of Table 23 reveals that a positive correlation seems to exist between the organic matter and available nutrients. Land use classes (deciduous forests, hay/pasture and coniferous soils) having high % organic matter exhibit higher values of available nutrients. This can be attributed to to the association of nutrient ions by humus complex in soils (Kanthaliya and Bhatt, 1991).

pH (Table 23) was observed to be generally low for the forest soils i.e., deciduous forest (5.01), coniferous forest (5.57), hay/pasture (5.69). Whereas, high pH was recorded for arable soils i.e., agriculture (7.8) and horticulture (7.5) and bare land (7.1). The lower pH vaues are mostly atrributed to the decomposition of the organic matter which is more present in forest soils (Gupta and Verma, 1975; Minhas and Bora, 1982; Kale and Chevan, 1996). The negative correlation between pH and organic carbon is also attributed to the texture characteristics of besides, organic matter content, extent of slope and permeability of soils and concentration of organic acids particularly carbonic acid produced on decomposition of organic matter (Verma and De, 1969; Nitant, 1989; Verma *et al.*, 1990).

Soil texture results of Dal Lake Catchment (Table 24) reveal that 22.83% of the catchment is covered by sandy clay loam soils followed by sandy clay (19.41%), loam (18.67%), loamy sand (13.73%), silt loam (12.9%), clay (10.%16), silt clay loam (1.37%), clay loam (0.22%) and sandy loam (0.04%). Soil textural properties influence hydraulic properties of the soils and in turn can affect a number of hydrological processes at the watershed scale including the lateral and horizontal movement of sub-surface water (Entekhabi *et al.,* 1999). Soil hydrological groups as determined from the soil texture classes determine the runoff potential of different soils which play an important role in the sediment and nutrient fluxes across watersheds. Therefore, watersheds with large areas under C and D hydrological groups i.e. having clay loam, silty clay loam, sandy clay, silt clay, clay, and sandy clay loam textures shall contribute predominantly to run-off without much infiltration capacity. Similarly, the water holding capacity of the soils is greatly affected by texture of the soils that in turn influences the infiltration and evaporation process hence affecting the surface runoff of watersheds (Tansey and Milington, 2001).

7.3 Model Simulations

A comprehensive, GIS-based modelling approach used in the form of GWLF Model was able to provide accurate predictions of nutrient, erosion and sediment loads in watersheds throughout the Dal Lake Catchment. Results were obtained against the changing Land use/Land cover conditions to assess the impact on nutrient and sediment transport processes across the 13 watersheds of the study area. Increased sediment and nutrient loading is understood to be a primary factor in reduced water quality in tributaries, thus reducing water clarity in lakes (Boughton *et al.*, 1997).

7.3.1 Erosion and Sediment Loadings

Although soil erosion is as old as the earth itself (Yazidhi, 2003), but the interference by man in form of intensification of population, overgrazing, agricultural activities on steep slopes in combination with heavy and sporadic rainfall has accelerated the process and made huge areas extremely sensitive to erosion (Petter, 1992). Soil erosion and the consequent sedimentation is one of the main factors responsible for the reduction of size and depth of Dal Lake. The results of model simulations for the erosion and sediment loading rates (Table 25) show a significant increase against the changing land use/land cover conditions. It was observed that each one of these watersheds behaved differently depending upon the topography, Land use/Land cover, soil type etc. (Table 12, Table 17, Table 23) as these are the principal factors influencing contaminant transport in a watershed (Barnes, 1997). The increase although small in certain watersheds is by and large reflective of the changing biophysical charcteristics of these watersheds attributable mostly to the increased anthropogenic pressures. The increased loading rates are in particular observed for those watersheds where the stress on the vegetation is the maximum (Table 17). Watersheds namely DW5 followed by DW13, DW11, DW6, DW8 are the largest contributors to erosion and sediment loads (Table 25) because changes in their land use/ land cover characteristics have significantly affected the ecological landscape functions and processes. It is also observed that various agro-horticultural activities are largely carried out particularly in DW5, DW6, DW8 that accelerate the potential for the processes of surface runoff and soil erosion (Stoate *et al.*, 2001; Van Rompaey *et al.*, 2001; Yazidhi, 2003; Hansen *et al.*, 2004). The land use/ land cover results (Table 17) for these watersheds suggest that the stress on vegetation manifested due to biotic interferences such as overgrazing of grasslands beyond the carrying capacity, clearing of forest areas for contruction and agricultural purposes has lead to the creation of denuded patches that result in erosion (Bhat *et al.*, 2002). Moreover, increase in the barren and scrubland area (Table 17) during the said period shall contribute largely to runoff without much infiltration capacity. Such watersheds also have a fairly good area under steep and very steep slope classes (Table 13) that is an indication of generating quick runoff during rainfall or storm water events (Tucker and Bras, 1998). Stone quarring in DW8, although banned now, has resulted in largely degraded and defaced mountains that has placed a serious threat of soil erosion and landslides.The subsequent sediment loss, that is carried through the streams downslope pollutes the waters of Dal lake (Shah and Bhat, 2004).

Watersheds namely DW12, DW7, DW3, DW2, DW4, DW1 (Table 25) are other contributors, though, not much increase in the erosion and sediment yields is observed. In DW12, DW7 no major changes in the Land use/Land cover have taken place because of negligible anthropogenic pressures /activities. DW3, DW2, DW4 and DW1 because of their urbanised environment and impervious nature (Table 17) and flat slopes (Table 13) provide minimum probabilities of erosion and sediment loss, even though subject to high runoff. DW9 and DW10 are the least contributors owing to their highly forested nature and thick vegetative cover in form of grasslands that makes them less susceptible to erosion and sediment loss. Besides, their alpine nature makes them inaccesssible to the anthropogenic pressures which prevents the loss of vegetative and canopy cover. Vegetation changes are often the result of anthropogenic pressures (Rishi, 1982; Guerra *et al.,* 1998; Janetos and Justice, 2000).

Bare lands, hay/pastures and agriculture are the major source area contributors for erosion and sediment loads (Table 26). Observations during the present study suggest that it is primarily the sparsely vegetated or under pressure land use/land cover classes (bare land, agriculture, scrub/pastureland) that are more erodible than the vegetated areas (Singh and Prakash, 1985). The results are in conformity with Sharma and Qahir (1989) who suggest that the low organic matter content might not have infuenced the structural stability of barren soils. Soil erosion from cultivated areas is typically higher than that from uncultivated areas and pose a great threat to the aquatic environment by acting as a pathway for transporting nutrients, especially phosphorus attached to sediment particles (Brown, 1984; Ouyang and Bartholic,1997, 2001). Higher rates of soil and sediment loss are reported from agricultural fields (Dunne *et al.,* 1978; Kilwe, 1985, 1987; Omwega, 1989; Obando, 1990). Increased scrublands primarily due to the degradation of grasslands has resulted in increased loads of sediment and erosion from the said class. Forests, horticulture and developed areas are the least contributors because of their vegetative and impervious nature respectively In general, as the protective canopy of land cover increases, the erosion hazard decreases (Mkhonta, 2000), hence, forests contribute less as compared to the other classes and the loads, if any, are mainly from the degraded forests. The sediment/silt generated from various land use/ land cover classes in the catchment finally flows into the lake largely through the Telbal Nallah. It is apparent that with sedimentation / silt accumulation, the lake ages, maximum depth lessens and volume of deep water diminishes more strikingly (Kurta and Kira, 1990; Deevery, 1995). This is also corroborated by the studies of Zutshi and Yousuf (2000) that suggest that due to siltation carried by this Nallah, the reduction of water depth has reduced water volume and impacted thermal stability of the Dal Lake. Owing to the inadequate land use management in the catchment, Dal Lake receives large amounts of eroded soil that has disrupted the ecological balance of the lake.

7.3.2 Nutrient Loadings

Lakes and other water bodies depend mainly on their watersheds for nutrients and other substances to sustain biological activities. While these nutrients and substances are required for a healthy aquatic environment, an excess of these inputs leads to nutrient enrichment and eutrophication of the lake (Ritchie and Cooper, 1991). Dal Lake ecosystem has undergone severe nutrient enrichment particularly since the last few decades as a reaction to the human activities being carried out in the different watersheds of its catchment and manifest in the form of land use and land cover changes. Because of the fact that strong correlation exists between pollution loading and land use (Perry and Vanderklein, 1996), the nutrients (nitrogen and phosphorus) were assessed under changing land use/ land cover conditions. Besides, the land cover disturbances and its spatial pattern alter the vegetative communities and increase nutrient loading (Binford and Buchenau, 1993).

