A Geospatial Approach to Study Environmental Characterization of a Kashmir Wetland (Anchar) Catchment with Special Reference to Land use/Land Cover and Changing Climate

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A Geospatial Approach to Study Environmental Characterization of a Kashmir Wetland (Anchar) Catchment with Special Reference to Land use/Land Cover and Changing Climate

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University of Agricultural Sciences & Technology of Kashmir
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This is to certify that the thesis entitled, **"A Geospatial Approach to Study Environmental Characterization of a Kashmir Wetland (Anchar) Catchment with Special Reference to Land use/Land Cover and Changing Climate"** submitted in partial fulfillment 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 **Mansha Nisar (Regd. No. 2008-233-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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ABSTRACT

Catchment of a wetland has direct bearing on its ecological stability. Catchment hydrology directly influences the pollution load (nutrients, sediment) entering into an aquatic ecosystem. Climate and land use change can significantly affect wetland ecosystems. In recent years, land use/land cover analysis has become a major and fundamental tool in assessing the environmental consequences of human activities that negatively affect the whole ecosystem. Keeping in view the importance of catchment for a water body and the analysis of land use /land cover change, the current study was carried out. The objective of the study was to characterize the catchment of an important Kashmir Himalayan wetland Anchar with respect to changing land use land cover and climate. Anchar is basically an important shallow basined semi-urban aquatic body of Kashmir valley, located in the Sindh catchment 14 kms to the Northwest of Srinagar city. Over the years, various anthropogenic

pressures in its catchment have deteriorated its ecology and water quality; the main contributors being land-use changes in the catchment, unplanned urbanization, increased sedimentation, flow of fertilizers and pesticides from the catchment and encroachment. Most of the earlier studies conducted on Anchar have been conventional in nature with emphasis on the hydrochemistry and hydro-biology of the system. No generic approach to assess the implications of landscape pattern and climatic changes in catchment on the Anchar has been conducted till date. The various processes that were studied in the current research included land use/ land cover change detection analysis, topographical analysis, hydrometeorlogical data analysis, soil analysis, water analysis and quantification of sediment and nutrient loadings using GIS simulation model GWLF. The Land use/ Land cover change of the Anchar catchment revealed that the area of classes aquatic vegetation, horticulture, built-up, barren land has increased, while the vegetation cover (plantation, forests, grasslands) and water have decreased. During the study period 1992-2005, aquatic vegetation has increased by 6.46 Km^2, built-up by 15.72 Km^2, bare by 34.89 $Km^2$and horticulture by 9.02 Km^2. Grasslands and forests have decreased by 23.22 $Km^2$and 56.62 Km^2 respectively. The lake has become a victim of pollution due to these changes that have taken place in the land use/land cover of its catchment. Pollution is evident in the form of deterioration of the water quality of the lake. Water chemistry showed the alkaline nature of this aquatic body. The lower levels of dissolved oxygen and higher levels of conductivity especially at SKIMS site and in the main water body itself support the eutrophic status of the water body. The nutrient status of the key elements indicates high levels of total phosphorus and relatively low levels of nitrate nitrogen. Water quality modelling with the help of GWLF model revealed that highest sediment loads are contributed by stream banks followed by bare lands, agriculture, pastures and forests, whereas, the least loads were recorded for horticulture and built-up areas. The major sources of nutrients (dissolved and total forms of nitrogen and phosphorus) are ground water, bare lands, agriculture, and pastures Overall sediment and nutrient loadings under 1992 and 2005 land use/land cover from these sources indicated an upward trend from their 1992 values. Change of land use in the catchment has contributed significantly to the increase in nutrient and sediment loads. Analysis of hydro-meteorological data revealed that climate is changing in the catchment with precipitation showing a decreasing trend from 1981-2010, while as average maximum temperatures are increasing especially in winter. Decreased rainfall and higher temperatures through climate change can alter the hydrological dynamics of Anchar system by decreasing the water level and water spread area of the lake. The water extent of Anchar has decreased as well as deteriorated. This deterioration of water quality of the lake can be attributed to land use pattern changes like expansion of built up, increased use of agrochemicals for expanding horticulture coupled with decrease in vegetal cover that have taken place in the catchment over the years. Infact due to these landuse-landcover and climatic changes with rapid increase in built-up mainly in the agricultural lower plains of Sindh valley floor, water quality of Anchar has worsened during this span of 15 years. The conservation and management of this water body requires awareness, proper understanding, planning and implementation of the management strategies suggested in this research.

Key words: Anchar catchment, GIS, GWLF, Land use/Land cover, Nutrients, Sediment.

Signature of Major Advisor

……………………………...

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Dated: ***Mansha Nisar***

CONTENTS

Chapter	Particulars	Page No.
1	**INTRODUCTION**	**1-9**
	1.1 Background	1
	1.2 Distribution of Wetlands	4
	1.3 Wetland Degradation in Kashmir- A Threat to Ecological Balance	4
	1.4 Geospatial Tools for Wetland Management	6
	1.5 Research Rationale	7
	1.6 Research Hypothesis and Approach	9
	1.7 Objectives	9
2	**REVIEW OF LITERATURE**	**10-41**
	2.1 Ecological Studies on Anchar	10
	2.1.1 Macrophytes	10
	2.1.2 Phytoplankton	11
	2.1.3 Periphyton	11
	2.1.4 Zooplankton	11
	2.1.5 Fishes	12
	2.2 Limnological Studies on Anchar	12
	2.3 Watershed Modelling	15
	2.3.1 Studies on Water Quality Modelling	16
	2.4 Studies on Land Use/ Land Cover	31
	2.5 Studies on Impact of Climate Change on Wetlands	38
3	**STUDY AREA**	**42-51**
	3.1 Location	42
	3.2 Physiography	44
	3.3 Geology	45
	3.3.1 Triassic Formation	45
	3.3.2 Volcanic Formation	45
	3.3.3 Alluvium	47
	3.4 Drainage	47
	3.5 Climate	49
4	**DATA SETS USED**	**52-63**
	4.1 Satellite Data	52
	4.1.1 Landsat 7 TM Image	52
	4.1.2 IRS LISS III Image	57
	4.2 Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) DEM	60
	4.3 Field Study/ Lab Investigated Data	61
	4.4 Field Equipments	61
	4.5 Hydro-meteorological Data	61
	4.6 Secondary Data	63
	4.6.1 Topographic Maps	63
	4.7 Ground Truth Data	63

5	**METHODOLOGY**	**64-97**
	5.1 Environmental Characterization of Anchar Catchment	64
	5.1.1 Satellite data used for land use/land cover change detection	64
	5.1.1a Satellite data processing	66
	5.1.1b Supervised classification of satellite data using Maximum Likelihood Classifier	69
	5.1.1c Ground validation for accuracy assessment of supervised classification	72
	5.1.2 Field sampling/Lab analysis	77
	5.1.2a Physico-chemical analysis of soil	77
	5.1.2b Physico-chemical analysis of water	78
	5.1.3 Topographic analysis	81
	5.2 Geospatial Modelling	83
	5.2.1 Description and Mechanism of GWLF Model	84
	5.2.2 GWLF Input Data Preparation	89
	5.2.2.1 Land use/ Land cover Data	89
	5.2.2.2 Topographic Data	91
	5.2.2.3 Weather Data	91
	5.2.2.4 Transport Parameters	91
	5.2.2.4a Hydrological Input Parameters	92
	5.2.2.4b Sediment Input Parameters	94
	5.2.2.5 Nutrient Parameters	96
	5.2.3 GWLF Implementation	97
	5.3 Assessment of Climate Change Indicators	97
6	**RESULTS**	**98-146**
	6.1 Land Use/Land Cover Change	98
	6.1.1 Land Use/Land Cover Map: 1992	98
	6.1.2 Land Use/Land Cover Map: 2005	100
	6.1.3 Accuracy Assessment	110
	6.2 Topographic Analysis	115
	6.2.1 Slope Analysis of Anchar Catchment	117
	6.2.2 Aspect Analysis of Anchar Catchment	119
	6.2.3 Drainage Analysis of Anchar Catchment	119
	6.3 Physico-chemical Analysis of Soils of Anchar Catchment	122
	6.4 Physico-chemical Analysis of Water of Anchar	132
	6.5 Model Simulations	134
	6.5.1 Contribution from Catchment Sources	134
	6.5.1a Sediment Loadings from Source areas	135
	6.5.1b Nutrient Loadings from Source areas	137
	6.6 Hydro-meteorological Data Analysis	141
	6.6.1 Precipitation Data Analysis	141
	6.6.2 Temperature Data Analysis	141

7	**DISCUSSION**	**147-171**
	7.1 Land Use/Land Cover Change	147
	7.2 Soil Physico-chemical Characteristics	150
	7.3 Physico-chemical Characteristics of Water	154
	7.4 Model Simulations	160
	7.4.1 Sediment Loadings	160
	7.4.2 Nutrient Loadings	162
	7.5 Hydro-meteorological Data Analysis	164
	7.6 Conservation and Management Measures	167
8	**SUMMARY AND CONCLUSION**	**172-175**
	LITERATURE CITED	**i-lv**
	APPENDICES	**lvi-lxxiii**

LIST OF TABLES

Table No.	Particulars	Page No.
1	Morphometric data of Anchar	46
2	Characteristics of Landsat-1 to 5 Missions	54
3	Sensor Characteristics of Landsat-1 to 5 Missions	55
4	Thematic Mapper (TM) Spectral Bands	56
5	Characteristics of IRS-1A and IRS-1B	58
6	Characteristics of IRS-1C and IRS-1D	59
7	Characteristics of IRS-P6 and its sensors	59
8	ASTER characteristics	62
9	Land use/Land cover classes and their descriptions	99
10	Area under different Land use/Land cover classes in Anchar catchment (Landsat TM, 1992)	101
11	Area under different Land use/Land cover classes in Anchar catchment (IRS LISS III, 2005)	103
12	Change in the Land use/Land cover pattern of Anchar catchment	107
13	Overall Accuracy and Kappa Statistics of 2005 Land use/Land cover data	111
14	Accuracy Assessment of 2005 Land use/Land cover data	112
15	Area under different elevation classes in Anchar catchment	116
16	Area under different slope classes in Anchar catchment	118
17	Area under different aspect categories in Anchar catchment	120
18	Physico-chemical characteristics of soils under different Land use/Land cover classes in Anchar catchment	124

19	Area under different textural classes in Anchar catchment	131
20	Physico-chemical characteristics of water (winter)	133
21	Physico-chemical characteristics of water (summer)	133
22	Source area contribution to average annual sediment load in Anchar catchment (1981-2010) as a function of changing Land use/Land cover	136
23	Source area contribution to average annual nitrogen loads in Anchar catchment (1981-2010) as a function of changing Land use/Land cover	138
24	Source area contribution to average annual phosphorus loads in Anchar catchment (1981-2010) as a function of changing Land use/Land cover	140
25	Seasonal variations in average maximum temperature	144
26	Seasonal variations in average minimum temperature	146

LIST OF FIGURES

Fig. No.	Particulars	Page No.
1	Location of Anchar catchment	43
2	Landforms in Anchar catchment	46
3	Lithological map of Anchar catchment	48
4	Geological section along Sindh valley	48
5	Drainage network of Anchar catchment	50
6	Mean monthly precipitation in Anchar catchment (1981-2010)	50
7	Landsat TM Image of study area	54
8	IRS LISS III Image of study area	58
9	ASTER Digital Elevation Model of the study area	62
10	General methodology adopted during the study	65
11	Methodology adopted for Land use/ Land cover change detection of Anchar catchment	67
12	Water sampling sites in the study area	80
13	Methodology for the generation of topographic attributes	82
14	Model structure for nutrient source in GWLF	88
15	Methodology adopted for the GWLF Model	90
16	Land use/Land cover map of Anchar catchment (Landsat TM, 1992)	102
17	Area under different Land use/Land cover classes in Anchar catchment (Landsat TM, 1992)	102
18	Land use/Land cover map of Anchar catchment (IRS LISS III, 2005)	104
19	Area under different Land use/Land cover classes in Anchar catchment (IRS LISS III, 2005)	104
20	Change in Land use/Land cover pattern of Anchar catchment (1992-2005)	108
21	Elevation map of Anchar catchment	116

22	Slope map of Anchar catchment	118
23	Aspect map of Anchar catchment	121
24	Drainage map of Anchar catchment	121
25	pH map of Anchar catchment	125
26	Electrical conductivity map of Anchar catchment	125
27	Water holding capacity map of Anchar catchment	126
28	Soil organic matter map of Anchar catchment	126
29	Available nitrogen map of Anchar catchment	128
30	Available phosphorus map of Anchar catchment	128
31	Available potassium map of Anchar catchment	129
32	Soil textural classes in Anchar catchment	129
33	Soil hydrological groups in Anchar catchment	130
34	Soil erodibility factor (k) in Anchar catchment	130
35	Source area contribution to average annual sediment yields in Anchar catchment (1981-2010) as a function of changing Land use/Land cover	136
36	Source area contribution to average annual nitrogen loads in Anchar catchment (1981-2010) as a function of changing Land use/Land cover	138
37	Source area contribution to average annual phosphorus loads in Anchar catchment (1981-2010) as a function of changing Land use/Land cover	140
38	Total annual precipitation in Anchar catchment (1981-2010)	142
39	Mean monthly precipitation in Anchar catchment (1981-2010)	142
40	Average monthly maximum & minimum temperature (°C) in Anchar catchment (1981-2010)	143
41	Seasonal variations of average maximum temperature from 1981-2010	145
42	Seasonal variations of average minimum temperature from 1981-2010	145

LIST OF PLATES

Plate No.	Particulars	Page No.
1a	Landuse/Landcover of Anchar catchment	113
1b	Landuse/Landcover of Anchar catchment	114
2a	Animal waste deposits near pasture lands in Anchar catchment	165
2b	Animal waste deposits near pasture lands in Anchar catchment	165

LIST OF APPENDICES

Appendix No.	Particulars	Page No.
1	Error Matrix	lvii
2	GROUND TRUTH cum FIELD SURVEY Data Format	lviii
3	Critical source areas and their ET cover Coefficients	lix
4	Descriptions of Soil Hydrological Groups (Soil Conservation Service, 1986)	lx
5	Runoff Curve Numbers applied in the Anchar catchment (adapted from SCS, 1986)	lxi
	a) Runoff CN Values (Antecedent Moisture condition II) for cultivated Agricultural land	lxi
	b) Runoff CN Values (Antecedent Moisture condition II) for Grasslands & woodlands	lxii
	c) Runoff CN Values (Antecedent Moisture condition II) for Urban Areas	lxiii
6	Determination of the Soil Erodibility (K) factor of the USLE model (Steward *et al.*, 1975)	lxiv
7	**a)** Determination of the cover factor (C) of the USLE model	lxv
	b) Determination of the Support Practice (P) of the USLE model	lxvii
8	Determination of Sediment Delivery Ratio (Vanoni, 1975)	lxviii
9	Nutrient Concentration in runoff from land (Haith, 1987)	lxix
10	**a)** Total annual precipitation in Anchar catchment (1981-2010)	lxx
	b) Total monthly precipitation in Anchar catchment (1981-2010)	lxxi
11	**a)** Average monthly maximum temperature (°C) in Anchar catchment (1981-2010)	lxxii
	b) Average monthly minimum temperature (°C) in Anchar catchment (1981-2010)	lxxiii

Chapter 1

INTRODUCTION

Chapter-1

INTRODUCTION

1.1 Background

Life on earth is believed to have been evolved in water and the evolution of water bodies especially wetlands have been known to play an important role in shaping the history of planet earth with the swampy wetlands of the carboniferous period of history being reservoirs of many of the fossil fuels which are currently being used. Wetlands are basically ecotones (edges), transition zones between dry land and deeper waters; environments that are not always wet nor obviously dry. Realizing the special interest and importance of wetlands especially as waterfowl habitat, ecologists gathered at Ramsar in Iran in 1971 signed the famous Ramsar Convention, which has now grown into a big global body of wetland scientists. The convention provides framework for the conservation and wise use of wetland biomass. The Article 1.1 of this convention defines wetlands as, "Areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters". Cowardin *et al.* (1979) revised this definition a bit and defined wetlands as lands transitional between terrestrial and aquatic systems where the water table is at or near the surface or the land is covered by shallow water. Tiner (1991) recognizes wetlands as, "distinct ecosystems along the wetter end of the soil moisture gradient". However, these earlier definitions of wetlands are too broad and lack the precision necessary for scientific enquiry, this necessitates for a change in the definition of wetlands. A "Reference Definition" that could overcome these problems, was given by the Committee on Characterization of Wetlands (1995) which states that, "A wetland is an ecosystem that depends on constant or recurrent, shallow inundation or saturation at or near the surface of the substrate". According to this definition, the minimum essential characteristics of wetland are recurrent sustained inundation or saturation at or near the surface of substrate and the presence of physical, chemical and biological features reflective or recurrent. The three common diagnostic attributes of wetland ecosystems are: undrained hydric soils, their support of hydrophytic vegetation at least periodically and the saturation of substrate with water at some time during the growing season each year. These features are always present in wetlands except where specific physicochemical, biotic or anthropogenic factors have removed or prevented their development. In addition to these basic features, wetlands exhibit enormous diversity according to their genesis, geographical location, water regime and chemistry, dominant plants and soil or sediment characteristics. As regards the occurrence of wetlands, these occur over a wide range of hydrologic conditions, and common terms used to describe them have a long history (Denny, 1985; Symoens, 1988; Mitsch and Gosselink, 2000).

Wetlands are the cradles of biodiversity which harbour a wide variety of flora and fauna, thus being important repositories of aquatic biodiversity. Wetlands world over provide many ecological and socio-economic goods and services. Wetlands provide a wide range of valuable functions for humans (Bedford and Preston, 1988). They have local and international significance as regulators of the hydrological cycle, can improve water quality and have often been considered as natural treatment systems for polluted waters (Kadlec and Kadlec, 1979). Wetlands also provide important habitat for freshwater and marine organisms, and are critical to many bird species as breeding sites and staging areas during migration. It is, in part, the importance of wetlands for bird migration and for essential faunal habitat that has led to a variety of international agreements addressing wetland conservation and management (Maltby, 1986; Hollis *et al.*, 1989). Yet, in a landscape context, wetlands are also important regulators of nutrient and sediment fluxes between terrestrial and aquatic ecosystems (Forman and Godron, 1986). Wetlands help in controlling floods by buffering downstream areas and by reducing the peak flow in main rivers. In addition, they also function as recharge areas for ground water. They play a very important role in pollution abatement as well by removing or converting large quantities of pollutants from both point and non-point sources and by sequestering heavy metals and certain poisonous chemicals in anaerobic zones of soil. A summary of 17 published studies on nutrient trapping in wetlands by Valk *et al*. (1979) suggests that all wetlands are capable of improving water quality at least on a seasonal basis. Because of these roles of wetlands i.e. reducing flood impact by storage of floodwater and pollution abatement, they have been correctly referred to as “the kidneys of the planet”. On the other hand wetlands are a source of green house gases (methane emission) at the same time playing a significant role in carbon sequestration.

The benefits of wetlands, however, have tended to be taken for granted resulting in loss and degradation of wetlands world over (Scott and Poole, 1989). According to Dugan (1993), world may have approximately lost 50% of the wetlands that existed since 1900. According to the Organization for Economic Co-operation and Development-OECD (1996), much of the wetland loss occurred in the northern countries during the first 50 years of 20th century. In recent years, there has been increasing awareness regarding the valuable functions of wetlands (e.g. flood alleviation, ground water recharge, retention and regulation of pollutants and plant nutrients, biodiversity, aesthetic beauty for tourists, cultural heritage and archaeology) (Amoros *et al*., 1996; Robertson *et al*., 1999; Tockner *et al*., 1999; Bugenyi, 2001; Frazier *et al*., 2003). Despite this increasing awareness and importance given to wetlands worldwide, their conservation has been sadly neglected. Wetlands are under great pressure on account of manifold anthropogenic activities, which include development of urban centres, construction of roads and railways, agricultural activities, forestry, aquatic pollution due to municipality sewage, use of agrochemicals (pesticides and fertilizers), industrial effluents and consequent infestation with aquatic weeds and eutrophication, degradation of watersheds and increased siltation due to deforestation in the catchment areas, recreational activities, and tourism. This has resulted into increasing pressure for conversion to alternative land particularly in tropical and subtropical wetlands since the 1980s. By 1985, it was estimated that 56-65% of available wetlands have been drained for intensive agriculture in Europe and North America, 27% in Asia, 6% in South America and 2% in Africa (OECD, 1996). These activities have led to shrinking of wetlands and their biological resource potential, pollution, siltation and weed infestation. As a result wetlands world over have been lost, degraded, polluted and their ecological functions impaired. It was noted by Moser *et al.* (1996) that almost 84% of the wetlands listed as Ramsar sites had undergone or were threatened by ecological change. Over 70% of the world’s freshwater resources are used for agriculture and estimates for the past century indicate that upto 50% of wetlands have been lost (Zingstra and Wiseman, 2003).

1.2 Distribution of Wetlands

Wetlands are intricate ecosystems, which cover 8.56 million Sq.km i.e. 6.4% of the land surface of world (Schuijt, 2002). Out of these wetlands of world, nearly 30% is made of bogs, 20% of fens, 20% of swamps and 15% is in the form of floodplains. India with its extensive geographical stretch, varied topography and climatic regimes, supports unique wetland habitats which sustain diverse flora and fauna. Wetlands in India occupy 58.2 million hectares including areas under wet paddy cultivation (Directory of Indian Wetlands, 1993). There are 67,429 wetlands in India covering about 4.1 million hectares (excluding irrigated agricultural lands, rivers and streams) of which 2,175 wetlands occupying 1.5 million hectares are natural, while 65,254 wetlands occupying 2.6 million hectares are manmade. The coastal wetlands occupy an estimated 6,750 Km^2, largely dominated by mangroves (Ramchandra, 2001). Kashmir valley located in the northernmost part of India, by virtue of its mountainous terrain and varied climate, supports a rich diversity of freshwater lakes and wetlands 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). The natural wetlands of Kashmir valley include high altitude lakes and series of wetlands occurring all along the flood plain of river Jhelum and Sindh at the base of Kashmir Himalaya. Among these series of wetlands Anchar is one of the important Himalayan wetland of Kashmir valley.

1.3 Wetland Degradation in Kashmir- A Threat to Ecological Balance

Wetlands are one of the most threatened habitats of the world. Kashmir, since long, has had intimate socio-economic links with wetlands (Lawrence, 1895). However, the deterioration of wetlands in Kashmir is increasing at an alarming rate due to multiple anthropogenic pressures and changing climatic conditions. The major threat to these wetlands today is from increased siltation and eutrophication due to run-off from catchments (including fertilizers) and sewage disposal. Deposition of sediments is a continuous process, as seen in the various lakes and wetlands of Kashmir like Dal, Anchar, Wular, Hokersar and Nilnag. Some high altitude wetlands are also facing the problem of natural siltation where glacial silt has been rapidly filling up the lake basins (Pandit, 2002). Eutrophication of wetlands in Kashmir valley is a very recent event of the past 10-30 years, coinciding with a marked civilization evolution in the wetland catchment areas. The condition of Kashmir Himalayan wetlands ranges from the oligotrophic of Kounsernag to fully eutrophic lake of Anchar, while others are in process of continuous change towards eutrophication. Almost all the valley lakes are showing the signs of eutrophication, as is evident from the research conducted by various workers. Khan in a series of papers (1993a, 1993b, 2000c) reported an unprecedented outbreak and frequent seasonal recurrence of red tide in aquatic habitats of Kashmir since summer of 1991-which constitutes a new environmental threat to the aesthetic value and biological diversity of Kashmir wetlands. The occurrence of red tide was attributed to influx of untreated sewage from adjoining residential areas. Encroachment from agriculture land and willow plantations, receding upon water areas as a result of expanding reed belts, degradation of watersheds and over-exploitation are some other dangers facing these wetlands. Soil erosion and nutrient losses in watershed affect water quality and often generate long term environmental problems as accelerated eutrophication (Strobl *et al*., 2007). Large watershed areas of Kashmir wetlands have been stripped physically of their vegetation cover for human use. Resources of several Kashmir wetlands have been over-exploited, resulting in their decline and loses of many important plant and animal species, thus impairing the whole ecological balance of our valley ecosystems. One such example is the famous game sanctuary of Kashmir, the Hokersar wetland. This wetland which was once spread over 1800 hectares has now been reduced by approximately 28% (Khan *et al.*, 2004). The wetlands of Narkura (Budgam), Indra-nagar, Bemina (Srinagar), Poshkur (Pulwama), Boug (Sopore) are some other vivid examples of loss of wetlands in our valley.

Climate change is a major global problem, affecting almost all ecosystems. Wetland ecosystems with their hydrology dependent on precipitation are most sensitive to changes in temperature and precipitation (Winter, 2000). The wetlands present in our ecologically fragile Kashmir Himalayan region, are dependent on glacier melt and precipitation for their water levels. Therefore, climate change especially recession of Himalayan glaciers and changes in precipitation will have a significant impact on these habitats and their associated species. Kashmir valley is also witnessing the impacts of changing climatic patterns. The meteorological data reveals that in Kashmir region the air temperature has shown an increase of 1.4˚C (Jeelani *et al*., 2008). It is an established fact that glacier melting is an important indicator of climate change. The glaciers in the alpine catchment of Kashmir Himalayan region, which support most of the valleys wetlands by their melt, too are facing the brunt of climate change with their recession taking place at a fast pace due to increasing temperatures. Overall the volume of alpine glaciers has decreased by more than 50% since 1850. A rise of temperature by 1°C leads to shrinkage in area of alpine glaciers by 40% (Intergovernmental Panel on Climate Change –IPCC, 2001b; Centre for Science and Environment, 2002). In the recent past, it has become a common observation that the time period of snowfall has undergone a change with people experiencing scanty snow in the harshest period of Kashmir winter (locally called "Challai-Kalan"-extending from December to January) and heavy snowfall in the months of spring- February and March. Several studies have reported a general state of recession of the glaciers of Jammu and Kashmir since 1850s (Mayewski and Jeschke, 1979; Vohra, 1981; Ahmad and Rais, 1998; Dobhal *et al*., 2004; Kulkarni *et al*., 2007; Pandey *et al.,* 2011). Greater fragmentation of glaciers has also been reported in Chenab basin with an overall reduction of 21% in the glacial surface area. The mean area of glacial extent in this basin has also reduced from 1.4 Sq.Km to 0.32 Sq.Km during 1962-2001 (Kulkarni *et al*., 2007). This climate change-occurring in the form of glacier recession and alteration of precipitation pattern, is ultimately resulting in degradation of Kashmir wetlands and threatening its ecological stability.

1.4 Geospatial Tools for Wetland Management

Geospatial tools- remote sensing data in combination with Geographic Information System (GIS) are most effective tools for monitoring wetlands, providing useful information on them and finally for integration of such information to arrive at proper decisions for conservation and management of wetlands. The application of geospatial tools for wetlands encompass water resource assessment, hydrological modelling, flood management, reservoir capacity surveys, assessment and monitoring of the environmental impact of water resource projects and water quality mapping and monitoring (Jonna, 1999). In addition to these vegetation and inundation dynamics which include wetland ecology, seasonal monitoring and characterization of wetland biodiversity can be studied using geospatial technology which enables mapping in an integrated multi-layered structure using remotely sensed data. In case of wetland mapping, geospatial tools help to assess landscape changes, as well as assist in monitoring the pollution and siltation levels, weed infestation and aquaculture development. With the use of geospatial tools for wetland mapping, we get an advantage of more accuracy at minimal costs and manpower use. Remote sensing allows monitoring at multiple spatial and temporal scales, which supports better understanding of wetland ecosystem for continuous assessment and analysis of future trends. New generation satellites have sensors to improve accuracies of applications of geospatial tools for wetlands. At present, various geospatial tools are at our disposal from a range of GIS software's to remote sensing data, to give an accurate picture of wetland status and study of trends. Thus, this recent and innovative geospatial technology is bringing hope for an effective wetland management.

1.5 Research Rationale

Lakes in Kashmir, and immediately Dal Lake comes to our mind. Dal is rightly described as Lake Par-Excellence, but it's not the only of its kind in Kashmir. God has been gracious enough to bestow Kashmir with numerous other freshwater bodies, to which less attention has been paid. Anchar is one amongst these less known freshwater bodies, which is experiencing a high pollution load from its catchment. It's a semi-urban lake with its surrounding area comprising of Srinagar city and a number of bordering villages. In fact it is connected to the famous Dal Lake through a small inflow channel Nalla Amir-Khan. Anchar plays an important role in regeneration and conservation of biological resources besides irrigation, water supply, transportation, fishery and wildlife. At the same time it has become a victim of cultural eutrophication due to increase in anthropogenic pressure and siltation in its catchment area. To the northeast of Anchar is situated Sher-I-Kashmir Institute of Medical Sciences (SKIMS), Soura. Though a sewage treatment plant is in place, a general public perception prevails that waste/effluent materials from SKIMS complex do find their way into the wetland system. The State Control Pollution Board (SCPB) in its recent report based on on-spot assessment has found that the institute disposes its bio-medical waste and effluents without any scientific treatment into Anchar. The treated effluents discharged into the system do not confer to the standards prescribed by

SPCB. The SPCB has also reported that though incinerators are in place but they do not work regularly. Thus, effluents from SKIMS complex that are drained into Anchar have caused high nutrient enrichment and vandalized this ecosystem. In addition to this, it’s also affected by run-off from agricultural fields and sewage disposal from the catchment area resulting in its heavy infestation with macrophytic growth and littorals, constituting the major portion of lake, especially dominated by tall growing emergents. With the construction of Dr. Ali-Jan Road especially the portion from Ali Masjid upto SKIMS junction areas which were not accessible through mechanized transport to public became accessible. Thus the portions of Anchar along this road were filled and huge constructions came up. This too became a major source of shrinkage and pollution to the Anchar system. There has occurred shrinkage in the size of Anchar, which has adversely affected the biotic and abiotic characteristics of the lake (Bhat and Pandit, 2002). Furthermore, the mountainous catchment Sindh valley of this wetland is experiencing climatic changes. Some major glaciers of this catchment like Najwal Akal have completely disappeared while others like the Thajwas, Naranag which used to be large enough some decades back-today have been considerably reduced. The snowline too has receded from Sonmarg (3200m above msl) to Shiashnag at an altitude of 5000m.

Taking, note of this deteriorating condition of Anchar and simultaneously keeping in mind, that no generic approach to assess the implications of landscape pattern and climatic changes in catchment on the system has been made this research was proposed. The focus of this research is how catchment alterations and changing climate have affected this ecosystem. This research will identify the critical source areas causing nutrient pollution of Anchar. In order to effectively manage nutrient pollution of this ecosystem from its catchment nutrient management measures for all these indentified sources have been suggested in this research.

1.6 Research Hypothesis and Approach

The main hypothesis of this research is that, because of enhanced population explosion coupled with increased anthropogenic interventions in the catchment in the form of rapid rate of encroachment, increased agricultural and horticultural activities, disposal of sewage from adjoining settlements Anchar system has become a victim of cultural eutrophication and is undergoing fast environmental deterioration.

The research approach is based on field work/ lab investigation and data processing/ simulation using GIS modelling. This approach has been basically used to investigate whether really; nutrients released from various sources have led to eutrophication of Anchar wetland system. Field work/ lab investigation involved collection of data on land use, climate, nutrient, soil type and texture and water quality. This data was used to model fluxes of pollutants using GIS based model- Generalized Watershed Loading Function (GWLF). No, attempt has been made to study and understand Anchar system using scientific and modern geospatial tools. This research uses the GIS based modelling approach to thoroughly understand the Anchar wetland system and simulates water quality conditions and effluents loading to the system, provides insight into sources and impacts of non-point and point sources of pollution, and aids in designing management and restoration practices.

1.7 Objectives

1. Environmental Characterization of Anchar Lake Catchment.
2. Assessment of Changing Climatic Pattern in the Anchar Lake Catchment.
3. Assessment of the Pollution Load of Anchar Lake in Light of Changing Land use/Land cover and Climatic Pattern.

Chapter 2

REVIEW OF LITERATURE

Chapter-2

REVIEW OF LITERATURE

The valley of Kashmir located in the northwestern region of the great Himalayas with an average elevation of about 1600m above mean sea level, has been bestowed by nature with magnificent freshwater lakes and numerous wetlands. These wetlands play a vital role in maintaining the ecological balance and hydrological regimes of the entire valley. Various studies on different ecological and limnological aspects of lakes and wetlands of Kashmir have been undertaken in the past (Kaul and Zutshi, 1967; Kaul, 1977; Zutshi and Khan, 1978; Khan, 1979; Pandit, 1980, 1982; Kaul and Pandit, 1982; Kaul, 1983; Kak 1984a,1984b,1985; Khan 1984,1985,1986,1987; Pandit, 1988; Pandit and Qadri, 1990; Pandit, 1991; Khan and Zutshi, 1992; Kaul and Handoo, 1993; Pandit, 1996; Gangoo and Makeya, 2000; Khan, 2000a, 2000b; Zutshi and Gopal, 2000; Bashir *et al*., 2003; Khan and Shah, 2003; Khan and Shah, 2004a,b; Ravinder and Pandit, 2005; Bhat and Khan, 2006; Khan, 2008; Khan, 2009 and more recently Khan and Shah, 2010). These studies however, have paid little attention to the unique ecohydrological character of the wetlands and the driving mechanism of landscape pattern changes in catchment areas. Further, no study has been carried out to assess the climate change implications on these wetlands.

2.1 Ecological Studies on Anchar

Anchar, though ecologically very important is less known among the numerous wetlands of Kashmir, and consequently has received little attention. Scanty literature is available on ecological aspects of this aquatic ecosystem with studies pertaining mostly to the biological aspects of this wetland.

2.1.1 Macrophytes

Among the first ones to provide a comprehensive list of aquatic macrophytes from lakes and wetlands in Srinagar were, Kaul and Zutshi (1967). They collected and recognized 99 species of macrophytes from Anchar, next only to Dal which recorded the highest number (107) of macrophytic species. Later Zutshi (1975), studied associations of macrophytic vegetation in lakes and wetlands of Kashmir and recorded greatest diversity in Anchar with 20 associations. In another study Zutshi *et al.* (1980) compared the macrophytic vegetation of Anchar with some other lakes of the valley. They noted that in Anchar, submerged forms are not well represented. Only *M. spicatum* and *Potamogeton crispus* were found to be frequent in some areas, while as silted regions of the lake were found to mainly support *Potamogeton natans* and *Nymphoides peltatum*. Kak (1981) reported 42 macrophytic species from this natural water body of Kashmir.

Recently, Ali and Pandit (2009) studied the macrophytic diversity in Anchar. Their study revealed a total of 41 macrophytic species with emergent macrophytes having the highest diversity (24 species). The study concluded that there has been a considerable decline in macrophytic diversity and that the lake has been subjected to increasing eutrophication and is overgrown mainly by the aggressive interlopes like *Typha* sp., *Phragmites australis*, *Sparganium ramosum* and *Scirpus* sp.

2.1.2 Phytoplankton

With regard to studies on phytoplankton of Anchar, the number of species reported vary from 25 to 93 (Kaul *et al*., 1978).

Bhat and Pandit (2003) studied the phytoplankton dynamics of Anchar and reported 145 species of algae from it. Their study revealed that on the basis of phytoplankton population Anchar is undergoing accelerated cultural eutrophication.

2.1.3 Periphyton

Sarwar and Zutshi (1987, 1989) compared periphyton species of three different lakes of Kashmir including Anchar and found very little difference in the number of species. They reported 89 species of periphyton from Anchar.

2.1.4 Zooplankton

Kaul *et al*. (1978) investigated zooplankton of 15 lakes, wetlands and ponds of Jammu and Kashmir. They found 25 species of zooplankton from Anchar. Later, Balkhi *et al.* (1987) reported 87 species of zooplankton from Anchar which included 41 rotifers, 33 cladocerans and 13 copepods.

2.1.5 Fishes

The Palearctic fishes belonging to families Schizothoracinae, Botinae and Noemachilinae are commonly found in the aquatic bodies of Kashmir. Pandit (1991) reported that the number of fishes in wetlands of Kashmir is restricted to 5-6 species.

Shah *et al.* (2009) studied the impact of helminth parasitism on fish haematology of Anchar and found that the fish fauna - *Schizothorax* sp. and *Cyprinus* sp. inhabiting the lake carried cestode, trematode infestations. The results of their study showed a mean significant decrease from 9.39±0.18-7.39±0.14 g% and 10.57±0.23-7.62±0.13 g% in haemoglobin count of *Cyprinus* sp. and *Schizothorax* sp. respectively.

2.2 Limnological Studies on Anchar

Limnology--the scientific study of water bodies with reference to their physical and biological features is imperative to know the trophic state index of any water body. For proper conservation and management of a water body, the knowledge of its trophic status is must. Voluminous literature is available on the limnology of aquatic habitats of the valley, but very few limnological investigations have been carried out on the semi-urban aquatic body Anchar.

Zutshi *et al.* (1980) in their study compared both macrophytic vegetation and limnology of nine lakes of Kashmir including Anchar. On the basis of results of their limnological investigation, they concluded that Anchar is becoming a victim of cultural eutrophication due to increased anthropogenic pressure in its catchment.

Sarwar (1999) assessed the water quality of Anchar and analyzed various physico-chemical parameters of this lake including water temperature, depth, pH, specific conductivity, dissolved oxygen, calcium, magnesium, total alkalinity, chloride, total phosphorus and various forms of nitrogen. He reported high values of conductivity and low content of nitrate-nitrogen which was attributed to luxuriant macrophytic growth utilizing it. The study also revealed higher values of total phosphorus on the basis of which the lake was placed in moderate eutrophic category.

Pandit and Yousuf (2002) carried out investigation of certain limnological parameters of Anchar so as to assess its trophic status. Their study typified this semi-urban lake as eutrophic as nutrients (total phosphorus and total dissolved inorganic nitrogen) recorded their maximum values in this lake. Almost 75% of water samples collected from Anchar were found to be eutrophic in nature.

Another study pertaining to limnological investigation of Anchar was carried out by Bhat and Pandit (2002). Water samples were analyzed for parameters like pH, specific conductivity, dissolved oxygen, calcium, magnesium, total alkalinity, chloride, nitrogen, potassium and phosphorus. They concluded that Anchar is undergoing rapid eutrophication and attributed it to heavy population pressure in the catchment of the lake.

Some information is available on the impact of effluents from the SKIMS complex on the nutrient level of Anchar Lake. Bhat *et al.* (2001) reported that the toxic effluents from SKIMS complex are greatly responsible for the deterioration of the lake environment. This has subsequently disturbed the ecology and growth of plant and animal communities in this lake.

Mir *et al.* (2006) in another study on the impact of effluents from SKIMS on physico-chemical parameters of Anchar recorded lower values of water depth, transparency, pH and higher values of temperature, specific conductivity, ammonical-nitrogen, nitrate-nitrogen, chemical oxygen demand and total alkalinity at the SKIMS sites in comparison to the other sites of the lake. Thus, they too concluded that Anchar is deteriorating due to effluents discharged from SKIMS complex.

Despite wide range of ecological studies on Kashmir wetlands, very little attempt has been made to adopt more advanced and scientific methods for their study. Review of literature shows that exploration of Kashmir wetlands has not been made using modern geospatial techniques such as GIS and remote sensing which constitute an important tool for studying such fragile ecosystems. However, of late a few attempts (Amin and Romshoo, 2007; Badar and Romshoo, 2007; Romshoo and Muslim, 2011) have been made to study the hydrological characteristics, pollution status and changing patterns of lakes/wetlands of Kashmir using these advanced geospatial techniques and modelling.

The dynamic nature of aquatic bodies and their surrounding landscape necessitates the widespread and consistent use of satellite-based remote sensors and low-cost, affordable GIS tools for effective management and monitoring. A spatial approach provides a means for repetitive monitoring and also aids in identifying the indicators of change in the aquatic ecosystems. Remote sensing technology is an important tool in this assessment because it provides synoptic view of the earth which would not be possible from the ground without exhaustive field surveys (Prasad and Pattaniak, 2007). Studies on wetlands from space started back in the 1970s with the help of aerial photography. Aerial photographs were initially used to derive information on various natural resources including water bodies and to monitor changes in wetland resources (Kamphorst and Iyer, 1972; Iyer *et al*., 1975). One problem with use of these aerial photographs was that indentifying wetland sites on multiple years of photos was a significant time investment job (Ramsey and Laine, 1997). Water quality assessment of ocean and inland waters using satellite data has been carried out since the first remote sensing satellite Landsat Multi-Spectral Scanner (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. Imagery from satellite and aircraft remote sensing has been widely used in the assessment of water quality of aquatic bodies (Lillesand *et al.,* 1983; Lathrop and Lillesand, 1989; Ritchie and Cooper, 1991).

Tremendous research on wetlands from space actually began from 1990s. Landsat-MSS, Landsat Thematic Mapper (TM) and SPOT satellite system data have been used in many studies on wetlands (Lunetta and Balogh, 1999; Shepherd *et al*., 2000; Shaikh *et al*., 2001; Toyra *et al*., 2001). Most of the work carried out on wetlands using remote sensing has made use of visible region of spectrum via-Landsat MSS, Landsat TM and SPOT satellite data, though microwave remote sensing (radar) can play an important role in wetlands. Little research has been done on wetlands using microwave remote sensing - AVHRR, ERS, JERS-1, ERS-1, SIR-C, LIDAR and Radar data (Hess and Melack, 1994; Augusteijn and Warrender, 1998; Dwivedi *et al*., 1999; Alsdorf *et al*., 2001; Bourgeau *et al*., 2001; MacKinnon, 2001; Costa and Telmer, 2006; Touzi *et al*., 2007; Schroeder *et al*., 2010). Modern spatial technology tools, viz. remote sensing/ GIS have been successfully utilized globally to study wetlands proving to be quite effective in identifying the nature and types of pressures in the catchments threatening their existence, besides, facilitating their conservation and management (Desai *et al.,* 1991; Kedarnath *et al.,* 1994; Nayak *et al*., 1996; Ramachandran *et al.,* 1998; Chopra *et al.,* 2001; Khan *et al*., 2001; Liu and Yang, 2004; Manju *et al.,* 2005; Baker *et al.,* 2007; Devi *et al.,* 2007; Chaves and Lakshumanan, 2008; Roeck *et al.,* 2008; Sarkar and Jain, 2008; Reif *et al.,* 2009; Teferi *et al.,* 2010). The potential benefits of satellite-based remote sensing and GIS have been recognized by lake managers (Chipman *et al.,* 2004).

2.3 Watershed Modelling

There has been a growing understanding of the importance of looking at water resource issues from a watershed perspective in recent years. Watershed modelling implies the proper use of all land, water and natural resources of a watershed for optimum production with minimum hazard to eco-system and natural resources. A watershed model constitutes a primary tool for estimating changes resulting from future conditions and for testing alternative improvement scenarios. Watershed models provide forecasts of current and alternative impacts on water quality, give details of Nitrogen, Phosphorus and Sediment (NPS) estimation processes, establish critical areas, rank alternative measures and are often the only means of predicting water quality impacts for non-monitored sites (Novotny and Olem, 1994). These models can be used in combination with many other assessment techniques. Watershed loading models basically help to determine the amount of contaminants emanating from different sources on the land surface. Within the Tools for Watershed Assessment (Total Maximum Daily Load-TMDL) program they have been used to determine the source of contaminants, to estimate the amount of pollution contributed by each source, and to determine the optimal allocation or management scenario for pollution reduction. In fact, watershed simulation models 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. Haith and Shoemaker (1987) stated that certain equations help a great deal in the development of simulation models and help us to identify the sources of sediments. Many states, regional, and federal environmental agencies, use this technology routinely to support ongoing watershed modelling and assessment programs (Samuels, 1998).

Excellent historical overviews on the utility of computer models and the development of computational tools for quantifying and analyzing pollution problems within watersheds and supporting decisions in water management over the past three decades are provided (Moore *et al.*, 1991; Loucks, 1995; Wilson, 1996; Arnold *et al.,* 1998; Deliman *et al.,* 1999; Dai and Labadie, 2001). Due to the many inherent benefits, remote sensing and GIS software's have played a vital role in watershed modelling and planning over the last 10 to 15 years. The possibility of rapidly combining data of different types in GIS has led to significant increase in its use in watershed modelling. Watershed modelling is a reflection of our understanding of watershed systems. In recent years, an integrated approach to watershed modelling has become essential for sustainable development and management of our water resources.

2.3.1 Studies on Water Quality Modelling

One of the best tools available for determining the quantitative relationship between pollutant sources and water quality criteria is a water quality model. Water quality models are a group of receiving watershed models that are used in modelling the chemical and biological processes occurring within a water body. Infact, water quality models are important tools used for developing TMDLs, which are used to implement water quality standards. Due to time and expense associated with surface water monitoring, simulation modelling has been relied upon more frequently to provide needed information for the development and implementation of non-point source control programs (Novotny and Olem, 1994).

The first step in the direction of preventing deterioration of our water resources and improving the overall quality of our environment was the development of models that predicted anticipated pollution. However, these models were difficult to use with large amounts of input data describing land areas that were not homogeneous (Engel *et al*., 1993; Srinivasan and Engel, 1994; Tim and Jolly, 1994). So the next step was improving the prediction of critical areas of non-point sources by integrating GIS with the water quality models. The GIS added the ability to store, manipulate, retrieve, and display spatial and non-spatial data (Tim *et al*., 1992; Mitchell *et al*., 1993; Savabi *et al.,* 1995). The development of remote sensing and GIS technologies has enabled effective water quality modelling (Carpenter and Carpenter, 1983; Lavery *et al*., 1993; Zilioli and Brivio, 1997; Shafique *et al*., 2001; Ostlund *et al*., 2001; Hakvoort *et al.,* 2002; Werdell and Bailey, 2005).

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. Since 1980s, the development of Non-point Source models (NPS) has been intensified. Singh and Woolhiser (2002) presented an extensive list of available NPS models. Systeme Hydrologique European- SHE (Abbott *et al.,* 1986), Agricultural Non-point Source Pollution-AGNPS (Young *et al.,* 1987), Areal Non-point Source Watershed Environment Response Simulation-ANSWERS (Bouraoui and Dillaha, 1996) and Soil Water Assessment Tool-SWAT (Neitsch *et al.,* 2001) are examples of distributed NPS models.

Rosenthal and Hipp (1993) conducted a study to analyze the impact of different turf grass fertilizer and pesticide management systems on runoff water quality. In their study, they used a hydrological and water quality model, Erosion Productivity Impact Calculator (EPIC) to estimate pesticide and nutrient concentrations in the runoff from turf grass on Houston Black Clay. They found that the nutrient and pesticide concentrations in the surface runoff increased significantly for highly maintained turf grass systems. A large fraction of the amount applied was observed in runoff for moderate application rate treatments.

Liao and Tim (1994) developed an interactive water quality modelling system within a GIS environment. The system combined soil erosion and pollutant export models with ARC/INFO GIS software and a graphic user interface. The system was designed to allow efficient and cost-effective use of simplified water quality models for the analysis of nonpoint source pollution problems in watersheds. This interactive modelling system was implemented on a colour-graphic engineering workstation where it permitted visualization of spatial distribution of model inputs and spatio-temporal variation of simulated model outputs. The goal of developing the interactive modelling system was to provide a spatial decision support tool for targeting critical areas of water quality problems in a watershed and for agricultural production planning, management and decision-making.

Srinivasan and Arnold (1994) integrated the SWAT water quality model with GRASS (Geographic Resources Analysis Support System) GIS. The integrated system was applied to simulate the upper portion of the Seco Creek Basin. The basin was subdivided into 37 sub-basins. The average monthly predicted stream flow of the basin was found to be in agreement with measured monthly stream flow values.

Hession *et al.* (1996) in their study carried out watershed-level ecological risk assessment of Wister Lake, Oklahoma using EUTROMOD model. They estimated annual watershed phosphorus loads from point and non-point sources, as well as lake response in terms of chlorophyll-a concentration. Alternate management scenarios were also tested within this modelling framework. Their results indicated that EUTROMOD is a useful tool in ecological risk assessment and it aids in making decisions on the management level.

Nuckols *et al.* (1996) used GIS-based hydrological/water quality simulation model GWLF for a 482 km^2 predominantly agricultural based (54% irrigated) watershed. The results of their research indicated that a source area approach using GIS technology can provide the level of detail necessary in order to apply a distributed non-point source pollution model like GWLF in such watersheds.

In another study in 1996, Swaney *et al.* used the same model to replicate a 1991 study that estimated loads of sediment and total organic carbon to the Hudson river from land surrounding it. The researchers modified the GWLF model with updated GIS layers and multiple environmental databases that helped improve model estimates. The authors found that the 1996 data estimated an increase of 10% for sediment loads and 20% for total organic carbon loads over those calculated in 1991. These results, stemming from the modifications, were found to be closer to measurement-based results. They concluded that GWLF is an excellent predictor of freshwater discharge for the Hudson river and its tributaries on a fine temporal scale, and a good predictor of inputs of sediment and organic carbon on a monthly to seasonal time scale.

Kazmi and Hansen (1997) in their study applied the MIKE-11 numerical water quality model to evaluate the existing water quality conditions and to predict the effects of different wastewater and other pollution control schemes under the Yamuna Action Plan. The Mawi-Delhi (Okhla Barrage) stretch was chosen as the study area. It was found that water quality between Mawi-Wazirabad reach was significantly affected by the large growth of phytoplankton's causing 80 % to 135 % dissolved oxygen saturation, while in Delhi the quality was found so bad that photosynthesis processes were absent. The calibrated model was subsequently applied for predicting the water quality for the waste load reduction schemes of the Action Plan. It was found out that the water quality of the river in upstream of Delhi would be increased form class B (BOD<3mg/L) to class A (BOD<2mg/L). The authors suggested that by applying certain dissolved oxygen control technologies along with the Action Plan, the water quality would improve to class D (BOD<6 mg/L) in Delhi segment and the water could be used for wildlife and fisheries.

Manguerra and Engel (1998) in their study described the important parameterization issues involved when modelling watershed hydrology for runoff prediction using SWAT. The emphasis was on how to improve model performance without resorting to tedious and arbitrary parameter by calibration. Synthetic and actual watersheds in Indiana and Mississippi were used to illustrate the sensitivity of runoff prediction to spatial variability, watershed decomposition, and spatial and temporal adjustment of curve numbers and return flow contribution. SWAT was used to predict stream runoff from actual watersheds in Indiana that had extensive subsurface drainage. The results of this study provide useful information for improving SWAT performance in terms of stream runoff prediction in a manner that is particularly useful for modelling ungaged watersheds wherein observed data for calibration is not available.

Peterson and Hamlet (1998) used SWAT incorporating a GRASS GIS interface to model the hydrologic response of the Ariel Creek watershed of Northeastern Pennsylvania. The Nash-Sutcliffe Coefficient for model evaluation was found to be -0.03. It was found during the study that the model performance was affected by unusually large observed snowmelt events and the inability of the model to accurately simulate base flow. Snowmelt events in the springs of 1993 and 1994, which were unusually severe, were not adequately simulated. The results of this study suggest that SWAT model is better suited to longer period simulations of hydrologic yields and that the snowmelt routine estimation using SWAT can be improved.

Abbasi *et al.* (1999) in their study carried out modelling of water quality of Buckingham Canal situated in a petrochemical industrial complex, in Chennai, India. The canal received wastewaters from Madras Refineries Limited (MRL), and Madras Fertilizers Limited (MFL). This canal was modelled using the software QUAL2E-UNCAS. This study enabled the forecasting of impacts of different seasons, base flows, and waste water inputs on the water quality of the Buckingham Canal.

Yang *et al.* (1999) in their study on the Te-Chi Reservoir in Taiwan used remotely sensed data in a water quality model - QUAL2E. They developed a forecasting system which was designed to predict water quality variables using remote sensing data as an input. This was done to initialize and update water quality conditions.

Lee *et al.* (2000) used an updated version of GWLF to model nutrient export in the Choptank river basin on the coastal plain of the Chesapeake drainage basin. It was found that at the decadal time scale (11-year period), GWLF made both accurate and precise predictions of stream flow, Total Nitrogen (TN) and Total Phosphorus (TP) export. Cumulative errors were found to be less than 1%. Model performance was found to degrade with decreasing time scale from annual to monthly. The authors pointed out that with model prediction accuracy ranging from 10-50% of observed values at the annual time scale, the GWLF model was deemed to be a useful model for estimation of fluxes of water, nitrogen and phosphorus over long time periods.

Mansell *et al.* (2000) developed a model for studying wetland hydrology. It was a multidimensional model describing water flow in variably saturated soil and evapo-transpiration. It was used to simulate successfully 3 years of local hydrology within the wetland area. A minimal observed parameter set of daily rainfall, daily air temperature, and soil characteristics were provided to the model as input. The model described temporal patterns of daily wetland water and ground water table elevations with relatively small average deviations of -2 and 11cm, respectively.

In a study in India, Putty and Prasad (2000) carried out a watershed model analysis to understand the catchment response and the relative importance of different runoff processes in the Western Ghat region of South India. A lumped parameter model simulating saturated source area runoff, lateral flow through pipes and the saturated zone groundwater flow was used. The model was calibrated on seven catchments using sufficiently long records of daily data. The model simulations were interpreted to infer that the pipe flow contributions augment the contributions of source area runoff to stream quick flow.

Bingner and Theurer (2001) studied the Annualized AGNPS model. They found that the version-2 of this model is capable of continuous simulation of hydrology, soil erosion, and transport of sediment, nutrients and pesticides. With continuous simulation capabilities, it was able to produce long-term chemical loadings making it more suitable for use in TMDL assessments as compared to AGNPS.

Fohrer *et al.* (2001) applied SWAT in Lahn Dill Bergland in the hilly midlands of Hesse, Germany- as a decision support tool for developing new concepts of land use and for assessing their economic and ecological impacts. Two watersheds of the region namely: Dietzholze (81.8 km^2) and Aar (59.8 km^2) were used for calibration and validation of the model. In Aar watershed two land use scenarios were proposed and SWAT was applied to evaluate the effect of these land use changes on water balance of the region. The results for land use changes showed that the total annual water budget only had a significant effect for changes, which affected more than 20% of the basin area. So, they concluded that for smaller shifts in land use a spatially distributed approach is indispensable. The efficiencies of SWAT model, as measured by Nash Sutcliffe Index were found to range between 0.74 and 0.79.

In another study on SWAT, Santhi *et al.* (2001b) evaluated it to determine management effects on point and non-point source pollution in the North Bosque river watershed, Texas. Best Management Practices (BMPs) for both agricultural land (dairy manure management) and wastewater treatment plants (WWTPs) were employed to reduce in-stream soluble phosphorus concentrations in two locations; Hico and Valley Mills, Texas. Stream flow was predicted for both locations with

Nash-Sutcliffe coefficient Efficiencies (E) ranging from 0.62 to 0.87 during monthly calibration (1993-97) and validation (1998) periods. Sediment and nutrient loads in Hico were all found to be satisfactory with E ranging between 0.53 and 0.80. Mineral N and soluble P were predicted for Valley Mills. Validation results were not found to be satisfactory in this location with E being 0.23, 0.43 and 0.39 for sediment, organic N and organic P respectively. Overall, they concluded that SWAT model is a useful tool for studying the effects of different BMPs on reducing contamination from point and non-point sources in a large watershed.

Jia and Cheng (2002) in their study used Water Quality Analysis Simulation Program "WASP5" model in an integrated system for water quality management in the Miyun reservoir in Beijing, China. Validation of the hydrodynamic portion of the model indicated that WASP5 could represent the hydrodynamic behavior of the Miyun reservoir. On verification of this water quality model they found that the predicted values of dissolved oxygen were fairly close to observed measurements. After testing the model under different scenarios, the authors of this study found that the water quality of the reservoir could be improved by banning cage fishery in it.

Ning *et al.* (2002) presented a new and fast methodology for catchment land-use identification and waste load estimation by properly integrating the skills of remote sensing, GIS, Global Positioning System (GPS) and GWLF model. During their study, they identified eight types of land-use patterns in the watershed area of the Kao-Ping river basin using supervised classification technique from SPOT satellite images. Hydrological and geographical features were derived from the Digital Elevation Model (DEM) using GIS techniques. The GWLF model was used to estimate the waste loads of non-point sources in terms of the TP and TN. The results of GWLF showed that the variations of TN and TP loadings were closely related to the amount of rainfall over seasons.

In another study in 2002, Tong and Chen used a watershed-based water quality assessment tool, the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS), to model the plausible effects of land use on water quality in a local watershed in the East Fork Little Miami River Basin. The statistical analysis of their study revealed that a significant relationship existed between land use and in-stream water quality, especially for nitrogen, phosphorus and fecal coliform. GIS spatial analysis was used to identify the watersheds that had high levels of contaminants and percentages of agricultural and urban lands. The hydrologic and water quality modelling carried out during this study showed that agricultural and impervious urban lands produced a much higher level of nitrogen and phosphorus than other land surfaces. This study revealed that BASINS is a very useful and reliable tool, capable of characterizing the flow and water quality conditions for the study area under different watershed scales. The authors reported that with little modification, this model should be able to adapt to other watersheds and simulate other contaminants.

Yuan *et al.* (2002) in their study on analysis of nitrogen loading from a small agricultural watershed in the Mississippi Delta tested the prediction capability of Annualized AGNPS 2.0. In this study they revealed that soil initial nitrogen concentration and crop nitrogen uptake had the most significant effect on nitrogen loadings. In terms of predictability, AnnAGNPS estimated long-term monthly and annual nitrogen loadings within 127% of the monitored data.

Borah and Bera (2003) compared SWAT with several other watershed-scale models. In this paper, the authors report that DWSM, HSPF, SWAT, and other models have hydrology, sediment, and chemical routines applicable to watershed scale catchments. They concluded that SWAT is a promising model for continuous simulations in predominantly agricultural watersheds.

Evans *et al.* (2003) developed a GIS-based technique for estimating stream bank erosion rates for predicting more accurately the total sediment loads at the watershed scale without the use of detailed field data. The technique relied on the use of data sets that were easily available and could be expressed as GIS data layers. For this purpose an algorithm for estimating stream bank erosion was incorporated into a GIS-based GWLF watershed model. In this study, the authors compared the simulated and observed sediment loads for twenty-eight watersheds in Pennsylvania. The results obtained suggested that the model performed very well. The estimated lateral erosion rates were found to be similar to the rates reported in the previous literature. The stream bank-derived fractions were also found to coincide with estimates derived by other researchers in watersheds having similar characteristics to those used in the study reported.

Meamarian *et al.* (2003) estimated the sediment yield potential of Kashmar urban watershed in Iran using MPSIAC model in the GIS framework. For this purpose they use existing maps, statistical information, field investigation, topographic maps, aerial photographs and GIS software's Arc view, Arc/info, R2V and Auto CAD. The results of their study indicated that in the rocky regions the amount of sediment yield was high due to effect of slope and land use factors on the amount of sediment yield. It was found from the sediment map that in the higher part of rocky basin only mechanical erosion was prevalent while as in the lower part of the basin, light rill and surface erosion was prevalent. The main reason of erosion in the lower parts of the basin was found to be overgrazing. They concluded that by applying reformatory programs, managing grazing, and considering that the basin is not sensitive to erosion, the basin erosion could be decreased.

Saleh and Du (2004) conducted a study to evaluate the major watershed scale models- SWAT and HSPF (Hydrological Simulation Program Fortran) included within the BASINS 3.0 system. The models were calibrated and verified with data from the Upper North Bosque River Watershed (UNBRW), an intense dairy producing region located in central Texas. The accuracy of the models was evaluated using Nash Sutcliffe Model Efficiency (E) and Mean Error (ME). The average daily flow, sediment, and nutrient loading simulated by SWAT were found to be closer to measured values than HSPF during both calibration and verification periods at the outlet of UNBRW. E for daily flow temporal variations for HSPF was found to be 0.72 and 0.70 during the calibration and verification, while the same for SWAT was found to be 0.17 and 0.62 during the calibration and verification, respectively. For sediment the E value during the calibration and verification was found to be 0.11 and 0.23 in case of HSPF model and −2.50 and −3.51 for SWAT, respectively. The authors during this study found that SWAT was more user friendly and generally proved to be a better predictor of nutrient loading during both the calibration and verification periods.

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

Coskun *et al.* (2006) used remote sensing with computer-based GIS techniques for monitoring the water basin area and water quality in a comparatively less polluted catchment of Istanbul Water Dam Reservoir- Terkos. For this purpose SPOT-PAN, XS and IRS-1C/D PAN satellite data of 1993 and 2000 were used for carrying out the urban analysis. In addition Landsat-TM and LISS-III satellite data of 1992 and 2000 were used for water quality monitoring. For calibration and validation, ground truth samples were collected from the study area. On the basis of results of landuse changes and water quality monitoring, the authors suggested certain recommendations for planning and management of the environment of the Terkos catchment.

Kang *et al*. (2006) used SWAT to develop TMDLs for suspended sediments, total nitrogen, and total phosphorus in a small watershed (385 ha) in Korea containing16 irrigated rice paddy fields. In their study, they made use of GIS and remote sensing as well. Results of the study indicated that simulated runoff and water quality values were acceptably close to observed data. It was observed that one of the urbanized sub-watersheds required the largest allocation of load reduction mainly because it was largest in area and was most concentrated in terms of residences and other community activities. Thus, SWAT in integration with GIS and remote sensing was found to be a useful tool for planning TMDLs for small watersheds including rice paddies in Korea.

