ENVIRONMENTAL GEOMORPHOLOGY OF JIADHAL RIVER BASIN, ASSAM AND ARUNACHAL PRADESH: QUEST FOR SUSTAINABLE DEVELOPMENT

Thesis submitted to the Nagaland University for the award of the Degree of Doctor of Philosophy (Ph.D.) in Geography.

By

CHANDRA KUMAR DUTTA

Department of Geography, School of Sciences,

Nagaland University,

Lumami – 798627.

2020

NAGALAND UNIVERSITY

(A Central University Estd. By the Act of Parliament No. 35 of 1989)

DEPARTMENT OF GEOGRAPHY

School of Sciences, Nagaland University, Lumami,-798627

CERTIFICATE

This is to certify that the thesis entitled "ENVIRONMENTAL GEOMORPHOLOGY OF JIADHAL RIVER BASIN, ASSAM AND ARUNACHAL PRADESH: QUEST FOR SUSTAINABLE DEVELOPMENT" is submitted by Mr. Chandra Kumar Dutta for the Degree of Doctor of Philosophy in Geography of this University. The work presented embodies the original work of the candidate. According to the best of my knowledge, this thesis has not been submitted for the award of any other degree of this university or any other university.

Mr. Chandra Kumar Dutta has put in work more than two hundred days of research work in the Department of Geography under my supervision.

(M. S. Rawat) 09.09.2020
Ph. D. SUPERVISOR

Counter signed by

09/09/2020
(Prof. Lanusashi Longkumer)
Head of the Department

DECLARATION

I, Mr. Chandra Kumar Dutta, hereby declare that the thesis entitled "**Environmental Geomorphology of Jiadhal Basin, Assam and Arunachal Pradesh: Quest for Sustainable Development**" submitted by me in partial fulfillment of the requirement for the award of Ph.D degree in Geography, is my bonafide research work and that this thesis has not been submitted in part or full by me to any other University / Institution for the award of any research degree, diploma or other similar titles.

09/09/2020

Chandra Kumar Dutta

Department of Geography,

School of Sciences, Nagaland University,

Lumami – 798627.

09-09-2020

ACKNOWLEDGEMENT

I am immensely pleased to express my deep sense of gratitude and indebtness to my esteemed supervisor Professor. M. S. Rawat, Department of Geography, School of Sciences, Nagaland University, Lumami, Zonauboto, Nagaland for his continuous interest, careful guidance, valuable suggestions, and encouragement during the entire research work. I owe a lifelong obligation for his co-operation and extraordinary patience, especially during the final stage of this work. I will cherish the moments of working with him for my entire life.

I acknowledge my sincere regards to the Dean, Faculty of School of Sciences, Nagaland University and Head, Department of Geography, Nagaland University for giving me opportunity to pursue my Ph.D. research in the Department of Geography under School of Sciences.

I sincerely acknowledge my regards to the Dean, Faculty of Research Council (DRC), Nagaland University for giving the valuable approval to get Non-Net Fellowship for three (3) years, which helped me financially to carry out my research in the Department of Geography under School of Sciences.

I am indebted to all the faculties and official staff of the Department of Geography for their kindness and supportive nature in entire periods of my work. Especially I would like to mention Assistant Prof. Kedovikho Yhosu for his valuable moral support and technical help for the successful completion of this research work.

I am thankful to the Assam Water Recourse Management Institute, Basistha, Guwahati, Brahmaputra Board, Guwahati and Lakhimpur, Assam; National Hydroelectric Power Corporation, Gerukamukh; Water Resources Department, Dhemaji, Government of Assam; for supply of maps and information to me without which I could not have come up with this thesis.

I am thankful to Dr. Sirumoni Boruah (Principal), Asst. Prof. Dharmendra Dutta, Bordoloni Central College, and beloved Rikiranjan and Geography students of Bordoloni Central College, Dhurba, Nitish, Kandarpa, De-Don and Jagadish for their support and cooperation to do the rigorous fieldwork as well as household socio-economic survey of the area.

I owe lifelong obligation to my family members and my friends for being patiently, sharing my agonies and ecstasies throughout the period of my research. And last but not the least to my daughter my wife Joram Yapar, daughters Hami, Sejal, my niece Monalisha, Kariahma, Junmoni and Joram Jum for their sacrifices and understanding, without which it's impossible to complete my research work.

Date: 09-09-2020

09/09/2020

(Chandra Kumar Dutta)

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

CHAPTER-1

INTRODUCTION

INTRODUCTION:

Geomorphology is defined as the science of landforms with an emphasis on their origin, evaluation, form and distribution across the physical landscape (Briney 2020). It involves the natural processes that are responsible for the present situation of the earth's landscape, particularly the landforms, relief features, their morphology and developments processes. Thus it is an important branch of regional and spatial studies of the phenomena prevailing in the earth's surface that determines it's structure, pattern and forms including their processes of genesis and development. Geomorphology deals with the landform development, processes of development and the various factors on regional basis that is responsible for the process of the particular landform development. The factors involves are the climate, temperature, duration of sunshine, rainfall, humidity, topography, relief feature, geology, hydrology and morphometry of the earth surface on which it is active (Merritts, 2010).

Geomorphology is the scientific study of the genesis and development of land features created by agents of denudation processes including physical, chemical or biological processes active in the Earth's surface. It Deals with the phenomenon involving in the development of a particular landscape at a particular space with the distinct variables involved as i.e. climate, parent geology and geomorphic process responsible for the landscape development. The processes involved in the development and consequences of the mechanism of land form development are the assessment of geomorphology. The proper understanding of the geomorphology of a region would help in management of the environmental development prevailing in the region. The relief features and geology of the area determines the phenomenon active in the region with reference to the climatic condition of the region. The study region is in the monsoon region of north east India and receives an annual precipitation about 200 cm and often receives 300 cm of diurnal rainfall in rainy season. The other important factor is the agents of the geomorphic processes with respect to the regional environmental concerns as, continental, marine, mountainous terrain of the region etc. The periphery of geomorphology get broaden with the inter-disciplines or sub branches of geomorphology such as structural geomorphology, climatic geomorphology, fluvial geomorphology and environmental geomorphology etc. Environmental geomorphology is relatively new and relevant area that focuses on the various environmental aspects as well as landform process and it's became the prime subject for understanding the natural or environmental problems and issues of the worlds related to natural phenomenon. In fact, it is a significant aspect of applied geomorphology where the scientific observation is applied to our other daily activities including agriculture, engineering, mining, construction, landscaping etc.

Environmental geomorphology on other hand is the practical use of geomorphology and geological understanding for the solution of environmental problems where humans wish to transform or to use and change surface processes according to his wants and desires. The major aspects of Environmental development include, the understand the geomorphic processes and terrain that affect man and his activities, the analysis of environmental problems where human act as a geomorphic agents, and has or planned to adopt the changes in natural environment by its degradation of the land- water ecosystem, and how the science of geomorphology can be used in environmental planning and management for sustainable development by reducing the impact of the effect of natural calamities or disasters. Mainly triggered to curve out management plan and project for sustainability of environmental geomorphology and to find solution for the prevailing environmental hazards. Help the decision making authorities in computing and analyzing the effect, trend and implementation of the project for sustainable development. Environment geomorphology includes a wider perspective of the river basin, its various environmental aspects that lead to the formation of landforms and associated hydro-geomorphological processes on the development of various fluvio- sedimentary aspects including pattern of flow in the river, water yield of the basin, nature of sediment production, transportation and deposition in the basin, intensity of natural hazards like flood, erosion, sedimentation and landslide etc. (Rawat, 2012). UNEP (2006) advocated that the environmental geomorphology is the solution for the problems in the natural environment including the natural calamities, induced problems like deforestation, landslide, erosion and degradation of environments.

The aspects of environmental stability is concern with geomorphological and hydrological characteristics of a basin involving floods, water logging, scarcity of water, ravination, channel shifting etc. (Dubey A., 1990). Kubalikova (2013), confined environmental geomorphology within this environmental component, humans represent human activity on natural settings and its vulnerability over nature as well as social geography of the basin. Human interruption is considered the most commendable factor for environmental changes mainly includes human activities such as buildings and structures, infrastructures, economic activity, social organization and any expansion and development. A river basin is a geomorphological unit (geomorphic system) that drains through a common point and from a distinct hydrological unit. Flood, erosion, sedimentation, mass-wasting and landslide are the common problems of a river basin. But by constructing dams, embankments, unplanned roads, railways, buildings and houses as well as the rapid land use changes, they made these hazards more destructive in some areas. So protection of land, water and forest resources of the river basin is a suitable long-term strategy for sustainable development (Rawat, 2011). Wise management of land, water and forest resources in the geodynamically sensitive and tectonically active domain like the North East Region of India requires knowledge of the interactions within the environment and numerous geomorphic processes. Many current problems in the environmental geomorphology and landscape ecology can be better addressed when placed broad conceptual framework provided by the analysis of all the degradation processes of the river basin. Such analysis provides an understanding of geomorphic system of the drainage basin. The propose research will try to bring together the geomorphological materials that have relation to environmental management and integrated water shed management for sustainable development. Geomorphology of a river basin plays an important role in the overall development strategies of the basin. Through geomorphology it is possible to know the basic characteristics of the physical properties of the landform which is a prime factor controls the land and water management of the region.

The proper management of the land and the water resources of the river basin, reflects the utilization of the natural resources of the basin and its sustainability. The study area 'Jiadhal River Basin' is a river system from the sub- Himalayan ranges of the southern part of the Kangku circle of West Siang district of Arunachal Pradesh to the extensive plain of Assam particularly the Dhemaji district. The environmental problems of the basin of Jiadhal need a serious consideration of both the states, Arunachal Pradesh and Assam jointly for the sustainable development of the basin (Bormudoi, 2015). The research triggered to understand the environmental as well as geomorphological importance of the phenomenon prevailing with reference to find solution to natural calamities of the river basin. The environmental problems in watershed are concentrates with the geology and hydrology of the region influenced by the climatic conditions. The physical factors includes the geological structure, composition and overall environmental as well as anthropogenic activities in the geographical unit composites the phenomenon. Apart from physical factors socio-economic activities in the region including, utility of natural resources by human also accelerated natural phenomenon.

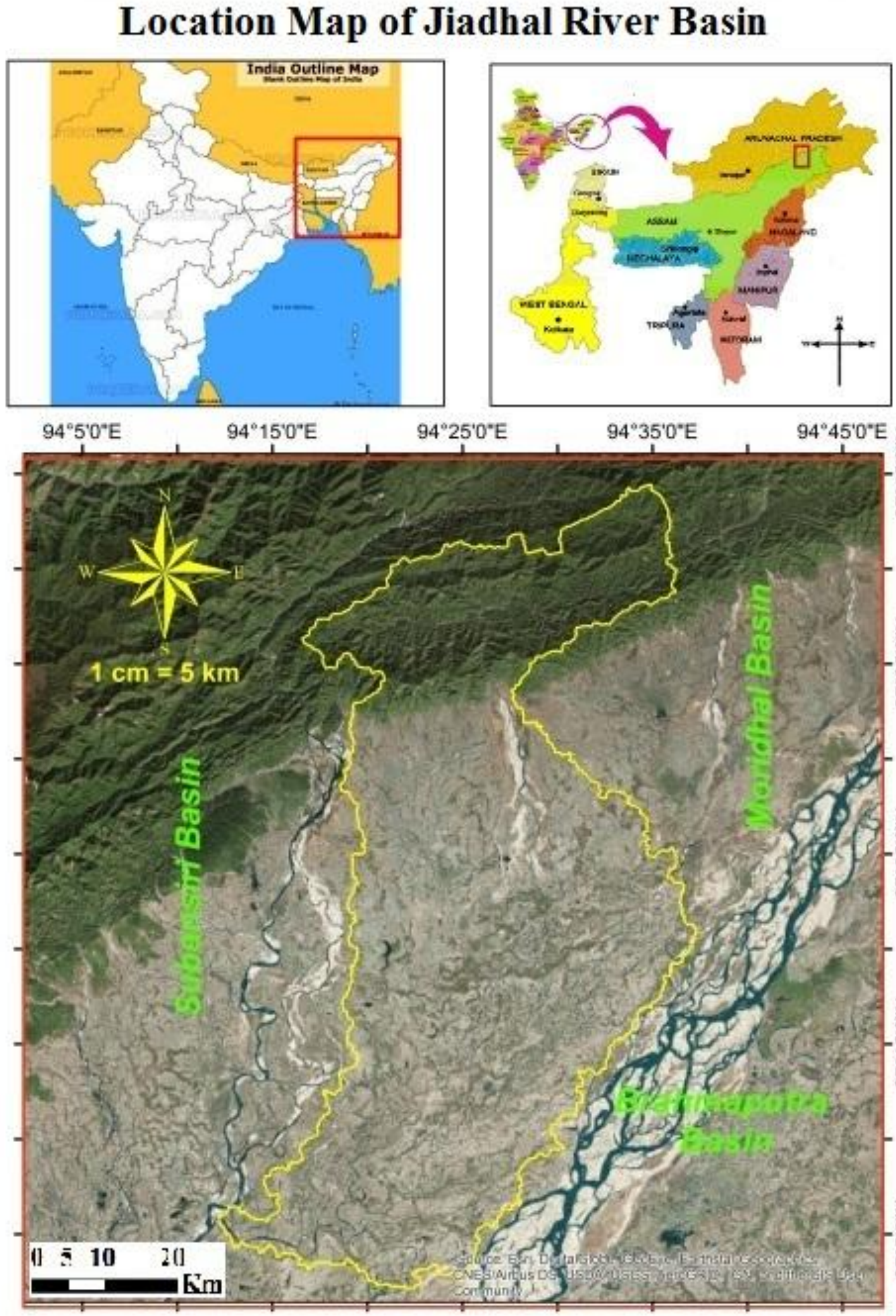


Fig. 1.1 : Jiadhal River Basin on Satellite image.

Location Map of Jiadhal River Basin

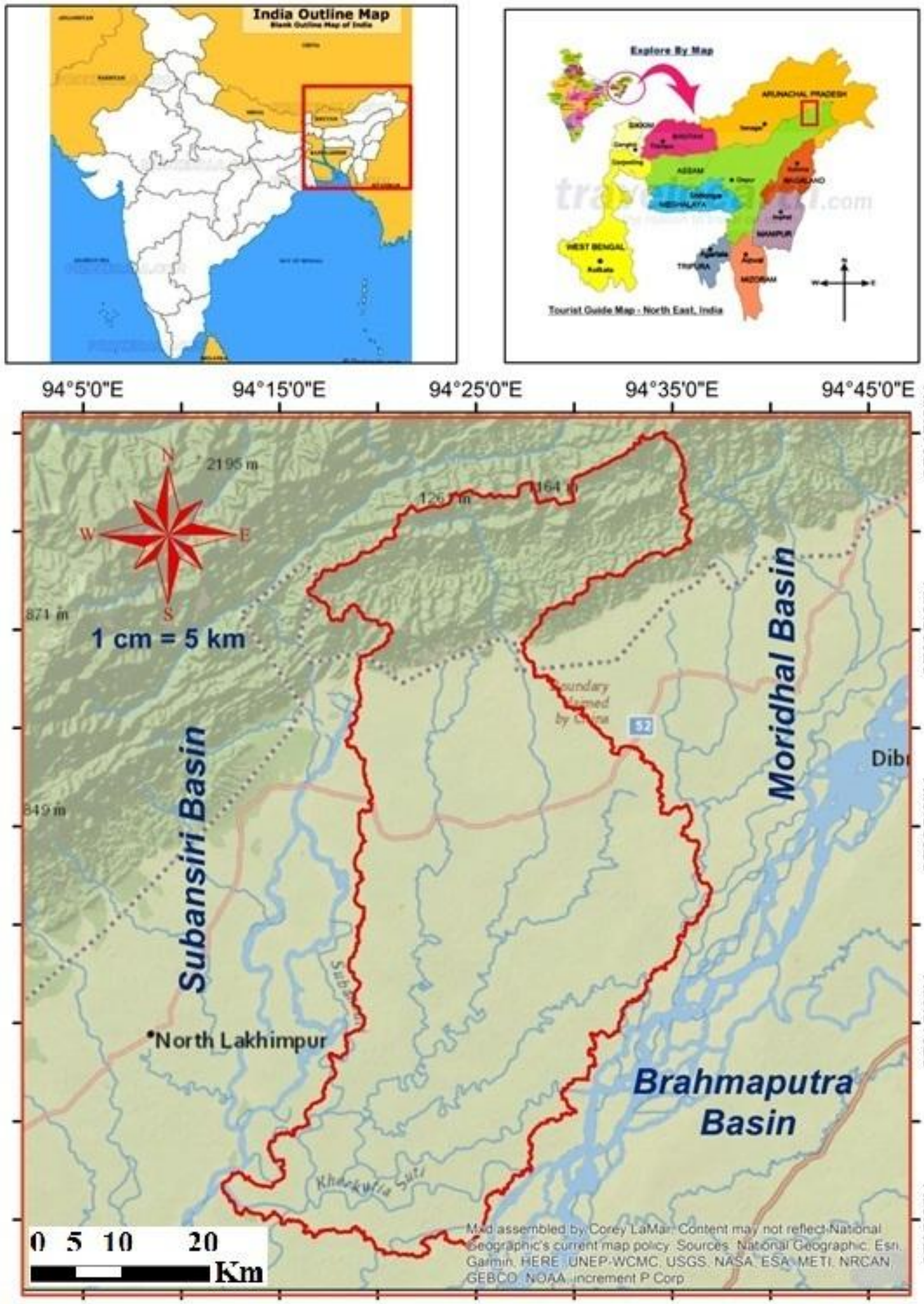


Fig. 1.2 : Jiadhal River Basin on Street Map (ArcGIS 10.1)

Plate.1.1 : Photograph of Jiadhal river basin in Piedmont areas.

The study area is located in the lower belt of Arunachal Himalayas and extended to the flood plain and thus has heterogeneous characteristics both in environmental as well as geomorphological settings. The physiographic division is demarcated on the basis of structure height and situation of geographical unit. The northern part of the basin is mountainous and covered with natural vegetation, mostly undisturbed by human intervention. Northern part of the basin is dominated by lofty mountain ridges of Siwaliks Himalayas with deep valley and youth river system. The terrain is influenced by the geomorphology as well as geology for the fluvial processes to develop the natural landscape of the region. The basin enjoys monsoon climate and occasional heavy to very heavy shower, energizing the natural springs and rivulets for denudation process. The denudation process active in northern hilly region produces natural hazards as landslide, soil erosion, slope failure, deforestation, valley deepening, and sediment load in the river course. The loosed materials transported by the river flow creates serious hazard in lower basin as, sedimentation, siltation, bleaching of river banks, bank erosion and seasonal flood devastating environment as well as social life to the lower basin areas (Taha, 2017). The southern part of the basin is a level land with less range of elevation, and is mostly associated with agricultural economy. The increase of rainfall intensity causes water logging in low lying areas, agricultural fields and even in settlement areas creating flood like situation. Thus watershed management of the basin area is the triggered for the sustainable development of the entire basin. As the basin has vast topographical variation, the strategic plan for watershed management for each area would be different in respect to local requirement and importance. Understanding the environmental geomorphology of the basin including physiography, drainage parameters, slope stability, land use and land cover as well as anthropogenic factors are the basic determinants of the plan (Elsoghier, 2018).

ENVIRONMENTAL GEOMORPHOLOGY AND SUSTAINABLE DEVELOPMENT

The present phenomenon of rising pressure on land capacity is concerned to the growing population and their requirements for survival. According to Guerra and Marcal (2005), the problems in environmental geomorphology arises mainly due to human intervention on geomorphological processes and the evolution of landforms, or the man acting as a geomorphological agent. Humans have destroyed nature due to their various harmful activities and contributed to eco- degradation hazard and spurred the need for 'eco-protection', causing geomorphology to come closer to environmental science. He, further, mentioned several relevant problems, such as the protection of the environmental diversity, establishing ecological balance, and 'eco-development' as part of conservation of the environment. Early days when there was abundant of free land, people use to choose the appreciate plot for their activities like, settlement, agriculture, livestock rearing, forest areas etc. But the scarcity of land and the effect of natural climatic as well as hazards population are forced to live in hazard prone areas. The settlements on yester decades were made considering availability of fertile cultivable land and thus all the flat river basin is found to have major population habitats. As the flat plain along the river side are rich in fertile alluvial soil are suitable for the agricultural purpose and that attracts the human settlement, but it as fact that these areas are natural hazard prone. As the origin of the fertile low land itself defines its hazardous behavior that the plain is develop along the river side due to flood and siltation in long course of time. And the phenomena still exist as long as the natural process prevails in the earth. The space facing the problem of natural hazards like flood, drought, cyclone, tsunami etc. would get encounter the same natural hazard with a frequency of interval in a regular basis. So the process of the nature couldn't be checked to have less effect in coming days while facing the hazard or even disaster. It is the concern of the humans to created the plan and development works that could reduce the worst effect if the natural calamities and to reduce it to be a minimum affect. This is possible only with a combination of work and plans, to be carried out with all the concern branches and disciplines of studies, geomorphology and environmental geomorphology plays an leading role in the process and investigation.

Geomorphology in regional studies helps to understand the physical properties of the landform and its processes involved for the development of the natural phenomenon of the region with respect to its environmental surroundings. Understanding geomorphology not only provides the base of the regional studies but also the historical background of the region, on which the present phenomenon are prevailing. Being geomorphology is another interdisciplinary subject, its better understand with help of sister disciplines as climatology, geology, mineralogy, botany, agriculture, forestry and other environmental studies too. The human brings the changes in the natural environment for living, and thus they are the prime factor involved in the slowest and sharp affect to the natural environment which led to the beginning of many natural hazards and disasters that prevails today. Thus the concern of Environmental Geomorphology exist in the functional world to understand the base of the phenomenon exist in a geographical unit of area. The Human induced changes in the environment are often considered to be a smaller and slow as the effect is not directly visible and the impact need to be analyzed critically for the batter sustainability of the natural environment. In comparison to natural hazards like landslides, mass wasting, weathering, debris flow, avalanches, volcanicity etc. are prominent natural phenomenon involving in a greater change in the landforms development processes. Which are the result of the combination of the natural forces i.e. endogenetic and exogenetic forces that prevails in the earth surface. These forces are responsible for the greater changes in the physical world of landform development, but in mean while another force the responsible in equilateral from is the human induced or the anthropogenic force. Thus to find the solution of the changing world and the demanding natural hazards and disaster all sorts of fields should be analyzed and the proper plan and management framework could be traced out for the sustainability of the natural environment and even to mitigate the worst effect of these hazards in future for the better safety and development of the mankind as well as the environment. watershed management means management of water resources, land resources, vegetation, air and also human and animal resources available within the watershed to obtain optimum sustainable benefit. It involves mainly conservation of soil against loss and management of land and water in the watershed**.** Sustainable development means the development that meets the needs of the present without compromising the ability of future generations to meet their own needs (the Brundtland report of Our Common Future, 1987).

ENVIRONMENTAL PROBLEMS

Geographers and environmentalist are interested to illustrate the issues and problems occurring in the worldwide that comprise the intensity to change the natural phenomenon of earth system. Trying to confine to geographical point of view, the problems that occurs in the earth surface that modifies the earth setting is environment problems. This includes the natural phenomenon prevailing in the earth surface, which comprises the endogenetic, exogenetic forces and well as the anthropological intervention as cultural force that modifies the natural settings in different magnitude. Environmental geomorphology are concern about the elements that are responsible for the alternating the earth surface. The natural phenomenon including endogenetic forces like earthquakes, volcano, tsunami in higher order and the geological elements like the structure, fracture, fold, faults, joints and hardness of the lithosphere. On the other hand the exogenetic element that acts for the alternating the physical earth including the geomorphological processes, fluvial, glacial, eolian, underground water, sea wave and climate. The component of cultural geography is always been there that alters the earth crust in greater extent but rarely noticed in early days. Now in present context the cultural element is termed as anthropogenic intervention in earth surface alternation.

Earthquake can be considered one of the major elements of the natural catastrophic process that transforms the earth physical settings. The study region falls in Zone 5 areas with the highest risks zone that suffers earthquakes of intensity MSK IX or greater (Medvedev–Sponheuer–Karnik scale). The Indian region of Kashmir, the Western and Central Himalayas, North and Middle Bihar, the North-East Indian region, the Rann of Kutch and the Andaman and Nicobar group of islands fall in this zone. The other aspects to consider are the geological structure of the region. Volcocity is another important sudden catastrophe changing the landscape, but are not very influential in the study area, as there is no such physical active volcocity situated around the area considered for study.

Among the exogenetic forces the fluvial process and underground water plays the vital role in the landscape transformation in the study area. The agent of landform alternation is the running water or the surface runoff in different magnitude, including surface flow, rill, gully, channel, stream and river. The factors affecting the magnitude of the fluvial phenomenon on a specific region includes the relief, gradient of slope, structure, geology, hardness of the lithosphere, weathering magnitude, intensity of water supply, climate and the vegetative coverage of the region. In addition to these natural elements the human in venture influenced the greatest.

The major problems prevails in the study region is the flood and its related problems including soil erosion, landslide, sedimentation in lower basin, siltation in flood basin, and the related socioeconomic aspects regarding loss of properties and life. The study area consist of basically two geomorphological divisions, first the Upper Jiadhal River basin which is situated in the hilly track of Arunachal Himalayas, in the West Siang District, and another in the extensive flood plain of Assam, in Dhemaji District. Thus the environmental issues and problems are considers with fluvial environmental geomorphology.

The hilly region of Arunachal Himalaya in a rough terrain with an average altitude of 800 meters above mean sea level. The lowest elevation in the river bed is found to be 200 m and the highest elevation is 1200 m. on the other hand the flood plain has the average elevation of about 100 m (80 m to 200m) and comparatively a flat land. Thus the drainage system creates a vital problem in the plains during rainy seasons due to amerce supply of water and sediments, creating a flood situation in regular interval. The human intervention in the hilly track of upper Jiadhal river basin has greatly impact the situation. The human activity if careless and incentive deforestation in the upper ridges of the basin creates the situation of vulnerability of slope aspects of the mountain system. Although the upper reaches of the Jiadhal river is highly mountainous consisting the Arunachal Himalayas , whereas the lower part of the basin in Assam is very flat and composed of Quaternary alluvial deposits. Because of geo-environmental factors like heavy rainfall, weak geology and frequent landslide activities in the upper reaches, the Jiadhal river carries high water and sediment load downstream. The high intensity of stream flow with huge sediment loads in rainy season creates hazards associated with flood, erosion, sedimentation, channel migration, normally triggered by intense rainfall episodes and river bank erosion in lower Jiadhal basin.

STUDY AREA

The study area selected for the research is a river basin of district Dhemaji, Assam, which is havoc in the form of river system. Jiadhal covers an area of 1851.43 km^2 having latitudinal and longitudinal extensions of 27^o 08' N to 27^o 45' N and 94^o 15' N to 94^o 38' E respectively. Out of its total basin area 1851.43 km^2, Arunachal Pradesh occupies 370.63 km^2 i.e. 20 % of the total basin area and rest 1480.80 km^2 i.e. 80 % of the basin area drains to the state of Assam. The basin is bounded by Moridhal river basin on the east and Subansiri river basin on the west (Gogoi, and Chetia, 2011). The river Jiadhal comprises a clear history of natural hazards associate with fluvial processes and is havoc to the lower basin as a flood prone river system. The intensity of flood is customary to lower basin areas as each year it occurs with devastation to agricultural fields, life and properties, ruining socio-economy of the lower basin. The upper reaches of the river is highly mountainous along the lesser Arunachal Himalayas and the lower part of the river is lies in Dhemaji district of Assam is a flat and composed of quaternary alluvial deposits. Because of geo-environmental factors like, high rainfall, week geology and frequent landslide activities in the upstream areas, the Jiadhal River carries high water and sediment load downstream. And due to its high water and sediment loads, geotectonically fragile environmental setting and loose nature of bank materials, the lower part of the basin is always affected by hazards associated with erosion, sedimentation, channel migration, normally triggered by intense rainfall and landslides, the Jiadhal River carries a high water resources potential that can be harnessed for agriculture, hydro power generation and various other human uses.

In view of the geomorphological, hydrological and environmental problems, the study of environmental geomorphology of the drainage basin will provide a knowledge base necessary for formulation of strategies for compressive integrated watershed management for sustainable development of the study area.

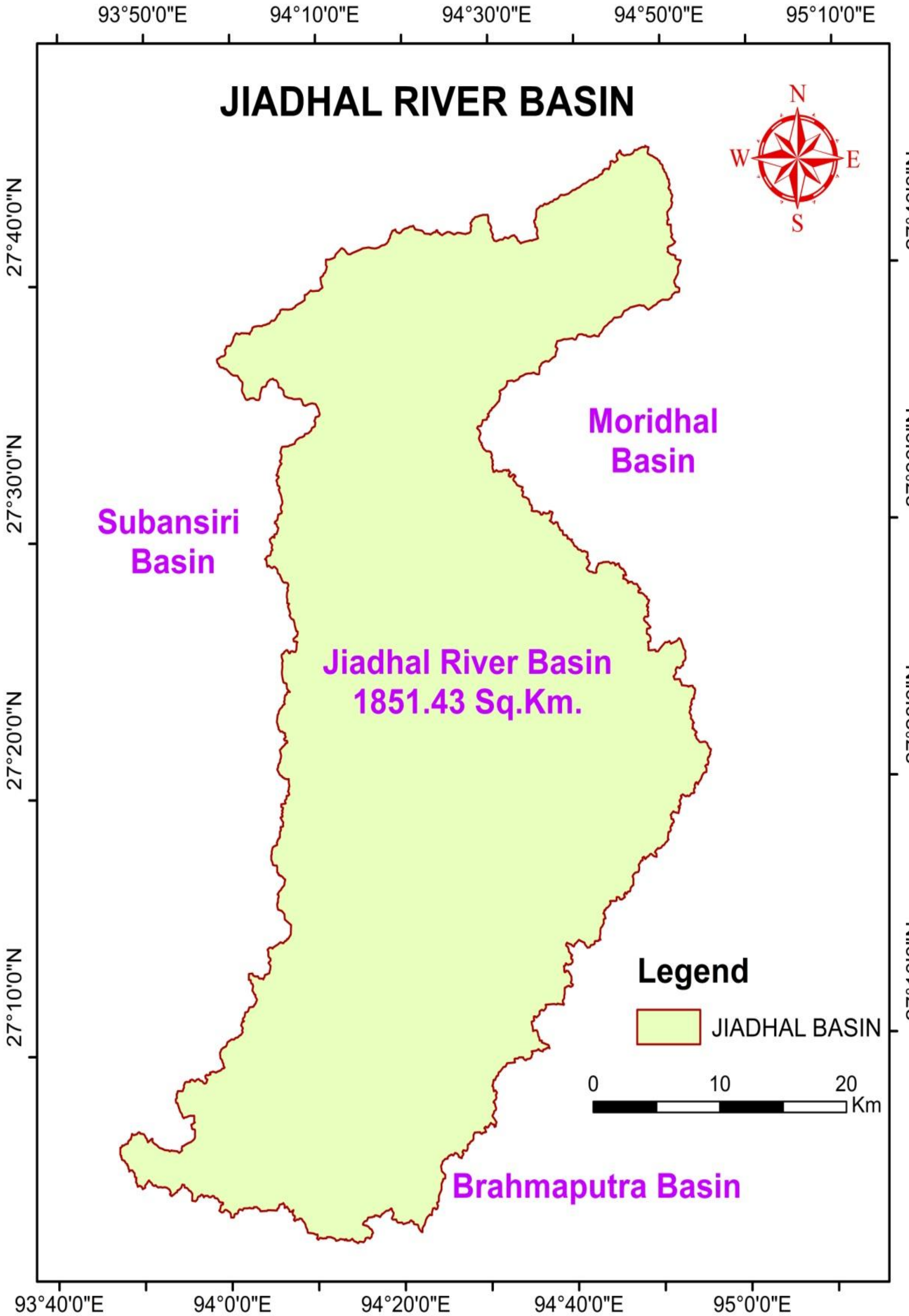


Fig.1.3: Outline map of Jiadhal River Basin.

OBJECTIVES

1. To study the geomorphological, hydrological, meteorological, topographical and anthropological characteristics of the study area.
2. To analyse the changing landuse and land cover of the Jiadhal River Basin.
3. To make a geographic appraisal of the selected headwater catchment.
4. To study the geomorphological processes and to identify the sediment sources areas.
5. To propose comprehensive watershed management plan for sustainable development of the study area.

RESEARCH METHODOLOGY

The science of geomorphology has witnessed many new approaches and the use of different tools and techniques. The data of this topic and study are available in the form of Topographical Maps, Satellite Imagery, and Aerial Photographs. The proposed study will be purely based on the field observation and data analysis using both primary and secondary data. For the primary data base field observation of the area, taking measurements and Photographs of the important affected areas following Rawat (2011), Chorley (1965,1967), Goudie (1990), Gragory and Walling (1979). and perceptions on the issues of sustainable development. For secondary data base Topographical Maps with the scale 1:50,000, hydrological and meteorological data compiled by CWC, RWD, Brahmaputra Board office, Central and State Government Departments.

The detailed research work conducted systematically as per the following methods and materials.

A. Laboratory works:-

Drawing and preparation of base maps of the study area (in Cartographic Laboratory). Delineation of identified watersheds, sub-watersheds and head-watersheds of the study area (in cartographic laboratory). Creation of spatial database of land, water and forest resources of the study area (in GIS and Remote Sensing Laboratory). Detailed study and analysis of the Topographical Maps (in cartographic laboratory).

B. Field Works :-

Collection of Primary data on Geomorphic, Hydrological processes and Socio-economic status. Collection of Secondary data from different sources- organization/ institutions/ Govt. Departments in both Assam and Arunachal Pradesh.

C. Use of Research Materials, Instruments and GIS Software:

Survey of India- Topographical Maps of Assam and Arunachal Pradesh.

Satellite imagery, Arc-GIS and ERDASIMAGINE Software, Altimeter, Current Meter, Abney Level, Brunton Compass etc. and other field equipments, measuring tape. Pedometer and GPS Handset.

REVIEW OF LITERATURE

A number of studies have been conducted so far on drainage basin as an geographical unit for environmental geographical studies as well as for sustainable development of a region, both in abroad and within India. Various sources including published research papers in national and international journals and reports of conferences and seminars conducted by various organizations were followed. Published thesis on open access portal of Indian and abroad were followed for the literature survey. Apart from mentioned sources relevant government office report and plans were consulted regarding the aspects of the studies. Few of them are mentioned below in respect of their relevance of the topic both international and national standard.

International Status of Research:

A watershed is a topographically delineated area that is drained by a stream system; it is also a hydrological unit, a biophysical unit and a holistic ecosystem in terms of the materials, energy, and information that flow through it **(**Wang, 2016). Bloom (1979) defines geomorphology as a science that deals with the systematic description, analysis and understanding of landscape and processes that changes them. Barnard et al. (2001) in the research paper examined the factors inducing the landslides in Garhwal Himalayas. The landslides in the Himalayas is triggering due to the seismic activity i.e. earthquake , mass movement and heavy rainfall along with the human interventions. Ozdemi and Bird (2009) emphasized on the drainage analysis with topographical map and DEM for detail study of drainage morphometry to determine the influence of sub-basins to flooding on the main channel. They conclude that the sub-basin with having a dam has low contribution then the others without dams. The discharge in dammed sub-basin is lower than the discharges in the free flowing sun-basins. Offiong, Uzoezie and Umoh (2018) focuses on the pattern of land use change due to human desire activities mainly influenced by economy, industrialization as well as urbanization. It emphasizes the exploitation of natural landscape for human for economic benefits. Pradhan (2011) used satellite imaginaries and DEM for mapping of landslide hazard map of the Balik Pulau area in Penang Inland of Malaysia. The result of the analysis was correlated to environmental management as well as socio-economic aspects of the studied area influencing the risk of environmental degradation, transportation and communication failure, economic crisis etc. could be reduced by proper mapping and adopting measures of management of the same for the sustainable development. Bello, Adzandeh and Rilwani (2014) had used digital elevation model (DEM) for analyzing the basin area and its morphometric aspects of the basin with ArcGIS as main tool and concluded that its application in drainage basin management is commendable.

National Status of Research:

Environmental Geomorphology involves the study of river dynamics (including runoff, discharge, erosion and many), transport of suspended sediment load and bed load. Environmental geomorphology of the Trans-Yamuna region of Allahabad was studied by Dubey, (1990) revealing various functional relationship among the complex components of factors geomorphic environment: like morphodynamic processes and associated morphological features, man as a geomorphological agent and degrading environment of the geomorphological milieu. He estimated the rates of aggradations and degradation of the Brahmaputra River in its different reaches in Assam and found that the present rate of denudation of the Himalaya may be attributed mainly and to the high susceptibility of erosion of geologic formations within the intense monsoon rainfall regime. Land capacity depends on the carrying capacity of the ecosystem including the properties of soil and rock in broader sense of geomorphology. The rock properties particularly their strength to withstand the loads and associated stresses of structure like high-rise buildings, dams, bridges, roads, canals, etc. Thus the investigation is based on geomorphological studies is pre- requisites for all the developmental activities for the intregrity and stability of the terrain and its ecosystems, Valdiya (1991,1998). The Geological Survey of India investigated on geomorphology and geohydrology of four major north bank tributary basins of the Brahmaputra and they are the Manas, the Pagladiya, the Jiabharali and the Subansiri, Goswami (1985) has studied the physiography, basin denudation and channel aggradation of the Brahmaputra River. Goswami (1998), in his Ph.D. thesis studied the fluvial processes and groundwater prospect evaluation of the lower Subansiri basin. He discussed about channel migration, morphometry and morphological changes of the basin. Goswami (1998) has analyzed the flooding of Brahmaputra basin at the back drop of unique environmental setting, heavy rainfall along with seismic and geological conditions of the region which make it one of the most flood prone area of the world. Rawat, (2011) highlighted in his book on all the aspects of applied geomorphology of a Himalayan watershed and provides a useful introductory survey for those interested in exploring practical applications of geomorphology for environmental management, watershed management and sustainable development. The main thrust of the book- anthropogenic degradation of the physical landscape is important in view of the widespread ecological imbalance being causes in the fragile mountain ecosystem of the headlong academic development in recent years. Sustainable development of a drainage basin lies in the concept of developing and utilizing land and water resources of the area in order to meet the need of the people and maintain the sustenance of the productivity and environment for the future generation also. (Chennaiah, Dutta and Dutta, 1998). The dimension of soil erosion much higher in the North East Region of India, mainly due to high rainfall and rugged topography of the region because of the steep slopes are more prone to erosion (Sharma and Mishra, 1998). The extensive shifting cultivation cannot be replaced but it can be suitably modified as per the farmers and as per the agro-climatologic setting of any zone (Ramakrishnan 1990, Borthakur 1998, Lal 1998, Mishra and Gupta, 1998). Deforestation in the upper catchment, highly meandering nature of the river in the plain are identified as the root cause of the disasters in the region (Mandira&Monimugdha, 2014). North Eastern Council (NEC) reflects that the avulsed course of river Jiadhal, a number of houses, schools and other building but agricultural lands and homestead lands were inundated by the flood water. Das, **(**2012) has conducted soil tests in 346 agricultural plots in the Jiadhalbasin of the Dhemaji district show high concentrations of coarse sand, low pH, low organic carbon and nutrients. Bormudoi, (2015) stressed on the current Disaster Management Plan of the state of Assam needs to highlight a concrete strategy to deal with the aftereffects of the sand casting in Dhemaji district. The policy of the Arunachal Pradesh disaster management opens up a scope to integrate this problem in their landslide mitigation plan. However, integrated management plan combining the both states are required for the sustainable development of the entire basin. Such management plan includes combination of structural and non-structural measures in the upstream as well as downstream to reduce degradation and erosion to cope up the natural calamities like flood and siltation in the plains of Assam. Kattelmann (1987) has produced a valuable overview of geomorphological in terms of development of Himalayan land and water resources. Among the rare studies, the works of Bartarya (1991), Validiya and Bartarya (1991), Rawat (2010) and Rawat and Furkumzuk (2012) in the Himalayan catchment ecosystems stand out as pioneering ventures.

SCOPE OF THE STUDY

Mass movement, flood and siltation are the prominent natural havoc in the proposed study area. It is necessary that the real causes of disaster should be found out and thus only a sustainable development could be attained. For the sustainable development of the Jiadhal river basin the environmental geomorphology of the river basin is given a prime trigger to desired goal of the entire drainage basin. The Jiadhal River basin geographically comprises the bi-state of Arunachal Pradesh and Assam. The upper basin of Jiadhal River exists in the West Siang district of Arunachal Pradesh and the lower basin comprise the plain of Assam, particularly the Dhemaji district.

The environmental as well as geomorphologic characteristic of the river basin depicts the real cause and effect of the entire natural hazards and disaster that prevails in the basin. The upper basin erosion and the down slope siltation is a significant issue and therefore, greatly significant for the disaster mitigation programmes. The results obtained from the proposed research will provide a wider understanding of the land and water resource, which will help their conservation and management. The work when completed will add knowledge to the subject matter in different aspects of Geography in general and Environmental Geomorphology, Applied Geomorphology, Hydrology, Meteorology, Watershed Management and Sustainable Development Plans for the region. This work will also play an important role in strengthening applied research which will highlight the need of such studies for sustainable development. Inspite of the above, this work will be helpful to environmentalist, policy makers, researchers, scientists, academician, Central and State Government officials and N.G.O's engaged in extension works, research and development at various levels of River Basin Management.

REFERENCES

Barnard, Patrick L., Owen, Lewis A., Sharma, Milap C. and Finkel, Robert C.(2001): Natural and human-induced land sliding in the Garhwal Himalaya of northern India, Geomorphology, Vol. 40, pp. 21-35.