Major loadings for both dissolved and total forms of nitrogen and phosphorus (Table 27) under the 1992 and 2005 land use/land cover conditions are contributed by the DW5 followed by DW2, DW1, DW8, DW3, DW6 and DW4 with an increasing trend observed in all the watersheds from 1992 to 2005. The key reason for the increased nutrient loads from these watersheds is that all of these are urban /rural watersheds and are subject to maximum anthropogenic pressures. Increase in the area of bare lands, built up, degradation of pasturelands in these watersheds from 1992-

2005 (Table 17) and practising of various intensive agro-horticultural activities also contributes to the higher nutrient loadings. Thus, water quality of the Dal lake has greatly been affected as a result of the alteration of the landscape, intensive agro-horticultural practices and increase of anthropogenic activities in these watersheds resulting in excessive nitrogen and phosphorus enrichment which can directly or indirectly be attributable to the activities of man (Hammer, 1971). It has also been that these watersheds are also subject to higher erosion and sediment yields (Table 25). Steep slopes and erodible soils are also biogechemically linked to ecosystem dysfunction; disturbances on steep slopes and erodible soils have been reported to increase nitrate, total and soluble phosphorous, and suspended sediment (Byron and Goldman, 1989).

Agriculture, ground water, built up areas and bare lands are the major sources of the nitrogen and phosphorus loadings (Table 28) (Johnson and Juengst, 1997; Smith *et al.,* 1999; Solim and Wanganeo, 2008). From a land use perspective, agricultural activities have been identified as major sources of nitrogen and phosphorus pollutants (Viessman and Hammer, 1993) and are known to impact water quality. Phosphorous and nitrogen have been identified as the major culprits in accelerating the eutrophication process (Edwards and Goodman, 1972; Frecker and Davis, 1975). Agricultural areas are also subject to high runoff, increased erosion and increased sediment yields and the transport of nitrate and phosphate fertiliser laden sediments by the waters bring in the nutrients into the lake (Sarkkula, *et al.,* 2003, 2004; WUP-FIN, 2003). The erosion and transport of soils from agricultural lands during intense rainstorms can rapidly mobilize the phosphorus (Sharpley, 1993; Sharpley *et al.,* 1998), which affects the freshwater trophic status (Ryding and Rast, 1989; Correll, 1999; Smith *et al.,* 1999).

Residential/urban/built-up areas are another dominant factor in generating large amounts of nitrogen and phosphorus pollution from storm-water discharge and have a greater capacity to carry non-point source (NPS) pollutants into the water bodies (Civco and Hurd, 1997; Sleavin *et al.,* 2000; Prisloe *et al.,* 2001). The sources of nitrogen and phosphorous particularly nitrites to the waters are the domestic sewage, agricultural drainage and overall activities of man (Hutchinson, 1957;

Hammer, 1971). Urban development within the watersheds has long been identified as an important source of nitrogen and phosphorus loadings, thus affecting the trophic status of a lake (Vollenweider, 1968; Dillon and Kirchner, 1975; Canfield, 1983). As a result of the increased urbanised areas in the above watersheds of the Dal Lake, the imperviousness of the ground cover has increased to a significant extent and has implications for a number of watershed impacts. Implications in the form of stream bank erosion carries more sediments into the streams from surrounding lands, elevated nutrient loadings thus disrupting and degrading ecological balance of the lake (Klein, 1979; Schueler, 1994; Jennings and Jarnagin, 2000; Dougherty *et al.*, 2004). Arnold and Gibbons (1996) also reported that increase in imperviousness of the ground cover due to expansion of road networks, parking lots and dwellings, and increase in the human activities in the immediate vicinity of lake contribute to enhanced nutrient loading. Discussing the pollution aspects of the upper lakes of Bhopal, Prasad and Qyum (1976) reported increase in various forms of nitrogen as signs of pollution in the lake which receives waste garbage from densely populated areas. The least loadings are recorded form forests, golf courses and low intensity developed areas. From a high altitude forest lake Nilnag (Kashmir), Kaul *et al.*(1981) reported low values of phosphorous and nitrogen in the absence of any major sewage contamination.

The rest of watersheds DW7, DW9, DW10, DW11, DW12 and DW13 are found to contribute in comparatively smaller quantities even though the nutrient loadings are showing an increasing trend from 1992 to 2005. The main reason for this could be that these watersheds are located at higher elevations and anthropogenic pressures are not that much compared to the low altitude watersheds of the lake where the population density is higher. Besides, these are largely covered by thick, dense forests and lush grasslands that prevent the nutrient runoff. The small increase in nutrient loading is attributed to the changing land use/ land cover in these watersheds although occurring on a smaller scale (Forney *et al.,* 2001; Merrill, 2001).

7.4 Integrated Impact Analysis and Watershed Prioritization of Dal Lake Catchment

The present research is a comprehensive analysis of environmental and socioeconomic processes at the watershed level and their integrated impact on the current status of Dal Lake. This in-depth investigation was carried out in all the 13 watersheds of the Dal Lake Catchment and included the land use/ land cover change detection analysis, topographical analysis, hydrometeorlogical data analysis, soil analysis, quantification of erosion, sediment and nutrient loadings and socioeconomic analysis. All such factors have a profound effect on lakes and their assessment helps in understanding the complex lake ecosystem interactions, besides identifying the critically impaired watersheds and prioritizing them accordingly. Geospatial techniques help us to integrate data and model the phenomena across the disciplines (Grayson *et al.,* 1993).

The results of the prioritization analysis (Table 32) reveal that of the 13 watersheds, 5 watersheds namely DW5>DW2>DW6>DW8>DW1 rank highest and are considered under high priority based on the cumulative weightage of different biophysical (land use/land cover, erosion, sediment, nutrient loads) and socioeconomic variables (total population and total households) carried out in the GIS environment. These high priority watersheds experience maximum anthropogenic pressures. Hydro-geological and biophysical environments in such watersheds are directly affected by changes in land use and socioeconomic processes, which are largely controlled by human activities (Moldan *et al.,* 1997; Peters and Maybeck, 2000). Alteration of the landscape and other human caused disturbances have been shown to be important factors affecting mass transport (loading) of principal nutrients (nitrogen and phosphorus) and sediment to the lakes (Loeb, 1988). The interactions among social agents and the environment are ultimately responsible for the evolution of nutrient loads (i.e., nitrogen and phosphorus) (Cole *et al.,* 1993; Vitousek *et al.,* 1997; Bennet *et al.,* 2001). Thus, socioeconomic GIS has emerged as a new and promising field that provides insights into the socioeconomic aspects of environmental and physical problems and could be used as a useful aid for linking the environmental problems to communities (Buckle *et al.,* 2006). These watersheds can be taken up to develop a robust strategy for mitigation and control of the lake deterioration on a sustainable basis with immediate effect to prevent the further degradation of the Dal Lake.

Out of the remaining 8 watersheds, 5 watersheds viz. DW13>DW3> DW4> DW11>DW7 fall under the medium priority category, whereas, 3 watersheds DW12>DW9>DW10, belong to low priority category (Table 32). The low prioritized watersheds may be taken up for development and management plans in a phased manner (Vittala *et al.,* 2008). Since this approach is considered to be the most ideal as it helps in maintaining the ecological balance (Sahai, 1988), it shall, greatly help in devising the conservation and management strategies for the restoration of the lake ecosystem (Prasad *et al.,* 1997; Biswas *et al.,* 1999; Khan *et al.,* 2001; Gosain and Rao, 2004).

Scenario analysis results (Table 34, Table 35) have revealed very encouraging and significant reductions in the sediment and nutrients loads to the Dal Lake from the catchment once the BMPS are implemented. Similar works carried out by scientists and water resource managers world over also suggest the efficacy of the BMPS in checking the pollutant loads entering the water bodies from different sources. The restoration and improvement in water quality from best management practices and cost-effective removal performances have been widely reported (Ellis, 1996; Pennsylvania Conservation Partnership, 2000; Hayes *et al.,* 2006; Chaubey *et al.,* 2008; Boomer and Weller, 2009).

7.5 Conservation and Management Measures

Dal Lake Ecosystem’s significance as an ecologically and socioeconomically integral component of the state of Jammu and Kashmir necessitates its sustainable management through appropriate conservation mechanisms. The conservation and management of this lake is a state-wide priority and failure to restore this ecosystem will result in irreparable environmental, social, cultural and economic damage.

The results of the current study have established that the Dal Lake represents a case of threatened ecosystem in dire need of management with Land use/Land cover changes, erosion, sedimentation, enhanced nutrient enrichment and rising human population in its Catchment as the major pressures/threats to its existence. The management strategy for the Dal Lake does not stop at the lakeshore, but extends into the basin, and beyond, because all the lake issues reported during this research originated from their upstream or downstream basins. For addressing these issues, implementation of a watershed approach is just beginning to emerge on lakes around the world and can be achieved only by the integrated management of the whole catchment area and the lake ecosystem. Such an approach is essential for environmentally and socio-economically sustainable development of Dal Lake from a long term perspective. The present research of the Dal Lake Catchment specifies that the following conservation and management strategies shall go a long way in restoring the lake for long-term sustenance:

The preliminary results for the best management practices (BMPS) implementation in the Dal Lake Catchment have proved to be very encouraging. The restoration programmes with an ecosystem approach through BMPS shall help in correcting the point and non-point sources of pollution and can prove to be a vital factor in designing any conservation and management plan. The BMPS can be implemented to start with the impaired watersheds utilizing both the natural landscape as well as artificial structural options. The best management practices particularly related to the urban and the agriculture areas can be very valuable in controlling/checking the inflow of nutrients and sediments into the lake.