A GIS-based watershed load model AVGWLF was applied in another study in 2006 by Markel *et al.,* to the Lake Kinneret watershed of Israel, encompassing an area of 167 km^2 and supplying some 30% of the country's fresh water. Pollution from anthropogenic sources and water abstraction for domestic and agricultural uses had been threatening the water quality of the lake. Though it was found that point-source pollution in the watershed had decreased drastically with the development of wastewater treatment, but diffused pollution from agricultural activities was still an unresolved issue. AVGWLF allowed the authors to simulate daily stream flows and monthly sediment, nitrogen, and phosphorus loads discharged to the lake from the surrounding watershed. Results from simulations yielded a satisfactory correspondence between simulated and measured daily water volume. Partition by source of total phosphorus delivered to the lake in the period of 2000–2004 confirmed the reduction in point source nutrient contribution due to improvement of wastewater treatment facilities in the area. The authors suggested that future management of the watershed should focus on reduction of nutrients originating from septic systems (point sources) and pasture and cropland areas (diffuse sources). They concluded that the results from the simulations of their study would enable the watershed managers to prioritize effective management alternatives for protecting the water quality of the lake.

Burgholzer and Sweeney (2007) in their study applied a web-GIS-based interface watershed model- the Chesapeake Online Assessment Support Tool (COAST). The authors on the basis of this study claimed that this modelling framework is capable of being used in watersheds of any size and composition whether inside or outside of the Chesapeake Bay watershed.

Another model Drivers-Pressures-State-Impacts-Responses (DPSIR) was used by Lin *et al.* (2007) to analyze temporal changes in structure and function of a regional coastal wetland ecosystem in Xiamen, China from 1950 through 2005. The study period was divided into four parts for comparative analysis: pre-1980s, 1980s, 1990s, and 2000 to 2005. The results of their study showed that anthropogenic drivers of coastal wetland degradation in the region had increased substantially since 1950, and as a result coastal wetland functions had declined over the same period.

In another study in 2007, Wu *et al.* investigated the influence of recent and future land-cover changes on stream flow of a watershed in Northeastern Puerto Rico using revised GWLF. In this study they compared the monthly and average annual stream flows between an agricultural period (1973–1980) and an urbanized/reforested period (1988–1995). The results of the study showed that a smaller proportion of rainfall became stream flows in the urbanized/forested period compared with the agricultural period. This was attributed to reforestation. Sensitivity analysis of the model showed that evapo-transpiration, precipitation, and curve number were the most significant factors influencing stream flow. Simulations of projected land-cover scenarios indicated that annual stream flows would increase by 9·6% in a total urbanization scenario, while as it would decrease by 3·6% in a total reforestation scenario, and by 1·1% if both reforestation and urbanization continued at their current rates to 2020. The authors suggested that managing the local land-cover changes could have important consequences for water management owing to the environmental setting of the study area, where sea breezes caused by temperature differences between land surface and the ocean dominated the local climate.

Adeka *et al.* (2008) in their study applied the GWLF model to simulate nutrient transport processes in the watershed of Lake Elementaita, located in the Rift valley of Kenya. Hot springs were introduced in the model as point sources. In addition to this, they also studied the spatial variation of water quality. Results of the study indicated that hot springs were an important source of dissolved phosphorus, dissolved nitrogen and total phosphorus for the lake. Agricultural land use was found to be an important source of total nitrogen. This was attributed to the use of fertilizers for agricultural purposes. The spatial variation of electrical conductivity was found to be a good indicator of the water quality variation being influenced by winds, springs and surface water inflow.

Mahay (2008) studied the ecohydrology of Kirumi wetland using SWAT. Rainfall data was used as input to the model and flow data from a gauging station at Mara was used to calibrate the model. A simulation of 25 years was done (1973-1977) for the current situation and another 25 years for future scenario where land use changed to reflect the future developments. The results indicated that there was no remarkable change in the water yield for the two scenarios (only 1.4% from the present to future scenarios).

Prasanna and Kumar (2008) carried out an integrated watershed modelling approach for sustainable development of water and land resources in Kundapallam watershed. The overall objective of their study was to address the ecostatus using GIS and to arrive at watershed modelling for the Kundapallam. The major results of their study were: 1). The runoff was estimated to be 903.48mm by curve technique. The runoff was found to be very low in 2004 as compared to 1994 because of lower rainfall in 2004. 2). From the land use map of 2004 it was observed that 12% of the dense forest area had been converted to horticulture, agricultural area and village. Thus, urbanization and human impacts were found to be the major causes of degradation in the watershed in 2004. 3). Using Musgrave's equation for computation of the topsoil loss 2.5% of the total area (degraded forest), 65.81% of total area (dense forest and horticultural plantation) were placed under very high prone zone with relation to soil loss while 2% of total area (village) was placed under medium prone zone. 30.27% of total area (agricultural land, forest plantation, grassland, land with or without scrub and open forest) was found to be less prone to soil loss. 4). MUSLE was used to calculate the sediment yield in the watershed and the sediment value was found to be very low in 2004 as the runoff and peak flow rate was also comparatively low when compared to that of 1994. 5). Stehlik soil loss model was also used to calculate the soil loss. The soil loss was found out to be 138.5977 ton/ha/year in 1994 and 168.54 tons/ha/year in 2004. The gross erosion of the Kundapallam watershed was found to be 168.54 tons/ha/yr.

In yet another study, Yuan *et al.* (2008) using AnnAGNPS identified critical areas where conservation practices could be implemented and predicted their impact on Beasley Lake water quality in the Mississippi Delta. First model evaluation was performed which demonstrated that the model had satisfactory capability in simulating runoff and sediment at an event scale. During this study, the authors indentified high sediment-producing areas for nonpoint source pollution control where sediment loads could be reduced by 15% to 77% using conservation practices. Simulations predicted that converting all cropland to no-till soybeans would reduce sediment load by 77% whereas no-till cotton would reduce it to 64%. The authors finally suggested that the approach taken in their study could be used elsewhere in applying AnnAGNPS to ungauged watersheds or watersheds with limited field observations for conservation program planning or evaluation.

AbuSharkh (2009) in his study used Watershed Modelling System (WMS) with GIS to estimate the surface runoff from Wadi Hasca watershed located in the Hebron District of Palestine. The morphological parameters for the watershed were determined. Rainfall data of ten years was used for the analysis and estimation of the direct runoff for the study area. The results of his study showed that the average annual runoff depth of watershed was 95 mm, and the average volume of surface runoff from the same watershed was 693500 cubic meter per year. The amount of runoff represented 19% of the total rainfall.

Strobl *et al.* (2009) in their study assessed nutrient loads from all adjacent coastal catchments of the Mediterranean sea region-an important regional European Union (EU) sea, often used to assess the global change of the environment because of its practically enclosed character. For this purpose, the GIS interfaced hydrologic/water quality model ArcView GWLF was used. Results showed that the modelled average stream flow and nutrient loads were within the ranges reported in the previous literature. So, they concluded that successful application of this model is feasible. The results of their study helped to determine the effects of the European Union Water Framework Directive legislation. During this study the authors suggested that for improved representation of the actual Mediterranean sea stream flow and nutrient status, more accurate input data are required, particularly for the Asian and North African regions.

Recently, Chikondi *et al.* (2010) carried out a study to investigate the fluxes of nutrients and sediments in Linthipe river catchment of Lake Malawi basin and the manner in which it is affected by anthropogenic activities and natural processes. Data on climate, nutrients, land use, soil and hydrology were collected to model fluxes of nutrients and sediments using the GWLF model. The correlation coefficient (r2) derived from comparing the observed and simulated river discharge was found to be 0.92. For sediments, total nitrogen and total phosphorus, comparison of predicted values with observed data were not found to be statistically significant. The data was also used to model hypothetical management scenarios. They concluded that a hypothetical 10% deforestation of the catchment may lead to an increase in annual sediment, nitrogen and phosphorus loads by 27.1, 15.7 and 2.9%, respectively. Results from this study suggest that anthropogenic activities (agriculture and deforestation) may be by far the largest source of sediment and nutrient loading especially during the rainy season. By reviewing this paper, GWLF approach overall appears to provide reasonably good estimates of mean annual sediment and nutrient loads.

The GWLF model has been used to study the effect of climate change on water resources by various researchers. Jennings *et al.* (2009) in their study used it to quantify the impact of projected climate change, and potential changes in population and land use, on phosphorus export from a sub-catchment in Southwest Ireland. GWLF simulations results for the catchment indicated significant increases in stream flow in winter and spring and decreases between June and November driven by changes in both precipitation and air temperature. Overall results of their study indicated that increase in annual total phosphorus loads attributable to climate change was greater than that from either population or land use change. So, the authors concluded that future climate variability would pose an increasingly significant threat to the successful long-term implementation of catchment management initiatives and projected changes in climate should be included when undertaking modelling exercises in support of decision making for catchment management plans.

Recently Markensten *et al.* (2010) used this watershed model to investigate the impacts of a regional climate scenario on productivity of Lake Malaren in Sweden. They also quantified the response in biomass of three phytoplankton groups. The results of the study indicated that a future scenario with increased warming will lead to a longer growing season for phytoplankton, slightly increased levels of total biomass, and a distinct shift in phytoplankton groups to favor nitrogen-fixing cyanobacteria at the expense of diatoms in Malaren Lake basin. The changes in the timing of nutrient export from the catchment were found to be the primary cause of cyanobacteria dominance over diatoms. Elevated lake temperatures were found responsible for the increase in total phytoplankton biomass.

In another recent study, Schneiderman *et al.* (2010) modelled the effects of climate change on catchment hydrology with this model. The authors reported that catchment hydrology is central to any assessment of the impact of climate change on lakes as it influences the volume and timing of water inputs to water bodies, and the material loads of nutrients, sediment, and pollutants entering the water body. They found that climatic changes in the form of changes in the timings and amount of precipitation, particularly when coupled with a change in air temperature, influence all the major components of the hydrological cycle, including evapo-transpiration, snow dynamics, soil moisture, groundwater storage, baseflow, surface runoff, and stream flow.

2.4 Studies on Land Use/ Land Cover

Land use land cover is an important component in understanding the sequence of changes in the catchment characteristics and the interactions of the human activities with the environment. Land cover refers to the physical material covering the surface of the earth including vegetation, water, soil and artificial surfaces built by human activities. On the other hand, land use refers to the way and how land is used by humans and their habitat (Ramachandra and Kumar, 2004). It's basically a product of interactions between a society's cultural background, state, and its physical needs on one hand, and the natural potential of land on the other (Ram and Kolarkar, 1993). 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). The study of land use and land cover changes has become an important factor for global change in recent years because of having direct impacts on any environment. Infact, land use /land use cover analysis has become a major and fundamental tool in assessing the environmental consequences of human activities, that negatively affect the whole ecosystem. The land use / land cover information helps us to identify areas where immediate attention is required. Even, the amount and degree of water pollution in rivers, lakes, and other water bodies can be predicted on the basis of past and future trends in land use change. Available data on land use land cover changes can provide critical input to decision-making for environmental management and for planning the future (Prenzel, 2004; Fan *et al*., 2007).

Remote sensing and GIS are powerful tools to derive accurate and timely information on the spatial distribution of land use/land cover changes over large areas (Carlson and Azofeifa, 1999; Guerschman, *et al*., 2003; Rogana and Chen, 2004;

Zsuzsanna *et al*., 2005). The use of multi-data satellite remote sensing for the land use/land cover studies goes back to 1970s (Singh, 1989). Before that in early 1970s most of the studies on land use/land cover were carried out using exhaustive field surveys and remote sensing through interpretation of aerial photographs. 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 (Rogana and Chen, 2004). Remote sensing is an excellent tool for indentifying threats generated by land use change to different natural environmental resources including aquatic resources.

Land use change has been mapped and monitored systematically and effectively using satellite data (Ayad, 2005; Bothale and Sharma, 2007; Kent and Gullari, 2007; Taubenbock *et al*., 2008). The combination of improved satellite remote sensing and GIS is an effective and powerful tool for collection and analysis of land cover data (Star *et al*., 1997; Li and Yeh, 2004). GIS provides a flexible environment for collecting, storing, displaying and analyzing digital data necessary for change detection (Demers, 2005; Wu *et al*., 2006). In recent years, these geospatial tools have been widely used for studying the spatial and temporal transformation of land cover, which these tools provide in less time, at lower cost and with better accuracy (Kachhwaha, 1985; Sharma *et al*., 1989; Petit and Lambin, 2001; Apan *et al.*, 2002; Sudhira *et al*., 2004; Huang *et al*., 2008; Deng *et al*., 2009; Manonmani, 2010). Over the last decades, numerous advances have been made in the development of remote sensors and 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). Researchers have carried out several studies using modelling for detecting land changes (especially for urban land use) and their impacts (Batty *et al*., 1999;

Pijanowski *et al*., 2002; Herold *et al*., 2005; Jantz *et al*., 2010; Poelmans and Rompaey, 2010).

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.

Sangchan (2000) after studying the land use/ land cover changes in eastern region of Thailand concluded that remote sensing technology in combination with 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 development, as well as pressure of intense population that appeared to play a fair role as an important driving force during the study time.

Tadesse *et al.* (2001) commented that the information about changes in land use/ land cover provide valuable insights while devising future natural resource management strategies and that remotely sensed data serves 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.

Nagamani and Ramachandran (2003) in their study evaluated the effectiveness of high-resolution satellite data and computer aided GIS techniques in assessing land use / land cover change detection of Pondicherry for the period 1990 to 2002. The results of land use/cover assessment based on visual interpretation for three different years of satellite data between 1990, 1998 and 2002 showed an increase in settlements and a significant reduction in cropland. This they attributed to the change in population density, labour force in agriculture and population growth. In short the most common variable explaining these changes in land use and land cover in their study was the found to be population growth. Their study revealed that satellite data has the unique capability to detect the changes in land use quickly and accurately.

Yang *et al.* (2003) developed a Sub-pixel Imperviousness Change Detection (SICD) approach to detect urban land-cover changes using Landsat and high-resolution imagery in Georgia. The accuracy of the approach was found to be reasonable on comparison with independent reference data. The average absolute error between predicted and reference data was found to be 16.4 % for 1993 and 15.3% for 2001. The study revealed that this approach is objective and repeatable and can be used for monitoring urban land-cover/land-use change over large geographical areas.

Prenzel (2004) studied the use of remote sensing for quantification of land use/ land cover change for planning. The author pointed out that much of the information on land cover and land use that can be derived using remote sensing cannot, or can only with great difficulty and/or cost, be obtained using in situ methods. One of the most important distinguishing characteristics of remote sensing , relative to other data acquisition approaches, was found to be it being able to provide detailed, quantitative land surface information at large spatial coverages and at frequent temporal intervals. The author concluded that the capacity for quantitative land-surface monitoring over large areas makes remote sensing well-suited for a very wide range of disciplines, including that of land-use planning.

Chauhan and Nayak (2005) in their study used IRS LISS III sensor data to find out the rate of land use/land cover changes in Hazira area near Surat, Gujarat. Because of major industrial activities this area had become a hot spot area and required regular monitoring. In this study, land cover information of the period 1970–1972 from the Survey of India topographical maps, and satellite data of the year 1989 and 1999–2002 were used and visual analysis was carried out to measure the land use/land cover changes. Erosion and deposition were observed around the newly constructed jetty. Forest and agriculture area was found to decrease, whereas built-up area was found to increase.

Giri and Jenkins (2005) prepared a new land cover database of Greater Mesoamerica using Moderate Resolution Imaging Spectro-radiometer (MODIS, 500 m resolution) satellite data. The new land cover data was found to be an improvement over traditional Advanced Very High Resolution Radiometer (AVHRR) based land cover data in terms of both spatial and thematic details. The dominant land cover type in the region was found to be forest (39%), followed by shrubland (30%) and cropland (22%). Country analysis showed forest as the dominant land cover type in Belize (62%), Cost Rica (52%), Guatemala (53%), Honduras (56%), Nicaragua (53%), and Panama (48%), cropland as the dominant land cover type in El Salvador (60.5%), and shrubland as the dominant land cover type in Mexico (37%). An error matrix generated using unseen training data provided an overall accuracy of 77.3% with a Kappa coefficient of 0.73608. Overall, MODIS 500 m data was found to be quite useful for broad-scale land cover mapping of Greater Mesoamerica.

Shalaby and Tateishi (2007) applied the Maximum Likelihood Supervised classification and post-classification change detection techniques to Landsat images acquired in 1987 and 2001 to map land cover changes in the Northwestern coast of Egypt. During the study period, changes among different land cover classes were assessed. It was found that a very severe land cover change had taken place as a result of agricultural and tourist development projects. These changes in land cover had led to vegetation degradation and water logging in parts of the study area.

Reis (2008) in his study investigated land use/land cover change by using remote sensing and GIS in Rize, North-East Turkey. For this purpose, Supervised Classification Technique using Maximum Likelihood Method was applied to Landsat images acquired in 1976 and 2000. The results indicated that the region had experienced severe land cover changes in agricultural (36.2%) (especially in tea gardens), urban (117%), pasture (-72.8%) and forestry (-12.8%) between 1976 and 2000. It was observed during the study that the land use/land cover changes had mostly occurred in coastal areas and in areas having low slope values.

Diallo *et al.* (2009) assessed the changes in land use/land cover in the Southern part of Yunnan, China over a nine year period. The study made use of Landsat imageries of 1990 and 1999. The images were classified using Maximum Likelihood Classification method in ENVI 4.3 and mapped using ArcGIS. The results indicated that severe land cover changes had occurred in croplands (+24.90%), forest or shrub land (-18.77%) and built-up (+16.72%). Their study highlights the importance of digital change detection in apprehending the environmental situation in the Yunnan Province.

In another study Zhang *et al.* (2009) reviewed the land use/land cover change in the Pearl River Delta region, where great land use/land cover changes coupled with rapid industrialization and urbanization had deteriorated the water quality. The study emphasized on time series of analysis of land use/land cover trends related to annual sediment yields and critical source areas of erosion for the region since 1980s. This analysis of land use/land cover trends since the 1980s, helped in better understanding of the sediment supply in the region.

Alexander and Mwasi (2010) used Landsat 7 Enhanced Thematic Mapper Plus (ETM+) imagery which has a 15m resolution panchromatic band, for urban mapping through band combination using data fusion techniques. The results of their study indicated that incorporation of a higher spatial resolution panchromatic image improves the land use/land cover classification and mapping accuracy.

Baboo and Devi (2010) detected the changes in land use/land cover pattern of Coimbatore District in Tamil Nadu between 2004 to 2007. They linked land use change with socio- economic change of Coimbatore for that period. The result of their work showed a rapid growth in land use of Coimbatore**.** Cropland was found to be decreasing at the cost of haphazard growth of plantation and settlements. This study revealed that satellite data has the unique capability to detect the changes in land use quickly and accurately. From the analysis carried out during this study, it was found that satellite data is very useful and effective for getting the results of temporal changes.

Dadhich and Hanaoka (2010) studied the spatial and temporal change of land use of Jaipur district, India over a period of 27 years (1975-2002). They used Markov method for this purpose which is based on remotely sensed data. The authors found no stability in land use change process of the Jaipur city and significant increase in built up area, which was found to be more on fringes and periphery of the city as compared to the city centre. Infact, all categories of land use were found to be changing very fast with time. Barren land and water bodies were found to be decreasing rapidly. The authors with the help of this study described how such studies of land use change are important to reduce the effects on environment.

Prabaharan *et al.* (2010) used geospatial tools to study land use/land cover changes in a coastal area. They found that the important coastal land use types of Vedaranniyam coast had been reduced drastically in their extent due to reclamation, dredging, tipping and other anthropogenic activities along the coastal zone. In yet another study on land use/ land cover carried out in 2010 Prakasam studied the changes in land use and land cover in Kodaikanal over 40 years period (1969-2008) through remote sensing approach using Landsat imageries and Survey of India (SOI) maps of the region. GIS software was used to prepare the thematic maps. Ground truth observations were also performed to check the accuracy of the classification. The land use and land cover analysis carried out during this study revealed that forests occupied about 70 per cent of the area in 1969 that decreased to 33 per cent in 2008. Agricultural land, built up area, harvested land and waste land was also found to experience change. Built-up lands (settlements) were found to increase from 3 per cent to 21 per cent. The author concluded that proper land use planning is essential for the sustainable development of Kodaikanal region as it has been identified as one of the bio-diversity rich areas in India.

2.5 Studies on Impact of Climate Change on Wetlands

The term “climate change” refers to any change in climate over time, whether due to natural causes or as a result of human activities (Intergovernmental Panel on Climate Change –IPCC, 2001b). The subject of climate change has in the recent past attracted the attention of researchers in different fields ranging from engineering, physical science, to social science and politics. There is evidence that most of the warming observed over the last 50 years is attributable to human activities (IPCC, 2001b). Impacts of climate change observed around the world include among others the increase in surface temperature, sea-level rise, changes in precipitation and decreased snow cover (IPCC, 2001b). These would in turn impact on other issues such as industry, human health, shortage of water supply, biodiversity and ecosystem. A number of studies have been conducted on climate and land cover change impacts on water resources (Arnell, 1992; Bouraoui *et al*., 1999; Hernandez *et al*., 2000; Xu, 2000; De Roo *et al*., 2001; Fohrer, *et al*., 2001; Fontaine *et al*., 2001; Krause, 2002; Niehoff *et al*., 2002; Ren *et al*., 2002; Eckhardt *et al*., 2003; Legesse *et al*., 2003; El Ghissassi, 2005; Guo *et al*., 2005). Fowler (1999) identified the likely limits of potential climate change impact on water resources in the Auckland region (New Zealand) which served as guidance to planners when ascertaining possible extremes in impact and the most likely direction of change. Bennani *et al*. (2001) quantitatively estimated the possible impacts of climate change on water resources in Morocco and recorded a decrease of 10 to 15 percent of the surface water and groundwater. Miller *et al*. (2003) investigated the hydrological response to different climate change scenarios for six river basins in California. An important result of their study was that for all snowmelt driven runoff basins the late winter snow accumulation was likely to decrease by 50 percent towards the end of the century. These and many more other studies show the importance of linkages between land use/land cover, climate change and hydrological regimes and how these impact on the water resources. Climate affects all aspects of the hydrologic cycle namely rainfall, runoff and evaporation Changes in these components in turn affect the water availability and variability worldwide. Thus a change in climate is likely to affect water supplies and demands as well as ecosystems, migration of population which would pose significant social, economical and political problems.

The IPCC forecasts significant changes in precipitation, evaporation and temperature as a result of this climate change, which is likely to affect many fresh water ecosystems of the world. These are likely to suffer from hydrological changes, especially at catchment level. There could be either increases or decreases in the volume of water entering the lakes, changes in seasonality of the inflows, increased temperatures of lakes and increased evaporation from lake surfaces. Changes in lake stratification could also occur affecting the biological and chemical process of the lakes making them more susceptible to eutrophication. Among the fresh water habitats of the world, wetlands being ecologically situated at the land-water interface are particularly vulnerable to the potential impacts of climate change. Peat lands will become vulnerable with the reduction of permafrost which is a key factor in maintaining their water tables. It has been estimated that an increase in temperature of 1˚ to 2˚C, if accompanied by decreasing soil moisture, would reduce peat formation by 25% (Burkett and Kusler, 2000).

Oechel *et al.* (2000) in a study on assimilation of ecosystem carbon dioxide exchange in response to climate change illustrated that the diversity of response of wetlands to climate change is in reality a result of a balance between changes in water table, temperature, nutrient cycling, physiological acclimatization and community reorganization.

Winter (2000) undertook a hypothetical assessment of wetlands in different hydrological and landscape settings and concluded that wetlands whose hydrology is dependent on precipitation are more vulnerable to climate change than those fed by ground water.

In a study on climate change impacts on fresh water wetland habitats Dawson *et al.* (2003) undertook a modelling assessment of water balance of UK and Ireland using current and future climate scenarios in a GIS based environment. Their results showed that North West Scotland could have a small increase in water availability in summer, whereas Southern England would experience a decrease and associated lowering of wetland water tables.

Johnson *et al.* (2005) carried out a study on vulnerability of Northern Prairie wetlands to climate change. In this study, they modelled water table levels and vegetation in these wetlands and found that climate change would result in a shift in productive habitat for breeding waterfowl.

Clement and Aidoud (2007) reported that oligotrophic habitats were the most sensitive palustrian wetlands to climate change.

In another study on impact of climate change on Estonian coastal and inland wetlands Kont *et al.* (2007) reported climatically induced changes in water levels in the Estonian inland bog over a 47-year period. Ground water levels were found to be rising and falling, demonstrating the potential complexity of wetland response to climate change.

Acreman *et al*. (2009) provided a simple framework for evaluating regional wetland ecohydrological response to climate change in Great Britain. Their paper presents a frame work that can be used for combining models and available data at regional scale and is appropriate for different wetlands, in different countries and for different levels of data availability. The simple models are based on broad conceptual understanding of wetland hydrology and are intended to describe basic ecohydrological processes within the constraints of data availability. Data from Great Britain was used to demonstrate each step in the framework for two temperate wetland types: rain-fed wetlands and flood plain margins. Results for Great Britain predicted reduced summer rainfall and increased summer evaporation that will put stress on wetland plant communities in late summer and autumn with greater impacts in South and East of Great Britain.

On reviewing the literature on lakes and wetlands in Kashmir, it was found that no such approach to study the impact of climate change on these aquatic ecosystems has been made using the scientific and advanced geospatial tools- remote sensing and GIS.

Chapter 3

STUDY AREA

Chapter-3

STUDY AREA

A description of the study area is presented in this chapter indicating various characteristics like location, physiography, geology, drainage and climate. The research was conducted on Anchar catchment.

3.1 Location

The Kashmir valley is a longitudinal depression in the great northwestern complex of the Himalayan ranges and constitutes an important relief feature of geographic significance. Carved out tectonically, the valley has a strong genetic relationship with the Himalayan complex, which exercises an all-pervading influence on its geographic entity. Anchar catchment with an area of 1663.84 Km^2 lies in the Northeastern part of this Kashmir valley between the geographical coordinates of 34°6' – 34°27' N latitude and 74°40' – 75°35' E longitude. The location of the catchment is shown in Fig. 1.

The catchment begins from Ganderbal and ends near Baltal at the base of Zoji-La pass. Ganderbal district has been recently carved out from Srinagar district in the state of Jammu and Kashmir. Anchar is basically a shallow marsh covering a substantial portion of the extensive delta formed by the river Sindh and its numerous branches once they enter the plains of Kashmir valley. The Sindh with a course of about 116 kilometers and a basin area exceeding 1,556 Sq km is perhaps the most developed side valley of Jhelum. Its upper most feeders rise below the lofty peaks near Zoji-La (3256m) as a number of other head streams join from the Amarnath (5270 m), Kolahoi (5425m) and Panjtarni snow fields. The picturesque topography of the catchment is varied exhibiting altitudinal extremes of 1568m (near Anchar) to 5236m above mean sea level. A number of high altitude lakes like Gangabal, Nundkol and Harnag are situated in this area. In addition, the most famous tourist destination of Kashmir- Sonamarg "meadow of gold" also lies in this catchment. Sindh meanders along Sonamarg which has its backdrop of snowy mountains against a cerulean sky. The catchment with its high altitudinal variations consists of deep rock girt gorges, glaciers, forests, open grassy meadows and village dotted slopes. However, these natural resources of the beautiful but environmentally fragile valley of Sindh are at present facing tremendous pressure due to varied anthropogenic activities.

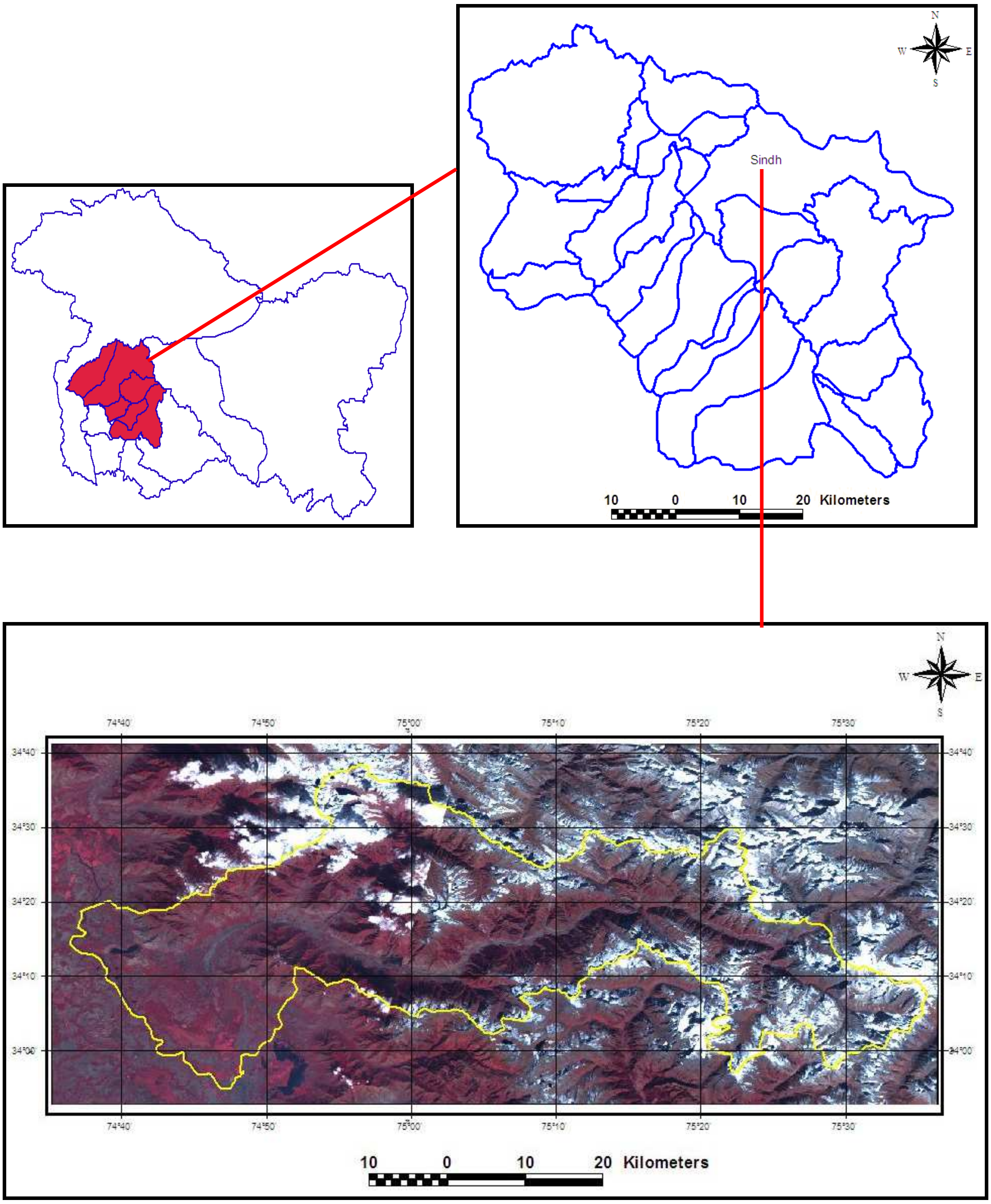

Fig. 1: Location of Anchar catchment

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.

Anchar catchment is represented by three physiographic divisions viz; valley floor (plain area), foot hills or rim lands and upper hills or highly elevated areas. The average altitude of valley floor is (1980 ms), foot hills (2650 ms) and highly elevated areas is 3220 ms. Fig. 2 shows these physiographic landform elements of the study area. The valley floor is the most important and a striking feature of the catchment. It is not a monotonous flat plain but rather much varied in its surface characteristics. It contains a combination of depositional and erosional features. The low-lying areas which are either water logged or subjected to recurrent inundation go on receiving layer after layer of fine silt and coarse gravel. The numerous effluents of the Jhelum which drain the slopes of the bordering mountains bring huge detrital material to the valley floor, building leeves and deltaic fans over extensive areas. The alluvial flats are bordered by the Karewas. The Karewa formation is a unique physiographic feature of the Kashmir valley. Karewa are flat topped or undulating surfaced mounds on the sides of the Jhelum flood plain.

The surface structure of the foothill region seems to be undulating throughout the catchment. High elevated region is highly mountainous and rugged. The important mountain ranges of this region on the northern side of the valley are: Arhama bal, Kangan bal, Harmukh bal, Gund bal, Shitkari bal, Sonamarg bal. Towards the south of the valley some of the important ranges are: Thajwas bal, Sumbal bal, Amarnath cave. Wangat valley is the only side valley of the catchment carved out by Kankanaz Nalla.

The extreme eastern part of the catchment is more than 5000 meters above sea level where as the extreme south western part is having very low altitude of less than

1600 meters near Anchar lake and Naran Bagh. At this point river Sindh discharges its water in river Jehlum. The valley floor consists of 80 percent of total population while as rest of the 20 percent is scattered on foot hills roughly at an altitude of 3500 meters. The region has got such a varied type of relief that the altitudinal range between south and eastern corner of the valley has been estimated about 3861 meters.

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). Geologically Anchar is believed to have been evolved during the Triasic age of Mesozoic era. The study area Anchar catchment has a very complex and rugged topography with very high relief and steep slopes. It geologically consists mainly of Alluvium, Cambrio, Ord, Silurian and Panjal Traps. Volcanic and Triassic limestone and Alluvium are spread over a large area than other formations in the catchment.

3.3.1 Triassic Formation

These rocks are extensively developed in Kashmir they can be traced conveniently all along the plains of Pir Panjal in Lidder valley, Wardwan valley and Guraiz valley and also north of River Jhelum. These rocks are compact, homogeneous and have a light blue or grey tint. Triassic formation is divided into upper, middle and lower Triassic. The upper division of the Triassic is largely devoid of fossils, while as the lower and middle sections of the system are rich in fossils. The lower Triassic is over 100 m thick, the middle 300m and the upper Triassic is hundreds of meters thick.

3.3.2 Volcanic Formation

Volcanic formation took place in the Upper Carboniferous age. Volcanic Agglomerate Slate deposits are found in Panjal Traps. These mainly consist of basic rocks, and a few intermediate and acidic rocks. Basic types are mainly basalt, and andesitic basalt, while acidic and intermediate rocks are represented by augite-andesites, trachyte, keraphyre, rhyolite and acidic tuffs.

Table 1: Morphometric data of Anchar (Pandit and Yousuf, 2002)

Parameter	Value
Maximum length (Km)	6.00
Maximum breadth (Km)	2.76
Maximum depth (m)	1.75
Mean depth (m)	1.60
Surface area (Km^2)	6.80
Marsh land area (Km^2)	3.80

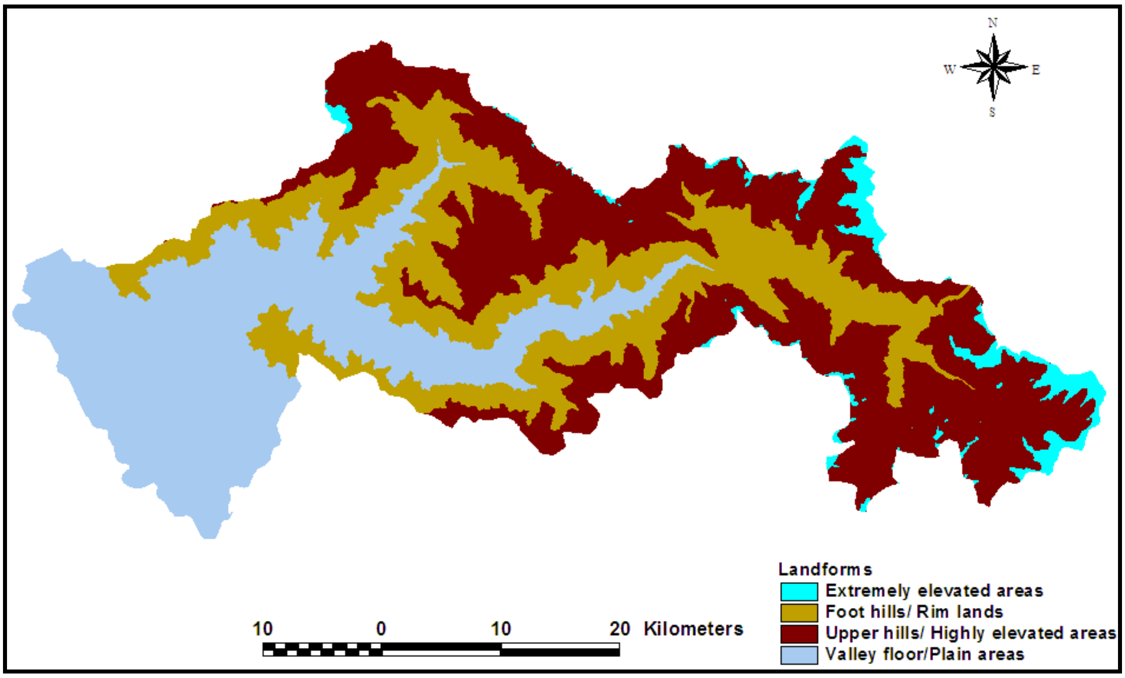

Fig. 2: Landforms in Anchar catchment

3.3.3 Alluvium

These are the recent age deposits of Kashmir. These include the Pleistocene deposits of fluvio-lacustrine or glacial origin known as Karewas. Lithologically the alluvium consists of clay, shale and sand of various hues, textures and structures. The size of grains ranges from fine, medium to coarse, and the cover of the alluvium varies from dark brown, reddish to flesh red. The lithological map of the study catchment is shown in Fig.3.

The formation of the study area has been folded into an Anticline (Sindh Anticline) shown in geological section (Fig.4) which is commonly known as Samasbari Anticline. It is a measure doubly plunging anticline in the Northern half of the area the axis of which passes through Chandanwari, Kolahoi peak, Gund, Kangan, and Ajas. River Sindh obliquely cuts across this anticline from Sonamarg to Ganderbal. In this anticline a Slate and Phyllite sequence (Cambrio-Sularien) Sryingothyris Limestone, Agglomerate Slates, Panjal Traps, Zewan formation have all been folded. Among the permain members, the freshwater beds are however not present. On the other hand Agglomerate Slates are exposed on the both limbs and in the axial part on the eastern half of the structure. In the western half they are not found. Panjal Traps encircle the Anticline but the Zewan Formation outcrops only on the northern flank. To the east of the Ganderbal the dips of the Panjal Traps shows a distinct reversal which may in fact be a local feature developed due to the intrusion of granite body near Kangan.

3.4 Drainage

Anchar has an open type of drainage. It is connected on its eastern side to the famous Dal Lake through a small inflow channel “Nalla Amir-Khan”. Network of channels resulting in a delta type formation from river Sindh enter the lake on its northern end. The southern end of the lake receives water from Khushalsar. The upper most feeders of Sindh rise below the lofty peaks near Zoji-La (3256m). A number of other head streams join it from the Amarnath (5270m), Kolahoi (5425m) and Panjtarni snow fields. At Sonamarg the gushing torrent flows through a narrow channel with deeply incised caves in the bordering rocks on either bank. Further down the river bed deepens more and more to assume the character of a gorge.

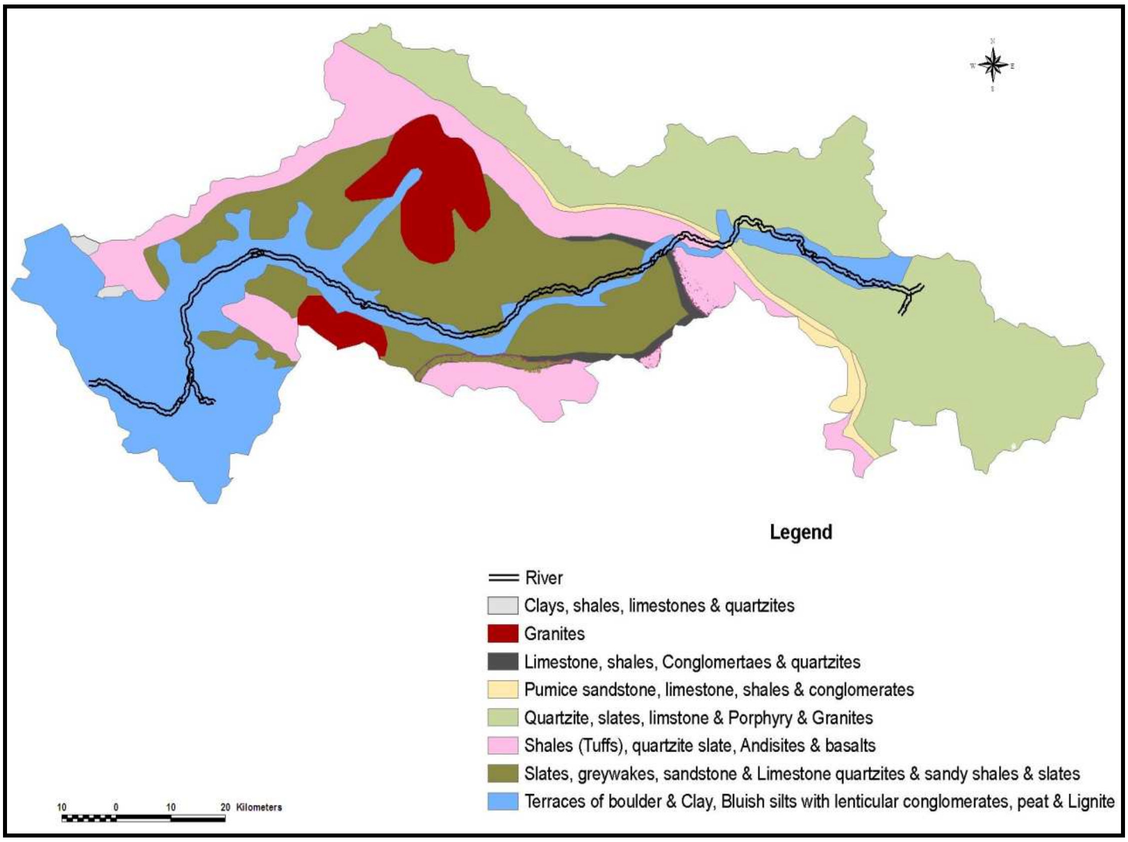

Fig. 3: Lithological map of Anchar catchment

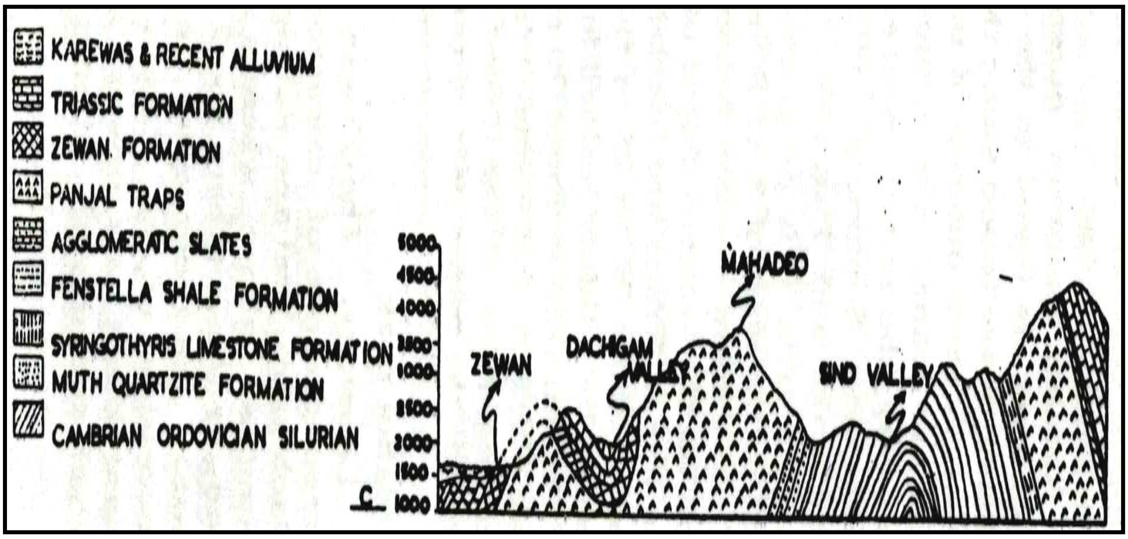

Fig. 4: Geological section along Sindh valley (Raza *et al*., 1978)

Below Kangan the valley widens out. The Sindh receives the Wangat on its right bank a little above Dragti-yung. The river makes a knee bend above Ganderbal before entering into a wide flood plain. As the river sheds its load, its own channels choke with debris and the main stream bifurcates into a number of channels over an extensive deltaic core. One of branches escapes in to the Anchar while others merge with Jehlum near Shadipora. From Kangan to Shadipora the gradient is gentle. Fig. 5 shows the drainage network of Anchar 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 Bagnolus 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.

The climate of Anchar catchment is same as prevailing in Kashmir valley and can be described as temperate montane valley climate the main features of which are wet and cold winters and relatively dry and moderately hot summers. The average maximum and minimum temperatures during summers have been recorded as 20^0 C and 18^0 C respectively. While as the winter minimum and maximum temperatures have been recorded as 0^0 C and 8^0 C respectively. The range in summer temperatures is very low of about 2^0 C and it is very high during winter about 8^0 C. The average diurnal range of temperature during summer and winter months has been recorded as 6^0 C and 10^0 C respectively.

The study area receives an average annual rainfall of 551 mm with Sonamarg receiving 1810 mm. Fig. 6 shows the mean monthly precipitation received in the catchment from 1981-2010. Most of the precipitation is received in the form of snow. The variation in snowfall is quite remarkable in terms of amount between high and low altitudinal areas of the catchment. The areas below the altitude of 2560 meters experience comparatively less snowfall than the areas ranging within the altitudes of

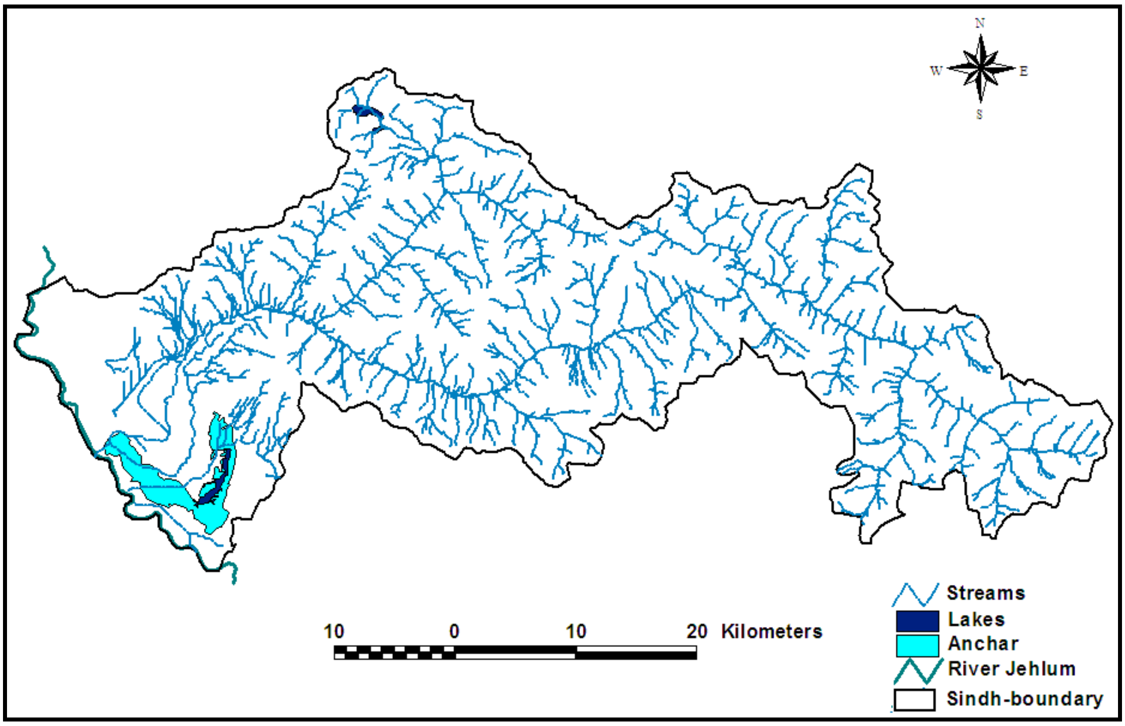

Fig. 5: Drainage network of Anchar catchment

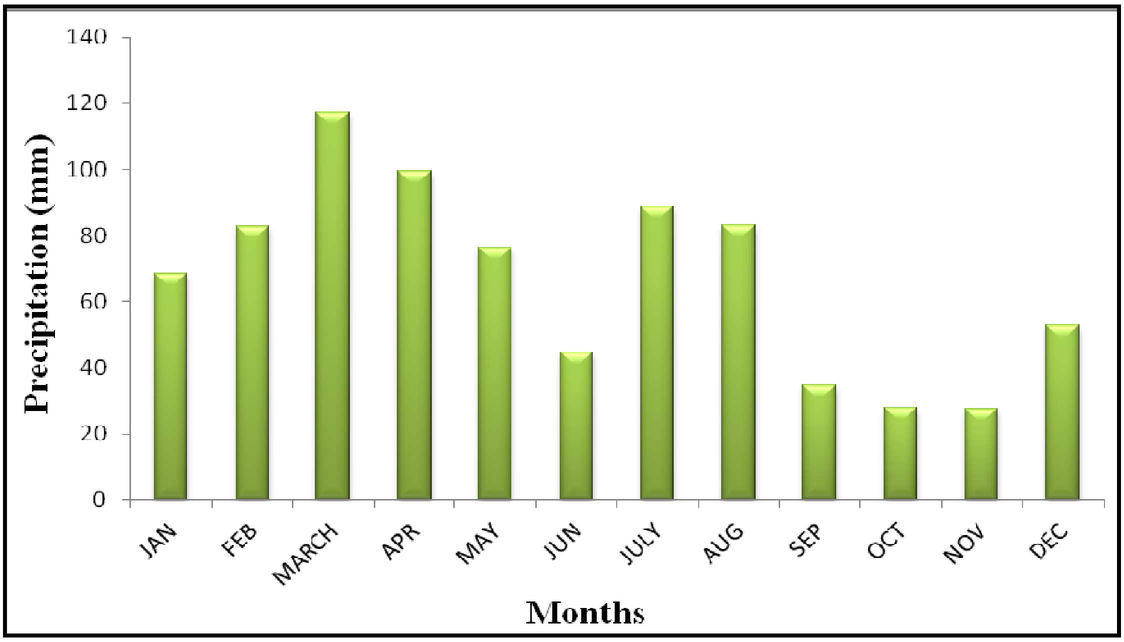

Fig. 6: Mean monthly precipitation in Anchar catchment (1981-2010)

2560 to 5444 meters. So it becomes clear that the upper hill or glaciated region witnesses heavy snowfall. It would be more understood by the fact that the road from Gund onwards till Baltal (which is the extreme north-eastern barrier of the region) remains closed completely for five months. No doubt the lower elevated regions also receive snowfall but it does not persist for long and has no effect on communicational services. The maximum daily humidity of the study area ranges from 80-90% throughout the year and it drops to about 70% at night during winter and to 40% during summer.

Chapter 4

DATA SETS USED

Chapter-4

DATA SETS USED

This chapter gives the details of various datasets employed to carry out the research. A variety of data sets which included satellite images, digital elevation model, field study/ laboratory investigated soil and water data, hydro-meteorological data, and secondary data in the form of topographic maps, published reports and journals, were employed during the research. Ground truthing was also carried out for validation of results. During field study various field equipments were used.

4.1 Satellite Data

Satellite images are photographs depicting pictorial representation of earths features taken from space by electronic devices – the satellites. Satellite imagery is used for recognition of synoptic data of earth's surface (Ulbricht and Heckendorf, 1998). In order to investigate the change in land use/land cover of Anchar catchment, multi-date geometrically corrected satellite images in the form of Landsat Thematic Mapper (TM) image of October 1992 (Fig.7) and Indian Remote Sensing System - IRS-P6 Linear Imaging Self Scanning Sensor (LISS III) image of October 2005 (Fig.8) were used. The most important reason for the use of these satellite images was their rich archive and spectral resolution. Most land-cover/land-use change studies utilize Landsat data due to the uniqueness of the dataset as the only long-term digital archive with a medium spatial resolution and relatively consistent spectral and radiometric resolution (Yang *et al*., 2003)

4.1.1 Landsat 7 TM Image

The Landsat program which was initially known as the Earth Resources Technology Satellites (ERTS) is a series of earth observing satellite missions that was initiated in 1967 jointly by the National Aeronautics Space Administration (NASA) and the U.S. Department of Interior. The ERTS program was officially named as Landsat by NASA in 1975. Till 1986 five Landsat satellites had been successfully launched and since then the Landsat satellites have collected enormous information about earth and its resources from space. This experimental program has today evolved into an operational global resource monitoring program. We can say that the science of remote sensing has matured with the Landsat program. Three different types of sensors were flown in various combinations of the five Landsat missions namely; Return Beam Vidicon (RBV), Multispectral Scanner Systems (MSS) and Thematic Mapper (TM). The characteristics of Landsat 1 to 5 missions and their sensors are summarized in Table 2 and Table 3 respectively.

The Thematic Mapper (TM) is a highly advanced multispectral scanner that was first placed aboard on Landsat -4. Both Landsat 4 and 5 have this advanced sensor developed by NASA onboard. TM incorporates a number of spectral, radiometric and geometric design improvements relative to the Multispectral Scanner Systems (MSS) sensor. Spectral improvements include the acquisition of data in seven bands instead of four, with new bands in the visible (blue), mid-infrared, and thermal portions of the spectrum. The location and wavelength range of the TM bands was chosen to improve the spectral differentiability of major earth surface features. Table 4 gives a description of the spectral bands of TM. Radiometrically TM sensor is advanced than MSS as it performs onboard analog -to-digital signal conversion over a quantization range of 256 digital numbers (8 bits) as compared to only 64 digital numbers (6 bits) used by MSS. It provides a spatial resolution of 30m in all bands except a resolution of 120m in the thermal band. Geometrically TM is a whisk broom sensor that acquires data during both the forward (west-to-east) and reverse (east-to-west) sweeps of its scan mirror. This sensor has a total field of view of 15.4°. In comparison to MSS, TM uses more number of detectors for its various bands 16 for non-thermal bands and 4 for the thermal band. The Landsat TM images find their usefulness for a much wider range of applications than Landsat MSS images because of increase in number of spectral bands (Table 4) and improved spatial resolution.

During the research TM 3-band image of 1992 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 of 4:3:2 (IR:R:G) was used to generate the land use/ land cover map of the year 1992.

Table 2: Characteristics of Landsat-1 to 5 Missions

Satellite	Launch	Sun-synchronous Orbit	Swath Width	Data Rate	Inclination	Temporal Resolution	Radiometric Resolution
Landsat -1	1972	919km	185 km	15Mb/s	99°	18 days	6 bit
Landsat- 2	1975	919km	185 km	15Mb/s	99°	18 days	6 bit
Landsat -3	1978	919km	185 km	15Mb/s	99°	18 days	6 bit
Landsat -4	1982	705km	185 km	85Mb/s	98.2°	16 days	8 bit
Landsat -5	1984	705km	185 km	85Mb/s	98.2°	16 days	8 bit

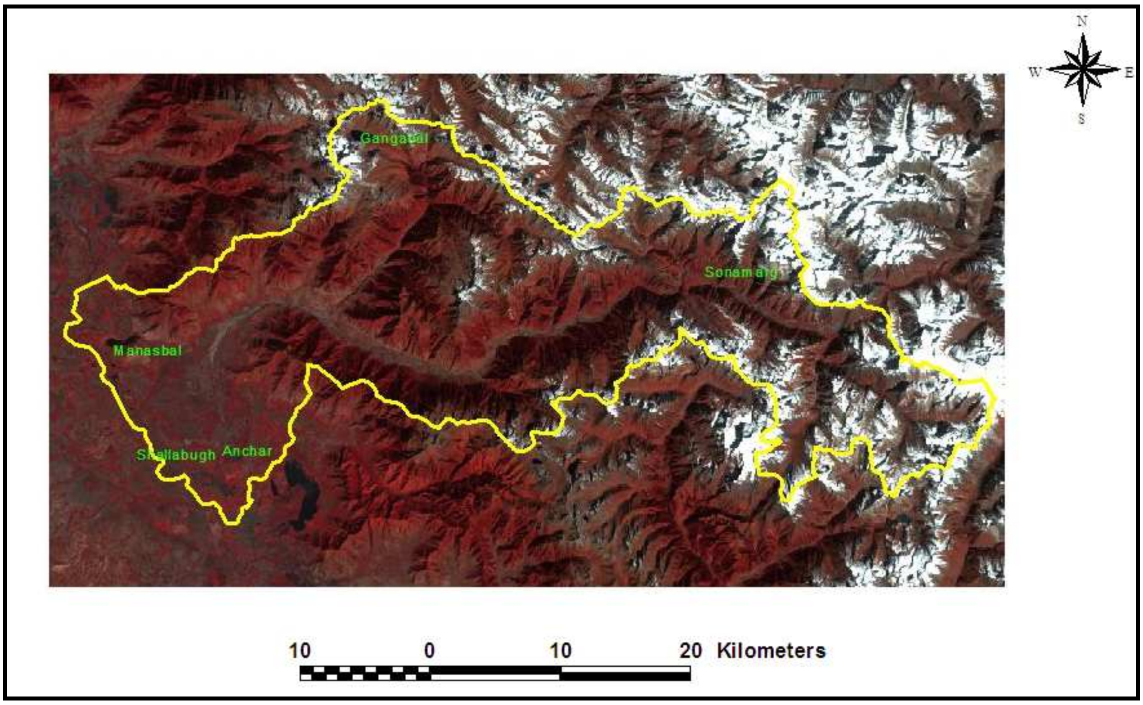

Fig. 7: Landsat TM Image of study area

Table 3: Sensor Characteristics of Landsat-1 to 5 Missions

Satellite	Sensor	Bands	Spectral Resolution(µm)	Spatial Resolution(m)
Landsat -1, 2 and 3	**RBV**	1	0.475-0.575	80
		2	0.580-0.680	80
		3	0.690-0.830	80
		4	0.505-0.750	30
	MSS	4	0.5 – 0.6	79
		5	0.6 – 0.7	79
		6	0.7 – 0.8	79
		7	0.8 – 1.1	79
		8	10.4 – 12.6	240
Landsat-4 and 5	**TM** (In addition to **MSS**)	1	0.45 – 0.52	30
		2	0.52 – 0.60	30
		3	0.63 – 0.69	30
		4	0.76 – 0.90	30
		5	1.55 – 1.75	30
		6	10.4 – 12.5	120
		7	2.08 – 2.35	30

Table 4: Thematic Mapper (TM) Spectral Bands

Band	Wavelength (μm)	Nominal Spectral Location	Principal Applications
1	0.45 – 0.52	Blue	Coastal water mapping, Soil vegetation discrimination, Forest type mapping.
2	0.52 – 0.60	Green	Vegetation discrimination and vigor assessment, Cultural feature identification.
3	0.63 – 0.69	Red	Plant species differentiation.
4	0.76 – 0.90	Near-infrared	Vegetation type determination, Biomass estimation, Soil moisture determination, Water body delineation.
5	1.55 – 1.75	Mid-infrared	Vegetation and soil moisture discrimination, Differentiating snow from clouds.
6	10.4 – 12.5	Thermal- infrared	Vegetation stress analysis, Thermal mapping applications.
7	2.08 – 2.35	Mid-infrared	Mineral and rock type discrimination, Hydrothermal mapping.

4.1.2 IRS LISS III Image

Indian Remote Sensing System (IRS) is a series of earth observation satellites built, launched and maintained by the Indian Space Research Organization (ISRO). ISRO has launched several Indian Remote Sensing (IRS) Satellites: IRS-1A, IRS-1B, IRS-1C and IRS-1D (Table 5-6). The sensors onboard these satellites utilize linear array sensor technology. During this research, IRS P6 LISS III sensor image was used for generating the land use/ land cover for the year 2005.

IRS P6 also known as Resourcesat-1 was launched on 17th October, 2003 by ISRO's Polar Satellite Launch Vehicle (PSLV-5). This satellite is equipped with four sensors namely: LISS III (improved), advanced LISS IV (multispectral), LISS IV Panchromatic (PAN) which permit to receive the earth images with resolution of 5.8 m both in mono and multispectral modes with the enhanced radiometric quality and a new generation Advanced Wide Field Sensor (AWiFS). Through these sensors from a common platform IRS P6 offers a unique opportunity of simultaneous observations at three different spatial scales (Oza *et al*., 2008). All sensors are push broom .The details of this satellite and the sensors onboard it are provided in (Table 7). IRS P6 is basically the continuation of IRS-1C/1D missions with considerably enhanced capabilities providing imageries with improved spatial resolution, additional spectral bands and enhanced radiometric resolution. It carries three cameras similar to IRS-1C/1D but with vastly improved resolutions. IRS P6 is intended not only to continue the remote sensing data services provided by IRS-1C/1D both of which have far outlived their designed mission lives, but to also vastly enhance data quality. The overall objective behind its launch was to provide continuous remote sensing data on an operational basis for integrated land and water resources management. It primarily monitors natural resources like water, vegetation and gathers land management data.

Linear Imaging Self Scanning Sensor (LISS III) is basically a medium resolution, multispectral sensor which was onboard the IRS-1C, IRS-1D and now is onboard the IRS P6 (Resourcesat -1) and Resourcesat-2 satellite systems. This sensor has the feature of on-board detector calibration using LEDs. It can be operated either in real time mode by direct transmission to ground station or in record and playback mode using an on-board 120 GB capacity solid state recorder.