Bartarya, S.K, (1991): Watershed Management strategies in Central Himalaya: The Ganla river basin, Kumaun, India. Land Use Policy, Vol.8, No.3, pp.177-191.

Bebarta. K.C, (2004). Forest Resources and Sustainable Development, Principle,Perspectives and Practice, Concept publishing com. New Delhi, ISBN-8180698954, pp-436.

Bello, I.E., Adzandeh, A., & Rilwani, M.I. (2014): Geoinfromatics characterisation of Brainage system within Muya watershed in the Upper Niger Drainage basin, Nigeria, International Journal of Research in Earth & Environmental Sciences, (https://www.academia.edu) Vol. 2. No. 3 pp. 18-36.

Bloom, A.L. (1979): Geomorphology: A systematic analysis of Late Cenozoic landforms. Prentice Hall of India, Pvt. Ltd., New Delhi, pp. 16-170.

Briney, A (2020): "Geography of the Ganges River." ThoughtCo, Feb. 11, 2020, thoughtco.com/ganges-river-and-geography-1434474.

Brmudoi, A. (2015): From Crisis Management to Mitigation Jia Dhal Basin, Dhemaji, conference paper, Research Gate. e-publication, https://www. researchgate.net/ publication/287999393.

Chennaiah. C. H, H. Dutta and S. K. Dutta. (1998): Remote sensing application for sustainable development of land resources- A case study of Pasighat area. Perspectives for Planning and Development in North East India, GB Pant Institute of Himalayan Environment & Development, Almora India. Pp.32-39.

Chorley, R.J. (1965): Introduction to Geomorphological Hydrology (ed.) Methun Landon, pp. 1-316.

Chorley, R.J. (1967): Water Earth and Man. Methun Landon, pp. 1-193.

Elsoghier, M. (2018): Morphometric Analysis of a selected drainage system in the northern part of the Western Desert of Egypt. International Journal in Physical and Applied Sciences Volume 5 Issue 08, ISSN: 2394-5710, pp-23-31.

Dudey, A. (1990): Environmental geomorphology: a study of Trans-Yamuna region, Inter-Indian publication, 1990, c 1986,ISBN: 8121002443, pp-59-64.

Gogoi, S and Chetia. B.C., (2011): Fuzzy role-based flood forecasting method of Jiadhal River Basin Dhemaji, Assam, India. International Journal of fuzzy Mathematics and System. www. ripublication.com , Vol.-1 No-1 pp. 59-71.

Goswami, D. C., (1985): Brahmaputra River. Assam, India: Physiography, Basin, Denudation and Channel Aggradation. Water Resource Research, 21 pp-759-798.

Goswami. D. C., (1998): Fluvial Regime and Flood Hydrology of the Brahmaputra River, Assam, In: Flood studies in India, Lle, V.S. (ed). Memoir 41, Geographical Society of India, pp.-53-75.

Goswami, D. C. (1985): Brahmaputra River, Assam, India; Physiography, Basin Denudation and Channel Aggradations, Water Resources Research, Amex Geophys Union, Vol. 21, No. 7, pp. 959-978.

Goudie, A. (1990): Geomorphological techniques, the British Geomorphological Research Group, Landon (2nd ed.) Unmin Hyman, pp. 1-570.

Gregory, K.G. and Walling, D.E. (1979): Drainage Basin: Form and Processes, Landon Arnold, pp. 1-200.

Guerr, A.J.T., and Marcal, M. D, S. (2005): Erosive Processes in Urban Areas in the Island of Maranhao-Brazil, Research Gate, Siciedade and Natureza, Uberlandia, Special Issue, pp-161-173.

Kattelmann, (1987): Uncertainly in assessing Himalayan Watershed Resources. Mountain Research and Development, 7(3). Pp. 279-286.

Kubalikova, L (2013): Geomorphosite assessment for geotourism purposes. Czech Journal of Tourism,VERSITA, vol-2(2), 80-104. DOI: 10.2478/cjot-2013-0005, pp-80-104.

Merritte. D. J (2010) : Landscapes on the edge, new horizon for research on Earth's Science, National Research Council, The Nation Academic Press, Washington, pp-164.

North Eastern Council (NEC, 2013): Evaluation of NEC funded projects in Assam "controlling of Jiadhal River in Dhemaji district, Phase I"- November, 2013.

Offiong, V.E., Uzoezie, A.D & Umoh, R.J. (2018): Spatial Variation of Commercial land Use Rental Value in Southern Calabar, Cross River State, Nigeria-A Quantative Judgement for Planning Intervention, International Journal of Innovative research and Advance Studies(IJIRAS) Vol. 5. No. 1. pp-122-128 .

Ozdemir, H., & Bird, D.(2009) Evaluation of morphometric parameters pf drainage networks derived from topographical maps and DEM in point of floods. Environ Geol, (https://www.academia.edu) 56;1405-1415.

Pradhan, B., Mansor, S., Pirasteh, S and Buchroithner, M.F (2011): Landslide hazard and risk analyses at a landslide prone catchment area using statistical based geospatial model. International Journal of Remote Sensing, Vol. 32, No. 14, pp-4075-4087.

Ramakrishnan, P.S. (1990): Agriculture system of the North Eastern Hill Region of India. In: Agro-ecology: Researching the ecological basis for sustainable agriculture.

Rawat, M.S. (2010): Environment, Tribal culture and Resource management in Kiliki watershed of Zunheboto Hlls, Nagaland, Biodiversity to Biotechnology: Intellectual Property Rights (Kumar, A. & Sas, G. eds),. Narosa Publishing House, New Delhi, pp. 129-160.

Rawat, M.S., (2011): Environmental Geomorphology and Watershed Management. Concept Publishing Company Pvt. Ltd. New Delhi, pp.-1-286.

Rawat, M.S, Furkumzuk, C. 2012: Environment, Development and Prospects of Sustainable Development in the Kiliki Watershed of Zunheboto District, Nagaland: Indian Journal of Environmental Studies, ISSN: 2278-8220 Vol-01, issue-01,september, 2012. pp-26-43.

Sharma, U.C. and Mishra, A. K. (1998): Deforestation in North Eastern region of India and traditional wisdom in range management for resource and environment conservation. International symposium on agro-environmental Issues and future strategies: Towards 21st Century, May 25-30, 1998, University of Agriculture, Faisalabad, Pakistan.

Taha, M.M., Elbarbary, S.M., Naguib, D.M. and El-Shamy, A.Z., (2017): Flash flood hazard zonation based on basin morphometry using remote sensing and GIS techniques: A case study of Wadi Qena basin, Eastern Desert, Egypt, Elsevier, Remote Sensing Applications: Society and Environment, Vol-8, pp-157-167.

UNEP (2006): Environment and Disaster Risk Emerging Perspectives, ISBN: 978-92-807-2887-3 https://postconflict.unep.ch/publications/env_vulnerability.pdf, pp 1-34.

Valdiya, K.S. and Bartarya, S.K. (1991): Hydrological studies of springs in the catchment of Ganla river Kumaun Lesser Himalayas, India. Mountain Research and Development, Vol.11. pp-239-258.

Valdiya, K.S (1998), Dynamic Himalaya, University Press India p.ltd, Hyderabad pp-179.

WCED (1987): Our Common Future, the World Commission on Environment and Development, Sustainability, Oxford University Press, pp- 383.

CHAPTER-2

GEOGRAPHICAL OVERVIEW OF THE JIADHAL RIVER BASIN

INTRODUCTION

The chapter triggered to understand the significant location of the study area in the broader section the North Eastern Region of India and find its justified explanation. The environmental geomorphology is more or less confined to a vast geographical region with homogeneous characteristics on the variables that control the environmental phenomenon. Thus a strategic study would help to understand the watershed regime with a unique geographical region and the study area, Jiadhal River Basin is a part of the Subansiri basin which is the largest tributary to mighty Brahmaputra. Thus, Brahmaputra regime which dominates the entire North Eastern Region of India is considered as higher order geographical unit mainly in contrast to river basin environmental geomorphology.

THE NORTH EASTERN REGION OF INDIA

The North East India or the North Eastern Region of India is the easternmost geographical identity of India. North East India is organized of eight states- Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura and Sikkim. The aerial extension of the region is 2,62,230 sq.km situating 21^{0}56'N to 29^{0} 22'N latitudes and 28^{0} 0' E to 29^{0}22' E latitudes and extended up to 27^{0}7' East latitude along western margins of Sikkim. The North Eastern region is predominantly concern to the Mighty Brahmaputra River and its tributaries along with mountains tracks of Eastern Himalayas and the Purvanchal hilly ranges. The Brahmaputra basin spread over 580,000 sq.km which covers China (50.5%), India (33.6%), Bangladesh (8.1%) and Bhutan (7.8%), (Singh and Sharma et.al, 2004) The basin lies between 88°11'E to 96°57'E longitudes and 24°44'N to 30°03'N latitudes and covers as area of 1,94,413 sq.km. Indian Part of Brahmaputra basin is spread over the states of Arunachal Pradesh, Assam, West Bengal, Meghalaya, Nagaland and Sikkim (Kar, 2012). Towards the north the Greater Himalayan ranges bordered as water divide from the Chinese part and along the eastern margin lies over the Patkai ranges running along the India-Myanmar border. The Barial range to the south demarcating Chindwin River basin flowing to Myanmar and the ridges of Himalaya (Siwaliks) and Darjeeling Himalayas separate it from the Ganga Basin to the west.

The climate of North East Region experiences summer, monsoon and autumn / post monsoon followed by winter season. The basin experience heavy rainfall during summer and monsoon season also its intensity remains active during retrieving monsoon waves that means the region experiences rainfall throughout the year. The maximum and minimum temperature of the basin is 16 °C and autumn 38 °C respectively and the rainfall intensity is more in southern part of the basin and experiences 6000 mm per annum. The Himalayan peaks experiences lowest temperature and snowcap prevails there.

The major portion of the basin is occupied by natural forest vegetation. The low-lying areas along the Brahmaputra valley are water logged wetland areas with huge drainage network. The predominant soil type found in the basin is the red loamy soil and alluvial soil and other important soil are sandy, loamy, clayey soil, their combinations and literate soil along the hill ranges. The entire north east region of India falls in the Eastern Himalayan agro-climatic zone (Planning Commission,1989). The north eastern region further subdivided into three agro-climatic zones. Most of the northern part of north eastern region falls in the 'warm pre humid eco-region with brown and red hill soils'; The central Brahmaputra valley area is dominated by ' hot sub-humid (moist) to humid eco-region with alluvial derived soil'; and the southern part is falls under 'warm pre-humid eco-region with red and lateritic soil'(CWC, 2011). Geologically the entire region except the portion of West Bengal and Sikkim falls under the category of 'seismic zone-V' and thus are prone to seismic and tectonic activities, the Seismic zone-IV occupies the W. Bengal and Sikkim Himalayas.

The North Eastern Region of India is categorized mainly in five physiographic divisions (NATMO, 1981).

Assam Valley: It is an elongated and narrow flood plain valley extended about 640 Km length and width varies from 60 to 90 km. The valley exist in between the Himalayan ranges in the north and the Patkai hills in the east, the Meghalaya plateau towards the western margin and it continued to the extensive plain extended in Bangladesh. The valley comprises about 56,274 Km2 extending from Arunachal foothills to Bangladesh border.

North Bengal Plain: A narrow steep of about 150 m along the Sikkim Himalayan foothill towards the western margin to West Bengal around the bottle neck corridor of Sikkim and Konchbehar area.

Eastern Himalayas (East): The region comprises the highest mountain tracks of Eastern Himalayas from Sikkim Himalaya, Arunachal Himalaya and extend to the deep gorges of Brahmaputra river in Arunachal Pradesh.

Meghalaya and Mikir Region: This is a plateau region comprising an extension of Deccan plateau with a highest elevation of 2000 m along Khasi and Jayantia hills of Meghalaya. Average elevation of the Mikir hills average elevation is 1000 m adjoining to isolated hills of Karbi- Anglong and North Kachar hill districts of Assam, the hilly tracks extended to Nogaon, Golaghat, Tezpur areas of Assam with an average elevation of 700m.

<u>Purvanchal ranges</u>: Purvanchal ranges occupies the eastern part of Brahmaputra basin comprising part of Naga hills, Tirap tracks and the Lohit of Arunachal Pradesh, the elevation increases towards north-east and altitude ranges from 900-2100 m, covering Naga hills. The East Arunachal Himalayas have average elevation of 3000m. Purvanchal hilly ranges runs parallel form south-west to north-east direction.

The study area is situated in the lower Siwalik range of Eastern Himalaya and the northern Brahmaputra valley (Fig. 2.1). The Brahmaputra Valley is mainly a Quaternary filled valley with a few isolated sedimentary residual hills in Upper Assam and inselbergs and hills of gneissic rocks in the Darrang, Kamrup, and Goalpara districts. The drainage pattern in the valley apparently seems to be of antecedent type. The often changing meandering course of the Brahmaputra and its tributaries are not only due to lateral erosion because of the low gradient of the rivers but also due to periodic, local and sudden changes in the basement levels due to the neo tectonic activity in the region and are found responsible in Jiadhal too (Kesari, 2009).

Geological characteristic of the basin the reveals that along the northern foothills of Eastern Himalaya facing the northern border of Assam a narrow strip of Siwalik rocks are exposed the Quaternary deposits comprising of Older and Newer Alluvium occur in flood plains and terraces of the Brahmaputra valley, Surma valley and other river basins of Assam (Keshri, 2009). In Upper Assam, Disang Group comprises of a thick sequence of alternating splintery shale with thin partings of hard greyish flaggy sandstone and sandy shales (Kesari, 2010). They are generally iron stained, light to dark grey and carry fine streaks of carbonaceous matter. Along the northern border of the state, facing the southern foothills of eastern Himalayas, light greyish, fine to coarse, micaceous sandstone having a typical "pepper and salt" texture with thin beds of shale are exposed below the terrace deposits. The group designated as Subansiri Formation of Siwalik Group is equivalent to Tipam Group. These sandstones are invariably associated with fragments of semi silicified, semi carbonized fossil wood, with minor seams of lignite and rarely with thin impersistent layers of pebble. The shale is rarely carbonaceous. The Siwalik beds are well exposed in Subansiri river section in Dhemaji, Lakhimpur district and Bharali River in Darrang district (Kesari, 2010).

<u>Siwalik Group</u>: The Siwalik Group is bounded to the north by the Main Boundary Fault along which the Pre-Tertiary sequence has been brought over. The southern extentions are the quaternary deposit of old and new alluvium of the Brahmaputra River. Karunakaran and Rao, (1979) classified the Tertiary sequence of Arunachal Pradesh foothills into Dafla, Subansiri and Kimin Formations broadly corresponding to the Lower, Middle and Upper sub-divisions of the Siwalik Group of northwestern. The Subansiri Formation is represented in the area by micaceous massive fine to medium grained pale brown sandstone while the Kimin Formation in the area comprises soft, grey sandstone with bands of claystone. The Lower, Middle and the Upper Siwalik are separated from each other by reverse faults and the three units are stacked in a reverse stratigraphic order (Chakraborty, 2000). A generalized description of the Upper, Middle and Lower Siwaliks is given below:

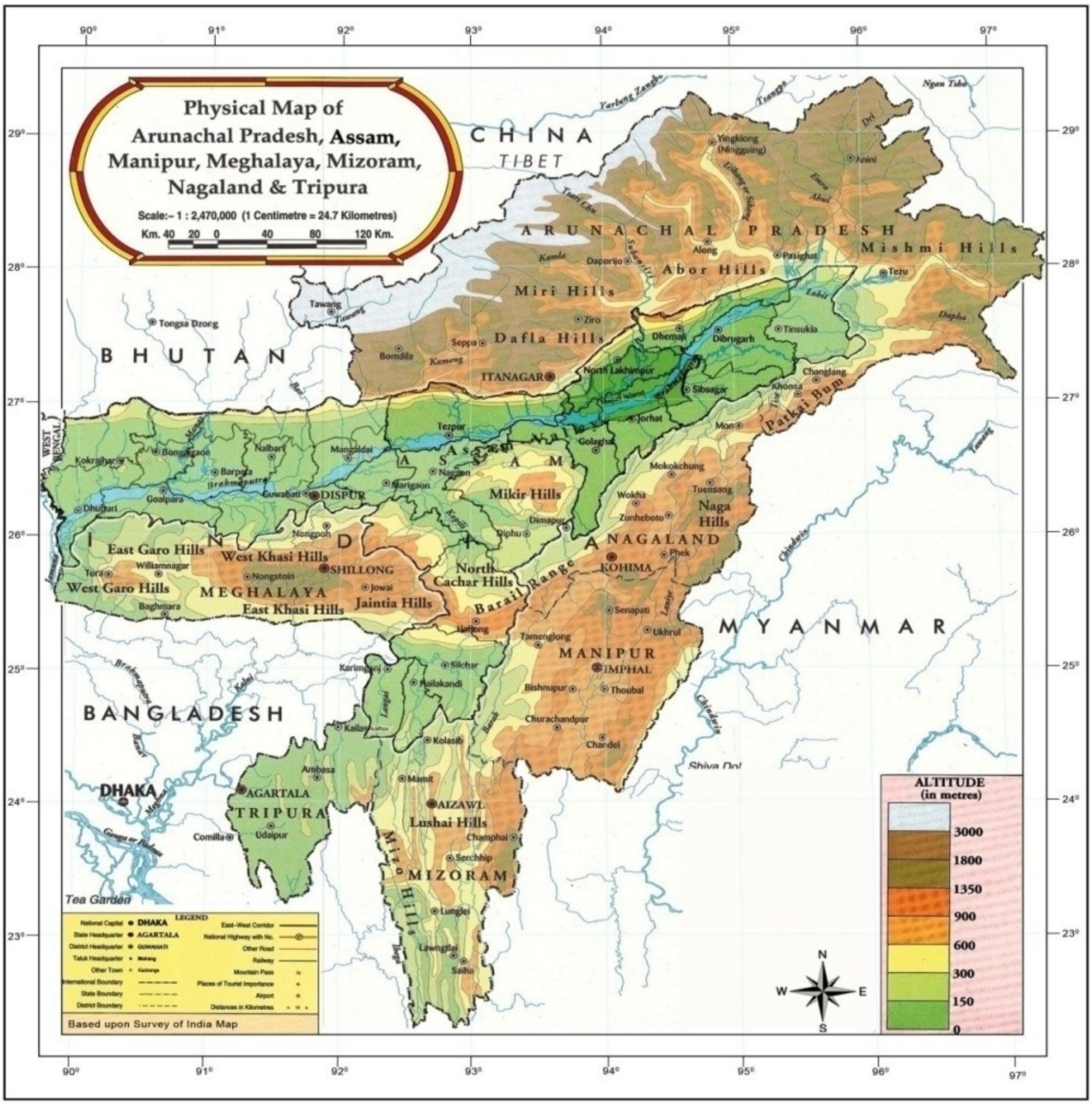


Fig. 2.1: Physiographic map of North east India, excluding Sikkim (source: AWRMI, Guwahati, 2018.)

(i) <u>Kimin Formation (Upper Siwalik):</u> Best developed sections of the Upper Siwalik are found east of Bhareli River, between Banderdewa and Itanagar and around Kimin and Likabali. The lithology is mainly represented by loosely packed very coarse to fine grained, friable, grey sandstone which is highly limonitised at places. The sandstone is pebbly at places and is intercalated with claystone and shale which are frequently nodular. The boulders are of quartzite, gneiss, granite, schist and basic rock. Petrified and carbonised wood fragments upto 2 m in length and charcoal clasts are often found. Several isolated thin outcrops of calcareous sandstone have been reported from the area from the south of MBF to the north of MBF at Sissni, Sessa, Rengging near Pasighat (Liebke, Antolie and Appel (2011)

(ii) Subansiri Formation (Middle Siwalik): The Middle Siwalik rocks are generally poorly indurated, medium to coarse grained, salt and- pepper textured multistoried sandstone with calcareous concretions of various shapes and sizes and grey shale intercalations. Conglomerate bands are noted in the Foothills-Chaku section and Siku river section.

(iii) Dafla Formation (Lower Siwalik): It consists of indurate, medium to fine grained, well sorted, bluish grey sandstone, subordinate feldspathic micaceous sandstone and bluish grey, greenish grey and nodular silty shale. Commonly observed bedforms in the Lower Siwalik are laminated to massive, large trough cross beds, festoon cross beds, planar curved cross beds, tabular cross beds and ripple cross laminations (Chakraborty, 2000).

(iv) Hapoli Formation (Newer Alluvium): This is also represented by two levels of terrace deposits comprising unoxidised sediments of the active channels found in all the rivers. The limnic deposits in Arunachal Pradesh are encountered over a large area around Hapoli in the Ziro valley. The sequence designated as Hapoli Formation comprises sand, clay and peat. The Hapoli Formation is considered equivalent to the Karewa Group of Kashmir valley (Kar, 2012).

Drainage: The river Brahmaputra receives a number of tributaries at its north and south banks, in the catchment area in India.

Table 2.1: The major tributaries to Brahmaputra

North bank Tributaries	South bank Tributaries
The Siang	The Noa Dehing
The Semen,	The Buridehing
The Gai,	The Debang
The Jiadhal	The Dikhow
The Subansiri	The Dhansiri(S)
The Ranga Nadi	The Kopili
The Dikrong	The Digaru
The Kameng (Jiabharali in Assam)	The Dudhnai
The Dhansiri(North)	The Krishnai
The Puthimari	
The Pagladiya	
The Manas	
The Champamati	
The Saralbhanga	
The Aie	
The Sankosh	

Along the northern bank, the Brahmaputra River is joined by the tributaries like Subansiri, Ranga Nadi, Dikrong, Gabharu, North Dhansiri, Pagladiya, Manas, Aie, Beki, Champamati, Gangadhar, and Raidak are mainly perennial river system. The characteristics of this river are mountainous origin, and all these tributaries are more or less flow in straight courses up to the junction of the main river. On the south bank tributaries like Benhi-Dihing, Disang, Dikhau, and South Dhansiri originate from Naga- Patkai Hills. The Kopili River originates from North Cachar Hills, while the Digaru, Bharalu, Kulsi, Singra, Dudnai and Krisnai originate from Meghalaya Plateau (Kesari, 2010). The Subansiri Basin is the main and the largest sub-basin of the mighty Brahmaputra River Basin and the Present study area 'the Jiadhal River basin' is a catchment of lower Subansiri basin originating in the hilly terrain of Arunachal Himalayas and flowing to the narrow flat flood plains of Assam.

The Subansiri River Basin: The Subansiri is one of the principal tributaries of the Brahmaputra River and forms one of its largest sub basins. It originates in the Great Himalayan range (central Himalaya) in Tibet at an altitude of about 5,340 meters m.s.l and then flows through the hills of Arunachal Pradesh and plains of Assam before it reaches its confluence with the river Brahmaputra. The Subansiri basin lies in between latitudes 26^{o} 54'14.72 " N and 28^{o} 55'24.79" N, and longitudes 91^{o} 33'09.83" E and 95 ^{o} 04'38.44" E (Boruah, 2000). The catchment area of the sub-basin partly lies in the Himalayan ranges of Arunachal Pradesh including Tibet and partly in the Himalayan foothills of Assam. The river, as it approaches the Miri hills in the Arunachal Pradesh after crossing the international boundary runs through deep gorges to the valley. The main course of the Subansiri after entering the Arunachal Pradesh runs between Dafala and Abor hills. Debauching from the hills near Dolongmukh the course of the river lies in the fertile plain of Dhemaji, North Lakhimpur and Majuly districts of Assam. In the broad and flat valley, the river flows in lazy and sinus curves. Subansiri is a composite basin with three major sub basins viz. the Ranganadi sub basin and Dikrong sub basin both in the northern and south western part of the Lesser Himalayan zone and Jiadhal in the south eastern foothill flow through the hilly terrain to the plains of Assam and finally meet the Subansiri before the latter meets the Brahmaputra.

THE JIADHAL RIVER BASIN

The river is a venture of three streams namely Siri, Sika and Sido and enters the plains of Assam and named as Kumotia or Jiadhal and subsequently flows to Subansiri River. These river tributaries has its origin in the hilly track of the Arunachal Himalayas, particularly east of the Subansiri River valley situated in the lower Abor Hills in the Kangku

Circle, West Siang District of Arunachal Pradesh (Gogoi, 2013). Flowing through narrow gorge in Arunachal Pradesh Himalayas, it enters the plains of Assam in Dhemaji district where it flows in braided channels. The river has different local names it known as 'Kumotiya' from the Railway line to the Gogamukh – Ghilamara P.W.D. road and there after it is known as the river 'Sampara'. The river use to finally debouch into the river Brahmaputra near Selamukh. But after construction of the embankment over the Kherkutiya Suti of the Brahmaputra, the river diverted and now flows into the Subansiri River (Dhemaji Handbook, 2011).

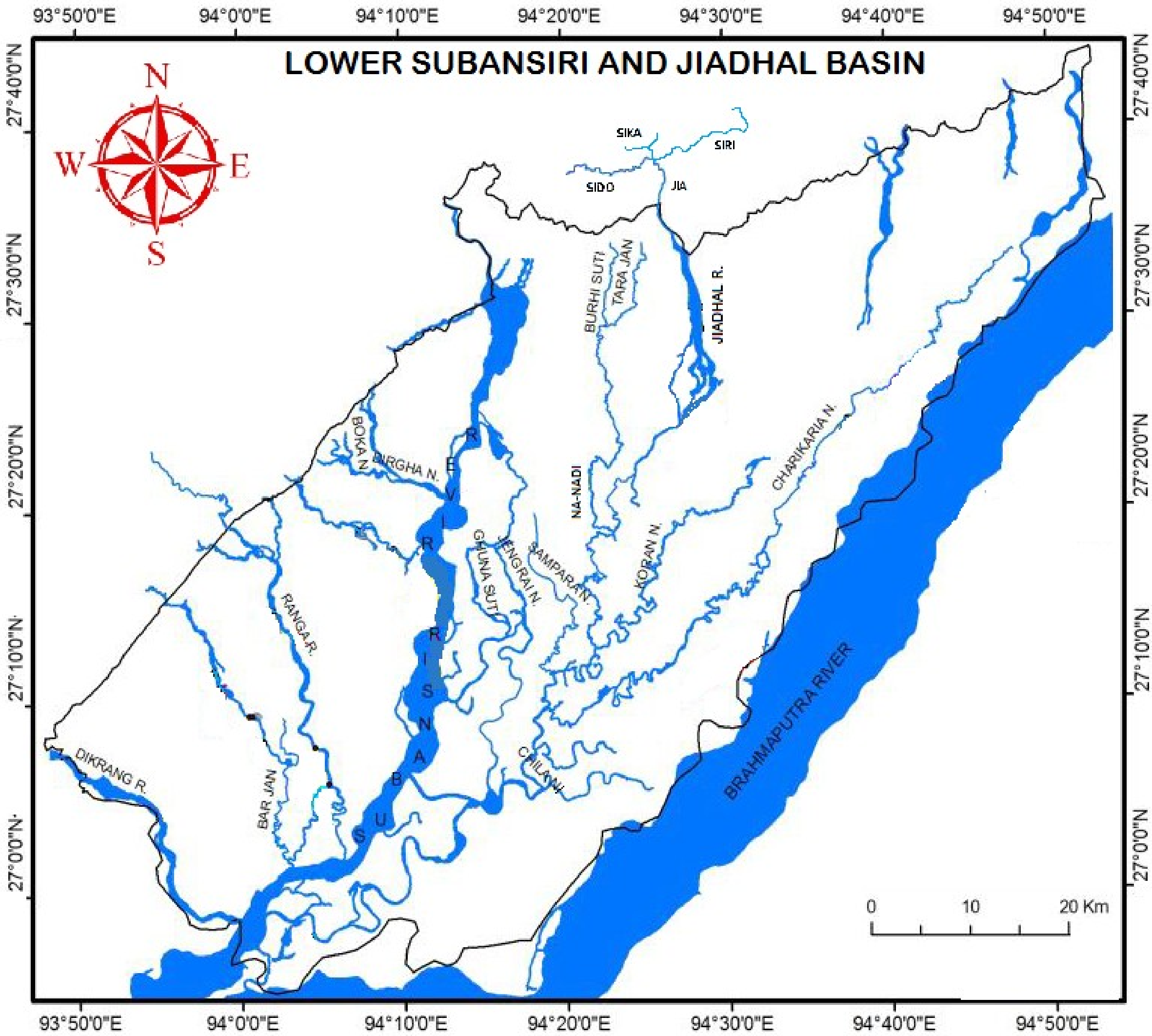


Fig. 2.2 : The Lower Subansiri and Jiadhal river basin (Map after DC Goswami, 1985)

<u>Physical Background</u>: The total catchment area of the river Jiadhal is 1851.43 sq. km of which 370.63sq. Km (20%) is in Arunachal Pradesh and 1480.80 sq. Km (80%) is in Assam. The whole sub-basin experiences heavy rainfall. The average annual rainfall of Dhemaji is recorded 3,500 mm. The basin is adjacent to Moridhal river basin in the east, Subansiri river basin in the west and River Brahmaputra in the South. The river basin is prone to landslide and severe soil erosion in the hill slope of Arunachal Pradesh results a huge discharge of sand and silt to the low lying plain of Dhemaji of Assam. Due to tradition of forest degradation, the slope of the upper basin is vulnerable to massive erosion and landslides during the monsoon and flood seasons.

Plate. 2.1: a) Jiadhal foothill area, b) Jiadhal outlet c) Jiadhal Tin-Suti Junction upper basin, and d) Bleaching point in lower basin.

Jiadhal extended to a distance of 65 km through mountains and hills and after passing through a narrow gorge in Arunachal Pradesh river enters the plains of Assam in Dhemaji district where it flows a braided pattern (Gogoi, 2013). The river in the downstream did not have a permanent course and thus subjected to frequent shifting of the river as per the trend of the river history. The river Jiadhal carries heavy silt load from the heavy catchment area during peak flow and deposits the silt on its bed in the plains. Due to this fact, the riverbed has risen up considerably with braided stream pattern (Gogoi, 2013). The main tributaries in plain of Assam are Na-Nadi, Koran, Charikaria, Chila , Sampara, and Jengrai Fig. 2.2)

Physiography and Geology: The Jiadhal Basin is a part of the greater Subansiri drainage basin and characterized with physiographical variation from a flat flood plain in Assam to hilly tracks of Siwaliks in Arunachal Pradesh. The Geology of Jiadhal basin reflects the Pliocene-Pleistocene age and the terraces of Siwalik groups are lying in the lower Arunachal Himalayas comprising the Kimin and Subansiri formation consisting soft sandy, silt, clay, conglomerates, grit and micaceous sandstone respectively.

Table 2.2: Stratigraphic sequence of Jiadhal River Basin

Age	Group Name	Formation (Thickness)	Lithology
Middle to Upper Pleistocene	Quaternary Sediments	Older Alluvium	Unconsolidated sediments represented by boulders, cobble, pebble, sand and sandy clay beds
-------------------------- Main Frontal Fault -------------------------------			
Mio-Pliocene	Siwalik Group	Kimin Formation (Upper Siwalik)	Boulder conglomerate, pebble, Sandstone with clay stone
Mio-Pliocene		Subansiri Formation (Middle Siwalik)	Micaceous sandstone, Salt and pebble lithic arenite
Miocene		Dafla Formation (Lower Siwalik)	Micaceous sandstone with calcareous concretions

Sources: Geology and mineral resources of Assam geological survey of India,2009 Miscellaneous Publication No. 30 Part IV Vol 2(i) Assam , Geology and mineral resources of Arunachal Pradesh geological survey of India,2010 Miscellaneous Publication No. 30 Part IV Vol I(i) Arunachal Pradesh .

Quaternary Sediments: The post-Siwaliks quaternary sediments of Arunachal Pradesh are represented by fluvial deposits. The fluvial deposits occur as two to three cycles of valley fill deposits exposed at different levels on either side of almost all the river valleys. These are broadly classified into an Older Alluvium of the Brahmaputra Plain (Middle to Upper Pleistocene) and a Newer Alluvium of Holocene to Recent age. The Brahmaputra valley covered by the Pleistocene and Recent alluvial deposits represents the easterly extension of the Indo-Gangetic alluvium (Kesari, 2010).

Table 2.3: Tectonostratigraphic succession of the Palaeogene-Neogene sequence of Arunachal Himalaya.

Permian	Gondwana Group
	------------------------- Thrust ----------------------------
Palaeogene	Rengging Formation/ Kimin Beds
	---------------- Main boundary faults -------------------
Neogene	Lower Siwalik (Dafla Formation)
	------------------------ Thrust ----------------------------
	Middle Siwalik (Subansiri Formation)
	------------------------- Thrust ---------------------------
	Upper Siwalik (Kimin Formation)
	---------------- Main Frontal Fault --------------------
Quaternary	Assam Alluvium

Sources: Geology and mineral resources of Arunachal Pradesh GSI,2010. Miscellaneous Publication No. 30 Part IV Vol I(i) Arunachal Pradesh .

Siwalik Group : The upper tertiary (mio-pliocene) molassic sediments consisting the Siwaliks occurs as a linear belt along the foothills of Arunachal Himalayas adjacent to Assam plain. Siwalik group is bounded to the north by the Main Boundary Fault along which the pre-tertiary sequence has been brought over. Its southern limit with the alluvium of the Brahmaputra River is also at places marked by a tectonic plane-the Foot Hill Fault. Karunakaran and Rao at Kesari et.al (1979) classified the Tertiary sequence of Arunachal Pradesh foothills into Dafla, Subansiri and Kimin Formations broadly corresponding to the Lower, Middle and Upper sub-divisions of the Siwalik Group of northwestern The Lower, Middle and the Upper Siwalik are separated from each other by reverse faults and the three units are stacked in a reverse stratigraphic order (Chakraborty, 2000). The Subansiri Formation is represented in the area by micaceous massive fine to medium grained pale brown sandstone while the Kimin Formation in the area comprises soft, grey sandstone with bands of claystone. Dafla Formation (Lower Siwalik) is consists of indurated, medium to fine grained, well sorted, bluish grey sandstone, subordinate feldspathic micaceous sandstone and bluish grey, greenish grey and nodular silty shale. (Chakraborty, op. cit.). Sandstone and shale of the Lower Siwalik are rich in plant fossils and have yielded dicotyledon leaf impressions, stems and seeds. Subansiri formation (middle Siwaliks) is generally poorly indurated, medium to coarse grained, salt and- pepper textured multistoried sandstone with calcareous concretions of various shapes and sizes and grey shale intercalations. Bed forms in the middle Siwaliks are tabular cross beds, amalgamated planar and curved cross beds, plane laminated beds, curved crested and ripple-cross lamination.

Soft sediment deformational structures such as convolute lamination, flame structure and clastic dykes are very common. Kimin formation (upper Siwaliks) around Kimin and Likabali. The lithology is mainly represented by loosely packed very coarse to fine grained, friable, grey sandstone which is highly limonitised at places. The boulders are of quartzite, gneiss, granite, schist and basic rock. Petrified and carbonised wood fragments upto 2 m in length and charcoal crusts are often found.

GENERAL PHYSICAL GEOGRAPHY

The Study area is situated in the trance physiography of Himalaya consisting 20% of the northern part in mountainous terrain and the rest is a comparatively low flood plain. The northern terrain is dominated by Siwalik mountain system of Himalayan ranges followed by foothills areas to extensive flood plain towards the south. The width of the Siwalik ranges varies from 10 to 50 km, their average elevation is 250 to 2,000 m. The Siwaliks lithologies belongs to the Tertiary deposits and are mainly composed of sandstone and conglomerate rock formations and so are fragile in nature (Dhital, 2015).

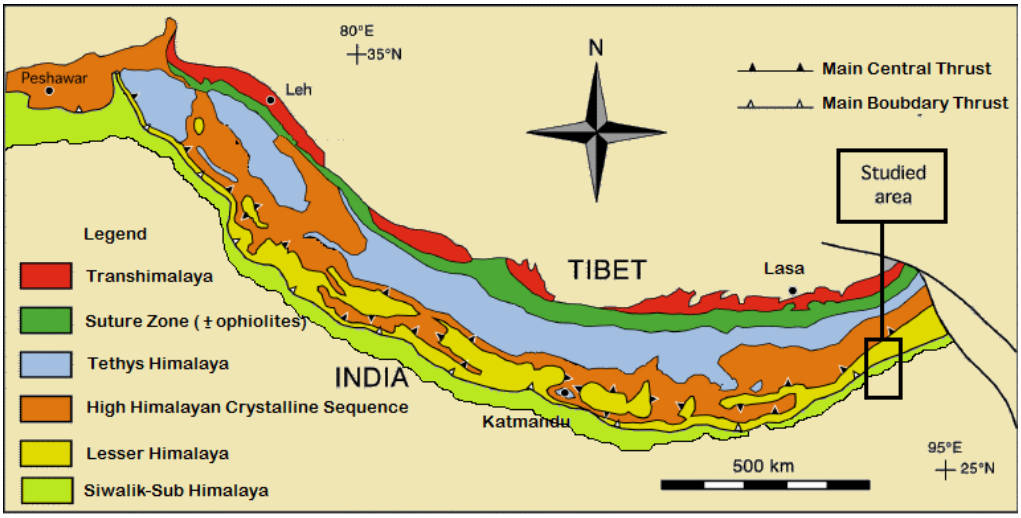


Fig.2.3 : Geology of Himalaya and the location of Study Area. (Map after GSI.2009)

The Siwaliks are poorly consolidated, due to high fragile and structural composition mainly resultant of the different fringes of the mountain building processes and different intensities of folding and faulting. The rugged Siwalik ranges are commonly broken by south facing scarps, which on their steepened northern slopes dash down rushing streams through unending cascades and waterfalls. The numerous river and streams flowing south ward from the Himalayas plays an important role on the discontinuity of the Siwaliks. The ranges of lofty hillocks are found in this region with deep down cutting river beds and valleys. This ranges or sub-ranges are bounded on the north by the Main Boundary Thrust separating it from the Lesser Himalaya and towards the south by a fault system called the Main Frontal

Thrust or Himalayan Frontal Fault, with steeper slopes on that side, Acharya and Saha(2013) (Fig.2.3) . The Foothill and the piedmont region of the Siwalik are constituted by coarse alluvial Bhabar zone makes the transition to the nearly level plains mainly comprises of boulders and regolith deposits. The Bhabar region are characterized by shallow river zone called blind valleys, as the surface runoff get vanished under the regolith and boulders of the bhabar and is predominantly dominated by depositions of regolith and boulders extended to the new alluvial plain or Khadar. Khadar is the swamps or marshy plains which forced the water to regain surface runoff as springs and marshes along the southern edge of the Terai belt. This region is water saturated and thus the surface run off of the blind valleys of Bhabar reappears and the rivers get continues surface flow.

<u>Drainage of Himalaya</u>

The Himalayan Mountain is purely dissected by the trance drainage system prevailing since its evaluation as the rivers are said to be existed even when the mountain building process was active. The lofty young fold mountain ranges of Himalayas are thus dissected severely by these drainage systems bisecting the Himalayan ranges into slices. Almost all the river system of Himalaya has the characteristics to be trance Himalayan drainage system as their origin is beyond the mountain range and all have dissected it to flow southward to Great Indian Plain including the Ganga, Kali, Kali-Gandaki (Gandak) Arun (Koshi), Tista, Manas, Subansiri, Dibang and Lohit Rivers. The study region 'The Jiadhal River Basin' is an important part of the Subansiri River Basin and occupies a vulnerable geographical unit with lots of natural characteristics of the Brahmaputra flood plain.

The Subansiri is one of the largest north bank tributaries of the river Brahmaputra. The Subansiri Basin comprises of the hilly terrain, deep gorges and river valley terraces. Its upper basin covers the part of districts of Upper Subansiri, Lower Subansiri and Kurung Kumey while lower basin comprises of parts of Lakhimpur Dhemaji and Majuli districts (Choudhury and Sen, 1977).

The geology of the terrain is dominated by sandstone and a part of the Kimin and Abor formation of Arunachal Himalayas. According to the Geological and Mining report of Arunachal Pradesh, the Sub-Himalaya or the foothill is represented by the Siwalik hill range varying in width from 10 to 20 km and the altitude ranges from 250 m to 2000 m, the study area situated in this belt. The Himalayan landform, in general, represents a mega folded, faulted and thrusted terrain. The region is fragile in terms of rock strength and composition, so are prone to erosion and landslides. Due to presence of geological fractures like tectonic lineament and heterogeneity in lithology with approaching immaturity of dissection, this landform has attained a high degree of relief. The drainage system prevailing in the area is mainly of youth state and so is pronounced in fluvial processes and is responsible for the degradation of the region. In this process the region is dissected into a macro relief of parallel ridges and valleys with the characteristics of landforms led by fluvial erosion. Coggin Brown (1912) worked on the Abor Volcanics and brought it in the stratigraphic map of India. Ghosh, (1935) made geological observation along the left bank of Dibang River. The upper Jiadhal basin is situated in the Kangku circle of West Siang district of Arunachal Pradesh (Fig.2.4).

GENERAL HUMAN GEOGRAPHY

Upper Basin - West Siang District of Arunachal Pradesh

West Siang District of is located in the central part of Arunachal Pradesh. It lies between 27°29'N – 29°23'N latitude and 94°02'E – 95°15'E longitude. The area is bounded in the north by Tibet (China), on the east by East Siang and Upper Siang districts, on the south by Dhemaji district of Assam and on the west by Upper Subansiri and Lower Subansiri districts of Arunachal Pradesh. The district measures an area of approximately 8,325 square kilometers. The entire district is mountainous terrain forming a part of the Eastern Himalayas. West Siang district presents a varied topography of hills and perennial rivers that dissect the mountains into deep gorges and narrow valleys. The study area is the southern most part comprising Kangku circle of the district.