Agricultural BMPS such as cover crops, strip/contour farming, terrace farming and grazing land management should be promoted in the catchment keeping in view their efficacy in controlling the erosion and sediment loadings. It is also suggested to use various soil binding plant species like Acacia (*Robinia pseudoacacia*), Willow (*Salix sp.*), and Popular (*Populus sp.*) to help control erosion and soil loss.

BMPS in form of agriculture to forest and wetland conversion provide a good prospectus for improving the water quality of the lake. Agricultural practices in the vicinity of the lake such as cultivation of paddy should be shifted to medicinal plants and other crops which emanate fewer pollutants and at the same time are commercially viable. Open spaces between the agricultural land and the lake should be utilized as buffers to reduce the impact of the runoff carrying both the sediment and nutrients.

Structural BMPs such as the vegetated buffer strips also called as conservation buffers, buffer zones, or filter strips should be utilized for the purpose of trapping pollutants contained in surface runoff from cropland or confined animal facilities. These buffers can take many forms including permanently vegetated strips located between larger crop strips on sloping land, bands or strips of permanent vegetation established at the edge of agricultural fields and areas of trees, shrubs, and/or grasses adjacent to streams, lakes, ponds or wetlands.

Urban BMPS such as the detention basins and constructed wetlands can prove to be very effective in controlling the pollutant loads particularly along the Foreshore Banks of the Dal Lake where the natural vegetation can be fully optimized for the said purpose. Detention basins should be designed for the temporary capture and storage of surface runoff during high rainfall events. These structures are sized based on the amount of water expected to be generated during specific rainfall events. More structures like the Telbal Settling basin shall be very useful in checking the amount of sediments and nutrients before the water is released downstream.

Constructed wetlands (or constructed treatment wetlands) can prove to be valuable in achieving specific water quality objectives before the water is released, and can be an efficient method for removing a wide variety of pollutants including suspended solids, nutrients, heavy metals, toxic organic pollutants, and petroleum compounds. These structures are essentially artificial shallow water-filled basins that have been planted with emergent plant vegetation. Natural landscape conditions all along the Foreshore Road of the Dal Lake provide very encouraging environment to be utilised for such purposes. Constructed wetlands can also be effective means of reducing peak runoff rates and stabilizing flow to adjacent streams and waterways that is ultimately carried into the lake. The water that is detained in such basins being rich in nutrients can be diverted and utilised for the irrigation purposes.

Plantation along the lake littoral areas should be encouraged. Preserving and utilizing such natural or created wetlands shall aid in increased infiltration and storing excess storm water runoff. Slowing down the expressway of polluted runoff by utilizing grasses, filter strips or vegetated buffers should be endorsed in place of curbing and piped drainage whenever possible. Regular maintenance such as sweeping streets, cleaning storm drains, and removing sediment from detention/retention ponds should be ensured from time to time.

Land use and water quality are inseparable. Regulation of a proper land use plan in the Dal Lake Catchment is vital for preventing the further nutrient enrichment and sedimentation of the lake waters. The land cover disturbance and its spatial pattern alter the vegetative communities and increase nutrient loading and sedimentation. The results from the current study have revealed that the land use combination of agriculture, horticulture and residential/urban/built-up area in close proximity to the lake system is linked to the concentration of nutrients like nitrogen and phosphorus. Such lands were found to be associated with higher nutrient levels as compared to forests and pastures. Although agricultural and horticulture area has decreased from 1992 to 2005, intensive application of fertilisers and pesticides still persist in the Catchment. Controlled use of fertilizers and domestic animal waste (mostly cow dung) in the agricultural fields nearby the lake should be made mandatory. The results also indicate that with the integration of GIS and modelling, a LU/LC management decision support system can be developed to manage NPS pollution (in this case nitrogen and phosphorus) at the catchment and watershed scales.

Impervious surface covers near the lake peripheral areas should be minimized. Increase in the residential/urban/built-up areas in Dal Lake Catchment from 1992-2005 has strongly impacted the water quality of the Dal Lake. As areas become more developed, the amount of impervious cover increases that subsequently increases their storm-water discharge, and even small rains are capable of washing accumulated pollutants into surface waters. Hydrologically, this means reduced volumes of water to recharge base flows and increased runoff from rains, increasing peak flows. Understanding the degree and location of impervious surfaces and limiting the amount of impervious surfaces in the Dal Catchment can be used as a measurable and scientifically defensible technique to protect the water quantity and quality of Dal Lake.

An effective and well defined urbanization plan needs to be laid out to minimize the pressures of increased anthropogenic interference in the Dal Lake ecosystem. The demarcation of buffer zones all along the periphery of the lake can be helpful in decreasing the nutrient loads coming via storm water runoff particularly during high rainfall events.

The socioeconomic pressures at the watershed level could be better identified and assessed with availability of the latest Census data. The current study made use of the 2001 Census data.

The installation of more waste water treatment plants in the Dal Lake Catchment catering particularly to the severely congested and densely populated areas shall significantly aid in the reduction of the pollutants reaching the lake waters. The efficiency of the current waste water treatment plants functioning in the catchment for reducing the nutrient loads can be to a great extent improved upon by the incorporation of the tertiary stages of waste water treatment.

Watershed prioritization is one of the most important aspects of planning for implementation of its development and management programmes. An integrated strategic approach covering the bio-physical and socio-economic aspects of these watersheds needs to be taken into account. The watershed prioritization that was carried out in this study may be taken up in a phased manner with the initial thrust being upon the critically impaired watersheds. These watersheds may be taken up with detailed survey for soil and water conservation measures, water resources development, scientific land-use planning for preservation of eco-diversity, integrated study for development of natural as well as social resources, moisture conservation, sustainable farming system, etc. to accelerate the rehabilitation of the micro-environment and to generate a detailed database in each natural resources theme, which is a pre-requisite for formulation of watershed plan for its sustainable development and management.

Broad-based, regional-scale monitoring is critical for making informed lake management decisions. Water quality monitoring should be done with greater frequency and results should be made public. Although being carried out by the LAWDA some time back, it was stopped due to unknown reasons. Data from monitoring programs can be used frequently to estimate expected ranges in water quality for Dal Lake, examine differences, and investigate the relationships between landscape conditions and water quality. Satellite technology can provide spatially unbiased information on different characteristics of Dal Lake and its catchment and has considerable potential to serve as a cost-effective complement to ground-based monitoring programs. Another important use of this type of lake data would be to examine the relationships between lake and watershed characteristics and water quality.

Temporal environmental and other related changes taking place in the lake environs should be monitored with the help of high resolution satellite data in conjunction with ground based information. Geospatial data should be used as a basic input parameter for environmental mapping and monitoring of the lake and its environs.

There is a need for better and long term data measurements for the validation of the GWLF model simulations. The lack of long term nutrient and sediment discharge data records hampers the effectiveness of the validation process. It is, therefore, of paramount importance to regularly monitor and record such data on a much broader scale. In order to have a better assessment of the erosion, sediment and nutrient fluxes across the watersheds of Dal Lake Catchment, better and high resolution soil data can prove to be quite effective. The methodology for the soil mapping can be further improved upon to facilitate the hydrological simulations for effective management of Dal Lake Ecosystem.

CHAPTER-8

SUMMARY AND CONCLUSION

This chapter provides a summarized account of the approach used in the research programme and the key findings and conclusions derived by analyzing the results carried out at the various spatial scales as described in details in the previous chapters. The research programme entitled "Integrated impact analysis of environmental and socioeconomic factors on pollution status of Dal Lake using Geospatial tools" proved to be very useful in understanding the nature and magnitude of the impact of different catchment scale processes on the Dal Lake ecosystem. The basis for integrating the environmental and the socioeconomic variables at the watershed level arose as a result of the lack of such an understanding for the Dal Lake degradation. World over, the use of remote sensing and GIS has been thoroughly exploited for understanding different phenomena related to both biotic and abiotic aspects of air, water and soil ecosystems. Geospatial techniques help us to integrate data and model the phenomena across the disciplines. Remotely sensed data coupled together with GIS simulation modeling has been observed to have a potential scientific value for the study of human-environment interactions, and has, therefore, been identified as a useful tool to aid such processes in case of lake ecosystems. This study is a step forward in this direction as it provides a holistic view of the different processes responsible for the current status of the Dal Lake.