Table 5: Characteristics of IRS-1A and IRS-1B

Sensor	Bands	Spectral Resolution(µm)	Spatial Resolution (m)		Swath Width		Orbit (km)	Inclination	Revisit
			LISS-I	LISS-II	LISS-I	LISS-II			
LISS-I and LISS-II	1	0.45-0.52	72.5	36.25	148km	146km	904	99.5°	22 days
	2	0.52-0.59	72.5	36.25					
	3	0.62-0.68	72.5	36.25					
	4	0.77-0.86	72.5	36.25					

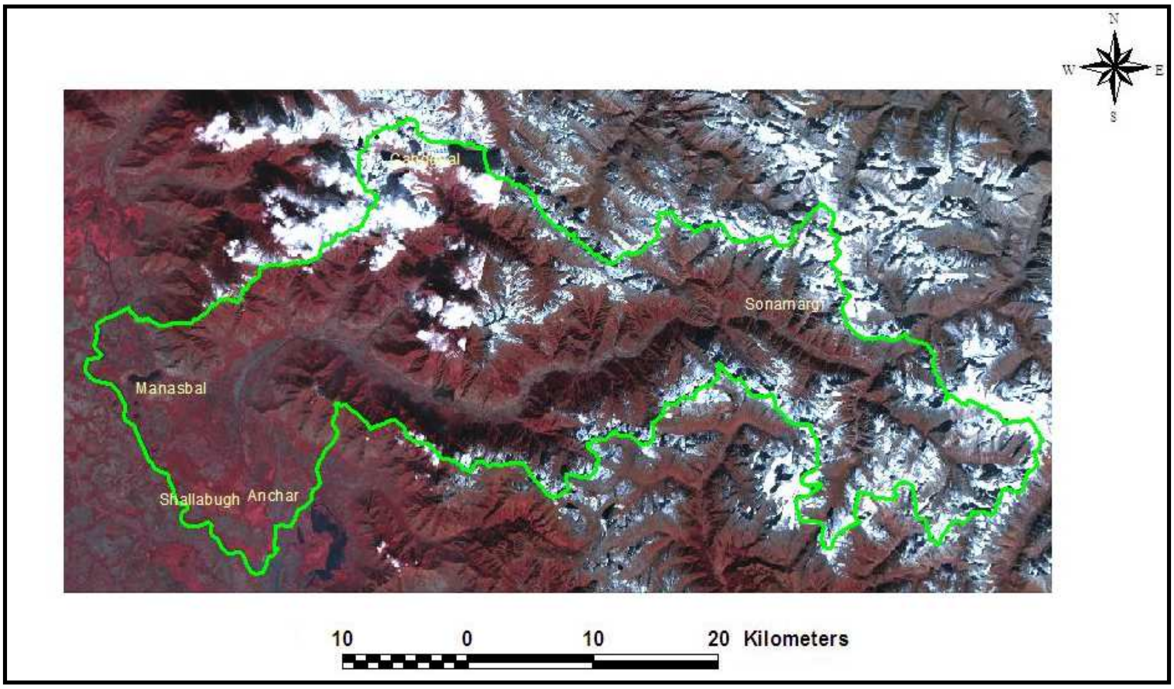

Fig. 8: IRS LISS III Image of study area

Table 6: Characteristics of IRS-1C and IRS-1D

Sensor	Bands	Spectral Resolution (µm)	Spatial Resolution (m)	Swath Width	Orbit (km)	Inclination	Revisit
LISS-III	1	0.45-0.52	23	142 km	817	98.69°	24 days
	2	0.52-0.59	23	142 km			
	3	0.62-0.68	23	142 km			
	4	0.77-0.86	23	142 km			
	5	1.55-1.70	70	148 km			
WiFS	1	0.62-0.68	188	774 km	817	98.69°	5 days
	2	0.77-0.86	188	774km			
PAN	1	0.50-0.75	5.8	70 km	817	98.69°	5 days

Table 7: Characteristics of IRS-P6 and its sensors

Sensor	Bands	Spectral Resolution (µm)	Spatial Resolution (m)	Swath Width	Orbit (km)	Inclination	Revisit	Quantization	Uses
LISS-III	2	0.52 - 0.59	23.5	141 km	817	98.7°	24 days	7 bits	Agricultural monitoring- Crop identification & discrimination, Land cadastre, Disaster management.
	3	0.62 - 0.68	23.5	141 km					
	4	0.77 - 0.86	23.5	141 km					
	5	1.55 - 1.70	23.5	141 km					
LISS- IV	2	0.52 - 0.59	5.8	23.9 km	817	98.7°	5 days	10 bits	
	3	0.62 - 0.68	5.8	70 km (PAN)					
	4	0.77 - 0.86	5.8						
AWiFS	2	0.52 - 0.59	56	740 km	817	98.7°	5 days	10 bits	Exploration work, Small-scale thematic mapping.
	3	0.62 - 0.68	56	740 km					
	4	0.77 - 0.86	56	740 km					
	5	1.55 - 1.70	56	740 km					

4.2 Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) DEM

Digital Elevation Model (DEM) also referred to as Digital Terrain Model (DTM) is defined as a statistical representation of the continuous surface of the ground by a large number of selected points with known X, Y and Z coordinates in an arbitrary coordinate field. DEM is basically a data file containing an array of elevation values. It is a storehouse of immense information revealing terrain characteristics. A DEM offers the most common method for extracting vital topographic information and even enables the modelling of flow across topography. DEMs have been increasingly used for visual and mathematical analysis of topography, landscapes and landforms, as well as modelling of surface processes. 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 30 m ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) DEM was used to generate topographic details of Anchar catchment including slope, elevation, aspect 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. Besides, it also formed an integral component of the GIS based AVGWLF model used for estimating sediment and nutrient loads. Fig. 9 shows the ASTER digital elevation model of the study catchment.

ASTER is a high-spatial-resolution, multispectral imaging system flying aboard TERRA, a satellite launched in December 1999 as part of NASA’s Earth Observing System (EOS). An ASTER sensor captures high resolution data in 14 spectral bands that range from visible to thermal infrared and provides stereo viewing capability for digital elevation model creation. It is comprised of three separate instrument subsystems representing different ground resolutions: three bands in the visible and near infrared spectral range (VNIR, 0.5-1.0 μm) with 15 m spatial resolution, six bands in the shortwave infrared spectral range (SWIR, 1.0-2.5 μm) with 30 m resolution, and five bands in the thermal infrared spectral range (TIR, 8- 12 μm) with 90 m resolution. In the VNIR one nadir looking (3N, 0.76-0.86 μm) and one backward-looking (3B, 27.7° off-nadir) telescope provides black-and-white stereo images, which generate an along-track stereo image pair with a base-to height ratio of about 0.6. The objective of 3B band is to obtain stereoscopic image that can be processed to generate a digital elevation model. The potential accuracy for the DEM from ASTER could be on the order of ±7 to ±50 m. ASTER is capable of recording 771 digital stereo pairs per day, and cross-track pointing out to 136 km allows viewing of any spot on earth at least once every sixteen days. Table 8 presents the characteristics of ASTER.

4.3 Field Study/ Lab Investigated Data

Field survey formed an important aspect of this study programme. The survey was conducted at different time periods during the research period for collection of soil and water samples. Soil samples pertaining to different land use land cover categories were collected from the Anchar catchment. These were then analyzed for different parameters viz. pH, electrical conductivity, soil texture, available water holding capacity, organic carbon and NPK in the laboratory.

Water samples too were collected from various sites of the Anchar and analyzed for various water quality parameters which included water temperature, pH, electrical conductivity, dissolved oxygen and NPK.

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. Trowel and polythene sheets were used for the collection of soil samples which were then stored in 1 kg capacity polythene bags. Water samples were collected in1 liter capacity plastic bottles.

4.5 Hydro-meteorological Data

The hydro-meteorological data was collected from the SKUAST-K, Shalimar station, Srinagar from 1981-2010. The data consisted of daily rainfall and daily temperature (minimum and maximum).

Table 8: ASTER characteristics

Launch date	18 December 1999		
Duration	16 days		
Altitude	705-Km		
Characteristic	**VNIR**	**SWIR**	**TIR**
Ground resolution (m)	15	30	90
Data rate (Mbits/sec)	62	23	4.2
Swath width (Km)	60	60	60
Quantization (bits)	8	8	12

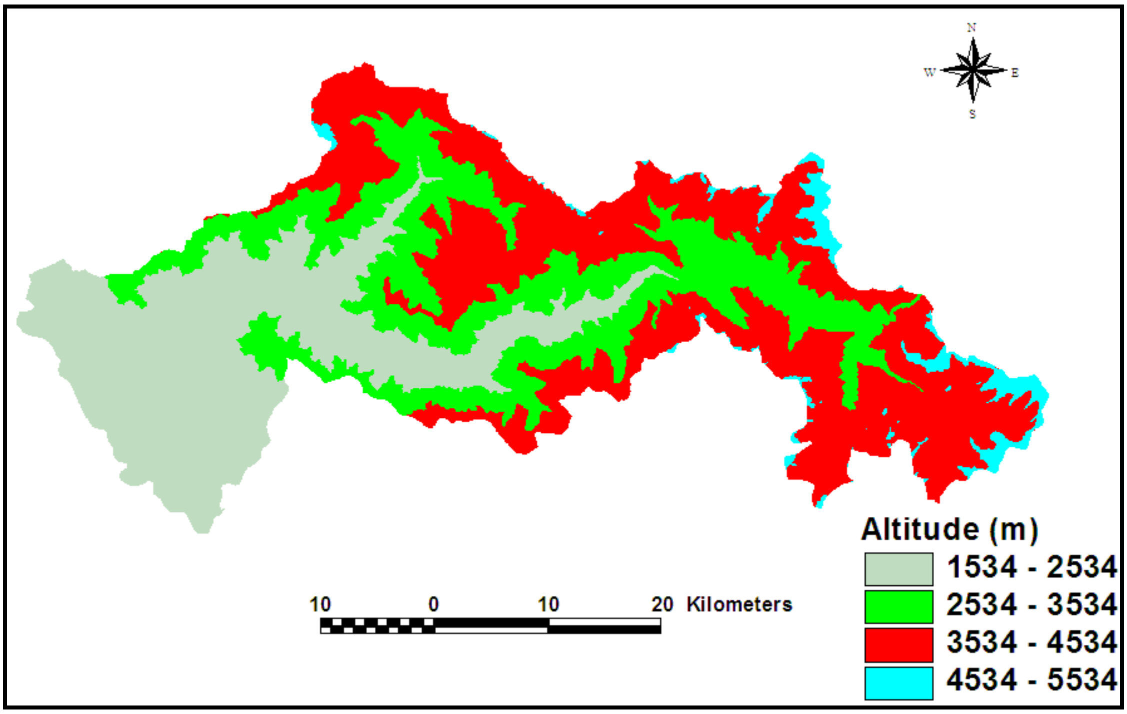

Fig. 9: ASTER Digital Elevation Model of the study area

4.6 Secondary Data

Secondary data defined as the data collected by someone other than the user has a tremendous importance for any study. This data helps in planning for the collection of primary data. Secondary data sources provide vital information required for conducting a research. Secondary data sources which included topographic maps, published reports and journals were used during this research.

4.6.1 Topographic Maps

A topographic map is a large scale detailed two-dimensional representation of natural and human-made features on the earth's surface. In a topographic map the three-dimensional shape of the earth's surface is modelled by the use of contour lines. Contours are imaginary lines that connect locations of similar elevation. Contours make it possible to represent the height of mountains and steepness of slopes on a two-dimensional map surface. These maps use a variety of symbols to describe both natural and human made features such as roads, buildings, quarries, lakes, streams, and vegetation. Topographic maps are mostly used as general purpose and reference maps for GIS based studies. 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.

4.8 Ground Truth Data

During the research ground truth investigations were carried out to validate the land use/land cover maps generated through remote sensing images. Ground truth collection is the ground based measurement or observation of earth surface materials whose reflectance and/ or emittance is being remotely sensed. Ground truth basically refers to information that is collected on location. In remote sensing, this is especially important in order to relate image data to real features and materials on the ground. The collection of ground-truth data enables calibration of remote-sensing data, and aids in the interpretation and analysis of what is being sensed.The main purpose of ground truth data collection was to get a realistic picture of the study area. Various management practices like the use of cover crops, terracing/ contour farming etc. carried out in the catchment were identified during ground survey.

Chapter 5

METHODOLOGY

Chapter-5

METHODOLOGY

The methodology employed for this research involves the use of satellite remote sensing data in a GIS environment combined with field investigation, hydrological data, digital elevation data, secondary/ ancillary data, and simulation modelling. Detailed methodology consisting of schematic flow chart of the methods used to address the research objectives is shown in Fig.10. This chapter will provide a description of all these methods including those used in preparation of input data for GWLF model for simulating nutrient and sediment loads.

5.1 Environmental Characterization of Anchar Catchment

The activities within the catchment of a water body have a direct bearing on its ecological stability. Basically, it's the nature of the catchment (i.e. topography, soil strata) that determine the hydrological characteristics and overall ecology of the water body. Catchment hydrology directly influences the pollution load (nutrients, sediment) entering into an aquatic ecosystem. It is, therefore, imperative to evaluate the entire catchment to better understand the aquatic system. In this objective, the environmental factors prevalent in Anchar catchment were analyzed, which included land use/ land cover change, topography and physico-chemical analysis of soil and water samples collected from the catchment. The sequential details of the methodology adopted for carrying out the various tasks related to the environmental characterization of the catchment are discussed in the following paragraphs.

5.1.1 Satellite data used for land use/land cover change detection

The land use land cover changes in Anchar catchment were investigated using remote sensing and GIS. These are powerful tools which help to derive accurate and timely information on the spatial distribution of land use/land cover changes over large areas. The aim of change detection process is to recognize land use land cover on digital images that change features of interest between two or more dates (Muttitanon and Tripathi, 2005). LANDSAT TM and IRS LISS III remotely sensed images of the study area for the years 1992 and 2005 respectively were used together with ground measurements to analyze the change in land use land cover. The flow

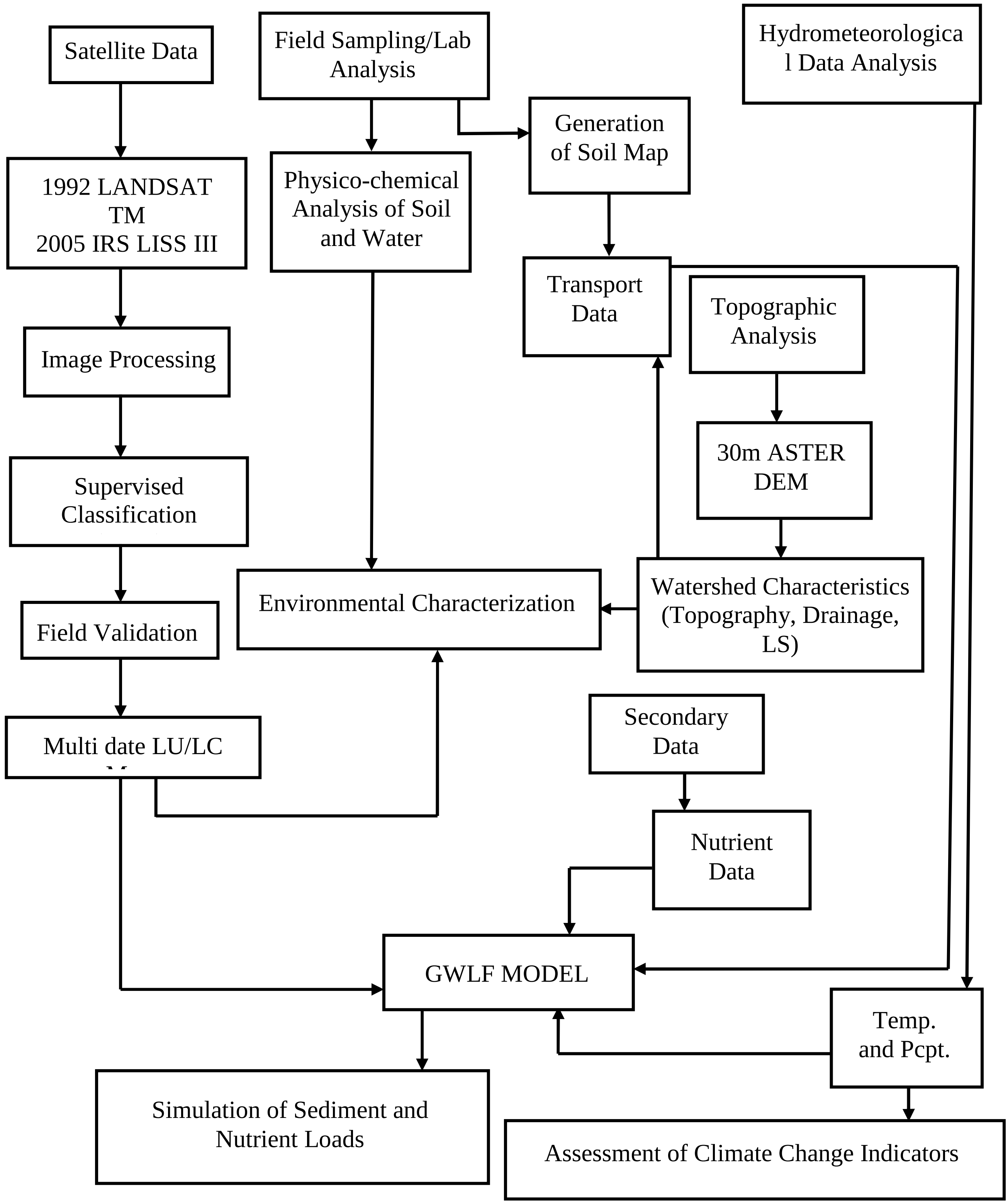

Fig. 10: General methodology adopted during the study

diagram indicating the methodology for land use/cover change detection is given in Fig. 11. The methods employed for this purpose are discussed below in detail.

5.1.1a Satellite data processing

Satellite image processing involves changing the nature of an image to improve its pictorial information for human interpretation and thus to render it more suitable for autonomous machine perception. Several digital image processing methods involving the correction of geometric distortions, radiometric calibrations and elimination of noise were implemented prior to using the satellite images for classification to generate multi-date land use land cover maps and change detection. Digital image processing is the use of computer algorithms for the manipulation and interpretation of digital images. Digital image processing basically involves the use of a computer to change the nature of a digital satellite image.

Geometric correction

Geometric distortions manifest themselves as errors in the position of a pixel relative to other pixels in the scene and with respect to their absolute position within some defined map projection. If left uncorrected, these geometric distortions render any data extracted from the image useless. This is particularly so if the information is to be compared to other data sets, be it another image or a GIS data set (Kumar, 2004). So, geometric correction was a must before going for the classification of imagery and change detection.

Geometric distortions occur due to changes in platform attitude, altitude and velocity, earth's rotation, earth curvature, panoramic distortion, atmospheric refraction, relief displacement and detector delay. The purpose of geometric correction is to correct pixel locational errors, thereby placing ground features in their correct positions throughout the image. These corrections address errors in the relative positions of pixels. Geometric rectification of satellite imagery is a simple process of geometrically correcting an image so that it can be represented on a planar surface, conform to other images or conform to a map, so as to create a faithful representation of the original scene. It is based on a mapping transformation relating real ground coordinates to pixel coordinates. Geometric correction is achieved by establishing the relationship between the image coordinate system and the geographic coordinate system using the calibration data of the sensor, the measured data of position and altitude and the ground control points.

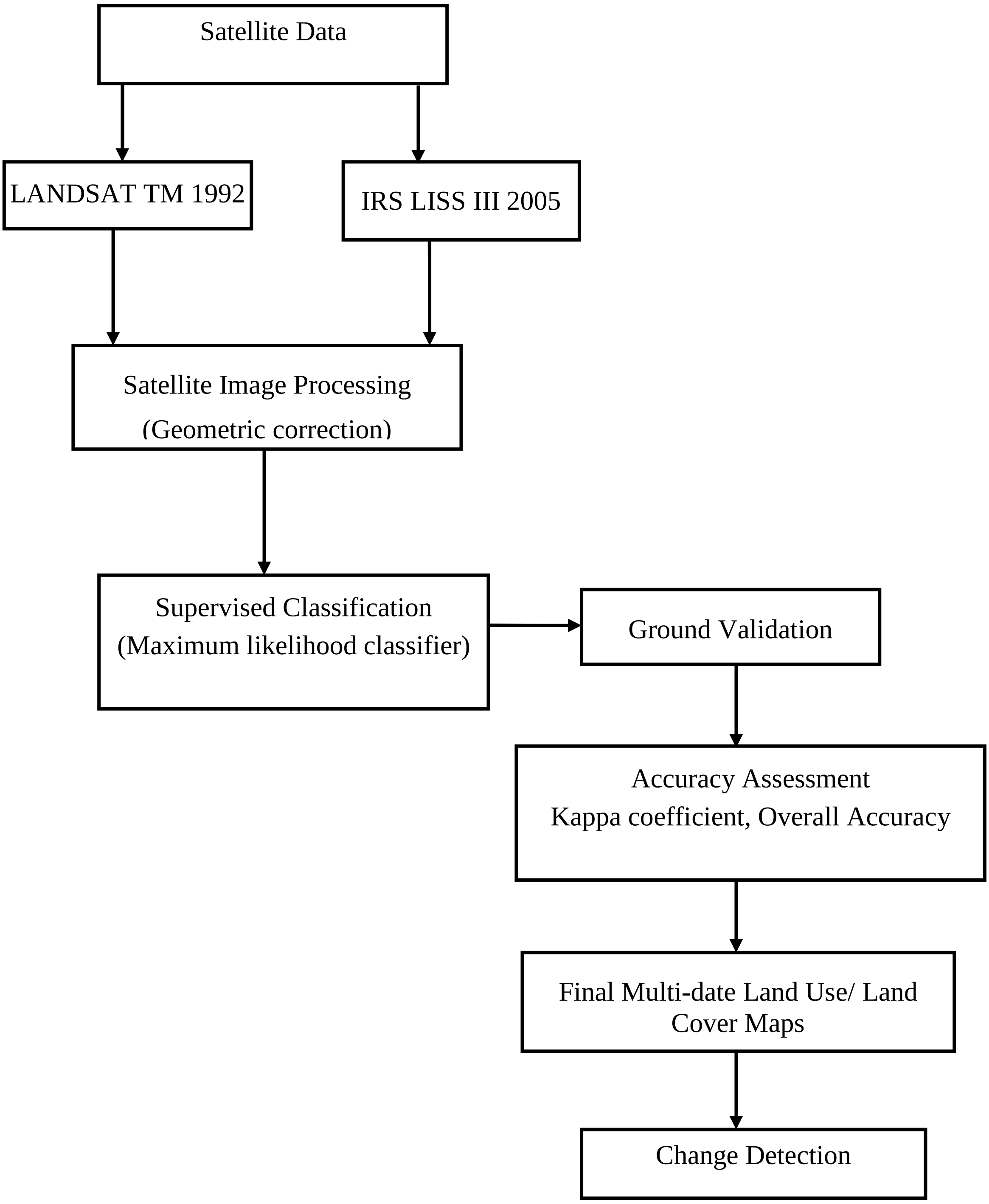

Fig. 11: Methodology adopted for Land use/ Land cover change detection of Anchar catchment

Geometric correction includes the selection of a map projection system and the co-registration of satellite image data with other data that are used as the calibration reference. The images were geometrically corrected in ERDAS Imagine and referenced to Universal Transverse Mercator (UTM) coordinate system with WGS 84 datum. Geometric distortions were corrected by taking 80 Ground Control Points (GCPs) from different parts of the study area. Ground Control Points (GCPs) are the specific pixels in the input image for which the output map coordinates are known. The GCPs 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 then 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. Once mapping transformation was done, then resampling procedure was employed. Resampling matches the coordinates of image pixels to their real world coordinates and writes a new image on a pixel by pixel basis. The nearest neighbor resampling method was used as it offers computational simplicity with real pixel values directly copied from the image and no interpolation algorithms are used. This resampling method simply chooses the actual pixel that has its centre nearest the point located in the image. The final rectified image was obtained with Root Mean square error (RMSE) of 1.146.

Radiometric correction

Radiation from the earth's surface undergoes significant interaction with the atmosphere before it reaches the satellite sensor. This interaction with the atmosphere is stronger when the target surface consists of objects, such as water bodies or vegetation. This problem is especially significant when using multi-spectral satellite data for monitoring purposes, such as agricultural or land use studies (Hadjimitsis *et al*., 2010). Hence, it becomes essential to go for correction of atmospheric effects. Radiometric correction addresses variations in the pixel intensities (Digital Numbers-DNs) including atmospheric effects, topographic effects, differing sensitivities or malfunctioning of the detectors. The purpose of radiometric correction is to eliminate the differences of values between the sensor measured reflected or emitted energy and the object's spectral reflectance or spectral radiance. These corrections are done to improve the visual appearance of image. Radiometric correction is performed for two basic reasons i.e. for the removal of noise and to convert DNs to radiance values. This is done by accounting for solar illumination, atmospheric variables and topographic variations.

Radiometric correction of satellite imagery falls into two broad categories: absolute and relative (Du *et al.,* 2002; Cohen *et al.,* 2003; Coppin *et al.,* 2004). Absolute radiometric correction converts the digital number of a pixel to a percentage reflectance value using established transformation equations (Richter, 1990). This correction is aimed toward extracting the absolute reflectance of scene objects at the surface of the earth, requiring the input of simultaneous atmospheric properties and sensor calibration (Chen *et al.,* 2005). Absolute radiometric correction relies on sensor calibration coefficients, atmospheric correction algorithms, and illumination and observation geometry coefficients. Relative radiometric correction normalizes multiple satellite scenes to each other. This type of radiometric correction has several advantages over absolute radiometric correction. The methodology is usually simpler, requires less computer operating time and less theoretical understanding. More complicated algorithms do not necessarily perform better, and for most studies relative radiometric correction is recommended (Song *et al*., 2001). Relative radiometric correction usually involves the selection of ground targets whose reflectance values are considered constant over time.

The radiometric errors had already been corrected by the data set providers so the data used in the research had been radiometrically corrected prior to its acquisition.

5.1.1b Supervised classification of satellite data using Maximum Likelihood Classifier

One of the main purposes of satellite remote sensing is to interpret the observed data and classify features. Multispectral satellite data is used to perform classification. Image classification, in a broad sense, is defined as the process of extracting differentiated classes or themes (e.g. land use categories, vegetation species) from raw remotely sensed satellite data. The overall objective of image classification is to automatically categorize each cell or picture element (pixel) of the satellite digital data into different land use/ land cover classes or appropriate thematic categories. The end product of classification of remotely sensed image is a class map with each pixel assigned to a unique category or class. The output of classification is a classified image usually called as thematic map of image (Lillesand *et al.,* 2004). Techniques for image classification are of two types: traditional and improved. The traditional methods of image classification include unsupervised and supervised approaches.

For the present study, the two dated images were compared using supervised classification technique. The images of different dates were independently classified using this classification technique. The supervised classification technique was preferred, because there was a prior knowledge of the study area and there was no problem of matching spectral categories on the final map with the informational categories of interest. Supervised classification is basically the process of using samples of known identity to classify pixels of unknown identity. Samples of known identity are those pixels located within training areas. Supervised classification involves various steps namely: selection of training samples, selection of appropriate classification algorithm and accuracy assessment. In this research, supervised classification of satellite data was carried out using training samples and error matrix for accuracy assessment.

Training Samples

Supervised classification is a classification technique in which the image analyst defines on the image a small area, called a training site which is representative of each category or class. In this approach to classification, the image analyst supervises the pixel categorization process by specifying to the computer algorithm numerical descriptors of the various land cover types present in the scene. To do this, representative sample sites of known cover types, called training areas or training sites, are used to compile a numerical interpretation key that describes the spectral attributes for each feature type of interest. Each pixel in the data set is then compared numerically to each category in the interpretation key and labeled with the name of the category it looks most like. During the study, the objective of selecting training samples was to assemble a set of statistics that described the spectral response pattern of each land cover type to be classified in the image. For this purpose different training sets were developed after analysis of various visual (colour, tone, texture, shape, size, association, convergence of evidence, etc.) and statistical (mean, standard deviation, etc.) characteristics of the image data. The training sets were taken from homogeneous cover types and size was taken proportional to class size and variability of the classes. This was done keeping in view the importance of uniformity for a good training area and to ensure that spectral properties of each land use land cover category are represented. Samples were taken with minimum possible standard deviation.

Classifier refers loosely to a computer program that implements a specific procedure for image classification. Here, Maximum Likelihood Classifier was employed to detect the land use land cover types in ERDAS Imagine 9.1. The maximum likelihood decision rule assigns each pixel having pattern measurements or features X to the class c whose units are most probable or likely to have given rise to feature vector x. This method of classification considers not only the mean or average values in assigning classification, but also the variability of brightness values in each class. It's one of the most widely used supervised classification algorithms (McIver and Friedl, 2002; Wu and Shao, 2002). The maximum likelihood decision rule is based on the probability that a pixel belongs to a particular class. The basic equation assumes that these probabilities are equal for all classes, and that the input bands have normal distributions. 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):

$$g\ (x) = log\ \rho\ (w_i)\ .\rho\ (x\ /\ w_i) \quad \textbf{(1)}$$

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:

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

or simply,

$$g_i(x) = \frac{-\log|\Sigma_i| - 1\log[(x-\mu_i)^t.\Sigma_i^{-1}(x-\mu_i)]}{2} \quad \textbf{(3)}$$

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 $i \neq j$.

5.1.1c Ground validation for accuracy assessment of supervised classification

To increase the credibility of a remote sensing derived land use land cover map and to make the information contained in it more effective and useful in management decisions an accuracy assessment needs to be performed. In other words, the data must be checked against the physical land features for accuracy; its accuracy must be assessed. For quantitative assessment of classification accuracy the collection of some in situ data or a prior knowledge about some parts of the terrain is required which can then be compared with the remote sensing derived classification map. During the research, well planned field survey was organized to validate the generated land use/land cover map using GPS and printed satellite imagery. This trip spanned over a period of one week. During field survey, observations and verifications for the ground features were collected for most part of the study area where the location could be reached. The remote sensing derived land use/land cover map was compared with actual land use land cover features present on ground. This helped to identify the misclassified classes and hence to overcome the discrepancies in the classified map.

Since it is impractical to have a complete pixel-by-pixel ground truth map, an adequate subset or sample number of points (pixels) is needed for there to be a rigorous accuracy assessment of a classification. This set of sample points or pixels is called a set of reference pixels. 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). Accuracy assessment can be defined as a comparison of a map produced from remotely-sensed data with ground truth or another map from some other source. It's an important step in the classification process whose goal is to quantitatively determine how effectively pixels were grouped into the correct feature classes in the area under investigation. Accuracy assessment was carried out by using around 150 randomly selected points that were collected during the field survey to determine the accuracy of the land use/ land cover classification. The accuracy of classification results was assessed by computing the error matrix, which compares classification results with ground truth information. Error matrix is one of the most common and useful means of evaluating the effectiveness of classification of remotely-sensed data. It's a means of reporting site-specific error (Campbell, 1987). The error matrix is derived from a comparison of reference map pixels to the classified map pixels and is organized as a two dimensional matrix (Appendix 1). This matrix takes the form of columns representing the reference data by category and rows representing the classification by category. An error matrix is also referred to as a confusion matrix or contingency table, in which classification categories are arranged in columns and reference data is represented along the rows of the matrix (Janssen and Van der Wel, 1994).

Error matrix, derived from image map and field data, was generated for the accuracy assessment. From this matrix, measures of classification accuracy including percentage of pixels correctly classified, errors of omission, and errors of commission were calculated. Errors of omission refer to pixels in the reference map that were classified as something other than their known or accepted category value. In other words, pixels of a known category were excluded from that category due to classification error. Errors of commission refer to pixels in the classification map that were incorrectly classified and did not belong to the category to which they were assigned according to the classification. In other words, pixels in the classified image were included in categories to which they did not belong. Non-diagonal values in each column represent errors of omission and non-diagonal values in each row represent errors of commission (Campbell, 1987). Additionally, a coefficient of agreement between classified image data and ground reference data was calculated using Kappa statistics. Briefly, Kappa statistic considers a measure of overall accuracy of image classification and individual category accuracy as a means of actual agreement between classification and observation.

Overall Accuracy

The percent correctly classified index represents the overall accuracy of the data. It is determined by dividing the total number of correctly classified pixels (sum of elements along the major diagonal) by the total number of reference pixels. It's computed from the error matrix, by using the following equation:

$$OA = \frac{\sum_{K=1}^{N} a_{kk}}{\sum_{K=1}^{N} a_{kk}} = \frac{1}{n} \sum_{K=1}^{N} a_{kk} \quad \textbf{(4)}$$

The overall accuracy provides a relatively simple measure of attribute accuracy (Veregin, 1995), but it does not differentiate between the errors of omission and commission. Indices of these two types of errors are provided by the producers and users accuracy. The relationships are:

Error of omission= 100 - Producers Accuracy

and

Error of commission= 100 - Users Accuracy

Producer's Accuracy

Producer's accuracy is the probability of a sample spatial data unit being correctly classified. It is so called because it indicates how accurate the classification is at the time when the data is produced. It's an indication of how well the training set pixels of a given cover type are classified and is determined by dividing the number of correctly classified pixels in each category by number of training sets used for that category (column total).

$$\text{Producers Accuracy} = C_i / C_t \times 100 \qquad \textbf{(5)}$$

Where,

C_i = correctly classified pixels in the category (column)

C_t = total number of sample locations in the column

User's Accuracy

User's accuracy indicates the probability that a pixel classified into a given category actually represents that category on ground. It is computed by dividing the number of correctly classified pixels in each category by the total number of pixels that were classified in that category (row total).

$$\text{Users Accuracy} = R_i / R_t \times 100 \qquad \textbf{(6)}$$

Where,

R_i = correctly classified pixels in the category (row)

R_t = total number of sample locations in the row

Kappa Statistics

The Kappa statistics is a discrete multivariate measure that differs from the usual measures of overall accuracy assessment in two ways: firstly, the calculation takes into account all of the elements of the error matrix, not just the diagonals of the matrix and secondly it takes into account chance agreement in the classification (Foody, 1992). The chance agreement is indicated by the row and column totals (i.e., marginal's). 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). This statistic was introduced by Congalton and Mead (1983). Kappa statistic is defined as follows:

$$k = ((\theta 1 - \theta 2))/((1 - \theta 2)) \quad \textbf{(7)}$$

k gives an estimate of the overall accuracy.

$$\theta 1 = \sum xii/N \quad \textbf{(8)}$$

Where i=1 to r

$$\theta 2 = \sum x_{i+} + x_{+i}/N^2 \quad \textbf{(9)}$$

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

$$var\ (k) = (\theta 1(1 - \theta))/(1 - \theta 2)^2 + 2(1 - \theta 1)(2\theta 1\theta 2 - \theta 3)/(1 - \theta 2)^3 + (1 - \theta 1)^2\ (\theta 4 - 4\theta 2)^2)/(1 - \theta 2)^4 \quad \textbf{(10)}$$

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

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

The value of Kappa lies between 0 and 1, where 0 represents agreement due to chance only and 1 represents complete agreement between the two data sets. It is usually expressed as a percentage (%).

Proforma that was used for ground truth-cum-field survey is presented in Appendix 2.

Using the methodology described in detail above, final multi-date land use/land cover maps for the year 1992 and 2005 of the Anchar catchment were obtained. The main purpose of generating these multi date maps was to carry out the change detection in land use/land cover of the catchment from 1992-2005 i.e., 15 years. The change detection of Anchar catchment was done by using post-classification change detection method. From the maps generated, the change in each land use/land cover class in the terms of area was determined to have an understanding of changing land use pattern in the study area and to assess how this change has impacted upon the sediment and nutrient fluxes in the catchment.

5.1.2 Field sampling/Lab analysis

The success of a remote sensing application depends on matching ground truth and carrying out field and laboratory measurements (Singh, 2006). In order to completely characterize the Anchar catchment and to have a thorough understanding of the wetland system, the task of carrying out the physico-chemical analysis of soil and water samples collected from the catchment was performed. This task involved field work for the collection of samples as well as the laboratory investigation for determining the various physico-chemical properties of these samples.

5.1.2a Physico-chemical analysis of soil

Soil is an important and significant catchment factor that determines the overall hydrology of a water body located in the catchment. Soil characterization data is a key piece of the picture of how an aquatic ecosystem works. The information about soil properties makes the evaluation of quality of natural resources effective. Therefore, there must be a basic knowledge of the soil types and important properties of soils present in the catchment. For this purpose, field sampling was done to collect soil samples in the Anchar catchment. During the field investigation program which was spread over a period of one week, soil samples of different land use were collected by employing stratified sampling technique. The soil samples so collected were then brought to the laboratory and analyzed for various physico-chemical parameters which included: pH, electrical conductivity, soil texture, water holding capacity, organic carbon, available nitrogen, available phosphorus and available potassium. The standard methods by which each of these parameters were determined are given as follows:

i) **pH:** Digital pH meter (Jackson, 1967)

ii) **Electrical conductivity:** Digital conductivity meter (Jackson, 1967)

iii) **Soil texture:** International Pipetting Method (Piper,1966)

iv) **Water holding capacity:** Keen-Raczkowski Box Method as described by Piper (1966)

v) **Organic carbon**: Rapid Titration Method (Walkley and Black, 1934)

vi) **Available Nitrogen:** Subbiah and Asija (1956)

vii) **Available Phosphorus:** Olsen's Method (1954)

viii) **Available Potassium:** Jackson's Spectrophotometric Method (1967)

5.1.2b Physico-chemical analysis of water

The ever increasing importance of lakes on one hand and the fast environmental deterioration on the other hand coupled with threats to long term sustainability faced by urban lakes like Anchar due to urbanization and other anthropogenic activities in its catchment make the analysis of water quality especially physico-chemical characteristics of Anchar lake extremely important.

The water of Anchar was assayed by collecting site specific samples and subjecting them to analysis in the laboratory. The sampling was carried out on monthly basis for a period of one year (December, 2009 - November, 2010). The water samples were collected from six specific sites Fig. 12 (W1, W2, W3, W4, W5 and W6). These sites were selected on the basis of nature of distribution of pollution load, human activities and sewage in the lake. Site W1 was chosen near Khushalsar, W2 near the outlet of Sher-I-Kashmir Institute of Medical Sciences (SKIMS), W3 near the inflow channel Nallah Amir –Khan which connects Anchar with Dal Lake, W4 from the open water area of Rakh-Kujar, while sites W5 and W6 were located near emergent vegetation zone of Shallabugh wetland to the west of Anchar and within the main Anchar water body itself respectively. These six sites covered almost all directions of the lake helpful for the analysis of Anchar Lake as a whole. Water samples were collected from these sites in acid washed one litre capacity plastic bottles with necessary precautions (Brown *et al*., 1974). These samples were then analyzed in the laboratory for various physico-chemical parameters like water temperature, pH, electrical conductivity, dissolved oxygen, nitrate-nitrogen, total phosphorus and potassium to get a picture of the overall water quality of Anchar. The determination of temperature as well as the fixation of the water samples for estimation of dissolved oxygen was done in field only. The methods used for the analysis of these parameters are:

i) **Water Temperature:** Digital Thermometer

ii) **pH:** Digital pH meter (APHA, 1998)

iii) **Electrical conductivity:** Digital conductivity meter (APHA, 1998)

iv) **Dissolved oxygen:** Iodometric-Azide Modification Method (APHA, 1998)

v) **Nitrate-Nitrogen:** Phenol disulphonic Acid Method (Mackereth, 1963)

vi) **Total Phosphorus:** Ascorbic Acid Spectrophotometric Method (Wetzel and Likens, 2000)

vii) **Potassium:** Using Flame Photometer (APHA, 1998)

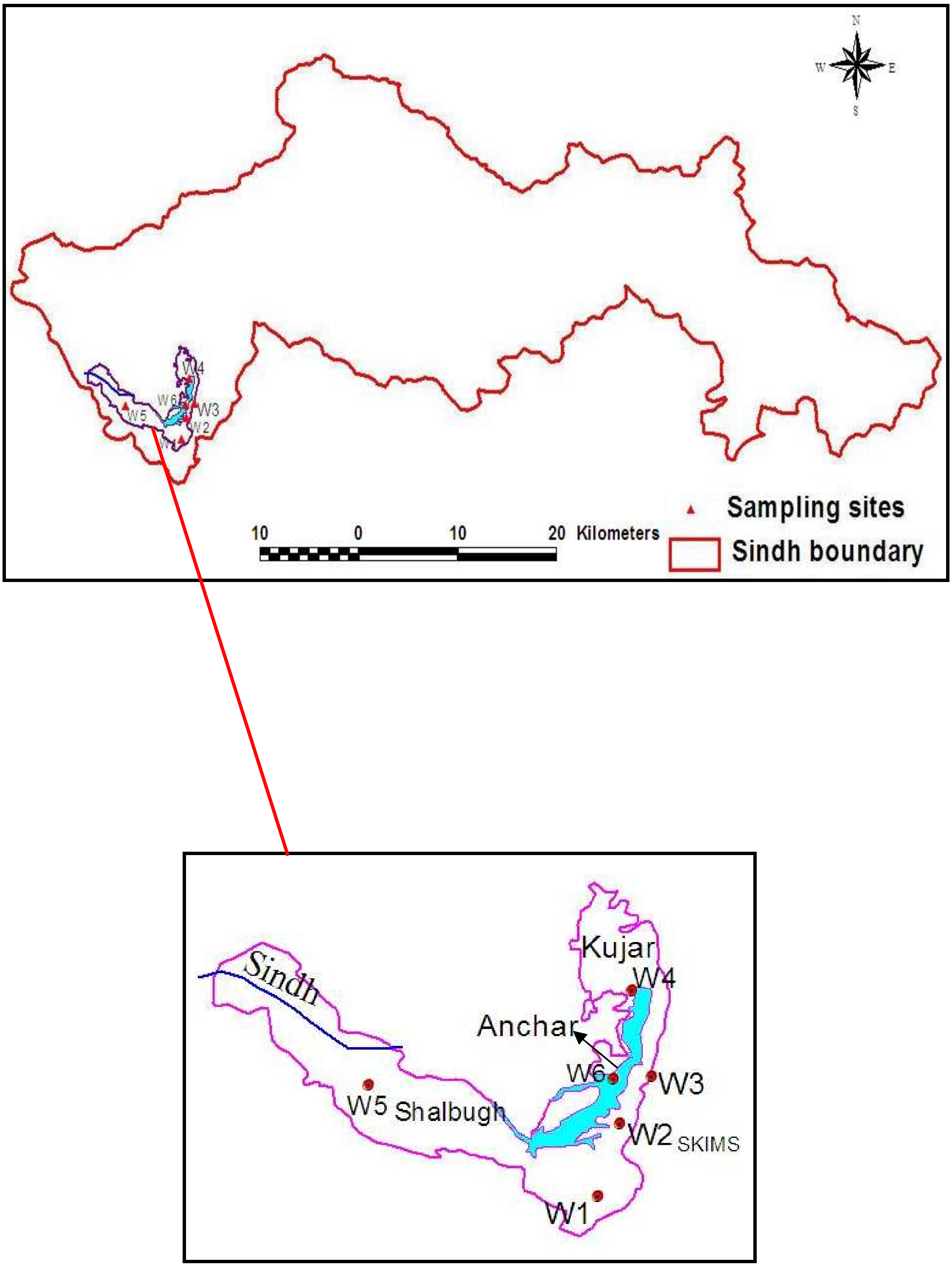

Fig. 12: Water sampling sites in the study area

5.1.3 Topographic analysis

Topographic analysis is the quantitative analysis of topographic surfaces with the aim of studying surface and near-surface processes. This analysis gives us a general understanding about an area, its land form and ground surface variability i.e. terrain. These are represented in the form of specific catchment area, slope, aspect, hill shade, contour, directional flow (curvature), volume, profile and steepest path. Topographic attributes including slope, aspect, relief, elevation and drainage pattern are important to understand and fully characterize a catchment.

In order to topographically characterize the Anchar catchment, the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) digital elevation model was used. The digital elevation model was processed, which involved filling of depressions, generation of flow direction and flow accumulation. After processing topographical attributes which included elevation, slope, aspect and drainage network were calculated from it. The general methodology that was adopted for generating these topographical attributes of the study area is given in the Fig. 13.

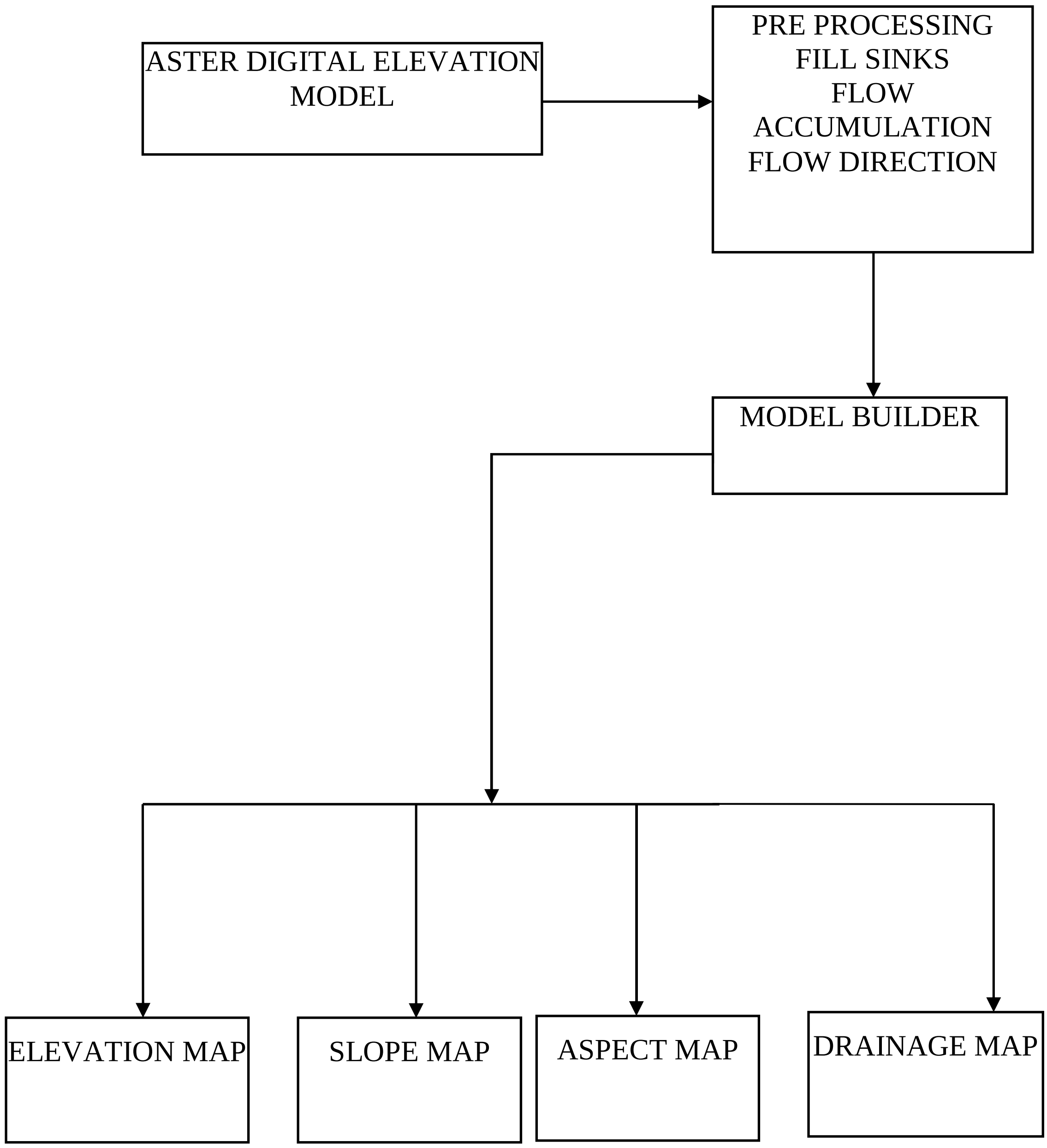

Fig. 13: Methodology for the generation of topographic attributes

5.2 Geospatial Modelling

Geospatial modelling is an analytical set of procedures that simulates real world conditions within a geographical information system using the spatial relationships of geographic features. Geospatial modelling provides new tools and processing structures for incorporating spatial relationships that aid in decision-making processes. In recent years, geospatial modelling especially with distributed and/or lumped models is rapidly gaining ground in providing pollution estimates. Models are simplified mathematical representations of real systems, processes or objects that are created to allow simulation or prediction and to improve a quantitative understanding of a system. Geospatial models are the representation of scientific understanding of the cause-effect mechanism of source of pollution and impairment conditions (National Research Council, 2002). The use of geospatial models for pollution assessment is being increasingly appreciated throughout the world. The use of these models has provided watershed managers with access to more information for making management decisions (Miller *et al*., 2004). These models help users to understand the dynamics of physical watershed systems that include sources of water and pollutant, and the receiving waters such as lakes, rivers, estuaries, and coastal areas (Borah *et al*., 2006). Geospatial models provide a framework for conceptualizing and investigating relationships between climate, human activities (e.g., land-use change) and water resources (Legesse *et al*., 2003).

Identifying the pollution sources and characterizing the timing of pollutants loading into a water body is essential for developing effective management strategies to control pollution of water bodies. Geospatial simulation modelling is useful for characterizing the magnitude and timing of pollutant export from a catchment. The main focus of geospatial water quality models is to determine the critical areas of a watershed so that changes can be made in land use or management practices to alleviate a pollution problem (Tim *et al*., 1992). In this research, water quality modelling method was used for assessing the pollution load of Anchar. A GIS-based catchment scale water quality model, namely Generalized Watershed Loading Function (GWLF) Model was applied to estimate sediment and nutrients entering into the Anchar from its catchment.

5.2.1 Description and Mechanism of GWLF Model

The Generalized Watershed Loading Function (GWLF) is a mid-range watershed loading model with a moderate level of complexity that was developed to estimate stream flow and nutrient loads from ungauged watersheds (Haith and Shoemaker, 1987). It is used to assess, sediment and nutrients loading from urban and rural watersheds. GWLF is one of the tools identified and endorsed by Environmental Protection Agency “EPA”, U.S. as a good mid-level model that contains algorithms for simulating most of the key mechanisms controlling nutrient fluxes within a watershed and has the necessary functionality for use in Total Maximum Daily Load (TMDL) development (USEPA, 1997a; USEPA, 1999b). GWLF model provides the ability to simulate runoff, sediment, and nutrient loadings (N and P) from a watershed given variable-size source areas (e.g., agricultural, forested, and developed land) on a continuous basis (Haith *et al.,* 1992; Lee *et al.,* 2001; Evans *et al.,* 2008). It also has algorithms for calculating septic system loads, and allows for the inclusion of point source discharge data. This model is considered to be a combined distributed/lumped parameter watershed model (Haith and Shoemaker, 1987; Haith *et al.,* 1992). For surface loading, the approach adopted 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. The model does not spatially distribute the source areas, i.e., there is no spatial routing, but simply aggregates the loads from each area into a watershed total. For sub-surface loading, the model acts as a lumped parameter model 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.

GWLF is basically a continuous simulation spatially lumped model, which provides monthly stream flow, soil erosion and sediment yield values. It uses daily time steps for weather data and water balance calculations. Monthly calculations are made for sediment and nutrient loads based on daily water balance. Runoff is simulated based on the Soil Conservation Service's Curve Number method (SCS, 1986) with daily weather (temperature and precipitation) inputs. Erosion and sediment yield are estimated from a modification of the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978; Schwab *et al*., 1981). Sediment delivery is a function of watershed area and erosion estimates from the modified Universal Soil Loss Equation. In addition to runoff and sediment, the model estimates dissolved and total nitrogen and phosphorus loads delivered to streams from watersheds with both point and nonpoint sources of pollution. The model considers flow input from both surface and groundwater. This model includes both dissolved and solid phase nitrogen and phosphorus in stream flow from various sources. Land use classes are used as the basic unit for representing variable source areas. For nutrient simulations, GWLF uses a loading function approach, where dissolved or particulate concentrations are associated with flow volumes or sediment loads, respectively, from various land uses or pollutant source inputs (Yagow, 2004).

The value of GWLF lies not only in the fact that the model is well founded and tested, but also in the fact that it can be ideal for application in different parts of the world to provide valid predictions even in situations where detailed environmental data of all types may not always be available (Strobl, 2002). The advantage of this model is the ease of use and reliance on input datasets less complex than those required by other watershed loading water quality models such as SWAT, SWMM (Storm Water Management Model) and HSPF (Deliman *et al*., 1999).

Mathematical Description of GWLF Model

GWLF estimates both dissolved and solid phase nutrients (nitrogen and phosphorus) in stream flow from various sources. Dissolved nutrients are associated with runoff, point sources and groundwater discharges to the stream. Solid-phase nutrients are due to point sources, rural soil erosion or wash off of material from urban surfaces (Fig. 14).

The model estimates dissolved liquid and solid phase nitrogen and phosphorous in stream flow using the equations 11 and 12 given below.

$$LD_m = DP_m + DR_m + DG_m + DS_m \quad \textbf{(11)}$$

$$LS_m = SP_m + SR_m + SU_m \quad \textbf{(12)}$$

Where,

LD_m & LS_m = dissolved and solid phase nutrient load respectively (kg)

DP_m & SP_m = point source dissolved and solid phase nutrient load respectively (kg)

DR_m & SR_m = rural runoff dissolved and solid phase nutrient load respectively (kg)

DG_m = Ground water dissolved nutrient load (kg)

DS_m = Septic system dissolved nutrient load (kg)

SU_m = Urban runoff nutrient load (kg)

Dissolved nutrient loads from each source area are estimated by multiplying runoff by dissolved concentration as given in equation 13.

$$LD_m = 0.1\sum_{t=1}^{d_m} Cd_k * Q_{kt} * AR_k \qquad \textbf{(13)}$$

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 14

$$Q_{kt} = \frac{(R_t + M_t - 0.2DS_{kt})^2}{R_t + M_t + 0.8DS_{kt}} \qquad (14)$$

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 curve number (CN) values with the equation 15 given below:

$$DS_{kt} = \frac{2540}{CN_{kt}} - 25.4 \qquad \textbf{(15)}$$

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

Monthly solid phase nutrient load are estimated using equation 16 given below. The solid phase rural nutrient loads are given by the product of the monthly sediment yield and average sediment nutrient concentration.

$$SR_m = 0.001 * C_s * Y_m \qquad \textbf{(16)}$$

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:

$$X_{kt} = 0.132 * RE_t * K_k * (LS)_k * C_k * P_k * AR_k \qquad \textbf{(17)}$$

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

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

$$DG_m = 0.1 * C_g * AT * \sum_{t=1}^{d_m} G_t \qquad \textbf{(18)}$$

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).

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.

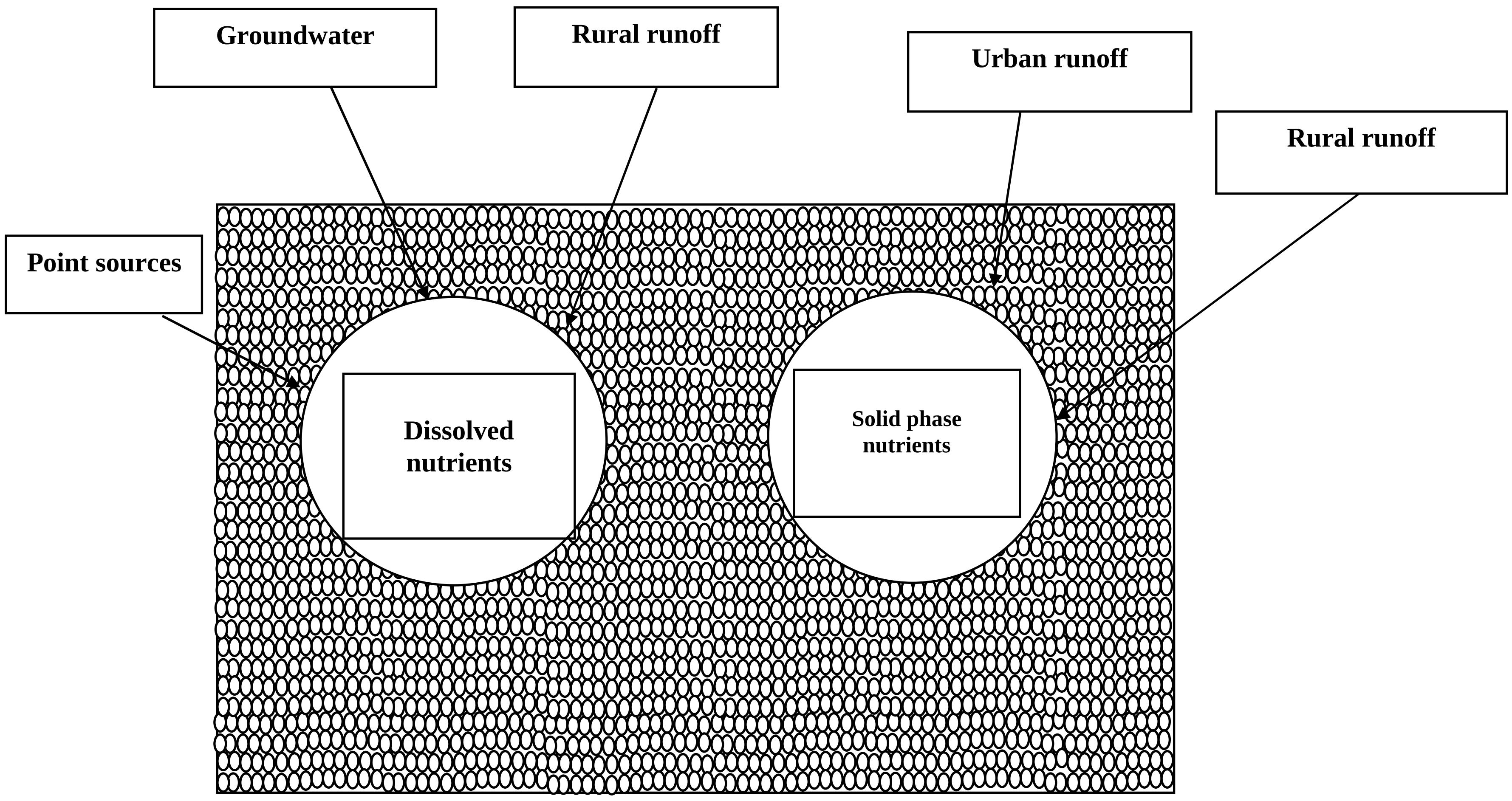

Fig. 14: Model structure for nutrient source in GWLF (adapted from Haith *et al.*, 1992)

5.2.2 GWLF Input Data Preparation

GWLF is a comprehensive model that requires a diversity of information for simulating the sediment and nutrient loads from the catchment areas. It requires the preparation of various separate input files containing information on land use/land cover, topography, weather (daily hydro-meteorological data), transport parameters (hydrological and sediment) and nutrient parameters (nitrogen and phosphorus). Fig.15 depicts the methodology adopted for the model, for the purpose of simulating catchment level sediment and nutrient loads. In the paragraphs written below, preparation of each of the input files required by GWLF for simulation is discussed in detail.

5.2.2.1 Land use/ Land cover Data

Land use and land cover are linked to hydrology, climate and weather in complex ways and are critical inputs for modelling. Land use/land cover information is of great importance, in geospatial modelling as it helps to determine model variables and parameters that account for the volume and timing of runoff. 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). To properly estimate hydrology and nutrient loads within a catchment, the areal extent of various source areas (i.e. sub-units of land defined by different land use/cover types) is required. A digital land use/ land cover layer helps in calculating the extent of different source areas required by GWLF model. Infact, land use data consists of the areas of various rural and urban runoff sources with which dissolved and solid phase nutrients (nitrogen and phosphorus) estimated by the model are associated.

The land use/ land cover input data required to determine the area covered by each land-use type, was prepared by collecting the training samples during field-survey, and then by carrying out supervised classification of multi-date LANDSAT TM (1992) and IRS LISS III (2005) images of the study area using maximum likelihood method.

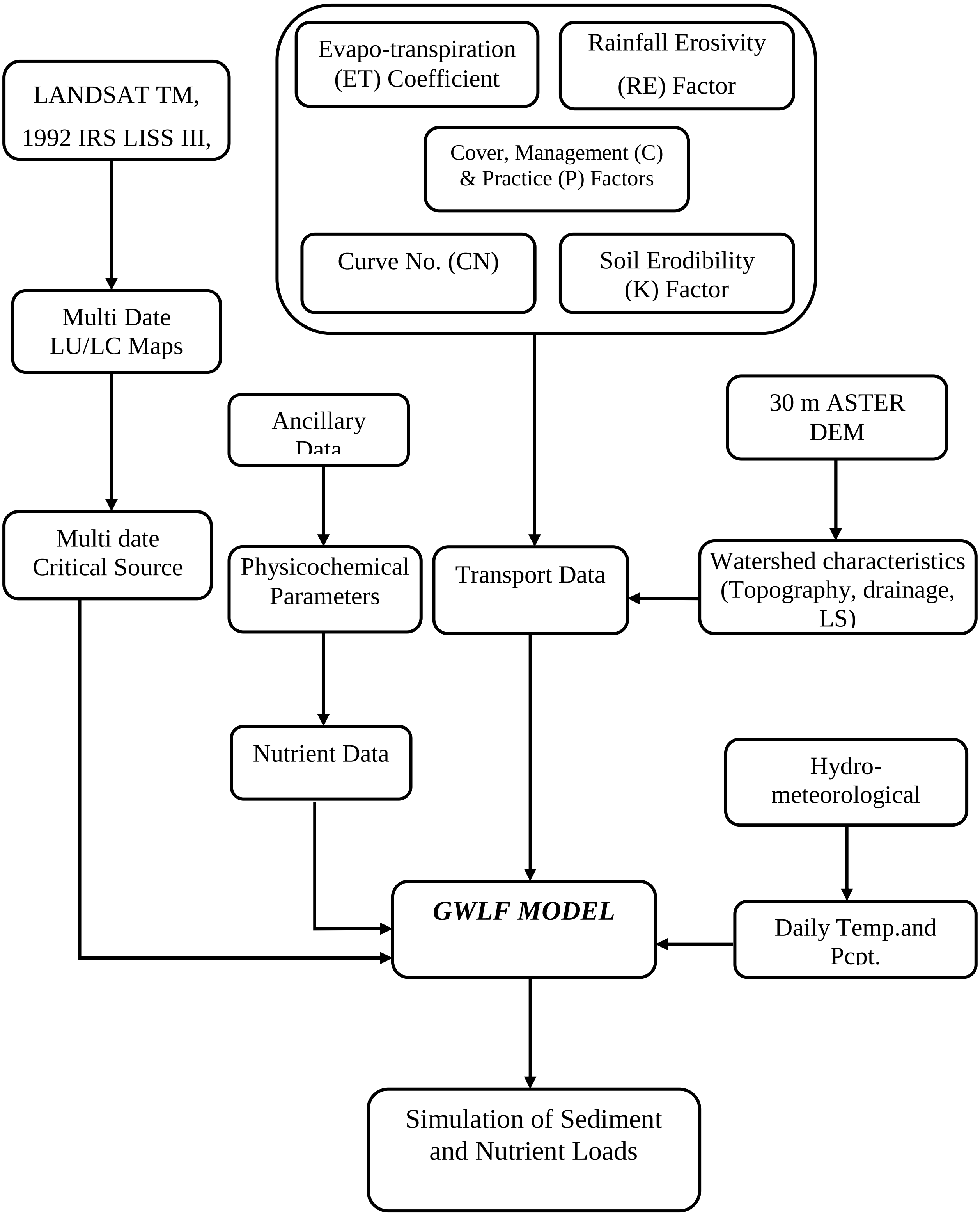

Fig. 15: Methodology adopted for the GWLF Model

Ground truthing was also performed to assist in the imagery classification and to verify the final multi-date land use/ land cover data generated. The detailed explanation of these methods and the flow chart of methodology adopted to generate this input data for use by GWLF have been given in 5.1.1a, 5.1.1b and 5.1.1c and in Fig.11 respectively.