Demography of West Siang: According to the 2011 Census West Siang district has a population of 112,272. The district has a population density of 13 persons per square kilometer. Its growth rate of population over the decade 2001–2011 was 8.04%. The sex ratio of West Siang is 916 females for every 1000 males, and a literacy rate of 67.62%. The Study area is located in the Kangku circle under Likabali development block consisting 21 revenue villages with 418 households having a total population of 2114 of which 1047 are male and 1067 are female population (MSME 2014). The indigenous population is Scheduled Tribe (ST) population and its concentration is highest in this belt comprising total population of 2041 of which 1012 is male and 1029 is female ST population remaining are literally outsiders and thus comprises a little amount of population. The sex ratio of the districts is 913. Various tribal and sub-tribes of the Adi people comprises Galo, Minyong, Memba and Khamba tribes live in the district. The Adi follow generally follow Donyi-Polo, although some have embraced Baptist, Catholic and Revivals Christianity in recent years (Borbora and Post, 2008). The study area is predominated by Adi-Galo tribe and the remaining population comprises mainly of outsiders who are mainly government service personals and population engage in business and labourers.

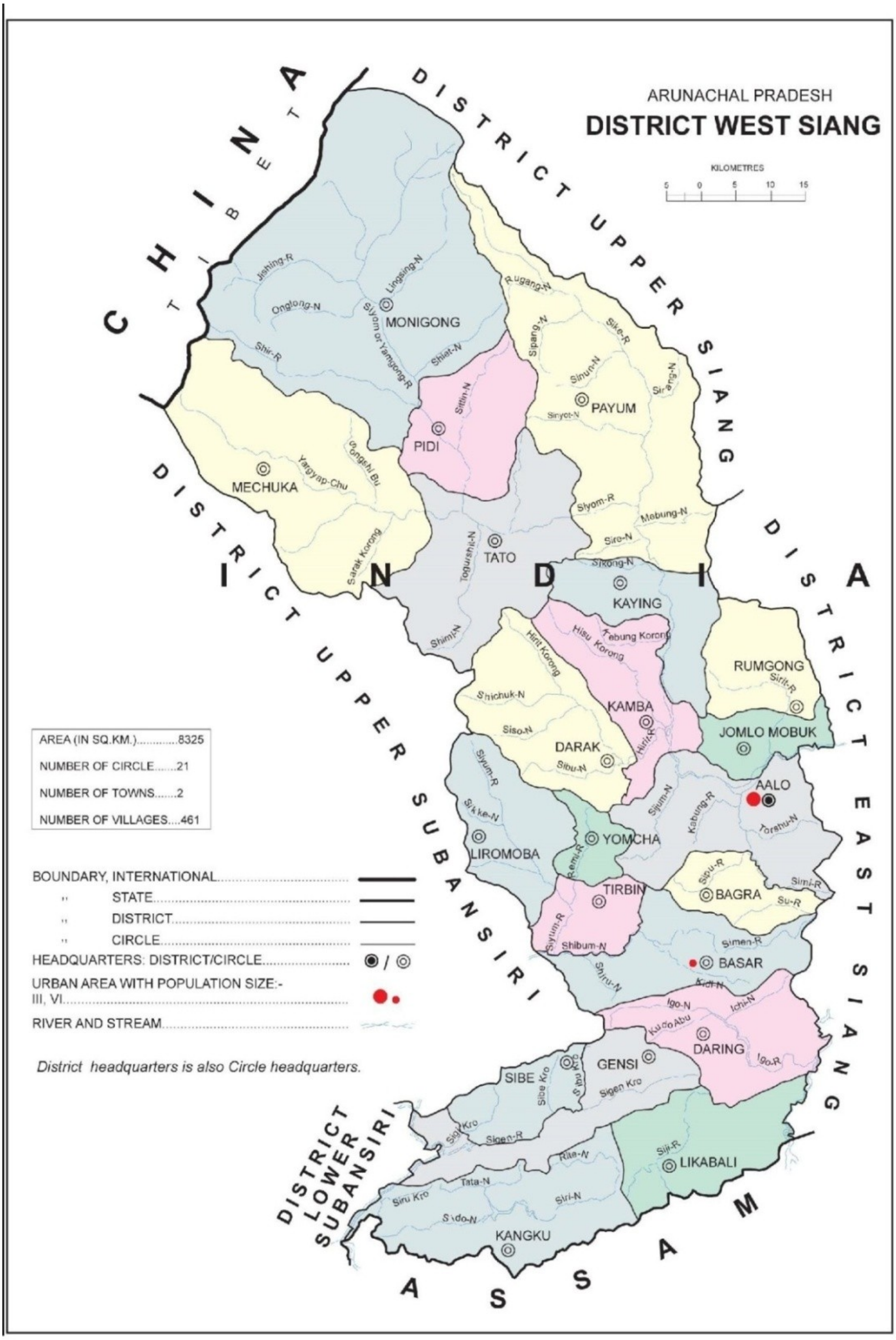


Fig. 2.4: District Map West Siang, District Census Handbook West Siang, Directorate of Census Operations, Arunachal Pradesh, 2011.

Agriculture :

Agriculture is a priority sector in the district. Agriculture has traditionally been and continues to be the mainstay of the inhabitants. Above 80% of the people are engaged in agriculture activities as primary occupation. Rice is the staple food. It occupies about 55.5 percent of the total cultivated area and constitutes about 75 percent of the total food grain production of the district. Other crops include maize, wheat, millet, linseed, potato, pulses, soya beans, sugarcane, jute, ginger, turmeric, chilly, etc., however, it is not self-sufficient in food and still depends on the import of food supplies from other states (Lombi, 2015). Agriculture is one of the significant contributors to the net domestic product and is the largest employer of the workforce. Though the dependency for employment on agriculture has declined it continues to be the main source of livelihood. Shifting and terrace cultivations remain the dominant forms of land use practice. Production of agriculture crops of West Siang District during 2010-11 is shown in the table-2.4.

Table 2.4: Production and Yield Rate per Hector of Agriculture Crops of West Siang District during the year 2010-2011

Sl.No.	Name of Crops	Area (in Hectors)	Production (in M.T.)	Yield (in M.T.)
1	Paddy	25146	33854	1.35
2	Maize	3480	4443	1.28
3	Millet	2622	2281	0.88
4	Wheat	77	97	1.26
5	Pulses	660	653	0.99
6	Oil Seeds	1764	1863	1.06
7	Ginger	298	2867	9.62
8	Chilly	166	264	1.59
9	Turmeric	59	269	4.56
10	Sugarcane	96	2785	29.01
11	Potato	363	2317	6.38
12	Vegetables	354	1996	5.64

Source : District Agriculture Officer, Aalo, Arunachal Pradesh, 2018.

Horticulture:

The agro-climatic condition of West Siang District is very suitable for the cultivation of various types of horticultural crops. It provides the undulating terrain an immense scope for growing a wide variety of tropical, sub-tropical, temperate fruits, vegetables, spices and other economical crops like medicinal, aromatic plants, mushroom, and ornamental flowers etc. The horticulture plants includes, apple, walnut, kiwi. pears, plum, orange. pineapple, guava, banana and cardamom (Lombi, 2015). The Govt. is assisting the indigenous farmers of Arunachal Pradesh by providing Horticulture inputs on free of cost like fencing materials, planting materials, fertilizers, plant protection chemicals (organic/inorganic) and technical guidance to the farmers. In order to produce sufficient planting materials, the Department of Horticulture has opened one progeny orchard cum nursery for both spices and citrus development. For speedy coverage of the area under fruit plantation and control of shifting cultivation, 6509 hectares have been covered under different schemes. For domestic consumption of the product, the Govt. has opened one fruit processing unit at Aalo (Teegalapalli and Datta, 2016).

Industry:

The development of Industries is mainly based on the resources available in the district. Though the growth of industry is hindered by lack of infrastructure facilities, the availability of resources is a boon for scope and development of Industries in the district. The resources based Industries which are encouraged in the district are as follows:

(a) Industries based on Forest Products.

(b) Industries based on Agricultural Products.

(c) Industries based on Animal Husbandry/Livestock/Fisheries etc.

(d) Cottage Industry.

Forest Based Industries

There are number of Industries in the district which are based on forest products such as Sawmill, Tea-chest batten, Wood carving, Wood seasoning cane and bamboo furniture Industry. At present, there are 4 Nos. Sawmill in the district which are located in Likabali and Kamba Industrial Estate (mainly for WBI). Entrepreneurs Memorandum (EM) for a new Sawmill has been granted by District Industries Centre (DIC), Aalo. The district produces fine wood carving articles. Wood carving Industries are mostly based in Mechuka Circle. Cane and bamboo are available in plenty in the district. A number of bamboo furniture making units are functioning in the district.

Agro Based Industries:

Various types of agricultural crops are grown in the district such as sugar-cane, ginger, maize, millet and fruits like orange, pineapple, banana etc. There is one Horticulture Processing Industries at Nigmoi near Aalo and number of units has been set up in the district.

Cottage Industries:

Cottage Industries are mainly manufacturing the traditional goods which are prevailing in the village to meet the demand of villagers. The district is rich in traditional handlooms and handicrafts which are extensively used amongst the local people in everyday life such as Egin, Hobuk, Piter, Lelli, Patu, Ebar and Bolup and are in regular demands. The women folk of the district are engaged in producing handloom goods which are from time immemorial used by local people. The traditional handloom goods are Gale, Galup, Scrorf, Side bags, Shawl etc. In addition to this, two Industrial Estate (WBI) have been set up at Kamba and Likabali areas.

Lower Basin - Dhemaji

Dhemaji district is one of the remotest districts at the eastern-most part of Assam. The District is situated on the north-east corner of the State which lies between 26°48′and 27°53′N Latitudes and 93°41′ and 95°31′E longitudes. The district is bounded on the north by Arunachal Pradesh and Dibrugarh District on the south, Tinsukia district on the East and Lakhimpur District on the West. It occupies an area of 3,237 sq.km. As the major part of the district is located near the foothills of Arunachal Pradesh, it exhibits difference in temperature, rainfall, fog, wind etc. The climate is per-humid characterized by high rainfall, mild summer and winter and falls under cool to warm per-humid thermic-agroecological sub zone. The Dhemaji revives an annual rainfall of ranges from 2600 mm to 3200 mm. Rainfall generally begins from April till the end of September and July marks the heaviest rainfall month. The general and average soil character of cultivable land in this district is mainly alluvial and composed of mixture of sand (coarse to fine) and clay in varying proportions. The general geochemical characteristic of the soil is highly acidic and the new alluvial soils formed due to siltation by rivers contain more percentages of fine sand fine silt and are less acidic. Such soils are more fertile and alkaline in nature, mostly suitable for paddy cultivation. Large expanse of lowlying land characterized by heavy clayish soil with a high percentage of nitrogen is good for rice cultivation. Abundant rainfall and excessive humidity throughout the year also greatly favor cultivation of paddy in the district.

Demography:

The population concentration of Dhemaji is composite with divergence of tribes and sub tribes and non-tribal populations. The population is mainly composed of various indigeneous tribes like Mising, Sonowal Kachari, Bodo Kachari, Deori and Laloong. In addition to this different tribes e.g. Ahom, Rabha, Tai - Khamti, Konch, Keot, Koiborta, Brahman, Kayastha, Kalita, Bangoli, Tea tribes, Napalis etc. were migrated during different periods of time. A small amount of Hazong (Chakma) population is also dwells in the district (Konch, 2018). Dhemaji district was sheltered a population of 571944 as per 2001 census, which includes 294643 males and 277301 females, sex ratio being 936 females per thousand males. In the district, there are 2 statutory towns.viz. Dhemaji (TC) and Silapathar (TC) .There are 2 Census towns in the district viz. Jonai Bazar (CT) and Lakhi Nepali (CT) (Handbook, 2011).

Table 2.5: Population trend of Dhemaji district 2001- 2011

Sl. No.	Tahsils	Population						Percentage Decadal Variation			%Urban Population	
		2001			2011							
		Total	Rural	Urban	Total	Rural	Urban	Total	Rural	Urban	2001	2011
1	Dhemaji	123017	111154	11863	139920	127104	12816	13.74	14.35	8.03	9.64	9.16
2	Sissibarag-aon	184173	161657	22516	234030	208368	25662	27.07	28.90	13.97	12.23	10.97
3	Jonai	143199	138746	4453	169898	160091	9807	18.64	15.38	120.23	3.11	5.77
4	Dhakuakh-ana	26657	26657	0	29575	29575	0	10.95	10.95	0	0	0
5	Subansiri	11152	11152	0	13950	13950	0	25.09	25.09	0	0	0
6	Gogamukh	83746	83746	0	98760	98760	0	17.93	17.93	0	0	0
	Total	571944	533112	38832	686133	637848	48285	19.97	19.65	24.34	6.79	7.04

Sources : Dhemaji District Census Hand Book, Directorate of Census Operation Assam , 2011

The table 2.5 shows the decadal change in population of Tahsils by residence in rural and urban of Dhemaji district during 2001 and 2011 Censuses. It is clear from the table that the total population of the district is 6,86,133 out of which 6,37,848 lives in rural and 48,285 lives in the urban and the Percentage Decadal Variation from 2001-2011 is recorded as 19.97 out of which19.65 percent in rural and 24.34 percent in urban. The percentage of urban population is 7.04 percent in 2011. Among the revenue Circles, Sissibargaon recorded the highest growth rate of 27.07 percent followed by Subansiri Revenue Circle with 25.09 percent and the lowest is in Dhakuakhana Revenue Circle with 10.95 percent. In term of total population of 2011 Census, Sissiborgaon Revenue Circle is the highest with 234030 population out of which 208368 rural population which is also highest in terms of rural population. Again, in terms of urban population, Sissiborgaon Revenue Circle recorded the highest with 25,662 persons and Jonai Revenue Circle lowest with 9,807 persons. The other 3 Revenue Circles recorded no urban populations. The percentage share of Urban population in Sissiborgaon Revenue Circle is 10.97, in Jonai Revenue Circle it is 5.77 percent and in Dhemaji Revenue Circle it is 9.16.The Study area mainly occupies the three rural revenue circles and a part of Dhemaji circle.

Sex Ratio:

Table 2.6, shows Sex ratio of the state and district over the decade since, 1901-2011. It is seen that the total sex ratio in the state, from 1901 to 1931 goes on the decreasing trend, but from 1951 to 2011 the trend is increasing. District wise, the sex ratio showed fluctuating trend during the period 1901 to 1971, while from 1991 onwards (927) till 2011 Census (953) the district has recorded an increasing trend in sex ratio.

Table 2.6: Sex Ratio of State and Dhemaji District, 1901-2011

Census Year	Assam			Dhemaji		
	Total	Rural	Urban	Total	Rural	Urban
1901	919	929	576	863	863	-
1911	915	923	626	883	883	-
1921	895	906	613	870	870	-
1931	874	885	574	818	818	-
1941	875	886	605	847	847	-
1951	868	878	663	886	886	-
1961	869	887	661	883	883	-
1971	896	912	744	874	874	-
1981	-	-	-	-	-	-
1991	923	934	838	927	932	717
2001	935	944	872	941	947	870
2011	958	960	946	953	955	934

Sources: Dhemaji District Census Hand Book, Directorate of Census Operation Assam , 2011.

In 2011 Census the district total of sex ratio was 953 (rural 955, urban 934) which is lower than the state total of sex ratio 958 (rural 960, urban 946). On other hand as of the Dhemaji district is concern the table-2.7 gives the CD Block-wise sex ratio. Out of 5 CD Blocks in the district, Machkhowa CD Block recorded the highest sex ratio of 995 and the lowest sex ratio is found in the Sissiborgaon CD block with 932 females per 1000 males.

Table 2.7: Sex ratio of Dhemaji District by CD Blocks, 2011.

Sl. No.	Name of the C D Block	Sex Ratio
1	Sissiborgaon	932
2	Murkongselek	949
3	Dhemaji	958
4	Bordoloni	982
5	Machkhowa	995
Sex Ration of Dhemaji District		955

Sources: Dhemaji District Census Hand Book, Directorate of Census Operation Assam , 2011.

Economy of Dhemaji:

The Physiographical extension of Dhemaji district in the fertile flood plain makes it an agro-based economic district. The occupations concern with agriculture in mostly for sedentary agricultural system with a popularity of commercial agriculture in terms of livestock ranching, horticulture, sericulture, fishing and driftwood business are practiced in smaller scale. However, erosion, degradation of soil properties, water logging, sand deposition and other adverse effects of chronic floods on fertile agricultural land have made it vulnerable. Thus many farmers prefer alternate livelihood works apart from agriculture and its popularity increasing with time. The economic sustainability demands good communication system, management to power, land, water, labor, capital and marketing, etc. In Dhemaji district, about 98% of the total populations live in the rural areas. As per 1991 census, 45% of the population is workers, while 55% of the population is non-workers. Out of the total workers, the break up is as follows:

Table 2.8: Working Population of Dhemaji District, 2011

Sl. No.	Occupation	Percentage of Population
1	Cultivators	60
2	Agricultural labourers	3.7
3	Livestock, forestry, fishery etc.	1
4	Marginal workers & other services	30
5	Trade, Commerce, storage etc.	4
6	Manufacturing, processing, repairing	1.3

Sources: Dhemaji District Census Hand Book, Directorate of Census Operation Assam , 2011.

Agriculture:

Agriculture is the principal occupation of Dhemaji district comprising more than 85% of the total population depends on it. Agricultural practices are mainly of traditional system of subsidiary cultivation and are rain-fed agricultural system. Mainly paddy cultivation is popular in this part due to high fertile alluvial soil deposited by the river system in the district. Dutta, 2013 identified *Sali, Ahu* and *Boro* are the three main varieties of rice commonly grown in the plains of jiadhal. In addition, few standing crops are also grown like sugarcane and mustard. The commonly grown pulses are Matimah (*Phaseolus mango*), Magumah (*Phaseolus aureus*), Arhar (*Cajanus cajon*), Masurmah (*Pisum sativum*).

Horticultural Crops:

Apart from agriculture of cereals crops and pulses horticulture has important role in the economy of the Dhemaji district. Horticulture is a practice both traditionally and in firm pattern. The traditional pattern implies the plantation of plants in the household premises for self consumption as well as for commercial purposes. All the varieties of banana are abundantly found in the district. Besides banana, mangoes, jack fruit, papaya, orange, pineapple, areca nut, coconut etc. are also grown in the district. Kitchen gardening is another aspect of horticulture and practiced by every household for domestic use and even for sale. Vegetables like Brinjal, Cabbage, Cauliflower, Okra, Papaya, Tomato etc are extensively grown.

Sericulture:

The age long practice of handicraft and handloom is well established in Dhemaji district. Sericulture is another age-old traditional cottage industry. Sericulture is alternate livelihood for the plains of Assam as it comprising large number of employment in the rural areas with minimum investment cost. It plays a vital role in the socio-economic of the rural inhabitants of the flood plain as an alternate to agriculture. Mainly three different kinds of silks – *Pat, Muga* and *Eri* are produced in this region which has a very high demand in the national and international markets. Muga silk (*Antheraea assamensis*) and Eri Silk (*Samia cynthia ricini)* worm rearing and production of silk yarn and fabric is wide spread amongst the people of Dhemaji and Dhakuakhana (Mahan, 2012). Weaving is a secondary occupation of every household mainly the women folk are well equipped with customary practice and even the male population are expert in these activities of rearing, production of yearn and weaving as well as for its commercialization.

Livestock Rearing:

The flood plains have plenty of grassland and swamps which have very rich natural fodder for the domesticated animals of the district. Livestock rearing is practiced in every household in different scales, ranging for domestic uses and even for commercial marketing. The district of Dhemaji has large varieties of livestock species. Agriculture is predominant in the district as major source of livelihood and therefore cattle, buffaloes; goats are of common sight with every household particularly in the rural areas. Besides these pigs, ducks, sheep, fowls, pigeons etc. are reared in almost all the households traditionally without any scientific technologies. The high breed species of poultry and piglets are available in the market and are brought and reared in village environment both in firm and domestic way. The commercialization of livestock rearing is also in wide practice and mainly associates with fowls, duck (poultry), pig (piggeries), goat and breaded cow (jurssy) are also reared with modern techniques.

Fishery:

The level low land is associated with swamps and thus the water level of Dhemaji is just near to the surface which makes it a suitable for fisheries and ponds. As the low lying areas is associated with flood, so the wild species of fish has a vast diversity in Dhemaji. Thus apart from wild fishes of the district, fishes are reared in natural swamps and depressions called beels etc. (Sinha, Kedia and Kumari,2015). Fish is reared on commercial basis in the beels, rivers, swamps, forest derelicts, ponds and tanks. Various types of breed are found in beels and rivers in the district. Fishes like Rohu (Labeo Rohita), Barali, Chital, Kaliajora, Kurhi, sol etc are found in wetland and swamps (beels). Fishes that are found available anywhere are Kawoi, Magur (Walking Catfish), Singra (Mystus Tengara), Singi, Puthi, Darikana (Biswas, 2015).

Fish drying:

Fish drying is another practice carried out during the monsoon season, mainly by the people living near the rivers. The market value of the produce is high, but poor communication facilities in the district, especially during the monsoon months, result in high transportation costs. The availability of fish seasonally let the practice on, so that the storage of the food item is maintained for the vulnerable days due to flood like situations when neither fresh food nor good connectivity to procure some.

Weaving and Textiles:

Weaving is an important cottage industry active in household activities of the rural population of Dhemaji. This important cottage industry is practiced by the woman folk of the rural areas of the district from time immemorial. As of tradition it is mostly practices to fulfill basis need of clothing for all including women, man and even for other materials like home decors, mosquito nets etc. Many household derives their livelihood from it. Many households also practice weaving as subsidiary occupation. The most popular attires includes Gamusha, (Towel) Mekhla, Chadar, Aronai (scarf), Tomal (kamar band) which has high demand in the market and earns a livelihood to many rural households.

Industries, Trade & Commerce:

The region has no large industrial sector, only small scale industries are there but with low profile. The population has tradition of handicraft mainly of cane and bamboo materials; otherwise there is no other industrial practice in the district. Few technical students have opened some wooden, metal furniture units and workshops of automobile repairing. The Timber industry flourished in the Dhemaji and Jonai is the only bigger units and is functional seasonally. Some of the small-scale units are registered as weaving or cane and bamboo industries, however the actual production does not have any market value due to competition from highly finished machine goods that are cheap and maintenance free. The silk industry has the potential to be commercially tapped. Some local people of the area also produce mustard, but they are not able to compete with the non-local businessmen who control the market. Apart from this some mining units and stone crusher units are operated with due permit from the government agencies.

The lower Jiadhal river basin is built up of alluvial deposits carried by the rivers from the uplands and is a fertile flood plain of Assam. On the other hand the hilly part of the river basin of Arunachal Himalayas has low human concentration and free from human intervention due to less accessibility. The river is the only transportation route to the upper basin or catchment areas; however it is not a navigable river. The tracking along the river course is the only means to reach its source region. Thus the region has very low human settlement. The people (indigenous) of West Siang district of Arunachal Pradesh owned this geographical extension, and having the indigenous properties right in the forest of upper river basin. Due to less populated area the forest is the only resources that are most extensively used by the indigenous population. The agroforestry is practiced in some extent by the local population like cultivation of bamboo, toko leaves, cane and other forest products for domestic uses. The practice of shifting cultivation is another phase of the use of highlands and is mainly concentrates to the peripheral areas of the human settlement and on the hillocks with gentle slope. The inaccessibility to the interior of the upper catchment make it more vulnerable, as the activities going there is unobserved by the common people and the government agencies like forest departments. Thus a vast area of upper basin is prone to legal cum illegal victim of the poachers and timber workers in dry season. The wild life and the biodiversity are disturbed by improper and uncontrolled use of forest resources in seasonal activities like lumbering for the commercial purposes. The control over the high reaches can't be provided, as there is no road communication and the forest range offices are located in the foothills and only a tracking on the river course fulfill the route to upper reaches of the basin. Thus even the permitted or legal lumbering activities by the indigenous as well as by the timber business personals are free from ground surveillances. The improper use and uncontrolled lumbering activities in the upper reaches of the basin make the region prone to erosion and deforestation in larger extent. The Lower Basin is extensive plain with high population concentration and is based on agricultural economy. The agriculture includes all the cereals, food grains, fruits and vegetables and standing crops as plantations too. The agriculture of the basin is vulnerable due to the flood by the river system, thus only subsidiary sedentary cultivation is done in larger scale. Even commercialization of agriculture is prevailing in cash crops like mustard vegetables, sugarcane, tea sericulture and pisciculture etc. In general the environmental and ecological balance of the basin is the prime factor determining the socio-economy of this region. For a proper development these environmental factors should be given priorities to be solved first, so the sustainability can be maintain.

ENVIRONMENTAL PROBLEMS IN THE JIADHAL RIVER BASIN

Beginning with the scenario of the basin area, the physical, topographical variance of the entire basin is optimum, as the upper portion of the basin is a tough mountainous region with lofty mountain ranges and deep valleys with numerous natural springs. Thus the problems in the basin is varies with the geographical situations, with combination to the local natural phenomenon, including topography, relief, climate and socio-economic status of the region. It is mainly analyses with the prospects of sustainable development of the entire region irrespective of the diversities. The prevailing landscape of the region dominates the impact of the socio-economy of the region. The upper jiadhal basin is sparsely populated and thus remains in natural settings, without much human intervention. On the other hand the plain or the lower Jiadhal basin part has the highest concentration of population, which is primarily associated with agricultural based economy. The climate of the region is mainly dominated by the monsoonal influences, thus receives high precipitation throughout the year with short dry season, particularly during the months of mid of December to March. The relief features act accordingly for the local climatic phenomenon resulting for orographic rainfall and even conventional rainfall along the river courses. Thus the supply of rainfall is a continuous process in the entire basin. This increases the surface runoff and the accumulation of the water in the stream or river make it plentiful to erode enormous load towards the mouth of the river. The intensity of rainfall is the main problem of the region which represents the issues related to soil erosion and deposition in the lower sections of the river. The region receives highest rainfall in summer season mainly in four months viz. June to September of each year. The water discharge of the Jiadhal river course increased alarmingly from the upper catchment. It varies with season as in summer due to high rainfall intensity it is in peak flow and winters very less discharges are observed. Even in same season there may be different discharges in the channel due to sudden bleaching of the embankment (Plate. 2.2). Meanwhile the high intensity of rainfall in the flood plain creates a flood like situation even on a day long rainfall with 100 cm rainfall per day. The plains of the lower basin are mainly composed of new and old alluvial deposits and have very low range of elevation variation. The slope gradient of the river course is very low, and thus the river course has the meandering characteristics. The river does not have its permanent course due to over siltation and sallow depth in peak season its water get overflow from weaker sections to different courses. Several villages along side of the river are facing the issue of bank erosion siltation and the greater extent the socio-economy of the villages are ruined due to flood effects.

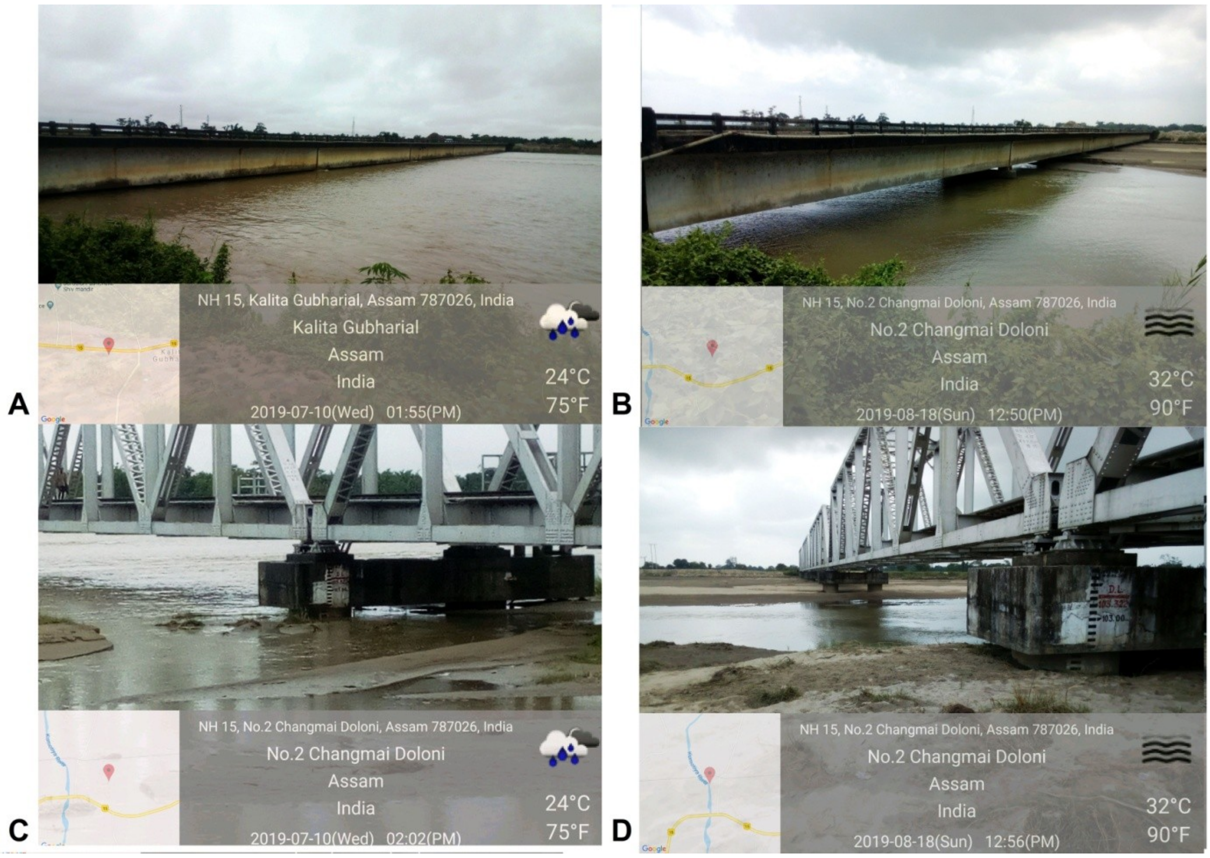


Plate. 2.2: Different flow in same season due to bleaching (2019). a) Bridge point in peak flow, b) Bridge point after bleaching, c) Railway bridge point on high discharge and d) same after bleaching.

The major environmental problems prevails in the study region are

1. Forest degradation, desertification
2. Soil degradation
3. Landslide
4. The perennial flood
5. Siltation and sedimentation
6. River bed rising due to sedimentation
7. Shifting of river channel
8. Water logging in low-lying areas including residential areas
9. Ruining of Agricultural crops and fodders
10. The problems related socio-economic aspects regarding loss of properties and life.

The study area consist of basically two geomorphological divisions, first the Upper Jiadhal River basin which is situated in the hilly track of Arunachal Himalayas, in the West Siang District, and another in the extensive flood plain of Assam, in Dhemaji District. Thus the environmental issues and problems are dealt with fluvial environmental geomorphology. The Hilly tracks of Arunachal Himalaya in a rough terrain with an average altitude of 800 meters above mean sea level. The lowest elevation in the river bed is found to be 200 m and the highest elevation is 1200 m. on the other hand the flood plain has the average elevation of about 100 m (80 m to 200 m) and comparatively a flat land. Thus the drainage system creates a vital problem in the plains during rainy seasons due to immense supply of water and sediments, creating a flood situation in regular interval. The human intervention in the hilly track of upper Jiadhal river basin has impact greatly the situation. The human activity of careless and incentive deforestation in the upper ridges of the basin creates the situation of vulnerability of slope aspects of the mountain system. Although the upper reaches of the Jiadhal river is highly mountainous consisting the Arunachal Himalayas , whereas the lower part of the basin in Assam is very flat and composed of Quaternary alluvial deposits. Because of environmental factors like heavy rainfall, weak geology and frequent landslide activities in the upper reaches, the Jiadhal river carries high water and sediment load downstream. And due to its high water and sediment loads, geotectonically fragile environmental setting and loose nature of the bank materials, the lower part of the basin in Assam is always affected by hazards associated with flood, erosion, sedimentation, channel migration, normally triggered by intense rainfall episodes and occasionally aided by earthquake and landslides. The lower Jiadhal river basin is a low lying plain and associated with wetland and swamps which has a tremendous bio-diversity. These wetland and swamp is the breading ground of wild species of fish, and due to various factors these wetlands, swamps and depressions are degraded and this the wetland biodiversity is threatened. These not only affect the ecological balance but also the socio-economy of the rural population, because these areas are the sources of income to many households of the region.

REFERENCES

Acharya, S.K. and Saha, P. (2013): Age and Tectono-Megmatic satting of Abor Volcanics, Siang Window, Eastern Himalayan Syntaxial Area, India. Journal of Applied Geochemestry, Vol. 15, No. 2. pp.170-192.

Barrow, C. J (1998): River Basin Planning and Development: A Critical Review. WorldDevelopment, researchgate.net/publication/22247473726(1)(1):171-186 · January 1998 *with*753 Reads.

Biswas, S.P.(2015): An Overview on the Threats of Aquatic Ecosystem in Upper Brahmaputra Basin, IUCN,River of Life, Proce. of International Symposium on River Biodiversity: Ganga-Brahmaputra-Meghna River System, pp.46-53.

Borbora, M and Post, M, (2008): Quest of a Script, North East Indian Linguistics, ResearchGate: DOI: 10.1017/UPO9788175968431.017, pp. 255-270.

Boruah, J.K.(2000): Geomorphic study of lower Subansiri basin, Assam, Suodhganga.net, http://hdl.handle.net/10603/61665, pp-9-160.

Chakrabarti, B.K (2000): Geology of the Himalayan Belt, Deformation, Metamorphism , Stratigraphy, ELSEVIER, ISBN: 978-0-12-802021-0, pp-145-248.

Choudhury, S. and Sen, N. 1977. On a collection of fish from Arunachal Pradesh with some new records. Newsletter Zoological Survey of India, 3(4): 217-223

Coggin Brown. J (1912): A geological reconnaissance through the Dihing valley being the geological result og the Abor Expedition. Rec. GSI. Vol-42, pp-232-264.

CWC (2011): Handbook for Design of Flood Protection, Anti Erosion Measures and River Training Works, GOI,CWC, New Delhi, pp-104.

Dhital, M.R. (2015): Geology of the Nepal Himalaya: Regional perspective of the classic collided orogen, ResearchGate: DOI: 10.1007/978-3-319-02496-7.

Dutta, P (2013): Biometrical and Biochemical Evaluation of Indigenous Rice Cultivars of Dhemaji District of Assam. Ph.D thesis Shodhganga@INFLIBNET, http://hdl.handle.net/10603/32798, pp-213.

Ghosh, A. M.N. (1956): Resent advance in geology and structure of eastern Himalayas, Proceeding 43rd Sess. Indian Sc. Congress, pt 2 pp85-99.

Gogoi, C., Goswami. D.C.,and Phukan. S.(2013): Flood risk zone mapping of the Subansiri sub-basin in Assam, India, International Journal of Geomatics and Geosciences, Volume 4 Issue, pp-2-13.

Kar, M (2012): The Brahmaputra: Flood and Its Preventive Measures, Eastern book Publisher, ISBN-13-9788190781213 pp- 20-230.

Kesari, G.K., DasGupta, G. and Prakash, H.S.M. (2009): Geology and Mineral Resources of Assam, GSI, 30 Part IV Vol 2(i) Assam. pp.51.

Kesari, G.K., DasGupta, G. and Prakash, H.S.M. (2010): Geology And Mineral Resources Of Arunachal Pradesh, GSI, 30 Part IV Vol I(i) Arunachal Pradesh. pp.22-60.

Konch, K. (2018): The Scenario of Crime in Dhemaji District of Assam: An Analytical Study, MSSV Journal of Humanities and Social Sciences, Vol. 3 N0. 1 [ISSN 2455-7706.

Mahan, B. (2012): Silk Industry among the Tai-Ahom of Assam, India as an Attraction of Tourist, International Journal of Scientific and Research Publications, Volume 2, Issue 12, ISSN 2250-3153, pp.4.

MSME, (2014): State Profile of Arunachal Pradesh, GOI, Ministry of MSME, Itanagar, E.Mail:brmsme.itan@gmail.com.pp. 1-114.

Li, Tianchi. (2004): Mountain Hazards in China, Owens, Philip & Slaymarker, Olav (ed.) Mountain Geomorphology, Edward Arnoid Pub. ltd, pp 219-241.

Liebke, U., Antolie, B., and Appel, E. (2011) : Indication for clockwise rotation in the Siang window south of the eastern Himalayan syntaxis and new geochronological constraints for the area, Growth and Collapse of the Tibetan Plateau. GS, London, 353, 71-97. DOI: 10.1144/Sp353.5. 0305-8719/11.

Lombi, P., (2015): Shifting cultivation in the foothills-a case study of West Siang district, Arunachal Pradesh, Dutta, C.K. et. al, Biodiversity of North East India, Kiran Prakashan, Dhemaji, ISBN: 9789382746850 pp- 187-198.

Rao, K.V.S. (2000): Watersheds comprehensive development, B.S. Publications, Hydrabad ISBN:8178000040, PP-1-367.

Riba. T and Borua, B (2015): Shrinking wetland of Assam:a geographical study of Bordoibaam wetland (Dutta, C.K. et.el) Biodiversity of North East India, Kiran Prakashan, Dhemaji, pp57-67.

Singh, V.P and Sharma, N.(2004): The Brahmaputra Basin Water Resources (Water Science and Technology Library Book 47) Kindle Edition, Springer; 2004 edition (9 March 2013)p-613.

Sinha, R.K., Kedia, D.K., and Kumari, A.(2015): Overview of Higher Vertebrates in the Ganges-Brahmaputra-Meghna River Basin: Their Status, Threats and Conservation, IUCN,River of Life, Proce. of International Symposium on River Biodiversity: Ganga-Brahmaputra-Meghna River System, pp.116-123.

Teegalapalli, K and Datta, A (2016): Shifting to settled cultivation: Changing practices among the *Adis* in Central Arunachal Pradesh, north-east India, Springer, doi: 10.1007/s13280-016-0765-x, Vol. 45(5): 602–612.

CHAPTER-3

GEOMORPHOLOGICAL AND HYDROLOGICAL ANALYSIS

INTRODUCTION

The Brahmaputra river system is one of the largest in the world. In the volumes of water and sediment that it gathers and passes on, the power with which these flows are routed, and the scale of changes that these powerful flows bring upon the landscape (Pahuja and Goswami, 2006). Geo-environmental studies aim to examine the geographical system 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. The chapter is discussing the geomorphological and hydrological characteristics of the Jiadhal River basin. It includes the basic geo-environmental analysis of the basin to understand the environmental problems of the basin. Jiadhal river has long been considered as a problematic river in the history of Dhemaji district of Assam due to recurrent and extensive flooding and siltation characterized by their extremely large magnitude, high frequency and extensive siltation. The lower basin of the Jiadhal is very prone to flood and siltation because of various hydrometeorological and topographical reasons. During the recent past it has been found that the extensive flood and siltation in the basin has changed the socio-economic activities of the people. The understanding of the environmental geomorphology would be the outcome for planning measures for sustainable development of the basin.

GEOMORPHOLOGY OF JIADHAL RIVER BASIN

The Jiadhal Drainage basin is a havoc for the entire basin both in the upper and the lower basin, and the Jiadhal covers an area of 1851.43 km^2 having latitudinal and longitudinal extensions of 27° 08’ N to 27° 45’ N and 94° 15’ N to 94° 38’ E respectively. Out of its total basin area 1851.43 km^2, Arunachal Pradesh occupies 370.63 km^2 i.e. 20 % of the total basin area and rest 1480.80 km^2 i.e. 80 % of the basin area drains to the state of Assam. Jiadhal River is a model example of the flashy river produces floods with a regular high discharge over short time intervals with a high sediment load and debris during the monsoon season. The accumulation of sediment, mainly course sediment within the river bed or shifting of river channel and even the suspended load spilled out in peak flow creates flood plain (Rawat, 2011). Deforestation in the upper catchment, highly meandering nature of the river in the plain are the root cause of the disasters in the region (Mandira & Monimugdha, 2014). The Monsoon rain is not only the factor responsible for degradation of the area; geology and geomorphology of the region are other aspects behind the alarming flooding occurred.

The physiography prevails in the geographical unit of Jiadhal river basin have a distinct variation of elevation, thus it could be divided into two broader unit. The basin comprises higher elevated part occupying the Arunachal Himalayas in West Siang district of

Arunachal Pradesh, and the low lying flood plain having uniform lower elevation comprises the plain of Dhemaji District of Assam. The upper catchment areas termed as 'The Upper Jiadhal Basin' is a rough terrain composed of Arunachal Himalayas. The region is thinly populated with dense vegetative cove and receives average rainfall of 3500 mm annually. The lower part is termed as 'The Lower Jiadhal Basin'. The Jiadhal River is braided and unstable in its entire reach in the plain areas in Assam Valley. As the river flowing from an average altitude of 800 meters above sea level, it has a greater potentiality of erosion and down cutting activities. The river carries huge sediment and silt to the downstream and creates an extensive flood plain with characteristics of unstable river course. The river often shifting its courses during the peak flow seasons during flood and after flood the situation changes.

