CHAPTER I

1.1 INTRODUCTION

India is a vast landmass having a large number of rivers flowing in it. The rivers may be broadly classified into Himalayan, peninsular, coastal and inland drainage-basin rivers. The Himalaya is the main source of water for the rivers in the Indo-Gangetic plains, and all the major river systems of north India- the Ganga, Brahmaputra and Indus originate from the Himalayan snow and ice fields (Singh et al., 1998). The Himalayas constitute the largest reservoir of snow and ice in the world outside the Polar Regions. Glaciers in the Himalayas cover an area of around 38,039 sq. km. The water yield from a high Himalayan basin is roughly twice as high as that from an equivalent basin located in the peninsular part of India. Because of variation in climatic conditions and changes in the areal extents of snow-covered area (SCA) and snow-free area (SFA) with time, the contributions from the rain and snow to the stream flow vary with season (Singh and Jain, 2003). The Himalaya is a unique mountain system in the world with their lofty snow capped summits, deeply-dissected topography, youthful drainage, complex geological structure and rich biodiversity. The region is broadly divided into three river basins—The Indus, the Ganga and the Brahmaputra. The Himalayan sector receives 500 cm of rainfall per year, the lower ranges receiving more than the higher area. Monsoonal rains from June to September account for 60-70% of the annual rainfall (Goswami, 1985). The Brahmaputra carries higher average discharge at its mouth compared to the Ganga. Its sediment yield per unit area of the basin is also higher than the Ganga. In terms of channel morphology, the Ganga has a meandering pattern while the Brahmaputra is braided (Goswami, 1998). Since the Himalayan rivers traverse through poorly consolidated sedimentary rocks affected by folds, faults and thrusts, there is greater erosion and removal of silt in these rivers (Rao, 1975). The Himalaya plays a very significant role in influencing the climate of India. The Himalayan climate is largely controlled by the mid-latitude westerlies and Indian summer monsoon (ISM). The Himalaya acts as a natural frontier separating India, Bhutan and Nepal from China. Based on relative dominance of these two weather systems, the Himalaya can be divided into three zones, *viz*., western, central and eastern zones. The Eastern Himalaya is predominantly influenced by the ISM implying that it receives rain and snowfall mainly during the summer season. The western Himalaya is dominated by the mid-latitude westerlies and receives snowfall during winter (Benn and Owen, 1998). The eastern Himalaya, in general, provides moisture surpluses from direct runoff of the abundant summer monsoon rainfall and the snow-melt contribution is comparatively less. With increasing distance toward the west-northwest, melt water becomes critically important (Ives and Messerli, 1989). This mountain range has a significant influence on the life and living of the people and shapes the destiny of the nation.

From recent studies, it is found that there is an observed reduction in snowfall, change in intensity of rainfall and significant shift in temperature indicating the effect of climate change in the Himalayan region in recent years owing to global warming. Keeping these issues in view, the present study attempts to examine and compare the salient features of hydrometeorological conditions and geoenvironmental, eco-biological, landuse/land cover and anthropogenic factors affecting the two representative river basins viz. Alaknanda and Subansiri of western and eastern Himalayas respectively.

Geoenvironmental studies aim to examine the geosystem response to various types of active interactions; it is an in-depth treatment of the relations between man and his geologic, geomorphic, physical and cultural environments (Balram et al., 2013). It deals with the various aspects such as topography, geology, seismicity and tectonics, water and soil quality along with the climate and meteorology. The Himalaya has a unique geo-environmental setting marked by a dominant set of features and processes. The mountain range is different from the other mountain systems of the world because of its unique geoenvironmental setting.

Ecological balance and its richness reflect the health of an environment. The ecology of the Himalayas varies with climate, rainfall, altitude, and soils.The Himalayas richly deserve their Sanskrit name which means an “abode of snow.” The thick blankets of white snow cover across long stretches make the mountain range the largest non-polar ice mass in the world. It is often referred as the ‘third pole’ meaning the largest snow-covered areas after the two Polar Regions i.e. North Pole and South Pole.