5.2.2.2 Topographic Data

Topography plays an important role in the distribution and flux of water and energy within natural landscapes. Topographic data and its derived physical characteristics are widely used in many environmental modelling applications. Watershed models require physiographic information such as surface elevation, slope length, drainage network, location of drainage divides, and sub catchment geometric properties. In case of the model used in this research, the topographical grid layer is used to calculate land slope related data and contains information on topographic parameters slope length and slope steepness, together designated as LS factors. This input data layer consisting of surface elevation, LS factors and drainage information was prepared from 30m ASTER (Advanced Space-borne Thermal Emission and Reflection Radiometer) digital elevation model after it's processing.

5.2.2.3 Weather Data

Hydrology in GWLF is simulated by a water-balance calculation, based on daily observations of precipitation and temperature. Thus, the weather file required for running the GWLF model should contain daily total precipitation and daily average temperature data. So it involved the preparation of daily data for the precipitation and temperature. The weather data with a time step of 30 years was thus prepared for input into the model. In addition, mean daylight hours for the catchment with latitude 34^0N were obtained from literature (Haith *et al.,* 1992 and Evans *et al.,* 2008).

5.2.2.4 Transport Parameters

The transport data input file required for execution of the model defines the necessary transport parameters for each source, which are those aspects of the catchment that directly and/or indirectly influence the movement of the runoff and sediments from any given cell in the catchment down to the lake. The transport input parameters are used by GWLF to compute water balances and sediment movement. These parameters consist of both hydrological and sediment parameters including runoff curve numbers for antecedent moisture conditions and erosion products- Soil Erodibility Factor (K), Slope Length Factor (LS), Cover and Management (C) and Practice (P) factors for each runoff source. The preparation of each of these input parameters is explained below:

5.2.2.4a Hydrological Input Parameters

These include parameters like Evapo-transpiration (ET) Cover coefficients and Runoff Curve Numbers. Soil data is also an important input parameter required by GWLF for the simulation of hydrological responses.

Evapo-transpiration (ET) Cover coefficients

Evapotranspiration is determined by the model by using daily weather data and a cover factor dependent upon land use/cover type. This cover factor is the Evapotranspiration (ET) cover coefficient. 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). This coefficient relates to the relative amount of evapotranspiration occurring within a given watershed and is based upon existing vegetation cover. It varies with 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.

In GWLF model, ET coefficients are assigned by land use/land cover type and are area-weighted to determine average values for each month of the year. 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

These are empirically derived values used in hydrological simulation studies. The runoff curve number or simply curve number-CN is an empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess (SCS, 1986). This hydrologic parameter describes the storm water runoff potential for a catchment and is a function of land use, soil type, and soil moisture. 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). So, the curve number is assigned on the basis of different combinations of soil and land use/cover type (McCuen, 1989).

In GWLF, the curve number 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

A complete input of soil properties is required to run a catchment scale model in order to assess the hydrological behavior of the catchment. Soil data pertaining to various physico-chemical properties of soil is a basic requirement of hydrological studies and for simulation of various processes. The soil input layer used in GWLF contains information on various soil related properties. Texture, organic carbon/organic matter and available water holding capacity are the soil parameters which form the basis for determining important soil properties such as soil hydrological group and erodibility factor in this model. These soil parameters required for the catchment were obtained by analyzing the soil samples collected during field survey, in the laboratory. Soil texture analysis was carried out by International Pipetting Method (Piper,1966), soil organic carbon / organic matter percent was determined by Rapid Titration Method (Walkley and Black, 1934) while as available water holding capacity was determined by Keen-Raczkowski Box Method (Piper,1966).

5.2.2.4b Sediment Input Parameters

Sediment parameters include Universal Soil Loss Equation (USLE) - rainfall erosivity factor (RE), soil erodibility factor (K), slope length factor (LS), cover and management factor (C), and practice factor (P), sediment delivery ratio (SDR). The product of the USLE parameters, RE * K * LS * C * P is entered as input to GWLF. The following subsections indicate how each of these factors was derived:

Rainfall Erosivity Factor (RE)

The rainfall erosivity factor (RE) represents a measure of the erosive force and intensity of rain in a normal year (Goldman *et al*., 1986). This factor is based on kinetic energy considerations of falling rain and signifies the potential of the rain, or sum of rainfall, during a definite period, to erode the definite soil type. In GWLF, the rainfall erosivity factor is used to estimate rainfall intensity in the Universal Soil Loss Equation algorithm, and varies with season and geographic location.

RE is associated with two components the total energy and the maximum 30-min intensity of storms (i.e., the EI factor as defined by Wischmeier and Smith, 1978). 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 by the joint research centre of the European Soil Bureau (Montanarella *et al.,* 2000). The factor is estimated in the GWLF model using the following equation:

$$RE_t = 64.6 * a_t * Rt_t^{1.81} \qquad \textbf{(19)}$$

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).

The coefficient a_t varies with season. A coefficient of 0.28 for the wet season and 0.18 for the dry season was given as input to the GWLF model (Montanarella *et al.,* 2000).

Soil Erodibility Factor (K)

The soil erodibility factor (K) is a measure of soil's inherent erodibility potential i.e. the susceptibility of soil particles to detachment and transport by rainfall and runoff. It affects the amount of soil erosion from a given field. For a particular soil, the soil erodibility factor is the average soil loss in tons/acre per unit area. K is primarily a function of soil texture, but soil composition (organic matter) and slope also affect it. So, estimation of this factor requires information on the soil texture and soil organic matter of the study area. The value of K factor was determined by using the index given by Steward *et al.* (1975) (Appendix 6).

Slope Length Factor (LS)

This is yet another input factor required by the GWLF model for use in the Universal Soil Loss Equation. This factor is a function of overland runoff and slope. LS factor is basically a combination of two parameters slope length (L) and slope steepness (S) (Arhounditsis *et al.,* 2002). Slope length and slope steepness strongly influence the transport of soil particles once the soil particles are dislodged by raindrop impact or runoff. This factor accounts for the effect of topography on erosion. For use in GWLF, the LS factor was estimated from the Digital Elevation Model of the study area.

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

C and P are two additional factors used by GWLF in the Universal Soil Loss Equation. C the crop management factor has been defined by Wischmeier and Smith (1978) as the ratio of soil loss from land with a specific vegetation cover to the corresponding soil loss from continuous fallow ground. This factor represents the effect of ground cover conditions, soil conditions and general management practices on soil erosion. P which is the conservation practice factor depicts the effectiveness of various structural and non-structural control practices in reducing soil erosion on cultivated land. It is defined as the ratio of soil loss with a specific support practice to the corresponding loss with up-and-down-slope cultivation. This factor 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). The values of both of these factors vary with region, ranging between 0 and 1, the higher the values, the higher the potential of soil erosion (EPA, 2003a).

These factors for each land use/land cover category were estimated following the guidelines given in GWLF User's Manual (Haith *et al.*, 1992). The tables from which C and P factors were determined are given in Appendix 7.

Sediment Delivery Ratio (SDR)

Sediment delivery ratio (SDR) is defined as the fraction of gross erosion that is transported from a given catchment in a given time interval. It is based on the premise that a certain percentage of the material eroded from the land surface (usually the heavier soil particles) is deposited prior to reaching nearby water bodies. The sediment delivery ratio specifies the percentage of eroded sediment delivered to surface water and is empirically based on catchment size. The amount of eroded material that does not reach surface water is the sediment yield.

In the model used in this research, the sediment yield is estimated by multiplying sediment delivery ratio (SDR) with the estimated erosion. So, this ratio converts erosion to sediment yield. 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:

$$SDR = 0.451(b^{-0.298}) \quad \textbf{(20)}$$

Where,

SDR = Sediment delivery ratio

b = Catchment area in square kilometers

5.2.2.5 Nutrient Parameters

The nutrient input parameters are used by GWLF to determine runoff of nitrogen (N) and phosphorus (P) from rural and urban land uses. Nitrogen and phosphorus runoff loads from rural land uses are determined by GWLF separately for dissolved and solid phase components. Collection of runoff from each and every field crop for assessment of nutrient concentrations was one of the greatest challenges of the study and because of the resource and time constraints, this research made use of the values estimated by Haith (1987) (Appendix 9) for different source areas which are more or less representative of the study area.

5.2.3 GWLF Implementation

The GWLF model was implemented using the input data, whose preparation has been discussed in the above paragraphs of this chapter. The model was run for 30 years and the simulation for the same time period 1981-2010 was carried out as a function of changing land use/land cover using the data for 1992 and 2005.

5.3 Assessment of Climate Change Indicators

For assessment of climate change indicators in this research, trends in hydro-meteorological data in the Anchar catchment were examined. For this purpose time series of hydro-meteorological data collected from SKUAST-K, Shalimar weather station was analyzed. The meteorological variables considered were: minimum temperature, maximum temperature, and precipitation for a period of 30 years (1981-2010). Simple monthly average values of the data were calculated to analyze the trend.

Chapter 6

RESULTS

Chapter-6

RESULTS

This chapter illustrates the results obtained during the course of this study. These results are discussed below objective wise.

6.1 Land Use/Land Cover Change

Land use land cover change is the human modification of earth's natural environment or wilderness into built environment such as fields, pastures, and settlements. Land cover actually refers to the physical and biological cover over the surface of land. One of the main manifestations of the human influence on the environment is the direct or indirect transformation of land cover which in turn has a significant impact on local environmental conditions. In the context of environment change, land use change study becomes important (Dadhich and Hanaoka, 2010). In this study, land use land cover change was investigated in Sindh valley- the catchment of Anchar by generating multi-date Land use/ Land cover maps for the year 1992 and 2005 from remotely sensed images as per the National Natural Resources Management System (NNRMS) standards.

The Land use/ Land cover maps generated of the lake catchment for both the years, revealed different land use/cover types, which were grouped into thirteen land use land cover classes namely: agriculture, aquatic vegetation, bare land, built-up, coniferous forests, bare exposed rock, grasslands, horticulture, plantation, river bed, scrubland, snow and water. A description of these land use/land cover classes is presented in Table 9. The results of land use land cover classification for the year 1992 and 2005 are summarized below:

6.1.1 Land Use/Land Cover Map: 1992

Land use/Land cover map gives an account of spatial distribution and areal extent of various categories of land use/land cover. Fig.16 presents the land use/land cover map of the Anchar catchment for the year 1992.

Table 9: Land use/Land cover classes and their descriptions

Land use/Land cover Class	Description
Agriculture	Land areas under different crops
Aquatic Vegetation	Vegetation found in lake waters including mainly macrophytic vegetation
Bare Land	Areas with no vegetation cover
Built up	Areas of settlement, residential, commercial, and industrial establishments
Coniferous Forests	Western Mixed Coniferous Forests- consisting of trees that don't patch off (Fir, Pine)
Bare Exposed Rock	Areas of bed-rock exposure devoid of any vegetation at higher elevations
Grasslands	Moist-alpine pastures – consisting mainly of *Ephedra* formations
Horticulture	Areas under fruit and nut crops
Plantation	Land under natural trees as well as trees planted
River Bed	Bottom of rivers and streams including boulders
Scrubland	Moist-alpine scrub (*Hippophae*, *Myricaria)* formations and open-scrub consisting of shrubs with mid-dense foliage
Snow	Areas covered by snow
Water	Areas under water bodies such as rivers, lakes and streams

The map depicts thirteen major land use land cover classes: agriculture, aquatic vegetation, bare exposed rock, bare land, built-up, coniferous forests, grasslands, horticulture, plantation, river bed, scrubland, snow and water. The areal extent of these land use land cover classes is presented in Table 10. The dominant class in the catchment is coniferous forest (27%), followed by scrubland (21.6%), snow (14.42%), bare exposed rock (9.9%), and agriculture (8.58%). Grasslands, plantation and horticulture cover 5.20%, 3.8% and 3.33% of the catchment area respectively, while as aquatic vegetation occupies 1.99% of the area. On the other hand, river bed area (1.3%), water bodies (1.04%), built-up areas (0.93%) and bare land (0.91%) are the less dominant classes.

6.1.2 Land Use/Land Cover Map: 2005

In the 2005 Land use/Land cover map of the catchment there are yet again thirteen land use land cover classes namely agriculture, aquatic vegetation, bare exposed rock, bare land, built-up, coniferous forests, grasslands, horticulture, plantation, river bed, scrubland, snow and water as shown in Fig.18. The graphical representation of the land use land cover is shown in Fig.19, while the statistics is given in Table 11. From the statistics, it's clear that again coniferous forest (23.6%), is the dominant class in the Anchar catchment followed by scrubland and snow which cover an area of 325.38 Km^2 (19.55%) and 316.44 Km^2 (19.01%) respectively. Water occupying 0.89% of area is the least dominant class. Agriculture, horticulture, grasslands, plantation, bare land and aquatic vegetation occupy 7.71%, 3.88%, 3.81%, 3.13%, 3.01% and 2.4% of the catchment respectively. Built-up covers an area of about 31.34 Km^2 (1.9%).

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Table 10: Area under different Land use/Land cover classes in Anchar catchment (Landsat TM, 1992)

S.No.	Class Name	Area (Km^2)	% age to Total
1	Agriculture	142.80	8.58
2	Aquatic Vegetation	33.05	1.99
3	Bare Land	15.30	0.91
4	Built up	15.62	0.93
5	Coniferous Forests	449.22	27
6	Bare Exposed Rock	164.50	9.9
7	Grasslands	86.67	5.20
8	Horticulture	55.55	3.33
9	Plantation	63.10	3.8
10	River Bed	21.45	1.3
11	Scrubland	359.26	21.6
12	Snow	239.96	14.42
13	Water	17.36	1.04
Total		**1663.84**	**100%**

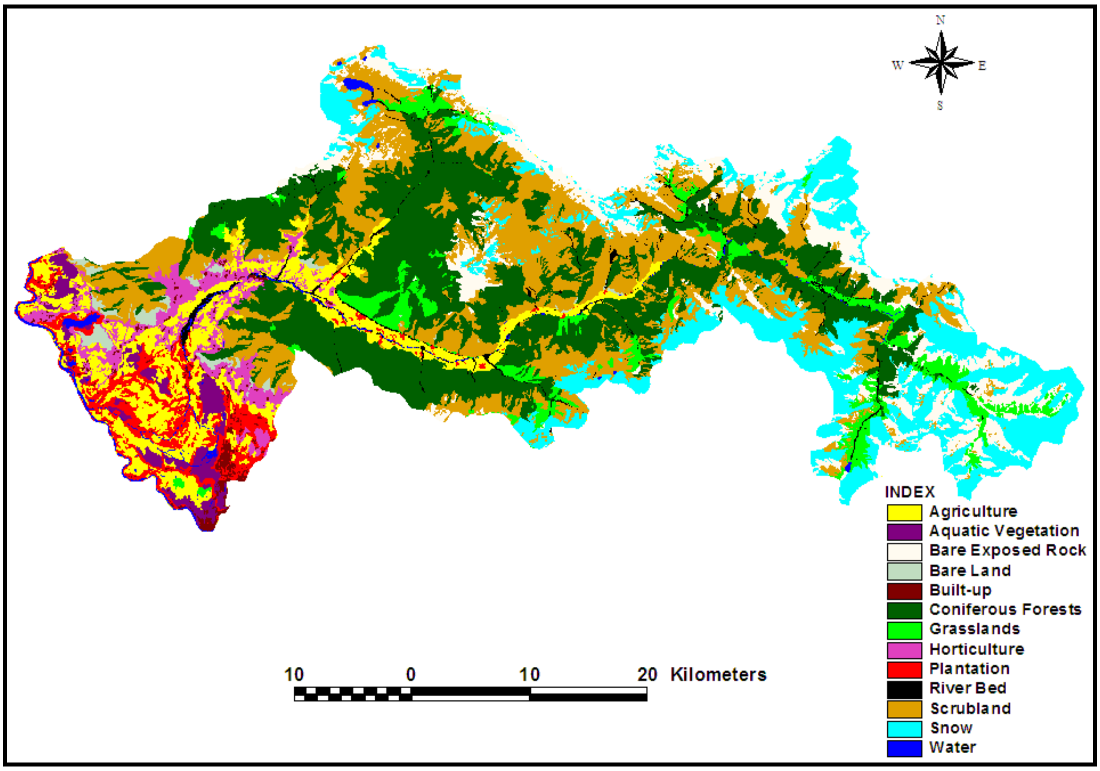

Fig. 16: Land use/Land cover map of Anchar catchment (Landsat TM, 1992)

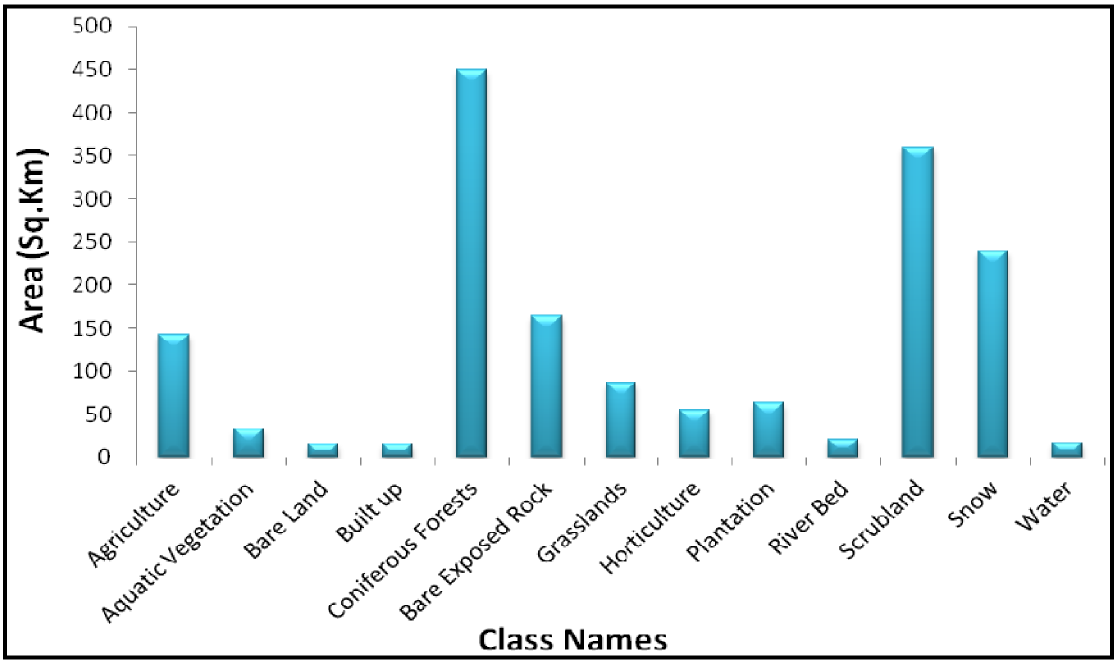

Fig. 17: Area under different Land use/Land classes in Anchar catchment (Landsat TM, 1992)

Table 11: Area under different Land use/Land cover classes in Anchar catchment (IRS LISS III, 2005)

S.No.	Class Name	Area (Km^2)	% age to Total
1	Agriculture	128.38	7.71
2	Aquatic Vegetation	39.51	2.4
3	Bare Land	50.19	3.01
4	Built up	31.34	1.9
5	Coniferous Forests	392.60	23.6
6	Bare Exposed Rock	158.02	9.49
7	Grasslands	63.45	3.81
8	Horticulture	64.57	3.88
9	Plantation	52.11	3.13
10	River Bed	27.10	1.62
11	Scrubland	325.28	19.55
12	Snow	316.44	19.01
13	Water	14.85	0.89
Total		**1663.84**	**100%**

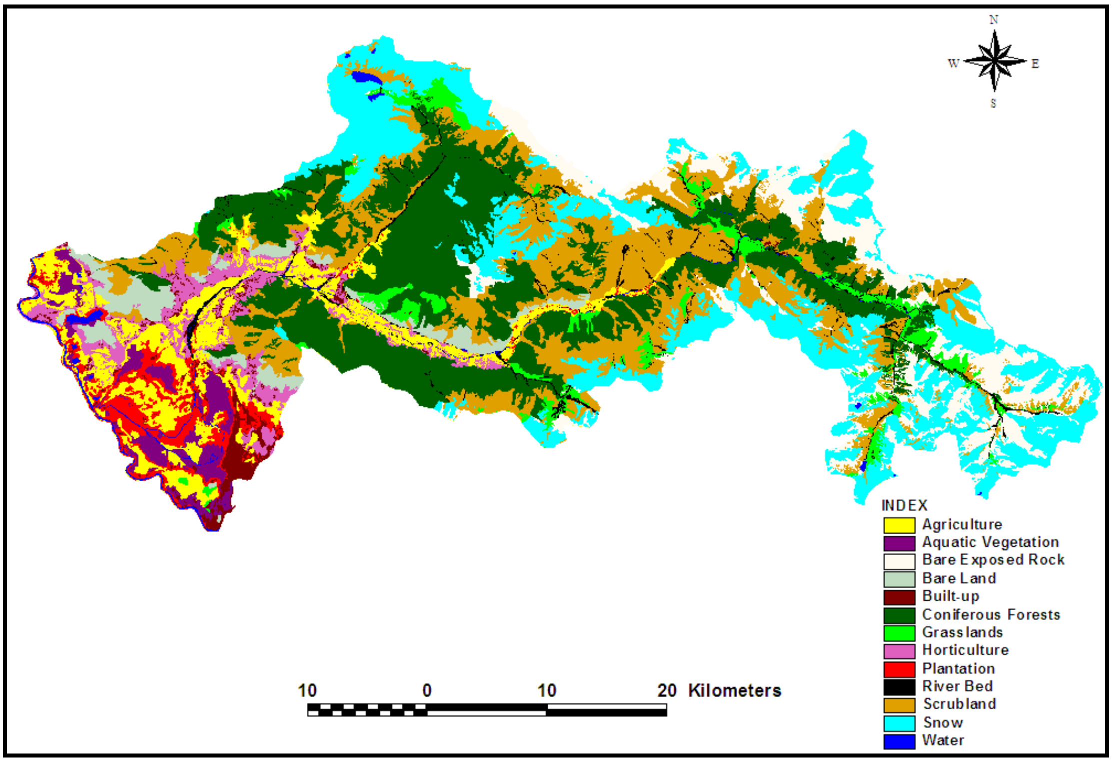

Fig. 18: Land use/Land cover map of Anchar catchment (IRS LISS III, 2005)

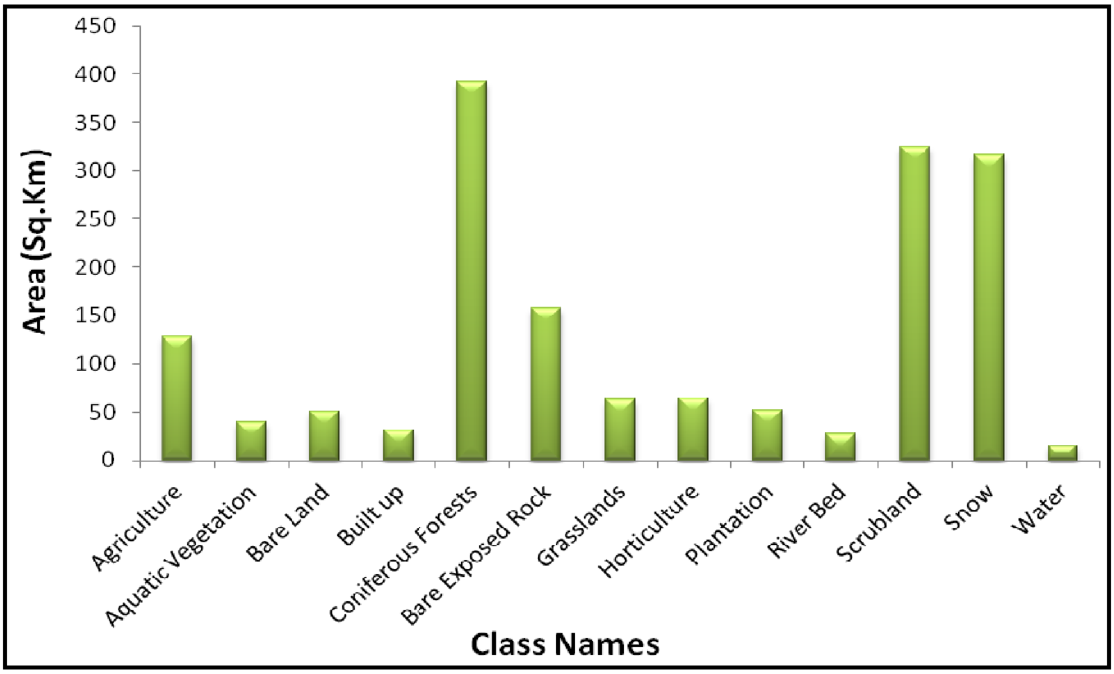

Fig. 19: Area under different Land use/Land classes in Anchar catchment (IRS LISS III, 2005)

Satellite data has the unique capability to detect the changes in land use land cover quickly and accurately (Nagamani and Ramachandran, 2003). With regard to the changes in the land use/ land cover of the Anchar catchment, many changes in the land use/ land cover were observed from the information contained in the land use/ land cover maps derived from LANDSAT TM (1992) and IRS LISS III (2005) satellite data, mainly in the agricultural lower plains of the study catchment valley floor with increase in built-up indicating urbanization. During the span of 15 years i.e. 1992-2005, vegetal cover of the catchment in the form of coniferous forests, scrubland, grasslands and plantation have all registered a decline, while as impervious land surfaces like built-up and bare land have increased. These changes are quite apparent from the Fig.20 and the statistics presented in Table 12.

Agricultural land is the land base on which different types of crops are raised. Agricultural land in the Anchar catchment is mainly devoted to paddy and maize cultivation. Paddy is cultivated in the flood plains of the region, which are highly productive in terms of rice cultivation. On its western side Anchar is surrounded by these agricultural fields. Maize is grown on the long stretches of elevated plateau land mainly in Kandi belts of side valleys of the main catchment. The stretches of elevated land on the northwestern side of catchment are used for raising multiple crops. Most of population in the catchment is dependent on this class as it provides a source of employment. The statistics of this class reveal that the area of land under agriculture has decreased from 142.80 Km^2 in 1992 to 128.38 Km^2 in 2005 i.e. a decrease of 14.42 Km^2 (10% decrease).

Aquatic vegetation and water jointly account for 3.03% of the total area of the catchment in 1992 and for 3.29% of the total area in 2005. With regard to water bodies, besides Sindh River and Anchar Lake, the catchment encompasses other water bodies as well. These include the River Jehlum, semi-urban lake Mansbal and high-altitude lakes-Gangabal, Nundkol and Harnag. Although these high-altitude lakes have not undergone much change spatially due to their location and less anthropogenic influences, but overall the area of water bodies (Mansbal, Anchar) has declined by about 2.51 Km^2 from 1992 to 2005. On the other hand, aquatic vegetation comprising mainly of vegetation found in lake waters has increased by 6.46 Km^2 from 1992-2005. High-altitude lakes are devoid of macrophytic vegetation, however the valley lakes of this catchment like Anchar support thick cover of aquatic vegetation mainly the macrophytic littorals including species of *Phragmites, Myriophyllum, Potamogeton, Nelumbo,* and *Nymphoides.*

In the study catchment, impervious land surfaces like built-up and bare land have been found to increase in area. Built-up area consists of anthropogenic land cover features, ranging from small hamlets in rural areas to large cities including residential, commercial, and industrial establishments. This class is mainly confined to the lower plains of the catchment. Built-up which constituted a mere 0.93% (15.62 Km^2) of the catchment in 1992 increased by about 15.72 Km^2, constituting 1.9% (31.34 Km^2) of the catchment in 2005. The increase in spatial extent of this class is mainly reflected in the lower area of the catchment valley floor. Bare land class includes those areas which have no vegetation cover. The statistics (Table 12) of this class reveals that the area of this class has increased from 15.30 Km^2 in 1992 to 50.19 Km^2 in 2005 i.e. an increase of 34.89 Km^2. In the Anchar catchment this class occurs both at the lower as well as the higher elevations.

Bare exposed rock category includes those areas of bed rock exposure which are devoid of any vegetation cover because of being present at higher elevation and experiencing low temperature. Bare exposed rocks are found in very steep slope regions of the Anchar catchment which remain under the cover of snow for most part of the year. This class has decreased from 164.50 Km^2 in 1992 to 158.02 Km^2 in 2005 i.e. a decrease of about 6.48 Km^2.

From the land use land cover change statistics presented in Table 12, it is clear that vegetation cover (coniferous forests, grasslands and scrubland) in the Anchar catchment has decreased. The western mixed coniferous forests found between elevation of 3000 and 3500 meters cover a substantial portion of the catchment as quite a large portion of this catchment lies in this elevation region. In these forests are found species of Blue Pine, Sliver birch and Fir. Kashmir birch (*Betula utilis*) is found in the famous Sonamarg area of this catchment. The state of these forests of the catchment from 1992-2005 provides a grim picture. Statistics (Table 12) for this period reveal that coniferous forests have reduced from 449.22 Km^2 in 1992 to 392.60 Km^2 in 2005 showing a decline of 56.62 Km^2 (12.6%).

Table 12: Change in the Land use/Land cover pattern of Anchar catchment

S.No.	Class Name	Area (Km^2)		Area change (Km^2)	% change to Total	% change
		1992	2005			
1	Agriculture	142.80	128.38	-14.42	-0.87	10
2	Aquatic Vegetation	33.05	39.51	+6.46	+0.41	16.3
3	Bare Land	15.30	50.19	+34.89	+2.1	69.5
4	Built up	15.62	31.34	+15.72	+0.97	50.1
5	Coniferous Forests	449.22	392.60	-56.62	-3.4	12.6
6	Bare Exposed Rock	164.50	158.02	-6.48	-0.41	3.93
7	Grasslands	86.67	63.45	-23.22	-1.39	26.7
8	Horticulture	55.55	64.57	+9.02	+0.55	13.9
9	Plantation	63.10	52.11	-10.99	-0.67	17.4
10	River Bed	21.45	27.10	+5.65	+0.32	20.8
11	Scrubland	359.26	325.28	-33.98	-2.05	9.45
12	Snow	239.96	316.44	+76.84	+4.59	24.16
13	Water	17.36	14.85	-2.51	-0.15	14.45
Total		**1663.84**	**1663.84**			

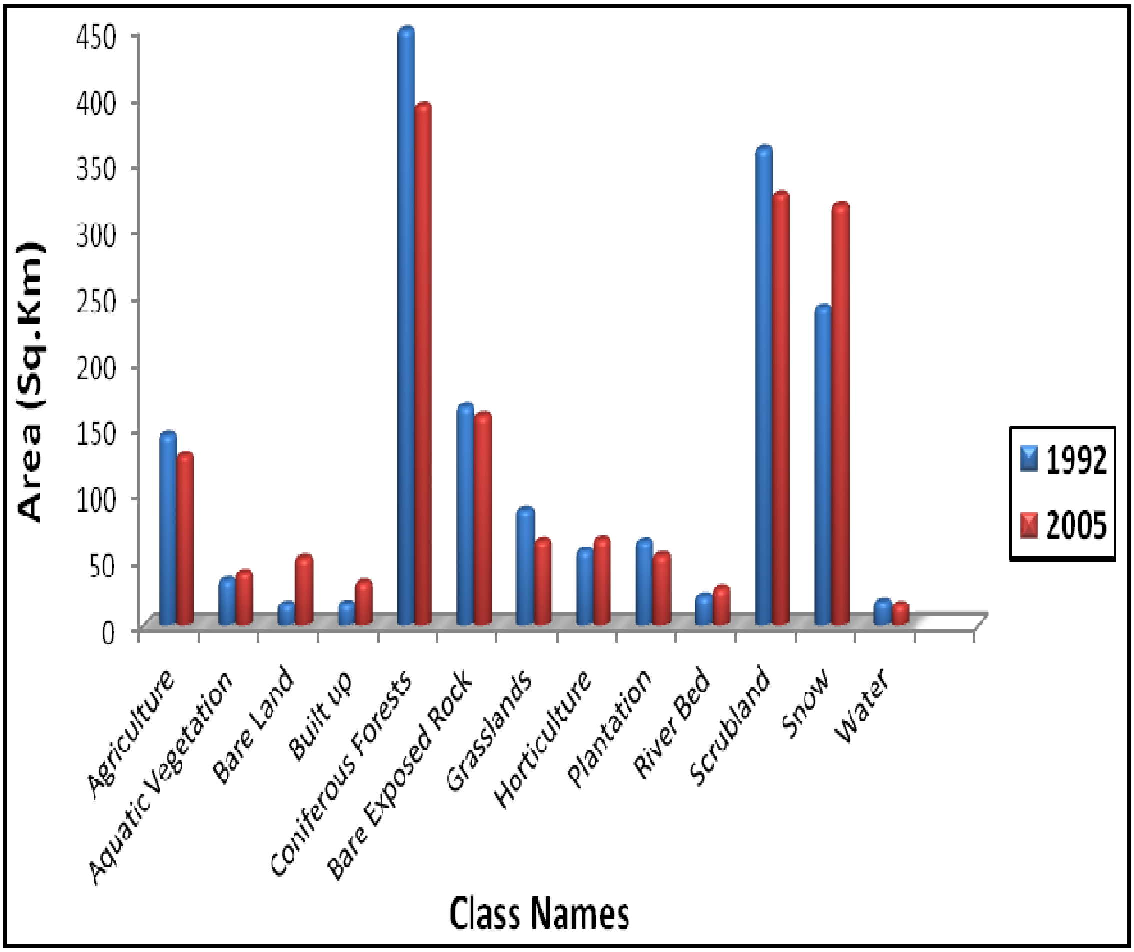

Fig. 20: Change in Land use/Land cover pattern of Anchar catchment (1992-2005)

The results of the change in land use/land cover pattern of Anchar catchment (Table 12) also show that the grasslands have decreased from 86.67 Km^2 in 1992 to 63.45 Km^2 in 2005- a decrease of 23.22 Km^2 (26.7%), while as scrubland has decreased from 359.26 Km^2 in 1992 to 325.28 Km^2 in 2005 i.e. a decrease of 33.98 Km^2 (9.45%). The grasslands found in the region, mainly include moist alpine pastures, while as scrubland includes moist alpine and open scrub areas. The moist alpine pastures start from treeline and extend up-to perpetual snowline. These basically are long sloppy stretches of land covered predominantly with grasses consisting mainly of *Ephedra* formations. Moist alpine scrubs occur above the tree-line in the wetter parts of the catchment and consist mainly of *Hippophae*, *Myricaria* formations. The open scrub areas found at elevations of less than 3000 meters mainly included shrubs with mid-dense foliage dominated by *Indigofera heterantha*, *Randia tetrasperma*, *Daphne oleoides* and *Viburnum* sp. Sizable pockets of these grasslands and scrub found in the steep river bed facing slopes of the Anchar catchment attract shepherds and nomadic tribesmen with their cattle and herds of sheep and goat from far and near for grazing.

Plantation includes land areas with natural plantation or trees as well as land areas on which several trees are planted. In the Anchar catchment, plantation was observed all along the banks of River Jhelum, Sindh and near the wetlands Shallabugh, Kujar and Tulmul. The plantation species that were observed included Willows (*Salix* sp.), Poplars (*Populus* sp.), and Walnut *(Juglans regia).*Walnut plantation was observed in the Kulan area of the catchment. Statistics of this class reveal that the area under plantation has decreased by 17.4 % from 1992 to 2005.

Horticultural class comprises of cultivated land under fruit gardens and nut crops. These horticultural gardens or fields are usually patterned. The horticultural plantations found in the catchment included apple (*Pyrus malus*), pear (*Pyrus communis*), apricot (*Prunus armenica*), walnut (*Juglans regia*), and in some places mixed plantations of cherry (*Prunus avium*) and plum (*Prunus domestica*). The area under these horticultural plantations was found to increase (Table 12) from 55.55 Km^2 in 1992 to 64.57 Km^2 in 2005.

River bed is basically the channel bottom of the rivers and streams found in the Anchar catchment and includes the boulders along these rivers and streams. These river beds are exposed during autumn and winter, while as in summer their major portion is under water. Table 12 shows an increase of 0.32 Km^2 in the area of this class i.e. from 21.45 Km^2 in 1992 to 27.10 Km^2 in 2005.

Snow covers quite a large portion of the Anchar catchment. Infact, higher elevations of this catchment remain under the cover of snow almost throughout the year. 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. Statistics reveal that snow cover in the catchment increased from 239.96 Km^2 in 1992 to 316.44 Km^2 in 2005. This class can be considered as an important resource of the catchment as it's of vital importance for the sustenance of agriculture in the catchment, and secondly it allows for the generation of clean hydro-power.

6.1.3 Accuracy Assessment

The accuracy assessment of the generated land use land cover maps was carried out by computation of error matrix and subsequent calculation of the overall accuracy and Kappa coefficient. For this purpose, field-surveys for ground verification were carried out during the study period. Since, the study catchment exhibits varied topography with certain altitudinal extremes, so certain areas of the catchment were not accessible for ground validation. As such field-survey was supplemented with latest high resolution satellite data to get a complete picture of the catchment (Plates 1a, b). Around 150 validation points were used for assessing the classification accuracy. Table 13 and Table 14 give the results for accuracy assessment of the 2005 classified data. The results show that the overall accuracy is 92.66 % with a Kappa coefficient of 0.914 (Table 13). Classes aquatic vegetation and water were found to give good classification accuracies, while as grasslands, scrubland and bare land had lower user accuracies (Table 14).

Table 13: Overall Accuracy and Kappa Statistics of 2005 Land use/Land cover data

	A.G.	Aq.	B.L.	Bu.	C.F.	B.E.R	Gl.	Ht.	P.T.	Sl.	S.W.	Wt.	Total
A.G.	**12**		1										13
Aq.		**5**											5
B.L.	1		**16**	1									18
Bu.				**6**									6
C.F.					**31**					3			34
B.E.R						**4**							4
Gl.					1		**5**						6
Ht.								**16**	1				17
P.T.									**10**				10
Sl.					3					**26**			29
S.W.											**2**		2
Wt.												**6**	6
Total	13	5	17	7	35	4	5	16	11	29	2	6	**150**

NOTE: - A.G. = Agriculture; Aq. = Aquatic vegetation; B.L. = Bare land; Bu. = Built-up; C.F. = Coniferous forests; B.E.R. = Bare exposed rock; Gl. = Grasslands; Ht. = Horticulture; P.T. = Plantation; Sl. = Scrubland; S.W. = Snow and Wt. = Water.

Overall Accuracy = 92.66%

Kappa coefficient = 0.914

Table 14: Accuracy Assessment of 2005 Land use/Land cover data

Class Name	Producers Accuracy (%)	Users Accuracy (%)
Agriculture	92.30	92.30
Aquatic Vegetation	100.00	100.00
Bare Land	94.11	88.88
Built up	85.71	100.00
Coniferous Forests	88.57	91.17
Bare Exposed Rock	100.00	100.00
Grasslands	100.00	83.33
Horticulture	100.00	94.11
Plantation	90.90	100.00
Scrubland	89.65	89.65
Snow	100.00	100.00
Water	100.00	100.00

Scrubland

Grasslands

Plantation

Agriculture

Horticulture

Plate 1a: Landuse/Landcover of Anchar catchment

Water body (Anchar) **Built-up**

Wetland **Forests**

Exposed rock

Plate 1b: Landuse/Landcover of Anchar catchment

6.2 Topographic Analysis

The knowledge of surface topography is basic to many earth surface processes analysis (Taramelli *et al*., 2008). During this study, the knowledge of topographic details of the Anchar catchment including elevation, slope, aspect and drainage was acquired from the ASTER digital elevation model of the study catchment. Elevation, aspect, and slope are the three main topographic factors that control the distribution and patterns of vegetation in mountain areas (Titshall *et al*., 2000). Elevation along with aspect and slope in many respects determines the microclimate and thus large-scale spatial distribution and patterns of vegetation.

Elevation is the most important topographic factor in mountain areas. Fig.21 shows the elevation map of the Anchar catchment generated from ASTER digital elevation model. The elevation of the catchment ranges from 1534 meters to 5534 meters. Table 15 shows the area under different elevation classes in the Anchar catchment. The western part of the catchment shows lower relief, while as the north-eastern parts of the catchment show maximum relief. It's in these western lower plains of the catchment that mainly settlements and agricultural activities are confined. The maximum elevation shown by the ASTER digital elevation model in the catchment area is 5534 meters. Table 15 reveals that maximum area of the lake catchment (38.47%) lies in the elevation zone 3534-4534 meters, followed by the elevation zone of 1534-2534 meters, in which 30.3% of the catchment area lies. The latter elevation zone comprises mainly of built-up areas, agricultural fields, and horticultural plantations. In the elevation zone of 2534-3534 meters coniferous forests (>3000ms), scrubland and grasslands are found. The elevation region (3534-4534 meters), which covers the maximum portion of the catchment comprises of scrubland, alpine grasslands, bare exposed rocks, and snow. In this elevation zone the high-altitude lakes of the catchment Gangabal and Nundkol are located. Minimum area of the catchment (3.33%) lies in the elevation zone 4534-5534 meters. It's this zone of the catchment, which is under snow cover almost throughout the year. The results of slope, aspect and drainage analysis of Anchar catchment are provided below:

Table 15: Area under different elevation classes in Anchar catchment

S.No.	Altitude (meters)	Area (Km^2)	Area (%)
1	1534-2534	504.18	30.30
2	2534-3534	464.20	27.9
3	3534-4534	640.12	38.47
4	4534-5534	55.34	3.33
Total		**1663.84**	**100**

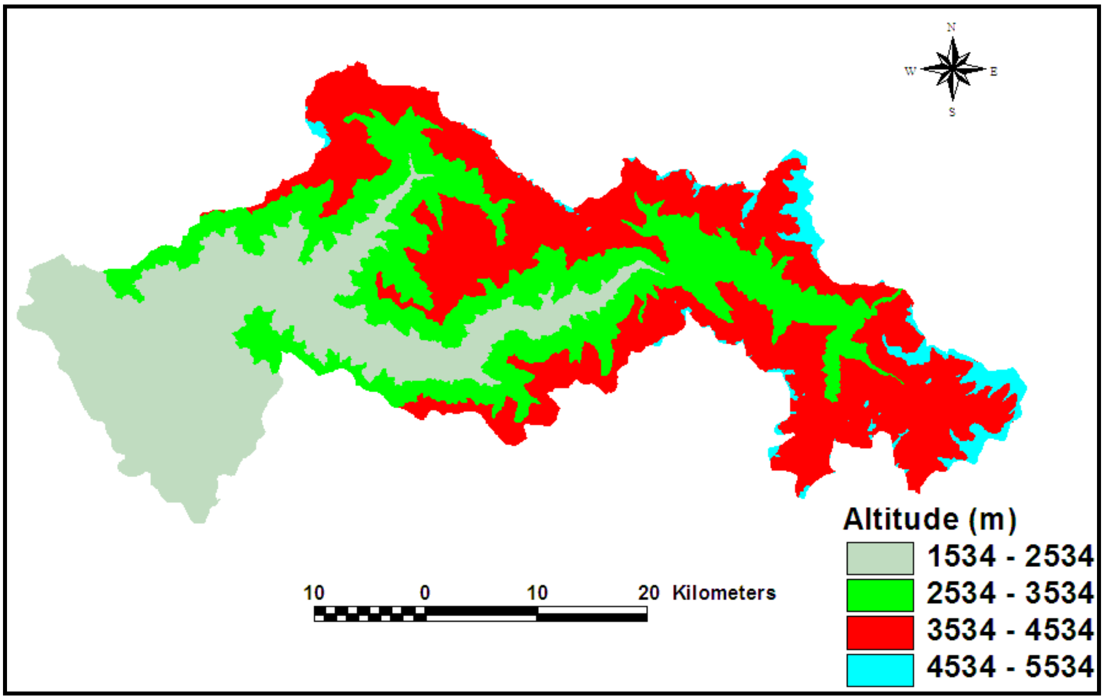

Fig. 21: Elevation map of Anchar catchment

6.2.1 Slope Analysis of Anchar Catchment

Land surface from summit of hills to the bare valleys is bounded by sloping surface or slope. Slope measures the rate of change of elevation at a surface location. This topographic variable plays an extremely important role in controlling soil erosion and in distribution of utilities-facilities for proper planning and development of an area (Kumar and Srivastav, 2010; Mondal *et al*., 2011). In addition, terrain slope also determines the land-use of a particular area. Slope analysis is important for many earth resource evaluation studies and hydrological modelling. The slope map of Anchar catchment is given in Fig. 22. Slope describes the steepness or incline of an area. As evident from Fig. 22, the slope of the Anchar catchment has been classified into five classes namely: 0-10˚ (Flat to gentle), 10-20˚ (Moderate), 20-30˚ (Steep), 30-40˚ (Very steep) and greater than 40˚ (Highly steep).

The topography of the Anchar catchment can be described as steep to very steep. Table 16 shows the area under different slope classes in the Anchar catchment. It's clear from the table that dominant slope classes in the study catchment are 30-40˚ (very steep) and 20-30˚ (steep). Maximum area (29.9%) of the catchment is under very steep slope region (30-40˚), covering an area of 497.15 Km^2, followed by the steep slope region (20-30˚) covering an area of 388.28 Km^2 i.e. 23.33 % of the catchment. Minimum area of the catchment (11.37%) is under highly steep slope region (>40˚) covering an area of 189.23 Km^2. Flat area to gentle slopes 0-10˚ constitute 21.21% of the catchment covering an area of 353.06 Km^2. This slope region (0-10˚) comprises of low-lying plains and flat lands and is conterminous with the flood plain of river Jehlum and Sindh. It's in this flat to gentle slope region that extensive marshes and lakes like Mansbal and Anchar are found. Settlements are also confined to the lower-plains of this slope region. Agricultural and horticultural practices are practiced on the gentle (0-10˚) to moderate slopes (10-20˚) of the catchment. The steep slope region (20-30˚) consists of mountain ridges and ramparts. This slope region comprises of bare land, coniferous forests, scrubland and grasslands. The very steep slope region (30-40˚) of the catchment comprises of highly rugged mountains dissected by narrow and deep river beds and is dominated by bare exposed rocks and snow. Highly steep regions (>40˚) are observed in small pockets in the north-eastern part of the catchment. These comprise of deep-gorges and peaks and are mostly under snow cover.

Table 16: Area under different slope classes in Anchar catchment

S.No.	Slope Classes (Degrees)	Area (Km^2)	Area (%)
1	Flat to gentle (0-10)	353.06	21.21
2	Moderate (10-20)	236.12	14.19
3	Steep (20-30)	388.28	23.33
4	Very steep (30-40)	497.15	29.9
5	Highly steep (>40)	189.23	11.37
Total		**1663.84**	**100**

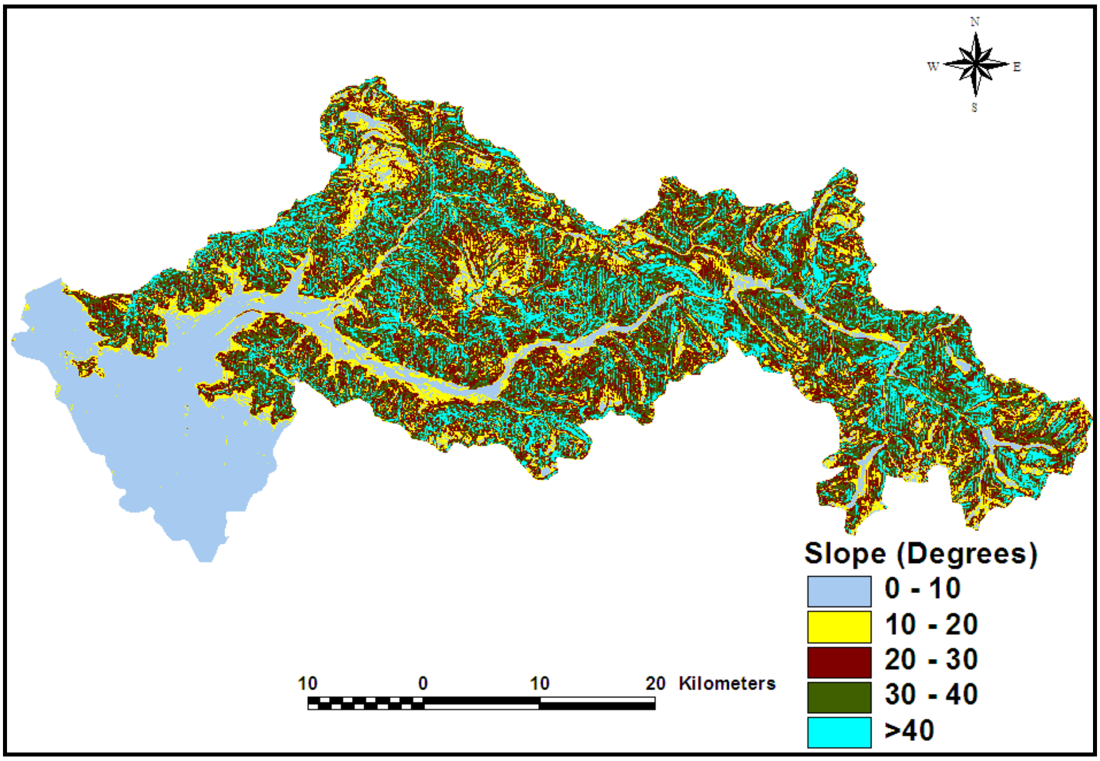

Fig. 22: Slope map of Anchar catchment

6.2.2 Aspect Analysis of Anchar Catchment

Aspect is the directional measure of slope. It starts with 0˚ at the north, moves clock-wise, and ends with 360˚ also at north. As basic elements for analyzing and visualizing landform characteristics, slope and aspect are important in studies of catchment scale and watershed units, landscape units and in many other analysis. Fig. 23 and Table 17 show the aspect map of Anchar catchment and the area under different aspect categories respectively. The aspect of the study catchment has been classified into eight principal directions: north, north-east, east, southeast, south, southwest, west and north-west. Table 17 reveals that maximum area (15.26%) of the catchment lies in the eastern direction.

6.2.3 Drainage Analysis of Anchar Catchment

River Sindh and its numerous branches on entering the plains of Kashmir valley form the extensive shallow marsh Anchar. Thus, river Sindh and the numerous streamlets which feed it during its course through the mountain ramparts constitute the drainage network of Anchar catchment. Network of channels from river Sindh enter the Anchar on its northern end. The drainage of Sindh valley is an essential component of the landscape of Anchar catchment. Fig.24 shows the drainage map of the Anchar catchment.

The snow covered and ridge protruded mountain ranges encircling the Sindh valley, provide ground for the development of a number of streams which form the important component of the drainage of Anchar catchment. The headstreams of Sindh rise below the peaks of Mushran Bal and the holy Amarnath peak (5270m) in the northeastern part of the Kashmir valley. A few kilometers above Baltal a headstream is received from Kolahoi glacier. At Baltal a headstream from Zojila pass joins Sindh. At the famous spot Sonmarg, the gushing waters of Sindh flow through a narrow channel with deeply incised caves in the bordering rocks on either bank, draining its way through pine forests and beautiful pastures. Further down, the river bed deepens more and more to assume the character of a gorge. After emerging out from the gorge near Gagangir, the Sindh valley starts widening out.

Table 17: Area under different aspect categories in Anchar catchment

S.No.	Aspect	Area (Km^2)	Area (%)
1	Flat	66.23	4
2	North	206.01	12.38
3	North-east	180.00	10.81
4	East	254.05	15.26
5	Southeast	192.21	11.55
6	South	239.02	14.4
7	Southwest	234.05	14.0
8	West	99.22	6
9	North-west	193.05	11.60
Total		**1663.84**	**100**

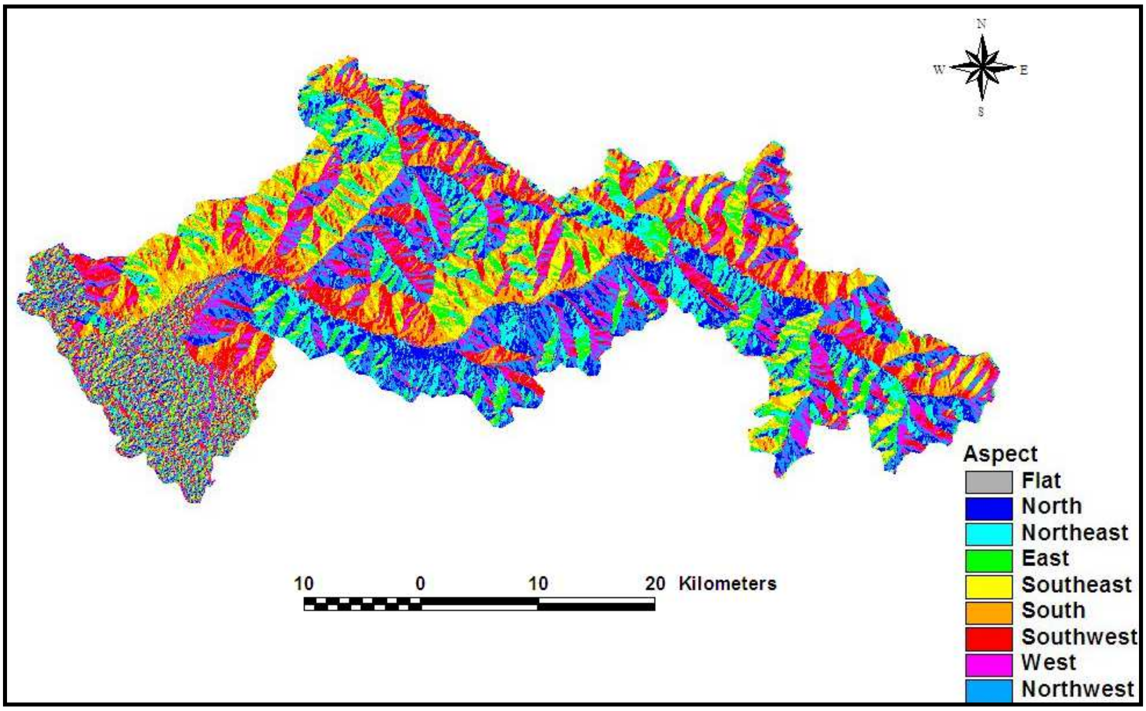

Fig. 23: Aspect map of Anchar catchment

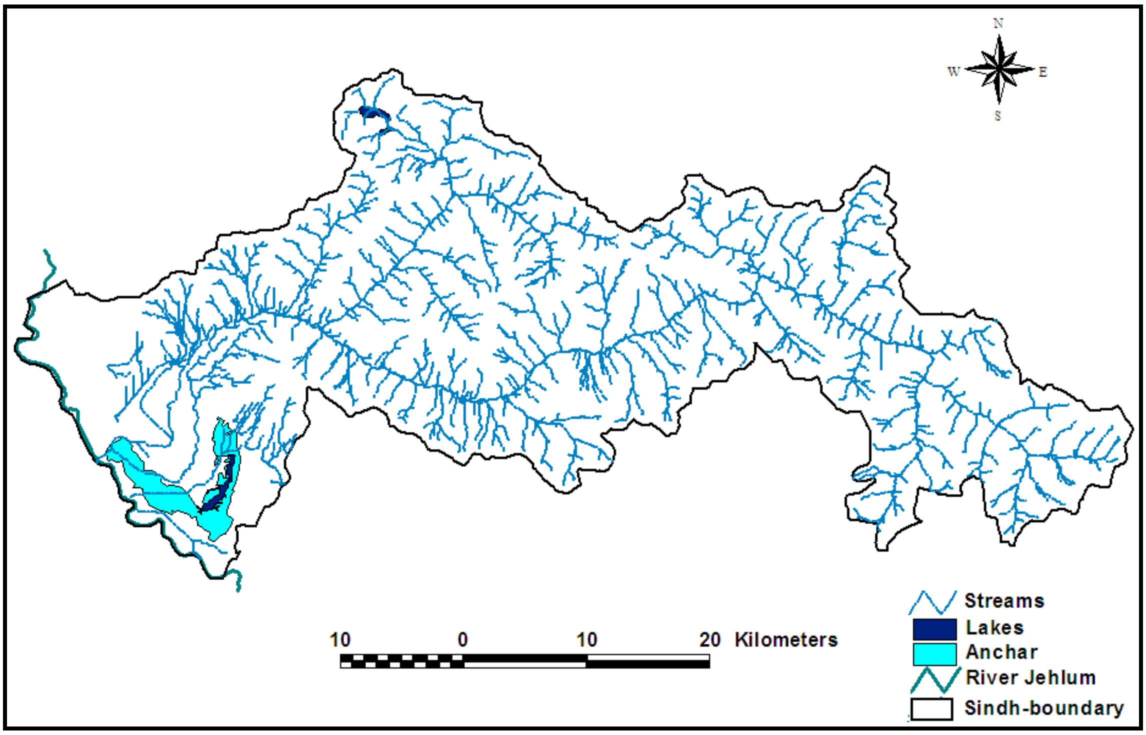

Fig. 24: Drainage map of Anchar catchment

The most significant tributary which joins the Sindh during its course through forest covered mountains is Kanaknaz. This tributary joins it on its right bank at village Kazipura near Kangan. The Kanaknaz drains the picturesque valley of Wangat and has its main source in the Gangabal Lake below Harmuk. The lake is situated at an elevation above 3500 meters. One branch of the Kanaknaz flows alongside the Sindh and falls into the Mansbal Lake. Flowing in almost a westerly direction on the northern flank of a projected ridge culminating in Harwar (3449 ms), the Sindh makes a sharp bend above Ganderbal before entering into a wide flood-plain. As the river rebounces into the plain-area it bifurcates into a number of channels and its one of these channels that escapes into the Anchar, while the other merges with Jehlum near Shadipur.

6.3 Physico-chemical Analysis of Soils of Anchar Catchment

Soil samples of different land use/land cover classes of the catchment which were collected during field-survey and analyzed for various physico-chemical parameters in the laboratory (as per the methods described in Chapter-5) were utilized for generation of soil maps of different parameters of Anchar catchment. The various physico-chemical characteristics of soils of the catchment under different land use/land cover classes are given in Table 18. The data reveals that these soil characteristics vary with different land use/land cover types.

pH value is a measure of the hydrogen ion activity of the soil water system and expresses the acidity and alkalinity of soil. The pH is a very important property of soils as it determines the availability of nutrients, microbial activity and physical condition of the soil. The pH map generated for the Anchar catchment is shown in Fig.25. From the figure it’s clear that the pH of various soils in the catchment ranges between 3.29 and 8.20 i.e. the soils are acidic to alkaline in nature. Soils of the bare exposed region were found to be extremely acidic (3.29) (Table 18). Wetland soils were also found to be acidic in nature with a pH of 5.25. In the current study, soil pH was found to increase in cultivated lands with horticulture, agriculture, and plantation areas showing higher values of 7.56, 7.60 and 8.20 respectively. Coniferous forests (6.70) and pasture (6.28) soils were found to have lower pH values than cultivated soils (Table 18).

The electrical conductivity soil map of Anchar catchment is shown in Fig. 26. Electrical conductivity of aqueous soil extracts estimates the amount of soluble salts present in the soil samples. The electrical conductivity values of soils in the catchment were found to range between 128 and 396µS/cm. The values that have been presented in Table 18 reveal that soils of wetland with a value 396µS/cm show maximum electrical conductivity; followed by soils of built-up with an electrical conductivity of 310µS/cm. Minimum electrical conductivity with a value of 128µS/cm was found in bare exposed soils. Values indicate that the rest of the land use land cover types did not differ much in terms of electrical conductivity (Table 18).

Water holding capacity is defined as: "the amount of moisture in soil when its total pore space both macro and micro are completely filled with water". This parameter of the soils of Anchar catchment was found to range between 32.7% and 87.2% (Fig. 27) with wetlands showing highest water holding capacity of 87.2% and horticultural class showing the lowest 32.7% (Table 18).