During the present research, remote sensing and GIS techniques were used to conduct an in-depth investigation of different catchment/watershed scale processes in all the 13 watersheds of the Dal Lake Catchment and quantify their impacts on Dal Lake. These included the Land use/Land cover change detection analysis, topographical analysis, hydrometerlogical data analysis, soil analysis, quantification of erosion, sediment and nutrient loadings and socioeconomic analysis. All such factors have a profound effect on lakes and their assessment helps in understanding the complex lake ecosystem interactions, besides identifying the critically impaired watersheds and prioritizing them accordingly. This contemporary approach was fully aided by the extensive field surveys carried out for ground truthing of the remote sensing data as well as for the sampling purposes. In this research, we made use of an integrated approach based on the use of multi-sensor and multi-temporal satellite data, GIS simulation models (GWLF, PredICT) together with extensive field observations for different watersheds of the Dal Lake catchment. While remote sensing data was used to generate up to date information about different parameters, simulation models and geospatial techniques were used to simulate the hydrological, sediment, erosion, pollution processes as well as management scenarios.

The research findings are summarized as under:

- The Land use/Land cover change detection from 1992-2005 revealed significant changes in the Catchment of Dal Lake in general and watersheds in particular. It was observed that during the study period, Built up showed a change of +12.08 Km^2, Agriculture (-1.84 Km^2), Fallow (-0.076 Km^2), Horticulture (-7.57 Km^2), Coniferous forest (-5.67 Km^2), Deciduous forest (-1.8 Km^2), Sparse forest (-0.96 Km^2), Grasslands (-7.89 Km^2), Scrublands (+11.97 Km^2), Plantation (-12.9 Km^2), Aquatic vegetation (+3.47 Km^2), Bare land (+4.44 Km^2), Bare exposed rocks (+1.61 Km^2), Water bodies (-0.91 Km^2), Water channel area (+0.06 Km^2), Snow (+5.45 Km^2) and Golf course/Turf (+0.51 Km^2) in the catchment. Accuracy assessment results revealed 89.67 % accuracy for 1992 classified data with a Kappa coefficient of 0.8541 and 93.67 % accuracy for 2005 land use/ land cover data with a Kappa coefficient of 0.913.
- Soils in the study area mainly fall into nine textural classes viz. sandy clay loam covering 76.93 Km^2, sandy clay (65.41 Km^2), loam (62.91 Km^2), loamy sand (46.27 Km^2), silt loam (43.47 Km^2), clay (35.72 Km^2), silt clay loam (5.39 Km^2), clay loam (0.74 Km^2) and sandy loam (0.13 Km^2).
- Maximum increase in the erosion yield was recorded for DW5 with 236.93 tons/yr followed by DW6 (76.49 tons/yr), DW8 (56.16 tons/yr) and DW11 (54.55 tons/yr). DW9 (12.82 tons/yr), DW10 (10.04 tons/yr) and DW13 (7.96 tons/yr) recorded the least increase. Similarly, the highest increase in sediment loadings was recorded for DW5 (36.7 tons/yr) followed by DW8 (15.2 tons/yr), DW3 (12.3 tons/yr) and DW6 (10.42 tons/yr) and DW2 (7.57 tons/yr). DW4 (4.06 tons/yr), DW12 (2.82 tons/yr) and DW10 (0.94 tons/yr) showed less increase in the sediment loadings. The land use/land cover or the source area contribution towards the erosion and sediment yields was highest for stream

banks followed by bare lands, agriculture, hay/pasture and forests, whereas, the least loads were recorded for horticulture, turf/golf course, high intensity and low intensity developed areas.

- Overall nutrient (dissolved and total forms of nitrogen and phosphorus) loadings under 1992 and 2005 land use/land cover come from the watershed DW5 followed by DW2, DW1, DW8 and DW3 with an upward trend from their 1992 values. DW5 recorded an increase of 89.38 tons/yr in DN, 59.81 tons/yr in TN, 4.42 tons/yr in DP and 10.77 tons/yr in TP. This was followed by DW2 where an increase of 24.21 tons/yr in DN, 59.49 tons/yr in TN, 4.27 tons/yr in DP and 11.66 tons/yr in TP was observed. DW1 showed an increase of 13.74 tons/yr in DN, 60.64 tons/yr in TN, 0.68 tons/yr in DP and 9.28 tons/yr in TP. DW8 recorded an increase of 6.93 tons/yr in DN, 16.23 tons/yr in TN, 0.12 tons/yr in DP and 6.13 tons/yr in TP. It was observed for DW3, DN recorded an increase of 13.84 tons/yr, TN increased by 34.09 tons/yr, DP by 0.94 tons/yr and TP increased by 9.79 tons/yr. The watersheds DW9 and DW10 were found to contribute least even though the nutrient loadings are showing an increasing trend. DW9 recorded an increase of 1.13 tons/yr in DN, 4.84 tons/yr in TN, 0.4 tons/yr in DP and 2.41 tons/yr in TP. For DW10 an increase of 1.18 tons/yr in DN, 1.9 tons/yr in TN, 0.37 tons/yr in DP and 2.12 tons/yr in TP was recorded. Agriculture, ground water, high intensity urbanised areas, and bare lands are the major sources of the nitrogen and phosphorus loadings. The least loadings were recorded form forests, golf course and low intensity developed areas.
- The socioeconomic analysis of the watersheds in the Dal Lake Catchment showed that only 7 out of the 13 watersheds are inhabited. Among the populated watersheds, DW2 has the highest population (65,228 individuals) and the highest number of households (9,562). This is followed by DW1 (28,463 individuals and 3,921 households), DW4 (17,473 individuals and 2,578 households), DW6 (14,980 individuals and 2,169 households), DW5 (14,672 individuals and 3,921 households), DW3 (10,519 individuals and 1,555 households). DW8 (1,731 individuals and 243 households) has the lowest population and lowest number of households. The rest of the watersheds i.e.

DW7, DW9, DW10, DW11, DW12 and DW13 did not record any human habitation.

- Integrated impact analysis of the environmental and socioeconomic factors was carried out in the GIS environment for all the watersheds. The prioritization analysis results revealed that DW5>DW2>DW6>DW8>DW1 rank highest in the overall weightage and are considered under high priority. They can be taken up to develop a robust strategy for mitigation and control of the lake deterioration on a sustainable basis with immediate effect to prevent the further degradation of the Dal Lake. Out of the remaining 8, 5 watersheds (DW13>DW3>DW4>DW11>DW7) fall under the medium priority category, whereas, 3 watersheds (DW12>DW9>DW10), fall under low priority category. These prioritized watersheds may be taken up for development and management plans in a phased manner.
- Scenario analysis was the most significant aspect achieved through the incorporation of Best Management Practices (BMPS). This was carried out in the form of three scenarios (namely baseline, MSCN1 and MSCN2) using the PredICT Model that incorporated different BMPS related to agriculture, urban and streams. Although, still preliminary, the results proved to be quite encouraging with significant reductions being observed in the sediment and nutrient loads in the Dal Lake catchment. Management scenario MSCN2 was the most effective, bringing in 36.53% decrease in sediment and 37% and 40% reduction in nitrogen and phosphorus estimates respectively.
- The integration of the biophysical and the socioeconomic environment taken up at the watershed level during the current study for determining its overall impact on the current status of the Dal Lake ecosystem shall aid in developing and designing the conservation and management plans vis-à-vis water quality restoration programmes. The watershed prioritization, in particular, shall facilitate the development of a robust strategy in the critically impaired watersheds for the control of pollution and conservation and management plans with immediate effect. The research methodology established during the present study should help in the effective conservation and management of other threatened lacustrine ecosystems of Kashmir Himalaya.

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Appendix 1
Error Matrix

		Reference Data				
Classification Data		**Class 1**	**Class 2**	**Class 3**	**Class N**	**Row Total**
	Class 1	A_{11}	A_{12}	A_{31}	A_{N1}	$\sum_{K=1}^{N} Ak1$
	Class 2	A_{21}	A_{22}	A_{32}	A_{N2}	$\sum_{K=1}^{N} Ak2$
	Class 3	A_{31}	A_{32}	A_{33}	A_{N3}	$\sum_{K=1}^{N} Ak3$
	Class N	A_{41}	A_{24}	A_{35}	A_{N5}	$\sum_{K=1}^{N} Ak4$
	Column Total	$\sum_{K=1}^{N} Ak1$	$\sum_{K=1}^{N} Ak2$	$\sum_{K=1}^{N} Ak3$	$\sum_{K=1}^{N} Ak4$	$\sum_{K=1}^{N} Akn$

Appendix 2

GROUND TRUTH cum FIELD SURVEY Data Format

1. Sample No.____________ Date:____________
2. Name of the location_____________ Tehsil ___________ District ____________

   Lat. _______ Long. _________ Alt. _________ GT Sheet No._____Scale_____
3. Dominant Land use/Land cover ____
4. Image characteristics: ____
5. Image Reference: Satellite/Sensor: _________ Path/row _________ Date: ______

   Spectral resolution: ___________ Spatial Resolution: ______________________
6. Distinct Landmark (if any) ____
7. Topography (Hilly / flat / undulating) ___________________________________
8. Land use (Homogeneous / Heterogeneous) _______________________________
9. Associated Land use/Land cover types: __________________________________
10. Geology of the area ____
11. Soil characteristics ____
12. Water Resources ____
13. Photograph No. ____
14. Rough sketch