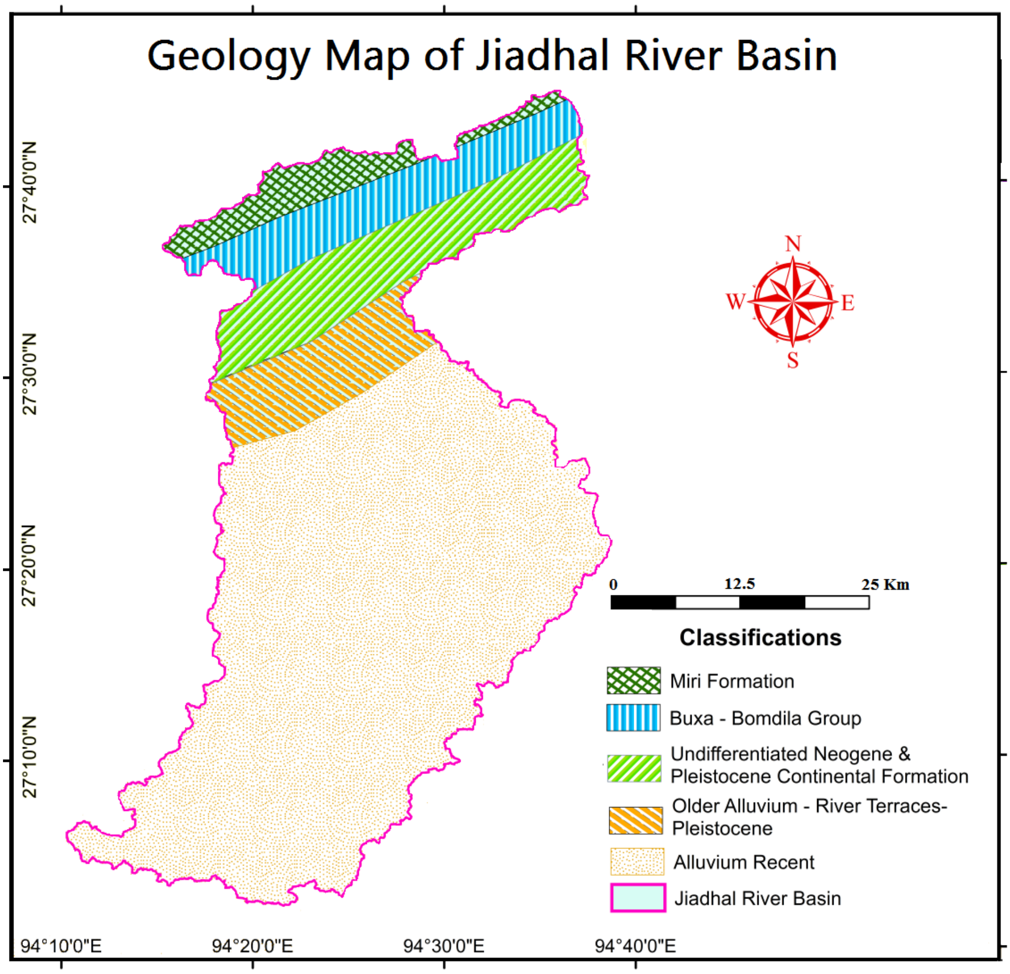


Fig.3.1: Geological map of Jiadhal River Basin , Arunachal and Assam, N- East India (After Baruah, 2000)

The Geology of Upper Jiadhal river basin (Fig.3.1) is dominated by fragile sand, silt, clay and micaceous sandstone of Kimin and Subansiri formation the northern part is dominated by Miri formation which are mainly composed of high fragmented sand stones and conglomerates (Chakrabarti, 2000). The south of Miri formation is the Buxa- Bomdila series composed mainly of dolomite, hard greyish flaggy sandstone and sandy shales with weaker zones of joints and fissures followed by the drainage system. The largest share is composed by undifferentiated Neogene and Pleistocene continental formation, mainly consisting medium to fine grained, well sorted, bluish grey sandstone, and subordinate feldspathic micaceous sandstone, which are fragile and prone to erosion. The piedmont areas are dominated by the Old alluvium- river terraces and are exposed to erosion in the river side, contributing huge sediment to the drainage system. The plain of Assam is the combination of old and new alluvium (recent alluvium) and composed of course to find sand and silt deposited by the river system during flood time to time.

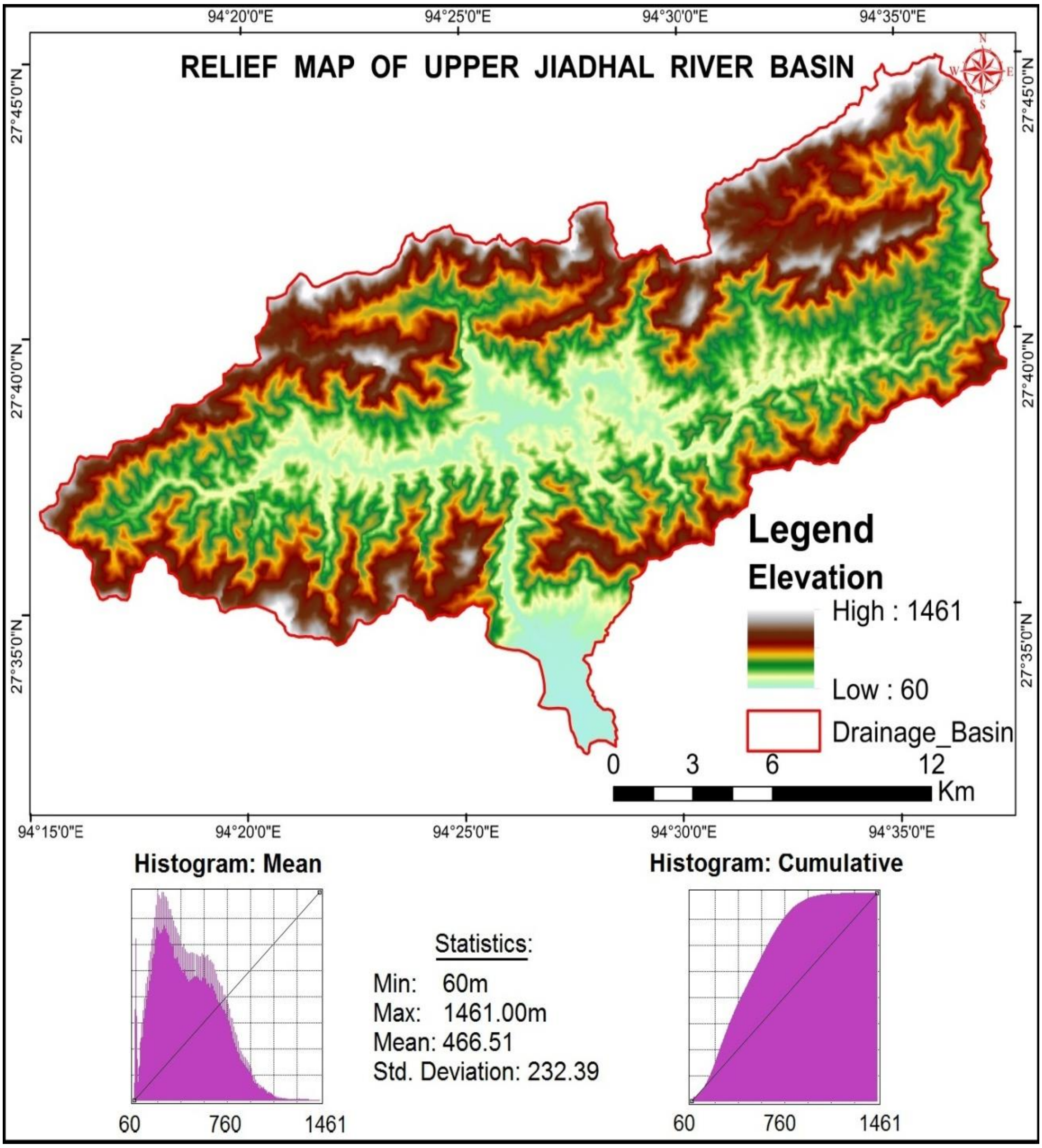


Fig.3.2: Showing Relief map of Upper Jiadhal Basin

The Upper Jiadhal relief map prepared from the digital elevation model depicts that the Structural geomorphology dominates the region, as the elevation ranges is high from 60meters to 1461 meters of height. The most of the portion ranges below 760 meters of elevation as mean. The fragile topography is associated with series of parallel ranges with a depression in between dominated by fluvial processes accompanied by numerous streams and mainly three tributaries from different direction to join at Tri-junction (Tini-Suti) to form Jiadhal river system.

GEOMORPHOLOGICAL PROCESSES

According to Thornbary (1954) the geomorphic processes involves the mechanism of leveling down through denudation process involving both degradation and aggradations. Thus the geomorphic process of fluvial denudation is active in the study area with respect to the climatic and relief factors responsible of the development in jiadhal river drainage basin. In response to various geomorphic processes active in river catchment, the fluvial process of denudation is the most active process in the study area. Strahler and Strahler (1993), studied that the geomorphic processes of the area are responsible for degradation of physical as well as chemical decomposition of the exposed earth crust. As the upper basin area is a rough terrain with high intensity of rainfall, the surface runoff is responsible for high load carrying capacity through the deep gorges with sharp stream courses. The geomorphic process is related to the environmental geomorphology of the area so it has a direct relationship with the geological character of the region. Geology governs the steer strength of the landform and the presence of week zones like faults, fissures and thrust lines, proved the lithology are prone to erosion or denudation because of the difference of steer strength. The geology of the study area is associated with Siwalik Himalaya in general and the Siang and Subansiri formations in particular. The Jiadhal basins comprises the old sandstone hills, thus composes of blocks of gray sandstone and are accompanied by conglomerates and bulk regolith strata's exposed to surface in the river side's in the upper basin.

Environmental degradation is inevitable under the operation of natural geomorphic processes. However the problem gets accelerate due to human interferes with the natural processes and accelerates these natural processes. The main active geomorphic processes have been identified in the study areas which are briefly described as follows.

Weathering : The disintegration of rocks or soil from the parent rock is termed as weathering. The activities are either natural or biological and even are human induced. In broader sense the weathering is determined by the agents of denudation and its physical as well as climatic environment concern to the spatial characteristics of relief, topography, structure, climate and time. It involves the mechanism of breaking of surface rocks and transportation of the weathered or loosened materials by various agents of gradation, mainly running water in Jiadhal River basin, and accompanied by depositional work that develops landforms in low lying plain and valley areas. Weathering is the initial phase in the denudation process of the landscape and the genesis of the landform development. It is the process involved with the physical characteristics of the geomorphology of the earthsurface, and the corresponding agencies of power or energy responsible for the phenomenon. The power is more or less natural, one is from the endogenetic origin and another is the exogenetic force active in the area. The other most important elements working for the weathering processes are the human induced or the human activity that accelerating the denudation processes. The endogenetic is termed as hypo-gene or constructional processes the process have its genesis below the earth interiors. The important of these forces are earthquake, plate tectonic, volconicity etc (Rawat, 2011). An earthquake is a shaking motion or vibration of the earth surface and its tremor that occur in three main forms, depending on the plate movements that occur earth's crust, mainly concentrates on convergent , divergent plate boundary or a transform fault. Convergent Boundary is the plate margin where two plates collides each other from opposite direction and one plate is forced over another creating a thrust fault is associated with continental drift theory and plate tectonic theory (Alfred Wegener and Arthur Holmes,1915,1919) is another aspect of fragile Siwaliks. Transform Fault is unlike convergent and divergent boundaries the plate margins which have a friction along the fault line in different directions. It is also known as Strike-Slip as the two plates passes each other along the fault and found active in upper basin areas along the Arunachal Himalayas (Kesari, 2009, 2010).

Mass-wasting : The movement of earth mass mainly because of gravity pull, towards downward along the weaken zones due to influence of various other elements is known as mass-wasting, slope movement or mass movement. Mass-wasting is an important geomorphological process led to alter the earth in greater magnitude. It occurrence may be sudden as landslide and even slowly as soil creep, that its impact couldn't be seen visually, but the characteristics may be observed in the affected areas. The gravitational force act against the slope gradient and geomorphic shear strength of the rock strata is the main factor of such degradation, other factors that change the potential of mass wasting include, intensity of rainfall, vegetation cover of soil and weight of the unconsolidated mass. The Upper basin of Jiadhal river experience large scale deforestation of natural forest cover whereas the lower jiadhal basin is prone to active degradation by flood, huge mass wasting occurs in regular interval of time.

Soil Creeps : The soil creep is a slow and long term mass movement under influence of gravitational pull and slope gradient properties of the lithosphere. The factors influences the soil creep are the moisture content of the soil, the vegetative type, fragmentation or cementation of the strata. Soil creeping is also observed in many places in the study area.

Landslides : Landslides denote downward movement of soil, it may be naturally due to environmental phenomenon of ,may be anthropogenic by origin. The factor trigger landslide are the earth's movements, slope gradient, the steepness, the material composition, shear strength of the lithosphere, moisture content and supply, vegetative coverage, and biological influence including human intervention (Rawat, 2011). They are more frequent landslides where the human development activities have modified slope profile. The deforestation in the hill slopes, forest fire and clearance of natural forest for agroforestry are some activities responsible for landslides in the upper basin of Arunachal Pradesh.

Fluvial processes: Fluvial process is the most dominant geomorphic agent in sculpturing the landscape of the area. The activities of stream or running water could be either erosional or depositional. The factors trigger fluvial processes on a geographical unit are the amount of precipitation, the nature and composition of the geomorphology, geology, composition of the lithosphere, steepness of the slope (slope gradient), vegetative coverage, biological influence including human interventions by activities altering the natural environment. The consequences of fluvial process are either constructive or even destructive triggering the environmental geomorphology. The constructive components interpret the various geomorphological landforms created by a stream in its course of flowage from the initial to its submergence to end. The destructive component involves the environment degradation due to its phenomenal acceleration of working magnitude. The excessive erosive work in the upper catchment led to circumstances like head water capture, rapid soil loss leading to environmental crisis. The depositional work of fluvial process in the genesis of plain in the foothills but the excessive deposition in the river course in foothill plain raise the river bed to sallow depth that couldn't accommodate the water discharge within the natural river course and creates catastrophes like flood. Flood is one of the most devastating natural calamities that have seriously affected the plain area of this region and affected the environment sustainability, degradation of biodiversity, socio-economy of the plain dweller greatly.

RELIEF MORPHOLOGY

Relief is the geomorphic characteristic of the landform comprising the dimensions of physical features of the earth surface. It may define as the difference in elevation (altitude) of any portion of the earth's surface or relative vertical inequality of land surface. Relief is related to geomorphic properties of each surface deals with the range of elevation (Chorley, 2019). Thus the shape, size, height, depth, slope gradient, direction and pattern are included in the morphometry of a relief feature. Morphometry on the other hand deals with the measurement and geometrical analysis of the configuration of the earth's surface (Clarke, 1966). Geomorphology and Environmental Geographical studies are more or less concern of the relief studies, as it is vital factor responsible for the various natural phenomena prevailing in the earth surface during a given time span and climatic condition. Relief analysis of a terrain of a geographical unit may be done with the help of morphometry. The morphometric element of relief feature includes relative relief, absolute relief, slope gradient, steepness direction, dissection index and drainage characteristics (Thakur, Laha and Aggarwal 2011). The other observation involved in the relief morphology is to analysis of the relation of the geology and hydrology and even the vegetative coverage of the specific spatial concern in concern of the relief morphology. The Study of the relief feature and its morphometry through light of historical past, as the landform development and processes responsible for the landform change an even its magnitude of change could be curved out from a systematic and detailed study. Relief morphometric analysis characteristics are fundamental requirement of landform study of any area. In other words it refers to the quantitative analysis of form, a concept that encompasses size and shape of the topography or relief features. Thus a geographical unit is used for the analysis of the morphometry and a river basin or a watershed is an ideal unit for the same to study relief and hydrological morphometric characteristics of the basin. Morphometry of a basin gives the quantitative description and analysis of landforms as practiced in geomorphology and hydrology that may be applied to a particular kind of landform or to drainage basins and large regions generally. The technique to be adopted depends upon the interest and the purpose of the analysis may vary from region to region. 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 system 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). It is further illiistrated by different geographers as Strahler (1952, 1957, and 1964), Schumm (1963), Morisawa (1985), Scheidegger (1965), Shreve (1967), Gregory (1966, 1968), Gregory and Walling (1973) were prominent. Geographical Information system (GIS) and Remote sensing techniques using satellite images are used as a convenient tool for morphometric analysis (Konwar, 2017).

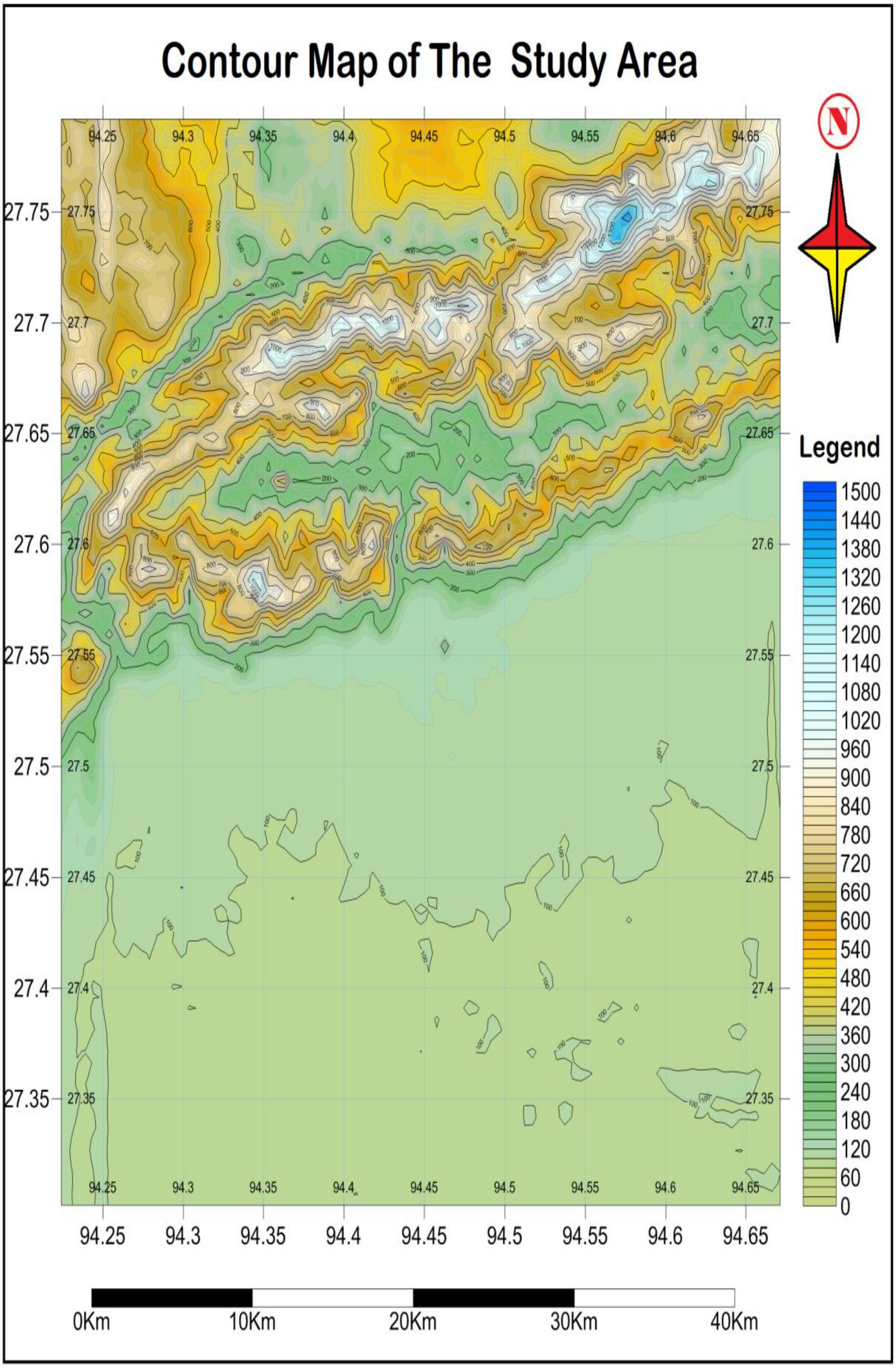


Fig. 3.3: Contour map of the study area and its surroundings (Surfer18).

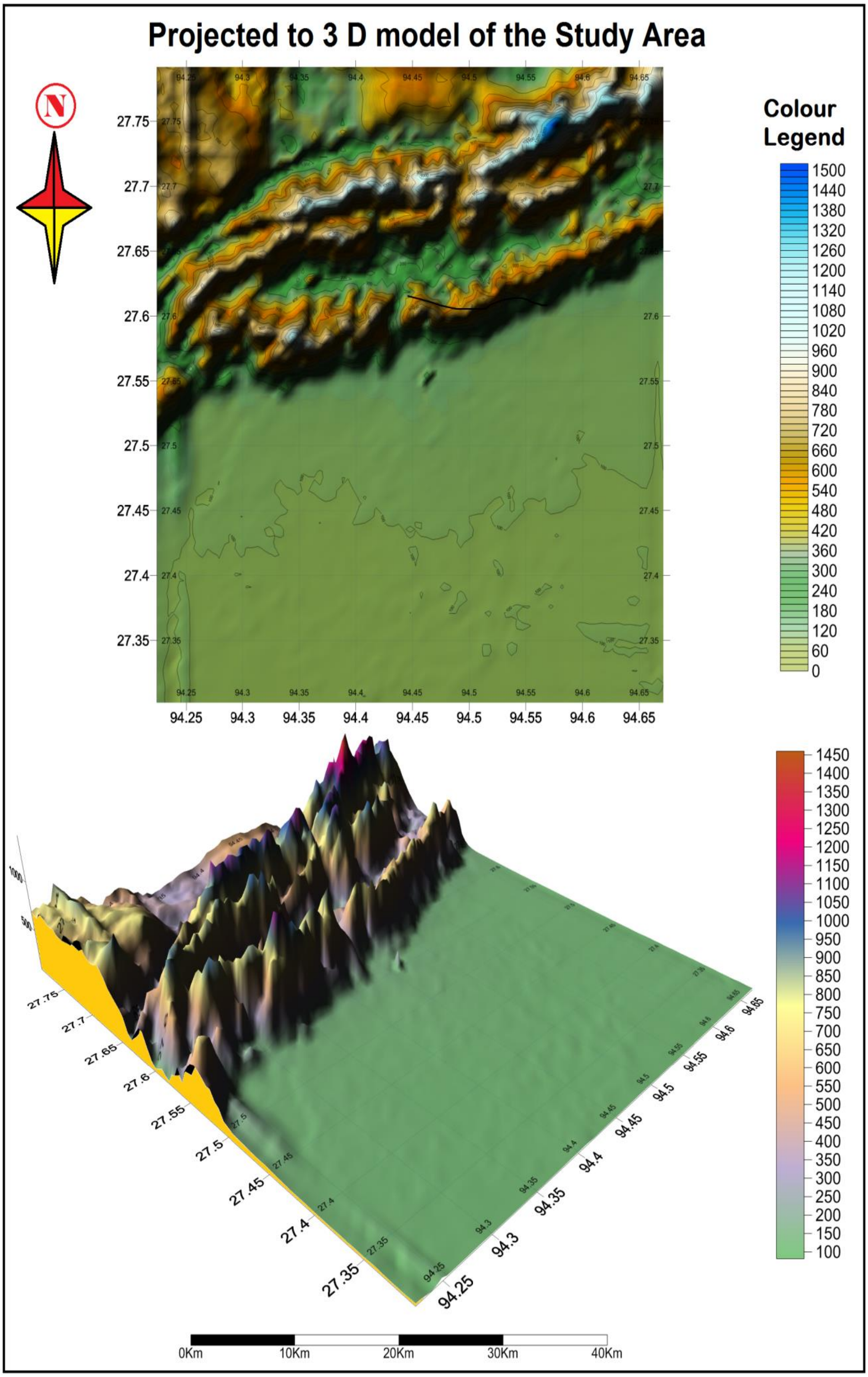


Fig. 3.4: Maps showing the 3-D model of the study area and its surroundings (Surfer18).

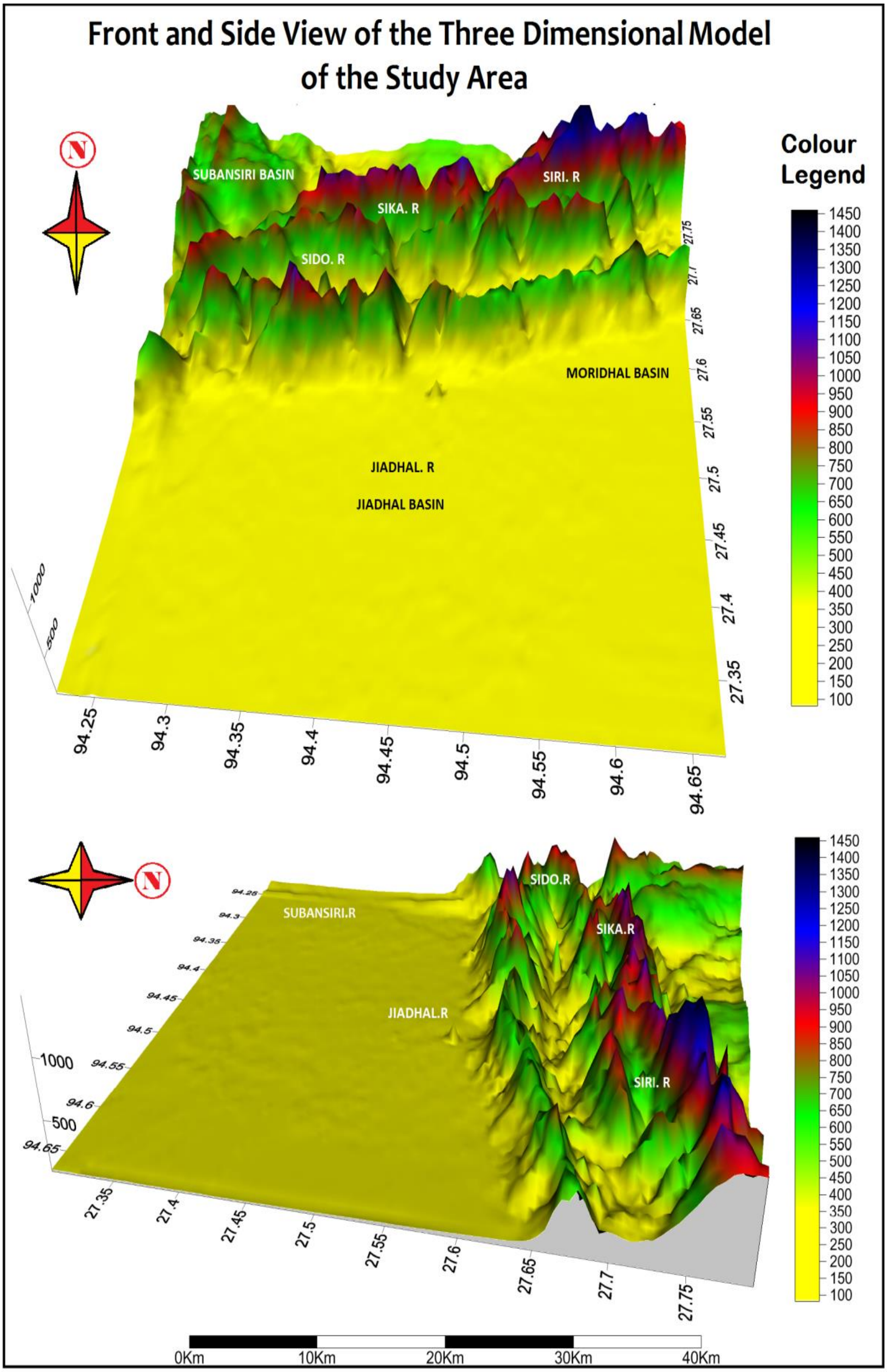


Fig. 3.5: Maps showing front and side view of the three dimensional model of the study area and its surroundings (Surfer18).

SLOPE ANALYSIS

The Slopes of the geographical unit helps to understand the basic geomorphological characteristic of the area. The environmental geomorphology of an area is more or less determined by the slope gradient. Thus it is an important analytical tool in the geomorphological studies; in general the areas with steep slopes are prone to erosion depending on its geological composition. The study area has vast difference in slope gradients considering to the geographical extent of the basin, the upper basin is a mountainous terrain with lofty Siwaliks ranging to the elevation of 1460 meters above mean sea level and the average elevation is recorder 800 meters above mean sea level (Fig 3.5 & 3.6). The drainage system dissects the basin to fragments and series of ranges, the northern range is comparatively higher than the southern range and the drainage is flowing in between. The valley comprises lower relief and so the slope gradient is lower, but the river cuts deep gorges to flow southward to extensive plain with lower relief. The elevation ranges from 30 meters to 250 meters with average altitude of 100 m above mean sea level (Fig 3.6).

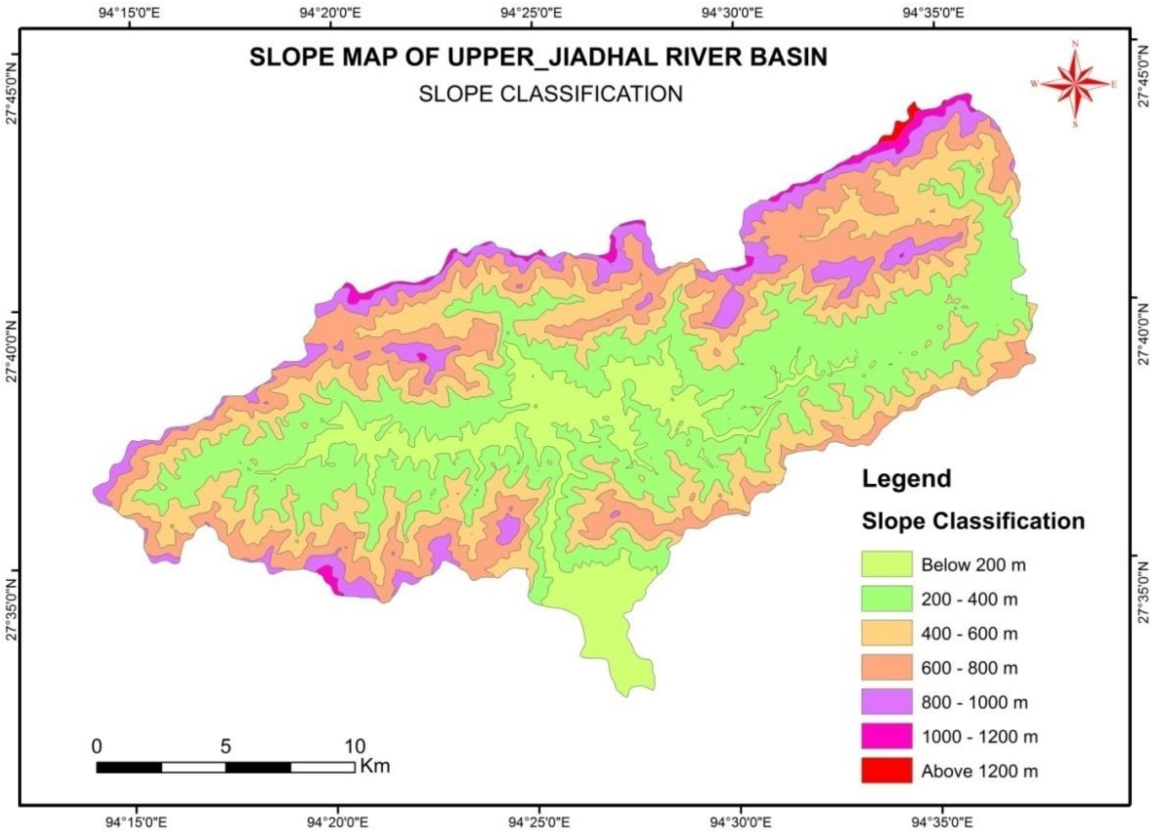


Fig. 3.6: Showing Slope classification of the Upper Jiadhal River Basin.

Slope classification map is prepared from the Digital Elevation Model (Aster-Dem) it is clear that the upper course of Jiadhal is a hilly terrain with a tri-junction of three tributaries in the flowing in the deep degraded V shape valley and often associated with deep gorges and free faces river side's that led the surface water flow of the river combine to the stream line. In winter the discharge is lowest and it becomes the communicative route for the inaccessible upper forest region. The relief or topography ranges from 200 meters (the river basin base) to 1400 meters with an average elevation of 800 meters above sea level.

Table 3.1: Showing slope classification of Jiadhal River Basin *(map attributes ArcGIS10.1)*

Contour Intervals (in Meters)	Area (M^2)	Area (Km^2)	Area coverage (in %)	Basic Characteristics
Below 100	1456346877.90	1456.35	78.66	Old and New Alluvium
100-200	45349581.22	45.35	2.45	Sand and Gravel deposits
200-300	70160196.33	70.16	3.79	Elevated valley plain , depositional landform
300-400	63532869.34	63.53	3.43	Degraded, debris and boulders.
400-500	51280107.89	51.28	2.77	Steep slope,
500-600	49454607.06	49.45	2.67	Degraded slope, low vegetation
600-700	45145008.83	45.15	2.44	Degraded slope, low vegetation
700-800	34437784.66	34.44	1.86	High vegetation cover
800-900	19948486.52	19.95	1.08	High vegetation cover
900-1000	10268307.60	10.27	0.55	Degraded and high vegetation cover
1000-1100	3906472.89	3.91	0.21	Degraded and high vegetation cover
1100-1200	1061891.08	1.06	0.06	High vegetation cover
1200-1300	384547.85	0.38	0.02	High vegetation cover
Above 1300	267568.39	0.27	0.01	High vegetation cover
TOTAL	1851544307.55	1851.54	100.00	

The contrast of elevation is highly varied in the river basin, as the upper basin is a mountainous region wearers the lower basin is a flat flood plain with highest elevation of 250m and the basically have numerous channels and lowlands even computed 60m above sea level. The area coverage of 1571.86 sq.km (84.89%) of the region have elevation below 300 meters comprising largest share of elevation ranging 200-300 meters (3.79%) mainly comprised by the alluvium plain in the lower basin and sand and gravel deposits along the river source in the upper basin. The lower areas in the upper basin above 200-300 meters comprise degraded land with depositional landforms mainly the debris slopes and boulders along the river course. The moderate height comprises 164.27 sq.km (8.87%) of area is ranged between 300-600 meters which are mainly associated with characteristics of degraded slope with debris and boulder deposits and the steep slopes are free face. The higher slope is category ranges from 600-900 meters, with degraded slope with low vegetative coverage and higher elevation have more vegetative coverage. The highest elevation categories ranges from 900 meters and above have less areal coverage with dense vegetative coverage and are less degraded.

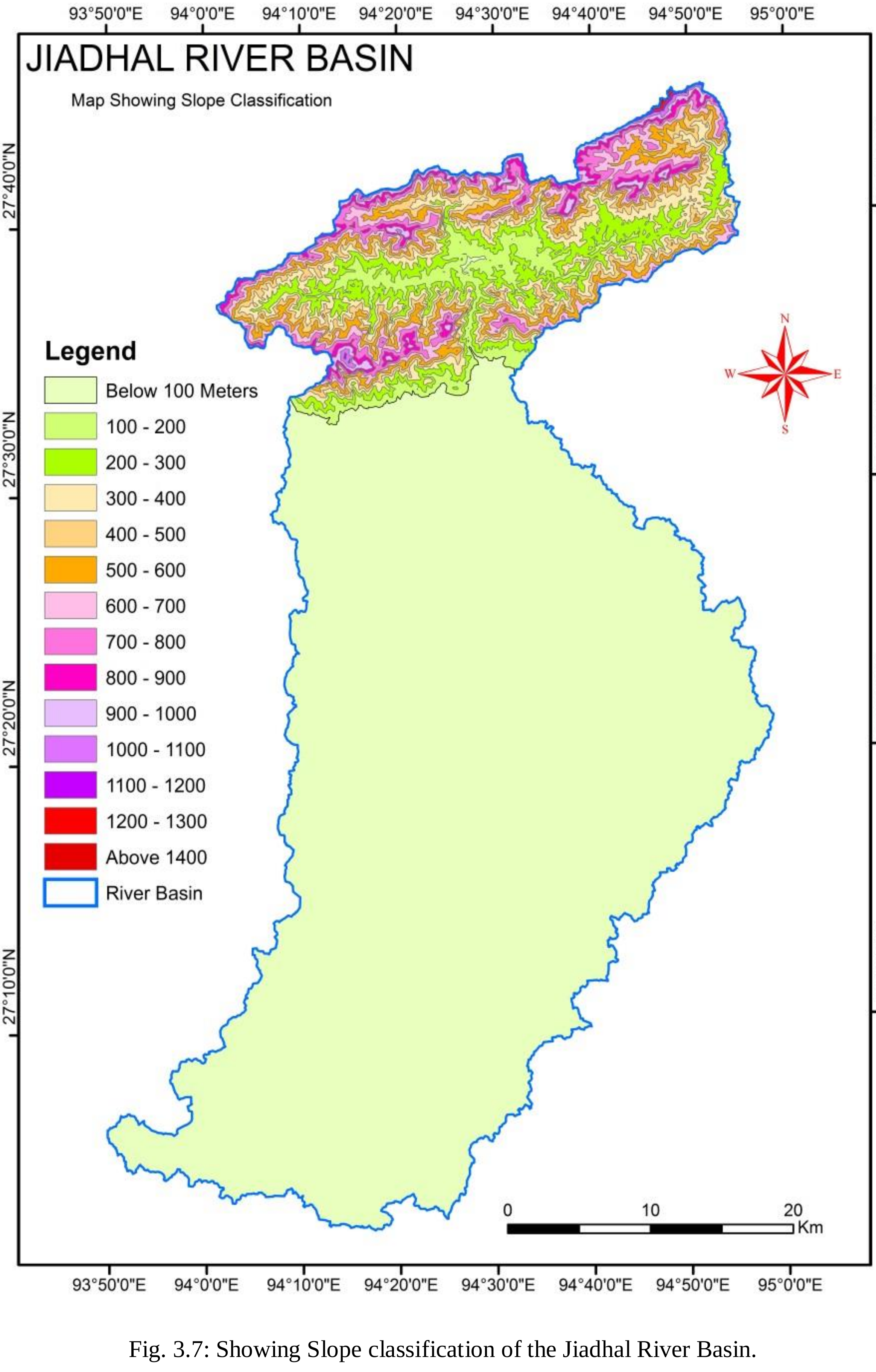


Fig. 3.7: Showing Slope classification of the Jiadhal River Basin.

Slope Aspects

The slope aspect map of the Jiadhal river basin is been assigned from the digital elevation model with the GIS software 10.1 edition. Various hydrological phenomena are correlated with the physiographic characteristics of a drainage basin such as size of the basin, slope gradient, shape of the drainage basin, density and length of the stream drainage etc.(Devi & Goswami,2015, Rastogi et al., 1976). The Geomorphic characteristic of the Jiadhal basin reflects that the northern catchment area has elevated mountainous terrain and the lower part is almost featureless plain. Thus the basin is firmly divided into Upper Jiadhal Basin having the hilly terrain and the Lower Jiadhal Basin comprising the foothill areas and the extensive flood plain. The Upper Jiadhal Basin is composed of parallel mountain ranges which are dissected by numerous streams down cutting deep gorges and steep fault lines with instable slope features. The rock and the lithology of the mountain is associated with the Siwalik Himalayas and accompanied by numerous fault lines responsible for the unstable slopes. The presence of two tectonic line viz. Main Boundary Fault and Himalaya Front Tectonic Line which do not run parallel to each other responsible for the fragile lithology of the region (Rawat. 2011). The Siwaliks are trend to be unstable to its southern slopes and thus the southward slope of the Jiadhal River basin is too fragile and prone to weathering and slide. The south facing slopes are prone to erosion in Siwaliks Himalayas and are the weaker zone contributing maximum slope failure areas. The fissures and Joints followed to the slope gradient works for its fragile characteristics (Patniak, 1993).

Table 3.2: Slope Aspects of Upper Jiadhal Basin (map attributes ArcGIS10.1)

Slope Direction	Slope Angle	Area sq.km.
North	337.5 - 22.5	48.00
Northeast	22.5 - 67.5	37.00
East	67.5 - 112.5	51.00
Southeast	112.5 - 157.5	53.00
South	157.5 - 202.5	51.00
Southwest	202.5 - 247.5	41.00
West	247.5 - 292.5	41.00
Northwest	292.5 - 337.5	48.00
Total		370.00

Source: Map attributes

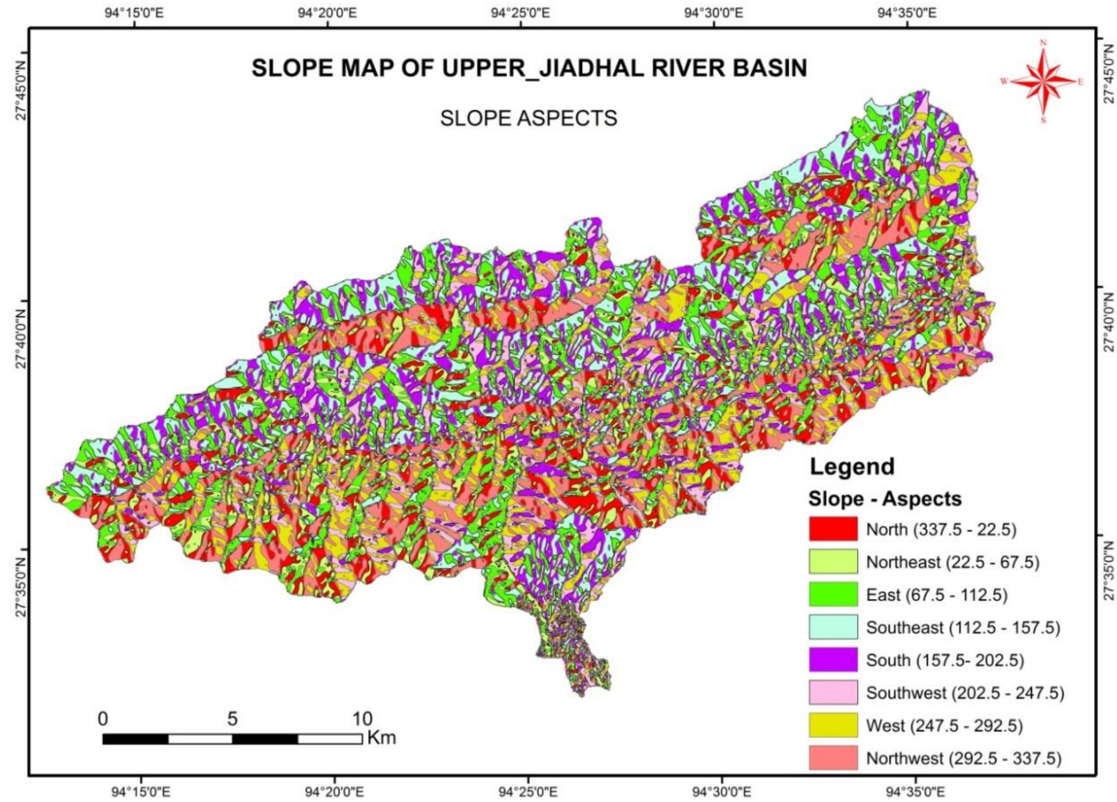


Fig. 3.8: Slope map of Upper Jiadhal River Basin.