Fig. 28 shows the soil organic matter map of the Anchar catchment. Soil organic matter plays an important role in enhancing crop production (Stevenson and Cole, 1999). Table 18 shows the percent organic carbon and organic matter content of soils under different land use/land cover categories in the catchment. From this table, the highest content of organic matter is observed in wetland soils-6.46%, followed by pasture (5.22%) and coniferous forest soils (4.08%). Cultivated soils are observed to comparatively have lower organic matter content with agricultural soils having organic matter content of 2.67%, followed by horticultural and plantation soils having 2.12% and 1.98% organic matter respectively. In the study, bare exposed regions were found to have the lowest (1.81%) organic matter content.

Table 18: Physico-chemical characteristics of soils under different Land use/Land cover classes in Anchar catchment

Land use/Land cover Class	pH	Electrical Conductivity (µS/cm)	Water Holding Capacity (%)	Organic Carbon (%)	Organic Matter (%)	Av.N (Kg/ha)	Av.P (Kg/ha)	Av.K (Kg/ha)
Agriculture	7.60	158	49.5	1.55	2.67	376.32	38.75	383.04
Wetland	5.25	396	87.2	3.75	6.46	427.20	40.10	424.50
Bare Land	6.79	140	44.2	1.17	2.01	228.12	21.82	118.12
Built up	6.91	310	43.2	1.21	2.08	337.04	33.20	305.20
Coniferous Forests	6.70	164	58.7	2.37	4.08	627.20	46.60	394.24
Bare Exposed Region	3.29	128	36.4	1.05	1.81	101.8	12.80	100.21
Horticulture	7.56	130	32.7	1.23	2.12	387.52	36.94	380.8
Plantation	8.20	160	48.6	1.15	1.98	323.48	35.82	392.47
Pastures	6.28	145	47.8	3.03	5.22	613.36	40.80	464.80

With regard to the content of available nutrients (Nitrogen-N, Phosphorus-P and Potassium-K) present in the soils of Anchar catchment, the levels of these nutrients are depicted in Fig.29-31. Phosphorus content (12.80Kg/ha-46.60Kg/ha) of soils was found to be low as compared to nitrogen (101.8Kg/ha-627.20Kg/ha) and potassium (100.21Kg/ha-464.80Kg/ha) content. In general, forests, pastures and wetlands were found to have higher content of these available nutrients, while as classes bare land and bare exposed areas were found to be low in these nutrients (Table 18).

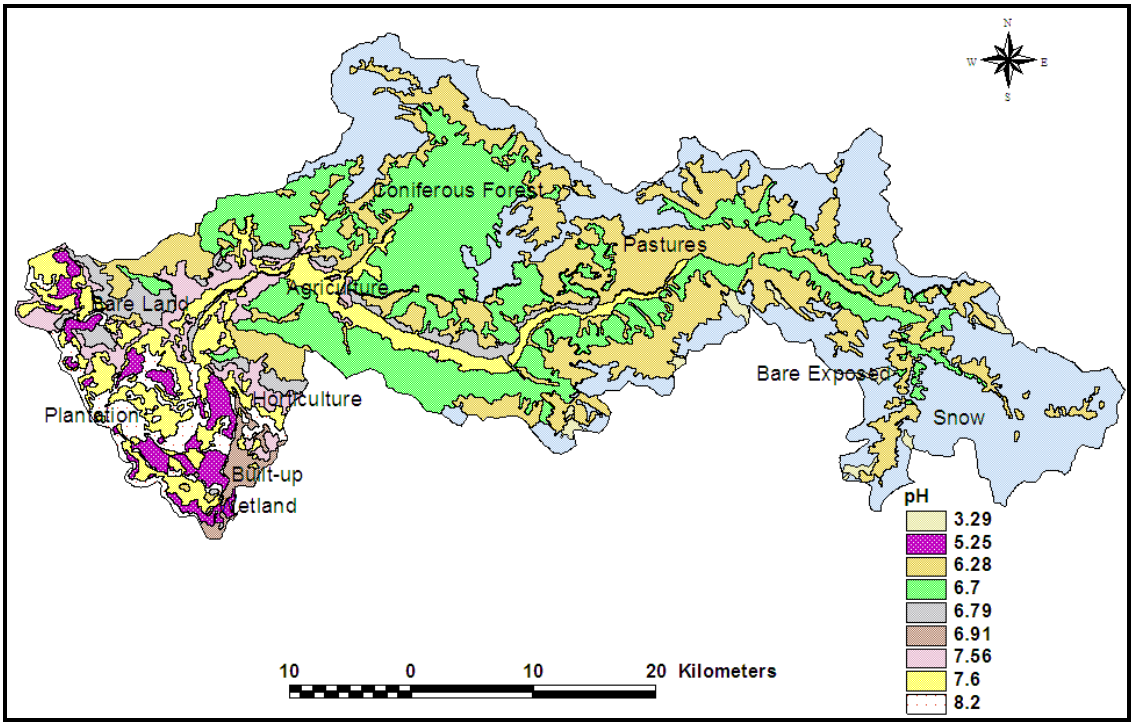

Fig. 25: pH map of Anchar catchment

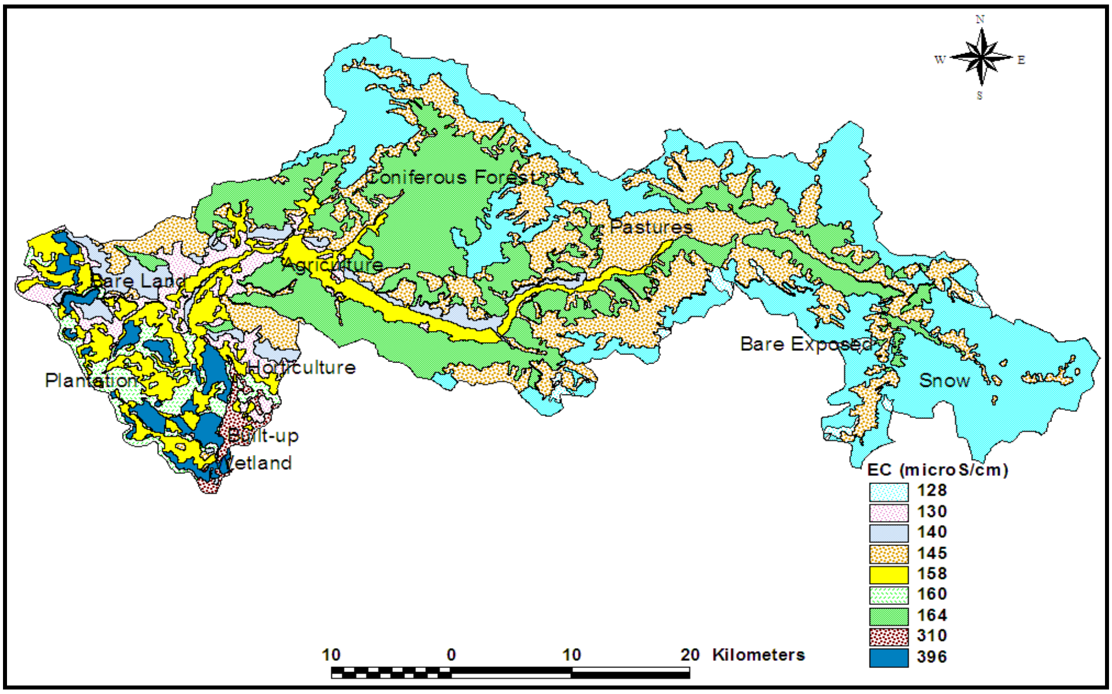

Fig. 26: Electrical conductivity map of Anchar catchment

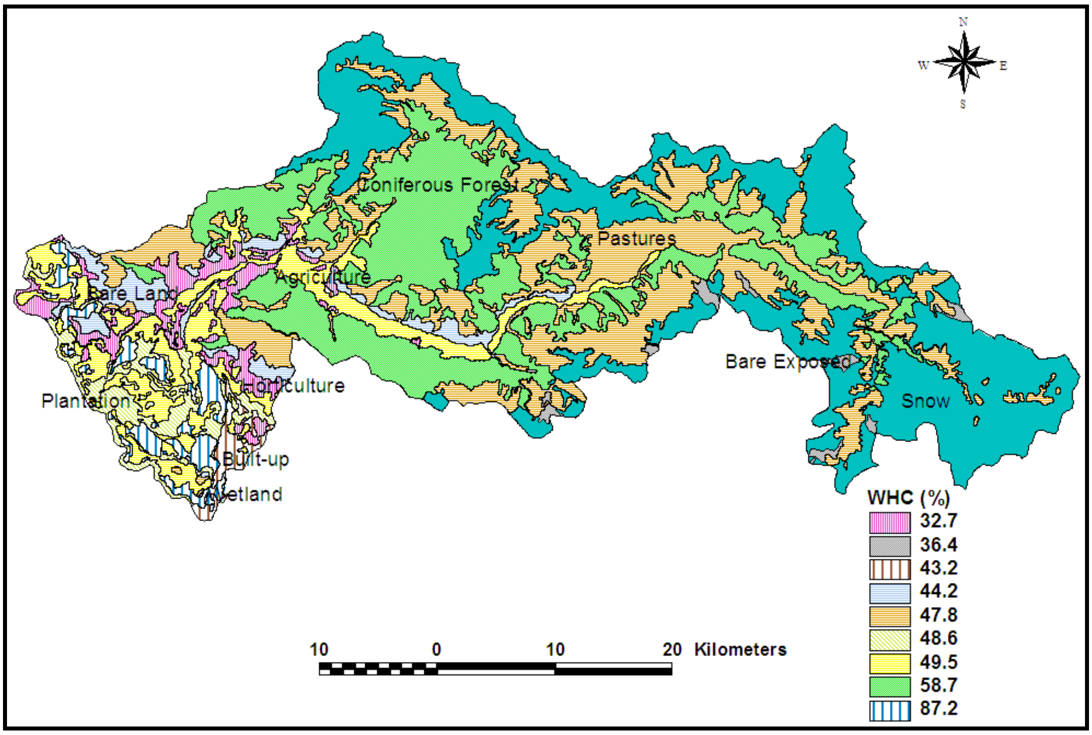

Fig. 27: Water holding capacity map of Anchar catchment

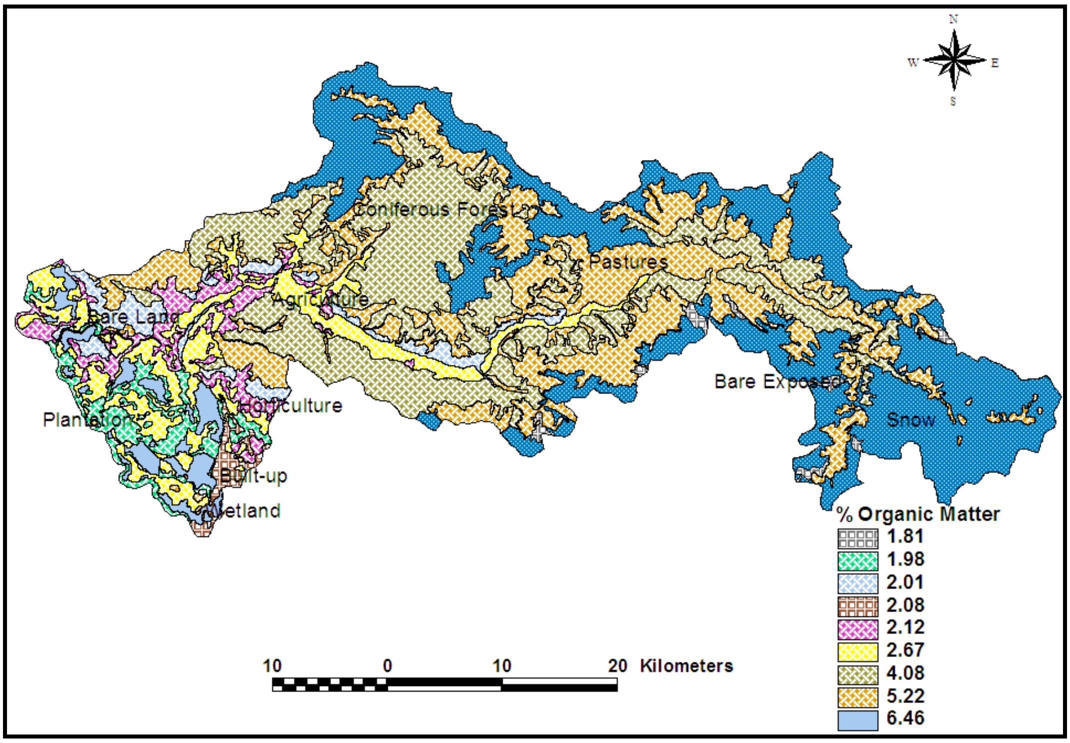

Fig. 28: Soil organic matter map of Anchar catchment

Soil Texture Analysis of Anchar Catchment

Textural analysis of soil samples collected from the Anchar catchment was carried out by the method described in Chapter-5. Texture is an important property of soil which shows proportional distribution of soil particles. Soil texture has profound effect upon other properties of soil including its water supplying power, rate of water intake, aeration, fertility and susceptibility to erosion. In addition this property is a guide to the value of land and determines land use capability and soil management practices as well.

The soil texture map of Anchar catchment is presented in Fig.32. In the catchment eight types of textural classes are reported namely: clay, clay loam, loamy sand, sandy clay loam, sandy clay, sandy loam, silt loam and silty clay loam. From the figure it's clear that soil texture ranges from clay to silty clay loam. Table 19 gives the area under these textural classes in the catchment. About 32.45% of the catchment is covered with sandy clay soils followed by clay loam (28.16%), sandy loam (20.22%) and clay (12%) soils (Table 19).

Soil texture determines the hydrological condition of soils i.e. soil water regimes. Soil hydrological groups as determined from the soil texture classes reveal that most of the soils in the Anchar catchment belong to the hydrological group D (Table 19), which represents those soils which have high runoff potential and very low infiltration rates.

Soil erodibility factor (k) in the Anchar catchment was determined from soil texture and its composition (organic matter). Fig.34 depicts soil erodibility factor in the Anchar catchment. This factor was found to range between 0.10 and 0.42.

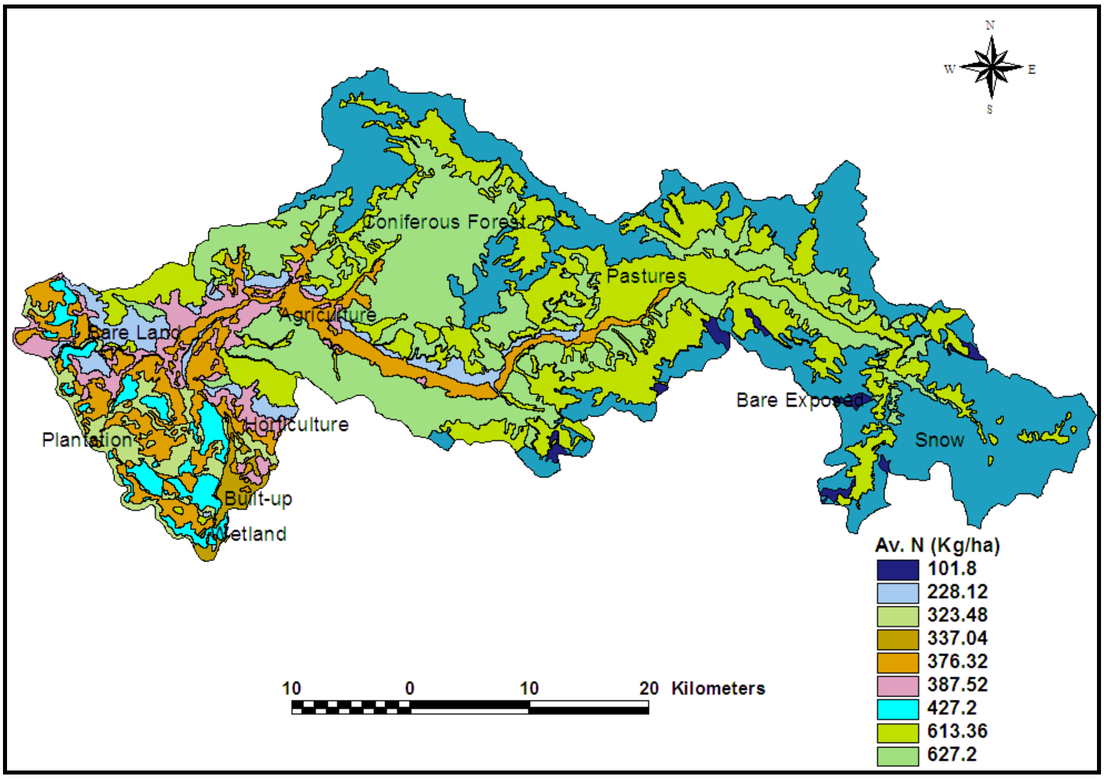

Fig. 29: Available nitrogen map of Anchar catchment

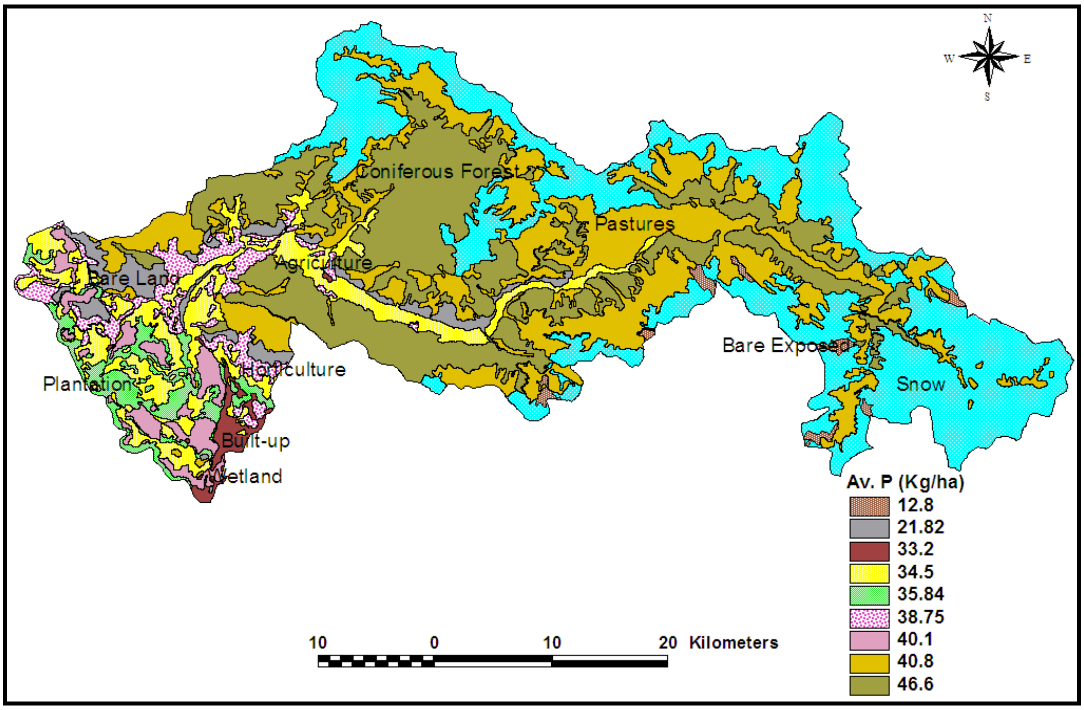

Fig. 30: Available phosphorus map of Anchar catchment

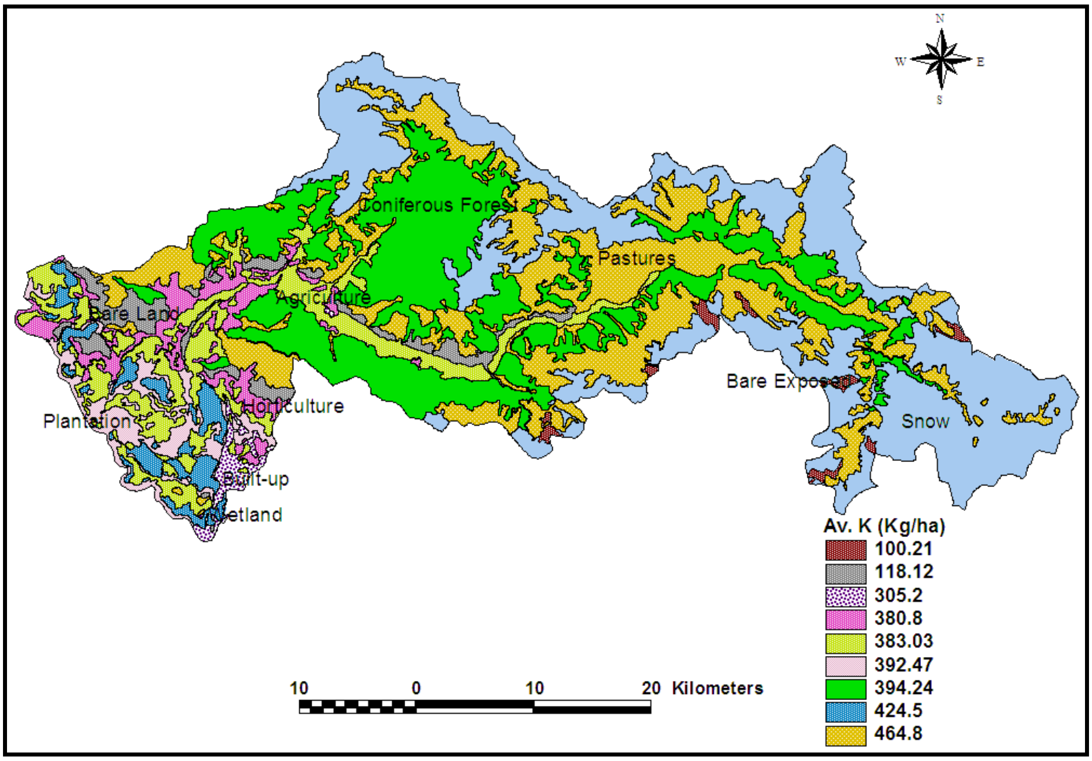

Fig. 31: Available potassium map of Anchar catchment

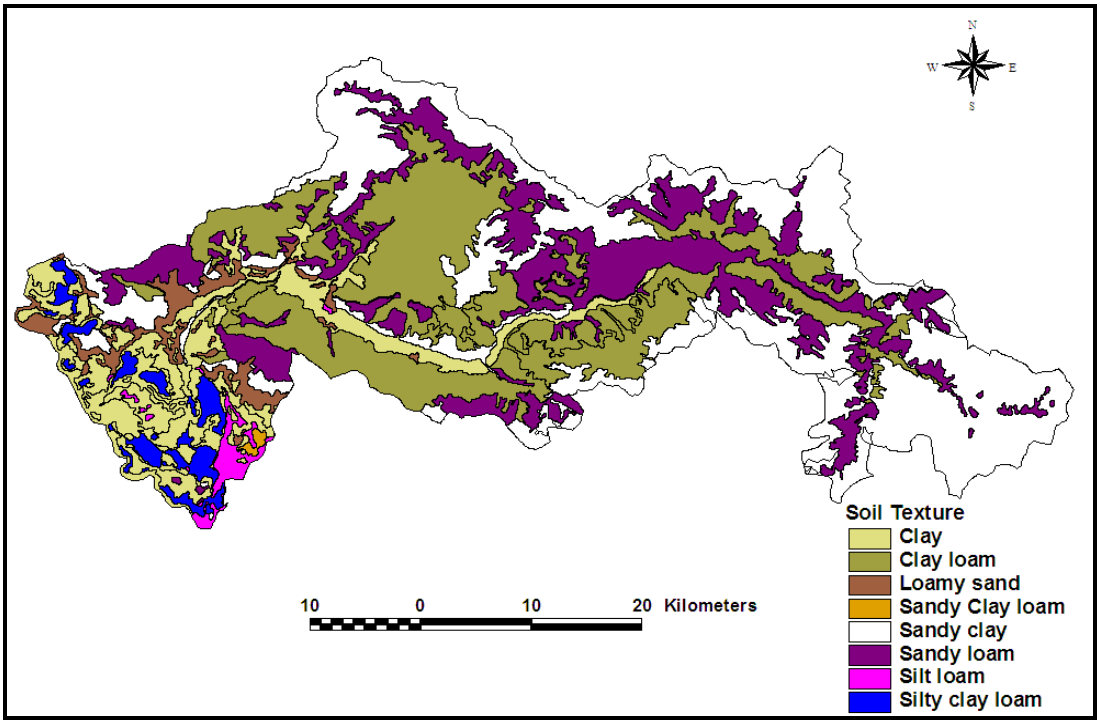

Fig. 32: Soil textural classes in Anchar catchment

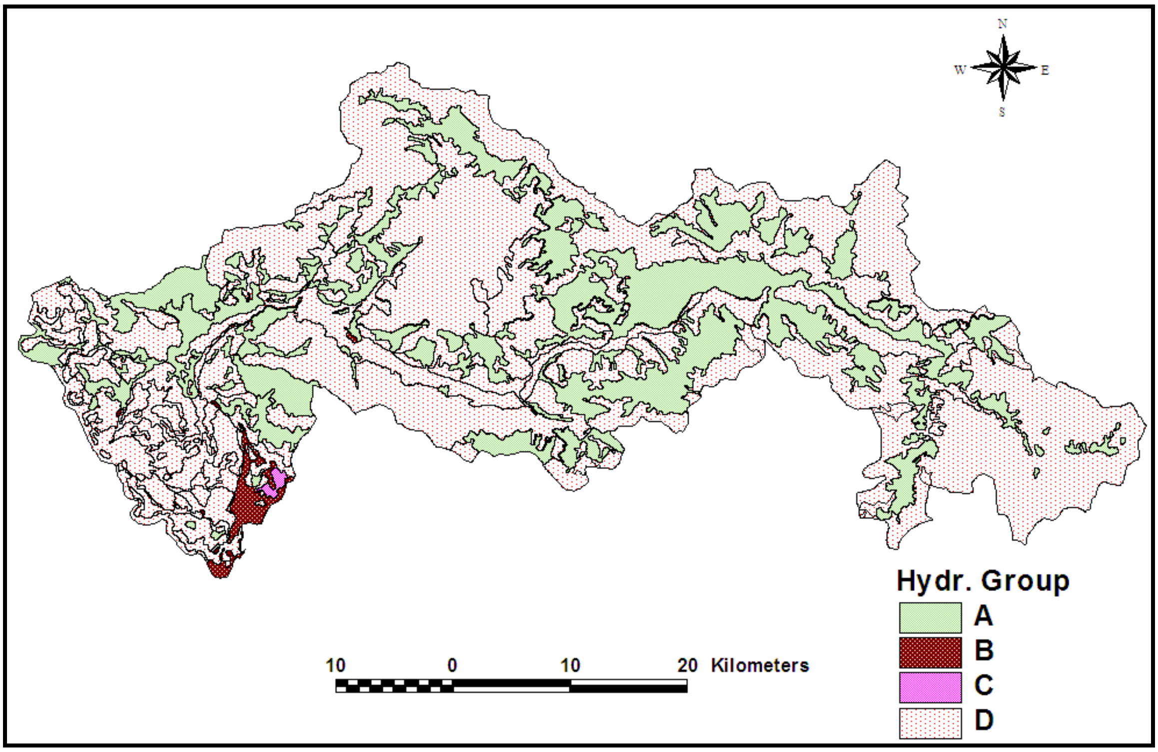

Fig. 33: Soil hydrological groups in Anchar catchment

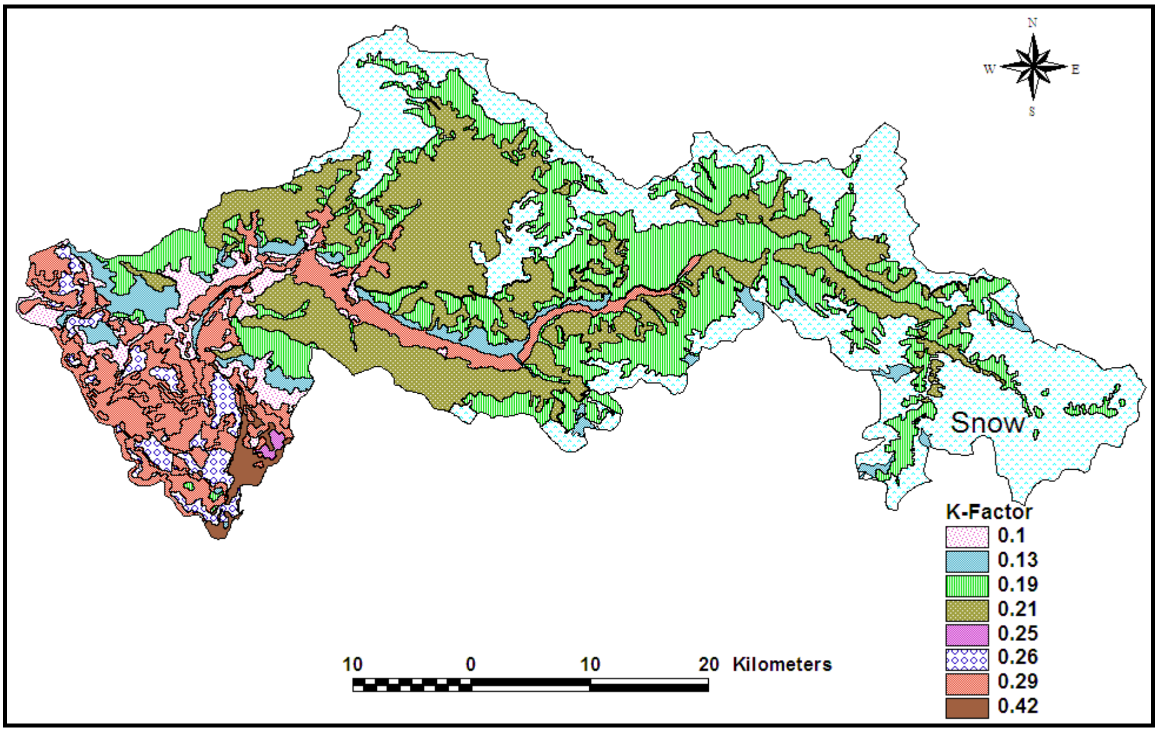

Fig. 34: Soil erodibility factor (k) in Anchar catchment

Table 19: Area under different textural classes in Anchar catchment

S.No.	Texture Class	Soil Hydrological Group	Area (Km^2)	Area (%)
1	**Clay**	D	199.32	12
2	**Clay loam**	D	468.66	28.16
3	**Loamy sand**	A	55.45	3.33
4	**Sandy clay loam**	C	2.50	0.15
5	**Sandy clay**	D	539.90	32.45
6	**Sandy loam**	A	336.56	20.22
7	**Silt loam**	B	18.47	1.11
8	**Silty clay loam**	D	42.98	2.58
Total			**1663.84**	**100**

6.4 Physico-chemical Analysis of Water of Anchar

The various physico-chemical characteristics of the Anchar lake water at six different sampling sites during winter and summer are presented in Table 20 and Table 21 respectively. The physico-chemical parameters were observed to vary with different sites due to varying anthropogenic pressures at these sites.

Water temperature which is the measure of intensity of heat stored in a volume of water is one of the most important factors in an aquatic environment as it affects both physical and chemical properties of water as well as the biological activities occurring within it. The water temperature was found to fluctuate between 5.6°C and 25.9°C showing a distinct seasonal trend of maximum values in summer and minimum in winter. Minimum temperature of 5.6°C was recorded at site W4 (near Kujar) in winter (Table 20) and maximum 25.9°C in summer at the same site (Table 21).

pH values the indicative of hydrogen ion concentration recorded during the study period exhibit alkalinity ranging from 7.6 to 8.27 units, the highest 8.27 being obtained at site W6 (main Anchar water body) during summer (Table 21) and lowest 7.6 at site W5 (near Shallabugh) in winter (Table 20).

The electrical conductivity of a lake is a measure of its capacity to conduct electric flow. Conductivity values were found to fluctuate markedly from 304.8 to 407.5 µS/cm. The highest and lowest electrical conductivity was recorded in winter and summer season respectively for the sites W5 (near Shallabugh) and W3 (Nallah Amir-Khan) respectively (Table 20, 21).

Table 20: Physico-chemical characteristics of water (winter)

Parameters	W1 Near Khushalsar	W2 Near SKIMS	W3 Nallah Amir-Khan	W4 Near Kujar	W5 Near Shallabugh	W6 Anchar
Water Temperature (°C)	6	6.8	7.1	5.6	6.9	6.8
pH	7.76	8.1	8.0	7.81	7.6	8.16
EC (µS/cm)	350.3	385.4	307.1	391.3	407.5	331.2
DO (mg/l)	6.3	3.83	4.08	9	8.5	3.4
NO_3-N (µg/l)	258.1	292.1	183.6	225.6	280	183.4
TP(µg/l)	364.4	558.2	393.4	335.4	371.4	542.9
K(mg/l)	3.9	2.8	2.9	4.95	5.5	3.4

.

Table 21: Physico-chemical characteristics of water (summer)

Parameters	W1 Near Khushalsar	W2 Near SKIMS	W3 Nallah Amir-Khan	W4 Near Kujar	W5 Near Shallabugh	W6 Anchar
Water Temperature (°C)	24.9	25.5	24.6	25.9	25	25.2
pH	7.97	8.15	8.10	8.17	7.67	8.27
EC (µS/cm)	339.1	362.8	304.8	351.6	362.6	311.3
DO (mg/l)	3.9	3.3	3.72	3.8	3.45	3.2
NO_3-N (µg/l)	192.6	219.1	174.5	160.5	159.7	211.7
TP(µg/l)	294.4	413.4	356.7	291.9	350.6	424.1
K(mg/l)	4.3	2.6	2.8	4.8	2.8	2.9

NOTE: - EC = Electrical conductivity; DO = Dissolved oxygen; NO_3-N = Nitrate-Nitrogen; TP = Total Phosphorus; and K = Potassium.

The chemical and biological processes undergoing in a water body are largely dependent upon the presence of oxygen. The main sources of dissolved oxygen in water are atmosphere and the photosynthetic process of the green plants. In the study, dissolved oxygen content ranged from 3.2 to 9 mg/l indicating significant seasonal variability. Minimum value of dissolved oxygen 3.2 mg/l was recorded at site W6 (main Anchar water body) in summer (Table 21) and maximum 9 mg/l at site W4 (near Kujar) in winter (Table 20).

Basic nutrients like phosphate and nitrate determine the productivity of lake water. In the present investigation, the seasonal values of nitrate were found to range between 159.7 µg/l at site W5 (near Shallabugh) and 292.1 µg/l at site W2 (near SKIMS). Total phosphorus was found to be present in the range of 291.9 to 558.2 µg/l, with highest being recorded at site W2 (near SKIMS) and lowest at site W4 (near Kujar) (Table 20, 21). The levels of potassium were found to fluctuate between 2.6 and 5.5 mg/l.

6.5 Model Simulations

Under this heading the results of GWLF model 30 year (1981-2010) estimates of sediment and nutrient loadings in the Anchar catchment have been presented. 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.

6.5.1 Contribution from Catchment Sources

Sindh catchment is a potential contributor of sediment and nutrient loadings to the Anchar. In order to reduce this pollution load (sediment and nutrients) it is vital to know various source areas in the catchment that contribute sediment and nutrient to Anchar, so that necessary remediation measures can be taken for the restoration of the Anchar system. Lake managers require an understanding of nutrient sources before developing plans to improve water quality of eutrophic lakes (Moss, 2007). The contribution of different lake catchment sources to the sediment and nutrients of the Anchar system are discussed under the following sub-headings:

6.5.1a Sediment Loadings from Source areas

Table 22 and Fig.35 give the detailed results of the average annual sediment loadings from the source areas (land use/land cover) in the Anchar catchment for the 30 year simulation period against the changing land use/land cover conditions. The results of the source area contribution to sediment loadings presented in the Table 22 show an increasing trend. The catchment on an average generates about 13274.1 metric tons of sediment/year under the 1992 land use/land cover, while as under the 2005 land use/land cover scenario this increases to 16707.1 metric tons of sediment/year exhibiting an increase of 20.5%. The major loadings for both 1992 and 2005 are recorded by stream-banks, bare land, agriculture and pastures (Fig.35). The data (Table 22) also reveals that increase in sediment load is highest for the stream banks (1777 tons/yr) followed by bare land (1037.3 tons/yr), agriculture (520 tons/yr) and pastures (82.3 tons/yr). The classes horticulture and built-up areas record insignificant contributions to sediment loadings.

Table 22: Source area contribution to average annual sediment load in Anchar catchment (1981-2010) as a function of changing Land use/Land cover

Source	Sediment (Tons/yr)		
	1992	2005	Change
Pastures	320.2	402.5	82.3
Agriculture	2022.1	2542.1	520.0
Forests	51.8	65.1	13.3
Horticulture	7.4	9.3	1.9
Bare land	4105.0	5142.3	1037.3
Built-up	0.2	1.4	1.2
Stream bank	6767.4	8544.4	1777.0
Total	**13274.1**	**16707.1**	**3433.0**

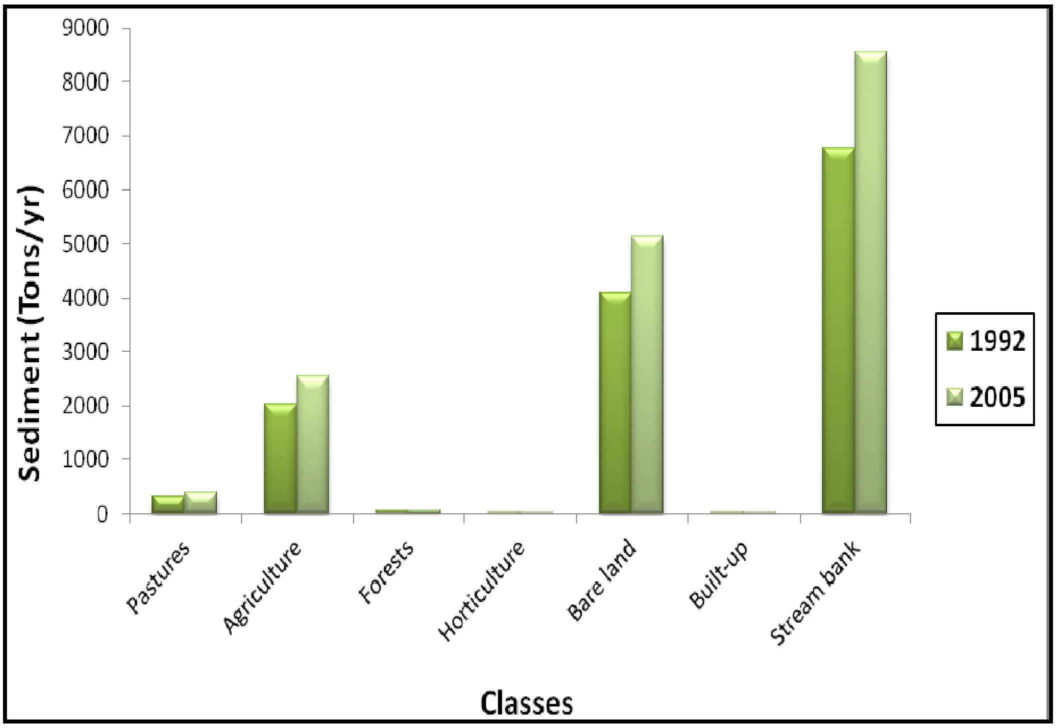

Fig. 35: Source area contribution to average annual sediment yields in Anchar catchment (1981-2010) as a function of changing Land use/Land cover

6.5.1b Nutrient Loadings from Source areas

The results of the source area (land use/land cover) contribution towards nutrient loadings against the changed land use/land cover conditions are given in Table 23-24. The nutrients loading into Anchar from the catchment include nitrogen and phosphorus (both dissolved and total). From the data presented in the tables it's clear that there is an increasing trend for the nutrient loadings (nitrogen and phosphorus) as a function of changing land use/land cover scenario. The major sources of nitrogen and phosphorus loadings are ground water, bare lands, agriculture and pastures.

Nitrogen Loadings

The simulations presented in Table 23 reveal that on an average, the catchment generates about 22654.2 Kg/yr of dissolved nitrogen with a total nitrogen load of 24826.2 Kg/yr under 1992 land use/land cover, while as 27157.7 Kg/yr of dissolved nitrogen with a total nitrogen load of 30747.3 Kg/yr is generated by the catchment under 2005 land use/land cover scenario, thus showing an increasing trend. Fig.36 depicts the source area contribution to average annual nitrogen loads in Anchar catchment for 30 year simulation period as a function of changing land use/land cover. Ground water is the largest source of dissolved and total nitrogen contributing about 9222.1 Kg/yr and 9984.7 Kg/yr of dissolved nitrogen under 1992 and 2005 land use/land cover respectively. This source contributes 9354.2 Kg/yr of total nitrogen under 1992 land use/land cover, while as under 2005 land use/land cover it contributes 11600 Kg/yr of total nitrogen. Ground water source is followed by bare land, agriculture and pastures as maximum contributors to nitrogen loadings to Anchar. Stream banks and built-up areas are significant source area contributors to total nitrogen loadings. Stream banks contribute about 307.0 Kg/yr and 387.6 Kg/yr of total nitrogen under 1992 and 2005 land use/land cover respectively, while as built-up areas contribute 7.4 Kg/yr of total nitrogen under 1992 land use/land cover and 14.8 Kg/yr under 2005 land use/land cover scenario.

Table 23: Source area contribution to average annual nitrogen loads in Anchar catchment (1981-2010) as a function of changing Land use/Land cover

Source	1992		2005	
	Dissolved Nitrogen (Kg/yr)	Total Nitrogen (Kg/yr)	Dissolved Nitrogen (Kg/yr)	Total Nitrogen (Kg/yr)
Pastures	2592.0	3342.7	2879.9	3978.2
Agriculture	3629.0	4232.1	6748.0	6926.8
Forests	557.2	623.4	643.9	723.7
Horticulture	111.0	132.8	130.4	141.4
Bare land	6542.9	6826.6	6770.8	6974.8
Built-up	0	7.4	0	14.8
Stream bank	-	307.0	-	387.6
Ground water	9222.1	9354.2	9984.7	11600.0
Total	**22654.2**	**24826.2**	**27157.7**	**30747.3**

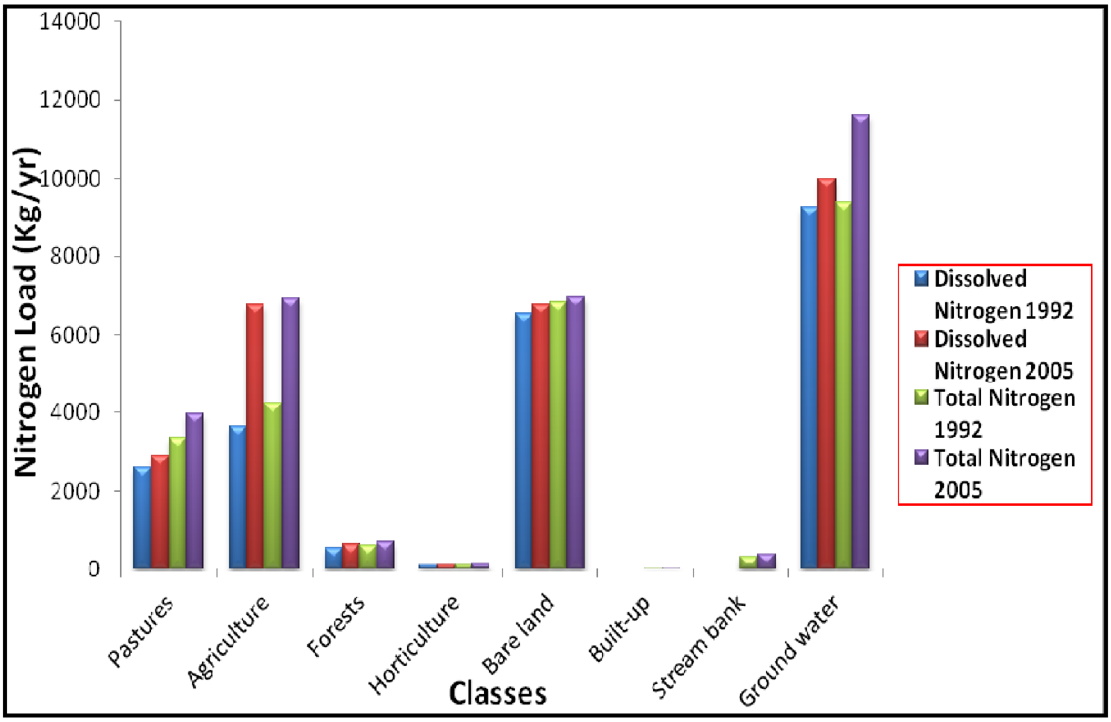

Fig. 36: Source area contribution to average annual nitrogen loads in Anchar catchment (1981-2010) as a function of changing Land use/Land cover

Phosphorus Loadings

The source area contribution to average annual phosphorus loads in Anchar catchment (1981-2010) as a function of changing land use/land cover is presented in Table 24; the graphical representation for the same is presented in Fig.37. It's evident from the data that Anchar on an average receives about 887.8 Kg/yr of dissolved phosphorus with a total phosphorus load of 1157.6 Kg/yr under 1992 land use/land cover which has increased to 1154.4 Kg/yr of dissolved phosphorus with a total phosphorus load of 1533.8 Kg/yr under 2005 from its catchment. In case of phosphorus loading into Anchar bare land, agriculture and pastures are the major contributing sources of both the dissolved and total phosphorus. Ground water contributes about 61.3 Kg/yr of dissolved phosphorus and 67.8 Kg/yr of total phosphorus under 1992 land use/land cover, while as under 2005 scenario, it contributes 67.7 Kg/yr of dissolved phosphorus and 74.8 Kg/yr of total phosphorus. Stream bank makes a significant contribution to the total phosphorus load generating about 135.1 Kg/yr and 170.5 Kg/yr of total phosphorus under the 1992 and 2005 land use/land cover scenarios respectively. Horticulture and built-up areas are the least contributing sources in terms of phosphorus loadings.

Table 24: Source area contribution to average annual phosphorus loads in Anchar catchment (1981-2010) as a function of changing Land use/Land cover

Source	1992		2005	
	Dissolved Phosphorus (Kg/yr)	Total Phosphorus (Kg/yr)	Dissolved Phosphorus (Kg/yr)	Total Phosphorus (Kg/yr)
Pastures	70.6	84.9	78.5	101.6
Agriculture	98.9	112.2	183.8	199.8
Forests	17.6	19.8	20.3	23.6
Horticulture	3.5	12.8	4.1	19.4
Bare land	635.9	724.2	800.0	942.5
Built-up	0	0.8	0	1.6
Stream bank	-	135.1	-	170.5
Ground water	61.3	67.8	67.7	74.8
Total	**887.8**	**1157.6**	**1154.4**	**1533.8**

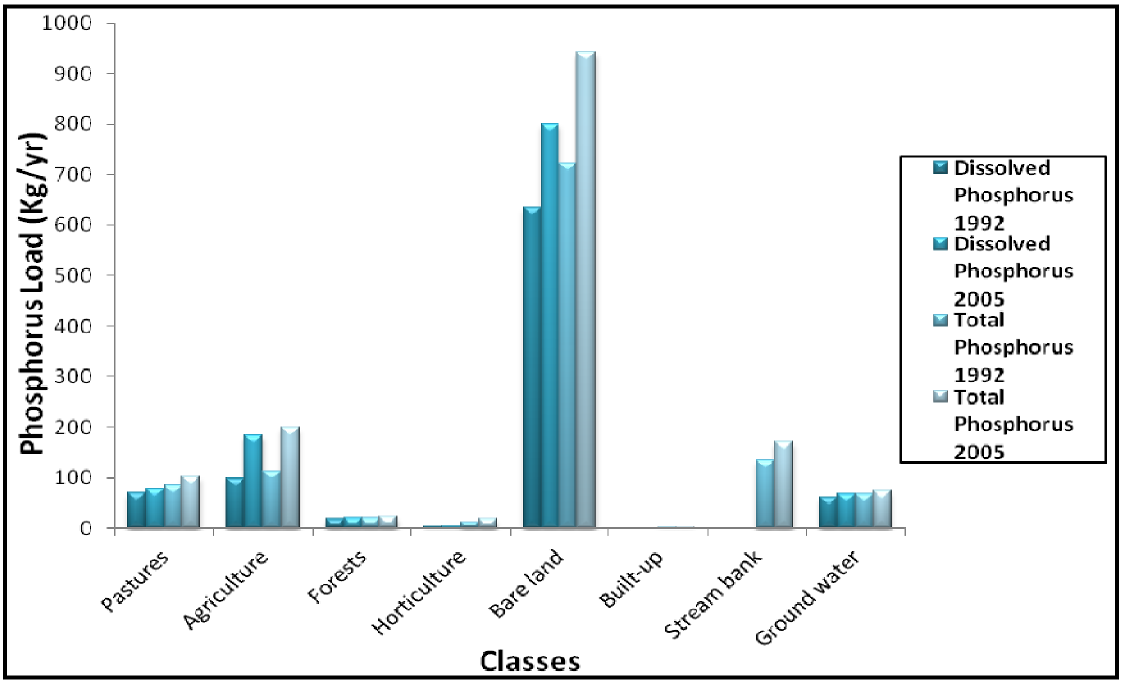

Fig. 37: Source area contribution to average annual phosphorus loads in Anchar catchment (1981-2010) as a function of changing Land use/Land cover

6.6 Hydro-meteorological Data Analysis

Impacts of climate change observed around the world include among others the increase in surface temperature, sea-level rise, changes in precipitation and decrease in snow cover (IPCC, 2001b). Climate affects all aspects of the hydrologic cycle namely rainfall, runoff and evaporation. Changes in these components in turn affect the water availability and variability worldwide. There are many different ways in which climate change may affect catchment behaviour, such as changes in rainfall totals, locations, seasonality and intensity, effects on temperatures, radiation, evaporation and drainage density (Moglen *et al.*, 1998; Roberts, 1998). For the purpose of achieving the objective of assessment of climate change indicators in the Anchar catchment, hydro-meteorological data from 1981-2010 was analyzed.

6.6.1 Precipitation Data Analysis

The total annual precipitation data for the Anchar catchment from 1981-2010 is given in Appendix 10a, while the analysis of the same is presented in Fig.38. The Appendix 10a reveals that the catchment received the highest annual precipitation in the year 1995 (1132 mm) and the lowest in the year 2000 (464.5mm). Analysis of this data also reveals that the catchment is witnessing a decreasing trend in the precipitation (Fig.38). On a monthly average basis (Fig. 39, Appendix 10b), the maximum precipitation was received in the month of March (117.11mm) and the least in the month of November (27.52mm).

6.6.2 Temperature Data Analysis

The analysis of average monthly maximum and minimum temperatures for 30 years (1981-2010) is given in Fig.40 (Appendix 11a, b). Analysis of the data reveals that the average daily maximum temperature was observed to be highest in the month of August (31.55°C) and lowest in the month of January (-0.6°C). Whereas, average daily minimum temperature from Fig.40 (Appendix 11b) was observed to be highest in the month of January (-6.22°C) and lowest in the month of July (19.80°C).

The seasonal variations in average maximum (Table 25, Fig.41) and minimum temperatures (Table 26, Fig.42) from 1981-2010 reveal an increasing trend of average maximum temperatures in winter and autumn seasons.

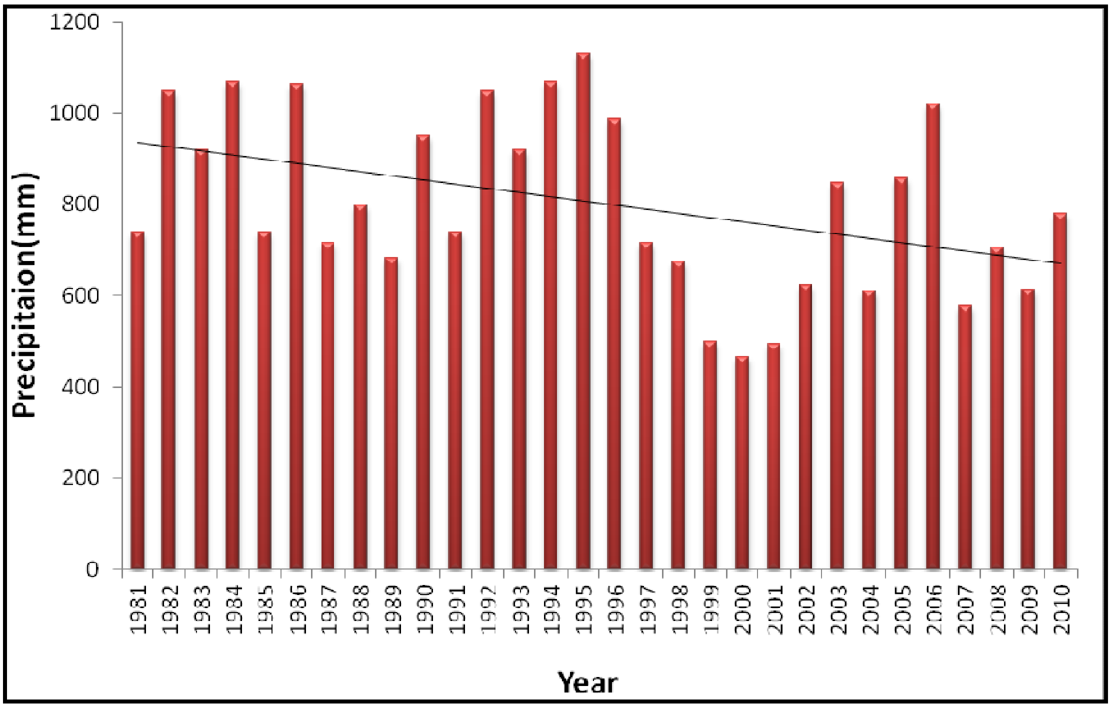

Fig. 38: Total annual precipitation in Anchar catchment (1981-2010)

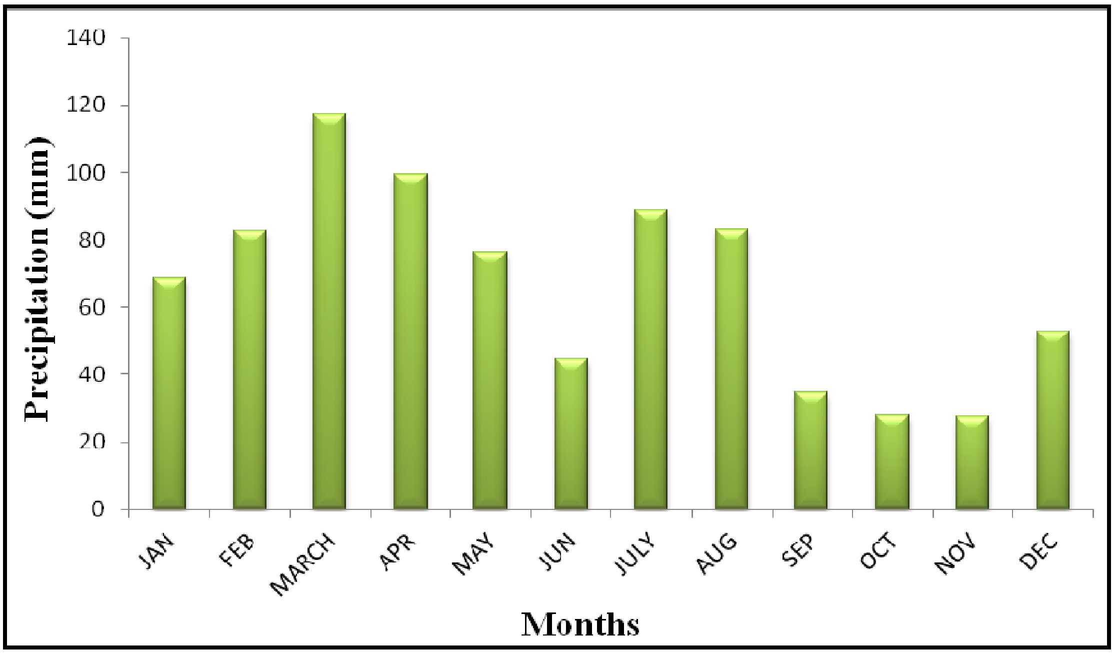

Fig. 39: Mean monthly precipitation in Anchar catchment (1981-2010)

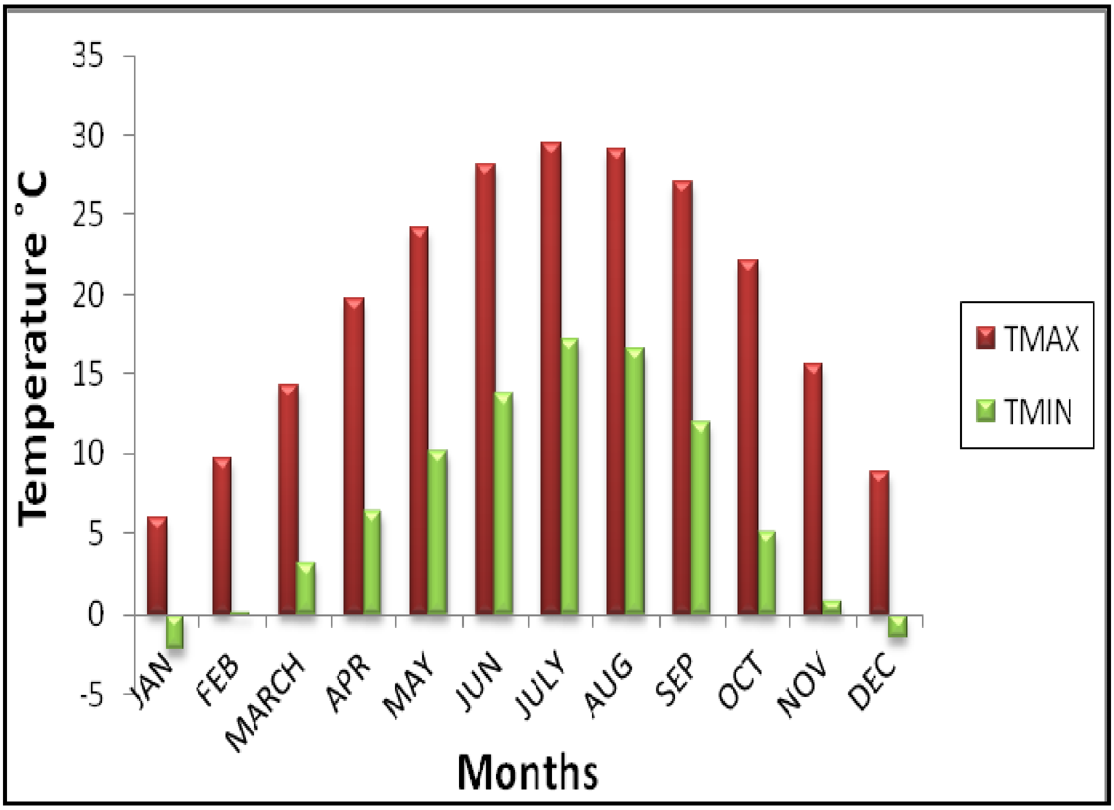

Fig. 40: Average monthly maximum & minimum temperature (°C) in Anchar catchment (1981-2010)

Table 25: Seasonal variations in average maximum temperature

Yr.	Winter	Spring	Summer	Autumn
1981	5.73	16.68	28.97	21.03
1982	7.92	17.22	28.16	20.36
1983	8.90	18.37	28.18	21.49
1984	7.12	18.60	28.98	20.77
1985	11.84	20.77	29.23	21.97
1986	3.91	17.54	28.52	20.97
1987	6.56	17.78	28.81	21.71
1988	9.66	20.45	28.77	22.11
1989	8.98	18.75	27.58	21.08
1990	8.55	19.85	29.72	21.73
1991	5.73	16.68	28.97	21.05
1992	7.92	18.93	28.16	20.36
1993	8.90	18.37	28.23	21.49
1994	7.12	18.60	29.01	20.77
1995	4.81	17.89	28.78	21.23
1996	7.42	17.77	27.53	19.50
1997	6.56	17.78	28.78	21.71
1998	7.50	19.00	29.25	22.52
1999	8.78	21.28	30.24	22.54
2000	8.64	21.74	29.57	23.13
2001	11.17	22.00	30.11	21.84
2002	8.94	20.64	29.73	22.07
2003	9.76	18.24	29.48	21.14
2004	9.16	22.11	28.76	22.83
2005	7.13	18.09	29.32	22.50
2006	8.04	21.47	29.10	20.45
2007	10.03	21.16	29.41	22.70
2008	7.56	21.14	29.64	21.34
2009	10.80	15.32	26.95	27.7
2010	13.30	16.62	25.2	26.4

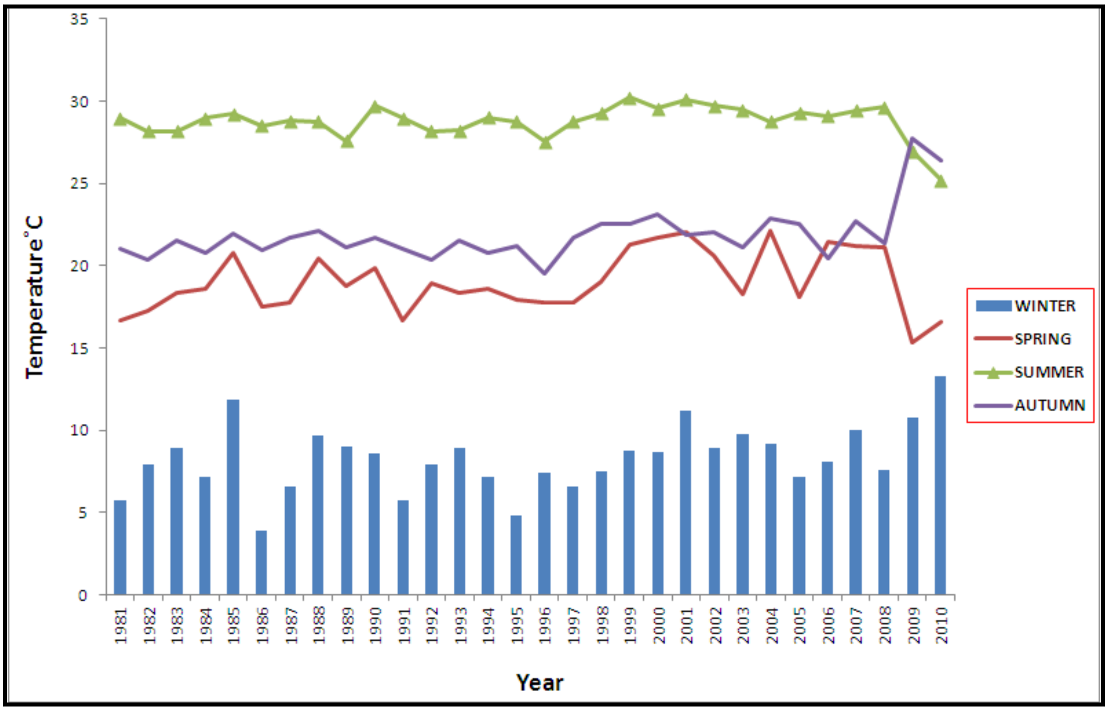

Fig. 41: Seasonal variations of average maximum temperature from 1981-2010

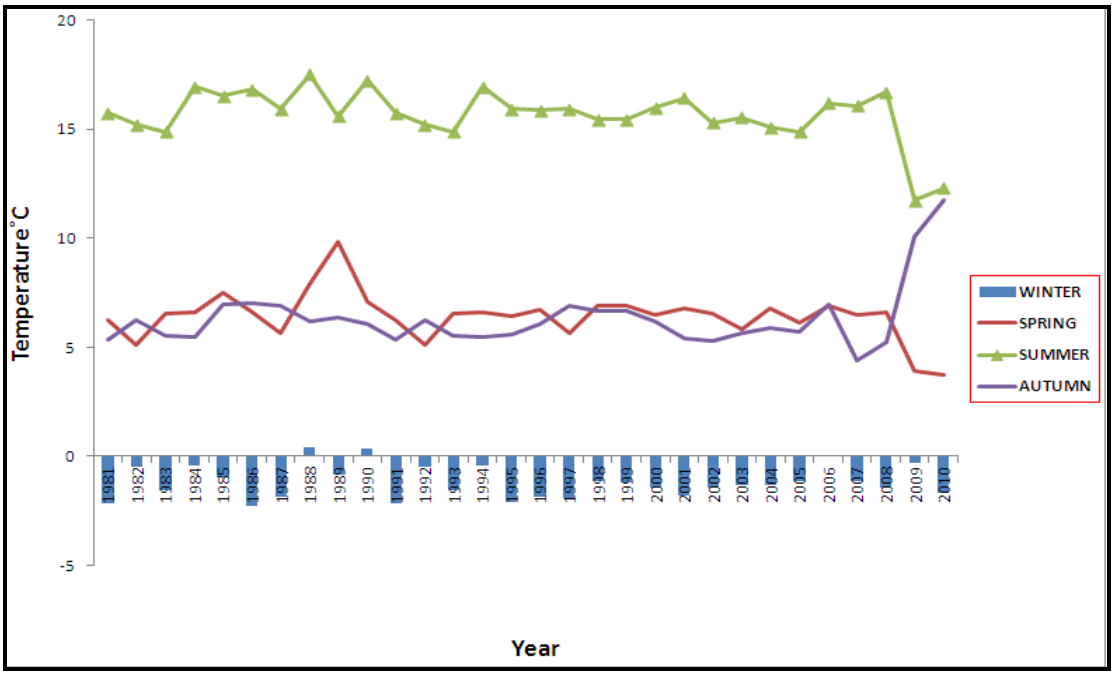

Fig. 42: Seasonal variations of average minimum temperature from 1981-2010

Table 26: Seasonal variations in average minimum temperature

Yr.	Winter	Spring	Summer	Autumn
1981	-2.15	6.25	15.75	5.37
1982	-0.47	5.13	15.20	6.24
1983	-1.55	6.55	14.87	5.53
1984	-0.40	6.58	16.96	5.49
1985	-0.96	7.52	16.52	6.95
1986	-2.31	6.60	16.84	7.00
1987	-1.88	5.65	15.93	6.89
1988	0.43	7.92	17.52	6.16
1989	-0.84	9.82	15.61	6.34
1990	0.36	7.11	17.25	6.05
1991	-2.15	6.25	15.75	5.37
1992	-0.47	5.13	15.20	6.24
1993	-1.55	6.54	14.87	5.53
1994	-0.40	6.58	16.96	5.49
1995	-2.11	6.41	15.93	5.60
1996	-1.85	6.74	15.86	6.05
1997	-1.90	5.65	15.93	6.89
1998	-1.15	6.88	15.44	6.68
1999	-1.18	6.88	15.44	6.68
2000	-1.45	6.46	15.98	6.19
2001	-1.81	6.76	16.45	5.42
2002	-1.44	6.55	15.30	5.27
2003	-1.30	5.85	15.55	5.67
2004	-1.33	6.79	15.10	5.90
2005	-1.15	6.10	14.88	5.71
2006	0.01	6.91	16.19	6.94
2007	-1.15	6.48	16.09	4.41
2008	-1.43	6.61	16.72	5.21
2009	-0.31	3.89	11.75	10.06
2010	-1.7	3.73	12.31	11.75

Chapter 7

DISCUSSION

Chapter-7

DISCUSSION

This chapter provides the discussion of the obtained results in relation to existing literature on the subject.