There are about 10,000 species of plants, nearly a 1000 species of birds, 300 species of mammals, and several reptiles and aquatic species as well; a significant number of these species are endemic to the region. The southern slopes of the Himalayas are very green, with alluvial plains and moist deciduous forests at the base, teeming with life, including several species of large mammals. Higher up there are temperate broadleaf forests and coniferous forests, and even higher beyond the tree line are alpine meadows with the rarest of plants, several possessing medicinal properties (HimalayanVoices,http://www.himalayanvoices.org/?q=onlinelib/readings/themes/ecology).

Hydrometeorology is a branch of meteorology and hydrology that studies the transfer of water and energy between the land surface and the lower atmosphere. Considerable emphasis is placed on determining, theoretically or empirically, the relationships between meteorological variables and the maximum precipitation reaching the ground. These analyses often serve as the bases for the design of flood-control and water-usage structures, primarily dams and reservoirs. Other concerns of hydrometeorologists include the determination of rainfall probabilities, the space and time distribution of rainfall and evaporation, the recurrence interval of major storms, snow melt and runoff, and probable wind tides and waves in reservoirs. Hydrometeorological hazards can be understood by investigating the hydrometerological data.

Morphometrics or morphometry refers to the quantitative analysis of *form,* a concept that encompasses size and shape. Morphometry of a basin gives the quantitative description and analysis of landforms as practiced in geomorphology that may be applied to a particular kind of landform or to drainage basins and large regions generally. With regard to drainage basins, many quantitative measures have been developed to describe valley side and channel slopes, relief, area, drainage network type and extent, and other variables. The morphometric analysis of the drainage basin and channel network plays an important role in understanding the geo-hydrological behaviour of drainage basin and expresses the prevailing climate, geology, geomorphology, structural antecedents of the catchment. Morphometric analysis is the most common technique in basins analysis, as morphometry forms an ideal areal unit for interpretation and analysis of landforms having fluvial origin where they exhibit an example of open systems of operation. The composition of the stream system of a drainage basin is expressed quantitatively with the help of parameters like stream order, drainage density, bifurcation ratio and stream length ratio (Horton, 1945). Horton's laws were subsequently modified and developed by several geomorphologist, most notably by Strahler (1952, 1957, 1958, and 1964), Schumm (1956), Morisawa (1957, 1958), Scheidegger (1965), Shreve (1967), Gregory (1966, 1968), Gregory and Walling (1973). Geographical Information system (GIS) and Remote sensing techniques using satellite images are used as a convenient tool for morphometric analysis.

Water is a precious gift of nature and a river is an open system that has a great influence on settlement pattern, land use and socioeconomy of a civilization. It can provide many facilities and potentialities in various fields like hydel power generation, irrigation, navigation and industrialization. On the other hand, the demographic pattern and socioeconomic status indicates the utility of a river basin. Socioeconomy and demographic profile indicates various aspects such as population density, literacy, livelihood, gender, number of employee, agriculture etc.

Land Use/Land Cover change detection is one of the most significant parameters to realise the population pressure on a specific area. It reflects not only the human interventions on the land area but also on other resources like forest canopy, wetlands and other water bodies and biodiversity. Land Use/Land Cover analysis is done in different levels using softwares like ERDAS IMAGINE, ArcGIS etc. Satellite based remote sensing data are used to extract different thematic layers to interpret the specific area. Land Use/Land Cover change detection also visualizes the population pressure on the land and their related activities to bring changes to that specific landscape.

Natural hazards are characterised as those elements of the physical environment, harmful to man and caused by the forces extraneous to him (Burton, 1978). Wrongful activities by human being can increase the frequency and intensity of the natural hazards. Natural hazards are common phenomenon in the river basins of India. The NE region is acutely prone to multiple natural hazards like earthquakes, flood, erosion and landslides. The Subansiri river basin of eastern Himalaya and the Alaknanda river basin of the western Himalaya are also not the exception. Cloudburst is a natural phenomenon in the Himalaya which has started to occur more frequently in recent years. It mostly occurs in areas where the landforms are southward facing, having agriculture land (Quaternary deposits) as the dominant land use (Asthana and Asthana, 2014). Cloudburst is relatively more common in the Alaknanda basin of Garhwal Himalaya. As the globe is warming and as a consequence, the climate is changing, the weather related hazards like cloudburst, flash floods, landslides and drought are becoming frequent in the river basins.