Appendix 3

Critical source areas and their ET cover Coefficients

Source Area	Development stage	ET coefficient
Bare area	N/A	1.0
Cotton	Final stage	0.4
Maize	Final stage	0.4
Grass	Final stage	1.0
Olive	Final stage	1.0
Ploughed fields	N/A	1.0
Sugar beet	Final stage	0.5
Sunflower	Final stage	0.3
urban	N/A	1.0
Vines	Final stage	0.4
Water melon	Final stage	0.7
Wheat	Final stage	0.4

Appendix 4

Descriptions of Soil Hydrological Groups (Soil Conservation Service, 1986)

Soil Hydrological Group	DESCRIPTION
A	Low runoff potential and high infiltration rates even when thoroughly wetted. Chiefly deep, well to excessively drained sands or gravels. High rate of water transmission (>0.75cm/hr).
B	Moderate infiltration rates when thoroughly wetted. Chiefly moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. Moderate rate of water transmission (0.40-0.75cm/hr).
C	Low infiltration rates when thoroughly wetted. Chiefly soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. Low rate of water transmission (0.15-0.40 cm/hr).
D	High runoff potential. Very low infiltration rates when thoroughly wetted. Chiefly clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface or shallow soils over nearly impervious material. Very low rate of water transmission (0-0.15 cm/hr).

Disturbed soils (major altering of soil profile by construction, development):

A	Sand, loamy sand, sandy loam.
B	Silt loam, loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay, clay.

Appendix 5

Runoff Curve Numbers applied in the Dal Lake catchment (adapted from SCS, 1986)

a) Runoff CN Values (Antecedent Moisture condition II) for cultivated Agricultural land

Land Use /Land Cover		Hydrological conditions	Soil Hydrological Group			
			A	B	C	D
Fallow Bare soil			77	86	91	94
Crop residue cover (CR)		Poor [a/]	76	85	90	93
		Good	74	83	88	90
Row Crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR+CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C+CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T + CR	Poor	65	73	79	81
		Good	61	70	77	80
Small Grains (SR)		Poor	65	76	84	88
		Good	63	75	83	87
	SR+CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C+CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T + CR	Poor	59	70	78	81
		Good	60	71	78	81
Close-SR seeded or broadcast or rotation meadow		Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

[a]Hydrological condition is based on a combination of factor that affects infiltration and runoff, including (a) density & canopy of vegetative areas, (b) amount of year round cover, (c) amount of close-seeded legumes in rotations, (d) percent of cover on the land surface (good ≥20%), & (e) degree of surface roughness.

b) Runoff CN Values (Antecedent Moisture condition II) for Grasslands & woodlands

Land Use /Land Cover	Hydrological conditions	Soil Hydrological Group			
		A	B	C	D
Pasture, grassland or range- continuous forage for grazing	Poor [a] Fair Good	68 49 39	79 69 61	86 79 74	89 84 80
Meadow –continuous grass, protected from grazing, generally mowed for hay		30	58	71	78
Brush-brush/weeds, grass mixture with brush the major element	Poor [b] Fair Good	48 35 30	67 56 48	77 70 65	83 77 73
Woods/grass combination (orchard or tree farm)[c]	Poor Fair Good	57 43 32	73 65 58	82 76 72	86 82 79
Woods	Poor [d] Fair Good	45 36 30	66 60 55	77 73 70	83 79 77
Farmsteads-buildings, lanes, driveways & surrounding lots		59	74	82	86

[a] Poor: <50% ground cover or heavily grazed with no mulch; Fair: 50 to 75% ground cover & not heavily grazed; Good: >75% ground cover & lightly or only occasionally grazed.

[b] Poor: <50% ground cover; Fair: 50 to 75% ground cover; Good: >75% ground cover.

[c] Estimated as 50% woods, 50% pasture.

[d] Poor: Forest litter, small trees and brush are destroyed by heavy grazing or regular burning; Fair: woods are grazed but not burned & some litter covers the soil; Good: woods are protected from grazing and litter and brush adequately cover the soil.

C) Runoff CN Values (Antecedent Moisture condition II) for Urban Areas

LAND USE	Soil Hydrological Group			
	A	**B**	**C**	**D**
Open space (lawns, parks, golf courses, cemeteries, etc:				
Poor condition (grass cover<50%)	68	79	86	89
Fair condition (grass cover 50-75%)	49	69	79	84
Good condition (grass cover>75%)	39	61	74	80
Impervious areas:				
Paved parking lots, roofs, driveways, etc	98	98	98	98
Streets and roads:				
Paved with curbs and storm sewers	98	98	98	98
Paved with open ditches	83	89	92	93
Gravel	76	85	89	91
Dirt	72	82	87	89
Western desert urban areas:				
Natural desert landscaping (pervious areas, only)	63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1-2 in sand or gravel mulch and basin borders)	96	96	96	96

Appendix 6

Determination of the Soil Erodibility (K) factor of the USLE model (Steward *et al.*, 1975)

Texture class	Organic Matter Content		
	<0.5%	2%	4%
Sand	0.05	0.03	0.02
Fine Sand	0.16	0.14	0.10
Very Fine Sand	0.42	0.36	0.28
Loamy Sand	0.12	0.10	0.08
Loamy Fine Sand	0.24	0.20	0.16
Loamy Very Fine Sand	0.44	0.38	0.30
Sandy Loam	0.27	0.24	0.19
Fine Sandy Loam	0.35	0.30	0.24
Very Fine Sandy Loam	0.47	0.41	0.33
Loam	0.38	0.34	0.29
Silt loam	0.48	0.42	0.33
Silt	0.60	0.52	0.42
Sandy Clay Loam	0.27	0.25	0.21
Clay Loam	0.28	0.25	0.21
Silty Clay Loam	0.37	0.32	0.26
Sandy Clay	0.14	0.13	0.12
Silty Clay	0.25	0.23	0.19
Clay	-	0.13-0.29	-

Appendix 7

a) Determination of the cover factor (C) of the USLE model

Crop, rotation & management [b/]	Productivity [a/]	
	High	Moderate
Continuous fallow, tilled up and down slopes	1.00	1.00
CORN		
1. C, RdR, fall TP, conv (1)	0.54	0.62
2. C, RdR, spring TP, conv (1)	0.50	0.59
3.C, RdL, fall TP, conv (1)	0.42	0.52
4. C, RdR, wc seeding, spring TP, con (1)	0.40	0.49
5. C, RdR, wc standing, spring TP, con (1)	0.38	0.48
6. C, fall shred stalks, spring TP, con (1)	0.35	0.44
7. C (silage)-W(RdL, fall TP) (2)	0.31	0.35
8. C, RdL, fall chisel, spring disk, 40-30% re (1)	0.24	0.30
9. C, (silage), W wc seeding, no-till pl in c-k W(1)	0.20	0.24
10. C(RdL)-W(RdL, spring TP) (2)	0.20	0.28
11. C, fall shred stalks, chisel pl, 40-30% re(1)	0.19	0.26
12. C-C-C-W-MM, RdL, TP for C, disk for W (5)	0.17	0.23
13. C, RdL, strip till row zones, 55-40% re (1)	0.16	0.24
14. C-C-C-W-M-M RdL, TP for C, disk for W(6)	0.14	0.20
15. C-C-W-M, RdL, TP for C, disk for W (4)	0.12	0.17
16. C, fall shred, no-till pl, 70-50% re (1)	0.11	0.18
17. C-C-W-M-M, RdL, TP for C, disk for W (5)	0.087	0.14
18. C-C-C-W-M, RdL, no-till pl 2nd &3rd C (5)	0.076	0.13
19. C-C-W-M, RdL, no-till pl 2nd C (4)	0.068	0.11
20. C, no till pl in c-k wheat, 90-70% re (1)	0.062	0.14
21. C-C-C-W-M-M, no till pl 2nd & 3rd C (6)	0.061	0.11
22. C-W-M, RdL, TP for C, disk for W (3)	0.055	0.095
23. C-C-W-M-M, RdL, no till pl 2nd C (5)	0.051	0.094
24. C-W-M-M, RdL, TP for C, disk for W (4)	0.039	0.074
25. C-W-M-M-M-, RdL, TP for C, disk for W (5)	0.032	0.061
26. C, no-till pl in c-k sod, 95-80% re (1)	0.017	0.53
COTTON		
27. Cot, conv (western plains) (1)	0.42	0.49
28. Cot, conv (south) (1)	0.34	0.4
MEADOW (HAY)		
29. Grass & legume mix	0.004	0.01
30. Alfalfa, lespedeza or sericia	0.02	-
31. Sweet clover	0.025	-
Sorghum, Grain (Western Plains)		
32. RdL, spring TP, conv (1)	0.43	0.53
33. No-till pl in shredded 70-5-% re	0.11	0.18

Contd.