7.1 Land Use/Land Cover Change

Land use/ land cover mapping is needed to better understand and manage emerging environmental problems arising from local to global scales. Change in land use and land cover is a dynamic process taking place on the surface, and the spatial distribution of the changes that have taken place over a period of time and space are of immense importance in many natural resources studies (Baboo and Devi, 2010). 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). In the present study carried out by using satellite data for the 15 year time period (1992-2005) remarkable changes were observed in the land use/ land cover of Anchar catchment. These changes are largely attributable to human activities or more specifically, people's responses to economic opportunities as mediated by institutional factors that drive land use/ cover changes (Lambin *et al.,* 2003).

The results of the land use/ land cover change (Table 12) indicate considerable changes in almost all the land use/land cover classes with severe changes having occurred in forests, scrublands, grasslands, bare land and built up areas during the 15 year period. One of the most significant changes observed from 1992-2005 is the decrease in forest cover of the catchment by about 56.62 Km^2. This decrease is mostly attributed to the large scale clearing/cutting of trees in the forests for various uses such as firewood, timber and clearing for agricultural purposes particularly along the higher reaches. The phenomenon of forest clearing is caused by anthropogenic disturbance (Chowdhury and Schneider, 2004). This large scale deforestation occurring in the study catchment, has made the soil vulnerable to different types of erosion and subsequently more production of sediment load. This is quite clear from the GWLF model simulations results (Table 22) for a period of 30 years, which reveal an increase of 13.3 metric tons/yr of sediment from the forest class under the changed land use land cover scenario.

Large scale decline in scrubland (33.98 Km^2) and grassland area (23.22 Km^2) (Table 12) from 1992-2005 in Anchar catchment reveals that these ecologically and socioeconomically important pasture lands are under tremendous pressure. These pasture areas of the catchment provide livelihood to a vast majority of people from different corners of the state who establish their temporary shelters during summer in this area to feed their cattle in these alpine scrub and grasslands. The main reasons for their decline are overgrazing beyond their carrying capacity, biotic interferences and clearing of the grasslands at the low altitudes for cultivation and exploitation for medicinal plants etc. Because of continuous and heavy grazing that too beyond carrying capacity the pasture lands have deteriorated to critical levels. Similar observations were made by Bhat *et al.* (2002) in relation to the human interfered temperate and alpine pasturelands of Dachigam National Park. With the ever increasing number of cattle and introduction of high yielding varieties of cattle by Animal Husbandry department, the stress on the grasslands of Sindh valley has increased tremendously (Ahmad *et al*., 2009). In the north-west Himalayan regions, edible species of grasses have vanished and most of the pastures besides having low biomass availability are predominantly covered with noxious weeds like *Stipa, Sambucus, Aconitum, Cincifuga, Adonis, Sibbaldia* etc. (Misri, 1988). In Central Himalaya too the area of the pastures has been found to be declining because of various biotic interferences (Ram and Singh, 1994).

Other significant changes observed during the present study include the increase in area of built-up (15.72 Km^2) and bare land (34.89 Km^2) classes both at the higher and lower elevations of the catchment. It has been found that overgrazed grasslands have paved the way for creation of bare area (Shah and Bhat, 2004). Also deforested areas of the catchment have resulted in the creation of bare lands. This is in conformation with the study of Reis (2008) who reported that the lands converted to the bare soil class are mostly forests, agriculture and pasture classes. Bare land class is very much vulnerable to increased runoff as well as increased sediment and nutrient yields. The data shown in Table 22-24 clearly reveals that this class is the largest contributor of sediment and nutrient loads to Anchar, with its contribution increasing under changing land use/land cover conditions. Increase in built-up is mainly caused by population growth and economic growth (Sudhira *et al*., 2004; Bhatt *et al*., 2006; Taubenbock *et al*., 2008). The retreating of areas covered with forests, scrubs, grasses and water, while on the other hand expansion of building areas mostly residential areas was commonly observed in the study catchment. This indicates the encroachment of built-up towards forest areas, wetlands and other water resources. The relationships between building areas expansion and the forest decrease have also been reported elsewhere (Fearnside, 2001; Lambin *et al*., 2003; Velazquez *et al*., 2003). Portions of wetland have been illegally encroached, earth-filled subsequently giving rise to built-up areas. Accelerated nutrient enrichment of lakes like Anchar due to incoming effluents and sewage discharged from these expanding built-up areas in the catchment results in the proficient and luxuriant growth of macrophytes. This causes decrease in open water extent of lakes with the surface water remaining covered by the decomposed thick mats of such vegetation, disrupting the ecological balance of the lake. As a result, 6.46 Km^2 increase in the area of aquatic vegetation and a decrease of 2.51 Km^2 in area of water bodies was recorded during the span of 15 years.

Another important change in the land use/land cover observed was 10% decrease in agricultural land area and subsequent 13.9 % increase in area under horticultural crops. The shift from agricultural crops to horticultural crops may be due to the lesser amount of water required by them and the more economic benefits associated with the horticultural sector in Kashmir.

The data on land use land cover change has been observed to have potential scientific value for the study of human-environment interactions and aids in ascertaining the impact of land use on the amount of pollution (Tong and Chen, 2002; Tang *et al.,* 2005; Tong *et al.,* 2008).

7.2 Soil Physico-chemical Characteristics

Soil is a complex system where in chemical, physical and biochemical factors are held in dynamic equilibrium. The physico-chemical characteristics of soils in the Anchar catchment have been presented in Table 18 and from this table it is clear that these characteristics of soil vary with different land use/ land cover categories.

In the current study, it was observed that wetland soils exhibited low pH value and high values of electrical conductivity, organic matter and available nutrients (N, P and K) (Table 18). The wetland soils were found to be acidic with a pH of 5.25. Wetlands with a pH of less than 5.5 have been classified as acid wetlands (Cowardin *et al*., 1979). High organic matter content (6.46%) in these wetlands can be attributed to increased soil water content, which slows microbial degradation of organic matter (Giese and Flannagan, 2006). Saturated soil conditions result in less diffusion of oxygen into wetland soil profile below the water level, which reduces aerobic decomposition of peat ending up in more storage of organic matter (Ullah *et al.,* 2009). Although, the organic matter degrades at a slow rate in these wetlands, but still this significantly higher quantity of organic matter influences the pH of these wetland soils. As organic matter undergoes decomposition by detritivores, carboxyl groups associated with organic matter break-down releasing hydrogen ions into the soil which lowers the pH of these soils (McBride, 1994; Sparks, 1995; Andersson *et al*., 2000; Baath and Anderson, 2003; Pietri and Brookes, 2008). Thus, it stands to reason that wetland soils with high organic matter will have lower pH levels. This high percentage of organic matter and low pH found in the wetlands is in agreement with the observations of Machung *et al*. (1996). The relatively high electrical conductivity (396µS/cm) and high content of nutrients N (427.20 Kg/ha), P (40.10 Kg/ha) and K (424.50 Kg/ha), in these wetlands can be attributed to the discharge of sewage and effluents from built-up areas and the leaching of excessive fertilizers from agricultural/horticultural fields surroundings the wetlands. Similar findings have been noted by Khan and Shah (2004b, 2010) in their studies on Hokersar wetland of Kashmir. The nutrients N and P have a positive correlation with organic matter, so higher the % organic matter higher will be the content of these nutrients.

The pH of cultivated lands viz; horticulture (7.56), agriculture (7.60), and plantation (8.20) was found to be higher than the pH of coniferous forests (6.70) and pasture soils (6.28) - Table 18. The lower pH values are mostly attributed to the decomposition of the organic matter which is present in higher amounts in pasture and forest soils (Gupta and Verma, 1975; Minhas and Bora, 1982; Kale and Chevan, 1996; Arao, 1999; Bardgett *et al*., 2001; Baath and Anderson, 2003; Perie and Ouimet, 2008). Jones *et al.* (2002) related the acidic value of soils to the higher rate of leaching and very high percentage of organic matter in the soils. Similar findings of natural forest and pasture soils being more acidic were reported by Kizilkaya and Dengiz (2010). The higher pH of cultivated soils is due to their karewa geology. Alkaline pH in these karewa soils can be due to higher calcium carbonate $CaCo_3$ (Sahu *et al*., 1990; Najar, 2002). A negative correlation seems to exist between pH and organic carbon. This can be attributed to organic matter content which on decomposition produces organic acids particularly carbonic acid and to various other soils characteristics like soil texture, permeability of soils and extent of slope (Verma and De, 1969; Nitant, 1989; Verma *et al.*, 1990; Mahapatra *et al*., 2000; Wani *et al*., 2009). The soils of bare exposed regions were found to be very acidic with quite a low pH of 3.29. This is due to the fact that these areas are located at higher elevations where precipitation is high. Infact, these regions of the study catchment are under snow cover during many months of the year. So, the reason for the low pH of soils of these bare exposed regions is that the hydrogen ions from the precipitation replace the basic cations of these regions resulting in low pH values. The more the hydrogen ions from rain water readily displace the basic cations the more is the amount of dissociable hydrogen ions which in turn is responsible for the low pH values and high exchangeable acidity (Osuji *et al*., 2010). Basically, acidic soils develop as a consequence of excessive leaching of basic cations, mainly Ca, Mg and K in climatic conditions characterized by excessive rainfall relative to evapo-transpiration.

Electrical conductivity of soils located at lower elevations like soils of low flood-plain wetlands (396µS/cm), built-up (310µS/cm) which is mainly confined to the lower catchment plains was found to be higher than soils of land use land cover classes like coniferous forests (164µS/cm), pastures (145µS/cm), bare exposed rock regions (128µS/cm) located at higher elevations (Table 18). Thus, electrical conductivity showed a decreasing trend with increase in altitude. This can be attributed to leaching of soluble salts from higher altitudes.

Water holding capacity of soils is affected by the amount of organic matter and the soil texture i.e. percentage of clay, sand and silt in soils (Gupta *et al*., 1988; Hudson, 1994). Table 18 reveals that soils with high organic matter and clay content recorded higher percentage of water holding capacity. Soil organic matter enhances available water holding capacity. Each 1% of organic matter adds 1.5% of available water capacity (Gol, 2009). Thus, wetland and forest soils with high organic matter recorded highest water holding capacity of 87.2% and 58.7% respectively. Sharma and Biswas (1972) reported high water holding capacity in forest soils due to high organic matter content. Bhatia and Vardani (1982) too found higher water holding capacity in forests soils as compared to cultivated and bare lands which they attributed to fine fractions and high organic matter content. Similar findings were reported by Kale and Chevan (1996), Singh and Kashyap (2007) and Bisht and Bhatt (2010). It is a known fact that sandy soils accept water at a higher rate than loam or clay soils, and water holding capacity is more in clay soils as compared to the sandy soils. The water holding capacity of the soils increases with increase in clay content of the soils (Senjobi and Ogunkunle, 2011). Lowest water holding capacity was recorded for horticultural (32.7%) and bare exposed region (36.4%) soils; this is due to the loamy sand and sandy clay texture of these soils coupled with low percentage of organic matter. Gupta *et al*. (2010) in their study on physical properties of some soils under different land uses from foothills of Siwaliks of Jammu, also observed that water holding capacity was highest in case of soils under forest land which they ascribed to the presence of high organic matter and clay fractions and lowest in case of barren land soils.

Soil organic matter is a critical component of soil-plant ecosystem and it changes with land use or agricultural management practices (Ghani *et al*., 2003). It is evident from the data (Table 18) that cultivated soils have low organic matter as compared to forest and pasture soils. Intensive cultivation degrades the soil structure which is reflected by a decrease in stability of soil aggregates. The lower stability is usually associated with a decrease in soil organic matter content. Soil structural stability and soil organic matter content usually decrease with cultivation (Eynard *et al*., 2004). The low organic matter content of cultivated soils is attributed to the fact that cultivation increases aeration of soil which enhances the decomposition of soil organic matter (Kizilkaya and Dengiz, 2010). On the other hand comparatively high percentage of organic matter in forest and pasture soils is ascribed to the fact that these soils are located at high altitudes and at these altitudes due to low temperature and heavy precipitation microbial growth is restricted and rate of mineralization is low as a result accumulation of organic matter is high. These findings are in confirmation with the observations of Talib and Verma (1990) and Verma *et al.* (1990). The findings are also in agreement with Mushki (1994), Nakashgir *et al.* (1997), Bossuyt *et al*. (2002) and Schindlbacher *et al*. (2010)**.** High organic matter content under pasture lands is attributed mainly to dung from grazing animals and turnover of grass roots (Campbell *et al*., 1992). Soils of bare exposed region with an organic matter of 1.81% have the lowest organic matter content. This is due to the fact that these soils are devoid of vegetation cover and presence of relatively coarse fraction (England and Lessesne, 1962; Singh and Prakash, 1985; Castillo *et al.,* 1997; Post and Kwon, 2000; Materechera and Murovhi, 2011).

Soil organic matter status is a significant indicator of amount of available nutrients present in soil especially nitrogen (Sabiene *et al*., 2010). Most of the available nutrients present in soils are closely associated with organic matter (Meysner *et al*., 2006). It's the major soil source of phosphorus and sulphur and the primary source of nitrogen (Brady, 1996; Wani, 2000). With regard to the available nutrients (N, P and K) in the soils of study catchment a positive correlation exists between the organic matter and available nutrients. A significant positive relationship of total phosphorus with organic matter has also been reported by Mandal et *al*. (1990). Land use classes (wetlands, coniferous forests and pastures) having high % organic matter exhibit higher values of available nutrients (Table 18). This can be attributed to the association of nutrient ions by humus complex in soils (Kanthaliya and Bhatt, 1991; Nguyen *et al*., 2004; Suhadolc *et al*., 2007; Deenik and Yost, 2008). During, the study it was observed that phosphorus content (12.80Kg/ha-46.60Kg/ha) of soils was lower as compared to the nitrogen (101.8Kg/ha-627.20Kg/ha) and potassium (100.21Kg/ha-464.80Kg/ha) content. This is due to the reason that phosphorus tends to bind with calcium which is present in high content in soils of Kashmir due to carbonaceous or lime-rich bed rock of valley thus phosphorus gets rapidly fixed and becomes less available than nitrogen and potassium. High content of available phosphorus in agriculture (38.75Kg/ha), horticulture (36.94Kg/ha), plantation (35.82Kg/ha) and built-up (33.20Kg/ha) soils can be attributed to the excessive use of fertilizers and discharge of domestic effluents.

Soil texture affects soil water characteristics, erosion potentials, budget of plant nutrients and dynamics of organic matter (Korkanc *et al*., 2008). Soil texture analysis of Anchar catchment (Table 19) revealed that the dominant textural class in the catchment is sandy clay (32.45%) followed by clay loam (28.16%). Clay content was found to be high in agricultural and forest soils with a texture of clay and clay loam respectively. The texture of bare land and bare exposed region soils was found to be sandy clay. These soils were found to have higher sand content than soils of cultivated lands and forests. This can be attributed to higher levels of erosion which these soils face because of being present on steep slopes. Similar findings were observed by Singh and Prakash (1985) in soils of hilly region of Uttar Pradesh in

North India. Soil hydrological groups as determined from the soil texture classes determine the runoff potential of different soils which plays an important role in the sediment and nutrient fluxes in the catchment. Most of the soils in the catchment were found to belong to the hydrological group D i.e. having clay, clay loam, sandy clay and silty clay loam textures. So, land use land cover classes like agriculture, forests, and bare areas with a texture of clay, clay loam and sandy clay falling in this hydrological group shall contribute predominantly to run-off without much infiltration capacity.

7.3 Physico-chemical Characteristics of Water

Water, an essential requirement for all forms of life, needs protection from pollution which otherwise poses a threat to life. Environmental conditions such as salinity, oxygen, temperature and nutrients influence the composition, distribution and growth of its biota (Swami *et al*., 2000). The assessment of these factors that determine water quality is essential as it aids in prevention of pollution. Water quality includes the physical, chemical and biological characteristics of water. Table 20 and 21 present the values of various physico-chemical parameters of Anchar analyzed during winter and summer seasons of the study period. From the values presented in the tables, it’s clear that the water samples of the lake show site specific as well as seasonal variability.

Water temperature is an important property affecting the physical and chemical properties of water and the aquatic vegetation, organisms and their biological activities. Temperature variation is one of the factors in swamps, which may influence the physico-chemical characteristics and the distribution and abundance of flora and fauna (Soundarapandian *et al*., 2009). The water temperature during the study period fluctuated from 5.6 – 25.9°C showing a distinct seasonal trend of maximum values in summer and minimum in winter. Maximum water temperature was recorded at site W4 (near Kujar), followed by site W2 (near SKIMS) and W6 (main Anchar lake) with temperature values of 25.9°C, 25.5°C and 25.2°C respectively (Table 21). The high temperatures recorded are the result of water depth and consequently the volume of water in contact with air as observed by Zutshi and Vass (1971) and Pandit (1980) in other eutrophic water bodies.

The pH (Potentia Hydrogeni) of a solution refers to its hydrogen ion activity and is expressed as the logarithm of the reciprocal of the hydrogen ion activity at a given temperature. It regulates most of the biological processes and bio-chemical reactions. pH along with free carbon dioxide has been reported to be a critical factor in the survival of aquatic organisms (Sculthorpe, 1967). During the present investigation of the water quality of Anchar, the pH was found to fluctuate from 7.6 to 8.27. Fluctuations in pH values mostly depend upon ingredient input in the water bodies (Mathur *et al*., 2008). The present findings are in support of observation of Spence (1967) that the pH of a typical eutrophic lake ranges from 7.7 to 9.6. So, Anchar is eutrophic on the basis of its pH range. Also, the pH values recorded are indicative of the alkaline nature of the water body. The highest pH value (8.27) was recorded in the main Anchar water body itself (Table 21). This can be ascribed to the production of salicilic acid by the hydrolysis of silicates in the rock beds of the catchment area (Zutshi *et al*., 1980). The lowest pH value (7.6) was recorded near the Shallabugh wetland (Table 20), which can be attributed to increased rate of decomposition of the organic matter which is present in higher amounts in the wetland (Siraj *et al*., 2010). The pH showed a summer maximum and winter minimum trend which corroborates with the trend suggested by Sreenivasan (1965). Similar trend was reported by Ekeh and Sikoki (2003) in the New Calabar River and also by Sawane *et al*. (2006) in river Irai. This trend is due to the changes in carbon dioxide content of water. During winter season, low photosynthetic activities result in the liberation of carbon dioxide that forms carbonic acid in water, which dissociates releasing hydrogen (H^+) ions which are responsible for lowering the pH, while in summer season increased photosynthetic activities of aquatic vegetation result in greater utility of carbon source thus giving rise to higher pH values as have been observed by Goldman (1972) and Otsuki and Wetzel (1974). Similar observations of lower pH values in winter months and higher in summer months were recorded by Araoye (2009) and Sharma and Capoor (2010). The seasonality in the pH of water may be due to the influx and decay of debris as well as imbalance level of H^+ ions input from surface run-offs during the rains (Abowei, 2010).

Electrical conductivity values an indication of total nutrient concentration mainly depend on ionic concentration or dissolved inorganic substances. Changes in conductivity reflect proportional changes in ionic concentration (Otsuki and Wetzel, 1974). The overall high conductivity of the waters of the Anchar depicts high ionic concentration. The higher values may be due to accumulation of ions owing to evaporation, biological turnover and interaction with sediments (Devi and Anandhi, 2009). The higher conductivity values, an indication of the total salt concentration, place this water body at a higher trophic level as electrical conductivity has a positive correlation with trophic gradient (Das *et al*., 2006). The highest electrical conductivity was recorded at site W5 (near Shallabugh) 407.5 µS/cm followed by site W4 (near Kujar) 391.3 µS/cm and site W2 (near SKIMS) 385.4 µS/cm (Table 20). The higher value of conductivity at these sites is an indication of high nutrient enrichment at these sites. Many workers have related increase in electric conductivity to the state of nutrient enrichment (Ali *et al*., 1999; Siddiqi, 2008). In general during the study period, lower values of electrical conductivity were recorded during summer months as compared to colder winter months (Table 20, 21). Indabawa (2009) observed similar seasonal variation in conductivity readings with highest readings being obtained in colder months and lowest in warmer months. The lower values recorded during summer are attributed to the intake of ions by plants during the growing season, while as the higher values during winter are related to the abundance of nutrients which are released due to decomposition of organic matter (macrophytes and animals) (Pandit, 1999; Lashari *et al*., 2009).

Dissolved oxygen content determines the nature of an entire aquatic ecosystem to a great extent. It is a factor which reflects the physical and biological processes taking place in a water body. Dissolved oxygen is one of the most reliable parameters in assessing the trophic status and the magnitude of eutrophication in an aquatic ecosystem (Edmondson, 1966). The concentration of dissolved oxygen in a water body depends on surface agitation due to temperature, respiration rate of the living organisms and decomposition rate of dead organic matter. The oxygen utilization results from decompositional consumption of materials both of allochthonous and autochthonous origin, settling in the bottom of the basin and resulting in an oxygen deficit in bottom waters (Jones and Bachmann, 1974). Low values of dissolved oxygen (less than 5mg/l) are an indication of tendency towards anoxic conditions (Bhat and Pandit, 2002; Saloom and Duncan, 2005). The low values of dissolved oxygen 3.2mg/l and 3.3mg/l recorded in the Anchar lake (site W6) and at SKIMS site (W2) respectively (Table 21) indicate anoxic conditions and polluted nature of water body at these sites which has restricted the growth and development of plant and animal life except those that thrive well under such conditions. Highest values of dissolved oxygen were recorded near Kujar (W4) - 9mg/l and Shallabugh (W5) – 8.5mg/l (Table 20). In case of the water samples collected near these wetlands, the higher content of dissolved oxygen is in consonance with the growth and abundance of macrophytes and phytoplankton of the wetlands releasing oxygen during photosynthesis.

In the present investigation, the oxygen maximas were recorded in winter and minimas in summer (Table 20, 21). The peak value during winter was also observed (Pahwa and Mehrotra, 1966; Kolekar, 2006; Negi *et al*., 2006; Upadhayay and Dwivedi, 2006; Sharma and Capoor, 2010). Depletion in dissolved oxygen with the progression of summer is attributed to faster rate of organic matter decomposition and limited flow of water in low oxygen holding environment due to high temperature (Goldman and Horne, 1983; Rani *et al*., 2004; Ayoade *et al*., 2006). Decomposition of organic matter may be an important factor in the consumption of dissolved oxygen, which becomes more vigorous in warm weather (Bagde and Verma, 1985). The increase in dissolved oxygen to its higher values in winter is due to the high solubility at low temperature and less degradation of organic matter (Carvalho *et al*., 2005; Riddhi *et al.,* 2011). The solubility of dissolved oxygen increases with decreasing temperature (Wetzel, 2001). Thus, a negative correlation exists between dissolved oxygen and water temperature. Such an inverse relationship has also been observed (Welch, 1952; Zutshi and Vass, 1982; Breitburg *et al*., 1997; Gurumahum *et al*., 2000; Agarwal and Thapliyal, 2005; Sumitra *et al*., 2007; Sharma *et al*., 2009).

Nitrate is the most abundant and important inorganic nitrogen compound present in water. The quantity of nitrate-nitrogen along with total dissolved phosphorus in any water body indicates its productive potential. High levels of both phosphate and nitrate can lead to eutrophication, which increases algae growth and ultimately reduces dissolved oxygen levels in the water (Johnson *et al.,* 2000; Sultan *et al.,* 2003). During the study period nitrate-nitrogen was found to range between 159.7µg/l and 292.1µg/l. Overall the nitrate-nitrogen content was found to be relatively low at the investigated lake sites. This relatively low content of nitrate-nitrogen can be ascribed to profuse and luxuriant macrophytic growth which utilize it during photosynthesis. This is in agreement with Freeman (2002) that in unhealthy water bodies nitrate-nitrogen may be depleted. The lowest value of nitrate-nitrogen was recorded near the wetland sites W5 (Shallabugh) and W4 (Kujar) with values of 159.7 µg/l and 160.5 µg/l respectively (Table 21), while the highest value of 292.1 µg/l was recorded at SKIMS site (W2) (Table 20). These low values obtained at the wetland sites can be attributed to the role of rich population of macrophytes and also sediments which act as major sinks of nutrients. On the other hand, the high amounts of nitrate-nitrogen at SKIMS site are attributed to the leaching of chemicals and discharge of effluents from the SKIMS complex and adjoining human habitations (Bhat *et al*., 2001). Storm water runoff and discharge of sewage are two common ways that various nutrients enter the aquatic ecosystems resulting in the pollution of those systems (Sudhira and Kumar, 2000; Adeyemo, 2003). During winter months higher values of nitrate-nitrogen were obtained than summer months however in the Anchar site (W6) lower value of nitrate-nitrogen (183.4 µg/l) was obtained in winter and higher (211.7 µg/l) in summer (Table 20, 21). The lower values recorded during summer months are attributed to the intake of nutrients by the macrophytes during the growing season, while as the higher values during winter months are due to the abundance of nutrients which are released due to decomposition of these macrophytes. Increase in nitrate content for site W6-Anchar from winter to early summer can be attributed to the increased runoff from the Sindh Nallah due to rising temperatures and subsequent melting of snow at higher elevations of the catchment.

Phosphorus like nitrogen is another key element in the productivity of lake waters. It is considered to be the most significant among the nutrients responsible for eutrophication of lakes, as it is the primary initiating factor (Adeyemo *et al*., 2008). During the study, total phosphorus was found to be present in the range of 291.9 to 558.2 µg/l. Total phosphorus can range from <5 µg/l in very unproductive lakes to >100 µg/l in very eutrophic lakes, although the usual range is between 10 and 50 µg/l in uncontaminated systems (Vollenweider, 1976; Wetzel, 2001). It can thus be inferred from the phosphorus range that Anchar is eutrophic. The values of total phosphorus that have been presented in Table 20 and Table 21 reveal that it shows considerable site specific and seasonal variation. The highest value of total phosphorus was recorded for site W2 -near SKIMS (558.2 µg/l) followed by site W6-Anchar (542.9 µg/l) (Table 20). This high value at these sites is attributed to the discharge of domestic effluents, sewage contamination from adjoining human settlements and use of fertilizers in agricultural fields of the lake catchment. The increase in the value of phosphate is mainly because of the run-off from catchment area including some agricultural fields (Upadhyay *et al*., 2010). Lowest value (291.9µg/l) of total phosphorus was recorded near Kujar wetland (Table 21) which is due to utilization of phosphorus by the rich population of macrophytes present in the wetland. The peak values of total phosphorus were obtained during winter period (Table 20) which is apparently related to the decomposition process.

The potassium content of the water samples investigated during the study period was found to be low fluctuating between 2.6 and 5.5 mg/l. Similar findings of potassium being the least dominant cation in wetland waters of Kashmir were noted by Siraj *et al.* (2010), which they attributed to marl character, typical of carbonaceous or calcium rich distinct geology of the Kashmir Himalayan water bodies. This also agrees with the observation in other Kashmir lakes and wetlands made by Khan *et al.* (2004).

7.4 Model Simulations

The GWLF model used in the current study highlighted the critical source areas in the Anchar catchment which contributed significantly towards the pollution loadings of the lake in terms of sediment and nutrient loadings. Results were obtained against the changing land use/land cover conditions to assess the impact on nutrient and sediment transport processes in the study catchment.

7.4.1 Sediment Loadings

Sediment production is of great significance in assessing the life of an aquatic system as sedimentation is one of the main factors responsible for the reduction of size and depth of water bodies. Fine sediment is also associated with the transport of much of the nutrients and contaminants to aquatic bodies (Prosser *et al*., 2001). Stream-banks, bare land, agriculture and pastures were identified as the major source area contributors of the sediment loadings (Table 22). Stream bank erosion contributes fine-grained sediment through many processes like mass wasting-instability of bank material and failure, fluvial entrainment-detachment and entrainment of particles by hydraulic forces on stream banks from flowing water (Lawler *et al*., 1997; Couper and Maddock, 2001; Wynn and Mostaghimi, 2006; Clark and Wynn, 2007; Wynn *et al*., 2008). A significant quantity of in-stream sediment results from stream bank erosion. Several studies have shown that sediment from stream banks may account for as much as 85% of catchment sediment yields (Odgaard, 1987; Burkart *et al*., 1994; Schilling and Wolter, 2000; Thoma *et al*., 2005; Papanicolaou and Abaci, 2008; Pizzuto, 2009; Harden *et al*., 2009). It's evident from the results obtained that sparsely vegetated or under pressure land use/land cover classes (bare land, agriculture, pastures) are main contributors. This is primarily because these areas are more erodible than the vegetated areas and hence contribute more sediment. Agriculture increases the risk of erosion through land use conversion and tilling of fields. Higher rates of soil and sediment loss have been reported from agricultural fields (Higgitt and Lu, 1999; Ouyang and Bartholic, 2001; Ouyang *et al*., 2005; Al-wadaey, 2009; Kimaro and Semalulu, 2010). Excessive grazing of pastures diminishes or eliminates this vegetation, thus potentially increasing sediment transport from this source. Grazing can lead to increased sediment moving into rivers and streams. Grazing animals can cause compaction of the soil, as well as a reduction in soil cover, both of which lead to increased runoff and less infiltration of water into the soil. Increased runoff can also lead to increased stream bank erosion (Bhat *et al*., 2002).

Forests, horticulture and built-up areas are the least contributors of sediment load (Table 22). This is due to the fact that erosion from forested lands, in general, is minimized by a considerable land cover that protects the soil from the energy of rainfall and runoff, and the impervious nature of built-up areas. In general, as the protective canopy of land cover increases, the erosion hazard decreases, hence, forests contribute less as compared to the other classes and the loads, if any, are mainly from the degraded forests. This observation is in agreement with Coelho *et al*. (2004) who in their study also observed that forests produced the least amounts of overland flow and the lowest soil erosion rates.

The results of model simulations for the sediment loading rates (Table 22) show a significant increase against the changing land use/land cover conditions. The land use/ land cover results (Table 12) suggest that the vegetation cover has decreased from 1992 to 2005 due to overgrazing of pastures (scrublands/grasslands) beyond the carrying capacity, and clearing of forest areas. These changes result in erosion and subsequently more sediment production. On the other hand increase in impervious surfaces- bare land and built-up (Table 12) is observed during the said period which contributes largely to runoff without much infiltration capacity. Similar findings have been reported by Khan and Shah (2004a) while studying the sediment from the catchment of another important wetland Hokersar in Kashmir. Their study reveals that vast area of the wetland catchment lacks vegetation or is sparsely vegetated leading to increased erosion and higher sediment loadings. Thus, it stands to reason that loss of vegetal cover and increase in impervious land surfaces are primarily responsible for production of more sediment loadings under 2005 land use/land cover scenario.

The sediment/silt generated from various land use/ land cover classes in the catchment finally flows into Anchar mainly through the Sindh Nallah. This has resulted in reduction of the depth of the water body and lower transparency. This is in conformation with the study of Pandit and Yousuf (2002), who reported that Sindh-nallah deposists large quantities of silt brought by it from the upper catchment areas into Anchar. Earlier Zutshi *et al*. (1980) also reported that light penetration is greatly diminished in most of the months in Anchar due to silt loaded inflow from river Sindh. Ali and Pandit (2009) also reported that the depth of Anchar has reduced considerably and much of it has been converted to marsh land. Studies on other lakes and wetlands of Kashmir have also revealed that sediment inflow through feeding channels has resulted in the reduction of water depth and water volume as well as impacted thermal stability of these water bodies (Pandit and Qadri, 1990; Zutshi and Yousuf, 2000; Khan and Shah, 2004a; Khan, 2008).

7.4.2 Nutrient Loadings

Nutrient and contaminant supply has significant implications for eutrophication and algal blooms, associated with the decline of water quality and ecological integrity (Lake and Marchant, 1990; Smith, 2003). While these nutrients and substances are required for a healthy aquatic environment, an excess of these inputs accelerates the natural process of lake eutrophication through excessive nutrient enrichment (Ritchie and Cooper, 1991). At present, the overriding influence on Anchar is nutrient enrichment or eutrophication caused by intensified anthropogenic activities in its catchment. The nutrient loadings to the lake are quite high. Numerous studies have demonstrated an association between catchment land use and nitrogen (N) and phosphorus (P) loadings to surface waters (Omernik *et al*., 1981; Jones *et al*., 2001; Strayer *et al*., 2003; Allan, 2004; Buck *et al*., 2004; Lewis and Grimm, 2007). Keeping this in view, in the current study the nutrients (nitrogen and phosphorus) were assessed under changing land use/ land cover conditions.

Ground water, bare lands, agriculture, and pastures are the major sources of nitrogen and phosphorus loadings (Table 23-24) to Anchar. Similar findings of these sources being major contributors to nutrient loads were observed by Smith *et al.* (1999), Solim and Wanganeo (2008). The contribution of groundwater is significant and is dependent on the soil type. The likely sources of nutrients especially nitrate contribution to Anchar through groundwater are domestic sewage, agricultural drainage and other human activities. Several researchers have identified groundwater as a potentially important source of nutrient pollutants being discharged into lakes (Brock *et al*., 1982; Shaw and Prepas, 1989a; Hagerthey and Kerfoot, 1998; Kishel and Gerla, 2002; Hunt *et al*., 2003; Kang *et al*., 2005; Holman *et al*., 2008; Nakayama and Watanabe, 2008; Schmidt *et al*., 2009). Bare lands have been found to be next major contributor to nutrient loadings in the study catchment. This is attributed to the fact that these land areas devoid of vegetation occupy a large portion of the Anchar catchment being located in steep to very steep regions and possessing soils of high runoff potential and very low infiltration rate (belonging to soil hydrological group D). The result is increased volume of runoff and greater potential for nutrient transport from these land areas. As vegetated areas decrease and the natural land is increasingly disturbed, the potential for sediment and nutrient pollution of surface water bodies increases (Lovell and Sullivan, 2006). Steep slopes and erodible soils are biogeochemically 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; Bronstert and Plate, 1997).

Agricultural lands and pastures contributed high nitrogen and phosphorus loads. This is ascribed to the application of fertilizers on croplands and grazing animal waste deposition (Plate 2) in case of pastures (Adeka *et al*., 2008). Pastures have been reported as an important nitrate source (Hart *et al*., 1993; Holloway and Dahlgren, 2001; Monaghan *et al*., 2007). A positive relationship between grasslands/pastures and lake total nitrogen and total phosphorus concentration was found by Goldstein *et al*. (2007) and Cherry *et al.* (2008) in their studies. From a land use perspective, agriculturally dominated areas have been recognized to produce elevated concentrations of dissolved salts and nutrients adversely affecting the water quality (Keeney and Deluca, 1993; Pekarova and Pekar, 1996; Smart *et al*., 1998; Turner and Rabalais, 2003). Agricultural areas because of being subjected to high runoff, increased erosion and sediment yields bring nutrients into the lake by transport of nitrate and phosphate fertilizer laden sediments. Majority of studies on land use and nutrient loadings conclude that agricultural land use strongly contributes to stream water nitrogen and phosphorus (Sharpley, 1993; Johnson *et al*., 1997; Sharpley *et al.*, 1998; Arheimer and Liden, 2000; Tong and Chen, 2002; Larned *et al*., 2004; Galbraith and Burns, 2007; McDowell, 2009; Noges, 2009; Sobota *et al*., 2009) thereby affecting the freshwater trophic status.

The results for the nutrient loadings both of nitrogen and phosphorus (Table 23-24) show a significant increase under the 2005 land use/land cover conditions. The reasons for the increased nutrient loads under 2005 land use/land cover are increase in the area of bare lands, built up, degradation of pasturelands from 1992- 2005 (Table 12) and practicing of various intensive agricultural and horticultural activities that contribute to the higher nutrient loadings.

7.5 Hydro-meteorological Data Analysis

Hydro-meteorologic parameters may change in long time period naturally or anthropogenically. Trend analysis is a basic tool to understand variations in time. In this present study, trends in hydro-meteorological data (precipitation and temperature) for a period of 30 years (1981-2010) in the Anchar catchment were investigated. This was done to get an idea about how climate is changing in the study catchment. There are many different ways in which changes in hydro-meteorological series can take place. A change can occur abruptly (step change) or gradually (trend) or may take more complex form. Climate change is often recognized as a progressive trend.

Precipitation has been widely considered as a starting point towards the apprehension of climate change courses, constituting one of the most substantial components of the hydrologic cycle. In the current study, analysis of precipitation data revealed that the catchment is witnessing a decreasing trend in the precipitation (Fig.38, Appendix 10a). Similar findings of precipitation showing a declining trend in Kashmir valley were recorded by Sultan and Shafi (2007) and Romshoo *et al*. (2011). The change in precipitation pattern with winter months receiving scanty or no precipitation is a dimension of climate change in Kashmir (Jeelani *et al*., 2008). This phenomenon of downward trend in annual rainfall has been reported in several other parts of the world as well (Lettenmaier *et al*., 1994; Turkes, 1996; Gong and Wang, 2000; Zhang *et al*., 2000; Qian and Zhu, 2001; Qian *et al*., 2002; Xu *et al*., 2003; Gemmer *et al*., 2004; Mosmann *et al*., 2004; Partal and Kahya, 2006; Karpouzos *et* *al*., 2010). Studies on climatologic parameters conclude that trend in observed precipitation comprises a complex function of the climatic environment, precipitation intensity and season (Osborn *et al*., 2000; Ventura *et al*., 2002).

Plate 2a: Animal waste deposits near pasture lands in Anchar catchment

Plate 2b: Animal waste deposits near pasture lands in Anchar catchment

Air temperature is generally recognized as a good indicator of state of climate globally because of its ability to represent the energy exchange process over the earth's surface with reasonable accuracy (Vinnikov *et al*., 1990; Thapliyal and Kulshrestha, 1991). Many studies on regional scale, in mountainous areas have demonstrated significant rise in air temperatures with alarming effects on their environment (Pant and Borgaonkar, 1984; Li and Tang, 1986; Seko and Takahashi, 1991; Brown *et al*., 1992; Borgaonkar *et al*., 1996; Diaz and Bradley, 1997; Beniston *et al*., 1997; Pant *et al*., 1999; Sharma *et al*., 2000; Thompson *et al*., 2000; Wibig and Glowicki, 2002; Beniston, 2003; Diaz *et al*., 2003; Villaba *et al*., 2003; Vuille *et al*., 2003; Rebetez, 2004). In response to global warming and temperature variation the mountains show high temperature trends as well as more inconsistency (Liu and Chen, 2000; Magnuson *et al*., 2000). The upward shift of isotherms along the southern slopes of Himalayas is the clear indication of increase in temperature averages (Ghulam *et al*., 2008).

The results of seasonal variations in average maximum (Table 25, Fig.41) and minimum temperatures (Table 26, Fig.42) from 1980-2010 of the present study, reveal that average minimum temperatures are increasing at a slow and steady pace, while as average minimum temperatures are showing an aggressive increasing trend in core-winter months. This agrees with the observations of Sultan and Shafi (2007). Salinger (2005) and Islam *et al*. (2009) attributed this warming trend in the winter months to the global warming and rise in surface air temperature coupled with local urban heat impact. Fazal and Amin (2011) suggested that the rise in mean maximum temperature in Srinagar area of Kashmir is mainly due to loss of water bodies, since a considerable amount of evapo-transpiration with a cooling effect might have been taking place in the past due to these valuable ecological assests. They also suggested that increase in the built-up land leads to increase in the temperatures due to impact of urban heat islands. Chen *et al*. (2007) in their study on historical temporal trends of hydro-climatic variables in Hanjiang basin also indicated a large scale climate warming, especially during winter when entering the 1990s with the extent of increase reaching to 1.09˚C. Ahmad *et al*. (2007) too observed an increase of about 0.6˚C in January temperature at national level in Pakistan over the period of 1961-2006. This they attributed to the phenomenon of global warming. Huang *et al*. (2005) showed the temperature rise in winter to be linked to the presence of an anomalously strong zonal circulation in Eurasia and a weak polar vortex since the 1980s.

7.6 Conservation and Management Measures

The results of the current study have established that Anchar has been subjected to various anthropogenic pressures in its catchment including land use/land cover changes, sedimentation, enhanced nutrient enrichment, rising human population, and changing climate which have resulted in depletion of its storage capacity and in deterioration of its water quality, making it a case of threatened ecosystem in dire need of management. Conservation is concerned with maintenance of natural systems and, where possible, with their utilization either directly or by way of information obtained from their study, for the long-term benefit of mankind. This concept is extremely relevant to the conservation and management of threatened ecosystems like Anchar. The concept can be achieved only by the integrated management of the whole catchment area and the lake ecosystem. The present study of Anchar catchment indicates that the following conservation and management strategies shall go a long way in restoring and preserving this aquatic ecosystem:

Land use and water quality are inseparable and often improper land use causes environmental degradation. Due to land use-land cover changes that have taken place in the catchment the water quality of Anchar has worsened during the span of 15 years. So, regulation of a proper land use plan in the Anchar catchment is vital for preventing the further deterioration of the lake waters and subsequently its degradation. Future land development and management should be considered with care. With a better land-use planning, curtailment of some of the water quality problems may be possible. 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. The horticulture area has increased from 1992 to 2005, and intensive application of fertilizers and pesticides is persistent in the catchment. Application of heavy doses of chemical fertilizers for agro/horticultural activities in the catchment should be strictly restricted through effective regulatory mechanism. Ecologically sustainable agriculture involving the use of eco-friendly technology like the use of bio-fertilizers, bio-pesticides should be encouraged among rural population to mitigate pollution hazards. The study recommends the scientific watershed/catchment area management by adopting integrated pest/nutrient management practices. In addition the results indicate that with the integration of GIS and modelling, a land use/land cover management decision support system can be developed to manage nutrient pollution (nitrogen and phosphorus) at the catchment and watershed scales.

Increase in impervious surfaces- bare land and built-up areas in the lake catchment especially in the immediate vicinity of Anchar from 1992-2005 has strongly impacted the water quality of the lake. So, restriction on human interventions/settlements in the vicinity of the lake should be effectively ensured. One of the main reasons for gross pollution of the Anchar system, is the discharge of effluents directly from Sher-I-Kashmir Institute of Medical Sciences (SKIMS) situated to the north-east of the lake. Proper management and treatment of these effluents prior to their discharge into the system is the urgent need of the hour. An effective and well defined urbanization plan needs to be laid out to minimize the pressures of increased anthropogenic interference in the lake catchment. There should be demarcation of buffer zones to prevent encroachment by human settlements in the lake area.

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. Urban runoff especially after a storm event has a tendency of washing pollutants off the streets, construction sites, pesticides from lawns. To reduce storm-water discharge installation of storm water treatment facilities is suggested. The cheapest method to keep pollutants out of runoff areas will require cooperate efforts from both the public and municipalities. For example, the public would be required to sweep paved areas in order to keep waste off the drains, limit fertilizer application on lawns, while on the other hand municipalities would be required to enforce laws on erosion control at construction sites, laws on design and management of storm water drains and at the same time have efficient waste collection and disposal systems. Understanding the degree and location of impervious surfaces and limiting the amount of impervious surfaces in the Anchar catchment can be used as a measurable and scientifically defensible technique to protect this ecosystem.

High sedimentation rates over the years have aggravated the ecological vulnerability of Anchar. So, sediment harvesting and removal needs to be considered as a management option. Settling basins near the inflow channels to Anchar should be constructed to arrest the sedimentation/siltation menace. These structures with size based on the amount of water expected to be generated during specific rainfall events like the Telbal settling basin which has been constructed near Dal Lake have proven to be very useful in checking the amount of sediments before the water is released downstream. Regular maintenance of these settling/detention basins and removal of sediment from time to time should be ensured. The simulation exercise using GWLF model identified the key sources of sediment loadings in the catchment which include mainly stream-banks, agricultural and pasture lands. Vegetative buffer strips also called as conservation buffers, buffer zones, or filter strips should be used along stream and river banks to slow down run-off and capture sediments 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. Agricultural best management practices 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. To overcome the problem of overgrazing which is associated with erosion and sediment yield, there is a need to increase the grazing area, either through the enlargement of natural vegetation areas or by maintaining wider agriculture areas under fallow, allowing the soil to recover and the herbs to feed.

Loss of forest cover in the lake catchment from 1992-2005 has increased land erosion and sediment transport into the aquatic system. Large-scale reforestation and afforestation programmes in the catchment areas to hold and conserve the soil can mitigate the problem of siltation. Best management practices in form of agriculture to forest and wetland conversion can provide a good prospectus for improving the water quality of the lake.

Enhanced nutrient enrichment/eutrophication problem in the study catchment, both now and in the future, needs to be managed to reduce the risk of total ecological failure of the Anchar system. This problem needs to be dealt at the sources of these nutrients, by reducing nutrient loads to the catchment and changing land use/land cover practices. The use of GWLF within this research has indentified the critical source areas of nitrogen and phosphorus loadings in the catchment to the Anchar Lake. In order to effectively manage the nutrient pollution from the Anchar catchment, a combination of nutrient management programmes for all the source areas is required. For managing the nutrients coming from agricultural and ground water sources, construction of riparian zones and artificial wetlands, bunds (embankments) could be useful for these provide effective sinks for nutrients in an agricultural watershed before runoff reaches the water body. These structures are essentially artificial shallow water-filled basins that have been furnished with buffers consisting of appropriate vegetation cover of emergent plant vegetation. Thus, this method is also quite useful in treatment of nutrient rich groundwater as the emergent plants utilize the nutrients from the ground water for their own growth, thereby purifying the water before it’s discharged into the water bodies. The artificial wetlands are an 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 utilized for the irrigation purposes.

Treatment of waste water at sewage treatment plants can significantly aid in the reduction of the nutrients reaching the lake waters from point sources. Installation of such waste water treatment plants with increased efficiency by the incorporation of the tertiary stages of waste water treatment in the lake catchment can help in reducing the nutrient loads to a great extent. Diversion of effluents by interceptor sewers constitutes effective strategy of combating accelerated eutrophication.

Watershed prioritization is one of the most important aspects of planning for implementation of development and management programmes. An integrated watershed management approach covering the bio-physical and socio-economic aspects of the watersheds in the catchment which is a pre-requisite for sustainable development and management of resources needs to be taken into account. The watershed prioritization in a phased manner with the initial thrust upon the critically impaired watersheds needs to be carried out in the Anchar catchment. 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.

There is a need for 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 validation process. It is, therefore, of paramount importance to regularly monitor and record such data on a much broader scale.

Concluding, the conservation and management of this water body requires coordination between different user organizations and stakeholders and a participatory approach to the implementation of all management action plans. It further requires the support by way of appropriate policies that consider water bodies in an integrated holistic manner. Adequate and appropriate institutional arrangements are also required to ensure the implementation of policies and management plans. Decision and policy makers in turn require the knowledge and an understanding of the contemporary science and technology related to the functioning and management of water bodies. Finally, the implementation polices and plans also require support from legal measures that may be brought in place through legislative action.

Chapter 8

SUMMARY AND CONCLUSION

Chapter-8

SUMMARY AND CONCLUSION

The conclusions presented in this chapter summarize this research. The chapter highlights the important findings derived by analyzing the results described in the previous chapters. This study proved to be very useful in understanding the nature and magnitude of the impact of different catchment scale processes on the Anchar ecosystem. The results included Land use/Land cover change detection analysis, topographical analysis, soil analysis, water analysis, quantification of sediment and nutrient loadings and hydro-meteorological data analysis indicating climate change. During the present research, remote sensing and GIS techniques were used to environmentally characterize and fully investigate different processes in Anchar Lake catchment and quantify their impacts on the water body. The 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. While remote sensing data was used to generate up to date information about different parameters, simulation model in the form of GWLF was used to simulate the sediment and pollution processes as well as to identify the critical source areas of pollution.

In summary, the important conclusions that can be drawn from the results of this research are as follows:

- The Land use/Land cover change detection from 1992-2005 revealed that all categories of land use/land cover in the catchment of Anchar have changed with time. It was observed that during the study period, vegetation cover of the catchment in the form of coniferous forests, scrubland, grasslands and plantation has decreased, while as impervious land surfaces like built-up and bare land have increased. Built up showed a change of +15.72 Km^2, Bare land (+34.89Km^2), River bed (+5.56 Km^2), Coniferous forests (-56.62 Km^2), Grasslands (-23.22 Km^2), Scrubland (-33.98 Km^2), Plantation (-10.99 Km^2), Water bodies (-2.51 Km^2), Aquatic vegetation (+6.46 Km^2). The present study reveals that the human need and greed has taken a heavy toll of the forests and pastures in the catchment. Agricultural practices were found be shifting towards horticultural practices with agriculture showing a change of (-14.42 Km^2) and horticulture of (+9.02 Km^2). Accuracy assessment results revealed

92.66 % accuracy for 2005 classified data and a Kappa coefficient of 0.914 with aquatic vegetation and water giving good classification accuracies.

- The physicochemical analysis of the Anchar catchment soils during the course of this study revealed different land uses to be associated with different soil conditions. Natural forests and pastures were found to be high in percentage of organic matter, water holding capacity and low in pH than cultivated arable lands. A positive correlation was found between organic matter and available nutrient content of different soils. Bare areas were found to have lowest pH, water holding capacity and organic matter due to loss of vegetation cover and coarse nature of soils. Soils in the study area were found to fall into eight textural classes viz. sandy clay covering 539.90 Km^2, clay loam (468.66 Km^2), sandy loam (336.56 Km^2), clay (199.32 Km^2), loamy sand (55.45 Km^2), silty clay loam (42.98 Km^2), silt loam (18.47 Km^2) and sandy clay loam (2.50 Km^2).
- Physico-chemical analysis of water indicated deterioration of the water quality of Anchar. Water chemistry showed the alkaline nature of this aquatic body. The lower levels of dissolved oxygen and higher levels of conductivity especially at SKIMS site and in the main water body itself support the eutrophic status of the water body. The nutrient status of the key elements indicates high levels of total phosphorus and relatively low levels of nitrate nitrogen. Concluding, low oxygen levels, high values of conductivity and nutrients near urbanized sites indicate the discharge of domestic effluents, input of heavy doses of sewage and leaching of agrochemicals leading to the nutrient enrichment of Anchar waters thus deteriorating water quality which has serious implications on the overall functioning of this ecosystem.
- The GIS based modelling approach for the quantification of sediment loading rates provided reliable estimates over variable source areas in the lake catchment. The land use/land cover or the source area contribution towards the sediment yields was highest for stream banks followed by bare lands, agriculture, pastures and forests, whereas, the least loads were recorded for horticulture and built-up areas. Overall sediment loadings under 1992 and 2005 land use/land cover from these sources indicated an upward trend from their 1992 values i.e. from 13274.1 metric tons of total sediment/year under

the 1992 land use/land cover to 16707.1 metric tons of total sediment/year under the 2005 land use/land cover. This high rate of sedimentation/siltation accounts for gradual decrease in the maximum depth of this water body posing potential threat to its survival.

- The GWLF model quantified the overall nutrient (dissolved and total forms of nitrogen and phosphorus) loadings from the catchment to the Anchar lake and indentified the critical source areas i.e. all the activities in the catchment that are contributing to these nutrient loads. These sources are ground water, bare lands, agriculture, and pastures. Urban runoff also contributes minute quantities of the total nutrient loadings. The overall nutrient loadings from these sources too show an upward trend from their 1992 values. The increased nutrient loads under 2005 land use/land cover are due to the changes that have taken place in the catchment during the period of 15 years. The estimation of nutrient loads from the source areas shall facilitate prioritization of the source areas for remedial measures to control the pollution in the Lake.

- The hydro-meteorological data analysis carried out during this research confirms the proximity of climate change by showing that precipitation is decreasing, while as temperatures are increasing. Seasonal average temperature trends indicate climate warming especially during winter primarily due to rapid increases in both, the maximum as well as minimum temperatures, with the maximum temperature increasing more rapidly. Decreased rainfall and higher temperatures through climate change can alter the hydrological dynamics of Anchar system by decreasing the water level and water spread area of the lake. Since, the high altitude lofty mountainous regions of the catchment remain unattended because of the available meteorological stations being located at the bottom of the valley therefore these observatories of changing precipitation and temperature may not be the true representative of the entire catchment. So these climatic changes occurring across the region require more detailed and in depth investigation.

- Based on the current available data, the GWLF model used in this research demonstrated its utility as a tool to understand processes in the catchment and as a basis for effective management of the Anchar system.

- The conservation and management of this water body requires awareness, proper understanding, planning and implementation of the management strategies suggested. The watershed prioritization is required that 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.

LITERATURE CITED

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Abbasi, S.A., Khan, F.I., Sentilvelan, K., Shabudeen, A. 1999. Modelling of Buckingham Canal water quality. *Indian Journal of Environmental Health* **44**(4): 290- 297.

Abbott, M.B., Bathurst, J.C., Cunge, J.A., Connell, P.E. and Rasmussen, J. 1986. An introduction to the European hydrological system- Systeme Hydrologique European, 'SHE' 2: Structure of a physically based, distributed modelling system Amsterdam. *Journal of Hydrology* **87:** 61-77.

Abowei, J.F.N. 2010. Salinity, dissolved oxygen, pH and surface water temperature conditions in Nkoro River, Niger Delta, Nigeria. *Advance Journal of Food Science and Technology* **2**(1): 36-40.

Abu Sharkh, M.S. 2009. Estimation of runoff for small watershed using Watershed Modelling System (WMS) and GIS. **In**: *Thirteenth International Water Technology Conference,* Hurghada, Egypt pp. 1185-1200.

Acreman, M.C., Blake, J.R., Booker, D.J., Harding, R.J., Reynard, N., Mountford, J.O. and Stratford, C.J. 2009. A simple framework for evaluating regional wetland ecohydrological response to climate change with case studies from Great Britain. *Ecohydrology* **2** (1): 1-7.

Adeka, J.E., Strobl, R.O. and Becht, R. 2008. An Environmental System Analysis of Lake Elementaita, Kenya with Reference to Water Quality. *Proceedings of TAAL 2007: The 12th World Lake Conference* 1365-1372.

Adeyemo, O.K. 2003. Consequences of pollution and degradation of Nigerian aquatic environment on fisheries resources. *The Environmentalist* **23**(4): 297-306.

Adeyemo, O.K., Adedokun, O.A., Yusuf. R.K. and Adeleye, E.A. 2008. Seasonal changes in physico-chemical parameters and nutrient load of river sediments in Ibadan city, Nigeria. *Global NEST Journal* **10**(3): 326-336.

Agarwal, N.K. and Thapliyal, B.L. 2005. Preimpoundment hydrological study of Bhilangana River from Tehri Dam reservoir area in Uttaranchal. *Environmental Geochemistry* **8**: 143- 148.

Ahmad, I., Zhaobo, S., Weitao, D. and Ambreen, R. 2007. Trend Analysis of January temperature in Pakistan over the period of 1961-2006: geographical perspective. *Pakistan Journal of Meteorology* **7** (13): 11-22.

Ahmad, N. and Rais, S. 1998. Climate effects and Himalayan glaciers. **In**: *Himalayan Glaciers*. APH Publishing Corporation, New Delhi, India. p.150.

Ahmad, P., Hassan, H., Masood, A. and Pandit, A.K. 2009. Land cover analysis of mountainous Himalayan system using geospatial tools: A case study of Sindh valley (Kashmir). *Journal of Himalayan Ecology and Sustainable Development* **4**: 59-66.

Akhavan, S.R., Koupai, J.A., Mousavi, S.F., Afyuni, M., Eslamian, S.S. and Abbaspou, K.C. 2010. Application of SWAT model to investigate nitrate leaching in Hamadan–Bahar Watershed, Iran. *Agriculture, Ecosystems and Environment* **139**(4): 675-688.

Alexander, K.W. and Mwasi, B. 2010. Image fusion techniques for land use mapping using Landsat ETM+ satellite imagery, for Kisumu Municipality, Kenya. *Journal of Geomatics* **4**(2): 83-89.

Ali, N. and Pandit, A.K. 2009. Macrophytic diversity of Anchar Lake, Kashmir. *Journal of Research and Development* **9**: 13-19.

Ali, M.B., Tripathi, R.D., Rai, U.N., Pal, A. and Singh, S.P. 1999. Physico-chemical characteristics and pollution level of Lake Nainital (U.P., India): Role of macrophytes and phytoplankton in biomonitoring and phytoremediation of toxic metal ions. *Chemosphere* **39**(12): 2171-2182.