1.2 SCOPE AND SIGNIFICANCE OF THE STUDY

The great mountain ranges of the Himalaya have been one of the most attractive areas of research from early times of history. The unique characteristics of the mountain range such as snow capped summits; deeply-dissected topography, youthful drainage system, complex geological structure and rich biodiversity attract many researchers from different parts of the globe. This study will provide a large volume of hydrometeorological information and databases on the selected river basins representing western and eastern sectors of the Himalayan range and the various scientific inferences drawn based on their analysis and interpretation. Further, it will enhance the existing knowledgebase on the geoenvironmental, ecological and socioeconomic characteristics of the Himalayas. Many researchers have done valuable research works on the eastern and western Himalayan region, but this is the maiden attempt being done to make a comparison between the eastern and western Himalayas taking one representative river basin from each part of the Himalayan arc. It is hoped that the study will help in better understanding the geo-environment and hazard scenario of the two sectors of the Himalayas especially in regard to the existing scenario of natural hazards including the probable impacts of climate change.

1.3 LITERATURE SURVEY

Literature survey in regard to the research includes study of various published research papers by different scientists and academicians, published reports and monographs from concerned authorities of the state and central government.

Karan P.P. (1966) explains the geographic features of the Himalayas along with cultural pattern of the inhabitants of the region in *Himalaya's landforms*. The author puts lots of valuable information regarding the socio-cultural pattern of the Himalayan region.

In the research paper *The climatology of Himalayas*, Ramanathan A.S. (1981) describes general climatology, complexity of relief features as well as differential effect of the weather systems in different regions which are responsible for a variety of climatic patterns in Himalayas. It reveals that there is difference of climate in the eastern and western Himalayas.

Basistha et al. (2007) on *Spatial Distribution of Rainfall in Indian Himalayas- A case Study of Uttarakhand* Region prepared the normal annual rainfall map of the Himalayan region of India lying in Uttarakhand at 1 km spatial resolution and found that the spatial average rainfall amounts were 1472 mm for Terai/Bhabar, 1782 mm for the Shiwalik ranges, 1591 mm for the Lesser Himalayas and 1635 mm for the Great Himalayan region. They found that the mean areal rainfall of the state as per the best estimate is 1608 mm/yr.

Montgomery David R. and Stolar Drew B. (2006) in the paper *Reconsidering Himalayan river anticlines* investigated the growth and development of Himalayan river anticlines and re-examination of the potential role of differential bedrock erosion suggests that rivers appear capable to influence the development of geological structures where there are sustained gradients in erosion rate and either a crustal rigidity low enough to permit localized isostatic rebound, or where facilitated by active feedback between tectonic and erosional processes like those leading to channelling of crustal flow.

In *The Himalayan Dilemma*, authors Ives Jack D. and Messerli Bruno (1989) explained the geography and environmental features of the Himalayan region very well.

They mentioned the degradation of the region. The book represents an exposition and critical analysis of the theory of environmental degradation from a physical process point of view along with their factors. This book seeks to examine the basis of the widely supported prediction that the Himalayan region is invariably drifting into a situation of environmental supererisis and collapse, a process of thought to which they refer as the theory of Himalayan environmental degradation.

Significant works on Himalayan geology have been done by Valdiya, K. S. In his book *Dynamic Himalaya* (1998) he discussed the structural architecture and the natural events that occurred and the processes that were in operation before the emergence of the giant Himalaya. In his research article *Lesser Himalayan geology: Crucial problems and controversies* (1985) he has made significant contributions to our understanding of the lithology and seismicity of the great Himalaya.

In *The Himalayan Frontal Fault System*, Yeats et al. (1992) depicts the Himalayan fault system and their characteristics, structural geology, geomorphology and seismicity. They have provided much valuable information regarding the above mentioned features. According to the authors the Himalayan Frontal Fault System marks the principal present-day tectonic displacement zone between the stable Indian plate and the Himalaya, with a convergence rate of 10-15 mm/yr, about one fourth of the convergence rate between the Indian and Eurasian plates.