34. B, Rdl, spring TP, conv (1) 35. C-B, TP annually, conv (2) B,no-till 36. pl 37. C-B, no-till pl, fall shred C stalks (2)	0.48 0.43 0.22 0.18	0.54 0.51 0.28 0.22
WHEAT		
38. W-F, fall TP after W(2)	0.38	-
39. W-F, stubble mulch, 500 ib re (2)	0.32	-
40. W-F, stubble mulch, 1000 Lb re (2)	0.21	-
41. Spring W, Rdl, Sept TP, conv (ND, SD) (1)	0.23	-
42. Winter W, RdL, Aug TP, conv (KS) (1)	0.19	-
43. Spring W, stubble mulch, 750 lb re (1)	0.15	-
44. Spring W, stubble mulch, 1250 lb re (1)	0.12	-
45. Winter W, stubble mulch, 750 lb re (1)	0.11	-
46. Winter W, stubble mulch, 1250 lb re (1)	0.1	-
47. W-M, conv (2)	0.0564	-
48. W-M-M, conv (3)	0.026	-
49. W-M-M-M, conv (4)	0.021	-

a/ high level exemplified by long-term yield averages greater than 75 bu/ac corn or 3 ton/ac hay or cotton management that regularly provides good stands and growth.

b/ numbers in parentheses indicate numbers of years in the rotation cycle. (1) indicates a continuous one-crop system.

c/ grain sorghum, soyabeans or cotton may be substituted for corn in lines 12, 14, 15, 17-19, 21-25 to estimate values for sod-based rotations.

B: soyabeans. **F:** fallow grass and legume. **C:** corn. **M:** hay. **c-k:** chemically killed.

pl: plant. **Conv:** conventional. **W:** wheat. **Cot:** cotton. **wc:** winter cover

lb re: pounds of residue per acre remaining on surface after new crop seeding

%re: percentage of soil surface covered by residue mulch after new cop seeding

xx-yy% re: xx% cover for high productivity, yy% for moderate

RdR: residues (corn stover, straw, etc.) removed or burned

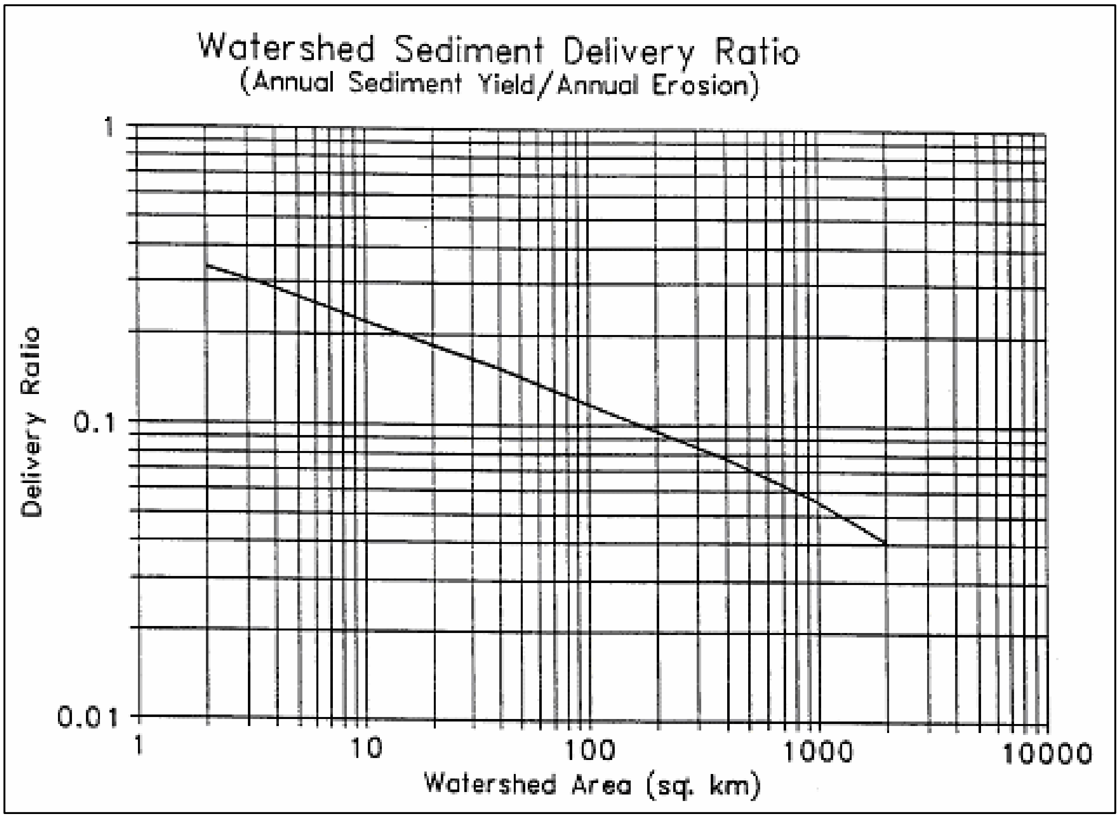
RdL: residues left on field (on surface or incorporated)

TP: turn plowed (upper 5 or more inches of soil inverted, covering residues

b) Determination of the Support Practice (P) of the USLE model

Practice	Slope (%)				
	1.1-2	**2.1-7**	**7.1-12**	**12.1-18**	**18.1-24**
No support practice	1.00	1.00	1.00	1.00	1.00
Contouring	0.60	0.50	0.60	0.80	0.90
Strip cropping					
R-R-M-M[a/]	0.30	0.25	0.30	0.40	0.45
R-W-M-M	0.30	0.25	0.30	0.40	0.45
R-R-W-M	0.45	0.38	0.45	0.60	0.68
R-W	0.52	0.44	0.52	0.70	0.90
R-O	0.60	0.50	0.60	0.80	0.90
Contour listing or ridge planting	0.30	0.25	0.30	0.40	0.45

Appendix 8
Determination of Sediment Delivery Ratio (Vanoni, 1975)

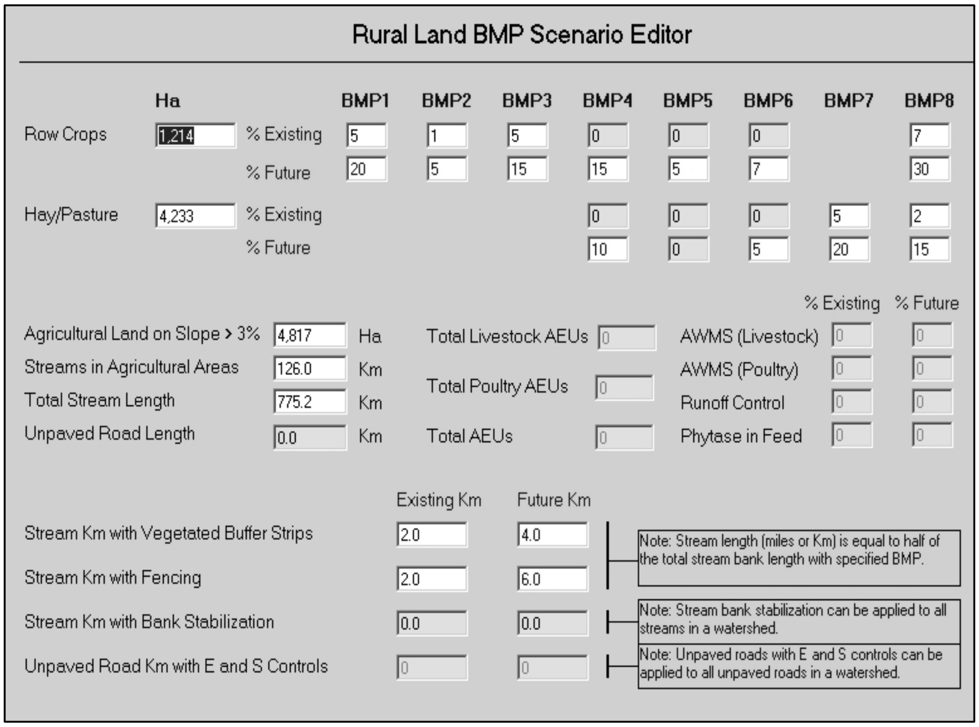


Appendix 9

Nutrient Concentration in runoff from land (Haith, 1987)

Source area	N (mg/l)	P (mg/l)
Bare areas	2.600	0.1000
Cotton	1.700	0.0690
Grass	3.000	0.3000
Olive	1.710	0.1040
Ploughed field	2.600	0.1000
Sugar beet	0.830	0.0830
Sun flower	1.800	0.3000
Urban area	0.045	0.0045
Vines	0.830	0.0830
Water melon	0.830	0.0830
Wheat	3.000	0.2500