Allan, J.D. 2004. Landscapes and riverscapes: the influence of land use on stream ecosystems. *Annual Review of Ecology Evolution and Systematics* **35**: 257–284.

Alsdorf, D.E., Smith, L.C. and Melack, J.M. 2001. Amazon floodplain water level changes measured with interferometric SIR-C Radar. *IEEE Transaction on Geoscience and Remote Sensing* **39**(2): 423-431.

Al-wadaey, A.M. 2009. Reducing phosphorus and sediment loss in runoff from agricultural land. *ETD collection for University of Nebraska - Lincoln.* Paper AAI3355611.

Amin, A. and Romshoo, S.A. 2007. Assessing the hydrologic characteristics of Dal Lake catchment using GIS. *Proceedings of TAAL 2007: The 12th World Lake Conference* 659-667.

Amoros, C., Gilbert, J. and Greenwood, M.T. 1996. Interaction between units of fluvial hydrosystem. **In**: *Fluvial Hydrosystems* (Eds. G.E. Petts and C. Amoros). London Chapman and Hall Press. pp.184-210.

Amy, G., Pitt, R., Singh, R., Bradford, W.L. and LaGrafti, M.B. 1974. Water quality management planning for urban runoff. U.S. Environmental Protection Agency, Washington DC. EPA-440/9-75-004.

Andersson, S., Nilsson, I. and Saetre, P. 2000. Leaching of dissolved organic carbon (DOC) and dissolved organic nitrogen (DON) in mor humus as affected by temperature and pH. *Soil Biology and Biochemistry* **32**: 1–10.

Apan, A.A., Raine, S.R. and Paterson, M.S. 2002. Mapping and analysis of changes in the riparian landscape structure of Lockyer valley catchment, Queensland, Australia. *Landscape and Urban Planning* **59:** 43-57.

APHA, 1998. *Standard Methods for the Examination of Water and Wastewater.* 20th Ed. American Public Health Association, Washington D.C.

Arao, T. 1999. In situ detection of changes in soil bacterial and fungal activities by measuring ^{13}C incorporation into soil phospholipid fatty acids from ^{13}C acetate. *Soil Biology and Biochemistry* **31**: 1015–1020.

Araoye, P.A. 2009. The seasonal variation of pH and dissolved oxygen (DO_2) concentration in Asa lake Ilorin, Nigeria. *International Journal of Physical Sciences* **4** (5): 271-274.

Arheimer, B. and Liden, R. 2000. Nitrogen and phosphorus concentrations for agricultural catchments; influence of spatial and temporal variables. *Journal of Hydrology* **227** (1–4): 140–159.

Arhounditsis, G., Giourga, C., Loumou, A. and Koulouri, M. 2002. Quantitative assessment of agricultural runoff and soil erosion using mathematical modelling: Application in the Mediterranean Region. *Environmental Management* **30**(3): 434-453.

Arnell, N.W. 1992. Factors controlling the effects of climate change on river flow regimes in a humid temperate environment. *Journal of Hydrology* **132**: 321-342.

Arnold, J.G., Srinivasan, R., Muttiah, R.S and Williams, J.R. 1998. Large area hydrologic modelling and assessment. Part I: Model Development. *Journal of the American Water Resources Association* **34**(1): 73-89.

Augusteijn, M. and Warrender, C. 1998. Wetland classification using optical and radar data and neural network classification. *International Journal of*

Remote Sensing **19**: 1545-1560.

Ayad, Y.M. 2005. Remote sensing and GIS in modelling visual landscape change: A case study of the Northwestern arid coast of Egypt. *Landscape and Urban Planning* **73:** 307-325.

Ayoade, A.A., Fagade, S.O. and Adebisi, A.A. 2006. Dynamics of limnological features of two manmade lakes in relation to fish production. *African Journal of Biotechnology* **5**(10): 1013-1021.

Baath, E. and Anderson, T.H. 2003. Comparison of soil fungal/bacterial ratios in a pH gradient using physiological and PLFA-based techniques. *Soil Biology and Biochemistry* **35**: 955–963.

Baboo, S.S. and Devi, M.R. 2010. Integrations of remote sensing and GIS to Land Use and Land Cover Change Detection of Coimbatore District. *International Journal on Computer Science and Engineering* **2**(9): 3085-3088.

Badar, B. and Romshoo, S.A. 2007. Assessing the pollution load of Dal Lake using geospatial tools. *Proceedings of TAAL 2007: The 12th World Lake Conference* 668-679.

Bagde, U.S. and Verma, A.K. 1985. Physico-chemical characteristics of water of JNU Lake at New Delhi. *Indian Journal of Ecology* **12**: 151–156.

Bagnolus, F. and Meher-Homji, V.M. 1959. Bio- climatic types of South East Asia. Travaux de la Section Scientific at Technique Institut Franscis de Pondicherry. p. 227.

Baker, C., Lawarence, R.L., Montagne, C. and Patten, D. 2007. Change detection of wetland ecosystem using Landsat imagery and Change Vector Analysis (CVA). *Wetlands* **27**(3): 610-619.

Balkhi, M.H., Yousuf, A.R. and Qadri, M.Y. 1987. Hydrobiology of Anchar Lake. *Comparative Physiology and Ecology* **12**: 131-139.

Bardgett, R.D., Jones, A.C., Jones, D.L., Kemmitt, S.J., Cook, R. and Hobbs, P. 2001. Soil microbial community patterns related to the history and intensity of grazing in sub-montane ecosystems. *Soil Biology and Biochemistry* **33**: 1653–1664.

Bashir, S., Yousuf, A.R. and Shah, A.M. 2003. Effect of bird foraging on dynamics of plant community in Hokersar wetland, Kashmir. *Journal of Research and Development* **3**: 109-115.

Batty, M., Xie, Y. and Sun, Z. 1999. Modelling urban dynamics through GIS based cellular automata. *Computers, Environment and Urban Systems* **23** (3): 205-233.

Bedford, B.L. and Preston, E.M. 1988. Developing the scientific basis for assessing cumulative effects of wetland loss and degradation on landscape functions: status, perspectives and prospects. *Environmental Management* **12**: 751-771.

Beniston, M. 2003. Climatic change in mountainous regions: a review of possible impacts. *Climate Change* **59**: 5–31.

Beniston, M., Diaz, F.D. and Bradley, R.S. 1997. Climatic change at high elevation sites: an overview. *Climate Change* **36**: 233–251.

Bennani, A., Buret, J. and Senhaji, F. 2001. Communication Nationale Initiale a la Convention Cadre des Nations Unies sur les changements climatiques. *Ministere de l'Amenagement du Territoire, de l'Urbanisme del'Habitat et de l'Environnement.* pp.101.

Bhat, A.K. and Khan, M.A. 2006. Adsorption of phosphate by sediments in the Dal Lake. *Environment and Ecology* **24**S (2): 352-354.

Bhat, G.A., Qadri, M.Y. and Zutshi, D.P. 2002. An ecological survey of Dachigam National Park, Kashmir with emphasis on grasslands. **In:** *Natural Resources of Western Himalaya* (Ed. A.K. Pandit). Valley Book House, Hazratbal, Srinagar, Kashmir. pp. 341-376.

Bhat, S.A. and Pandit, A.K. 2002. Limnological investigation of Anchar Lake, Kashmir. *Journal of Research and Development* **2**: 13-24.

Bhat, S.A. and Pandit, A.K. 2003. Phytoplankton dynamics in Anchar Lake, Kashmir. *Journal of Research and Development* **3**: 71-96.

Bhat, S.A., Rather, S.A. and Pandit, A.K. 2001. Impact of effluents from Sher-I-Kashmir Institute of Medical Sciences (SKIMS), Soura on Anchar Lake. *Journal of Research and Development* **1**: 30-37.

Bhatt, B., Gupta, A.K. and Gogoi, G. 2006. Application of remote sensing and GIS for detecting land use changes: A case study of Vadodara, GIS development. Available:
http: //www.gisdevelopmen.net/application/urban/sprawl/remotesensing.htm.

Bhatia, K.S. and Vardani, S. 1982. Physico-chemical and erosional behavior of red and black soils of Bundelkhand region of U.P. *Journal of Indian Society of Soil Science* **30**: 523-527.

Bingner R.L. and Theurer F.D. 2001. AnnAGNPS: Estimating sediment yield by particle size for sheet and rill erosion. **In:** *Proceedings of the Seventh Interagency Sedimentation Conference*, Reno, NV **1** (I): 1-7.

Bisht, A.S. and Bhatt, A.B. 2010. Physico-chemical Status of forest soils along altitudinal gradient in Western Uttarakhand Himalayas. *Indian Journal of Ecology* **37** (1): 65-69.

Borah, D.K. and Bera, M. 2003. Watershed-scale hydrologic and nonpoint-source pollution models: review of mathematical bases. *Transactions of the American Society of Agricultural Engineers* **46**(6): 1553-1566.

Borah, D.K., Yagow, G., Saleh, A., Barnes, P.L., Rosenthal, W., Krug, E.C. and Hauck, L.M. 2006. Sediment and nutrient modelling for TMDL development and implementation. *Transactions of the American Society of Agricultural and Biological Engineers* **49**(4): 967-986.

Borgaonkar, H.P., Pant, G.B. and Rupa Kumar, K. 1996. Ring-width variations in Cedras deodara and its climatic response over the western Himalaya. *International Journal of Climatology* **16**: 1409–1422.

Bossuyt, H., Six, J. and Hendrix, P.F. 2002. Aggregate protected carbon in no tillage and conventional tillage agro-ecosystems using C-14 labeled plant residue. *Soil Science Society of America Journal* **66**: 1965-1973.

Bothale, R.V. and Sharma, J.R. 2007. Rapid urbanization in desert towns- A case study of sun city Jodhpur using Geoinformatics. *Indian Society of Geomatics Newsletter* **13**(2-3): 4-12.

Bouraoui, F. and Dillaha, T.A. 1996. ANSWERS-2000: Runoff and sediment transport model. *Journal of Environmental Engineering* **122**: 493-500.

Bouraoui, F., Vachaud, G., Li, L.Z.X., Le Treut, H. and Chen, T. 1999. Evaluation of the impact of climate changes on water storage and groundwater recharge at the watershed scale. *Climate Dynamics* **15**: 153-161.

Bourgeau, L.L., Kasischke, E.S., Brunzelle, S.M., Mudd, J.P., Smith, K.B. and Frick, A.L. 2001. Analysis of space borne SAR data for wetland mapping in Virginia-riparian ecosystem. *International Journal of Remote sensing* **22**(18): 3665-3687.

Brady, N.C. 1996. The Nature and Properties of Soils. Prentice-Hall Pvt. Ltd. New Delhi.

Breitburg, D., Timothy, L., Carol, P. and Adam, G. 1997. Varying effects of low dissolved oxygen on trophic interactions in an estaurine. *Ecological Monographs* **64**: 489-507.

Brock, T.D., Lee, D.R., Janes, D. and Winek, D. 1982. Groundwater seepage as a nutrient source to a drainage lake; Lake Mendota, Wisconsin. *Water Research* **16**(7): 1255-1263.

Bronstert, A. and Plate, E.J. 1997. Modelling of runoff generation and soil moisture dynamics for hill slopes and micro-catchments. *Journal of Hydrology* **198**: 177–195.

Brown, E., Skougstad, M.W. and Fishman, M.J. 1974. Method for collection and analysis of water samples for dissolved minerals and gases. U.S. Department of Interior. Book 5. p. 126-129.

Brown, T.B., Barry, R.G. and Doesken, N.J. 1992. An exploratory study of temperature trends for Colorado paired mountain-high plains stations. American meteorological society sixth conference on mountain meteorology, Portland, OR. pp 181–184.

Buck, O., Niyogi, D.K. and Townsend, C.R. 2004. Scale-dependence of land use effects on water quality of streams in agricultural catchments. *Environmental Pollution* **130**: 287-299.

Bugenyi, F.W.B. 2001. Tropical fresh water ecotones: their formations, functions and use. *Hydrobiologia* (The Netherlands) **458**: 33-43.

Burgholzer, R.W. and Sweeney, J. 2007. A web-based interface to the Chesapeake Bay watershed model phase 5.0. **In:** *Watershed Management to Meet Water Quality Standards and TMDLs-Total Maximum Daily Loads* (Ed. A.S.A. McFarland). ASAE Publication San Antonio, Texas, USA. pp.477-484.

Burkart, M.R., Oberle, S.L., Hewitt, M.J. and Pickus, J. 1994. A framework for regional agroecosystems characterization using the national resources inventory. *Journal of Environmental Quality* **23**(5): 866-874.

Burkett, V. and Kusler, J. 2000. Climate change: potential impacts and interactions in wetlands of the United States. *Journal of the American Water Resources Association* **36** (2): 313-320.

Burn, D.H. and. Elnur, M.A.H. 2002. Detection of hydrologic trends and variability. *Journal of Hydrology* **255**: 107-122.

Byron, E.R. and Goldman, C.R. 1989. Land-use and water quality in tributary streams of Lake Tahoe, California-Nevada. *Journal of Environmental Quality* **18**: 84-88.

Campbell, C.A., Brandt, S.A., Biederbeck, V.O., Zentner, R.P. and Schnitzer, M. 1992. Effect of crop rotations and rotation phase on characteristics of soil organic matter in a dark brown chernoemic soil. *Canadian Journal of Soil Science* **72**: 403-416.

Campbell, J.B. 1987. Introduction to Remote Sensing. The Guilford Press, New York. pp. 340.

Carlson, T.N. and Azofeifa, S.G.A. 1999. Satellite remote sensing of land use changes in and around San Jose, Costa Rica. *Remote Sensing of Environment* **70**: 247–256.

Carpenter, D.J. and Carpenter, S.M. 1983. Modelling inland water quality using Landsat data. *Remote Sensing of Environment* **13**(4): 345-352.

Carvalho, P., Thomaz, S.M. and Bini, L.M. 2005. Effects of temperature on decomposition of a potential nuisance species: the submerged aquatic macrophyte E*geria najas* Planchon (Hydrocharitaceae). *Brazilian Journal of Biology* **65** (1): 767-770.

Castillo, U.M., Martnez-Mana and Albaladejo, J. 1997. Runoff and soil loss response to vegetation removal in semi-arid environment. *Journal of American Soil Science Society* **61**: 1116-1121.

Centre for Science and Environment, 2002. Melting into oblivion. *Down to Earth*.

Chauhan, H.B. and Nayak, S. 2005. Land use/land cover changes near Hazira Region, Gujarat using remote sensing satellite data. *Journal of the Indian Society of Remote Sensing* **33** (3): 413-420.

Chaves, A.B. and Lakshumanan, C. 2008. Remote sensing and GIS based integrated study and analysis for mangrove wetland restoration in Ennore Creek, Chennai, South India. **In**: *Proceedings of TAAL: The 12th World Lake Conference* (Eds. M. Sengupta and R. Dalwani) pp. 685-690.

Chen, H., Guo, S., Xu, C. and Singh, V.P. 2007. Historical temporal trends of hydro-climatic variables and runoff response to climate variability and their relevance in water resource management in the Hanjiang basin. *Journal of Hydrology* **344**: 171– 184.

Chen, X., Vierling, L. and Deering, D. 2005. A simple and effective radiometric correction method to improve landscape change detection across sensors and across time. *Remote Sensing of Environment* **98**(1): 63-79.

Cherry, K.A., Shepherd, M., Withers, P.J.A. and Mooney, S.J. 2008. Assessing the effectiveness of actions to mitigate nutrient loss from agriculture: A review of methods. *Science of the Total Environment* **406**: 1-23.

Chikondi, G.M., Joshua, V. and Phiri, S.J.K.S. 2010. Modelling the fluxes of nitrogen, phosphate and sediments in Linthipe catchment, Southern Lake Malawi basin: implications for catchment management. *African Journal of Agricultural Research* **5** (6): 424-430.

Chipman, J.W., Lillesand, T.M., Schmaltz, J.E., Leale, J.E. and Nordheim, M.J. 2004. Mapping lake water clarity with Landsat images in Wisconsin, USA. *Canadian Journal of Remote Sensing* **30**(1): 1-7.

Chopra, R., Verma, V.K. and Sharma, P.K. 2001. Mapping, monitoring and conservation of Harike Wetland ecosystem, Punjab, India through remote sensing. *International Journal of Remote sensing* **22**(1): 89-98.

Chowdhury, R.R. and Schneider, L.C. 2004. Land-cover/use in the southern Yucatan peninsular region, Mexico: Classification and change analysis. **In**: *Integrated Land-Change Science and Tropical Deforestation in the Southern Yucatan: Final Frontiers* (Eds. B. L. Turner II, J. Geoghegan and D. Foster). Oxford Geographical and Environmental Studies. Clarendon Press of Oxford University Press. pp. 105-144.

Clark, L.A. and Wynn, T.M. 2007. Methods for determining stream-bank critical shear stress and soil erodibility: Implications for erosion rate predictions. *Transactions of the American Society of Biological Engineers* **50**(1): 95-106.

Clement, B. and Aidoud, A. 2007. Hypothesis of changes in palustrian plant communities under climate change. *Ecohydrology* **2**: 1-17.

Coelho, C.O.A., Ferreira, A.J.D., Laouina, A., Boulet, A.K., Chaker, M., Nafaa, R., Naciri, R., Regaya, K., Hamza, A., Carvalho, T.M.M. and Keizer, J.J. 2004. Changes in land-use and their impact on erosion rates and overland flow generation in the Maghreb region. *Revue Des Sciences Del'Eau* **17**(2): 163-180.

Cohen, W.B., Maiersperger, T.K., Yang, Z., Gower, S.T., Turner, D.P., Ritts, W.D., Berterretche, M.A. and Running, S.W. 2003. Comparisons of land cover and LAI estimates derived from ETM+ and MODIS for four sites in North America: A quality assessment of 2000/2001 provisional MODIS products. *Remote Sensing of Environment* **88**(3): 233-255.

Committee on Characterization of Wetlands, 1995. *Wetland Characteristics and Boundaries*. Washington, D.C. National Academy Press.

Congalton, R.G. 1991. A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment* **37**: 35-46.

Congalton, R.G. and Mead, R.A. 1983. A quantitative method to test for consistency and corrections in photo interpretation. *Photogrammetric Engineering and Remote Sensing* **49**(1): 69-74.

Coppin, P., Jonckheere, I. and Nackaerts, K. 2004. Digital change detection methods in ecosystem monitoring: A review. *International Journal of Remote Sensing* **10:** 1565-1596.

Coskun, H.G., Gulergun, O. and Yilmaz, L. 2006. Monitoring of protected bands of Terkos drinking water reservoir of metropolitan Istanbul near the Black Sea coast using satellite data. *International Journal of Applied Earth Observation and Geoinformation* **8**(1): 49-60.

Costa, M. and Telmer, K. 2006. Utilizing SAR imagery and aquatic vegetation to map fresh and brackish lakes in the Brazilian Pantanal wetland. *Remote Sensing of Environment* **105**: 204-213.

Couper, P.R. and Maddock, I.P. 2001. Subaerial river bank erosion processes and their interaction with other bank erosion mechanisms on the River Arrow, Warwickshire, UK. *Earth Surface Processes and Landforms* **26**(6): 631-646.

Cowardin, L.M., Carter, V., Golet, E.C. and La Roe. 1979. *Classification of Wetlands and Deep Water Habitats.* USFWS/085-79/31, Office of the Biological Services, U.S. Fish and Wildlife Service, Washington, D.C. pp. 109.

Dadhich, P.N. and Hanaoka, S. 2010. Remote Sensing, GIS and Markov's Method for Land use change detection and prediction of Jaipur District. *Journal of Geomatics* **4**(1): 9-15.

Dai, T. and Labadie, J.W. 2001. River basin network model for integrated water quantity/quality management. *Journal of Water Resources Planning and Management* **127**(5): 295-305.

Das, R., Samal, N.R., Roy P.K. and Mitra, D. 2006. Role of electrical conductivity as an indicator of pollution in shallow lakes. *Asian Journal of Water, Environment and Pollution* **3**(1): 143-146.

Dawson, T.P., Berry, P.M. and Kampa, E. 2003. Climate change impacts on freshwater wetland habitats. *Journal for Nature Conservation* **11**: 25-30.

De Roo, A., Odijk, M., Schmuck, G., Koster, E. and Lucieer, A. 2001. Assessing the effects of land use changes on floods in the Meuse and Oder catchment. *Physics and Chemistry of the Earth, Part B – Hydrology, Ocean and Atmosphere* **26**: 593–599.

Deenik, J.L. and Yost, R.S. 2008. Nitrogen mineralization potential and nutrient availability from five organic materials in an atoll soil from the Marshall Islands. *Soil Science* **173**(1): 54-68.

Deliman, P.N., Glick, R.H. and Ruiz, C.E. 1999. Review of watershed water quality models. U.S. Army Corps of Engineers, Technical Report. W-99-1. pp. 26.

Demers, M. N. 2005. *Fundamentals of Geographic Information Systems*. John Wiley and Sons, Inc., New York, USA.

Deng, J.S., Wang, K., Hong, Y. and Qi, J.G. 2009. Spatio-temporal dynamics and evolution of land use change and landscape pattern in response to rapid urbanization. *Landscape and Urban Planning* **92**(3-4): 187-198.

Denny, P. (Ed.) 1985. *The Ecology and Management of African Wetland Vegetation*. Dr. W. Junk Publishers, Dordrecht. pp. 300.

Desai, P.S., Narain, A., Nayak, S.R., Manikiam, B., Adiga, S. and Nath, A.D. 1991. IRS 1A applications for coastal and marine resources. *Current Science* **61**(3&4): 204-208.

Devi, D. and Anandhi, D.U. 2009. Assessment of water quality for aquaculture- A case study of Madavara Lake in Bangalore. *National Environment and Pollution Technology* **8**(4): 755-760.

Devi, R.S., Srivastava, P. and Gupta, A. 2007. Catchment characterization of Loktak Lake using remote sensing and Geographical Information System (GIS) techniques. **In**: *Map Asia 2007: 6th Annual International Conference on Geospatial Information Technology and Applications* pp. 134-139.

Diallo, Y., Hu, G. and Wen, X. 2009. Applications of remote sensing in land use/ land cover change detection in Puer and Simao Counties, Yunnan Province. *Journal of American Science* **5**(4): 157-166.

Diaz, H.F. and Bradley, R.S. 1997. Temperature variations during the last century at high elevation sites. *Climate Change* **36**: 253–279.

Diaz, H.F., Grosjean, M. and Graumlich, L. 2003. Climate variability and change in high elevation regions: past, present and future. *Climate Change* **59**: 1–4.

Directory of Indian Wetlands, 1993. Compiled by World Wide Fund for Nature/ Asian Wetland Bureau. Published by WWF India, New Delhi.

Dobhal, D.P., Gergan, J.T. and Thayyen, R.J. 2004. Recession and morphogeometrical changes of Dokriani glacier- Garhwal Himalaya, India. *Current Science* **86**(5): 692-696.

Du, Y., Teillet, P. and Cihlar, J. 2002. Radiometric normalization of multitemporal high-resolution satellite images with quality control for land cover change detection. *Remote Sensing of Environment* **82**(1): 123-134.

Dugan, P. (Ed.) 1993. *Wetlands in Danger: A World Conservation Atlas*. IUCN/World Conservation Union. Oxford University Press, New York.

Dwivedi, R., Rao, B. and Bhattacharya, S. 1999. Mapping wetlands of the Sundarban Delta and its environment using ERS-1 SAR data. *International Journal of Remote Sensing* **20**: 2235-2334.

Eckhardt, K., Breuer, L. and Frede, H.G. 2003. Parameter uncertainty and the significance of simulated land use change effects. *Journal of Hydrology* **273**: 164-176.

Edmondson, W.T. 1966. Changes in the oxygen deficit of lake Washington. *Verhandlungen Internationale Vereinigung fur Theoretische und Angewandte Limnologie* **16**: 153-158.

Edwards, T.C., Deshler, E.Jr., Foster, D. and Moisen, G.G. 1996. Adequacy of wildlife habitat relation models for estimating spatial distributions of terrestrial vertebrates. *Conservation Biology* **10**: 263-270.

Ekeh, I.B. and Sikoki, F.D. 2003. The state and seasonal variability of some physico-chemical parameters in the New Calabar River, Nigeria. *Suplementa ad Acta Hydrobiologia* **5**: 45-60.

El Ghissassi, A. 2005. Moroccan National Committee reviews the press: Favorable to dams! *The Dams Newsletter* **4**: 11-16.

ENEX, 1978. Study of pollution in Dal Lake, Srinagar, Kashmir, India. ENEX Consortium Report ID2 (submitted under the auspices of the Commonwealth Fund for Technical Cooperation), New Zealand.

Engel, B.A., Srinivasan, R., Arnold, J., Rewerts, C. and Brown. S.J. 1993. Nonpoint Source (NPS) pollution modelling using models integrated with Geographic Information Systems (GIS).*Water Science Technology* **28**(3-5): 685-690.

England, A. and Lessesne, K. 1962. Effects of simple crop covers on runoff. *Journal of Soil and Water Conservation* **17**(1): 10-12.

EPA 2003(a). Modelling report for Wissahickon Creek, Pennsylvania. Siltation TDML Development Final Report. US Environmental Protection Agency, Philadelphia, Pennsylvania.

Ershadi, A., Khiabani, H. and Lorup, J.K. 2005. Applications of remote sensing, GIS and river basin modelling in integrated water resource management of Kabul river basin. **In:** *Proceedings of ICID 21st European Regional Conference*. 15-19 May 2005. Germany and Poland.

Evans, B.M. and Corradini, K.J. 2008. AVGWLF Version 7.2: A Guide to creating software-compatible data sets. Penn State Institute of Energy and the Environment. The Pennsylvania State University. p. 24

Evans, B.M., Lehning, D.W. and Corradini, K.J. 2008. AVGWLF Version 7.1: Users Guide. Pennsylvania State Institute of Energy and Environment. The

Pennsylvania State University, University Park, PA, USA, p. 117.

Evans, B.M., Lehning, D.W., Corradini, K.J., Petersen, G.W., Nizeyimana, E., Hamlett, J.M., Robillard, P.D. and Day, R.L. 2002. A comprehensive GIS-based modelling approach for predicting nutrient load in watershed. *Spatial Hydrology* **2**(2): 1-18.

Evans, B.M., Sheeder, S.A. and Lehning, D.W. 2003. A spatial technique for estimating stream bank erosion based on watershed characteristics. *Journal of Spatial Hydrology* **3**(1): 1-13.

Eynard, A., Schumacher, T.E., Lindstrom, M.J., Malo, D.D. and Kohl, R.A. 2004. Wettabiliy of soil aggregates from cultivated and uncultivated ustolls and usterts. *Australian Journal of Soil Research* **42**: 163-170.

FAO, 1980. Crop transpiration: Guidelines for computing crop water requirement. Rome. p. 56.

Fazal, S. and Amin, A. 2011. Impact of urban land transformation on water bodies in Srinagar city, India. *Journal of Environmental Protection* **2**(2): 142-153.

Fearnside, M.P. 2001. Saving tropical forests as a global warming counter measure: An issue that divides the environmental movement. *Ecological Economics* **39**: 167–184.

Fohrer, N., Eckhardt, K., Haverkamp, S. and Frede, H.G. 2001. Applying SWAT model as decision support tool for land use concepts in peripheral regions in Germany. **In**: *Sustaining the Global Farm* (Eds. D.E. Stott, R.H. Mohtar and G.C. Steinhardts). Purdue. pp. 994-999.

Fohrer, N., Haverkamp, S., Eckhardt, K. and Frede, G.G. 2001. Hydrologic response to land use changes on the catchment scale. *Physics and Chemistry of Earth* **26**(7-8): 577-582.

Fontaine, T.A., Klassen, J.F., Cruickshank, T.S. and Hotchkiss, R.H. 2001. Hydrological response to climate change in the Black Hills of South Dakota, USA. *Hydrological Science Journal* **46**(1): 27-40.

Foody, G.M. 1992. On the compensation for chance agreement in image classification accuracy assessment. *Photogrammetric Engineering and Remote Sensing* **58** (10): 1459-1460.

Fowler, A. 1999. Potential climate change impacts on water resources in the Auckland region (New Zealand). *Climate Research* **11**: 221-245.

Fan, F., Weng, Q. and Wang, Y. 2007. Land use land cover change in Guangzhou, China, from 1998 to 2003, based on Landsat TM/ETM+ imagery. *Sensors* **7**: 1323-1342.

Forman, R.T.T. and Godron, M. 1986. *Landscape Ecology*. John Wiley and Sons, New York, USA.

Frazier, P., Page, K., Louis, J., Brigg, S. and Roberston, A.I. 2003. Relating wetland inundation to river flow using Landsat TM data. *International Journal of Remote Sensing* **24**: 3755-3770.

Freeman, S. 2002. *Biological Science*. Upper Saddle River: Prentice Hall Press.

Fu, K.S. 1976. Pattern recognition in remote sensing of the earth resources. *IEEE Transactions on Geoscience Electronics* **14**: 10-11.

Galbraith, L. and Burns, C. 2007. Linking land-use, water body type and water quality in southern New Zealand. *Landscape Ecology* **22**: 231-241.

Gangoo, S.A. and Makeya, A.S. 2000. Changes in vegetation pattern of Hokersar (Wetland Reserve), Kashmir. **In**: *Environment, Biodiversity and Conservation* (Ed. M.A.Khan). APH. Publ. Corp. New Delhi. pp.107-112.

Gemmer, M., Becker, S. and Jiang, T. 2004. Observed monthly precipitation trends in China 1951–2002. *Theoretical and Applied Climatology* **77**: 39–45.

Ghani, A., Dexter, M. and Perrott, K.W. 2003. Hot water extractable carbon in soil: a sensitive measurement for determining impacts of fertilization, grazing and cultivation. *Soil Biology and Biochemistry* **35**: 1231-1243.

Ghulam, R., Dahe, Q.I.N. and Chaudhry, Q.Z. 2008. Global warming and melting glaciers along southern slopes of HKH Ranges. *Pakistan Journal of Meteorology* **5** (1): 63-76.

Giese, L.A.B. and Flannagan, C.T. 2006. Soil properties in northern Virginia created forested wetlands. *American Society of Agricultural and Biological Engineers.* Paper No. 701P0406.

Giri, C. and Jenkins, C. 2005. Land cover mapping of Greater Mesoamerica using MODIS data. *Cannadian Journal of Remote Sensing* **31**(4): 274–282.

Gol, C. 2009. The effects of land use change on soil properties and organic carbon at Dagdami river catchment in Turkey. *Journal of Environmental Biology* **30**(5): 825-830.

Goldman, C.R. and Horne, A.J. 1983. Limnology. McGraw–Hill, Internaal Book Company.

Goldman, J.C. 1972. The effect of inorganic carbon on eutrophication. **In**: *Proceedings of a Seminar on Eutrophication and Biostimulation* (Eds. R. L. Brown and M. G. Tunzi). San Francisco: Department of Water Resources. pp. 3–53.

Goldman, S.J., Jackson, K. and Bursztynsky, T.A. 1986. *Erosion and Sediment Control Handbook*. McGraw Hill, Inc. pp.449.

Goldstein, R.M., Carlisle, D.M., Meador, M.R. and Short, T.M. 2007. Can basin land use effects on physical characteristics of streams be determined at broad geographic scales? *Environmental Monitoring and Assessment* **130**: 495-510.

Gong, D.Y. and Wang, S.W. 2000. Severe summer rainfall in China associated with enhanced global warming. *Climatic Research* **16**: 51–59.

Guerschman, J.P., Paruelo, J.M., Bela, C.D., Giallorenzi, M.C. and Pacin, F. 2003. Land cover classification in the Argentine Pampas using multi-temporal Landsat TM data. *International Journal of Remote Sensing* **24**: 3381–3402.

Guisan, A. and Zimmermann, N.E. 2000. Predictive habitat distribution models in ecology. *Ecological Modelling* **135**: 147-186.

Guo, S., Chen, H., Zhang, H., Xiong, L., Liu, P., Pang, B., Wang, G. and Wang, Y. 2005. A semi-distributed monthly water balance model and its application in a climate change impact study in the middle and lower Yellow river basin. *International Water Resources Association* **30** (2): 250-260.

Gupta, R.D. and Verma, S.D. 1975. Studies on the soils of Udhampur district of Jammu and Kashmir in relation to parent material, climate and irrigation. *Fertilizer Technology* **12**(3): 231-235.

Gupta, R.D., Anand, R.R. and Sharma, P.D. 1988. Characteristics and genesis of some alluvium derived soils of J&K. *Proceedings of Indian National Science Academy* **54** (1): 120-130.

Gupta, R.D., Arora, S., Gupta, G.D. and Sumberia, N.M. 2010. Soil physical variability in relation to soil erodibility under different land uses in foothills of Siwaliks in N-W India. *Tropical Ecology* **51**(2): 183-197.

Gurumahum, S.D., Daimari, P., Goswami, B.S., Sakar, A. and Choudhury, M. 2000. Physico chemical qualities of water and plankton of selected rivers in Meghalaya. *Journal Inland Fisheries Society of India* **34**: 36 - 42.

Hadjimitsis, D.G., Papadavid, G., Agapiou, A., Themistocleous, K., Hadjimitsis, M.G., Retalis, A., Michaelides, S., Chrysoulakis, N., Toulios, L. and Clayton, C.R.I. 2010. Atmospheric correction for satellite remotely sensed data intended for agricultural applications: impact on vegetation indices. *Natural Hazards Earth System Science* **10**: 89–95.

Hagerthey, S.E. and Kerfoot, W.C. 1998. Groundwater flow influences the biomass and nutrient ratios of epibenthic algae in a north temperate seepage lake. *Limnology and Oceanography* **43**(6): 1227-1242.

Haith, D.A. 1987. Evaluation of daily rainfall erosivity model. *Transactions of American Society of Agriculture Engineering* **30**(1): 90-93.

Haith, D.A. and Shoemaker, L.L. 1987. Generalized Watershed Loading functions for stream flow nutrients. *Water Resources Bulletin* **23:** 471-478.

Haith, D.A., Mandel, R. and Shyan Wu, R. 1992. Generalized Watershed Loading Function Model: Users Manual. Ithaca, New York, USA 14853.

Hakvoort, H., Haan, J., Jordan, R., Vos, R., Peters, S. and Rijkeboer, M. 2002. Towards airborne remote sensing of water quality in the Netherlands validation and error analysis. *Journal of Photogrammetry and Remote Sensing* **57**(3): 171-183.

Harden, C.P., Foster, W., Morris, C., Chartrand, K.J. and Henry, E. 2009. Rates and processes of stream bank erosion in tributaries of the little river, Tennessee. *Physical Geography* **30**(1): 1-16.

Hart, R.H., Bissio, J., Samuel, M.J. and Woggoner, J.W. 1993. Grazing systems, pasture size, and cattle grazing behavior, distribution and gains. *Journal of Range Management* **46**: 81-87.

Hernandez, M., Miller, S.N., Goodrich, D.C., Goff, B.F., Kepner, W.G., Edmonds, C.M. and Jones, K.B. 2000. Modelling runoff response to land cover and rainfall spatial variability in semi-arid watersheds. *Environmental Monitoring and Assessment* **64**: 285-298.

Herold, M., Couclelis, H. and Clarke, K.C. 2005. The role of spatial metrics in the analysis and modelling of urban land use change. *Computers, Environment and Urban Systems* **29** (4): 369-399.

Hess, L.L. and Melack, J.M. 1994. Mapping wetland hydrology and vegetation with SAR. *International Journal of Ecology and Environmental Science* **20**: 197-205.

Hession, W.C., Storm, D.E., Haan, C.T., Burks, S.L. and Matlock, M.D. 1996. A watershed-level ecological risk assessment methodology. *Water Resources Bulletin* **32**: 1039-1054.

Higgitt, D.L. and Lu, X.X. 1999. Challenges in relating land use to sediment yield in the Upper Yangtze. *Hydrobiologia* **410**: 269–277.

Hollis, G.E., Holland, M.M., Larson, J. and Maltby, E. 1989. Wise use of wetlands. *Nature and Resources* **24**: 2-13.

Holloway, J.M. and Dahlgren, R.A. 2001. Seasonal and event-scale variations in solute chemistry for four Sierra Nevada catchments. *Journal of Hydrology* **206**: 106–121.

Holman, I.P., Whelan, M.J., Howden, N.J.K., Bellamy, P.H., Willby, N.J., Rivas-Casado, M., and McConvoy, P. 2008. Phosphorus in groundwater-an overlooked contributor to eutrophication? *Hydrological Processes* **22**: 5121-5127.

Huang, M., Peng, G.B., Leslie, L.M., Shao, X.M. and Sha, W.Y. 2005. Seasonal and regional temperature changes in China over the 50 year period 1951–2000. *Meteorology and Atmospheric Physics* **89** (1–4): 105–115.

Huang, W., Liu, H., Luan, Q., Jiang, Q., Liu, J. and Liu, H. 2008. Detection and prediction of land use change in Beijing based on remote sensing and GIS. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences* **XXXVII**: 75-82.

Hudson, B.D. 1994. Soil organic matter and available water capacity. *Journal of Soil and Water Conservation* **49**(2): 189-194.

Hunt R.J., Haitjema, H.M., Krohelski, J.T. and Feinstein D.T. 2003. Simulating ground water-lake interactions: Approaches and insights. *Ground Water* **41**: 227-237.

Indabawa, I.I. 2009. Studies on limnological parameters and phytoplankton dynamics of Nguru Lake, Yobe State Nigeria. *Bioscience Research Communications* **21**(4): 183-188.

IPCC (2001b). *IPCC Third Assessment Report- Climate Change*. Working Group I: Technical Summary. Geneva, WMO and UNEP.

Islam, S., Rehman, N. and Sheikh, M.M. 2009. Future change in the frequency of warm and cold spells over Pakistan simulated by the PRECIS regional climate model. *Climate Change* **94** (1-2): 35-45.

Iyer, H.S., Singh, A.N. and Kumar, R. 1975. Problem area inventory of parts of Hoshiarpur district through photo-interpretation. *Journal of Indian Photo-interpretation* **3**(2): 79.

Jackson, M.L. 1967. *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd. New Delhi. pp. 128-129.

Janssen, L.F. and Van der Wel, F.J.M. 1994. Accuracy assessment of satellite derived land-cover data: A review. *Photogrammetric Engineering and Remote Sensing* **60** (4): 419-426.

Jantz, C.A., Goetz, S.J., Donato, D. and Claggett, P. 2010. Designing and implementing a regional urban modelling system using the SLEUTH cellular urban model. *Computers, Environment and Urban Systems* **34**(1): 1-16.

Jeelani, M., Kaur, H. and Kumar, R. 2008. Impact of climate warming on the biodiversity of freshwater ecosystem of Kashmir, India. *Proceedings of TAAL 2007: The 12th World Lake Conference* 1103-1109.

Jennings, E., Allott, N., Pierson, D.C., Schneiderman, E.M., Lenihan, D., Samuelsson, P. and David, T. 2009. Impacts of climate change on phosphorus loading from a grassland catchment: Implications for future management. *Water Research* **43** (17): 4316-4326.

Jia, H. and Cheng, S. 2002. Spatial and dynamic simulation for Miyun reservoir waters in Beijing. *Water Science and Technology* **46**: 473-479.

Johnson, L.B., Richards, C., Host, G.E. and Arthur, J.W. 1997. Landscape influences on water chemistry in mid western stream ecosystems. *Freshwater Biology* **37**: 193-208.

Johnson, K.S., Elrod, V.A., Nowicki, J.L., Coale, K.H. and Zamzow, H. 2000. Continuous flow techniques for on site and in situ measurements of metals and nutrients in sea water. **In**: *In situ Monitoring of Aquatic Systems: Chemical Analysis and Speciation* (Eds. J. Buffle and G. Horvai). John Wiley.

Johnson, W.C., Millett, B.V., Gilmanov, T., Voldseth, R.A., Guntenspergen, G.R. and Naugle, D.E. 2005. Vulnerability of Northern prairie wetlands to climate change. *BioScience* **55**: 863–872.

Jones, C.A., Jacobsen, J. and Lorbeer, S. 2002. Metal concentrations in three Montana soils following 20 years of fertilization and cropping. *Communications in Soil Science and Plant Analysis* **33** (9 & 10): 141-414.

Jones, J.R. and Bachmann, R.W. 1974. Limnological features of some northwestern Iowa lakes. *Proceedings of the Iowa Academy of Science* **81**: 158-163.

Jones, K.B., Neale, A.C., Nash, M.S., Van Remortel, R.D., Wickham, J.D., Riitters, K.H. and O'Neill, R.V. 2001. Predicting nutrient and sediment loadings to streams from landscape metrics: a multiple watershed study from the United States Mid-Atlantic Region. *Landscape Ecology* **16**: 301–312.

Jonna, S. 1999. Remote sensing application to water resources: retrospective and perspective. **In**: *Proceedings of ISRS National Symposium on Remote Sensing Applications for Natural Resources* (Ed. S. Adiga). Dehradun. pp.368-377.

Kadlec, R.H. and Kadlec, J.A. 1979. Wetlands and water quality. **In**: *Wetland Functions and Values: The State of Our Understanding.* (Ed. P.E. Greeson). American Water Resources Association, Minneapolis, MN. pp. 436-456.

Kachhwaha, T.S. 1985. Temporal monitoring of forest land for change detection and forest cover mapping through satellite remote sensing. *Proceedings of the 6th Asian Conference on Remote Sensing.* pp.77-83.

Kak, A.M. 1981. Floristic composition, structure and ecology of some high altitude lakes of Kashmir Himalayas. **In**: *Ecology and Resource Management* (Eds. R.S. Ambasht and H.N. Pandey). Varanasi, U.P. pp.106-108.

Kak, A.M. 1984 a. Aquatic and wetland flora of the Northwestern Himalaya, XXII Aquatic Cyperaceae of Northwestern Himalaya. *Journal of Economic and Taxonomic Botany* **5** (3): 687-703.

Kak, A.M. 1984 b. *Potamogeton* in Northwestern Himalaya. *Journal of Bombay Natural History Society* **8**(2): 312-319.

Kak, A.M. 1985. Aquatic and wetland vegetation of Northwestern Himalaya, XXI Family Nymphaeceae in the Northwestern Himalaya. *Journal of Economic and Taxonomic Botany* **7** (3): 391-395.

Kale, V.B. and Chevan, A.S. 1996. Physicochemical characteristics Kumbhave -5 soil series of Konkan of Maharashtra State. *PKU. Research Journal* **20**(2): 136-140.

Kamphorst, A. and Iyer, H.S. 1972. Application of aerial photo-interpretation to ravine surveys in India. **In**: *Proceedings of 12th Congress of International Society for Photogrammetric Engineering.* Ottawa, Canada.

Kang, M.S., Park, S.W., Lee, J.J. and. Yoo, K.H. 2006. Applying SWAT for TMDL programs to a small watershed containing rice paddy fields. *Agricultural Water Management* **79**: 72-92.

Kang, W.J., Kolasa, K.V. and Rials, M.W. 2005. Groundwater inflow and associated transport of phosphorus to a hypereutrophic lake. *Environmental Geology* **47**: 565-575.

Kanthaliya, P.C. and Bhatt, P.L. 1991. Relationship between organic matter and available nutrients in some soils of sub humid zone. *Journal of the Indian Society of Soil Science* **39**: 781-782.

Karpouzos, D.K., Kavalieratou, S. and Babajimopoulos, C. 2010. Trend analysis of precipitation data in Pieria region (Greece). *European Water* **30**: 31-40.

Kaul, V. 1977. Limnological survey of Kashmir lakes with reference to trophic status and conservation. *International Journal of Ecology and Environmental Science* **3**: 29-44.

Kaul, V. 1983. Conservation of plant resources in aquatic ecosystems with reference to some aquatic habitats of Kashmir. **In**: *Conservation of Tropical Plant Resources* (Eds. S.K. Jain and K.L. Mehra). BSI, Calcutta. pp.118-131.

Kaul, V. and Handoo, J.K. 1993. Ecology and management of some typical wetlands of Kashmir. **In**: *Ecology and Pollution of Indian Lakes and Reservoirs* (Eds. P.C. Mishra and R.K. Trivedy). Ashish Publishing House, New Delhi. pp.112-130.

Kaul, V. and Pandit, A.K. 1982. Biotic factors and food chain structure in some typical wetlands of Kashmir. *Pollution Research* **1**: 49-54.

Kaul, V. and Qadri, B.A. 1979. Seasons of Kashmir. *Geographical Review of India* **41**(2): 123-130.

Kaul, V. and Zutshi, D.P. 1967. A study of aquatic and marshland vegetation of Srinagar. *Proceedings of the National Institute of Sciences* India **33**(B): 111-127.

Kaul, V., Fotedar, D.N., Pandit, A.K. and Trisal, C.L. 1978. A comparative study of plankton populations of some typical freshwater bodies of Jammu and Kashmir state. **In**: *Environment Physiology and Ecology of Plants*. (Eds. D.N. Sen and S.P. Bansal). Bishen Singh Mahendrapal Singh, Dehradun. pp.249-269.

Kazmi, A.A. and Hansen, I.S. 1997. Numerical models in water quality management: A case study for the Yamuna River (India). *Water Science and Technology* **36**(5): 193–200.

Kedarnath, M., Sundarshana, R. and Das, N. 1994. Remote sensing based study on spatio-temporal variabilities of the coastal lagoon features- A Case Study at Chilka Lake, India. **In**: *Conference Proceedings of Coastal Zone Canada, Co-operation in the Coastal Zone* **3**: 936-949.

Keeney, D.R. and Deluca, T.H., 1993. Des-Moines River nitrate in relation to watershed agricultural practices-1945 versus 1980s. *Journal of Environmental Quality* **22** (2): 267–272.

Kent, E.Z.B. and Gullari, A.I.K. 2007. Spatial and temporal dynamics of landuse pattern in Turkey: A case study in Inegol. *Landscape and Urban Planning* **81**: 316-327.

Kepner, W.G., Rubio, J.L., Mouat, D.A. and Pedrazzini, F. 2005. Desertification in the Mediterranean Region: A Security Issue. NATO Security through Science Series.pp. 3-605. Springer, the Netherlands. ISBN 1-4020-3758-9.

Khan, M.A. 1979. Some observations on trophic evolution of monomictic flood-plain lake. *Indian Journal of Ecology* **6**: 27-32.

Khan, M.A. 1984. Studies on primary productivity and some hydrochemical aspects of a polluted water body of Himalayan Jhelum Valley. *Acta Hydrochimica et Hydrobiologica* (Berl.)**12**: 539-548.

Khan, M.A. 1985. Spatio-temporal plankton variability in two Himalayan lacustrine ecosystems. *Acta Hydrochimica et Hydrobiologica* (Berl.) **13**: 249-257.

Khan, M.A. 1986. Hydrobiology and organic production in a marl lake of Kashmir Himalayan Valley. *Hydrobiologia* (The Netherlands) **135**: 233-242.

Khan, M.A. 1987. Observations on zooplankton composition, abundance and productivity on the flood-plain lakes of Kashmir Himalayan Valley. *Acta Hydrochimica et Hydrobiologica* (Berl.) **15**: 167-174.

Khan, M.A. 1993a. Occurrence of a rare euglenoid causing red-bloom in Dal Lake waters of the Kashmir Himalaya. *Archiv fuer Hydrobiol*ogie (Stuttgart) **127**: 101-103.

Khan, M.A. 1993b. Euglenoid red bloom contributing the environmental pollution of Dal Lake, Kashmir Himalaya. *Environmental Conservation* (Switzld.) **20**: 352-356.

Khan, M.A. 2000a. Wetland biodiversity in Kashmir Himalaya assessment and conservation strategies. In: *Environment, Biodiversity and Conservation* (Ed. M.A. Khan). Ashish Publishing House, New Delhi. pp. 69-93.

Khan, M.A. 2000b. *Euryale ferox Salisb,* a threatened aquatic plant species in Kashmir Himalaya. *Indian Journal of Environmental Science* **4**: 83-87.

Khan, M.A. 2000c. Anthropogenic eutrophication and red tide outbreak in lacustrine systems of the Kashmir Himalaya. *Acta Hydrochimica et Hydrobiologica* (Weinheim) **28**: 95-101.

Khan, M.A. 2008. Chemical environment and nutrient fluxes in a flood-plain wetland ecosystem, Kashmir Himalaya, India. *Indian Forester* **134** (4): 505-514.

Khan, M.A. 2009. *Ecology and Conservation of Hokersar Wetland: A Major Game Sanctuary in the Kashmir Himalaya.* SKAUST-K M/S Print Process, New Delhi. pp. 56.

Khan, M.A. and Shah, M.A. 2003. Phosphorus load concentration in a Kashmir Himalaya game reserve- Hokersar wetland. *Indian Journal of Soil Conservation* **31**: 243-247.

Khan, M.A. and Shah, M.A. 2004a. Hydrology and sediment loading of Hokersar wetland sanctuary in the Kashmir Himalaya. *Indian Forester* **130**: 899-910.

Khan, M.A. and Shah, M.A. 2004b. Land use pattern in the catchment and its impact on the ecology of a suburban wetland, Kashmir Himalayas. **In**: *Agriculture and Environment* (Eds. M.A. Khan and M.Y.Zargar). Ashish Publishing House, New Delhi. pp. 281-288.

Khan, M.A. and Shah, M.A. 2010. Studies on biomass changes and nutrient lockup efficiency in a Kashmir Himalayan wetland, ecosystem-India. *Journal of Ecology and Natural Environment* **21**(8): 147-153.

Khan, M.A. and Zutshi, D.P. 1992. Studies on evaluation of energy flux at primary producer level in three lakes of Kashmir, India. *Japanese Journal of Limnology* **53**: 217-221.

Khan, M.A., Gupta, V.P. and Moharana, P.C. 2001. Watershed prioritization using remote sensing and Geographic Information System: A case study from Guhiya. *Indian Journal of Arid Environment* **49**: 465-475.

Khan, M.A., Shah, M.A., Mir, S.S. and Bashir, S. 2004. Environmental status of a Kashmir Himalayan wetland game reserve aquatic plant communities and eco-restoration measures. *Lakes and Reservoirs Research and Management* (Blackwell, Australia) **9**(2): 125-132.

Kimaro, M.D. and Semalulu, O. 2010. Sediment production from settlements and farmlands within Lake Victoria shoreline zone in Uganda and Tanzania. *Tropicultura* **28** (2): 89-95.

Kishel, H.F. and Gerla, P.J. 2002. Characteristics of preferential flow and groundwater discharge to Shingobee Lake, Minnesota, USA. *Hydrological Processes* **16**: 1921-1934.

Kizilkaya, R. and Dengiz, O. 2010. Variation of land use and land cover effects on some soil physico-chemical characteristics and soil enzyme activity. *Zemdirbyste-Agriculture* **97**(2): 15-24.

Kolekar, V. 2006. Ecology and fisheries status of Keetham Lake of Agra (U.P.) in early nineteens. *Himalayan Journal of Environment and Zoology* **20** (1): 253- 260.

Kont, A., Endjarv, E., Jaagus, J., Lode, E., Orviku, K., Ratas, U., Rivis, R., Suursaar, U. and Tonisson, H. 2007. Impact of climate change on Estonian coastal and inland wetlands – a summary with new results. *Boreal Environment Research* **12**: 653-671.

Korkanc, S.Y., Ozyuvaci, N. and Hizal, A. 2008. Impacts of land use conversion on soil properties and soil erodibility. *Journal of Environmental Biology* **29**(3): 363-370.

Krause, P. 2002. Quantifying the impact of land use changes on the water balance of large catchments using the J2000 model. *Physics and Chemistry of the Earth* **27**: 663–673.

Kulkarni, A.V., Bahuguna, I.M., Rathore, B.P., Singh, S.K., Randhawa, S.S., Sood, R.K. and Dhar, S. 2007. Glacial retreat in Himalaya using Indian remote sensing satellite data. *Current Science* **92** (1): 69-74.

Kumar, M. 2004. Digital Image Processing. **In:** *Satellite Remote Sensing and GIS Applications in Agricultural Meteorology*. World Meteorological Organization. pp. 81-102.

Kumar, V. and Srivastav, A.K. 2010. Geographical Information System based morphometric analysis of Ghat Gad and Gheria Gad micro-watersheds of Ladhiya-Lahaghat watershed of Sarju River in Champawat, District, Uttaranchal. *Journal of Indian Society of Geomatics* **4** (1): 17-24.

Lake, P.S. and Marchant, R. 1990. Australian upland streams: ecological degradation and possible restoration. **In**: *Australian ecosystems: 200 years of utilization, degradation and reconstruction* (Eds. D.A. Saunders, A.J.M. Hopkins and R.A. How). Geraldton, Ecological Society of Australia. pp. 79-91.

Lambin, E.F., Geist, H. and Lepers, E. 2003. Dynamics of land use and cover change in tropical regions. *Annual Review of Environment and Resources* **28**: 205–241.

Larned, S.T., Scarsbrook, M.R., Snelder, T.H., Norton, N.J. and Biggs, B.J. F. 2004. Water quality in low-elevation streams and rivers of New Zealand: recent state and trends in contrasting land-cover classes. *New Zealand Journal of Marine and Freshwater Research* **38**: 347-366.

Lashari, K.H., Korai, A.L., Sahato, G.A. and Kazi, T.G. 2009. Limnological studies of Keenjhar Lake, District, Thatta, Sindh, Pakistan. *Pakistan Journal of Analytical and Environmental Chemistry* **10** (1 & 2): 39-47.

Lathrop, R.G. and Lillesand, T.M. 1989. Monitoring water quality and river plume transport in Green Bay, Lake Michigan with SPOT-1 imagery. *Photogrammetric Engineering and Remote Sensing* **55**(3): 349-354.

Lavery, P., Pattiarachi, C., Wyllie, A. and Hick, P. 1993. Water quality monitoring in estuarine waters using the Landsat Thematic Mapper. *Remote Sensing of Environment* **46**(3): 268-280.

Lawler, D.M., Thorne, C.R. and Hooke, J.M. 1997. Bank erosion and instability. **In**: *Applied Fluvial Geomorphology for River Engineering and Management* (Eds. C.R. Thorne, R.D. Hey and M.D. Newson). Chichester, Wiley. pp. 137-172.

Lawrence, R.W. 1895. *The Valley of Kashmir*. Oxford University Press, Oxford. pp. 478.

Lee, K.Y., Fisher, T.R., Jordan, T.E., Correll, D.L. and Weller, D.E. 2000. Modelling the hydrochemistry of the Choptank River basin using GWLF and Arc/Info: 1 Model validation and application. *Biogeochemistry* **49:** 143-173.

Lee, K.Y., Fisher, T. and Rochelle, N.E. 2001. Modelling the hydrochemistry of the Choptank River basin using GWLF and Arc/Info: 2. Model validation and application. *Biochemistry* **56**(3): 311-348.

Legesse, D., Coulomb, C.V. and Gasse, F. 2003. Hydrological response of a catchment to climate and land use changes in Tropical Africa: Case study South Central Ethiopia*. Journal of Hydrology* **275** (1-2): 67-85.

Lettenmaier, D.P., Wood, E.F. and Wallis, J.R. 1994. Hydro-climatological trends in the continental United States, (1948–88). *Journal of Climate* **7**: 586–607.

Lewis, D.B. and Grimm, N.B. 2007. Hierarchical regulation of nitrogen export from urban catchments: interactions of storms and landscapes. *Ecological Applications* **17**: 2347-2364.

Li, C. and Tang, M. 1986. Changes of air temperature of Qunghai–Xizang plateau and its neighbourhood in the past 30 years. *Plateau Meteorol* **5**: 322–341.

Li, X. and Yeh, G. 2004. Analyzing spatial restructuring of land use patterns in a fast growing region using remote sensing and GIS. *Landscape and Urban Planning* **69**: 335-354.

Liao, H.H. and Tim, U.S. 1994. Interactive water quality modelling within a GIS environment. *Computer, Environment and Urban Systems* **18** (5): 343-363.

Lillesand, T.M., Johnson, W.L., Deuell, R.L., Lindstrom, O.M. and Meisner, D.E. 1983. Use of Landsat data to predict the trophic state of Minnesota Lakes. *Photogrammetric Engineering and Remote Sensing* **49**(2): 219-229.

Lillesand, T.M., Kiefer, R.W. and Chipman, J.W. 2004. Remote Sensing and Image Interpretation. 5th Ed. John Wiley and Sons, New York.

Lin, T., Xue, X.Z. and Lu, C.Y. 2007. Analysis of coastal wetland changes using the "DPSIR" model: A case study in Xiamen, China. *Coastal Management* **35**: 289–303.

Little, K.W. and Williams, R. E. 1992. Least-squares calibration of QUAL2E. *Water Environment Research* **64**(2): 179-185.

Liu, H. and Yang, D. 2004. Study on dynamic change of wetland of Fujian based on remote sensing and Geographic Information System. **In**: *Geoscience and Remote Sensing Symposium, IGARSS Proceedings IEE International* **6** (20-24): 3636-3638.

Liu, X. and Chen, H. 2000. Climatic warming in the Tibetan plateau during recent decades. *International Journal of Climatology* **20**: 1729–1742.

Lopez, R. and Jacob, J. 2005. GIS tools to evaluate the impacts of urban sprawl on water quality: A quantitative approach. **In:** *Proceedings of Emerging Technologies for a Sustainable Environment*. 20-21 Oct. 2005. South Padre Island, Texas.

Loucks, D.P. 1995. Developing and implementing decision support systems: A critique and a challenge. *Water Resources Bulletin* **31**(4): 571-582.

Lovell, S.T. and Sullivan, W.C. 2006. Environmental benefits of conservation buffers in the United States: Evidence, promise, and open questions. *Agriculture Ecosystems and Environment* **112**: 249-260.

Lunetta, R. and Balogh, M. 1999. Applications of Multi-Temporal Landsat 5 TM imagery for wetland identification. *Photogrammetric Engineering and Remote Sensing* **65**(11): 1303-1310.

Machung, B.L., Brooks, R.P., Yates, S.S. and Hoover, K.L.1996. Soil properties of reference wetlands and wetland creation projects in Pennsylvania. *Wetlands* **16**(4): 532-541.

Mackereth, F.J.H. 1963. Some methods of water analysis for limnologists. *Fresh Water Biological Association Scientific Publications* **21**: 72.

MacKinnon, F. 2001. Wetland Application of LIDAR Data: Analysis of vegetation types and heights in wetland. *Applied Geomatic Research Group, Centre of Geographical Sciences, Nova Scotia* p.44.

Magnuson, J.J., Robertson, D.M., Benson, B.J., Wynne, R.H., Livingstone, D.M., Arai, T., Assel, R.A., Barry, R.G., Card, V., Kuusisto, E., Granin, N.G., Prowse, T.D., Stewart, K.M. and Vuglinski, V.S. 2000. Historical trends in lake and river ice cover in the Northern Hemisphere. *Science* **289**: 1743-1746.

Mahapatra, S.K., Walia, C.S., Sidhu, G.S., Rana, K.C. and Tarseam, L. 2000. Characterization and classification of soils of different physiographic units in the sub-humid ecosystem of Kashmir region. *Journal of the Indian Society of Soil Science* **48**: 572-577.

Mahay, H. 2008. Ecohydrology study of Kirumi wetland using hydroinformatic tools. *Nordic Hydrology* **23**: 265-274.

Maltby, E. 1986. *Waterlogged Wealth*. Earthscan Press, London, England. pp. 200.

Mandal A.K., Nath, S., Gupta, S.K. and Banerjee, S.K. 1990. Characteristics and nutritional status of soils of middle hill and upper hill forest of the eastern Himalayas. *Journal of Indian Society for Soil Science* **38**(1): 100-106.

Manguerra, H.B. and Engel, B.A. 1998. Hydrologic parameterization of watersheds for runoff prediction using SWAT. *Journal of American Water Resources Association* **34**(5): 1149-1162.

Manju, G., Chowdary, V.M., Srivastava, Y.K., Selvamani, S., Jeyaram, A. and Adiga, S. 2005. Mapping and characterization of inland wetlands using remote sensing and Geographic Information System. *Journal of Indian Society of Remote Sensing* **33**: 51-61.

Manonmani, I.K. 2010. Spatio-temporal analysis of land use in fringe area using GIS – A case study of Madurai city, Tamil Nadu. *International Journal of Geomatics and Geosciences* **1**(2): 264-270.

Mansell, R.S., Bloom, S.A. and Sun, G. 2000. A model for wetland hydrology: description and validation. *Soil Science* **165**: 384-397.

Markel, D., Somma, F. and Evans, B.M. 2006. Using a GIS transfer model to evaluate pollutant loads in the Lake Kinneret watershed, Israel. *Water Science and Technology* **53**(10): 75–82.

Markensten, H., Moore, K. and Persson, I. 2010. Simulated lake phytoplankton composition shifts toward cyanobacteria dominance in a future warmer climate. *Ecological Applications* **20**: 752–767.

Materechera, S.A. and Murovhi, R.N. 2011. Soil biological properties beneath canopies of *Acacia erioloba* (syn. *Acacia giraffae*) trees under different land use practices in a South African semi-arid environment. *Life Science Journal* **8**(S2): 33-39.

Matheussen, B., Kirschbaum, R.L. Goodman, I.A., O'Donnell, G.M. and Lettenmaier, D.P. 2000. Effects of land use change on stream flow in the interior Columbia River Basin (USA and Canada). *Hydrological Processes* **14**(5): 867-885.

Mathur, P., Agarwal, S. and Nag, M. 2008. Assessment of physico-chemical characteristics and suggested restoration measures for Pushkar Lake, Ajmer Rajasthan (India). *Proceedings of TAAL 2007: The 12th World Lake Conference* 1518-1529.

Mayewski, P.A. and Jeschke, P.A. 1979. Himalayan and Trans Himalayan glacier fluctuations since AD 1812. *Arctic Alpine Research* **11**(3): 267-287.