Bookhagen Bodo and Burbank Douglas W. (2010) in their research work entitled, *Toward a complete Himalayan hydrological budget: Spatiotemporal* *distribution of snowmelt and rainfall and their impact on river discharge*, used a combination of validated remotely sensed climate parameters to characterize the spatiotemporal distribution of rainfall, snowfall, and evapo-transpiration in order to quantify their relative contribution to mean river discharge. They observed a strong decoupling between the rainfalls on the Himalayan foreland versus that in the mountains. According to the authors a pronounced six fold, east west rainfall gradient in the Ganges plains exists only at elevations <500 msl. Mountainous regions (500 to 5000 msl) receive nearly equal rainfall amounts along strike. Secondly, whereas the Indian summer monsoon is responsible for more than 80% of annual rainfall in the central Himalaya and Tibetan region, the eastern and western syntaxes receive only 50% of their annual rainfall during the summer season. Thirdly, snowmelt contributions to discharge differ widely along the range.

Benn and Owen (1998) studied the the role of the Indian summer monsoon and the mid-latitude westerlies in Himalayan glaciation in the research article *The role of the Indian summer monsoon and the mid-latitude westerlies in Himalayan glaciation: review and speculative discussion. According to the authors* on millennial timescales, Himalayan glacier fluctuations are controlled by variations in both the South Asian monsoon and the mid-latitude westerlies. New dates for late Quaternary glaciations in the Himalayas show that, during the last glacial cycle, glaciations were not synchronous throughout the region.

Though several research works have been done on the river Alaknanda of western Himalayas but there is a relatively wider research gap on the river Subansiri of eastern Himalayas.

One of the most informative and significant research works on the river Brahmaputra was carried out by Goswami D.C. (1985), on the Brahmaputra River. The research depicts the geology, tectonics, climate, morphology, hydrology, channel migration and sediment budget of the mighty Brahmaputra primarily in its Indian portion. He estimated the rates of aggradation and degradation of the Brahmaputra River in different reaches in Assam and estimated the present rate of rapid denudation of the Himalayas which was attributed mainly to the rapid upliftment of the mountain and to the high susceptibility to erosion of geologic formation within the intense monsoon rainfall regime.

Goswami D.C. (1998) has analysed the flooding characteristics of the Brahmaputra basin based on its unique environmental setting, heavy rainfall along with seismic and geological condition of the region. The issues related to management of floods were also discovered.

Gogoi and Goswami (2014) in the research paper *A study on channel migration of the Subansiri river in Assam using remote sensing and GIS technology* mapped the the changing channel pattern of the Subansiri river in Assam for the period of 1828 to 2011 and found that the large discharge and heavy sediment load during floods cause the river to be extremely unstable, because of which it consistently migrates laterally from the eastern side to the western side of the basin abandoning the earlier channels, creating severe devastation in the adjoining floodplains. The geodynamic instability of the basin and its impact on the nature and behaviour of the river has also been discussed.

Fluvial process and morphology of the Brahmaputra River in Assam, India is another significant study carried out by Sarma J.N. (2005). The study depicts the morphology and fluvial process of the Brahmaputra River in Assam and found that the channel of the Brahmaputra river has been migrating because of channel widening and avulsion and shear failure of upper bank and liquefaction of clayey-silt materials are two main causes of bank erosion of the river.

Pattern of flood inundation in the Subansiri was examined by Goswami D.C. (1995) under a project related to Satellite Study of Flood Prone Areas of Subansiri River, Assam sponsored by Brahmaputra Board, Govt. of India. The study carried out mapping of the annual floods in the river basin and identified different areas of vulnerability.

Another important research was done by Goswami U., Sarma J.N. and Patgiri A.D. (1999) on *River channel changes of the Subansiri in Assam, India*. In this study the authors mentioned the factors like soil characteristics which lead to erosion and the earthquake of 1950 and the attendant historic floods responsible for the channel change and development of new mid channel bars of the Subansiri River.