The slope is comparatively equally occurred with largest share of southeast facing slope comprising 53 sq.km.14.32% of the basin slope. The second and third category slope is south and northeast facing slope with 51 sq.km of aerial extension (13.78%) each. Fourth and fifth category slope is the north and northwest facing slope covering 12.97% and an aerial extension of 48 sq.km each. The sixth and seventh position is occupied with an extension of 41sq.km. and 11.08% of the total slope by west and southwest facing slope. The north east facing slope comprises the lowest share of 37 sq.km with a 10% of the total slope of the basin. Thus the 39.19% of upper Jiadhal basin is highly prone to erosion and slope failure to the geomorphological characteristic of Siwaliks composed of south, south east and south west facing slopes.

Among the catchment of the upper Jiadhal basin the largest is the Siri catchment and also posses the highest share of 20% south facing slope and thus is termed to be highly fragile basin. It implies that the rivers is more erosive and thus have more chances of sediment load. It posses 48.98% south facing slope including the south east and south west facing slopes. The Sika is the second fragile catchment with 13.64% of south facing slope and compiles 39.77% including the south east and southwest facing slopes. The Sido catchment area consist 34.26% south facing slope including southeast and southwest slope. In comparison with Sika and Sido catchment the south ward facing slope of Jia-upper catchment has more south facing slope in percentage (48.65%) but its areal extension is less, whereas it is has the characteristic of trance Himalayan channel with deep gorges with free face side walls. This represents that Jia is more erosive due to the terrain morphology of the basin. Jia River cut gorges 5 km and 2 km of steep side wall with an average channel width of 30 meters in rainy days and 25 meters in dry seasons.

Table 3.3: Slope Aspects of selected catchment of Upper Jiadhal River Basin (370 sq.km)

Slope Aspects of Sido			Slope Aspects of Siri		
Slope Direction	Slope Angle	Area sq.km.	Slope Direction	Slope Angle	Area sq.km.
North	337.5 - 22.5	13	North	337.5 - 22.5	20
Northeast	22.5 - 67.5	14	Northeast	22.5 - 67.5	18
East	67.5 - 112.5	16	East	67.5 - 112.5	22
Southeast	112.5 - 157.5	13	Southeast	112.5 - 157.5	25
South	157.5 - 202.5	13	South	157.5 - 202.5	24
Southwest	202.5 - 247.5	11	Southwest	202.5 - 247.5	21
West	247.5 - 292.5	13	West	247.5 - 292.5	22
Northwest	292.5 - 337.5	15	Northwest	292.5 - 337.5	24
Total		108	Total		176

Slope Aspects of Sika			Slope Aspects of Jia		
Slope Direction	Slope Angle	Area sq.km.	Slope Direction	Slope Angle	Area sq.km.
North	337.5 - 22.5	5	North	337.5 - 22.5	3
Northeast	22.5 - 67.5	4	Northeast	22.5 - 67.5	3
East	67.5 - 112.5	6	East	67.5 - 112.5	5
Southeast	112.5 - 157.5	8	Southeast	112.5 - 157.5	6
South	157.5 - 202.5	10	South	157.5 - 202.5	7
Southwest	202.5 - 247.5	6	Southwest	202.5 - 247.5	5
West	247.5 - 292.5	4	West	247.5 - 292.5	4
Northwest	292.5 - 337.5	6	Northwest	292.5 - 337.5	4
Total		49	Total		37

Source : Map attribute table

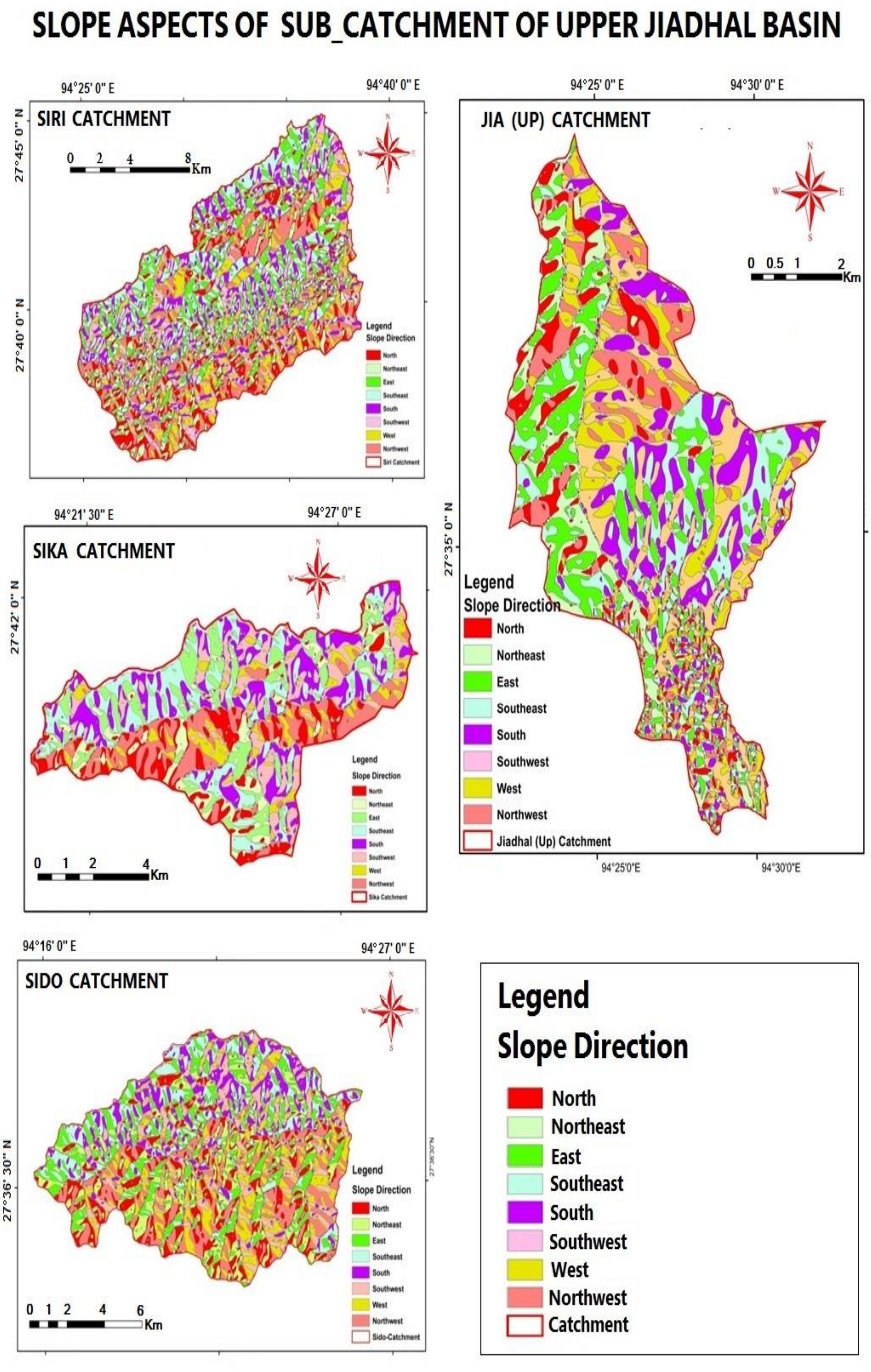


Fig. 3.9: Showing slope aspects in the Sub- Catchment of Upper Jiadhal Basin

GEOMORPHOLOGICAL HAZARDS

Geomorphic hazards are regarded as related to landscape changes that affect environmental systems. The processes that produce the landscape changes are related to geomorphological processes in collaboration of environmental aspects of a geographical area. It is a sudden change on the landscape due to few structural imbalances of the earth strata (Scheidegger, 1994). On the basis of genesis the geomorphic hazards can be categorized as endogenous and exogenous. Endogenous includes volcanism and neo tectonics whereas exogenous consist of hazards from geomorphic processes like floods, landslides, avalanche, massive erosion, sedimentation and siltation etc. (Slaymaker, 1996). Geomorphological or natural hazards are characterized as natural phenomenon in the environment but could be human induced too (Burton, 1964). Natural Hazards are more or less prove to environment friendly as they occur as a natural phenomenon for the process of equilibrium or the uniform-materialism concept of the earth surface, often responsible for the roots of disaster to environment, and human socio-economy. Un-scientific and careless activities by human being on natural environment increase the frequency and intensity of the natural hazards. Such geomorphological hazards are observed mostly in the hilly terrain and more specific in a river basin of a region.

The Jiadhal river basin has the tendency of annual occurrence of such hazards and acutely prone to multiple natural hazards like earthquakes, flood, erosion and landslides. The region receives intense rainfall in the monsoon season and the phenomenal cloudburst results the increase in the intensity of geomorphic hazards. Geologically the southward facing slopes in the region are prone to landslide and mass wasting, accompanied by anthropogenic activities like deforestation and agriculture practices. The impact of global warming and climate change are also responsible for the weather related hazards like cloudburst, flash floods, landslides and drought are becoming frequent in the river basins. The consequence of these natural phenomenon in the upper reaches of a drainage basin creates havoc to the lower basin areas due to its depositional activities of the river system. The siltation or sedimentation in the river course reduces the river depth and thus the occurrence of flood and bleaching of river side’s is a common phenomenon in the lower Jiadhal region. The flooding, siltation not only degrades the environment of the region but also ruins the livelihood of the population dwelling in the region. Some of the prime geomorphological hazards in the region are.

1) Landslide and Soil Erosion
2) Desertification and land degradation
3) Siltation and sedimentation

4) Flood hazards and water logging in the context of fluvial geomorphology

Land Slide and Soil Erosion: The degradation of soil in the hill slopes is the real problem of the environmental geomorphology of a drainage basin. The phenomenon of land degradation is a common hazard in mountainous region and is pronounce in the upper Jiadhal drainage basin. Loosing of soil by various agents of degradation in a drainage basin is characterized by fluvial processes. The geomorphology of the Upper Jiadhal river basin is a hilly track mainly composed of the Siwaliks and the presence of the thrust and fragile structures in the entire region make it vulnerable to erosion. According the Geological Survey of India, North Eastern Region, Shillong, 2010, The Sub-Himalaya or the foothill region is represented by the Siwalik hill range which are more or less fragile and prone to erosion due to presence to various geodynamic characteristics. The mountain ridges presence of tectonic lineament and heterogeneity in lithology with approaching immaturity of dissection, this landform has attained a high degree of relief, in general, represents a mega folded, faulted and thrusted terrain making it vulnerable to geomorphological hazards (Dikshit and Dikshit, 2014).

Desertification and Land Degradation: Deforestation of natural forest cover due to various activities is the root of desertification and land degradation. Desertification could be defined as a process of land degradation involving factors related to climate, geology as well as human involvement (Doula and Sarris, 2016). The physical causes include the geomorphic and hydrological factors and the biotic factors of deforestation and land degradation involves the living organism and the anthropogenic activities as prime. Other factors that cause desertification include climate change, human intervention or anthropogenic including deforestation, deforestation in the name of afforestation Infrastructural development and agriculture practices are prominent in the basin area. The effect of which could be traces in entire region as we observes the natural calamities, socio-economic development, agriculture scenario, water quality, and biodiversity of a region.

Flood Hazards: The overflow of river water from its regular course in high peal flow is termed as flood and its havoc for environment as well as mankind for its capacity of destruction both properties and life. Flood causes may be different base on the environment geomorphology of the region, but it is the excessive precipitation and surface run off that produces flood. Flood could be a flash flood, river flood, ponding flood or pluvial flood, urban flood and coastal flood on the other hand water logging due to excessive rainfall also created flood like situations in plains of Jiadhal river basin. The water logging, flash flood and river flood or fluvial flood is found active in the Jiadhal basin. The upper Jiadhal basin is a hilly terrain with deep river valleys thus flooding is not a concern for this region, but the high peak flow from a narrow gorges with turbulence and velocity is a characteristic of hazard. Siltation and sedimentation in the lower river bed led the riverbed rising and often prone to overflow in peak seasons. Again towards the lower basin the river has no permanent course to flow so have tendency to shift by even bleaching the river banks. Thus the hazards allocated with flood in Jiadhal river basin are siltation, sedimentation, river bed rising, bleaching, bank erosion, submergence of wetland and depressions etc.

ENVIRONMENTAL GEOMORPHOLOGY FOR SUSTAINABLE DEVELOPMENT OF WATERSHED

The geographical unit or a hydrological unit of earthsurface with a common outlet of water flow is considered as watershed or drainage basin. Rao (2000) defines watershed as natural hydrologic entity that cover a geographical unit with common surface runoff flows to a defined drain system. A watershed areal extension may varies from a few hectares as in the case of small ponds, or hundreds of square kilometers as in the case of rivers or sea. Thus for regional and specific studies it is further classified in terms of its size into: Basins, Catchments or Sub watershed. A watershed is mainly associated with the ridge line (line of delineation along the highest points in the given watershed area) often called watershed boundaries or water divide (through which water flows, along the slope) or the water accumulation and flowages to an common outlet (a point through which entire rain water that falls on the watershed surface drains out (Rao, 2000).

The watersheds are projected for sustainable development of basin area including land, water and plant resources for environment and well as socio-economy of the region Satapathy, (2003). The heterogeneous characteristics of Jiadhal river basin could be balanced by integral programmes of the drainage basin or the watersheds. It includes the integration of various independent programs of soil conservation, afforestation, minor irrigation, crop production, tree plantation, fodder development and other development activities into a well prepared micro-watershed project for the sustainable development of the watershed or drainage basin. It offers hope for bringing about sustained natural resources development. It also provides solution to many environmental problems like soil erosion, siltation, improper land use, lowering ground water table etc. Gunasekaran, (2014).

THE WATERSHED SYSTEM OF JIADHAL RIVER BASIN

The Drainage System that drains the study area is a young mountainous river system originated in the hilly terrain of Siwalik Himalayas of Arunachal Pradesh, particularly the Kanku circle of West Siang District. The basin is adjacent to lower eastern mountainous part of Subansiri River, and later it drains as its largest tributary in the plains of Assam. The Drainage Basin or Watershed of Jiadhal River has the areal extension of 1851.43 sq.km. The Drainage basin is divided into two geographical units mainly due to the physiographical difference in comparison to the drainage system prevailing as, Upper Jiadhal Basin and Lower Jiadhal Basin.

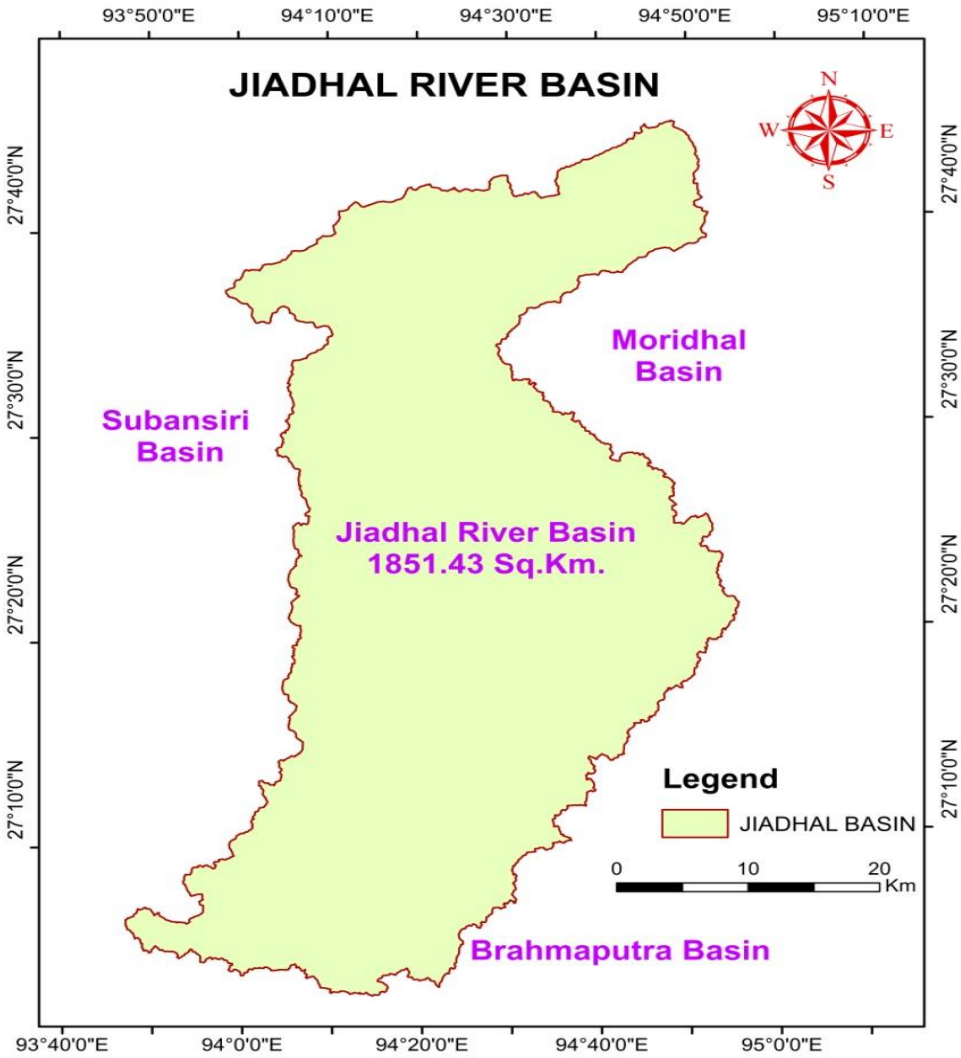


Fig. 3.10: Map showing the Jiadhal River Basin of Arunachal and Assam.

Table 3.4. Drainage area characteristics in the Jiadhal River Basin

River Section	Highest extent (East-West) in km	Highest extent (North -South) in km	Area (in sq.km)	Perimeter (in km)
Jiadhal Upper Basin	38.07	18.45	370.63	122.03
Jiadhal Lower Basin	34.35	60.83	1480.80	253.46
Jiadhal River Basin	34.35	84.89	1851.43	334

Sources: Geospatial map Attributes (ArcGIS10.1)

The geographical situation of extended from latitudinal and longitudinal extensions of 27º 08’ N to 27º 45’ N and 94º 15’ N to 94º 38’ E respectively. The upper basins is geopolitically situated at Arunachal Pradesh with an aerial extension 370.63 sq. km and have a drainage perimeter of 122.03 km comprising 20% of the total basin area. Aerially the highest length of the upper Jiadhal basin in 38.07 km from east to west and the width is 18.45 km from north to south. The highest extent of the Jiadhal Bain is 34.35 km from east to west and it is measures 84.89 km at the highest extent from north to south of the whole basin area. It comprises a perimeter of 334 km with an area of 1851.43 sq. km. occupying 80% of the total drainage area (table no. 3.4).

The Jiadhal is the largest tributary to Subansiri river system it has Moridhal basin lays towards the northeast margin and the Subansiri basin in the north and west of the Jiadhal river basin. The southern portion of the basin is adjacent to mighty Brahmaputra River. The Moridhal basin is combine with perennial streams and collectively forming the Moridhal river system, but in the after affect of the Assam earthquake the most stream of the river went dry so in local language the ‘Mori’ represents ‘Death’ and dhal means the river. Thus it is literally termed Moridhal river as its dried seasonally, the is a seasonal river system draining a geomorphological setting which did not follow the same course for a long time and thus it frequently change their course and the older courses become either misfit, dry or marginalized channels (Dhemaji district website).

The Subansiri is a Trans-Himalayan flowing from Tibetan Himalayas particularly near Mount Pororu (5059 m) and flowing 190 km through Tibet, it enters India. It continues its journey across Arunachal Himalayas for 200 km and enters into the plains of Assam through a gorge at Gerukamukh, near Gogamukh (Assam State Gazetteer General Vol.1, 1999, Dhemaji district website). The Brahmaputra towards the south is the soul drainage system of the region as all these mentioned drainage system is a part of greater Brahmaputra basin of Assam. The Brahmaputra receives many tributaries throughout its length and Jiadhal of the Subansiri river system is one of the most important right bank tributaries to Brahmaputra. Subansiri is the greatest tributary from northern flank of the basin (Rural Volunteers Centre, flood report).

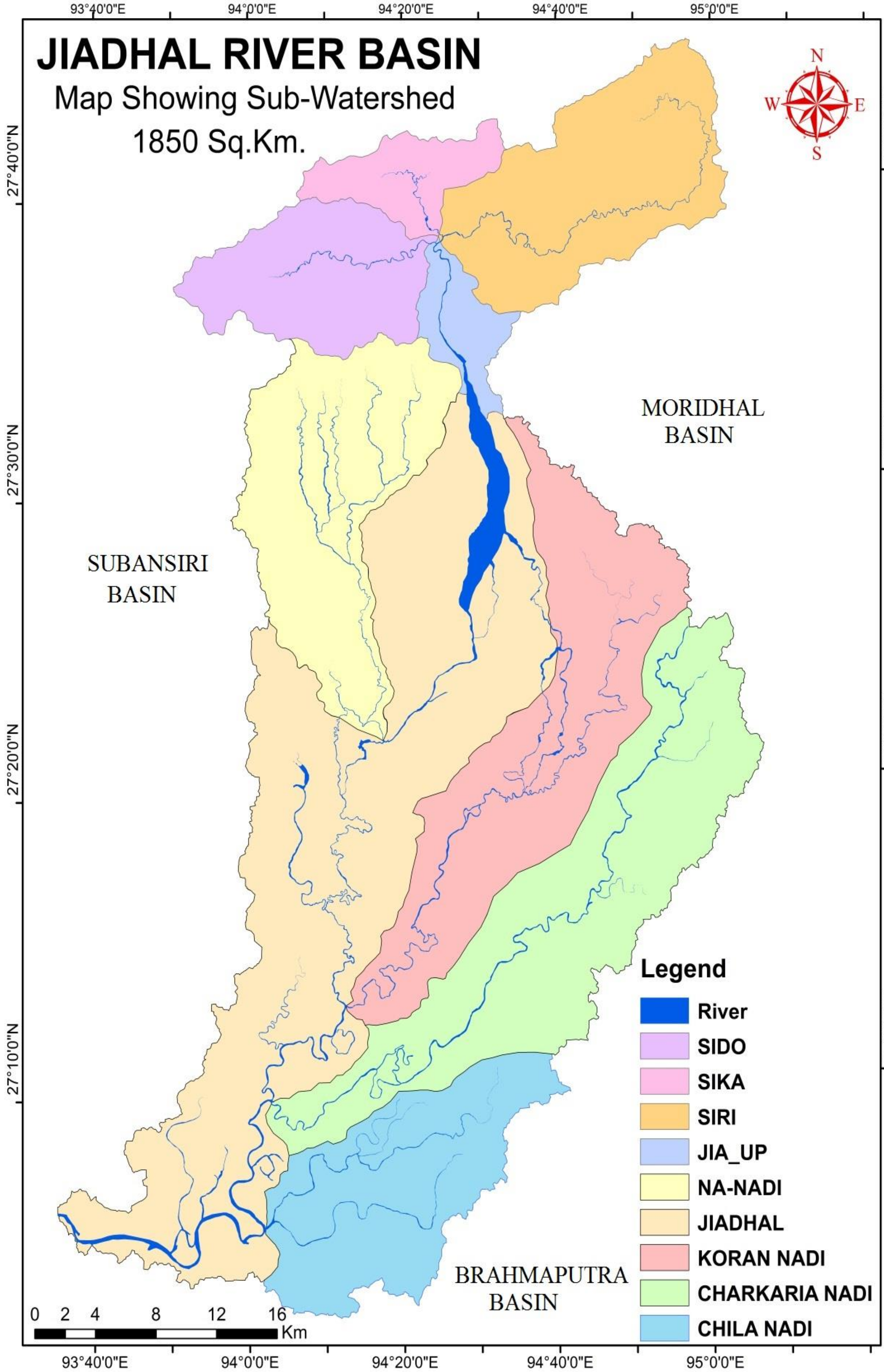


Fig. 3.11: Map showing Sub-Catchments of Jiadhal River Basin Catchments, Arunachal and Assam (ArcGIS-10.1)

SUB-WATERSHEDS OF UPPER JIADHAL WATERSHED

The Jiadhal Basin has heterogeneous characteristics mainly in regards to the terrain and topography, which reflects different environmental and well as geomorphological settings of the region. The geomorphological characteristic of the basin defines the physiographical units for the delineation of the watershed into two parts viz. Upper Jiadhal Basin and Lower Jiadhal Basin. The main criterion of basin delineation is the topography as the study and research of a river basin mainly triggers for its sustainable development. A watershed or a drainage basin with heterogeneity would not fulfill the requirement of a planning region, as for sustainable development of geographical unit its homogeneity is a prime factor. Upper Jiadhal Basin is been delineated from the basin mainly on the basin of the watershed and physiographical difference. The Upper terrain is drained by three tributaries of Jiadhal with a distinct geographical unit and has different characteristics. The three rivers are Sido, Sika and Siri, and their combination in a tri-junction is the origin of Jiadhal river system. Thus the sub watershed or catchment of the upper Jiadhal basin could be delineated on the basis of the water divide and accumulation of water to a common outlet. The Map prepared using ArcGIS 10.1 with ASTER DEM file obtained from open source data of USGS and ISRO's geoportal - Bhuvan portal and the watershed was extracted from the DEM of the entire basin. The Drainage analysis was run on the DEM to get the proper water flowage map in the spatial analysis tool available in the geo-spatial modeling in the ArcGIS 10.1 edition. Other geo spatial software used in this process is Quantum GIS3.1-Girona with Grass 7.4 edition (QGIS 3.1) which is available in open source geo-specific tools and software. The same drainage basin was further delineated on the basin of water acumination and drainage flow in a water divide into catchment areas viz. Sido Catchment, Sika Catchment, Siri Catchment and Jia Catchment areas.

Table 3.5: Selected sub-catchment of the Jiadhal Upper Basin

River Section	Highest extent (East-West) in km	Highest extant (North -South) in km	Area (in sq.km)	Perimeter (in km)
Sido Catchment	17.82	10.21	110.52	52.41
Sika Catchment	14.20	6.82	48.52	48.52
Siri Catchment	20.71	11.56	176.30	66.54
Jia-Up Catchment	7.12	11.80	35.29	35.32
Jiadhal Upper Basin	38.07	18.45	370.63	122.03

Sources: Geospatial map Attributes

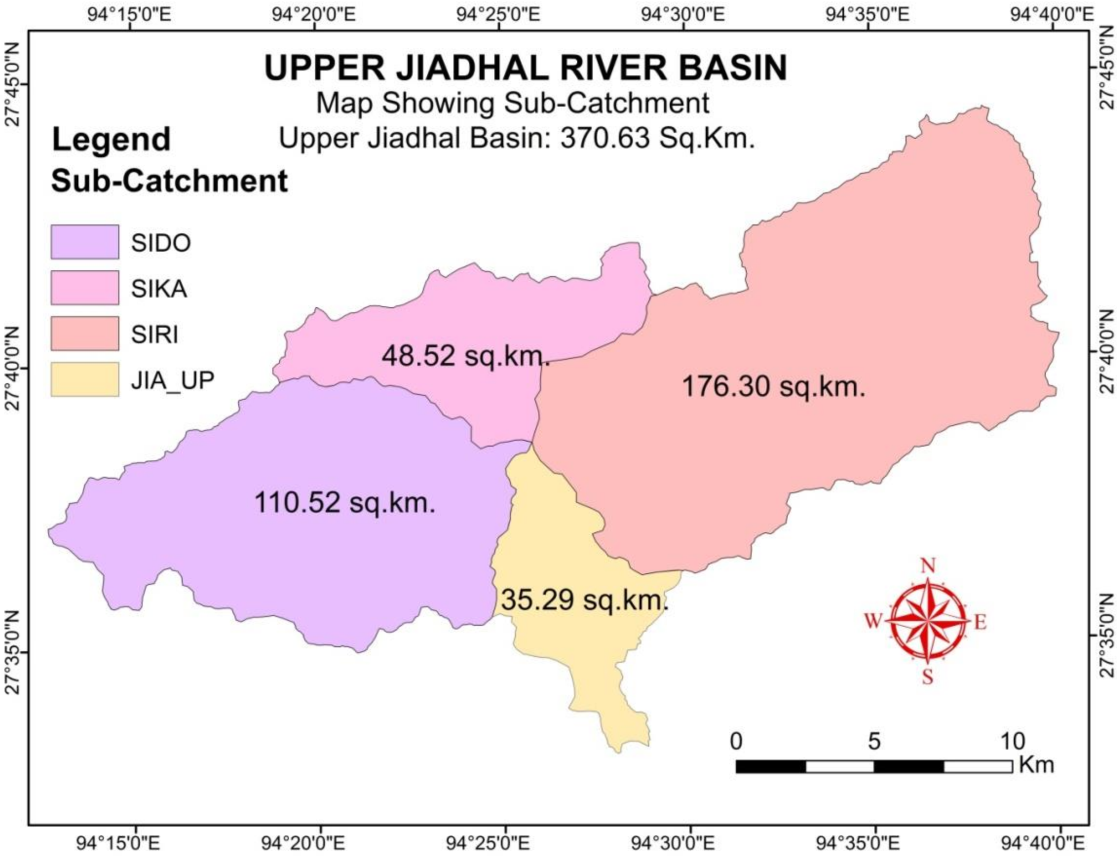


Fig. 3.12: The Sub-Catchments of Upper Jiadhal River Basin (ArcGIS10.1)

The Upper Jiadhal Basin is extended in the hilly tracks of Arunachal Himalayas and has a rough terrain with bisected river system. The stream dissected the terrain in numerous ridges and isolated with different drainage characteristics. The Jiadhal Upper Basin consists of 370.63 sq.km of aerial extension. The mapping indicated the highest width of the basin recorded as 38.07 km. from east to west extent and 18.48 km from north to south extent. Comprising mainly three tributaries joining together and the Jiadhal originated from the Tri-Junction. The physiography of the upper Jiadhal basin is highly dissected by the drainage system prevailing there and the rivers undercut deep gorges and valleys depending on its aerial extension of the catchment area. Among the four catchment of the Upper Jiadhal basin the Siri Catchment is the largest with 176.30 sq. km and Sido scores the second position with 110.52 sq. km. The Sika catchment is the third with 48.52 sq. km. of drainage area followed by the Jia catchment which has an area of 32.29 sq. km.

Sido Catchment: The Sido catchment is a more or less a circular block with Subansiri basin in the eastern margin, toward the north and north-east lays the Sika catchment and to the south-east lays the Jia catchment. The southern periphery is associated with the Lower Jiadhal basin. The Sido has a perimeter of 52.41 km with highest length of 17.82 km of east to west and 10.21 km of north to south extension comprises a drainage area of 110.52 sq. km.

Sika Catchment: The north central part of the upper Jiadhal basin lays the Sika Catchment with a perimeter of 48.52 km. Geometrically Sika catchment is elongated with a bulge in central part extending to 6.82 km width from north to southward, and 14.20 km length from east to west is the fardest extension occupying a area of 48.52 sq.km. The northern and north-western margin is associated with the Subansiri Basin, while in the east, south-east lays the Siri catchment and towards the south, south-west lies the Sido catchment.

Siri Catchment: The shape of Siri catchment is rectangular with Subansiri basin in the northern periphery, toward the east and south lays the upper reach of Moridhal basin. Towards the west and south-west lays the Sika and Jia catchment respectively. The Siri has a perimeter of 66.54 km with highest length of 20.71 km of east to west and 11.56 km of north to south extension comprises a drainage area of 176.30 sq. km.

Jia Catchment: The south central part of the upper Jiadhal basin lays the Jia catchment with a perimeter of 35.32 km. Geometrically Jia catchment is elongated north to southward with a highest extension of 11.80 km and 7.12 km of highest width in the central portion. Jia catchment occupying a area of 35.29 sq.km. The northern point of Jia catchment lays the tri-junction of the three catchment viz. Sido from the west, Sika from the north and Siri from the east. The southern portion is submerged with the Lower Jiadhal basin like a peninsula.

SUB-WATERSHED OF LOWER JIADHAL WATERSHED

The Lower Jiadhal Basin comprises numerous streams and channels extensively stretch over the low lying flood plain of Assam from the piedmont track of the Arunachal Himalayas of West Siang district of Arunachal Pradesh towards its northern extent. The northern peripheral part has some hilly terrain and the piedmont hill slopes with old alluvium plain resembles to the Terai belt. The extension of Lower Jiadhal Basin starts from the foot hill of Hilly tracks of Arunachal toward the north and in particular south to Sido, Jia-Up and Siri catchment. Towards the east it is adjacent to Subansiri River Basin and towards the east it has the Moridhal river Basin. The Brahmaputra river basin flows in the southern margin of the Lower Jiadhal Basin. The region has innumerous drainages and water bodies in the extensive low lying plain. The climate of the region plays a vital role in the characteristics' of the drainage basin or watershed along with the physiography. The lower basin area is almost featureless with an average elevation of 100 m above mean sea level, which is accompanied with numerous natural wetland and depressions with water logging throughout the year. In the rainy seasons almost the whole areas obtain heavy to very heavy rainfall which creates water logging in the plains due to low slope gradient and less outlet. Thus each drainage prevailing get inter connected and the river courses get diverted frequently, and in the dry reason the flow reduces and dried up even decreasing the water table. Keeping in view of the stream flows four catchment are delineated in the lower Jiadhal basin viz. Na-Nadi Catchment, Jiadhal Catchment, Koran Catchment, Charikaria Catchment and Chila Nadi Catchment.

Table 3.6: Sub-catchment of Lower Jiadhal River Basin

River Section	Highest extent (East-West) in km	Highest extant (North -South) in km	Area (in sq.km)	Perimeter (in km)
Na-Nadi Catchment	17.74	24.25	191.99	77.52
Jiadhal Catchment	13.92	58.17	635.65	198.04
Koran Catchment	23.96	40.48	266.25	140.72
Charikaria Catchment	41.28	13.18	288.26	126.31
Chila Nadi Catchment	18.74	9.23	168.65	63.07
Jiadhal Lower Basin	34.35	60.83	1480.80	

Sources: Geospatial map Attributes

Na-Nadi Catchment: The Na-Nadi catchment is a situated in the north-west of the lower Jiadhal basin, the Subansiri basin is toward the western margin and the Jiadhal basin in the east and south engraving Na-Nadi catchment within. The Na-Nadi catchment has a perimeter of 77.52 km with highest length of 17.74 km of east to west and 24.25 km of north to south extension comprises a drainage area of 191.99 sq. km.

Koran Nadi Catchment: It has an aerial extension of 266.25 sq.km. and its perimeter is 140.72 km occupying the second position of the aerial extension in lower basin. The fardest east to west extension is 41.28 km and 13.18 km from north to south. It is bordered by Moridhal basin towards the north-east, Jiadhal catchment in the west margin and Charikaria Nadi catchment from the south. It has a triangular shape and broad in upper portion and the lower portion is projected towards south west, it reflects the river flowing south-westward (Table 3.6 and Fig. 3.15).

Charikaria Nadi Catchment: The Charikaria-Nadi catchment is a situated in the central-west of the lower Jiadhal basin, the Brahmaputra basin is toward the eastern margin and the Jiadhal basin in the west and south. The Charikaria-Nadi catchment has a perimeter of 55 km with highest length of 41.28 km of east to west and 13.18 km of north to south extension comprises a drainage area of 228.26 sq. km. It is elongated in shape and extended south westerly (Table 3.6 and Fig. 3.15).

Chila Nadi Catchment: It is the smallest catchment with an aerial extension 168.65 sq.km. and 63.07 km of its perimeter. The highest east to west extension is 18.74 km and 9.23 km from north to south. It is bordered by Charikaria Nadi towards its north margin and Jia basin towards the west and towards west and south lies the Brahmaputra river.

Jiadhal Catchment: It occupies an aerial extension 635.65 sq.km, and its perimeter is 198.04 km, it is the largest catchment of the lower basin. The highest east to west extension is 13.92 km and 58.17 km from north to south. It is bordered by Subansiri basin towards the west, Na-Nadi in the north-west and Koran and Charikaria Nadi catchment in the east. It is long elongated shape extending north to south and a bend towards the east by a small tributary Chila Nadi (Table 3.6 and Fig. 3.15).

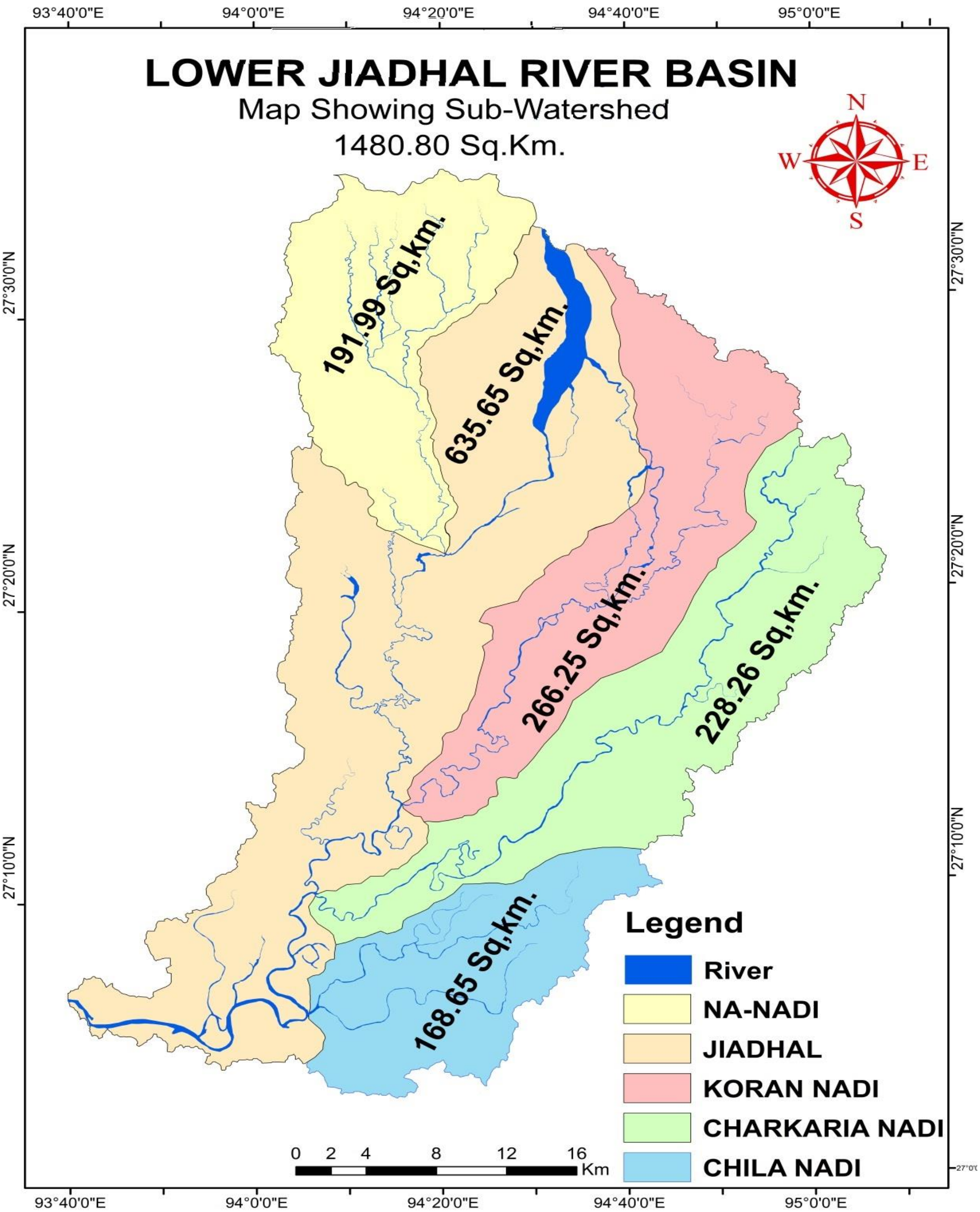


Fig. 3.13: The Sub Catchments of Lower Jiadhal River Basin (ArcGIS10.1)

DRAINAGE MORPHOLETRY

In geomorphology the development of landscape is studied by the measurement of the morphometry parameters of a region, including the relief properties (Rawat, 2011). Drainage morphology includes the physical properties of the geographical unit including the shape or geometry of the relief features, its pattern of existence and its importance on landform development (Strahler,1969). Horton (1932 and 1945) was the pioneer in this field to study the stream perimeters of a drainage system and which was later modified and developed by Strahler (1950), Schumm (1956), Chorley (1957), Melton (1959), Scheidegger (1965), Morisawa (1968), Shreve (1967), Woldenberg (1966), Lewin (1970) and many others (Rawat, 2011). In geomorphological studies the drainage characteristics in discussion are the stream ordering, drainage density, stream frequency etc.