McBride, M.B. 1994. Environmental Chemistry of Soils. Oxford University Press, New York. 406 pages.

McCuen, R.H. 1989. *Hydrologic Analysis and Design*. Prentice-Hall, Inc. Englewood Cliffs, NJ.

McDowell, R.W. 2009. Effect of land use and moisture on phosphorus forms in upland stream beds in South Otago, New Zealand. *Marine and Freshwater Research* **60**: 619-625.

McIver, D.K. and Friedl, M.A. 2002. Using prior probabilities in decision-tree classification of remotely sensed data. *Remote Sensing of Environment* **81**: 253-261.

Meamarian, H., Esmaeilzadeh H. and Tajbakhsh, S.M. 2003. The sediment yield potential estimation of Kashmar urban watershed using MPSIAC model in the GIS framework. **In**: *Map India 2003: 6th Annual International Conference on Geospatial Information Technology and Applications* pp. 7-10.

Mendis, W.T.G. and Wadigamangawa, A. 1996. Integration of remote sensing and GIS for land use/land cover mapping in Nil Wala Basin. GIS development>Proceedings>ACRS >1996. www.GISdevelopment.net.

Meysner, T., Szajdak, L. and Ku, J. 2006. Impact of the farming systems on the content of biologically active substances and forms of nitrogen in the soils. *Agronomy Research* **4**(2): 531-542.

Miller, N.L., Bashford, K.E. and Strem, E. 2003. Potential impacts of climate change on California hydrology. *Journal of the American Water Resources Association* **39**(4): 771-784.

Miller, R.C., Guertin, D.P. and Heilman, P. 2004. Information technology in watershed management decision making. J*ournal of the American Water Resources Association* **40**(2): 347-357.

Miller, S., Semmens, D., Goodrich, D., Hernandez, M., Miller, R., Kepner, W. and Guertin, D.P. 2007. The Automated Geospatial Watershed Assessment Tool. *Environmental Modelling and Software* **22**: 365-377.

Minhas, R.S. and Bora, N.C. 1982. Distribution of organic carbon and the forms of nitrogen in a topographic sequence of soils. *Journal of Indian Society of Soil Science* **30**(2): 135-139.

Mir, Q.A.B., Pandey, G.C. and Sarwar, S.G. 2006. Impact of SKIMS effluents on the water quality of Anchar Lake, Kashmir. **In**: *Industrial Pollution Problems and Solution* (Ed. A. Kumar). Daya Publishing House, Tri Nagar Delhi. pp.195-201.

Misri, B. 1988. Forage production in alpine and subalpine regions of North West Himalaya. **In**: *Pasture and Forage Crop Research - A State of Knowledge Report* (Ed. P. Singh). R.M.S.I., Ihansi. pp. 43-55.

Mitchell J.K., Engel, B.A., Srinivasan, R. and Wang, S.S.Y. 1993. Validation of AGNPS for small watersheds using an integrated AGNPS/GIS system. *Water Resources Bulletin* **29** (5): 833-842.

Mitsch, W.J. and Gosselink, J.G. 2000. *Wetlands*. Third Edition- Van Nostrand Reinhold Company, New York. pp. 920.

Moglen, G.E., Eltahir, E.A.B. and Bras, R.L. 1998. On the sensitivity of drainage density to climate change. *Water Resources Research* **34**: 855-862.

Monaghan, R.M., Hedley, M.J., Di, H.J., McDowell, R.W., Cameron, K.C. and Ledgard, S.F. 2007. Nutrient management in New Zealand pastures: recent developments and future issues. *New Zealand Journal of Agricultural Research* **50**: 181-201.

Mondal, M.S., Garg, R.D. and Garg, P.K. 2011. Site suitability analysis of future development for a new township using remote sensing and GIS techniques. *Journal of Indian Society of Geomatics* **5** (1): 37-42.

Montanarella, L., Jones, R.J.A. and Knijff, J.M. 2000. Soil erosion risk assessment in Europe. The European Soil Bureau.

Moore, I.D., Grayson, R.B. and Ladson, A.R. 1991. Digital terrain modelling: A review of hydrological, geomorphological and biological applications.

Hydrological Processes **5**(1): 3-30.

Moser, M., Prentice, C. and Frazier, S. 1996. A global overview of wetland loss and degradation. **In**: *Proceedings of the 6th Meeting of the Conference of Contracting Parties*, Brisbane, Australia, Papers, Technical Session B **12B**: 21-31.

Mosmann, V., Castro, A., Fraile, R., Dessens, J. and Sanchez, J.L. 2004. Detection of statistically significant trends in the summer precipitation of mainland Spain. *Atmospheric Research* **70**: 43-53.

Moss, B. 2007. The art and science of lake restoration. *Hydrobiologia* **581**: 15-24.

Mostaghimi, S., Park, S.W., Cooke, R.A. and Wang, S.Y. 1997. Assessment of management alternatives on a small agricultural watershed. *Water Research* **31**(8): 1867-1878.

Mushki, G.M. 1994. Studies on apple (*Malus Domestics Bockh*) orchard soils of Kashmir. M.Sc. Thesis. Sher-e-Kashmir University of Agricultural Sciences and Technology, Shalimar, Srinagar. p. 84.

Muttitanon, W. and Tripathi, N.K. 2005. Land use/land cover changes in the coastal zone of Ban Don Bay, Thailand using Landsat 5 TM data. *International Journal of Remote Sensing* **26** (11): 2311-2323.

Nagamani, K. and Ramachandran, S. 2003. Land use /Land cover in Pondicherry using remote sensing and GIS. In: *Proceedings of the Third International Conference on Environment and Health* (Eds. J. Martin, V. Bunch, M. Suresh and T.V. Kumaran). pp.300-305.

Najar, G.R. 2002. Studies on pedogenesis and nutrient indexing of apple (Red delicious) growing in soils of Kashmir. Ph.D. Thesis. Sher-e-Kashmir University of Agricultural Sciences and Technology, Shalimar, Srinagar. p. 204.

Nakashgir, G.H., Peer, G.H., Rafique, M.M. and Arora, C. L. 1997. Critical limits of potassium for rice in soils of Kashmir valley as influenced by altitude of the region. *Journal of Potassium Research* **13**(3 & 4): 249-256.

Nakayama, T. and Watanabe, M. 2008. Missing role of groundwater in water and nutrient cycle in the shallow eutrophic Lake Kasumigaura, Japan. *Hydrological Processes* **22**: 1150-1172.

National Research Council, 2002. Assessing the TMDL Approach to Water Quality Management. National Academy Press. Washington, DC. pp.122.

Nayak, S., Chauhan, P., Chauhan, H.B., Bahuguna, A. and Nath, A.N. 1996. IRS-1C applications for coastal zone management. *Current Science* **70**(7): 614-618.

Negi, R.K., Johan, N.S. and Negi, T. 2006. Study of the physico-chemical parameters of water of Pongdam reservoir, Himachal Pradesh: A Ramsar site. *Himalayan journal of Environment and Zoology* **20** (2): 247-256.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R. and Williams, J.R. 2001. Soil and Water Assessment Tool Theoretical Documentation Version 2000: Draft-April 2001. US Department of Agriculture – Agriculture Research Service, Temple, Texas.

Nguyen-Bao, V., Olk, D.C. and Cassman, K.G. 2004. Characterization of humic acid fractions improve estimates of nitrogen mineralization kinetics for low-land rice soils. *Soil Science Society of America Journal* **68**(4): 1266-1277.

Niehoff, D., Fritsch, U. and Bronstert, A. 2002. Land-use impacts on storm-runoff generation: scenarios of land-use change and simulation of hydrological response in a meso-scale catchment in SW-Germany. *Journal of Hydrology* **267**: 80–93.

Ning, S.K., Jeng, K.Y. and Chang, N.B. 2002. Evaluation of non-point sources pollution impacts by integrated 3S information technologies and GWLF modelling. *Water Science and Technology* 46 (6-7): 217-224.

Nitant, H.C., Bhushan, L.S. and Gavande, D. 1989. Implications of physicochemical properties of soils and water conservation practices of a watershed (Alarimpur, U.P). *Journal of Soil and Water Conservation of India* **33**: 31-38.

Noges, T. 2009. Relationships between morphometry, geographic location and water quality parameters of European lakes. *Hydrobiologia* **633**: 33-43.

Novotny, V. and Olem, H. 1994. *Water Quality: Prevention, Identification, and Management of Diffuse Pollution.* Van Nostrand Reinhold, New York. pp.1054.

Nuckols, J.R., Ellington, D. and Faidi, H. 1996. Addressing the non-point source implications of conjunctive water use with a geographic information system (GIS). *Application of Geographic Information Systems in Hydrology and*

Water Resources Management Proceedings of the Vienna Conference **235**: 341-348.

Odgaard, A.J. 1987. Stream bank erosion along 2 rivers in Iowa. *Water Resources Research* **23**(7): 1225-1236.

OECD/IUCN 1996. *Guidelines for aid agencies for improved conservation and sustainable use of tropical and subtropical wetlands.* Organization for Economic Cooperation and Development, Paris, France.

Oechel, W.C., Vourlitis, G.L., Hastings, S.J., Zulueta, R.C., Hinzman, L. and Kane, D. 2000. Acclimation of ecosystem CO_2 exchange in the Alaskan Arctic in response to decadal climate warming. *Nature* **406**: 978–981.

Olsen, S.R., Cole, C.V., Watanbe, F.S. and Dean, L.A. 1954. Estimation of available phosphorus by extraction with sodium bicarbonate. U.S. Department of Agriculture Circular 939: 19.

Omernik, J.M., Abernathy, A.R. and Male, L.M. 1981. Stream nutrient levels and proximity of agricultural and forest land to streams-some relationships. *Journal of Soil and Water Conservation* **36**(4): 227–231.

Osborn, T.J., Hulme, M., Jones, P.D. and Basnett, T.A. 2000. Observed trends in the daily intensity of United Kingdom precipitation. *International Journal of Climatology* **20**: 347-364.

Ostlund, C., Flink, P., Strombeck, N., Pierson, D. and Lindell, T. 2001. Mapping of water quality of Lake Erken, Sweden, from Imaging Spectrometry and Landsat Thematic Mapper. *The Science of the Total Environment* **268**(1-3): 139-154.

Osuji, G.E., Okon, M.A., Chukwuma, M.C. and Nwarie, I.I. 2010. Infiltration characteristics of soils under selected land use practices in Owerri, Southeastern Nigeria. *World Journal of Agricultural Sciences* **6** (3): 322-326.

Otsuki, A. and Wetzel, R.G. 1974. Coprecipitation of phosphate with carbonates in a marl lake. *Limnology and Oceanography* **17**(5): 763-767.

Ouyang, D. and Bartholic, J. 2001. Web-based GIS application for soil erosion prediction. **In:** *Proceedings of an International Symposium—Soil Erosion Research for the 21st Century*. Honolulu, HI. Jan. 3–5.

Ouyang, D., Bartholic, J. and Selegean, J. 2005. Assessing sediment loading from agricultural croplands in the Great Lakes Basin. *The Journal of American Science* **1**(2): 14-21.

Oza, M.P., Pandya, M.R. and Rajak, D.R. 2008. Evaluation and use of Resourcesat-I data for agricultural applications. *International Journal of Applied Earth Observation and Geoinformation* **10**(2): 194-205.

Pahwa, D.V. and Mehrotra, S.N. 1966. Observations on fluctuations in the abundance of plankton in relation to certain hydrological conditions of River Ganga. *Proceedings of the Indian National Academic Science* **36**(2): 157-189.

Pandey, A.C., Ghosh, S. and Nathawat, M.S. 2011. Evaluating patterns of temporal glacier changes in Greater Himalayan Range, Jammu & Kashmir, India. *Geocarto International* **99999**: 1-10.

Pandit, A.K. 1980. *Biotic Factor and Food Chain Structure in Some Typical Wetlands of Kashmir*. Ph.D. Thesis, University of Kashmir, Srinagar, India.

Pandit, A.K. 1982. Feeding ecology of breeding birds in five wetlands of Kashmir. *Indian Journal of Ecology* **9**: 181-190.

Pandit, A.K. 1988. Threats to Kashmir wetlands and their wild life resources. *Environmental Conservation* **15**: 266-268.

Pandit, A.K. 1989. Feeding ecology of wild ducks and geese overwintering in wetlands of Kashmir. *Ind. J. Ecol* **16**: 199-202.

Pandit, A.K. 1991. Conservation of wild life resources in wetland ecosystems of Kashmir, India. *Journal of Environmental Management* **33**: 143-154.

Pandit, A.K. 1996. Lakes in Kashmir Himalaya. **In**: *Ecology, Environment and Energy* (Eds. A.H. Khan and A.K. Pandit). University of Kashmir, Srinagar, J&K, India. pp. 1-40.

Pandit, A.K. 1996. Status of waterfowl in Kashmir Himalaya. **In**: *Ecology, Environment and Energy* (Eds. A.H. Khan and A.K. Pandit). University of Kashmir, Srinagar, J&K, India. pp. 149-184.

Pandit, A.K. 1999. Freshwater Ecosystems of the Himalaya. Parthenon Publishing, New York, London.

Pandit, A.K. 2002. Lakes in Kashmir Himalaya. **In:** *Natural Resources of Western Himalayas* (Ed. A.K. Pandit). Valley Book House, Hazratbal, Srinagar, Kashmir. pp. 12-13.

Pandit, A.K. and Qadri, S.S. 1990. Floods threatening Kashmir wetlands. *Journal of Environmental Management* **31**: 299-311.

Pandit, A.K. and Yousuf, A.R. 2002. Trophic status of Kashmir Himalayan Lakes as depicted by water chemistry. *Journal of Research and Development* **2**: 1-12.

Panigrahy, S., Singh, T.S., Patel, J.G., Romshoo, S.A., Qadri, T., Rashid, I. and Muslim, M. 2010. National Wetland Atlas: Jammu and Kashmir. MoEF and SAC/ISRO. Ahmedabad.

Pant, G.B. and Borgaonkar, H.P. 1984. Climate of the hill regions of Uttar Pradesh. *Himalayan Research and Development* **3**: 13–20.

Pant, G.B., Borgaonkar, H.P. and Rupa Kumar, K. 1999. Climate variability over the Western Himalaya since little ice age: dendroclimatic implications. **In**: *Proceedings of Technology in support of snow and avalanche research*.

Papanicolaou, A.N. and Abaci, O. 2008. Upland erosion modelling in a semi-humid environment via the water erosion prediction project model. *Journal of Irrigation and Drainage Engineering* **134**(6): 796-806.

Park, R.A. 1999b. Validation of AQUATOX 1.68 for Predicting Bioaccumulation of PCBs in the Lake Ontario Food Web. **In**: *AQUATOX for Windows: A Modular Fate and Effects Model for Aquatic Ecosystems Users Manual* (U.S. EPA) **1**: 3-27.

Partal, T. and Kahya, E. 2006. Trend analysis in Turkish precipitation data. *Hydrological processes* **20**: 2011-2026.

Pavanelli, D. and Bigi, A. 2004. Indirect analysis method to estimate suspended sediment concentration: reliability and relationship of turbidity and settleable solids. *Biosystems Engineering* **3**: 45-53.

Pekarova, P. and Pekar, J. 1996. The impact of land use on stream water quality in Slovakia. *Journal of Hydrology* **180** (1–4): 333–350.

Perie, C. and Ouimet, R. 2008. Organic carbon, organic matter and bulk density relationships in boreal forest soils. *Canadian Journal of Soil Science* **88**: 315-325.

Peterson, J.R. and Hamlet, J.M. 1998. Hydrologic calibration of the SWAT model in a watershed containing fragipan soils. *Journal of American Water Resources Association* **34**(3): 531-544.

Petit, C.C. and Lambin, E.F. 2001. Integration of multi-source remote data for land cover change detection. *International Journal of Geographical Information Science* **15**(8): 785-803.

Petrosillo, I., Muller, F., Jones, K.B., Zurlini, G., Krauze, K., Victorov, S., Li, B.L., Kepner, W.G. 2008. Use of landscape sciences for the assessment of environmental security. NATO Security through Science Series, Springer. The Netherlands. ISBN 978-1-4020-6588-0.

Pietri, A.J.C. and Brookes, P.C. 2008. Relationships between soil pH and microbial properties in a UK arable soil. *Soil Biology and Biochemistry* **40**: 1856–1861.

Pijanowski, B.C., Brown, D.G., Shellito, B.A. and Manik, G. 2002. Using neural networks and GIS to forecast land use changes: A land transformation model. *Computers, Environment and Urban Systems* **26**(6): 553-575.

Piper, C.S. 1966. *Soil and Plant Analysis*. Hans Publishers, Bombay, India. pp.646.

Pizzuto, J. 2009. An empirical model of event scale cohesive bank profile evolution. *Earth Surface Processes and Landforms* **34**(9): 1234-1244.

Poelmans, L. and Rompaey, A. 2010. Complexity and performance of urban expansion models. *Computers, Environment and Urban Systems* **34**(1): 17-27.

Post, W.M. and Kwon, K.C. 2000. Soil carbon sequestration and land-use change: processes and potential. *Global Change Biology* **6**: 317–328.

Prabaharan, S., Srinivasa, R.K., Lakshumanan, C. and Ramalingam, M. 2010. Remote sensing and GIS applications on change detection study in coastal zone using multi temporal satellite data. *International Journal of Geomatics and Geosciences* **1**(2): 159-166.

Prakasam, C. 2010. Land use and land cover change detection through remote sensing approach: A case study of Kodaikanal taluk, Tamil Nadu. *International Journal of Geomatics and Geosciences* **1**(2): 150-159.

Prasad, S.N. and Pattaniak, C. 2007. Role of geoinformatics and free and open source ICT tools in wetland research, inventory and management for the sustainable development in India. **In**: *National Conference on Wetlands, Science and Society- An Assessment of their Integration*. DUBS, Delhi. pp. 43-44.

Prasanna, P.R. and Kumar, M.M. 2008. Watershed modelling for Kundapallam watershed using remote sensing and GIS. **In**: *Map India 2008: 11th Annual International Conference on Geospatial Information Technology and Applications* pp.3-7.

Prenzel, B. 2004. Remote sensing-based quantification of land-cover and land-use change for planning. *Progress in Planning* **61**: 281- 299.

Prosser, I.P., Rutherford, I.D., Olley, J.M., Young, W.J., Wallbrink, P.J., and Moran, C.J. 2001. Large-scale patterns of erosion and sediment transport in river networks, with examples from Australia. *Marine and Freshwater Research* **52**: 81-99.

Putty, M.R.Y. and Prasad, R. 2000. Understanding runoff processes using a watershed model—A case study in the Western Ghats in South India. *Journal of Hydrology* **228** (3-4): 215-227.

Qian, W. and Zhu, Y. 2001. Climate change in China from 1880 to 1998 and its impact on the environmental condition. *Climatic Change* **50**: 419–444.

Qian, W., Kang H.S. and Lee, D.K. 2002. Distribution of seasonal rainfall in the East Asian monsoon region. *Theoretical and Applied Climatology* **71**: 151–168.

Quilbe, R., Rousseau, A.N., Moquet, J.S., Savary, S., Ricard, S. and Garbouj, M.S. 2008. Hydrological response of a watershed to historical land use evolution and future land use scenario under climate change conditions. *Hydrology and Earth System Science* **12**: 101-110.

Ram, B. and Kolarkar, A.S. 1993. Remote sensing application in monitoring land use changes in arid Rajasthan. *International Journal of Remote Sensing* **14**(17): 3191-3200.

Ram, J. and Singh, S.P. 1994. Ecology and conservation of alpine meadows in Central Himalaya, India. **In**: *High Altitudes of the Himalaya* (Eds. Y.P.S. Pangtey and R.S. Rawal). Gyanodya Prakashan Nainital.

Ramachandra, T.V. and Kumar, U. 2004. Geographic resources decision support system for land use, land cover dynamics analysis. *Proceedings of the FOSS/GRASS Users Conference*. Bangkok, Thailand.

Ramachandran, S., Sundaramoorthy, S., Krishnamoorthy, R., Devasenapathi, J. and Thanikachalam, M. 1998. Applications of remote sensing and GIS to coastal wetland ecology of Tamil Nadu and Andaman and Nicobar Islands with special reference to mangroves. *Current Science* **75**(3): 236-244.

Ramchandra, T.V. 2001. Restoration and management strategies of wetlands in developing countries. *Electronic Green Journal* **15**: 1-17.

Ramsey, E.W. and Laine, S.C. 1997. Comparison of Landsat Thematic Mapper and high resolution aerial photography to indentify change in complex coastal wetlands. *Journal of Coastal Research* **13**: 281-292.

Rani, R., Gupta, B.K. and Srivastava, K.B.L. 2004. Studies on water quality assessment in Satna city (M.P.): Seasonal parametric variations. *National Environment Pollution Technology.* **3**(4): 563-565.

Ravinder, K. and Pandit, A.K. 2005. Community architecture of macrophytes in Hokersar wetland, Kashmir. *Indian Journal of Environment and Ecoplan* **10** (3): 565-573.

Raza, M., Ahmad, A. and Mohammad, A. 1978. *The Valley of Kashmir—A Geographical Interpretation, The Land*. Vikas Publishing House Pvt. Ltd., New Delhi. Vol. I. pp.167.

Rebetez, M. 2004. Summer 2003 maximum and minimum daily temperature over a 3,300 m altitudinal range in the Alps. *Climate Research* **27**: 45–50.

Reif, M., Frohn, C.R., Lane, C.R., and Autrey, B. 2009. Mapping isolated wetlands in a karst landscape: GIS and remote sensing methods. *GIScience and Remote Sensing* **46**: 187-211.

Reis, S. 2008. Analyzing land use / land cover changes using remote sensing and GIS in Rize, North-East Turkey. *Sensors* **8**: 6188-6202.

Ren, L., Wang, M., Li, C. and Zhang, W. 2002. Impact of human activity on river runoff in the northern area of China. *Journal of Hydrology* **261**: 204–217.

Richter, R. 1990. A fast atmospheric correction algorithm applied to Landsat TM images. *International Journal of Remote Sensing* **11**: 159–166.

Riddhi, S., Vipul, S., Sudan, S.M., Kumar, V.B., Rachana, M. and Singh, G.K. 2011. Studies on limnological characteristic, planktonic diversity and fishes (species) in Lake Pichhola, Udaipur, Rajasthan (India). *Universal Journal of Environmental Research and Technology* **1** (3): 274-285.

Ritchie, J.C. and Cooper, C.M. 1991. An algorithm for estimation of surface suspended sediment concentrations with Landsat MSS digital data. *Water Resources Bulletin* **27**(3): 373-379.

Roberts, G. 1998. The effects of possible future climate change on evaporation losses from four contrasting UK water catchment areas. *Hydrological Processes* **12**: 727-739.

Robertson, A.I., Bacon, P. and Heagrey, G. 1999. Responses of flood-plain primary production to floods of different frequency and seasonal timming. *Journal of Applied Ecology* **38**: 126-136.

Roeck, E.R.D., Verhoest, N.E.C., Miya, M.H., Lievens, H., Betalaan, O., Thomas, A. and Brendonck, L. 2008. Remote sensing and wetland ecology: A South African Case Study. *Sensors* **8**: 3542-3556.

Rogana J. and Chen, D. 2004. Remote sensing technology for mapping and monitoring land-cover and land-use change. *Progress in Planning* **61**: 301 325.

Romshoo, S.A. and Muslim, M. 2011. Geospatial modelling for assessing the nutrient load of a Himalayan lake. *Environmental Earth Sciences* **64** (5): 1269-1282.

Romshoo, S.A., Ali, N. and Rashid, I. 2011. Geoinformatics for characterizing and understanding the spatio-temporal dynamics (1969 to 2008) of Hokersar wetland in Kashmir Himalayas. *International Journal of the Physical Sciences* **6**(5): 1026-1038.

Rosenfield, G.H. and Fitzpatrick-Lins, K. 1986. A coefficient of agreement as a measure of thematic classification accuracy. *Photogrammetric Engineering and Remote Sensing* **52**(2): 223-227.

Rosenthal, W.D. and Hipp B.W. 1993. Field and model estimates of pesticide runoff from turf grass. **In**: *Pesticides in Urban Environment* (Eds. D.R. Kenneth and A.R. Leslie). American Chemical Society, Vol. 522. pp. 208-213.

Sabiene, N., Kusliene, G. and Zaleckas, E. 2010. The influence of land use on soil organic carbon and nitrogen content and redox potential. *Zemdirbyste-Agriculture* **97**(3): 15-24.

Sahu, G.C., Patniak, S.N. and Dass, P.K. 1990. Morphology, genesis, mineralogy and classification of soils of northern plateau zone-Orissa. *Journal of the Indian Society of Soil Science* **38**: 116-121.

Saleh, A. and Du, B. 2004. Evaluation of SWAT and HSPF within BASINS program for the Upper North Bosque River Watershed in Central Texas. *Transactions of the American Society of Agricultural Engineers* **47**: 1039-1049.

Salinger, M.J. 2005. Guest editorial, increasing climate variability and change: reducing the vulnerability. *Climate Change* **70**: 1-3.

Saloom, M.E. and Duncan, R.S. 2005. Low dissolved oxygen levels reduce anti-predator behaviours of the fresh water Clam *Corbicula fluminea*. *Fresh Water Biology* **50**: 1233-1238.

Samuels, W. 1998. Case studies: Solving watershed-based problems through the use of GIS, Internet and EPA national data bases. **In:** *Watershed Management: Moving from Theory to Implementation.* Water Environment Federation, Denver, CO. pp. 1175-1182.

Sangchan, L. 2000. Land use/land cover change study in the Eastern Region of Thailand using remote sensing and GIS technology. GIS development>Proceedings> ACRS>2000. www.GISdevelopment.net.

Santhi, C., Arnold, J.G., Williams, J.R., Dugas, W.A., Srinivasan, R. and Hauck, L.M. 2001b. Validation of the SWAT model on a large river basin with point and nonpoint sources. *Journal of American Water Resources Association* **37**: 1169-1188.

Sarkar, A. and Jain, S.K. 2008. Using remote sensing data to study wetland dynamics-A Case Study of Harike Wetland. **In**: *Proceedings of TAAL: The 12th World Lake Conference* (Eds. M. Sengupta and R. Dalwani) pp. 680-684.

Sartor, J.D. and Boyd, G.B. 1972. Water pollution aspects of street surface contaminants. EPA-R2/72-081. U.S Environmental Protection Agency, Washington DC.

Sarwar, S.G. 1999. Water quality and periphytic algal component of Anchar Lake, Kashmir. **In**: *Inland Water Resources, India* (Eds. M.K. Durga Prasad and P. Sankara). Discovery Publishing House, New Delhi. pp. 237-250.

Sarwar, S.G. and Zutshi, D.P. 1987. Studies on periphyton populations of Himalayan lakes. I. Species composition and community structure on natural and artificial substrates. *Proceedings of the Indian National Science Academy* **B53**: 239-243.

Sarwar, S.G. and Zutshi, D.P. 1989. Periphytic algal flora of *Phragmites communis* Trin. *Journal of the Indian Botanical Society* **69**: 275-283.

Savabi, M.R., Flanagan, D.C., Hebel, B. and Engel, B.A. 1995. Application of WEPP and GIS-GRASS to a small watershed in Indiana. *Journal of Soil and Water Conservation* **50**(5): 477-483.

Sawane, A.P., Puranik, P.G. and Bhate, A.M. 2006. Impact of industrial pollution on river Irai, district Chandrapur with reference to fluctuation in CO_2 and pH. *Journal of Aquatic Biology* **21**(1): 105-110.

Schilling, K.E. and Wolter, C.F. 2000. Application of GPS and GIS to map channel features in Walnut Creek, Iowa. *Journal of the American Water Resources Association* **36**(6): 1423-1434.

Schindlbacher, A., Gonzalo, C., Diaz-Pines, E., Gorria, P., Matthews, B., Inclan, R., Zechmeister-Boltenstern, S., Rubio, A. and Jandl, R. 2010. Temperature sensitivity of forest soil organic matter decomposition along two elevation gradients. *Journal of Geophysical Research* **115**: 1-10.

Schmidt, A., Stringer, C.E., Haferkorn U. and Schubert, M. 2009. Quantification of groundwater discharge into lakes using radon-222 as naturally occurring tracer. *Environmental Geology* **56**: 855-863.

Schneiderman, E., Jarvinen, M., Jennings, E., May, L., Moore, K., Naden, P.S. and Pierson, D. 2010. Modelling the effects of climate change on catchment hydrology with the GWLF model. **In**: *The Impact of Climate Change on European Lakes* (Ed. D.G. George). Aquatic Ecology Series, Volume 4. Springer Sciences, Business Media Dordrecht. pp.33-50.

Schroeder, R., Rawlins, M.A., McDonald, K.C., Podest, E., Zimmermann, R. and Kueppers, M. 2010. Satellite microwave remote sensing of North Eurasian inundation dynamics: development of coarse resolution products and comparison with high resolution Synthetic Aperture Radar data. *Environmental Research Letters* **5**(1): 15-30.

Schuijt, K. 2002. Land and Water Use of Wetlands in Africa: Economic Values of African Wetlands. International Institute for Applied System Analysis, Interim Report. pp. 21-22.

Schwab, G.O., Frevert, R.K., Edminster, T.W. and Barnes, K.K. 1981. *Soil and Water Conservation Engineering*. 3rd ed. New York, John Wiley and Sons. pp.525.

Scott, D.A. and Poole, C.M. 1989. *A Status Overview of Asian Wetlands*. Asian Wetland Bureau. Publication No. 53. AWB, Kaulalumpur, Malaysia.

Scott, J.M.F., Davis, B., Csuti, R., Noss, B., Butterfield, C., Groves, H., Anderson, S., Caicco, F., D'Erchia, T.C., Edwards, Jr., Ulliman, J. and Wright, R.G. 1993. Gap Analysis: a geographical approach to protection of biological diversity. *Wildlife Monographs*. p. 123.

Sculthorpe, C.D. 1967. Biology of Aquatic Vascular Plants. Edward Arnold Pub. Ltd, London. pp.610.

Seko, K. and Takahashi, S. 1991. Characteristics of winter precipitation and its effects on glaciers in Nepal Himalaya. *Bull Glacier Research* **9**: 9–16.

Senjobi, B.A. and Ogunkunle, A.O. 2011. Effect of different land use types and their implications on land degradation and productivity in Ogun State, Nigeria. *Journal of Agricultural Biotechnology and Sustainable Development* **3**(1): 7-18.

Seto, K.C., Woodcock, C.E., Song, C., Huang, X., Lu, J. and Kaufmann, R.K. 2002. Monitoring land use change in the Pearl River Delta using Landsat TM. *International Journal of Remote Sensing* **23**(10): 1985-2004.

Shafique, N.A., Autrey, B.C., Fulk, F. and Cormier, S.M. 2001. Hyperspectral narrow wave bands selection for optimizing water quality monitoring on the Great Miami River, Ohio. *Journal of Spatial Hydrology* **1**(1): 1-22.

Shah, A.W., Parveen, M., Mir, S.H., Sarwar, S.G. and Yousuf, A.R. 2009. Impact of helminth parasitism on fish haematology of Anchar Lake, Kashmir. *Pakistan Journal of Nutrition* **8**(1): 42-45.

Shah, S.A. and Bhat, G.A. 2004. Land use pattern in Dal-Dachigam catchment. *Journal of Research and Development* **4**: 21-33.

Shaikh, M., Green, D. and Cross, H. 2001. A remote sensing approach to determine environmental flows for wetlands of the Lower Darling River, New South Wales, Australia. *International Journal of Remote sensing* **22**(9): 1737-1751.

Shalaby, A. and Tateishi, R. 2007. Remote sensing and GIS for mapping and monitoring land cover and land-use changes in the northwestern coastal zone of Egypt. *Applied Geography* **27** (1): 28-41.

Sharma, K.D., Nepal, S.S. and Bohra, D.N. 1989. Satellite remote sensing for detecting temporal changes in the grazing lands. *Journal of the Indian Society of Remote Sensing* **4**: 55-59.

Sharma, K.P., Moore, B. III and Vorosmarty, C.J. 2000. Anthropogenic, climatic and hydrologic trends in the Kosi Basin, Himalaya. *Climate Change* **47**: 141–165.

Sharma, R., Sharma V., Malera, H. and Sharma, M.S. 2009. Study of microbiology of Udaipur Lakes in relation to different limnological parameter. *Pollution Research* **28**(4): 565-569.

Sharma, R. and Capoor, A. 2010. Seasonal variations in physical, chemical and biological parameters of lake water of Patna bird sanctuary in relation to fish productivity. *World Applied Sciences Journal* **8** (1): 129-132.

Sharma, R.R. and Biswas, D.N.R. 1972. Erodibility of hill soils of Sutlej catchment area in Himachal Pradesh. *Journal of Indian Society of Soil Science* **42** (2): 161-169.

Sharpley, A.N. 1993. Assessing phosphorus bio-availability in agricultural soils and runoff. *Fertilizer Research* **36**(3): 259–272.

Sharpley A.N., Gburek, W. and Heathwaite, A.L. 1998. Agricultural phosphorus and water quality: sources, transport and management. *Agricultural and Food Science in Finland* **7**(2): 297–314.

Shaw, J.F.H. and Prepas, E.E. 1989a. Temporal and spatial patterns of pore water phosphorus and its potential transport into Narrow Lake, Alberta. *Cannadian Journal of Fisheries and Aquatic Science* **46**: 981-988.

Shepherd, I., Wilkinson, G. and Thompson, J. 2000. Monitoring surface water storage in the North Kent marshes using Landsat TM images. *International Journal of Remote sensing* **21**(9): 1843-1865.

Siddiqi, S.Z. 2008. Limnological profile of high-impact meteor crater Lake Lonar, Buldana, Maharashtra, India, an extreme hyperalkaline, saline habitat. *Proceedings of TAAL 2007: The 12th World Lake Conference* 1597-1613.

Singh, A. 1989. Digital change detection techniques using remotely-sensed data. *International Journal of Remote Sensing* **10**: 989–1003.

Singh, G.R. and Prakash, O. 1985. Characteristics and erodibility of some hill soils in Uttar Pradesh under varying land use, slope and terracing conditions. *Journal of the Indian Society of Soil Science* **33**: 858-864.

Singh, J.S. and Kashyap, A.K. 2007. Variations in soil N-mineralization and nitrification in seasonally dry tropical forest and savanna ecosystems in Vindhyan region, India. *Tropical Ecology* **48**(1): 27-35.

Singh, R.N. 2006. Sensing diversifies into remote sensing. *Journal of Indian Society of Remote Sensing* **34**(4): 436-452.

Singh, V.P. and Woolhiser, D.A. 2002. Mathematical modelling of watershed hydrology. *Journal of Hydrologic Engineering* **7**(4): 270-292.

Siraj, S., Yousuf, A.R., Bhat, F.A. and Parveen, M. 2010. The ecology of macrozoobenthos in Shallabugh wetland of Kashmir Himalaya, India. *Journal of Ecology and the Natural Environment* **2**(5): 84-91.

Smart, R.P., Soulsby, C., Neal, C., Wade, A., Cresser, M.S., Billett, M.F., Langan, S.J., Edwards, A.C., Jarvie, H.P. and Owen, R., 1998. Factors regulating the spatial and temporal distribution of solute concentrations in a major river system in NE Scotland. *The Science of the Total Environment* **221**(2–3): 93–110.

Smith, V.H. 2003. Eutrophication of freshwater and coastal marine ecosystems: A global problem. *Environmental Science and Pollution Research* **10**: 126-139.

Smith, V.H., Tilman, G.D. and Nekola, J.C. 1999. Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. *Environmental Pollution* **100**(1–3): 179–196.

Sobota, D.J., Harrison, J.A. and Dahlgren, R.A. 2009. Influences of climate, hydrology, and land use on input and export of nitrogen in California watersheds. *Biogeochemistry* **94**: 43-62.

Soil Conservation Service, 1986. Urban Hydrology for Small Watersheds. U.S. Department of Agriculture, Soil Conservation Service, Engineering Division. Technical Release 55. pp.162.

Solim, S. and Wanganeo, A. 2008. Excessive phosphorus loading to Dal Lake, India:

implications for managing shallow eutrophic lakes in urbanized watersheds. *International Review of Hydrobiology* **93(**2): 148 – 166.

Song, C., Woodcock, C.E., Seto, K.C., Lenney, M. and Macomber, S.A. 2001. Classification and change detection using Landsat TM data: when and how to correct atmospheric effects? *Remote Sensing of Environment* **75**: 230–244.

Soundarapandian, P., Premkumar, T. and Dinakaran, G.K. 2009. Studies on the physico-chemical characteristics and nutrients in the Uppanar estuary of Cuddalore, Southeast coast of India. *Current Research Journal of Biological Sciences* **1**(3): 102-105.

Sparks, D.L. 1995. Environmental Soil Chemistry. Academic Press, San Diego. pp.352.

Spence, D.H.N. 1967. The zonation of plants in fresh water lakes. *Advances in Ecological Research* **12**: 37-125.

Sreenivasan, A. 1965. Limnology and productivity of tropical impoundment Amravali Reservoir, Madras State, South India. *Hydrobiologia* **26**: 501-516.

Srinivasan, R. and Arnold, J.G. 1994. Integration of a basin-scale water quality model with GIS. *Journal of the American Water Resources Association* **30**(3): 453–462.

Srinivasan, R. and Engel, B.A. 1994. A spatial decision support system for assessing agricultural nonpoint source pollution. *Water Resources Bulletin* **30**(3): 441-452.

Star, J.L., Estes, J.E. and McGwire, K.C. 1997. *Integration of Geographic Information Systems and remote Sensing*. New York, NY: Cambridge University Press.

Stevenson, F.J. and Cole, M.A. 1999. *Cycles of Soil*. 2nd Edition. Wiley, New York. pp.427.

Steward, B.A., Woolhiser, D.A., Wischmeir, W.H., Carol, J.H. and Frere, M.H. 1975. Control of water pollution from cropland. US Environmental Protection Agency. Washington.

Strayer, D.L., Beighley, R.E., Thompson, L.C., Brooks, S., Nilsson, C., Pinay, G. and Naiman, R.J. 2003. Effects of land cover on stream ecosystems: roles of empirical models and scaling issues. *Ecosystems* **6**: 407–423.

Strobl, R.O. 2002. Water Quality Monitoring Network Design Methodology for the Identification of Critical Sampling Points. Ph.D. Thesis. Department of Agriculture and Biological Engineering. The Pennsylvania State University, Pennsylvania. pp.343.

Strobl, R.O., Forte, F. and Pennetta, L. 2007. Application of artificial neural networks for classifying lake eutrophication status. *Lakes and Reservoirs Research and Management* (Australia) **12**: 15-25.

Strobl, R.O., Somma, F., Evans, B.M. and Zaldivar, J.M. 2009. Fluxes of water and nutrients from river runoff to the Mediterranean Sea using GIS and a watershed model. *Journal of Geophysical Research* **114**: 1-14.

Subbiah, B.V. and Asija, H.L. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Current Science* **25**: 259-260.

Sudhira, H.S. and Kumar, V.S. 2000. Monitoring of lake water quality in Mysore City. *International Symposium on Restoration of Lakes and Wetlands: Proceedings of Lake.* 1-10.

Sudhira, H.S., Ramachandra, T.V. and Jagadish, K.S. 2004. Urban sprawl: metrics, dynamics and modelling using GIS. *International Journal of Applied Earth Observation and Geoinformation* **5**: 29-39.

Suhadolc, M., Dorfler, U., Lobnik, F. and Schroll, R. 2007. Glyphosphate degradation in an alluvial soil amended with sewage sludge. **In**: *Environmental Fate and Ecological Effects of Pesticides*. pp.146-151.

Sultan, B.M. and Shafi, B.M. 2007. Nature and magnitude of climatic change in Kashmir valley: A Spatio-temporal analysis of temperature and precipitation. *Annals of the National Association of Geographers* **27**(1): 48-59.

Sultan, S., Chauhan, M. and Sharma, V.I. 2003. Physico-chemical status and primary productivity of Pahunj reservoir, Uttar Pradesh. *J. Inland Fish. Soc. India* **35**: 73-80.

Sumitra, M., Sharma, R., Sharma V. and Sharma, M.S. 2007. Trophic status of Lake Pichhola in relation to physico-chemical characteristics of its water. *National Symposium on Limnology* 244-248.

Swami, B.S., Suryawanshi, U.G. and Karande, A.A. 2000. Water quality status of Mumbai harbour - an update. *Indian Journal of Marine Science* **29**: 111-115.

Swaney, D.P., Sherman, D. and Howarth, R.W. 1996. Modelling water, sediment and organic carbon discharges in the Hudson-Mohawk Basin: Coupling to terrestrial sources. *Estuaries* **4**: 833-847.

Symoens, J.J. (Ed.) 1988. *Vegetation of Inland Waters.* Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 404.

Tadesse, W., Tsegaye, T.D. and Coleman, T.L. 2001. Land use/cover change detection of the city of Addis Ababa, Ethiopia using remote sensing and Geographic Information System technology. **In:** *Proceedings of the Geosciences and Remote Sensing Symposium, 2001 IGARSS International* **1**: 462 – 464.

Talib, A.R. and Verma, S.D. 1990. Relationship between different forms of potassium and particle size in bench mark soils of Kashmir. *Indian Journal of Agricultural Sciences* **60**(9): 643-644.

Tang, Z., Engel, B.A., Pijanowski, B.C. and Lim, K.J. 2005. Forecasting land use change and its environmental impact at a watershed level. *Journal of Environmental Management* **76**: 35-45.

Taramelli, A., Reichenbach, P. and Ardizzone, F. 2008. Comparison of SRTM elevation data with cartographically derived DEMs in Italy. *Review Geogr. Academica* **2**: 41-52.

Taubenbock, H., Wegmann, M., Roth, A., Mehl, H. and Dech, S. 2008. Urbanization in India- spatio-temporal analysis using remote sensing data. *Journal of Computers, Environment and Urban Systems* **33**(3): 179-188.

Teferi, E., Uhlenbrook, S., Bewket, W., Wenninger, J. and Simane, B. 2010. The use of remote sensing to quantify wetland loss in the Choke Mountain Range, Upper Blue Nile basin, Ethiopia. *Hydrology and Earth System Sciences Discussions* **7**: 6243-6284.

Thapliyal, V. and Kulshrestha, S.M. 1991. Decadal changes and trends over India. *Mausam* **42**: 333–338.

Thiemann, S. and Kaufmann, H. 2000. Determination of Chlorophyll content and trophic state of lakes using field spectrometer and IRS-IC satellite data in the

Mecklenburg Lake District, Germany. *Remote Sensing of Environment* **73**: 277-235.

Thoma, D.P., Gupta, S.C., Bauer, M.E. and Kirchoff, C.E. 2005. Airborne laser scanning for riverbank erosion assessment. *Remote Sensing of Environment* **95**(4): 493-501.

Thompson, L.G., Yao, T., Mosley-Thompson, E., Davis, M.E., Henderson, K.A. and Lin, P.N. 2000. A high-resolution millennial record of the South Asian monsoon from Himalayan ice cores. *Science* **289**: 16–19.

Thuman, O.E., Andrew and Rees, T.A. 2003. Watershed and water quality modelling. Analytical report, Triad Engineering Incorporated, Indianapolis, Indaina. 46219.

Tim, U.S. and Jolly, R.1994. Evaluating agricultural non-point source pollution using integrated Geographic Information-Systems and Hydrologic/Water Quality Model. *Journal of Environmental Quality* **23**(1): 25-35.

Tim, U.S., Mostaghimi, S. and Shanholtz, V.O. 1992. Identification of critical non-point pollution source areas using Geographic Information Systems and Water Quality Modelling. *Water Resources Bulletin* **28**(5): 877-887.

Tiner, R.W.J. 1991. The concept of a hydrophyte for wetland identification. *Bioscience* **41**: 236-247.

Titshall, L.W., Connor, T.G. and Morris, C.D. 2000. Effect of long-term exclusion of fire and herbivory on the soils and vegetation of sour grassland. *African Journal of Range and Forage Science* **17**: 70–80.

Tockner, K., Pennetz, D., Reimer, N., Schiemer, F. and Ward, J.V. 1999. Hydrological connectivity and exchange of organic matter and nutrients in a dynamic flood-plain system. *Fresh Water Biology* **41**: 521-536.

Tong, S.T.Y. and Chen, W. 2002. Modelling the relationship between land use and surface water quality. *Journal of Environmental Management* **66**: 377- 393.

Tong, S.T.Y., Liu, A.J. and Goodrich, J.A. 2008. Assessing the water quality impacts of future land-use changes in an urbanizing watershed. *Civil Engineering and Environmental Systems*. www.informaworld.com.

Touzi, R., Deschamps, A. and Rother, G. 2007. Wetland characterization using polarimetric RADARSAT-2 capability. *Canadian Journal of Remote*

Sensing **33**: S56-S67.

Toyra, I., Pietroniro, A. and Martz, L.W. 2001. Multisensor hydrologic assessment of a freshwater wetland. *Remote Sensing of Environment* **75**: 162-173.

Turkes, M. 1996. Spatial and temporal analysis of annual rainfall variations in Turkey. *International Journal of Climatology* **16**: 1057–1076.

Turner II, B.L. and Butzer, K.W. 1992. The Colombian encounter and land-use change. *Environment* p. 16.

Turner, R.E. and Rabalais, N.N. 2003. Linking landscape and water quality in the Mississippi River Basin for 200 years. *BioScience* **53** (6): 563–572.

Ulbricht, K.A. and Heckendorf, W.D. 1998. Satellite images for recognition of landscape and land use changes. *ISPRS Journal of Photogrammetry and Remote Sensing* **53**: 235-243.

Ullah, S., Frasier, R., Pelletier, L. and Moore, T.R. 2009. Greenhouse gas fluxes from boreal forest soils during the snow-free period, Quebec. *Canadian Journal of Forest Research* **39***:* 666-660.

Upadhayay, B.L. and Dwivedi, D.D. 2006. Impact of human activities on physicochemical characteristics of Mansi Ganga water at Goverdhan (Mathura). *Himalayan Journal of Environment and Zoology* **20**(1): 131-133.

Upadhyay, K., Mishra, P. and Gupta, A.K. 2010. Studies on the physico-chemical status of two ponds at Varanasi and Bhadohi under biotic stress. *Plant Archives* **10** (2): 691-693.

USEPA 1997a. Compendium of Tools for Watershed Assessment and TMDL Development. *EPA841-B-97-006.* Office of Water, United States Environmental Protection Agency, Washington, D.C. pp. 118.

USEPA 1999b. Protocol for Developing Nutrient TMDLs. *EPA 841-B-99-007*. Office of Water, United States Environmental Protection Agency, Washington, D.C. pp. 135.

Valk, A.G., Davis, C.B., Baker, J.L. and Beer, C.E. 1979. Natural fresh water wetlands as nitrogen and phosphorus traps for land runoff. **In**: *Wetland Functions and Values: The State of Our Understanding.* (Ed. P.E. Greeson). American Water Resources Association, Minneapolis, MN. pp. 457-467.

Vanoni, V.A. 1975. Sediment Engineering. American Society of Civil Engineers, New York.

Velazquez, A., Durana, E., Ramirez, I., Mas, J.F., Bocco, G., Ramirez, G. and Palacio, J.L. 2003. Land use-cover change processes in highly biodiverse areas: The case of Oaxaca, Mexico. *Global Environmental Change* **13**: 175–184.

Ventura, F., Rossi Pisa, P. and Ardizzoni, E. 2002. Temperature and precipitation trends in Bologna (Italy) from 1952 to 1999. *Atmospheric Research* **61**: 203-214.

Veregin, H. 1995. Developing and testing of an error propagation model for GIS overlay operations. *International Journal of Geographical Information Systems* **9**(6): 595-619.

Verma, A. and De, S.K. 1969. Erosion of Uttar Pradesh soils by water and its relation to soil properties. *Journal of Soil and Water Conservation of India* **17**(2&4): 40-49.

Verma, K.S., Shyampura, R.L. and Jain, S.P. 1990. Characterization of soils under forests of Kashmir Valley. *Journal of the Indian Society of Soil Science* **38**: 107-115.

Villaba, R., Lara, A., Boninsegna, J.A., Masiokas, M., Delgado, S., Aravena, J.C., Roig, F.A., Schmelter, A., Wolodarsky, A. and Ripalta, A. 2003. Large-scale temporal changes across the southern Andes: 20th century variations in the context of the past 400 years. *Climate Change* **59**: 177–232.

Vinnikov, K., Graisman, P.Y. and Lugina, K.M. 1990. Empirical data on contemporary global climatic changes (Temperature and precipitation). *Journal of Climate* **3**: 662–677.

Vohra, C.P. 1981. Himalayan Glaciers. **In**: *The Himalaya: Aspects of Change* (Eds. J.S. Lall and A.D. Modi). Oxford University Press, Delhi. pp.138-151.

Vollenweider, R.A. 1976. Advances in defining critical loading levels for phosphorus in lake eutrophication. *Memorie dell'Istituto Italiano di Idrobiologia Marco de Marchi* **33**: 53-83.

Vuille, M., Bradley, R.S., Werner, M. and Keimig, F. 2003. 20th century climate change in the tropical Andes: observations and model results. *Climate Change* **59**: 75–99.

Walkley, A. and Black, C.A. 1934. An examination of the Degljareff method for determination of soil organic matter and a proposed modification of the Chromic Acid Titration method. *Soil Science* **37**: 29-39.

Wani, M.A. 2000. Effect of sulphur fertilization on soil properties and fractions of sulphur in calcareous soil of central Kashmir. *Applied Biological Research* **2**: 101-105.

Wani, M.A., Wani, J.A. and Bhat, M.A. 2009. Potassium forms, their interrelationships and relations with soil properties in rice soils of lesser Himalayas. *SKUAST Journal of Research* **11**: 1-7.

Welch, P.S. 1952. Limnology. McGraw Hill, New York.

Werdell, P.J. and Bailey, S.W. 2005. An improved in-situ bio-optical dataset for ocean color algorithm development and satellite data product validation. *Remote Sensing of Environment* **98** (1): 122-140.

Wetzel, R.G. 2001. *Limnology: Lake and River Ecosystems*. San Diego: Academic Press. 1006pp.

Wetzel, R.G. and Likens, G.E. 2000. *Limnological Analyses.* Springer-Verlag, New York. pp. 429.

White, K.L. and Chaubey, I. 2005. Sensitivity Analysis, Calibration, and Validation for a Multisite and Multivariable SWAT Model. *Journal of the American Water Resources Association* **41**: 1077-1089.

Wibig, J. and Glowicki, B. 2002. Trends in minimum and maximum temperature in Poland. *Climate Research* **20**: 123–133.

Wilson, J.P. 1996. GIS-based land surface/subsurface modelling: new potential for new models. **In:** *Proceedings of 3rd International Conference/Workshop on Integrated Geographic Information Systems and Environmental Modelling*. Santa Fe, NM.

Winter, T.C. 2000. The vulnerability of wetlands to climate change: A hydrological landscape perspective. *Journal of American Water Resources Association*

36: 305-311.

Wischmeier, W.H. and Smith, D.D. 1978. Predicting Rainfall-Erosion Losses: A Guide to Conservation Planning. Agriculture Handbook No. 537. US, Department of Agriculture, Washington, D.C.

Wu, Q., Li, H.Q., Wang, R.S., Paulussen, J., He, H., Wang, M., Wang, B.H. and Wang, Z. 2006. Monitoring and predicting land use change in Beijing using remote sensing and GIS. *Landscape and Urban Planning* **78**: 322–333.

Wu, W. and Shao, G. 2002. Optimal combinations of data, classifiers, and sampling methods for accurate characterizations of deforestation. *Canadian Journal of Remote Sensing* **28**(4): 601-609.

Wu, W., Hall, C.A.S. and Scatena, F.H. 2007. Modelling the impact of recent land-cover changes on the stream flows in Northeastern Puerto Rico. *Hydrological Processes* **21(**21): 2944-2956.

Wynn, T.M. and Mostaghimi, S. 2006. Effects of riparian vegetation on stream bank subaerial processes in southwestern Virginia, USA. *Earth Surface Processes and Landforms* **31**(4): 399-413.

Wynn, T.M., Henderson, M. and Vaughan, D. 2008. Changes in stream bank erodibility and critical shear stress due to subaerial processes along a headwater stream, southwestern Virginia, USA. *Geomorphology* **97**(3-4): 260-273.

Xu, C.Y. 2000. Modelling the effects of climate change on water resources in Central Sweden. *Water Resources Management* **14**: 177-189.

Xu, Z.X., Takeuchi, K. and Ishidaira, H. 2003. Monotonic trend and step changes in Japanese precipitation. *Journal of Hydrology* **279**: 144-150.

Yagow, G. 2004. Using GWLF for development of reference watershed approach TMDLs. *American Society of Agricultural and Biological Engineers* Paper No. 042262.

Yang, L., Xian, G., Klaver, J.M. and Deal, B. 2003. Urban land-use cover change detection through sub-pixel imperviousness mapping using remotely sensed data. *Photogrammetric Engineering and Remote Sensing* **69**(9): 1003–1010.

Yang, M.D., Merry, C.J. and Sykes, R.M. 1999. Integration of water quality modelling, remote sensing, and GIS. *Journal of the American Water Resources Association* **35**(2): 253–263.

Young, R.A., Onstad, C.A., Bosch, D.D. and Anderson, W.P. 1987. AGNPS, Agricultural Nonpoint Source Pollution Model: A Watershed Analysis Tool. Conservation Research Report No. 35, U.S. Department of Agriculture, Agricultural Research Service, Washington, D.C. pp.80.

Yuan, Y., Bingner, R.L. and Rebich, R.A. 2002. Application of AnnAGNPS for analysis of nitrogen loadings from a small agricultural watershed in the Mississippi, Delta. **In**: *Total Maximum Daily Load (TMDL) Environmental Regulations Conference.* American Society of Agricultural and Biological Engineers, ForthWorth, Texas, USA. pp. 268-279.

Yuan, Y., Locke, M.A. and Bingner, R.L. 2008. Annualized Agricultural Non-Point Source model application for Mississippi Delta Beasley Lake watershed conservation practices assessment. *Journal of Soil and Water Conservation* **63**(6): 542-551.

Zhang, X., Vincent, L.A., Hogg, W.D. and Niitsoo, A. 2000. Temperature and precipitation trends in Canada during the 20th century. *Atmospheric Ocean* **38**: 395–429.

Zhang, Y., Wang, Y., Wang, Y. and Xi, H. 2009. Investigating the impacts of Land Use-Land Cover (LULC) Change in the Pearl River Delta Region on water quality in the Pearl River Estuary and Hong Kong's Coast. *Remote Sensing* **1**: 1055-1064.

Zilioli, E. and Brivio, P.A. 1997. The satellite derived optical information for the comparative assessment of lacustrine water quality. *The Science of The Total Environment* **196**(3): 229-245.

Zingstra, H. and Wiseman, R. 2003. Foreword (Special Issue on Wetlands and Agriculture). *International Journal of Ecology and Environmental Science* **29**: 1-2.

Zsuzsanna, D., Bartholy, J., Pongracz, R. and Barcza, Z. 2005. Analysis of land-use/land-cover change in the Carpathian region based on remote sensing techniques. *Physics and Chemistry of Earth* **30**: 109-115.

Zutshi, D.P. 1975. Association of macrophytic vegetation in Kashmir lakes. *Vegetatio* **30**: 61-65.

Zutshi, D.P. and Gopal, B. 2000. State of biodiversity in lakes and wetlands of Kashmir valley. **In**: *Environmental, Biodiversity and Conservation* (Ed. M.A. Khan). A.P.H. Publ. Corp. New Delhi. pp. 51-68.

Zutshi, D.P. and Khan, M.A. 1978. On lake typology of Kashmir. **In**: *Environmental Physiology and Ecology of Plants* (Eds. D.N. Sen and R.P. Bansal). Bishen Singh Mahendrapal Singh, Dehra Dun, India. pp. 465-472.

Zutshi, D.P. and Vass, K.K. 1971. Ecology and production of *Salvinia natans* Hoffim. in Kashmir. *Hydrobiologia* **38**: 303-320.

Zutshi, D.P. and Vass, K.K. 1982. Limnological studies on Dal Lake, II- chemical features. *Indian Journal of Ecology* **5**: 90-97.

Zutshi, D.P. and Yousuf, A.R. 2000. Ecology and conservation of Dal Lake. Report prepared for AHEC, University of Roorkee, Roorkee. p. 105.

Zutshi, D.P., Subla, B.A., Khan, M.A. and Wanganeo, A. 1980. Comparative limnology of nine lakes of Jammu and Kashmir Himalayas. *Hydrobiologia* **72**: 101-112.

APPENDICES

Appendix 1
Error Matrix

		Reference Data				
		Class 1	**Class 2**	**Class 3**	**Class N**	**Row Total**
Classification Data	**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 Anchar catchment (adapted from SCS, 1986)

c) 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

c) 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

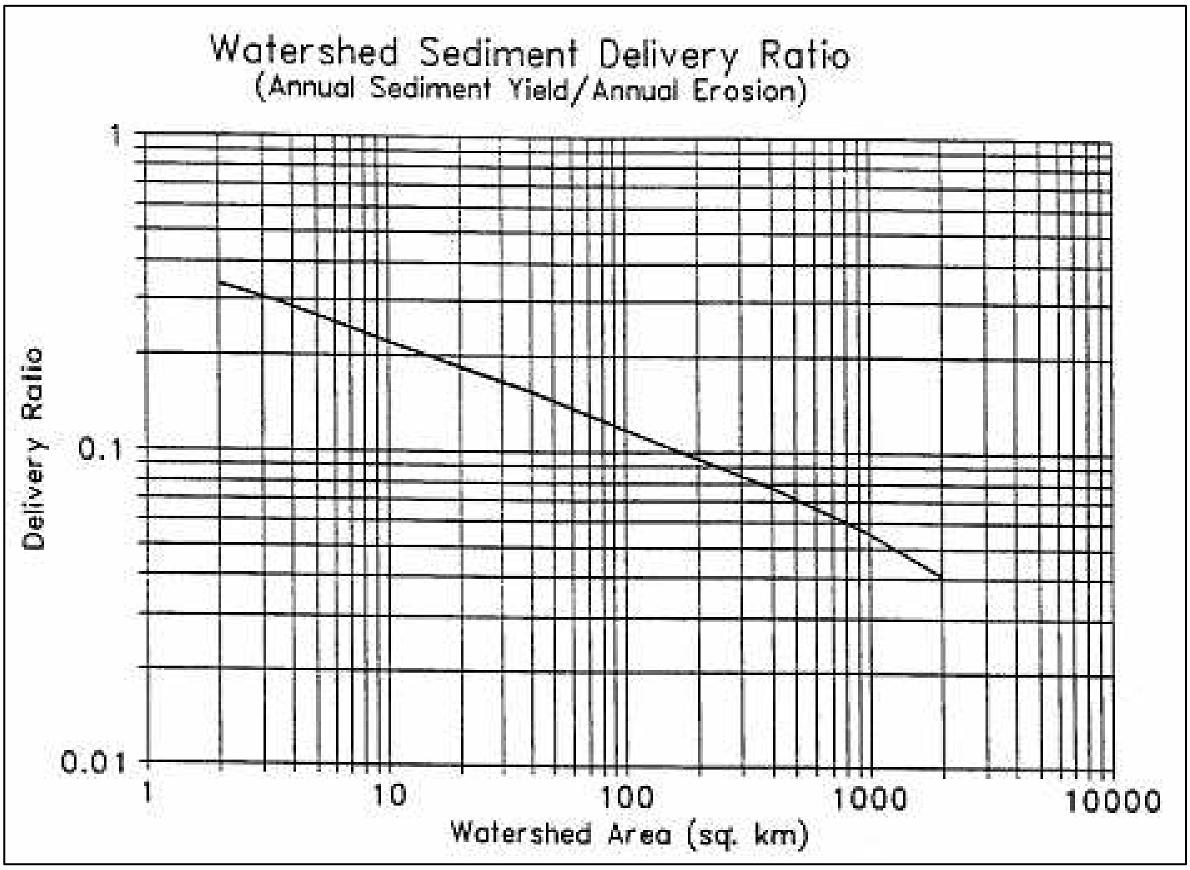
RdL: residues left on field (on surface or incorporated)

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

b) Total annual precipitation in Anchar catchment (1981-2010)

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
2009	612.1	1.67
2010	779.3	2.13

Appendix 10

c) Total monthly precipitation in Anchar catchment (1981-2010)

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
2009	85.6	106.8	48.2	81.3	51.1	66.8	48.2	35.8	27	2	45.2	14.1
2010	27.8	82.3	55.8	101	170.2	35.6	59.2	147.9	7.2	34	0	58

Appendix 11

b) Average monthly maximum temperature (°C) in Anchar catchment (1981-2010)

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
2009	8.27	10.42	15.65	19.91	24.94	26.22	29.71	31.55	28.94	22.70	14.08	10.07
2010	10.67	9.17	19.88	20.83	21.91	25.16	28.56	28.52	27.20	23.77	18.30	10.94

Appendix 11

c) Average monthly minimum temperature (°C) in Anchar catchment (1981-2010)

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
2009	-0.03	1.02	3.73	6.93	8.96	11.37	14.95	16.45	10.19	3.55	0.16	-1.07
2010	-1.92	0.05	4.65	6.46	9.82	10.78	16.42	17.63	12.15	5.50	1.46	-4.65

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Certificate

This is to certify that all the modifications/corrections suggested by the External Examiner **Dr. A.K. Bhat** in the thesis manuscript entitled, **"A Geospatial Approach to Study Environmental Characterization of a Kashmir Wetland (Anchar) Catchment with Special Reference to Land use/Land Cover and Changing Climate"** by **Mansha Nisar (Regd. No. 2008-233-D)** have been taken care of before final binding of the same.

(Dr. F. A. Lone)
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