Baruah, J.K. (2000) carried out the geomorphological study of the Lower-Subansiri basin, while Gogoi, C. (2013) in her doctoral research has done notable works at the back drop of the environmental geomorphology of the Lower Subansiri basin.

In the final technical report of G.B. Pant Institute of Himalayan Environment & Development, Uttarakhand (2007) *entitled Geo-Hydrological Studies for Augmentation of Spring Discharge in the Western Himalaya*, attempts to understand the effect of rainfall, physiography, lithology slope and aspect, land use practices, vegetation, soil type and anthropogenic interferences in spring recharge zone on water yield and water quality of selected springs in mid-altitudinal belt in the western Himalaya and depicts the influence of hydrometeorological parameters on the spring recharge zones of Uttarakhand of western Himalayan region.

Many researchers have done valuable works on the Alaknanda river basin of Uttarakhand Himalaya. Dutt Laxmi (1998) carried out study on landforms and land use management of the basin. Arora Nishant (2006) did the geospatial analysis of lower Mandakini valley and the issue of resources utilization pattern and process. Ballabh Hari (2008) studied the landform analysis and hydrological responses of Dhundsir Gad of the Alaknanda basin.

The flow pattern of the Alaknanda River in Uttarakhand was studied by Goswami D.C. (2009) in his study on Managed flow of the river under a project sponsored by World Bank.

Chakrapani and Saini (2009) in their paper entitled *Temporal and spatial variation in water discharge and sediment load in the Alaknanda and Bhagirathi Rivers in Himalaya, India* attempted to examine the pattern of sediment concentration in the upper reaches of the Ganga River for the duration of one year and estimated that the annual physical weathering rates in the Alaknanda and Bhagirathi basins at Devprayag are 863 tons/km^2/yr and 907 tons/km^2/yr (approximately 3.25 mm/yr) respectively.

One of the significant studies related to Subabsiri basin was carried out by the Expert Group comprising members from Gauhati University, IIT Guwahati and Dibrugarh University on the *Downstream Impact Study of the ongoing lower Subansiri Hydroelectric Power Corporation at Gerukamukh* undertaken by the National Hydroelectric Power Corporation (2010). The report includes various aspects of the hydroelectric project, especially geological and seismological appraisal of the proposed dam site and also its probable downstream impacts.

In the *Preliminary Feasibility Report (2004) of 360 MW Nalo Hydro Electric Project Arunachal Pradesh* by the Ministry of Power, Govt. of India, investigation was done in regard to geology, hydrology, power potential and environmental aspects of the Nalo Hydro Electric project site located in the upper Subansiri district of Arunachal Pradesh. In that report, the rainfall- runoff relationships were carried out and a runoff factor of 0.73 had been established after detailed rainfall-runoff analysis in the Subansiri basin.

Dutta and Sarma (2012) in the paper *Lower Subansiri Hydroelectric Power Project and future of the Subansiri River Ecosystem* explain the present biodiversity status of the Subansiri river along with the loopholes of the Environment Impact Assessment of this hydroelectric project prepared by the Water and Power Consultancy Services (WAPCOS) and the ongoing violations of environment and forest laws by the

National Hydroelectric Power Corporation (NHPC) during the different phases of construction of this hydroelectric project.

Sarmah et al. (2013) in their research on *Wetland medicinal plants in floodplains of Subansiri and Ranga rivers of Lakhimpur district, Assam* emphasises the need to conserve the plants of the wetlands of the Subansiri and Ranga river basins that contain medicinal property.

Central Water Commission in the report (2013) *Basin-wise Environmental Impact Assessment Study on Subansiri Subbasin in Arunachal Pradesh,* has described the ecology, hydrology, water quality, assessment of environmental flows and impact of the proposed dams in the subbasins of the Subansiri in Arunachal Pradesh were examined in considerable details.

A significant report was prepared for GMR Energy Limited, New Delhi by Centre for Inter-Disciplinary Studies of Mountain & Hill Environment (CISMHE), University of Delhi, on *Environmental Impact and Management Plan for Alaknanda H.E. Project, Uttarakhand.* In this report the impact of the proposed hydro electric project on the demography, air, water and land of the region are discussed.