Stream Ordering:

The stream ordering is one of the primary elements of the analysis of a drainage basin perimeter. Stream ordering was brought to geomorphological studies by Horton (1932 and 1945) and later modified by Strahler (1952) as was widely accepted. According the Strahler's method of stream ordering, the headwater stream are always treated the first order stream. The stream order changes to a higher order when two small ordered same joins. The stream order did not changes if any smaller order stream get joined, but as when two same order streams joins then the subsequent stream would be of higher order. Rawat, 2011 illustrated that the fingertip tributaries have been designated as first order streams and then two first order produce a second stream order simultaneously two second order produce a third order stream and so on (Rawat, 2011).

To determine the stream order of the Jiadhal river basin, the Strahler's method of stream ordering was adopted, as it has the advantage to be derived mathematically and need less time and effort for analysis. The ASTER DEM (Digital Elevation Model) file of the study area is used for the geospatial analysis on the Arc-GIS 10.1 edition. The watershed modeling tool available in the hydrological spatial analysis package in Arc-GIS 10.1 edition was used to delineation of the Jiadhal watershed and the sub-watershed or the catchment of Jiadhal basin. The basin area is projected considering the hydrological perimeters of fill direction of water, flow direction of water, accumulation of the water, and steam ordering analytical tools.

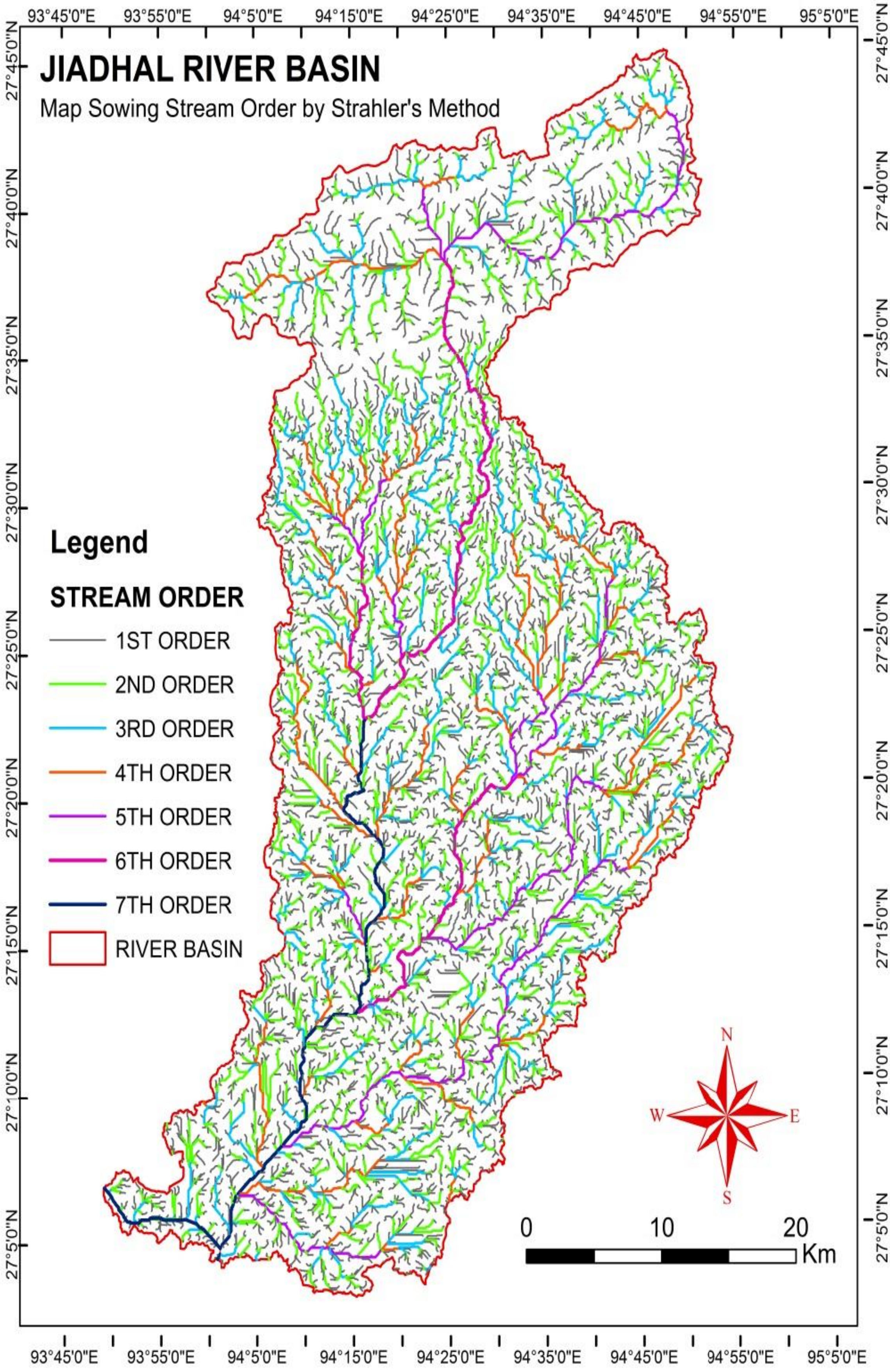


Fig. 3.14: Map showing Stream Ordering in the Jiadhal River Basin as per the Strahler's method (through Arc-GIS10.1)

Accordingly the stream ordering map was prepared on the Jiadhal River Basin.

Table 3.7:Stream Ordering of Jiadhal River Basin by Strahler's Method

STREAM ORDER	Shape Length (m)	Stream Length (Km)	Area coverage in (%)
1 ST	2271094.82	2271.09	51
2 ND	1131487.97	1131.49	25
3 RD	522197.48	522.20	12
4 TH	274002.75	274.00	6
5 TH	153978.06	153.98	3
6 TH	75738.47	75.74	2
7 TH	56640.12	56.64	1
Total	4485139.67	4485.14	100

Sources: Geospatial analysis attribute table (ArcGIS-10.1)

The stream order having a true pyramidal growth in stream length shows that the area is humid with highly degraded channels. The Stream characteristics of the upper Jiadhal basin are varies from the lower Jiadhal basin because of the vital difference of relief and topography. The upper Jiadhal basin prevails in a rough terrain with fragmented mountain ranges and thus the density is low in comparison to the low relief flood plain dominated lower Jiadhal basin. The first order streams in the Upper basin are mainly originates from natural springs whereas in the Lower basin areas it is merely an accumulation of surface runoff and often dried up in dry season. The 1st stream order river comprises the 51% drainage system of the entire basin with a total stream length of 2271.09 km, followed by the 2nd orders composed of 25% of the total and its stream length is 1131.49Km. The first order stream are numerous in the plains of Assam but are not perennial as dried up in the winters and in summer due to heavy rainfall the channel get interlinked. Thus it is difficult to trace all first order streams, the Digital Elevation Model of the basin is been organized into various phases to locate this streams. The 3rd order river system extended 522.20 km of total stream length with 12% of the regions drainage region. These third orders rivers have greater influence in the lower Jiadhal basin and have other physical characteristics. The third stream orders are perennial and have permanent courses contributing the landform development in fluvial process of the drainage basin. The 4th order rivers occupy 274 km of stream length and 6% of the total basin area, the streams has names in local languages. The 5th order streams are flowing in total 153.98 km in total consisting 3% of the drainage area and are has more or less permanent river course with an characteristic of meandering and frequent channel shifting due to flood affects. The 6th order streams comprise a total stream length of 75.74 km and posses only 2 % of the total drainage. The 7th order stream is the highest stream order of the Jiadhal drainage basin and its total length is 56.64 km out of the total stream length of 4485.14 km consisting only 1% of the drainage.

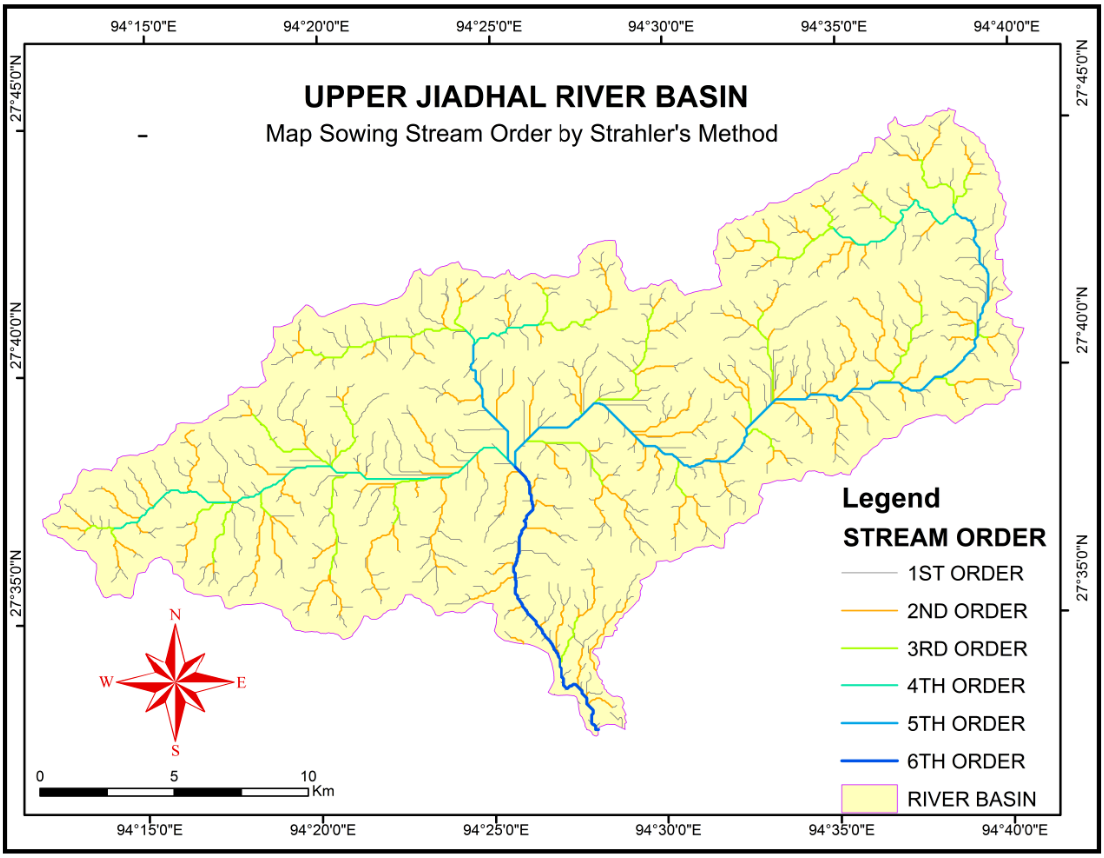


Fig. 3.15: Stream order map of Upper Jiadhal basin (through Arc-GIS10.1)

<u>Stream Number</u> (Nu):

The total number of particular stream order of the entire catchment or a watershed is the stream number, and its total is the total stream count of the watershed. The total of order wise stream segment is known as stream number, it is symbolically denotes as 'Nu' of a particular unit.

Nu= N1+\N2+… Nu

Where, N1 = First order stream
N2 = Second order stream
Nu = Number of streams

In general the stream number (Nu) gradually decreases as the ordering of the stream increases. This is in accord with the Horton's (1995) law which states that the "number of stream segments of each order forms an inverse geometric sequence with order number" (Venkatesan, 2015).

Table 3.8: Stream Numbers of the Upper Jiadhal River Basin

Catchment	High -est order	Stream order (U)						
		1st	2nd	3rd	4th	5th	6th	Total
Sido Catchment	4	169	38	9	1	0	0	217
Sika Catchment	5	77	16	4	2	1	0	100
Siri Catchment	5	193	74	16	2	1	0	286
Jia-Up Catchment	6	64	16	1	0	0	1	82
Upper Jiadhal Basin		503	144	30	5	2	1	685

Sources: Geospatial analysis attribute table (ArcGIS-10.1)

The Upper basin (Table 3.8) has a low drainage count then the lower basin area, as from the attribute table of the spatial analysis carried out in GIS software 10.1 edition the results were. The main stream of Sido occupies the forth (4th) ordered stream, the Sika and Siri is fifth (5th) and Jia is the sixth (6th) and continued to flow the lower drainage basin. The first (1st) order stream counts 503 nos. with Siri catchment having the highest count of 193 followed by Sido (169), Sika (77) and Jia (64) numbers of first order streams. The second (2nd) order basin is similar with Siri (74), Sido (38), and both Sika and Jia having 16 each. Siri has 16 third (3rd) followed by Sido with 9, Sika has 4 and Jia has only one. Siri and Sika has two (2) each and Sido has only one forth (4th) order stream, whereas only there is only one (1) fifth (5th) order stream in Siri and Sika both. This stream order reflects that the water volume is more at Siri followed by Sido than Sika accordingly of the three tributaries to join at a tri-junction to form the sixth (6th) order stream Jia.

The Lower Basin (Table 3.9) has five catchments out of which of Na-Nadi and Koran is of Sixth order stream and Charikaria and Chila Nadi is of fifth (5th) order stream. And the Jiadhal flowing from the upper basin as 6th order become seventh (7th) order stream in the middle course in the lower basin. The statistics of first (1st) order stream counts is highest in Jiadhal with 1307, followed by Koran (1099), Charikaria (593), Na-Nadi (420) and Chila (279) numbers of first order streams. The second (2nd) order basin is similar with Jiadhal comprising (343), Koran (310), Charikaria (150), Na-Nadi (110) and Chila (74). Koran has highest of 69 third (3rd) order stream followed by Jiadhal, Charikaria, Na-Nadi and Chila with 63,37,28 and 20 respectively. Forth order stream has equal share in Jiadhal and Koran catchment with 15 each and Na-Nadi and Charikaria with 9 each and the Chila has the lowest of 4 streams in forth order. Koran has 3 numbers of fifth (5th) order stream followed by Na-Nadi and Jiadhal consisting 2 each and both Charikaria and Chila has only one each.

All the catchment has one (1) sixth order stream except Chila catchment. These stream orders reflect that the water volume is more at Jiadhal followed by Koran whereas the ground truth is different the Jiadhal has low run off then the Koran and Charikaria system due to hydrological properties of the catchment and contributes a largest water volume to the main stream in the mid way of the lower Jiadhal river basin and drained to Subansiri as seventh (7^{th}) order river.

Table 3.9: Stream Numbers of The Lower Jiadhal River Basin

Catchment	Highest order	Stream order (U)							
		1st	2nd	3rd	4th	5th	6th	7th	Total
Na-Nadi	6	420	110	28	9	2	1	0	570
Jiadhal	7	1307	343	63	15	2	1	1	1732
Koran	6	1099	310	69	15	3	1	0	1497
Charikaria	5	593	150	37	9	1	1	0	791
Chila Nadi	5	279	74	20	4	1	0	0	378
Lower Jiadhal Basin		3698	987	217	52	9	4	1	4968
Total Jiadhal Basin		4201	1131	247	57	11	5	1	5653

Sources: Geospatial analysis attribute table (ArcGIS-10.1)

Stream Length (Lu)

The total length of the particular stream order of the entire watershed is known as stream length of the particular order.

Lu = L1+L2…/ Ln

Where, Lu = Stream length of the particular order
L1 = Length of the first order stream
L2 = Length of the second order stream
Ln = total number of stream length.

It is calculated by dividing the average length of the stream in each order by the total length of all streams in a particular order by the number of streams in the order. The stream length in each order increases according with increasing stream order (Oruonye, 2016). The total stream lengths of the study area have various orders, which have computed with the help of GIS software. Strahlers, 1964 advocates that the stream length of Horton's law support of the geometrical similarity is preserved generally in sub-basin of increasing order.

Plate.3.1: Photographs showing field survey for drainage morphometry , a) Stream speed b) Stream depth , c) Flood and altitude level, d)channel width, e) Culvert depth and width, and f) Stream depth from Bridge NH-15.

Table 3.10: Stream Channel Networks and Morphometric Parameters of the Upper Jiadhal River Basin

Morphometric Parameters	Symbol used	Stream order (Su)						
		1st	2nd	3rd	4th	5th	6th	Total
Total Number of Stream	Nu	503.00	144.00	30.00	5.00	2.00	1.00	685
Total Stream Length (km)	Lu	321.00	161.00	68.00	28.00	33.00	13.00	624
Mean Stream length (km)	Lum	0.64	1.12	2.27	5.60	16.50	13.00	0.91
Stream Length Ratio	Lurm	0	0.21	0.17	0.49	0.46	18.91	12.04
Total Basin Area (sq.km)	Ab	189.02	96.36	40.77	18.53	18.53	7.41	370.62
Mean Basin Area (sq.km)	Ab	0.38	0.67	1.36	3.71	9.27	7.41	0.54
Bifurcation Ratio	Br	3.49	4.80	6.00	2.50	2.00	0.00	1.90
Drainage Density (km/sq.km)	Dd	1.70	1.67	1.67	1.51	1.78	1.75	1.68
Basin Length (km)	Bl	0.64	1.12	2.27	5.60	16.50	13.00	39.12
Basin Perimeter (km)	Bp	189.02	96.36	40.77	18.53	18.53	7.41	370.62
Stream Frequency (no/sq.km.)	Sf	2.66	1.49	0.74	0.27	0.11	0.13	1.85
Drainage Texture	Dt	71.03	64.48	55.41	68.67	171.68	54.91	200.52
Basin Circularity Ratio	Cr	0.07	0.01	0.02	0.05	0.05	0.13	0.34

Sources: Geospatial analysis attribute table (ArcGIS-10.1)

Stream Length Ratio (Lur)

The stream length ratio is the ratio of the mean stream length of a particular stream order to the mean stream length is of the nest lower order. Stream length ratio has significant role in surface flow and discharge of a river basin (Horton,1945).

Lur = Lu / Lu-1

Where, Lur = Stream length ratio
Lu = Stream segment length of a particular order
Lu-1 = Stream segment length of the next lower order.

The stream length ratio (Lur) is the dividend between the successive stream orders of the basin by the measure of the next lower order value. It is varies to situation depending upon the geomorphological aspects like slope gradient, topography etc. (Rakesh, 2001). In general the stream length ratio of lower order increases shows the hydrological order of mature geographical stage from youth stage (Singh & Singh, 1997).

Mean Stream Length (Lum)

The mean stream length is a morphometric characteristic of the stream network system of the entire basin (Strahler,1964).

Lum = Lu / Nu

Where, Lu = Stream length of particular order
Nu = Total stream number

The mean stream length is the dividend of the total length of stream of an order by numbers of segments in the order. The total stream length is coming 0.91 km with a dimension of first, second, third, fourth, fifth and sixth order stream stand at 0.64, 1.12, 2.27, 5.60,16.50 and 13km respectively in the upper Jiadhal river basin.

Mean Stream Length Ratio (Lurm)

The mean stream length ratio is product of the total length of particular order with number of stream segment of that order.

Table 3.11: Stream Channel Networks and Morphometric Parameters Of The Lower Jiadhal River Basin

Morphometric Parameters	Symbol used	Stream order (Su)							
		1st	2nd	3rd	4th	5th	6th	7th	Total
Total Number of Stream	Nu	3698	987	217	52	9	4	1	4968
Total Stream Length (km)	Lu	1950	970	454	246	120	62	57	3858
Mean Stream length (km)	Lum	0.53	0.98	2.09	4.73	13.38	15.52	56.64	0.78
Stream Length Ratio	Lurm	0	0.23	0.25	0.27	0.25	32.05	0.00	6.54
Total Basin Area (sq.km)	Ab	755	370	178	89	44	30	15	1481
Mean Basin Area (sq.km)	Ab	0.20	0.38	0.82	1.71	4.94	7.40	14.81	0.30
Bifurcation Ratio	Br	3.75	4.55	4.17	5.78	2.25	0.00	0.00	0.00
Drainage Density (km/sq.km)	Dd	2.58	2.62	2.55	2.77	2.71	2.10	3.82	2.61
Basin Length (km)	Bl	0.53	0.98	2.09	4.73	13.38	15.52	56.64	0.78
Basin Perimeter (km)	Bp	755	370	178	89	44	30	15	1481
Stream Frequency (no/sq.km.)	Sf	4.90	2.67	1.22	0.59	0.20	0.14	0.07	3.35
Drainage Texture	Dt	154.23	138.85	145.51	151.81	219.28	219.28	219.28	441.38
Basin Circularity Ratio	Cr	0.02	0.00	0.01	0.01	0.02	0.03	0.07	0.16

Sources: Geospatial analysis attribute table (ArcGIS-10.1)

Bifurcation Ratio (Rb)

The Bifurcation Ratio is the statistical measure of the parameter of hydrological regime of a drainage basin under topological and climatic conditions to understand the runoff behavior. it is estimated by the ratio of the number of segments of a given order to the number of segments of the higher order is termed as bifurcation ratio expressed as

Br = Nu / Nu+1

Where, Br = Bifurcation ratio
Nu = Total number of stream of particular unit
Nu+1 = Number of streams of higher stream order

<u>Basin Circularity Ratio (Cr)</u>

The basin circularity ratio is a dimensionless parameter of the drainage basin. It was used by Miller (1953) to measure the shape or outline from of the drainage basin which is the ratio of the basin area of a circle with that of the basin perimeter. it is calculated as

$$Cr = 4 X Ab / Bp^2$$

When, Cr = Circularity Ratio
Ab= Area of Basin
Bp= Perimeter of the basin.

DRAINAGE ANALYSIS

The Upper Jiadhal Basin is been divided into four catchments and draining by Sido, Sika and Siri River. The Sido is in the western catchment adjacent to Subansiri drainage system towards its north and west margin. The topography of the Sido catchment is distinct with elevated dissected maintain ranges along the side of the river with a V shape valley and river is flowing eastward from the origin to the tri-junction point. The Sido catchment is the western most catchment of the basin having a tallies pattern of drainage is a consequent river system with almost all the tributaries are in perpendicular to the main stream, which implies that the topography is dominated by the faults lines and the river follows within. On the other hand the Siri drainage pattern is highly determined by the relief, the river origins in the northeastern mountain ranges as Rite Nala flow towards eastern direction and which took a curve loop to south and flow redirect to eastward through a deep gorge of about 6km. Its tributaries are associated with fault lines from the mountain ranges with deep gorges dissecting the range in fragments. The Siri has a critical banding in its lower course (27^{o}64' N,94^{o}44'E) with just 18 meters wide pass with side rocky structure raising 24 meters high which is dissected and eroded in the flood season. During peak flow it gets submerged under water (ground observation) reflects that the river has great influence on the river side's in peak flow. Fine to course sediment and mud is traced above the rock structure reflects that the rock was flood affect in yester season too.

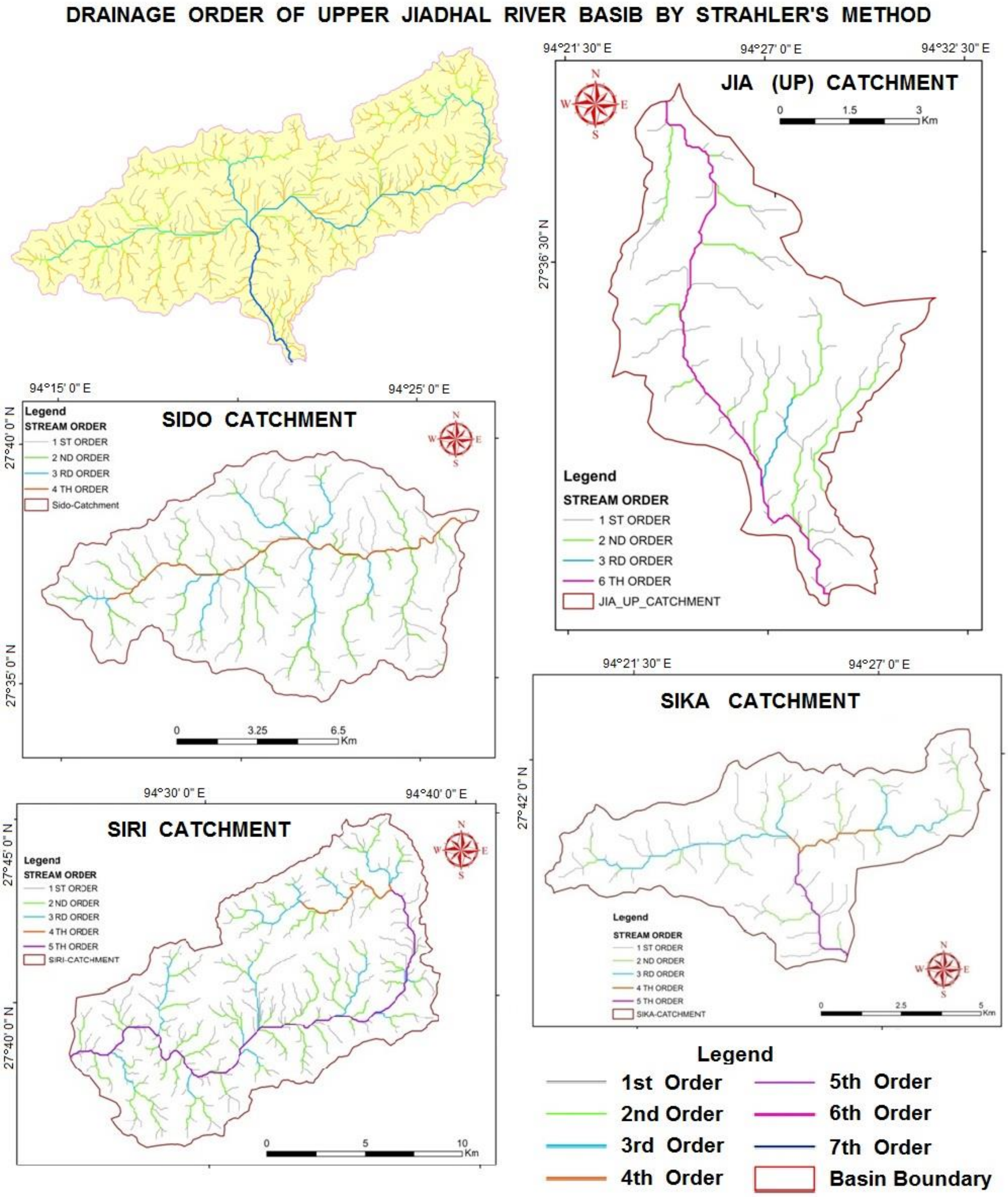


Fig. 3.16: Drainage order of Upper Jiadhal river basin (Arc-GIS10.1)

The Sika is a combination of two stream system locally termed as Tata and Sika is turbulent stream draining in between the lofty ranges and accompanied by rough course of flow with tremendous boulder across its river bed. From the ground in horizontal view the river is unseen due to presence of boulders spreading over the valley. This reflects the nature of the Sika catchment and the presence of huge boulders in the river course depicts that the terrain on which it flows is highly fragile. The boulders are on blackish-brown, grayish and faded yellow in colour which depicts that the deposits are made of gray sand stone and dolomites symbolizes the Main fault lines of Siwaliks.

The Jia Catchment is a structurally dominated and the river is flowing southward direction in a deep gorge extending 5 km of length. It is the combination of three upper tributaries at a tri-junction locally names ‘Tinisuti’. The catchment has low streams density as the river is a trance mountain in nature and flowing across the lower mountain range of the Siwaliks. The side of the gorges has fault lines and small streams are flowing in through it with huge erosive power as the mouths of the streams are filled with boulders and debris that the stream erodes along the fault line.

Drainage Density:

The drainage density of a drainage basin or a watershed reflects the hydro morphological characteristics of the region. The drainage density denotes the areas under high influence of fluvial process and influence of hydrological processes including weathering, soil-erosion, degradation of natural vegetation, biodiversity and human activities as well. The Drainage analysis of the whole river basin was done using ArcGIS-10.1 software with Karnal Density model on an Aster DEM file of the drainage basin. The outcome of the application is reflects that the Jiadhal river basin has a drainage density 19.5 sq.km. over a extension of total 1850.61 sq.km of area. The very low density area covers only 222.78 sq.km with 4.08 sq.km drainage density and mainly occupies the high ridges of the upper Jiadhal basin. The very high drainage density is the areas of high priority of hydrology natural storage of water in form of swamps and wetland or a depression with only 3.69 sq.km. The high density areas covers 79.80 sq.km of the basin and mainly comprises the areas of perennial river and swamps. The low and moderates are seasonal dried up streams comprising 890.33 sq.km. and 654.01 sq.km. respectively.

Table 3.12: Jiadhal River Basin- Drainage density (kernal density- Using DEM)

CLASS	Area (Sq.m)	Area (in sq.km)	Density (in m)	Density (in sq.km.)
VERY LOW	222775400	222.78	0.004079	4.08
LOW	890332600	890.33	0.002426	2.43
MODERATE	654008700	654.01	0.002840	2.84
HIGH	79803900	79.80	0.005162	5.16
VERY HIGH	3692300	3.69	0.004991	4.99
TOTAL		1850.61	0.019497	19.50

Sources: Geospatial analysis attribute table (ArcGIS-10.1)

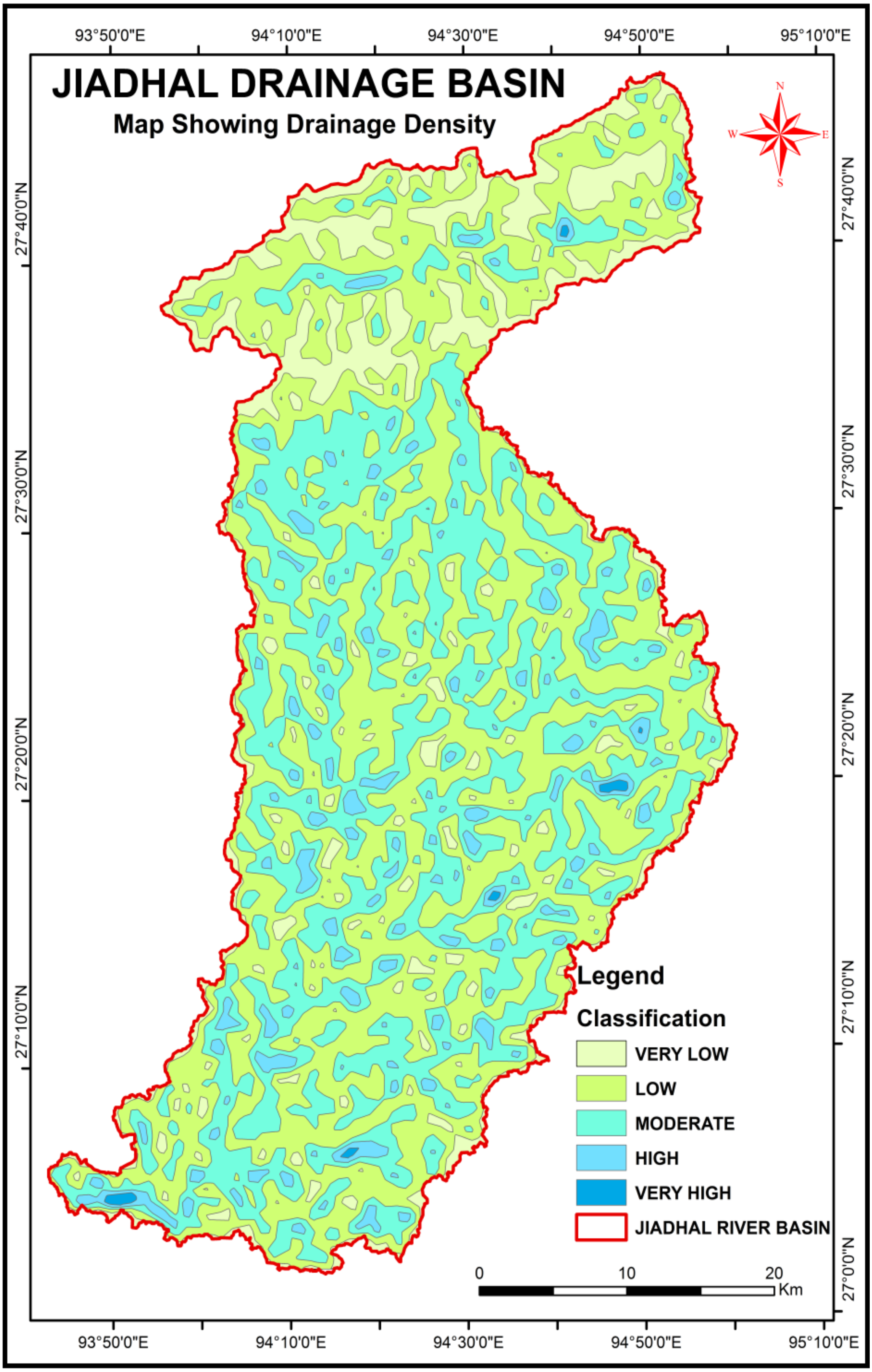


Fig. 3.17: Map showing drainage density of Jiadhal river basin of Arunachal and Assam.

The Upper Jiadhal Basin has lower drainage density having a mountainous terrain and the total share of low and very low is 283.67 sq.km and comprises 76.57 % of the whole upper basin. The lower basin area has larger share of 708.56 sq.km of 47.87% of the basin area of low drainage and 600.29 sq,km of 40.55% of moderate drainage density and only 74.05 sq.km of 5% occupying high drainage density.

Table 3.13: Drainage Density of Upper Jiadhal River Basin

CLASS	Shape_Length	Shape_Area	Area (sq m)	Area (sq.km)
VERY LOW	352524.10	111233682.07	111233700	111.23
LOW	485465.60	172441222.47	172441200	172.44
MODERATE	268441.73	75304688.34	75304690	75.30
HIGH	49164.49	10625076.98	10625080	10.63
VERY HIGH	4643.11	836187.89	836188	0.84
Total	1160239.03			370.44

Sources: Map attribute Table

Table 3.14: Drainage Density of Lower Jiadhal River Basin

CLASS	Shape_Length	Shape_Area	Area (sq m)	Area (sq.km)
VERY LOW	573763.17	93915000.40	93915003	93.92
LOW	1747454.69	708560808.98	708560811	708.56
MODERATE	1678880.30	600288970.18	600288935	600.29
HIGH	382870.82	74050992.05	74050993	74.05
VERY HIGH	16203.32	3349896.71	3349897	3.35
Total	4399172.29			1480.17

Sources: Map attribute Table

WATER RESOURCE MANAGEMENT

The water management of a drainage basin is a task of integration of various elements of the environmental as well as earth sciences. The elements included the geomorphology, hydrology, climatology, ecology as well as the environmental concern in relation to anthropogenic activities. The integration of these disciplines provides an ideal space to understand the natural phenomenon exist in the earth surface including those that transforms the drainage characteristics. It includes the proper understanding of the environmental condition of the specific region concerning the phenomenon like biodiversity, degradation of the biodiversity and hydrological perimeters.

Upper Basin

The agroforestry in the upper jiadhal basin is the appropriate solution to conserve the soil erosion and overcome the problem of environmental degradation. The excessive deforestation for timber in the upper ridges of the basin makes it vulnerable to erosion.

Plate. 3.2: Streams of Upper Jiadhal Basin: a) Sido associated with natural spring, b) Sika have exposed bedrocks along river, c)Siri associated with deep faults and joints with lots of sediment sources and d)Jia have larger discharge with large sediment ranging from fine to course gradient sand to boulders.

Drainage line treatment is a very important and most relevant aspect in watershed management. Erosion, runoff, velocity, discharge, and even load carrying capacity of the drainage could be checked by vegetative and structural measures over the stream in the upper reaches of the drainage. The sediment supply or the sediment source region should be identified before the planning and implementation of the projects. The drainage density is a prime perimeter to be considered to understand the physical properties of the drainage system followed by the physical properties like the topography, drainage pattern, and order of the drainage. Drainage density is the ration of the total length of all channels with in a drainage basin to the area of the basin-

$$\text{Drainage density:} \quad \frac{\text{Total length of the streams (Km)}}{\text{Unit area}}$$

Table 3.15:Relationship of erosion intensity and drainage density which direst revealed as follows.

Drainage Density	Erosion Intensity
Very High	Very Severe erosion
High	Severe erosion
Medium	Moderate to severe erosion
Low	Slight to moderate erosion.

Source: After . Rao.K.S. S (2000).

Stream Length : The total length of the drainage includes the length of all stream of a particular order in a specified drainage basin and the mean stream length is the mean of all stream length of a particular order with a specified drainage basin.

Drainage Treatment:

The measures are found applicable in Jiadhal River Basin too, which are to be considered while implementing drainage line treatment of watershed are (after Rao, 2000)-

Table 3.16: Watershed treatment plan after Rao, 2000.

Treatment Measures	Purpose	Effects
Plug the gullies since their beginning	Stops further deepening of gullies, Retains sediments of runoff.	Stops erosion, Ground water recharge at upper reaches
Create series of temporary barriers in the streams (nallas) which are unfit for water storage tanks.	Reduces runoff velocity, Sedimentation in the stream channels, hence oases clearer water to the downstream.	Delayed flow period, ground water infiltration
Treat the catchment of all types of structures before constructing them	Minimum sedimentation in the storage basins. Less runoff and its velocity.	Economic design, longer life. Less risk of damage
Use local materials and local skill for constructing the structure.	Lower cost of construction. Quality outputs due to local people's involvement.	Structures maintained locally

The structural measures for river basin are

a) Bank stabilization
b) Treatment of upper reaches
    i. Live Check dams, Vegetative Barrier
    ii. Boulder checks
    iii. Brushwood dams
c) Treatment of middle reaches.
    i. Earthen checks (reinforced with vegetation)
    ii. Loose boulder structure, gully plugging
    iii. Dugout ponds with vegetative inlet and outlets

d) Treatment of lower reaches (mostly water harvesting structures)

  i. Cement check dams (Nala-bunds)
  ii. Masonry check dams
  iii. Dugout shrunken structures
  iv. Farm ponds
  v. Percolation tanks (embankment percolation)
  vi. Gabion structures
  vii. Spill ways, silt structures

THE HYDROLOGICAL HAZARDS AND SUSTAINABLE DEVELOPMENT

Flood risk zone mapping

To understand the possibilities of management of the natural or environmental problems the analysis would involve every possible fields including the geology, geomorphology, hydrology, environmental studies. The combination of each variable is useful to visualize the geographical unit for the framework of any plan or execution. The basic problem in the study region is the flood and its related issues, which not only ruins the biodiversity of the basin but also responsible for the socio-economic development of the population dwells in the Flood plain. Thus Flood zone mapping of a river basin is an essential management strategy to regulate land use in order to restrict the damages in frequently flooded areas. The basic land use and land cover phenomenon prevailing in the region thoughts proper behavior of the flood and the environment response in the past history. Thus a case history of the region could be analyses for the understanding of the areas of variability and plan accordingly. The river Jiadhal is one of the largest east bank tributaries of the Subansiri which creates flood havoc almost every year affecting the people living in the lower part of the basin, i.e. the part which lies in the Dhemaji and Lakhimpur districts of Assam.

For the preparation of Flood zonation map the website of Bhuvan Portal (Indian Space Research Organization) and the satellite imageries of USGS, Earth Explorer and Earth Explorer Pro is been used. The Previous year’s satellite imageries were consulted to understand the trend of the flooding and its affect. Particularly the Landsat Data of January month of 2000, 2005 and 2009, and the years are selected due to availability of clear and good resolution satellite imageries of the concern region. The flood zonation map includes three zones viz. Flood Zone I- the rarely inundated, Flood Zone II- chronically inundated and Flood Zone III- occasionally inundated zones. The Dhemaji District occupies the larger part and a smaller portion towards the southern and the mouth of Jiadhal to Subansiri comprises the North Lakhimpur District (Dhakuakhana). The flood zone-III occupies an aerial extension of 110.18 sq.km. in the southern part of the basin having low relief features and composite of low lying swamps and wetlands, with lots of meanders and abound channels. It is particularly because of the feature less flood plain mainly composed of the alluvium deposits with lea elevation and more depression areas entire the basin. The raised river bed due to siltation is vulnerable not only to the floods of the Jiadhal and its tributaries, but also to breaching of the embankments of the river Subansiri and Brahmaputra. The second flood zone-II with 746.59 sq.km lay in the mid section across the river system which have experienced the flood effects in past decades is the vulnerable zone whereas the flood zone-I with 573.21 sq.km characterized with rarely inundated occurs to the north along the piedmont areas of the foothills of Arunachal Himalayas.

Geomorphological characteristics of a river basin is refers that it is an accumulation of the surface runoff drains through a common point downstream and forms a distinct hydrological unit. Thus the topography, slope gradient and the ground water capacity plays a vital role in the fluvial processes as well as the situation and landform development. The hill slopes are free from flooding effect because of the steepness and the gradient of slope which let the water outlet to its course without any literal expansion. But as river system enters a flat feature less alluvial plain which is only the product of the deposition of the sediments brought by itself. The Jiadhal river practices the same way as the river enters the plain of Dhemaji district it starts depositional process and the river course get sallower which led the spell of water from its course by bleaching the river banks. The Upper Jiadhal Basin or the catchment areas receives heavy cloud burst in the rainy season and thus a great amount of water is discharged through the narrow gorges of the Arunachal Himalayas and responding a flooding in lower basin. Flooding is a natural and recurring event for a river, denotes the process of inundation of an area by unexpected or sudden rise of water due to intensive rainfall in the upper reaches as well in the lower part of a basin (John, 2012). Jiadhal basin experiences a heavy or continuous rainfall exceeding the absorptive capacity of soil and the conveyance capacity of river channel. This causes a river to overflow its banks on to the adjacent lands in lower basin with almost flat alluvial floodplain. Floodplains are, in general, those lands situated adjacent to rivers and streams that are subject to frequent floods. Leopold et al, (1964) defined a flood plain as ‘a strip of relatively smooth land bordering a stream and overflowed at a time of high water’.