Appendix 10
Management Scenario (MSCN)
a) Agricultural and Stream BMPS



Rural Land BMP Scenario Editor

	Ha		BMP1	BMP2	BMP3	BMP4	BMP5	BMP6	BMP7	BMP8
Row Crops	1,214	% Existing	5	1	5	0	0	0		7
		% Future	20	5	15	15	5	7		30
Hay/Pasture	4,233	% Existing				0	0	0	5	2
		% Future				10	0	5	20	15

						% Existing	% Future
Agricultural Land on Slope > 3%	4,817	Ha	Total Livestock AEUs	0	AWMS (Livestock)	0	0
Streams in Agricultural Areas	126.0	Km			AWMS (Poultry)	0	0
Total Stream Length	775.2	Km	Total Poultry AEUs	0	Runoff Control	0	0
Unpaved Road Length	0.0	Km	Total AEUs	0	Phytase in Feed	0	0

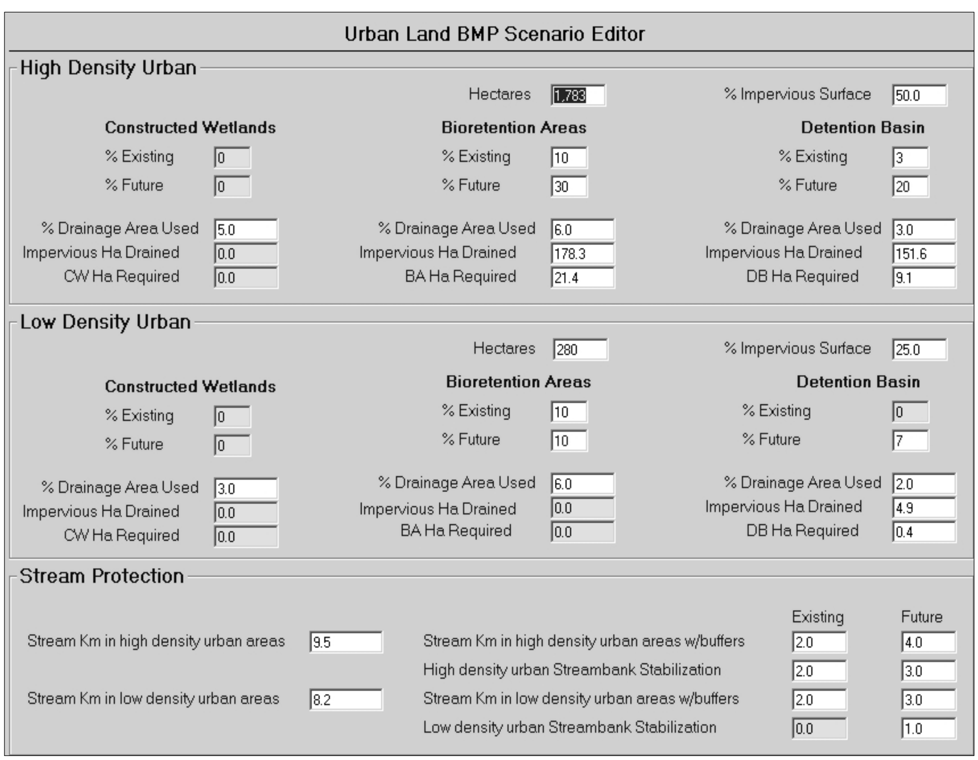
	Existing Km	Future Km
Stream Km with Vegetated Buffer Strips	2.0	4.0
Stream Km with Fencing	2.0	6.0
Stream Km with Bank Stabilization	0.0	0.0
Unpaved Road Km with E and S Controls	0	0

Note: Stream length (miles or Km) is equal to half of the total stream bank length with specified BMP.

Note: Stream bank stabilization can be applied to all streams in a watershed.

Note: Unpaved roads with E and S controls can be applied to all unpaved roads in a watershed.

Appendix 10
Management Scenario (MSCN)
b) Urban BMPS



Urban Land BMP Scenario Editor

High Density Urban

Hectares 1,783 — % Impervious Surface 50.0

Constructed Wetlands		Bioretention Areas		Detention Basin	
% Existing	0	% Existing	10	% Existing	3
% Future	0	% Future	30	% Future	20
% Drainage Area Used	5.0	% Drainage Area Used	6.0	% Drainage Area Used	3.0
Impervious Ha Drained	0.0	Impervious Ha Drained	178.3	Impervious Ha Drained	151.6
CW Ha Required	0.0	BA Ha Required	21.4	DB Ha Required	9.1

Low Density Urban

Hectares 280 — % Impervious Surface 25.0

Constructed Wetlands		Bioretention Areas		Detention Basin	
% Existing	0	% Existing	10	% Existing	0
% Future	0	% Future	10	% Future	7
% Drainage Area Used	3.0	% Drainage Area Used	6.0	% Drainage Area Used	2.0
Impervious Ha Drained	0.0	Impervious Ha Drained	0.0	Impervious Ha Drained	4.9
CW Ha Required	0.0	BA Ha Required	0.0	DB Ha Required	0.4

Stream Protection

			Existing	Future
Stream Km in high density urban areas	9.5	Stream Km in high density urban areas w/buffers	2.0	4.0
		High density urban Streambank Stabilization	2.0	3.0
Stream Km in low density urban areas	8.2	Stream Km in low density urban areas w/buffers	2.0	3.0
		Low density urban Streambank Stabilization	0.0	1.0

Appendix 11

a) Total annual precipitation in Dal Lake Catchment (1981-2008)

YEAR	PRECIPITATION (mm)	
	TOTAL ANNUAL	AVERAGE ANNUAL
1981	739.8	2.03
1982	1047.9	2.85
1983	918.7	2.51
1984	1069.6	2.92
1985	739	2.00
1986	1063	2.90
1987	716.6	1.95
1988	799.3	2.18
1989	681.7	1.87
1990	950.5	2.59
1991	739.8	2.03
1992	1047.9	2.85
1993	918.7	2.51
1994	1069.6	2.92
1995	1132	3.10
1996	987.7	2.70
1997	716.6	1.95
1998	673.4	1.87
1999	499.7	1.37
2000	464.5	1.27
2001	493.1	1.36
2002	622.5	1.73
2003	848.4	2.35
2004	609	1.67
2005	858.6	2.40
2006	1020.4	2.78
2007	577.2	1.57
2008	705.7	1.94

Appendix 11

b) Total monthly precipitation in Dal Lake Catchment (1981-2008)

Year	JAN	FEB	MARCH	APR	MAY	JUN	JULY	AUG	SEP	OCT	NOV	DEC
1981	24.90	81.00	97.60	183.70	130.30	18.30	49.40	66.40	38.20	12.00	0.00	38.00
1982	110.9	33.2	246.9	132.3	112.6	20.5	64.8	120.5	127.9	21.6	33	23.7
1983	117.5	88.2	244.9	43.8	109.2	77	159.5	17.2	20.3	0	41.1	0
1984	82.7	90	66.5	127.4	78.2	40.6	187.5	171	33.5	44.8	0	147.4
1985	60.1	40.8	52.8	71.8	100.7	15.2	133.4	32.2	0.2	74.5	1.6	155.1
1986	10	59.2	189.3	199.9	50.3	17	47.1	70.1	7.4	113.8	113.8	185.1
1987	31.5	20.9	112.5	114.2	70.3	76.5	18.6	112.1	11.2	49.8	37.2	61.8
1988	54.4	101.1	198.5	33.7	30.9	61.7	187.1	46.3	81	0.5	4.1	0
1989	13.3	78.9	94.4	91	72.8	34.8	94.7	68.6	7.8	48.6	32.5	44.3
1990	75.2	74.1	231.6	68.7	7.5	26	29.8	129.7	13.5	40	7.6	246.8
1991	24.9	81	97.6	183.7	130.3	18.3	49.4	66.4	38.2	12	0	38
1992	110.9	33.2	246.9	132.3	112.6	20.5	64.8	120.5	127.9	21.6	33	23.7
1993	117.5	88.2	244.9	43.8	109.2	77	159.5	17.2	20.3	0	41.1	0
1994	82.7	90	66.5	127.4	78.2	40.6	187.5	171	33.5	44.8	0	147.4
1995	53.5	150.6	107.7	133.2	65.1	27.8	297.9	169.4	6.4	36.9	39.8	43.7
1996	78.4	48	48	105.5	148.7	182.6	10.6	162.8	42.4	100.6	42.5	17.6
1997	31.5	20.9	112.5	114.2	70.3	76.5	18.6	112.1	11.2	49.8	37.2	61.8
1998	35.6	157.3	57.7	156.6	62.5	38.2	46.4	84.1	18.6	16.4	0	0
1999	122.8	37.1	64.7	64.7	26.5	16.8	30.9	64.7	24.4	0	47.1	0
2000	92.2	51.8	63.8	26.8	50.9	22.6	64.3	31.4	29.2	0	10.9	20.6
2001	38.2	47.4	45.9	73.8	43.7	63.9	50.6	21.9	34.1	9.6	44.8	19.2
2002	40.5	118	109	73.3	36.7	88.4	16.7	67.7	39.6	22.8	0	9.8
2003	39.1	185.8	152	128.3	85.4	17.2	47.4	48.2	51.1	8.8	14.4	70.7
2004	124.7	36.1	2	166.3	70.4	29.6	102.4	28.2	2.2	0	47.1	0
2005	99.5	277.5	99.3	39.4	92.9	12.3	140.7	40.6	24.6	19.6	11.2	1
2006	168.1	53.2	66.2	55.5	38.6	35.8	151.6	147	108	19	82.5	94.9
2007	8.9	50.5	281.8	1.4	44.5	49.7	57.6	46.4	23.2	0	0	13.2
2008	85.9	102.4	7.9	108	39.1	29.7	84	76.9	30.5	32	57.9	51.4