Valuable research works are done by the researcher Sati (2009) on the Alaknanda basin of western Himalaya. His project report on *The Alaknanda Basin (Uttarakhand): A Study on Enhancing and Diversifying Livelihood Options in an Ecologically Fragile Mountain Terrain* includes lots of valuable information and data on the Alaknanda river basin. Sati (2008) in his article, *Natural Resources Management and Food Security in Alaknanda Basin of Garhwal Himalaya* describes the richness of the natural resources of the basin in a wide context.

There is a lack of research on the morphometry of the Subansiri River and its tributaries especially in the upper part of the Subansiri basin. A notable number of studies have been done on the geomorphology and morphometry of river basins of abroad and India. Clarke (1996), Horton R.E. (1932), Smith, K.G.(1950), Leopold et al. (1964), Strahler (1964), Rastogi and Sharma (1976), Verstappen (1983), Nautiyal M.D. (1994), Rudraiah et al. (2008), Sreedevi et al. (2009), Magesh et al. (2013). Many of them used GIS and remote sensing technique to study the morphometry of the river basins. Singhal (1988) in his report *Studies on Some Aspects of Geomorphology in Alaknanda River Basin, Kumaon Himalaya Uttar Pradesh* did the geomorphological and hydrological analysis of the Alaknanda basin. In Geomorphological study of *Atagad Basin, Chamoli District, Uttarakhand: GIS and Remote Sensing approache*s, Khanduri (2011) has analysed the instability and morphometry of the Atagad basin which is one of the important tributaries of Pindar river a subbasin of the Alaknanda river of Uttarakhand. Pareta and Pareta (2011) in their research *Quantitative Morphometric Analysis of a Watershed of Yamuna Basin, India* using ASTER (DEM) Data and GIS found that remotely sensed data (ASTER-DEM) and GIS based approach in evaluation of drainage morphometric parameters and their influence on landforms, soils and eroded land characteristics at river basin level is more appropriate than the conventional methods.

Semwel and Akolkar (2006) in their research *Water quality assessment of* sacred *Himalayan rivers of Uttaranchal*, assessed the water quality of the sacred Himalayan rivers of Uttaranchal in view of their religious importance and ecological sustainability and found that the religious places have contributed significant levels of sulphates to water quality (1.66-20.0 mg/l) and also the agricultural practices on the river bank may have considerable impact on contribution of pesticide residues.

Bacterial indicators of faecal pollution and physiochemical assessment of tributaries of Ganges River in Garhwal, Himalayas was studied by Sati et al. (2011). They investigated the incidence of these indicator organisms, coliform, faecal coliform, faecal streptococci and physiochemical parameters during different seasons in the Alaknanda and the Bhagirathi, the two main tributaries of Ganges and observed the direct effect of season as well as anthropogenic activities at each sampling site that causing the pollution of the river water.

Kumar et al. (2014) in the article *Sustainability Assessment of Human Intervention in terms of Hydroelectric Project on Alaknanda River Valley* examined the processes and the steps involved in EIA for the development of projects which involve human intervention like dams in the Himalayan region, with the subsequent impact on the environment.

Yu et al. (2007) in the article *Land use/cover change and environmental vulnerability analysis in Birahi Ganga sub-watershed of the Garhwal Himalaya*, tried to understand the correlation between LUCC and environmental vulnerability in the Birahi

Ganga sub-watershed (Garhwal Himalaya). They observed that the human activities have increased recently in higher elevations as a response to increased population pressure. The study showed that a net increase in dense forest (especially from 1976 to 1990) resulted from the maintenance of environmental protection measures, while agriculture land expansion, forest resources extraction, increasing human and livestock population and other human interferences led to the continuous reduction of open forest area and their degradation.

Many researchers in India have done the works on Land use / Land Cover change (LULC) change detection on river basins using Remote Sensing and GIS techniques. *Hydrological simulation of Mahanadi river basin and impact of Land use / Land Cover change on surface runoff using a macro scale hydrological model* was carried out by V.K. Dadhwal, S.P. Aggarwal, and Nidhi Mishra (2010). They used Variable Infiltration Capacity (VIC); a macro-scale hydrological model and estimated an increase of annual stream flow by 4.53% (3514.2 x 106 m^3) at the Mundali outlet of the Mahanadi basin from 1972 to 2003 which may be due to the decrease in forest cover by 5.71%.