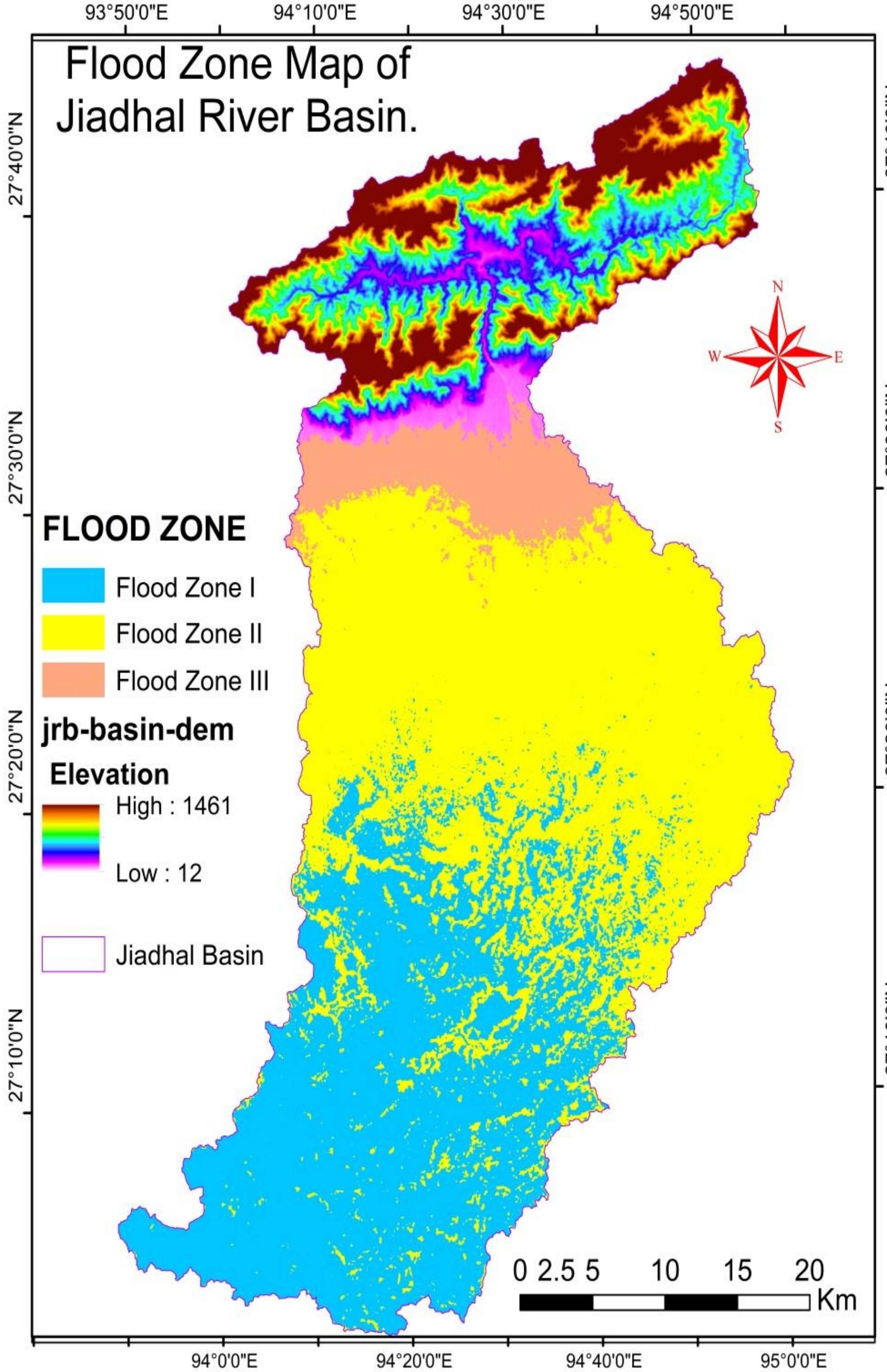


Fig. 3.18: Map Showing flood zones in the Jiadhal River Basin (ArcGIS-10.1)

Table 3.17: Flood Zonation in the Jiadhal River Basin

Flood Zone	Flood Zone Area (in sq m)	Flood Zone Area (in sq.km.)	Mean	Standard Deviation	Nulls
I	573211800.00	573.21	434251.3636	14402166.81	0
II	746591400.00	746.59	12016722.22	113070889.8	0
III	110182500.00	110.18	38619944.27	137852278.6	0
other	421630094.76	421.63			
Total	1851615794.76	1851.62			

Sources : Map attribute table (flood zone map)

The Jiadhal basin is characterized by highest temperatures during the southwest monsoon season i.e. from June to about the beginning of October which begins to drop considerably by the end of November. It also experiences a highly humid atmosphere throughout the year (Gogoi ,2013). Jiadhal experience the rainfall from mid of March and receives the heavy downpour in the month of June to October every year. Thus during these months the river course has plenty of water discharge along with sediment loads. The peak flow occurs from later July to October with tremendous velocity and speed resulting the bask failure and flooding to the adjacent lowlands. Morphometry of the Jiadhal river through light that the river course is above the adjacent low lying floodplain in the middle course i.e. the flood zone – II. The sediment load that the river brought down slope since the time immemorial has raised the bench mark of the flood plain and thus the river is unstable in its course and performs frequent shifting of channels. The river course is unstable and undefined and thus it is havoc for the population dwelling in either basks of the river.

The channels of the Jiadhal and its tributaries in the Subansiri River are inadequate to carry the abnormal quantity of water arising from monsoon rains causing the river to overflow its banks and inundate the settlement areas. Almost the entire lower basin is covered by the floodplains of the river Jiadhal and its tributaries mainly Na-nadi, Sonpara, Kaoran and Charikuria and Cila or Chiloni. The floodplains of the Jiadhal are mostly flat and fertile due to annual deposition of sediments and silt. About 81.11 % of the study area is covered by flat land between 50-200 meters above mean sea level mainly concentrate by agricultural lands, settlements, swamp and wetlands which are very much essential for the sustenance of its population inhabited the basin. Flood and siltation issue of the region creates havoc each year and its intensity varies with duration of its occurrence. The flood occurring in the month of June and July has highest effects. As the months experience the highest intensity of cloud burst due to monsoonal effect. Thus each year devastating flood creates disaster to the natural environment as well as the socio-economy of the region and mainly the agricultural sector. The flash flooding responsible not only for degradation of land in the basin but also ruins the agricultural economy of the lower basin by extensive damage to the crops. The flood zone mapping is the ultimate choice for proper land use planning and effective development of the area. Flood zoning of the lower part of the Jiadhal basin is essential and the present study is attempt to delineate the different zones of flooding of the river.

The main target is to analyze the flooding phenomena of the region, which will help in planning and designing appropriate flood mitigation measures as well as for adopting sustainable agricultural practices. These activities led the degradation of the embankments and make the weaker zones vulnerable to bleaching. The Jiadhal brings tremendous sediment load and frequently changes its course of flow due to siltation and over flow of the water to adjacent plains and a local accumulation and damming situation prevails within the river course. This led the shifting of channel flow and affects the weaker section of the embankment to erosion. This indicated that due to lower gradient of slope on the river course the water get spread over the stream channel and produce a water logged situation and thus the water level rises to create pressure on embankments to erode. Such situation prevails in the Kakuri, Dihiri, Ratuwa, Kachukhona and Gohaingaon Bank before the RCC Bridge Nos. 3.

The map evidence, together with record of flood history, indicate that regular large floods have breached the embankments, created areas of bar development and caused bank erosion and channel migration. Floods caused by sudden breaches of embankments are far more damaging than normal floods where overtopping of banks takes place during high flow conditions in the river. Every time a breach occurs, a sizable area and population is affected. Further, inundation caused by breaches leads to deposition of coarser sediments in large areas, leaving the land unsuitable for cultivation. The recovery period of such land is considerably high (Das et.al, 2012). Fig. 3.18 shows the points of breaching and their area of impact in different years which further aggravates the flood problem in this basin. Every year a large part of the basin is flooded causing damage to agricultural lands and affecting large number of people residing in the flood plain areas.

Plate.3.3: Stages of embankment failure on Jiadhal River RCC Bridge No. 3: a) Channel flow deflected due to siltation of front. b) Bleaching due to natural damming and narrow c) Bleaching point 2017 d) Abounded stream flow and backward flow, e) restoration of bleaching and f) temporary shelter at embankment.

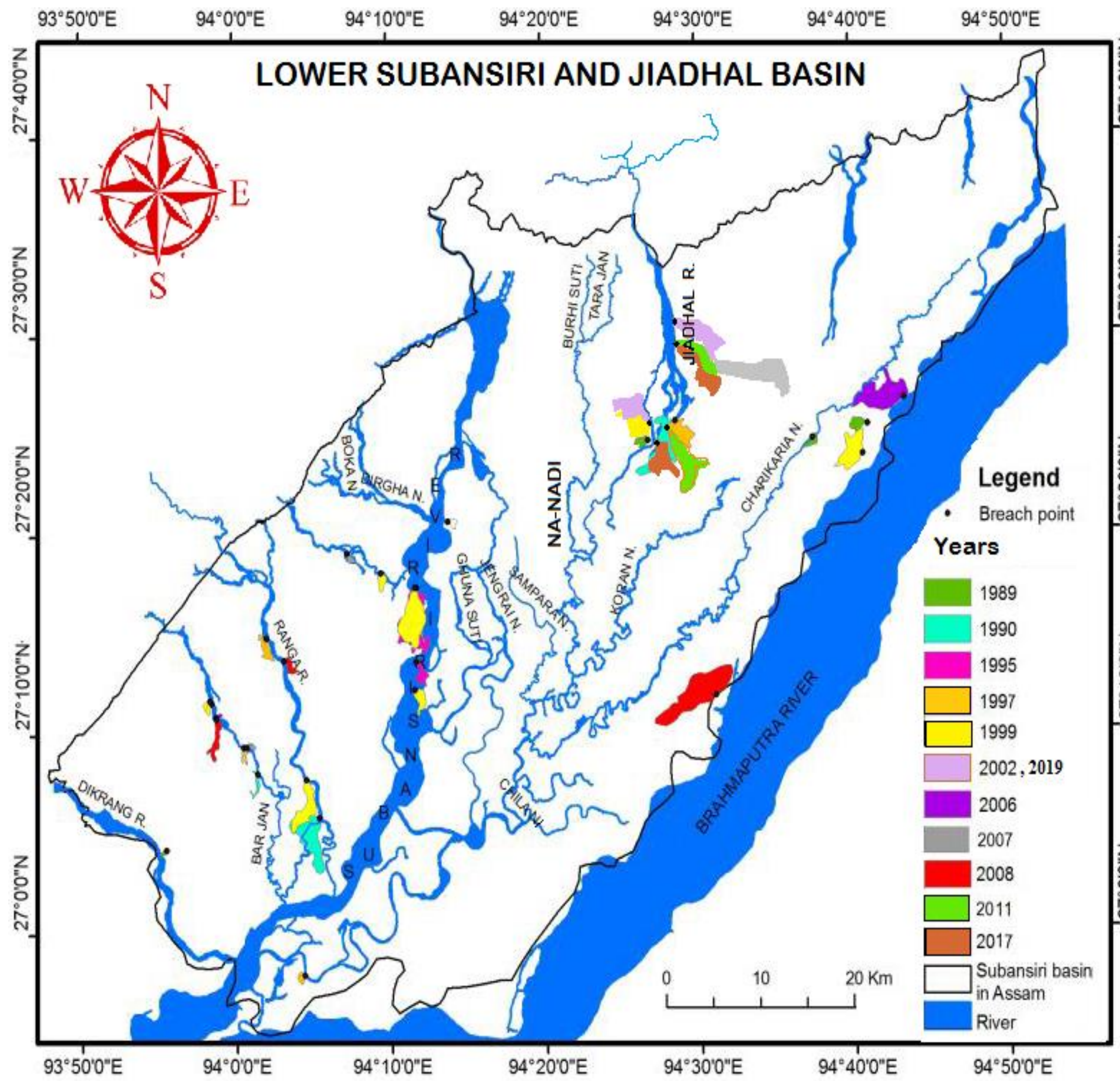


Fig. 3.19: Breach points along with the extents of area of breaching (Map after Goswami, 2009)

Further survey of 150 villages observation was carried out to understand the impact of flood and its consequences. A buffer zone along the river line was proposed with a radii of 2, 4, 6 and 8 kilometers from the river to illustrate the impact of losses. It is observed the villages within the 4 km of radii were more influenced then the peripheral areas. Though the impacts of water logging were through the plains of the basin, the villages in the left bank of the river have greater flood history. Out of 150 villages surveyed 23 village lies within 2 km buffer from the river with 2388 household and 13590 population comprising 1630 (42.02%) of Scheduled Tribe (ST) population and 32 (2.60%) of Scheduled Cast (SC) and rest 11928 (55.38%) are other population. The areas are highly prone to river bank erosion and have highest intensity of flood history. The 4 km buffer zone occupies 48 villages with 7086 households and 37510 population comprised 15721 (23.26%) of ST, 2335 (3.53%) of SC and 19454 (62.21%) are of others population. The zone is most influenced by flood water and water logging due to river water out spell or bleaching of embankments. The 6 km zone includes 49 villages with 7957 household with 38431 population comprising 28.79% (11998) of ST, 6.65% (2032) and 64.56% (24401) of others population. The zone is less effected in regular flood and more affected by water logging. The 8 km zone is the low affected cone in the region includes 30 villages with 4126 households and 22507 populations dominated by 50.77% (14767) ST and 8.50% of SC followed by 40.73% (6073) of others population.

Table 3.18: Population of 150 villages Jiadhal Buffer Zone along the river

Source: Bhuvan-ISRO portal Census: 2011 and field survey.

Buffer Zone	No of villages	Total Household	Total population	ST Population		SC Population		Others	
				Total	ST%	Total	SC%	Total	O %
2 Km	23	2388	13590	1630	42.02	32	2.60	11928	55.38
4 Km	48	7086	37510	15721	34.26	2335	3.53	19454	62.21
6 Km	49	7957	38431	11998	28.79	2032	6.65	24401	64.56
8 Km	30	4126	22507	14767	50.77	1667	8.50	6073	40.73
Total	150	21557	112038	42486	38.96	6034	5.32	61856	55.72

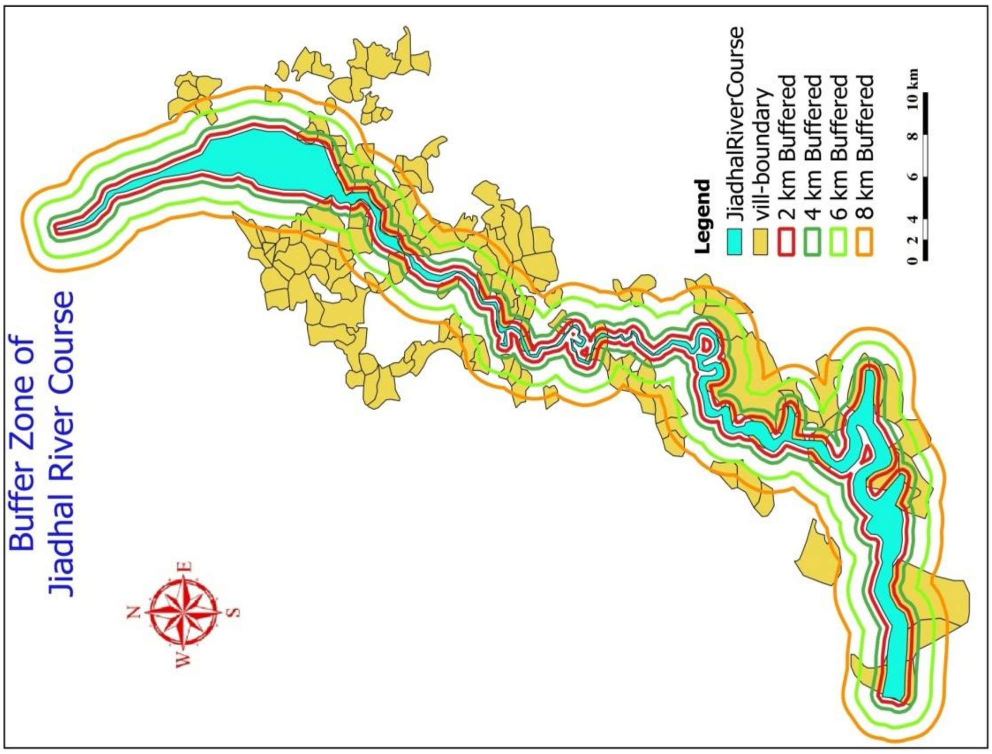


Fig 3.20: Map showing buffer zone of Jiadhal River and affected villages.

REFERENCES

Burton, I., Kates, R.W., (1964): The perception of natural hazards in resource management. Nat. Resour. J. 3, 412– 441.

Clarke, J.I. (1966): "Morphometry from maps." In Essays in Geomorphology, edited by G.H. Dury, 235-274. American Elsevier Publication. New York.

Chakrabarti, B.K (2000): Geology of the Himalayan Belt, Deformation, Metamorphism , Stratigraphy, ELSEVIER, ISBN: 978-0-12-802021-0, pp-145-248.

Chorley, R.J. (2019): Spatial Analysis in Geomorphology (et.al), Routledge, Taylors & Francis Group, New York. p374,pp. 3-16.

Das, P. J. (2012): Jiadhal River Catchment, Assam, India: Building community capacity for flash flood risk management, Aranyak (NGO) report on Case studies of flash flood risk management in the Himalayas.pp-24-30.

Devi, S. (2015): Geoenvironmental Characteristics Of Eastern And Western Himalayas A Comparative Study Of Subansiri And Alaknanda River Basins, Shodhganga, http://hdl.handle.net/10603/135281.pp- 116.

Dikshit, K.R and Dikshit, J K. (2014): North-East India: Land, People and Economy, Advance in Asian Human-Environmental Research, Springer, New, York London, ISBN-978-94-007-7055-3(e-Book), pp. 800.

Doula, M.K. and Sarris, A. (2016): Environment and Development Basic Principles, Human Activities, and Environmental Implications, ELSEVIER,https://doi.org/10.1016/B978-0-444-62733-9.00004-6. Pages 213-286.

Gogoi, C. 2013 : International Journal of Geomatics and Geosciences Volume 4, No 1, 2013 © Copyright 2010 All rights reserved Integrated Publishing services Research article ISSN 0976 – 4380 pp 75-88.

Gunasekaran. S, 2014, Planning and strategies of watershed management projects – an analytical study in Dindigul district, Tamilnadu (Thesis), The Gandhigram Rural Institute – Deemed University, Tamil Nadu, pp -1-203.

Horton, R.E. (1932): "Drainage basin characteristics". Trans. Am. Geophysical Union 13: 350-361.

Horton, R.E. (1945): "Erosional development of streams and their drainage basins, hydrophysical approach to quantitative morphology." Bull. Geol. Soc. Am. 56: No. 3,pp. 275-370.

Kesari, G.K., DasGupta, G. and Prakash, H.S.M. (2009): Geology And Mineral Resources Of Assam, GSI, 30 Part IV Vol 2(i) Assam. pp-51.

Kesari, G.K., DasGupta, G. and Prakash, H.S.M. (2010): Geology And Mineral Resources Of Arunachal Pradesh, GSI, 30 Part IV Vol I(i) Arunachal Pradesh. pp-22-60.

Konwar, S. 2017: Morphometric analysis of the Gai River Basin, NE Himalaya, India. IJAR Journal, http://dx.doi.org/10.21474/ijar01/4578, pp. 1-7.

Leopold, L. B. and Wolman, M. G.(1957), River channel patterns-braided, meandering and straight, USGS professional paper 282B.

Mandira, B. G. and Monimugdha, B.(2014): Impact of Flood and Siltation on Socio-Economy, Impact of Flood and Siltation on Socio-Economy A Case Study of Dhemaji Revenue Circle, District Dhemaji, Assam, Antrocom Online Journal of Anthropology 2014, Vol. 10. No. 2 – ISSN 1973 – 2880, pp.131-135.

Morisawa, M. (1985): Rivers (Forms and Processes), Longman, London and New York.

Oruonya, E.D., Ezekiel, B.B., Atiku. H.G.,Baba. E and Musa, N.I. (2015): Drainage Basin Morphometric Parameters of River Lamurde: Implication for Hydrologic and Geomorphic Processes, Journal of Agriculture and Ecology Research International, https://www.researchgate.net/publication/283341260, pp-1-12.

Pahuja, S. and Goswami, D. (2006): A fluvial geomorphology perspective on the knowledge of the Brahmaputra; Background Paper No.3;August 2006: Development and Growth in North East India: The Natural Resources, Water and Environment Nexus, pp.87-90.

Patnaik, S. K. (1993) : Hydrogeomorphologic characterization of Sankh head water catchment (Doctoral thesis) Shodhganga @ INFLIBNET/10603/20985 loded on 22-July-2014. pp 113.

Rao, K.V.S. (2000): Watersheds comprehensive development, B.S. Publications, Hydrabad ISBN:8178000040, PP-1-367.

Rastogi, R. A. and Sharma, T .C. (1976): Quantitative analysis of drainage basin characteristics. Journal of Soil and Water Conservation in India, Vol. 26, pp. 18–25.

Rawat, M.S., (2011): Environmental Geomorphology and Watershed Management. Concept Publishing Company Pvt. Ltd. New Delhi, pp.-1-286

RVC(2017): Rural Volunteers Centre , Annual Flood report, Akajan, Dhemaji, riverbasinfriends@yahoo.co.in,

Stapathy, K.K. and Sonowal,D.K.(2003): Integrated Watershed Development – A Sustainable Approach for Resource Conservation and Management, http://www.kiran.nic.in/pdf/publications/Watershed_Development.pdf, pp. 1-14.

Scheidegger, A.E. (1994): Hazards: singularities in geomorphic systems, Geomorphology, Vol.10, 19– 25.

Schumm S.A. (1963): A tentative classification of river channels, U.S. Geol. Survey Circular 477.

Schumm, S.A. (1968): River adjustment to altered hydrologic regimen – Murrumbidgee River and palaeochannels, AustraliaU.S. Geol. Surv. Prof. Pap. 598, pp. 65.

Slaymaker, O. (1996). Introduction. In: Slaymaker, O. (Ed.), Geomorphic Hazards. Wiley, Chichester, pp. 1 –7.

Springgay. E.(2017): Headwater Catchments : Foundation Pillars for Ecosystem Services. Křeček & Haigh at al, Ecosystem Services of Headwater Catchments https://www.springer.com/gp/book/9783319579450 (accessed on 31 August 2019).

Strahler, A.N. (1964). Quantitative geomorphology of drainage basin and channel networks. In: V.T. Chow (ed.). Handbook of applied hydrology (4-76). New York: McGraw Hill Book.

Strahler, A. N., (1950): Equilibrium theory of erosional slopes approached by frequency distribution analysis, Am. J. Sci., 248, No. 10, 673 696; No. 11, 800 814.

Thakur, P.K., Laha, C. And Aggarwal, S.P. (2011): River bank erosion hazard study of river Ganga, upstream of Farakka barrage using Remote Sensing and GIS; Natural Hazards doi 10.1007/s11069- 011- 9944- z.

Thornbury, W. D., (1954): Principles of Geomorphology, New York, John Wiley & Sons, 618 pp.

Venkatesan, A. (2015): Geoinformatics in fluvial geomorphological study of Thoppaiyar sub basin Tamil Nadu India (Ph. D Theses),Shodhganga a reservoir of Indian theses, http://hdl.handle.net/10603/51184, pp- 86-98.

CHAPTER-4

LANDUSE APPRAISAL OF THE

JIADHAL RIVER BASIN

INTRODUCTION

Land use is a vital component of environmental geography to determine the environmental quality of the earth. Land is also a vital part of physical geography, geology as well as geomorphology. It's utility varies with intention and practices of human activities resulting its use or misuse in occasional phenomenon. The ecology, biodiversity, climatic variability, demography, distribution, dispersion and development of biotic as well as abotic phenomenon in the earth surface is broadly concentrate on land. Land cover is considered to be the physical characteristics of the earth's surface, captured in the distribution of vegetation, water, soil and other physical features of the land, including the landscape created by man. It is defined as, the study of distribution of land under various natural environment its nature type as well as its uses in different socio-economic and environmental conditions (Mohammed, 1981). On the other hand land use defined as the prevailing human's activities on land, its utility for human satisfaction of needs (Clawson and Stewart, 1965). Whereas land cover is advocated as the natural form, pattern or characteristics of land in environment concern, include relief features, vegetation coverage, and the artificial constructions covering the surface. (Burley,1961) Thus land use is the product of natural environment and the man interaction for living and thus man find the utility and uses land in different forms and magnitude. It is the way by which land has been used, usually with accent on the functional role of land for anthropological activities including economic, social, infrastructural development etc.

The Jiadhal River basin is agro-based economic region and thus the land cover has the great impact in the socio-economy of the people in the region. The physiography of the study area has different magnitude of land cover and land use as well. The Upper Jiadhal basin which is a hilly terrain has the highest concentration of natural forest cover and low human settlement. The main problem of the upper Jiadhal basin is the inaccessibility, as there is no communication route or roadways to its interior. The river itself is the route in winter by manual trekking. The indigenous practice of timber collection and various forest products from the interior in winter make the interior upper catchment explored by human. The most vulnerability brings the timber industries and the lumbering activity in the interior of upper catchment, resulting its degradation if natural forest. For the Land Use and Land Cover analysis the Landsat-imageries of particular year of 2000, 2005, 2009 and 2019 have been studied, which is derived from the open sources of ISRO's portal Bhuvan and USGS's portal. The month of January images were selected mainly due to low climatic disturbances and clear image. The ArcGIS-10.1 is used for the map making process. The major Land Use and Land Cover of the Jiadhal basin is considered to of (9) nine categories based on the environmental geomorphic factors prevailing in the region.

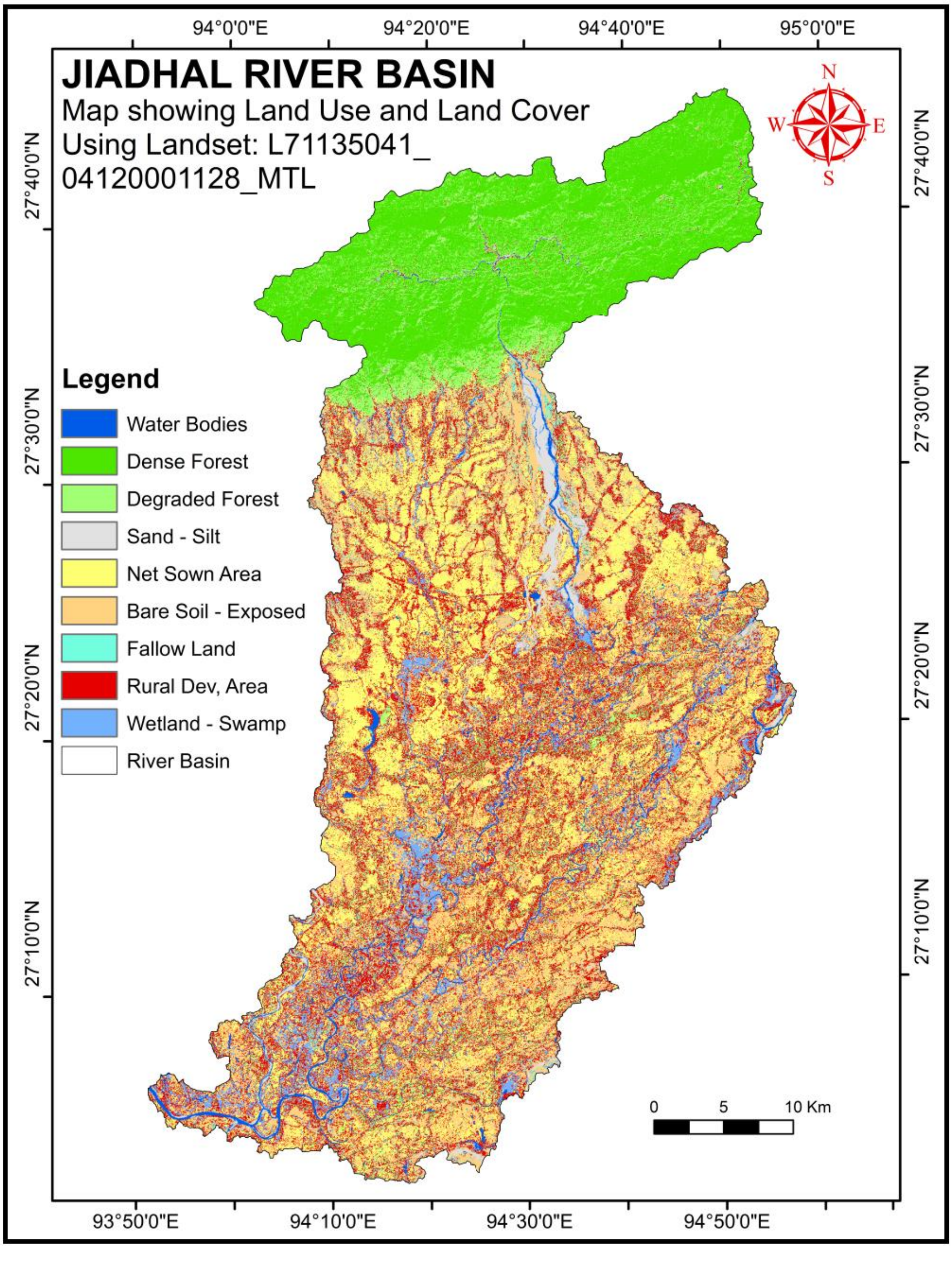


Fig 4.1: Land Use and Land Cover using Landsat: L71135041-04120001125-MTL.

<u>Major Land Use and Land Cover:</u>

The basic factors that determines the land use pattern is dominated by the geomorphology of the region and the other physical factors like topography, soil and climate as well as the anthropogenic elements including the density of population, the socio-economic condition, the administration, the planning either rural or urban, duration of occupation of the space, technical and occupational status of the population including the agriculture primitive to modern and industrialization effects too. Whereas the Land cover is purely based on environmental factor with influence of human activities including deforestation for agriculture or any infrastructural development.

Dense Forest: The dense forest occupies 381.70 sq. km comprising 20.61% share of the total land cover of Jiadhal basin in the year 2000 and mostly concentrates in the upper basin (Fig 4.1). This area includes the natural vegetative coverage including reserved or non reserved forests. Reserved forest includes the areas that are preserved under the observation of the government surveillance and the non reserve forest are the asset of the country of the region as applicable.

Degraded Forest: The forest area which has less vegetative coverage with light colour contrast is identified as degraded forest cover area, and mainly concentrates in the upper Jiadhal basin. The highest cover is recorded in the year 2009 comprising 217.58 sq. km (11.75%) of the area under forest cover. This comprises areas under shifting cultivation, agro forestry and low density natural forest due to lumbering practices by the indigenous inhabitants of the upper basin (Fig 4.1 & Table 4.1).

Sand & Silt: The category comprises the bare sand and silt deposits along the river sides and the affected flood plain. The region depicts the land cover having direct influence of the river due to flood and its consequences. Its share is recorded highest in the year 2000 with 47.12 sq. km. comprising 2.54% of the total area (Fig 4.1 & Table 4.1).

Bare Soil Exposed: The land cover includes the exposed weathered and denuded rocks mainly in the upper basin and the landuse for agricultural fields in the plain of the lower basin. This bare soil in the lower basin composite of old sedimentation by flood or tilled agricultural fields prone to weathering and degradation. It occupies highest share 274.06 sq.km 14.8% of the total area in the year 2000 (Fig 4.1 & Table 4.1).

Wetland- Swamp: The category includes the low lying depressions particularly in the lower basin with water logging and abound river courses with swamp. In the year 2009 it records the highest extension of 127.72 sq. km comprising 6.9% the basin area(Fig 4.1 & Table 4.1).

Water Body: The rivers, ponds and lakes are included in this category which have permanent water throughout the year. It has greater share in the lower basin then the upper basin. It occupies 62.72 sq. km in the year 2000 comprising 3.39% of the basin area (Fig 4.1 & Table 4.1).

Net Sown Area: The current agricultural areas in use is termed as net sown area, it represents the total area which is cropped once in a year. Being an agricultural economy the region has the highest percentage of share among the all. It has recorded 366.96 sq. km in

2009 with 19.08% of the basin area excluding the tilled and exposed soil due to the factor of FCC correction (Fig 4.1 & Table 4.1).

Fallow Land: The arable land which are not in use in current span of time. It includes all that land which was used for cultivation but is temporarily out of cultivation particularly due to local factors. Fallow land could be either current fallow (fallow since one year) or long time fallow land (fallow since two to five years). In hill slopes due to shifting cultivation this fallow land develop mainly as it is left uncultivated from 1 to 5 years to help soil recoup its fertility in the natural way. It extension is recorded highest in the year 2009, with 198.95 sq. km comprising 10.7% of the total area of the basin (Fig 4.1 & Table 4.1).

Rural Development: This land use is mainly the part of land that used for infrastructural development includes land occupied by villages, towns, roads, railways and agro forestry along the infrastructural areas. An area composition 697.64 sq. km (2005) is the highest record with 37.7% of the total basin area (Fig 4.1 & Table 4.1).

Land Use Land Cover Changes: The changes in land use and land cover are mainly influenced by the environmental geomorphology of the region and the human intervention for developmental activities in the region. The Flood and its consequences is the main factor determining the LULC of the Jiadhal basin.

Table 4.1: Land Use Land Cover during 2000-2009 in the Jiadhal River Basin.

Categories	Area in sq.km.			Change (2000-2005)	Change (2005-2009)	Rate/y (2000-2005)	Rate/y (2005-2009)	Mean rate (2000-2009)	Trend
	2000	2005	2009						
Dense Forest	381.70	368.07	196.12	-13.64	-171.94	-2.73	-42.99	-20.62	Negative
Degraded Forest	123.99	106.06	217.58	-17.93	111.52	-3.59	27.88	10.40	Positive
Sand & Silt	47.12	38.01	27.42	-9.11	-10.59	-1.82	-2.65	-2.19	Negative
Fallow Land	90.95	147.85	198.95	56.90	51.10	11.38	12.78	12.00	Positive
Rural Development Area	618.63	697.64	424.49	79.01	-273.15	15.80	-68.29	-21.57	Negative
Bare Soil-Exposed	274.06	131.71	242.40	-142.35	110.69	-28.47	27.67	-3.52	Fluctuating
Net Sown Area	190.49	292.08	366.96	101.60	74.87	20.32	18.72	19.61	Positive
Wetland-Swamp	61.94	61.01	127.72	-0.92	66.71	-0.18	16.68	7.31	Positive
Water Body	62.72	9.17	49.96	-53.56	40.79	-10.71	10.20	-1.42	Fluctuating
Total	1481	1481	1481	-	-	-	-	-	-

The trend of change in the land use and land cover since 2000 to 2009 is with Landsat satellite images obtained from ISRO and USGS portal (Table 4.1). The deforestation in the upper basin led the degradation of natural forest cover of the upper basin led to serious environmental degradation. The Dense forest cover of the basin is recorded in decreasing trend as it recorded 381.70 km^2 in 2000 and loose 13.64 km^2 till 2005 and reduces to 196.12 km^2 with 171.94 km^2 decreases during 2005-09. The rate of decrease was recorded as 2.73 km^2/year during 2000-2005 and increases to 42.99 km^2/year during 2005-2009. On the other hand the degraded forest cover has increased from 123.99 to 217.58 km^2 with an increase of 111.52 km^2 since 2000 to 2009. The rate of change is 3.59 sq.km/year during 2000-2005 and increases to 27.88 km^2/year during 2005-2009. The area covered by water is fluctuating due to environmental factors, the images under study are of January and it is a dry season in comparatively, so the rivers are having low volume of water. Whereas the Wetland and Swamp areas are in increasing trend as it is records 61.94 km^2 in 2000, 61.01 km^2 in 2005 and 127.72 km^2 in 2009. With reference to Sand and Silt the impact of flood in rainy days is traced and found in negative trend, as during 2000, it covers 47.12 km^2 is sand casted while in 2005 it record 38.01 km^2 and in 2009 it decreases to 27.42 km^2. Whereas the Rural landscape is the most dominant land use of the entire basin is in positive trend in the period 2000-2005 with an increase of 79.01 km^2 from 618.63 to 697.64 km^2, but again fall in the period 2005-2009 to 424.49 km^2 thus comparatively it is in negative trend. Particularly during 2000-2005 its rate if increase is recorded 15.80 km^2/year and during 2005-2009 it decreasing rate goes 68.29 km^2 /year. It is mainly due to increase in degraded forest, fallow land and wetland resulted flood consequences.

Table 4.2: Land Use Land Cover during 2000-2009 in the Upper Jiadhal Basin.

Categories	Area in sq.km.			Change (2000-2005)	Change (2005-2009)	Rate/y (2000-2005)	Rate/y (2005-2009)	Mean rate (2000-2009)	Trend
	2000	2005	2009						
Dense Forest	296.07	339.78	191.66	43.71	-148.12	8.74	-37.03	-11.60	Fluctuating
Degraded Forest	45.77	18.64	170.28	-27.14	151.64	-5.43	37.91	13.83	Positive
Sand & Silt	0.74	1.36	0.81	0.62	-0.55	0.12	-0.14	0.01	Fluctuating
Fallow Land	2.20	1.03	0.03	-1.17	-0.99	-0.23	-0.25	-0.24	Negative
Rural Development Area	13.42	4.82	0.70	-8.60	-4.12	-1.72	-1.03	-1.41	Negative
Bare Soil-Exposed	0.04	2.00	2.80	1.96	0.80	0.39	0.20	0.31	Positive
Net Sown Area	0.54	0.62	3.37	0.08	2.75	0.02	0.69	0.31	Positive
Wetland-Swamp	1.51	2.40	0.58	0.88	-1.82	0.18	-0.45	-0.10	Fluctuating
Water Body	10.51	0.17	0.59	-10.34	0.43	-2.07	0.11	-1.10	Fluctuating
Total	370	370	370	-	-	-	-	-	-

The situation in the Upper Jiadhal basin (Table 4.2) is different where the land coved by dense forest and degraded forest composing the 92.19% of the upper basin area. The region is less populated and natural environment is almost free from human settlement. The interior catchments are prone to environmental degradation. In upper basin the dense forest is in fluctuating trend as it recorded 296.07 km^2 in 2000 and a loop of 43.71 km^2 to 339.78 km^2 till 2005. It is mainly because during this period the timber works is officially stopped. The forest cover experiences a decrease of 148.12 km^2 which decreases at a rate of 37.03 km^2/year to 191.66 km^2 during 2005-2009. In the other contrast the Degraded Forest cover has decrease from 45.77 to 18.64 km^2 with a rate of 5.43 km^2/year during 2000 to 2005. During 2005-2009 it has an increase with rate of 37.91sq.km/year to 170.28 km^2, the mean increase is recorded 13.83 km^2. The region is inaccessible and thus less human activities are there even though the illegal and legal lumbering activity in the interior of upper catchment degrades the environment geomorphology of the basin. The bare soil – exposed rocks has increases from 0.04 km^2 to 2.00 km^2 in 2000-2005 and reaches to 2.80 km^2 during 2005-2009. It reflects the impact of deforestation in the upper reaches and the sediment supply to the drainage system in the area. The Net Sown Area has increased in mainly because the local population practices agricultural activities and agro-forestry in the interior areas of the basin too.

Table 4.3: Land Use Land Cover during 2000-2009 in the Lower Jiadhal Basin.

Categories	Area in sq.km.			Change (2000-2005)	Change (2005-2009)	Rate/y (2000-2005)	Rate/y (2005-2009)	Mean rate (2000-2009)	Trend
	2000	2005	2009						
Dense Forest	85.63	28.28	4.47	-57.35	-23.82	-11.47	-5.95	-9.02	Negative
Degraded Forest	78.21	87.42	47.30	9.21	-40.12	1.84	-10.03	-3.43	Negative
Sand & Silt	46.39	36.65	26.62	-9.73	-10.04	-1.95	-2.51	-2.20	Negative
Fallow Land	88.75	146.82	198.92	58.07	52.10	11.61	13.02	12.24	Positive
Rural Development Area	605.21	692.82	423.79	87.61	-269.03	17.52	-67.26	-20.16	Negative
Bare Soil-Exposed	274.02	129.71	239.60	-144.31	109.89	-28.86	27.47	-3.82	Fluctuating
Net Sown Area	189.95	291.46	363.59	101.52	72.13	20.30	18.03	19.29	Positive
Wetland-Swamp	60.42	58.62	127.14	-1.80	68.52	-0.36	17.13	7.41	Positive
Water Body	52.22	9.00	49.37	-43.22	40.37	-8.64	10.09	-0.32	Fluctuating
Total	1480	1480	1480	-	-	-	-	-	-

The Lower basin is prone to environmental degradation by both natural as well as anthropological factors. It is particularly a agricultural region thus the share of Rural area is the highest and in a negative trend, due to increase in the aerial extension of sand and silt, and wetland areas as well as increase in fallow and net shown areas (Table 4.3). The land pressure is growing with population and environmental issues caused by flood and siltation. Dense forest cover of the basin is recorded in decreasing trend which is recorded as 85.63 km^2 in 2000 and loose of 57.35 km^2 till 2005 it reduces to 28.28 km^2. It farther reduced to 4.47 km^2 during 2005-09. The rate of reduction was recorder 11.47 km^2/year during 2000-2005 and 5.95 km^2/year during 2005-2009 and mean decrease is 9.02 km2. Simultaneously the degraded forest cover has increased from 78.21 to 87.42 km^2 during 2000-2005, and reduces in 2005-2009 to 47.30 km^2. Sand and Silt is recorded in negative trend during 2000-2005 it occupies 46.39 km^2 and reduce further to 26.62 km^2 till 2009 with an mean decreasing rate of 2.20 km^2/year. In contrast to Wetland and Swamp has increasing trend in 2005-2009 with a mean increase of 7.41 km^2/year. The remarkable change in rural landscape is observed with a decreasing mean rate of 20.16 km^2/year against the categories of fallow land and net sown area which is increasing thoroughly with a mean increasing rate of 12.24 and 19.29 km^2/year.