Appendix 12

a) Average monthly maximum temperature (°C) in Dal Lake Catchment (1981-2008)

YEAR	JAN	FEB	MARCH	APR	MAY	JUN	JULY	AUG	SEP	OCT	NOV	DEC
1981	1.13	7.13	12.30	16.60	21.15	28.94	28.81	29.16	26.47	21.29	15.32	8.92
1982	5.87	8.40	11.43	18.16	22.06	27.31	28.81	28.38	24.89	20.93	15.26	9.48
1983	4.86	11.09	11.45	20.30	23.36	27.90	27.21	29.43	27.31	22.54	14.61	10.75
1984	6.62	7.53	14.95	17.53	23.33	28.36	29.30	29.28	26.09	19.93	16.30	7.20
1985	5.87	21.29	18.18	20.45	23.68	29.11	29.77	28.80	28.82	21.21	15.88	8.36
1986	-0.60	9.43	12.45	17.89	22.26	27.90	29.17	28.49	27.28	22.10	13.54	2.89
1987	2.54	9.65	13.16	18.51	21.66	26.54	31.19	28.70	27.46	19.09	18.58	7.47
1988	8.54	10.47	12.43	22.31	26.63	28.34	29.23	28.75	26.84	21.61	17.88	9.97
1989	8.47	9.20	13.61	18.98	23.65	27.97	27.71	27.05	27.97	22.49	12.79	9.28
1990	8.89	9.96	12.58	18.90	28.07	30.17	30.48	28.52	27.40	21.77	16.02	6.79
1991	1.13	7.13	12.30	16.60	21.15	28.94	28.81	29.16	26.47	21.35	15.32	8.92
1992	5.87	8.40	11.43	18.16	27.21	27.31	28.81	28.38	24.89	20.93	15.26	9.48
1993	4.86	11.09	11.45	20.30	23.36	27.90	27.28	29.51	27.31	22.54	14.61	10.75
1994	6.62	7.53	14.95	17.53	23.33	28.36	29.37	29.31	26.09	19.93	16.30	7.20
1995	2.94	6.26	12.43	16.84	24.40	29.62	28.78	27.93	26.90	21.21	15.58	5.24
1996	5.50	9.10	13.04	19.25	21.04	26.31	29.14	27.15	27.35	18.95	12.20	7.65
1997	2.54	9.65	13.16	18.51	21.66	26.54	31.19	28.61	27.46	19.09	18.58	7.47
1998	5.77	8.09	13.16	19.63	24.22	27.29	30.45	30.01	26.82	23.05	17.69	8.63
1999	4.75	9.26	14.65	23.98	25.20	29.73	31.37	29.62	29.10	23.99	14.52	12.31
2000	6.61	9.02	14.27	22.21	28.75	29.87	29.59	29.25	27.59	25.57	16.24	10.28
2001	10.98	12.76	16.75	20.81	28.45	29.35	30.36	30.63	26.92	23.74	14.85	9.75
2002	8.47	8.43	15.84	19.62	26.45	28.75	30.66	29.76	25.11	23.07	18.03	9.93
2003	10.72	9.58	12.68	20.31	21.72	29.29	30.70	28.45	26.49	22.51	14.42	8.98
2004	5.93	11.81	21.21	19.73	25.40	27.72	29.45	29.09	28.51	25.57	14.42	9.75
2005	6.31	5.29	13.54	19.95	20.78	29.00	28.62	30.34	29.15	22.92	15.43	9.80
2006	4.08	12.59	15.21	20.94	28.27	27.95	31.13	28.22	25.05	22.13	14.17	7.47
2007	9.36	11.11	13.36	25.00	25.13	28.54	29.90	29.79	26.88	24.03	17.20	9.60
2008	4.83	8.15	19.02	19.41	24.97	29.48	29.51	29.94	26.33	22.46	15.23	9.70

Appendix 12

b) Average monthly minimum temperature (°C) in Dal Lake Catchment (1981-2008)

Year	JAN	FEB	MARCH	APR	MAY	JUN	JULY	AUG	SEP	OCT	NOV	DEC
1981	-6.22	-0.65	3.38	5.87	9.49	14.99	16.23	16.04	13.09	4.14	-1.11	0.42
1982	-0.14	-0.54	2.78	4.87	7.74	12.44	16.65	16.50	11.86	5.95	0.91	-0.72
1983	-2.72	0.88	1.58	5.89	12.18	13.14	16.45	15.01	12.14	3.37	1.09	-2.81
1984	-0.28	-0.11	4.79	4.96	9.99	14.20	18.43	18.25	11.02	4.90	0.54	-0.80
1985	-1.12	-1.12	4.34	7.85	10.36	13.76	18.10	17.71	13.55	6.33	0.96	-0.65
1986	-5.51	0.06	2.76	7.21	9.83	14.27	18.72	17.52	12.20	6.86	1.94	-1.49
1987	-3.62	-1.84	2.83	6.03	8.09	13.39	18.63	15.78	12.08	6.90	1.68	-0.18
1988	1.34	1.36	3.99	8.59	11.18	15.50	19.80	17.27	13.14	5.26	0.08	-1.42
1989	-2.65	-0.44	3.60	6.18	19.68	13.96	17.03	15.84	11.56	5.34	2.13	0.55
1990	1.15	1.55	2.47	6.95	11.90	16.30	18.38	17.07	13.34	4.56	0.25	-1.61
1991	-6.22	-0.65	3.38	5.87	9.49	14.99	16.23	16.04	13.09	4.14	-1.11	0.42
1992	-0.14	-0.54	2.78	4.87	7.74	12.44	16.65	16.50	11.86	5.95	0.91	-0.72
1993	-2.72	0.88	1.54	5.89	12.18	13.14	16.45	15.01	12.14	3.37	1.09	-2.81
1994	-0.28	-0.11	4.79	4.96	9.99	14.20	18.43	18.25	11.02	4.90	0.54	-0.80
1995	-5.30	-0.80	3.22	6.49	9.53	12.95	17.65	17.18	11.16	6.21	-0.57	-0.22
1996	-2.57	0.22	3.46	6.72	10.04	14.74	16.25	16.59	12.57	5.10	0.49	-3.22
1997	-3.68	-1.84	2.83	6.03	8.09	13.39	18.63	15.78	12.08	6.90	1.68	-0.18
1998	-1.54	1.82	3.84	6.66	10.14	13.13	17.02	16.18	13.47	4.30	2.28	-3.72
1999	-1.54	1.71	3.84	6.66	10.14	13.13	17.02	16.18	13.47	4.30	2.28	-3.72
2000	-2.16	-0.77	1.64	6.29	11.45	14.95	17.20	15.79	11.81	4.45	2.32	-1.43
2001	-3.89	-0.91	1.97	7.13	11.19	15.52	17.66	16.18	10.20	5.41	0.64	-0.65
2002	-2.67	-0.76	3.32	7.06	9.28	13.71	15.35	16.84	10.42	5.29	0.09	-0.90
2003	-3.20	-0.15	2.85	7.21	7.49	13.13	17.61	15.92	12.77	4.08	0.16	-0.55
2004	-0.19	-0.09	3.97	6.96	9.45	13.88	15.39	16.02	11.13	4.30	2.28	-3.72
2005	-0.65	0.41	4.19	5.63	8.47	12.49	16.60	15.55	12.78	5.08	-0.73	-3.22
2006	-1.82	2.38	3.57	5.69	11.45	13.41	17.91	17.26	11.23	6.78	2.80	-0.54
2007	-2.96	1.80	2.05	6.87	10.52	14.55	16.86	16.86	12.35	2.71	-1.83	-2.29
2008	-2.61	-1.87	3.77	6.32	9.73	16.46	17.23	16.48	9.70	5.45	0.48	0.21

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Certificate

This is to certify that all the modifications/corrections suggested by the External Examiner …………………………..in the thesis manuscript entitled, "**Integrated Impact Analysis of Environmental and Socioeconomic Factors on Pollution Status of Dal Lake using Geospatial Tools" by** Bazigha Badar **(Regd. No. 2007-201-D)** have been taken care of before final binding of the same.

(Prof. M. A. Khan)
Chairman
Advisory Committee