Gajbhiye and Sharma (2012) studied *Land Use and Land Cover change detection of Indra river watershed* through Remote Sensing using Multi-Temporal satellite data and found that Indira nadi watershed have experienced rapid changes in land use/ land cover particularly in Farm land and Forest land which causes loss of natural ecosystem and biodiversity.

Mahapatra et al. (2013) carried out the *Mapping and monitoring of land use and land cover changes of the area around the Narmada river mouth, Gujarat, India* using Remote Sensing and GIS techniques.

Wasson et al. (2007) in their article *the mountain-lowland debate: Deforestation and sediment transport in the upper Ganga catchment* studied the impact of natural and anthropogenic factors which may cause erosion and sedimentation in the Alaknanda basin and found that though the identification of the role of human agency in the erosion and sediment transport system of the Himalaya is difficult still, using geochemical sediment source tracers and a historical approach set within a whole-of-catchment framework, it has been possible to show that deforestation had some impact on at last one very large erosion and sediment transport event in 1970 in the Alaknanda sub-catchment of the Upper Ganga catchment. But that both deforestation and its effects on erosion and sediment transport are far from uniform in the Himalaya.

Behera et al. (2014) in their article *Increase in agricultural patch contiguity over the past three decades in Ganga River Basin, India* analysed the landscape dynamics using three indices, i.e. class area, mean patch size and number of patches for 14 land-use and land-cover (LULC) classes using multi-temporal Landsat satellite datasets of 1975 and 2010. They observed the expansion of agricultural lands and human settlements and depletion of forest.

Wang et al. (2003) studied the *Temporal responses of NDVI to precipitation and temperature in the central Great Plains of USA* and found that temperature was positively correlated with NDVI early and late in the growing season, and there was a weak negative correlation between temperature and NDVI in the mid growing season. Precipitation has the primary influence on NDVI and hence on productivity. There is a strong relationship between precipitation and NDVI and predictable when viewed at the appropriate spatial scale.

Dubey et al. (2012) carried out the study of *Relationship between NDVI and Rainfall Relationship over India*. They concluded that the NDVI is mainly dependent on the rainfall and spatially very strong relationship in north east and southern part of the country. Many researchers from India and abroad have done valuable works on NDVI and its relation with rainfall and water availability, air temperature and soil moisture adequacy which has a strong influence on crop production. A few of the notable researchers are Davenport and Nicholson (1993), Aguilar et al. (2012), Sarma and Kumar (2006), Milesi et al. (2010), Gunnula et al. (2011), Svoray and Karnieli (2010) and Kumar et al. (2013)

In the paper *Participatory strategy for flood mitigation in east and northeast india: case study of the Ganges–Brahmaputra–Meghna Basin,* Ghani M.U. has discussed various problems related to the natural hazards of Ganges-Brahmaputra-Meghna basin of east and north east India.

A satellite data based assessment Study on the *stream bank erosion of main stem Brahmaputra and its major tributaries* was conducted by the Department of Water Resources Development and Management Indian Institute of Technology

Roorkee For National Disaster Management Authority of India (2012) entitled as Final Report on Study of Brahmaputra River Erosion and its Control.

Barnard et al. (2001) in the research paper *Natural and human-induced land sliding in the Garhwal Himalaya of northern India* examined the factors inducing the landslides in Garhwal Himalayas. The landslides in the region is triggering due to the seismic activity i.e. earthquake , mass movement and heavy rainfall along with the human interventions which influenced about two-thirds of the active landslides hence helping to accelerate denudation in that Himalayan region.

Anbalagan and Parida (2013), *Geoenvironmental problems due to Harmony landslide in Garhwal Himalaya, Uttarakhand, India* describes about the Harmony landslide caused traffic blockade and consequent economic and environmental losses in Uttarakhand. Authors also mentioned about impact of slide which was reactivated almost every year causing disruption of traffic along this important hill route, which is the only hill route, connecting Garhwal and Kumaun physiographic divisions of the state in upper hills.

Sundriyal et al. (2007) presented the landslide - dammed lake deposits located in the Srinagar Garhwal of the Alaknanda basin in their paper *Landslide- dammed lakes in the Alaknanda basin, Lesser Himalaya: Causes and implications* and found that activation of crumpled and unstable phyllite dominated slopes led to temporary damming of second and third order tributaries of the Alaknanda basin. Lakes disappeared due to the large –scale reactivation of the slopes around Mid-Holocene.

Tyagi et al. (2009) in the article *identifying areas of differential uplift using steepness index in the Alaknanda basin, Garhwal Himalaya* has expressed the high uplift areas are MCT, second zone of relatively higher surface uplift is identified as south of the MCT around Chamoli, Nandprayag and Karnprayag and these locations are traversed by the Chamoli, Nandprayag and the Alaknanda faults respectively. So there is a need of future earthquake risk evaluation, detailed geomorphological and seismotectonic studies should be undertaken in this area.

In the article *Widespread Climate Change in the Himalaya and Associated Changes in Local Ecosystem,* author Shrestha et al. (2012) used global mean monthly temperature, precipitation and GIMMS-NDVI dataset from 1982 to 2006 of the Himalayas. This study showed the significant changes in temperature, rainfall, and vegetation phenology across the Himalayas between 1982 and 2006. The average annual mean temperature during the 25 year period has increased by 1.5ºC with an average increase of 0.06ºC per yr. The average annual precipitation has increased by 163 mm or 6.52 mm/yr.

One of the significant studies on climate change of the western Himalayan region was carried out by Bhutiyani et al. (2007) entitled *Long-term trends in maximum, minimum and mean annual air temperatures across the Northwestern Himalaya during the twentieth century*. The study reveals significant rise in air temperature in the northwest Himalayan (NWH) region by about 1.6°C in the last century. Winters warming rate as well as the diurnal temperature range also showed a significantly rising trend which is due to rise in both the maximum as well as minimum temperatures, with the maximum increasing much more rapidly. The study also confirms that the NWH region has warmed significantly during the last century at a rate, which is higher than the global average.

In the research work *Impact of Climate Change on the Western Himalayan mountain ecosystem: An overview,* author Negi et al. (2012) Presents an over view of climate change impacts on agriculture, water and forest ecosystem in the western Himalayan Mountains based on literature and some anecdotal evidences.

Uttaranchal Himalaya India, Inventory of Glaciers and Glacial Lakes and the identification of potential Glacial Lake Out Burst Floods (GLOFs) Affected by global warming in the mountains of Himalayan region (2005) by Wadia Institute of Himalayan Geology, International Centre for Integrated Mountain Development, Asia-Pacific Network for Global Change Research, Global Change System for Analysis, Research and Training and United Nations environment Programme/ Regional Resource Centre Asia- Pacific have well documented the inventory of glaciers and its outburst using remote sensing and GIS. They delineated the glaciers of different types the Alaknanda basin which has 457 numbers of glaciers covering an area of 1434.61 sq. km.

Climate variability and trends in part of Brahmaputra river basin is another encouraging study done by Sarkar and Sharma (2012). They studied the trends in the annual and seasonal daily rainfall and temperature (maximum, minimum and mean) over Subansiri river basin for the assessment of the impacts of climate variability and change on the water resources of the Brahmaputra basin using daily gridded rainfall data for a period of 37 years and daily gridded temperature data for a period of 36 years and found that annual rainfall is increasing at one grid point but no observed trend in first four grids. The temperature analysis shows that minimum temperature in general is decreasing at all of the grid points but no observed significant trend in maximum and mean temperature in the basin.

In the study *Impact of Climate and Land Use Changes on the Flood Vulnerability of the Brahmaputra Basin* done by Ghosh and Dutta (2011) used a physically based macro-scale distributed hydrological model (DHM), which works on the concept of hydrological similarity classes (HSCs), reveals that the projected climate change would affect the flood vulnerability more significantly than the land use / land cover changes in the Brahmaputra basin and it will have a significant effect on agriculture in the valley.