THE IMPACT OF LAND USE CHANGES

The land use change is a cultural phenomenon prevailing in the natural region mainly in influence of human activities over the natural land coverage by intensifying the need of the increasing population. The identification of the land use change need a historical look back process of the selected region and analyze the changes occurred in particular region on a specified period of time. The human activities and needs are the controlling factor of the changes in land use pattern and intensity of a region. The natural calamities particularly flood and their consequence ruins the land use trend and even the socio-economy of the Jiadhal river basin. The Upper Jiadhal basin have low population concentration and though have less impact on land use changes due to less human activities, but the practices of landownership and protection of property is greatly affecting the region. The population from foothill often visits the upstream areas in winter season through the river and practices forest clearance to occupy and fencing work of their properties which degraded the natural forest coverage into agro-forestry. They use to clear the natural vegetation in the name of agro-forestry and plants horticulture crops. The part is not yet explored for human settlement but the approach is going on from the indigenous population of Arunachal Pradesh. Few settlement in the interior is mainly done for the protection of the land properties and they use to shift there during the winters for maintenance and, the road infrastructure is constructed to the interior than it will take no time for a full flange rural settlement.

The scenario of the lower Jiadhal basin is different; it is totally based on agro-economy. Each household practices agriculture as their primary occupation for their self reliance, whereas the trend is taking a commercial look in recent time. The main influence of its change is the natural hazard ‘Flood, erosion and Sedimentation’. The flood creates havoc to the agricultural population of Jiadhal plain, as it is perennial phenomena ruining the agriculture, fisheries, individual properties even life. The scenario is vast thus a case study of most vulnerable village is given priority to understand the ground truth of land use change and its impacts. The population is mainly based on agricultural economy, and practices intensive agricultural system. Rice is the staple crop of the area and reforms in agriculture is adopted in the daily life of the villages. The main reason of the same is the frequent flood in every year, which is havoc for the settlement in repent to human life as well as the agricultural practices. The sedimentation and siltation are the main problems apart from flash floods in the area studied. Each year the flash flood damaged crops by sedimentation of fresh sand and loamy clay brought with the flood water by river Jiadhal. The trend of big granaries were history for the farmers, they have very few cultivable land in compare to the early days. The shifting of river courses is a major problem for the agriculture which submerges a huge cultivable land into desert like sand deposits. Although these alluvium deposits are very fertile and rich in nutrition and minerals for agricultural production, but the excessive amount of sediment load in the flood water damages the cultivated crops. The standing crops as arcanut (bettle-nut) and leaves are highly dried up with lots of economic loss for the poor farmers.

Case study of the vulnerable villages of Jiadhal River Basin

The floods of the Jiadhal river system was observed to identify the most vulnerable villages of Jiadhal basin in respect to analyze the impact of flood and siltation on land use change. The area including ten (10) villages viz. Dihiri Chapori, Dulung Kan, Somora Jan, Ratuwa, Chechela, Jungle Block, No.1 Kechukhana and Naruathan which were worst effected to frequent flood and siltation, collapsing the entire socio-economy of the inhabitants of the villages during the last decades with frequent flood in the year 2002,2005,2007,2009,2010,2011,2015,2017 and 2019. Among them 2007, 2011, 2017 and 2019 were the worst. According to the government land survey (Table 4.4), the Dulung Kan has the high aerial extension of 323.5 hectares with 161.8 hectares of net sown area and 122.2 hectare of current fallow land. Out of 115 main working populations, main worker is 88 against 122 marginal worker (industrial) population reflects the agriculture is no longer remain the lifeline of the village. Dihiri Chapori has 297.2 ha. land area comprising 117 ha. of net sown area, 86.2 ha. of current fallow and 23 ha. of culturable west land is perennially affected by flood. with only 32 cultivators out of 219 main working population and 126 marginal worker. Whereas the No. I Kachukhona has 138.4 ha. comprising 40 ha. net sown area, 44 ha. fallow land including current fallow with , only 5 main worker and 177 marginal worker out of 182 main working population of the village (Table 4.5). Dihiri Panitula has 297 ha. comprising 149 ha. net sown area, 124 ha. fallow land including current fallow with , only 93 main worker and 108 marginal worker out of 219 main working population of the village.

The occupational structure shows a clear picture of the socio-economy of the people and the impacts of the land use pattern. The area is basically agro based economy but the share of secondary activities is dominating the region. The primary sector's main workers include the cultivators, agricultural labourers, household industrial worker and other worker. The marginal working population includes the cultivators (industrial) the population engage in cash crop cultivation, agricultural labourers of daily wagers and seasonal agricultural labourers and household industrial worker composite population adopt cottage industries as their livelihood including weaving, carpentry, construction workers etc. The share of marginal workers depict that the agriculture is no longer a prime choice of livelihood and thus the margin of fallow land is also high. This is mainly due to the flood consequences in these villages; people are adopting alternate living other than primary agriculture.

Table 4.4: Geographical attributes of selected villages of lower basin
(Source: Census book 2011 and field survey).

Particulars	Dihiri Capori	Dulung Kan	Dihiri Panitula	Somora Jan	Ratuwa	Nepali Khuti N.C	Chechela	Jungle Block	No.1 Kechukha	Naruathan
Total Un-irrigated Land Area	297	324	297	223	158	46.4	144	209	138	197
Total Irrigated Land Area	241	370	390	496	244	94	110	75	222	983
Net Area Sown	45	81	90	104	49	19	22	17	43	201
Current Fallows	3.2	0	0	0	0	0	0	0	0	0
Fallow lands other than current fallows	3.2	22.8	22.2	17	44.9	0	30	18.6	24	12.2
Culturable Waste Land	4.6	0	0	0	3	7	0	0	0	19
Land Under Miscellaneous Tree Crops etc.	4.6	0	0	0	0	0	0	0	0	0
Permanent Pastures and Other Grazing land	0	7.5	0	0	5	5	3	0	6	0
Barren and Un-cultivable land	23	9.2	2.5	2.4	30	10	24	90	24	100
Area under Non-agricultural Uses	0	0	0	0	20	10	20	70	24	23
Forest cover	86.2	122	124	92.2	5	5	4	20	20	26.2
Total Household of the village	117	162	149	112	50	9.4	63	9.9	40	17.1
Total Village Population	0	0	0	0	0	0	0	0	0	0
Total Village Area	117	162	149	112	50	9.4	63	9.9	40	17.1

Table 4.5: Socio-economic status of the selected villages of lower basin
(*Source: Census book 2011).*

Particulars	Dihiri Capori	Dulung Kan	Dihiri Panitula	Somora Jan	Ratuwa	Nepali Khuti N.C	Chechela	Jungle Block	No.1 Kachukhona	Naruathan
Working Population	116	237	219	335	123	54	60	56	182	466
Main worker	98	115	93	65	57	21	24	11	5	407
Cultivators	97	88	32	79	38	17	22	8	2	320
Agricultural Labourers	0	1	0	6	0	0	0	0	0	0
Household Industry worker	1	0	0	4	0	0	0	0	0	9
Other worker	0	26	61	9	19	4	2	3	3	78
Marginal Worker (Industrial)	18	122	126	240	66	33	36	45	177	59
Cultivators (Industrial)	17	105	108	236	63	33	33	45	173	2
Agricultural Labourers (Industrial)	1	11	13	4	1	0	2	0	0	4
Household Industrial Worker	0	1	3	0	0	0	0	0	3	20
Other worker (Industrial)	0	5	2	0	2	0	1	0	1	33
Non-worker	125	133	171	161	121	40	50	19	40	517

The environmental consequence of the flood ruins the socio-economy of the lower basin areas. Unavailability of good infrastructure, industrial scope apart from agro-based industries hampers the economic growth of the area. Prospects of agricultural based industries in support of the government agencies could stabiles the impact of the affected area. Horticulture sericulture, even standing crops including plantation industries could be develop in selected areas, but still the natural phenomenon of flood would be the higher dominating factor for the sustainable economic sector of the entire Jiadhal basin.

Lack of industries and other employment opportunities also hinder the area. The consequences of which is observed as the working population of the villages are migrating out to other parts of India in search of job as unskilled industrial, construction, security services and companies for livelihood. The villages are loosening strength of workforce, so agriculture looses strength in Jiadhal river basin area.

ENVIRONMENTAL CONSEQUENCES OF LAND USE CHANGE:

The existing land use pattern prevails for certain duration of time and due to various factors it gets modified in passage of time. Land use / Land cover change is linked to the intersection of natural and human influences on environmental change (Kanianska, 2016). The man and natural environment relationship explains that the man always utilizes the land in different intensity in different activities performed on land. The need and pressure on land is increasing rapidly due to increasing pressure of population growth, urbanization, agricultural practices, landscape development, technology development, infrastructural development and industrialization etc. (Cengiz, 2013)

Plate. 4.1: Bleaching consequences (2019). a) Land and Property loss, b) School building washed off, c) Sedimentation submerges properties and d) Sedimentation up to 6 feet of height.

On the other hand the natural phenomenon existing in the earth are equally responsible for the alternation of the land cover as well as the land use of the geographical unit. The phenomenon which are active in the study area like natural calamities including floods, flash floods, sedimentation, siltation, submergence due to deposition, desertification, climate change, earthquake and other natural hazards and disasters (Knap and Ivan, 2016). The prominent among them is concern with the study region are siltation of river channel, led to the braiding of channel, frequent shifting of river courses and bleaching of embankment during peak flow of water in rainy season. The Jiadhal river basin have a diverse range of physical relief ranging from contour height from 50 meters to 1400 meters and above, thus a perfect physiographical unit is delineated to the river catchments as Upper Jiadhal Basin and the Lower Jiadhal Basin. The Upper Jiadhal Basin compromises the geographic unit dominated by mountainous or high relief features. The topography of the upper jiadhal basin is highly dissected and series of ranges and hillocks are identified in respect of the sub-basin or the catchment areas as Sido, Sika, Siri and Jiadhal River catchment. The Geographical units have different characteristics prevailing in respect of the geology, vegetative cover, altitude, aerial extension as well as the human intervention or activities. Thus the land cover of the upper Jiadhal Basin is natural and dominated by natural forest with less human settlement, the forest cover is dominant. The intervention of human in the natural ecology of the Upper Jiadhal basin led to the degradation of the natural vegetation coverage. The need and intensity of exploiting timber from the natural forest region with less care led to the degradation of the forest ecology and simultaneously the geomorphological processes get activated in accelerating rate due to access to weaker section of the lithology, leading massive erosion and landslides degrading and producing high deposits of debris and silt in the source region. The practice of agriculture in form of shifting agriculture is another problem noticed in the study area. The area with low gradient of slope were cleared by slash and burn techniques for preparation of agriable field and the soil get exposed from the climatic agents for weathering activities involving the erosion, transpiration and deposition of the weathered materials. This process involves both the natural agents and anthropogenic agents for the occurrence and the anthropogenic agents made its intensity higher than the natural which caused land degradation (Plate. 4.1).

The Lower Jiadhal Basin consists of piedmont hills and an extensive flood plain with low and uniform elevation. According the field observation collected from local peoples, the region was a dense natural forest. After the intervention of humans the region transformed to present status. The natural forest coverage of the region is less, as the land were occupied and treated as personal property and thus they are fully enjoying the right of using owned properties in own knowledge, requirement and preferences. The population explosion and increasing demand of agricultural land led the clearance to natural forest into agriable land and the consequence is the present situation. The land use nearer and adjacent to human settlements comprises agro-forestry where species preferable for firewood supply, building materials, fruits and vegetables and fodder to animals. Even plots and agro-forestry as for rearing silk moth, standing crops are kept away from the regular settlement area. But due to shortage of land and the natural problems, the plots are now a part of the human settlement area. On the other hand the natural calamities prevailing in the area led the transformation of land use and land coverage in greatest extent. The main element on this category is the flood affected area of the Jiadhal river system, comprising the spelled water in flood plain resulting siltation if the river course as well as the area been flooded. The siltation and sand casting is the worst problem associated with the Jiadhal river flood. Flood water not only destroys agricultural fields and human settlement but also degraded the natural environment and ecosystems including ponds, swamps, and even standing crops (Plate. 4.1).

Table 4.6: Showing Jiadhal Buffer Zone along the river and Flood Zonation data.

Buffer Zone	No of villages	Total Household	Total population	Household affected	Pop. affected	No. of Household loss Land in Bighas				
						2	**6**	**8**	**10**	**10+**
2 Km	23	2388	13590	1569	8881	510	157	31	5	3
4 Km	48	7086	37510	1404	6762	231	81	20	11	10
6 Km	49	7957	38431	284	1309	69	14	12	5	3
8 Km	30	4126	22507	15	43	12	3	0	0	0
Total	150	21557	112038	3272	16995	822	255	63	21	16
Flood Zonation Map Data										
Zone I	25	2898	3115	121	495	62	26	12	6	2
Zone II	85	11207	10990	1561	7631	339	157	39	12	14
Zone III	40	7452	7452	1590	8869	421	72	12	3	0
Total	150	21557	21557	3272	16995	822	255	63	21	16

Sources: Primary village data considering 10 years of flood history, observation duration 2nd Oct 2017-18th Sep 2019.

Thus the land use and land cover of the lower Jiadhal river basin is more or less in vulnerable situation due to the increasing population pressure as well as from the natural phenomenon of flooding and siltation or sand casting by the river system. The primary data collected of 150 villages with a longitudinal periphery of 10 km along the river Jiadhal and analyzed the flood impact on land property of the villages. The aerial extension of buffer zone is curved out with aerial difference of 2, 4, 6 and 8 km with the flood zone map (Plate. 4.1, fig 4.2 & Table 4.6).The consequences of environmental hazards are reflected by the land degradation of the villages due to flood and sedimentation. In 150 villages surveyed, 23 villages are situated within 2 km buffer zone with 1569 households and 8881 population affected by flood and siltation out of 2388 households and 13590 populations. The land loss statistics within 2 km buffer zone shows 510 (72%) household loss 2 bighas, 157(22%) loss upto 6 bighas and 31(4.4%) losses 8 bighas and 8(1.1%) losses 10 and more than 10 bighas of land during flood. The land loss of 4 km buffer zone is rated second with 231 (65%) household loss 2 bighas, 81(23%) loss upto 6 bighas and 20(5.7%) losses 8 bighas and 8(3.1%) losses 10 and 10(2.8%) more than 10 bighas of land in flooding. The 6 km buffer zone is less affected by flood even though it has recorded the land loss of, 69 (67%) household loss 2 bighas, 14 (14%) loss upto 6 bighas and 12 (12%) losses 8 bighas and 8 (7.8%) losses 10 and 10+ bighas of land. The 8 km buffer zone is free from worst flood affects with 12 household loss 2 bighas and 3 households' losses 6 bighas of land (Fig 4.1, 4.2, 4.3 & Table 4.6).

The nature of environmental hazard is seasonal and mostly affected the regions with sharp geomorphological and hydrological properties. The low gradient of stream flow increased sedimentation in river source led to overspill of peak flow, and the accumulation of rainwater in depressions or wetlands increases the intensity of stranded water to a flood like situation due to water logging. Bleaching of river banks or embankments in peak flow creates siltation in arable land destructing economy of the population. Agricultural crops including standing crops, animal husbandry as well as human life and property are ruined in flood consequences. Land loss due to siltation and river shifting is common, it is not always destructive, sometimes proves to be constructive and beneficial as the depressed areas, large swamps and wetlands are raised up naturally by submergence. On the other hand the submergence of wetland ruins the environmental biodiversity mainly aquatic life of the area into a barren land with silt and sand not fit for next agricultural years.

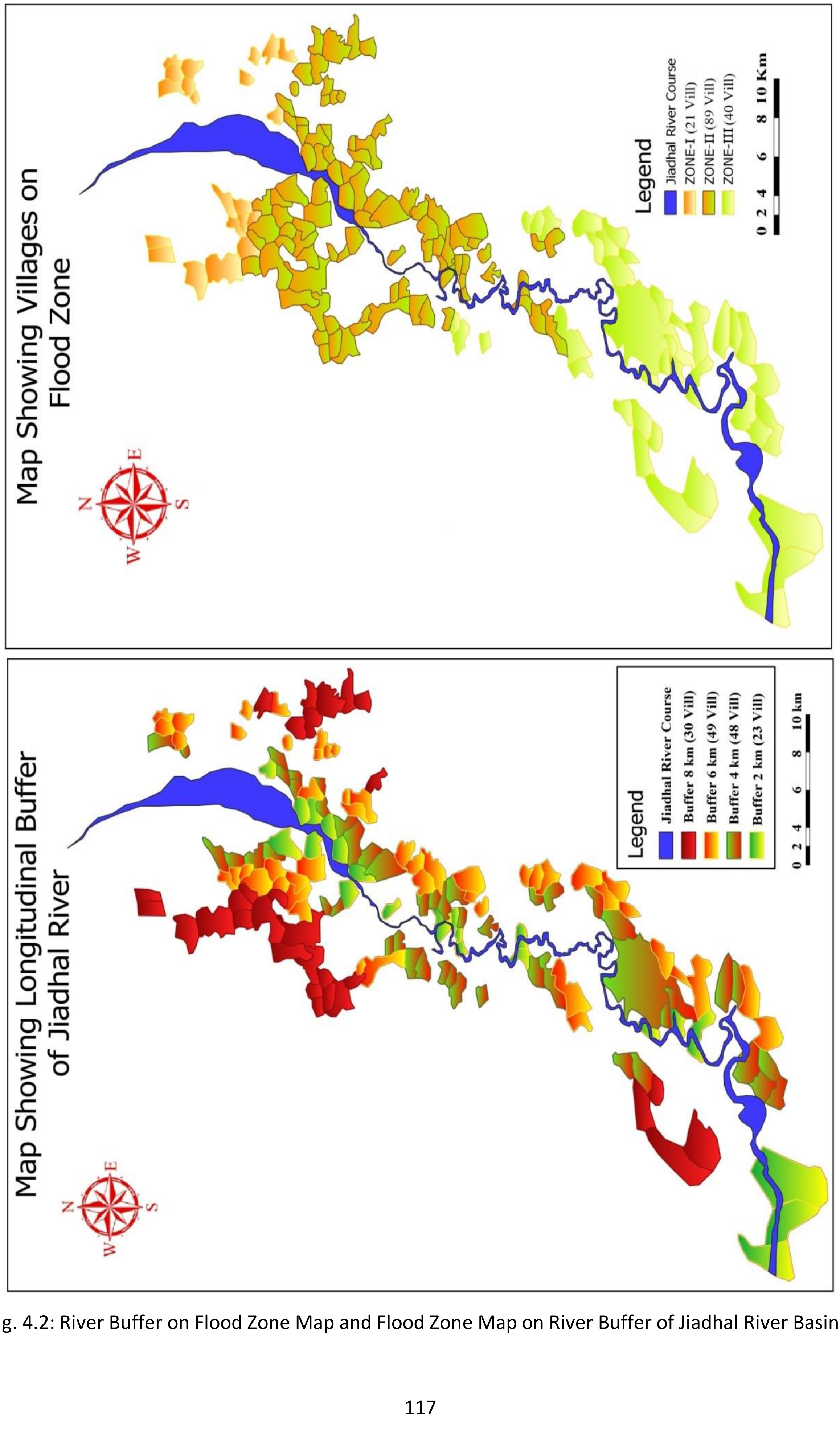
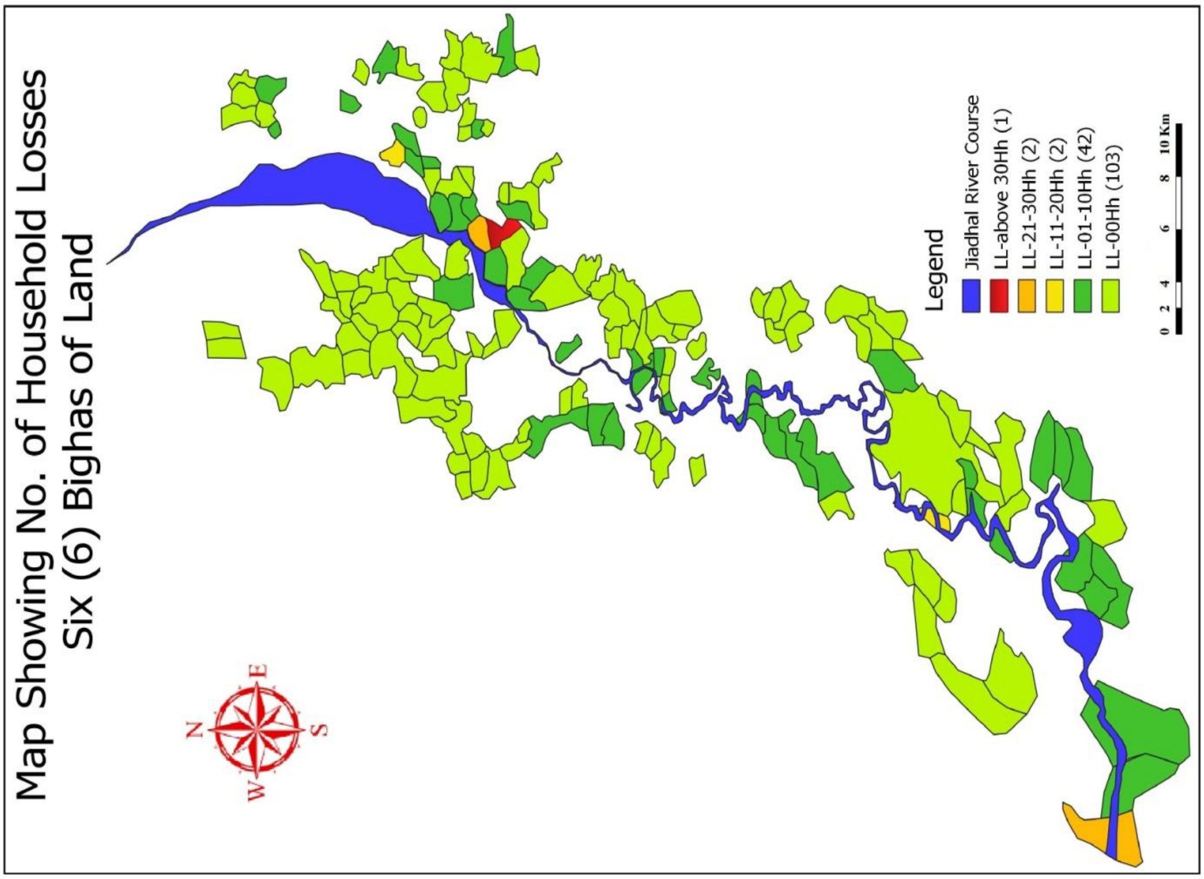


Fig. 4.2: River Buffer on Flood Zone Map and Flood Zone Map on River Buffer of Jiadhal River Basin



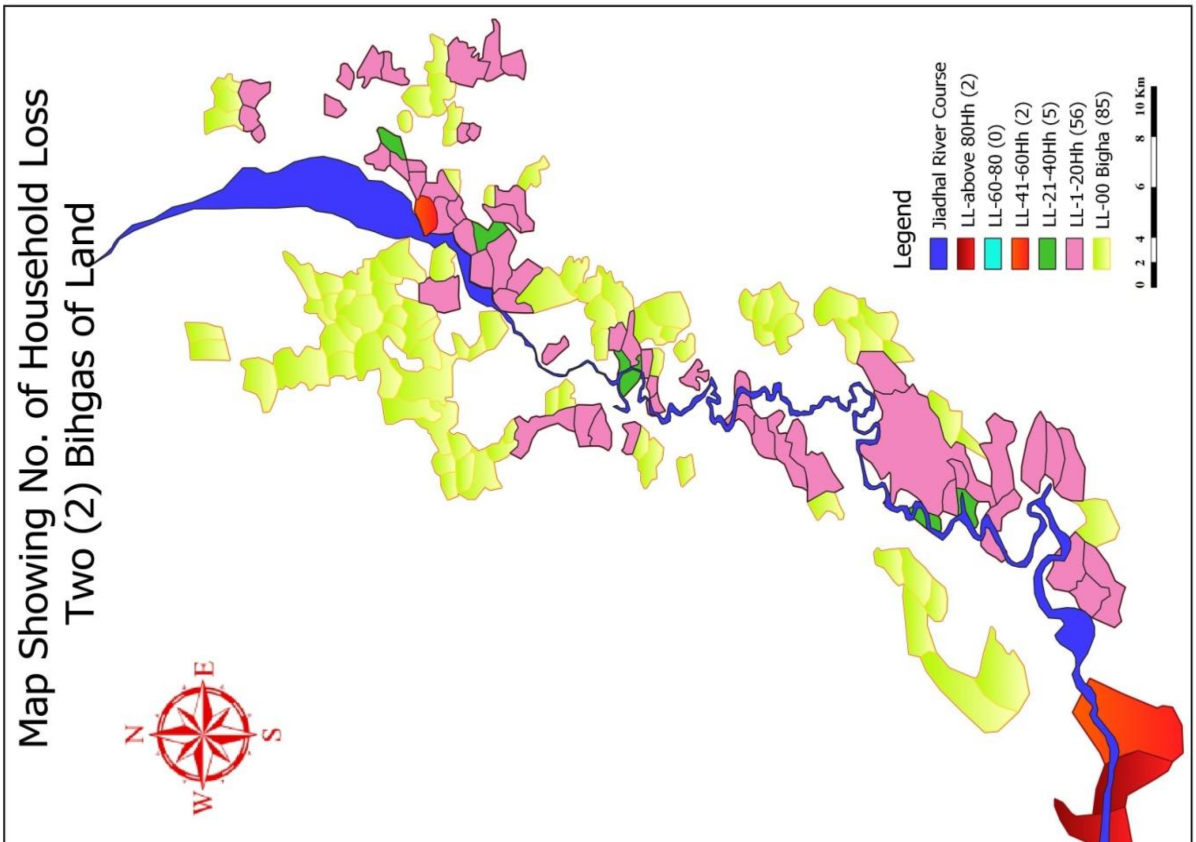
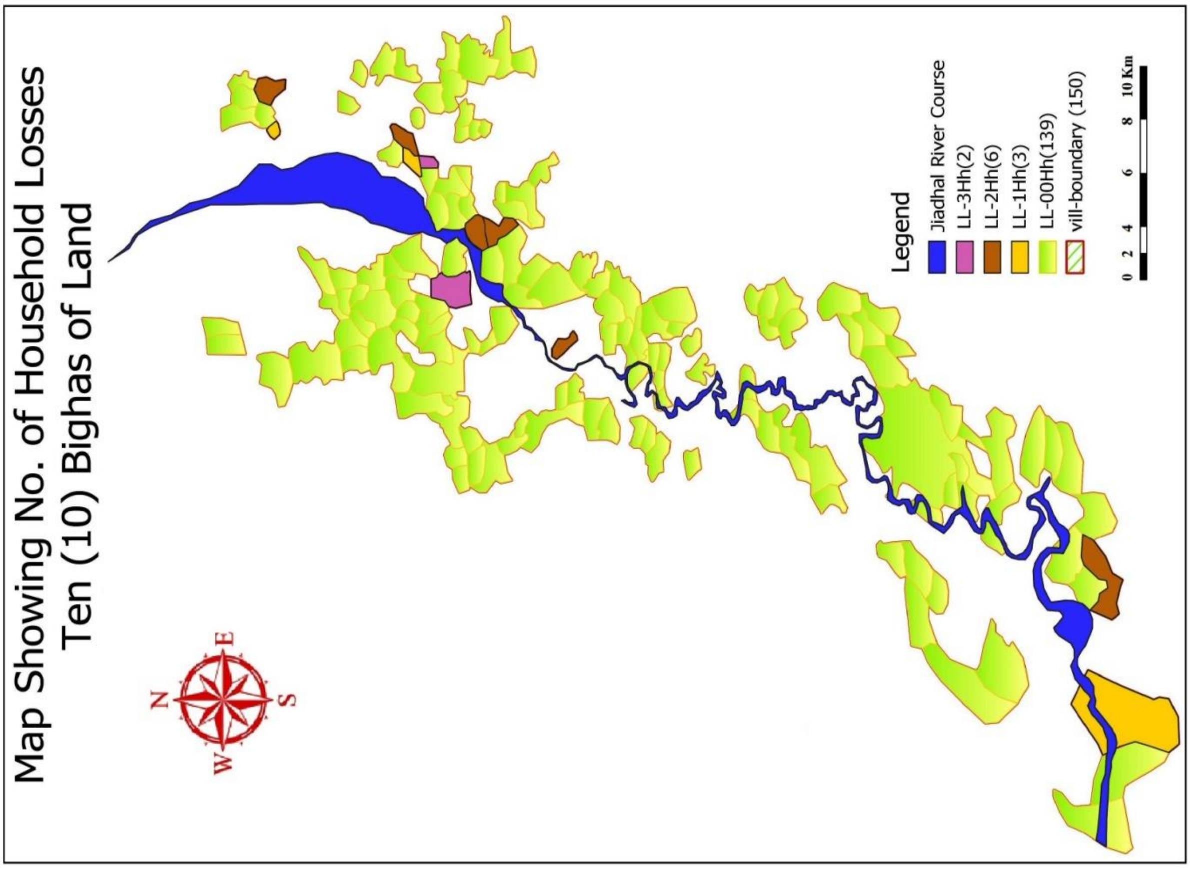


Fig. 4.3: Showing number of household loss land upto 2 bighas and 4 bighas in separate plates.



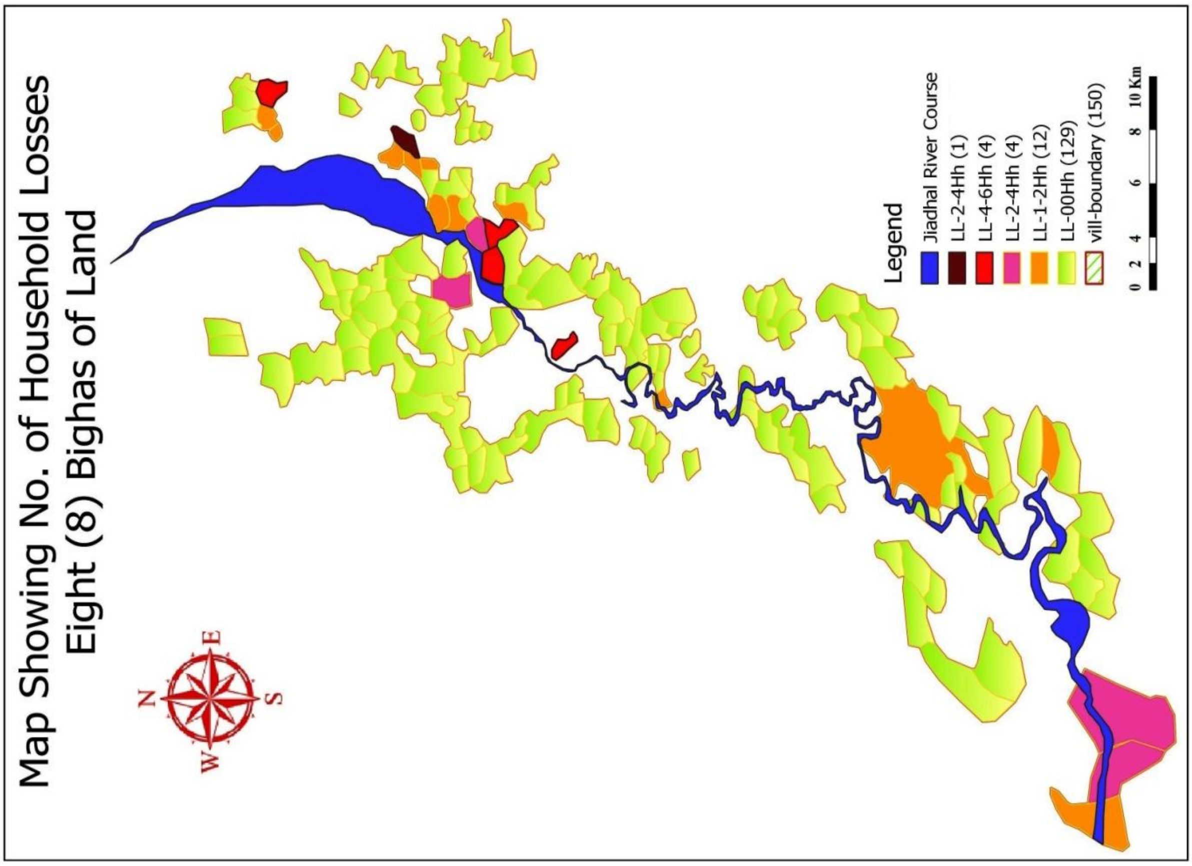


Fig 4.4: Showing number of household loss land upto 8 bighas and 10 bighas in separate plates.

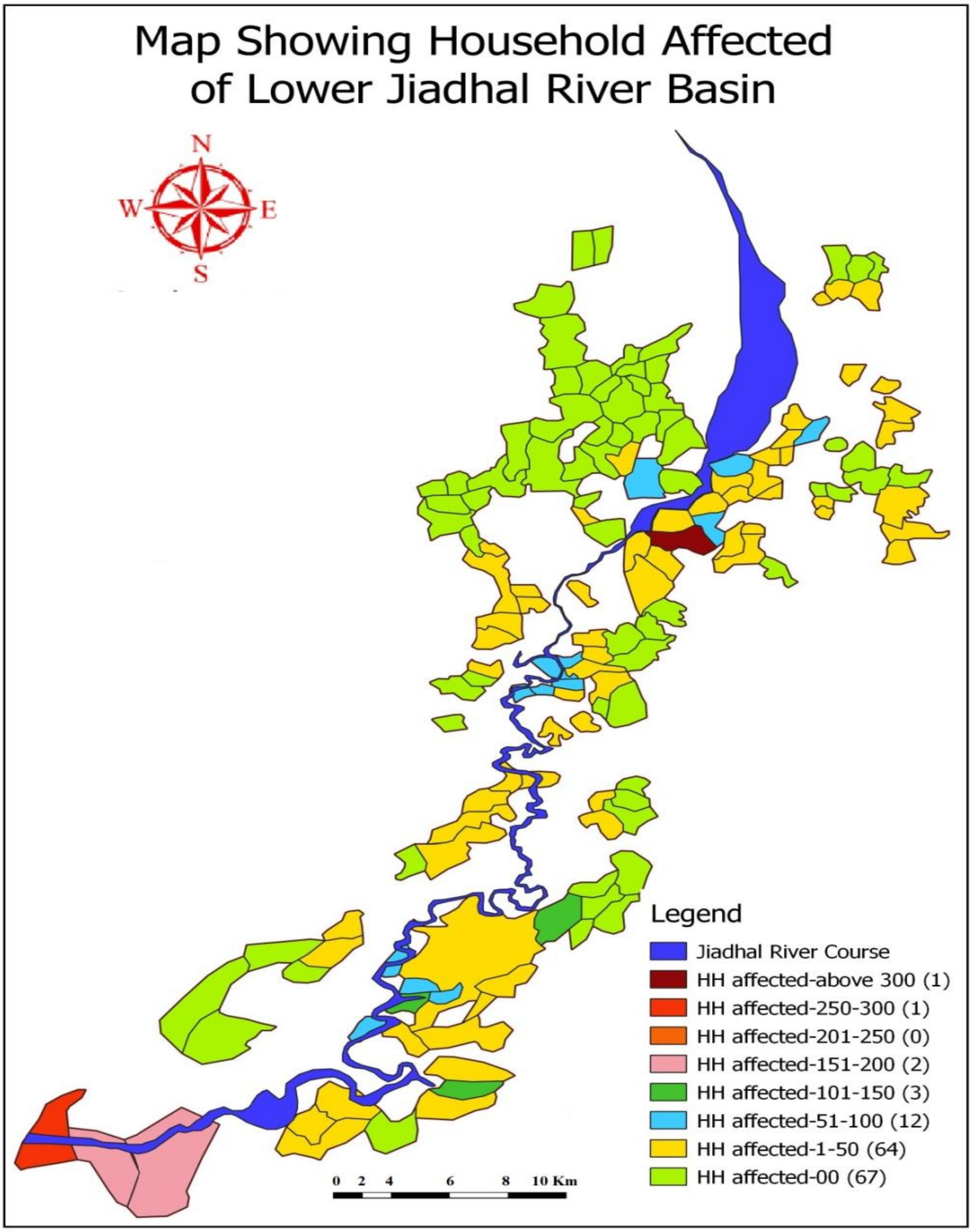


Fig. 4.5: Household Affected map of Jiadhal River Basin

This has been observed considering the flood zonation map and the results revealed that the flood zone II is more prone and experienced tragic flood disasters. The flood zone - I comprises 25 villages, 2898 household and 3115 population out of which 121 household and 495 population are affected by flood consequences. In flood zone-I, the land degradation is due to flooding which is nominal as it is situated in the northern part of the lower jiadhal basin. Households affected comprises 62 losses 2 bighas, 26 losses 6 bighas, 12 losses 8 bighas and 8 households that losses 10 or more than 10 bighas of land. Zone –II is rapidly affected by flood with 85 villages and 11207 populations within 10 km buffer zone of the Jiadhal River. It has 1561 households affected by flood and 339 (60%) households losses 2 bighas, 157(28%) losses upto 6 bighas and 39(7%) losses 8 bighas and 12(2.1%) losses 10 and 14(2.5%) losses more than 10 bighas of land. On the other hand Zone –III situated in the lower southern part of the lower Jiadhal basin is mainly a low lying plain with numerous channels and wetlands. It consist 40 villages and 7452 population within 10 km buffer zone of the Jiadhal river. It has 1590 households affected by flood and 421 (83%) household loss 2 bighas, 72 (14%) loss upto 6 bighas and 12 (2.4%) losses 8 bighas and 3 (0.6%) losses 10 bighas of land (Fig 4.3 & Table 4.5).

ENVIRONMENTAL CONSEQUENCES OF DEFORESTATION

The Deforestation: The degradation of forest cover or natural vegetation in any area, natural or anthropological is termed as deforestation (Riba and Boruah, 2015). It is the main problem faced by the natural environment of the study region especially the Upper Jiadhal basin which comprises the Arunachal Siwaliks Himalayas. Understanding the causes of deforestation, it could be further sub divided into certain categories on the basis of its nature as, physical, socio-economic, developmental activities and over utilization of resources. Thus the basic categories would be termed on the basic of its nature and origin as follows.

1) Physical cause includes earthquake, landslides.
2) Socio-economic factor includes poverty, firewood collection, timber selling, natural resource extraction, unequal distribution of land, low productivity, low infrastructure facilities, low economic development etc.
3) The developmental activities include industrialization, urbanization and rapid growth of population.
4) Under Utilization of resources it include over exploitation and utility, miss management of forest and deforestation of natural vegetation in the name of afforestation.

Thus another force active in deforestation and have the greatest share of the hold for the degradation of environment is the anthropogenic activities as

i) Legal and illegal Land Use Change,
ii) Ownership
iii) Indigenous Rights,
iv) Agro- forestry based Market and Industries and
v) Poaching and illegal lumbering.

Plate. 4.2: A) Lumbering for timber in Siri catchment, B) People sailing on timber raft through Jia Gorge,
C) Timber raft in Sido catchment, D) Temporary timber labour camp at Tin-Suti Junction.

The most prominent causes of deforestation on the study region are the forest fire, the Agro- forestry based market and industries, and the poaching or illegal lumbering. Shifting cultivation is an important feature of deforestation in the Arunachal Himalayas because it uses to destroy the natural vegetation by slash and burn techniques to prepare agriable land. The process is harmful if the practice is done in recklessly, i.e. if there is no any management activity or if the new forest were included for such purposes. But in traditional Jhumming or shifting cultivation prevailing in the forest region have limited areas and they use to perform it in a proper management of jhum cycle. Thus the jhum cycle of 5 to 7 years is followed for the replenishment of natural forestry and thus it not only rejuvenate the forest but also conserves the issue like soil erosion as the fields or hill slopes are not tilled in total to increase the soil erosion. They use traditional tilling and showing methods which did not led the top soil exposed for longer durations. It is observed that if the fallow period is maintained the shifting agriculture would rejuvenate forest rather than degrading is greater extent. It is true that clearance of forest natural vegetation would always degrade the environment, but the tradition of jhum cycle is the boon to forest replenishment (Lombi, 2015).

The Environmental Consequences: Deforestation in the natural vegetative cover of the region led the disintegration of the physical bonding and sheer capacity of the lithology and prone to degradation (Rawat, 2011). Thus deforestation causes the supply of sediment load to the drainage system of in the region. The study area received heavy rainfall and cloud burst which led to increase of surface runoff. Thus the surface runoff weakened the exposed soil or rock due to deforestation and causes the erosional activities which are the sources of sediment load of the surface runoff or streams (Patnaik, 1993) Apart from the natural causes of degradation of forest the worst affected by the anthropological factors or activities over the region. The environmental consequences of deforestation in upper basin are as follows-

Landslide is active phenomena prevailing in the region, the terrain have lofty mountain with steep slopes having low vegetative cover which are the vulnerable sites too. The rainfall intensity added more stress on the exposed land surface to landslides. The lithology composed of conglomerates are prone to Rock slide and it is been observed in the sites associated with Debris cone and Debris fan along the fault lines of the region associate with streams. The mouths of these streams are characterized with boulders, cobble, pebble and sand. The lithology of the region is composed of Lower Tipam Sandstone Formation comprising medium to coarse grained sandstones, bluish to bluish green which weather to brown colour, with occasional conglomerates, clay lenses and carbonised fossil wood and prone to fluvial degradation.(Kesari, 2010).

Soil erosion is another process of degradation active in the region and mainly occurs due to the adverse use of natural environment by human. The excessive and unscientific use of natural resources is the main cause of deforestation as well as soil erosion in the basin.

Forest fire is another important aspect of forest degradation, the upper basin experience forest fire in winter season for clearance of forest for shifting cultivation and agro-forestry plantation.

Apart from all these consequences in upper Jiadhal basin the sediment supply to river is the worst as it is not only degrades the upper catchment but also responsible for environmental degradation in the lower basin. The deforestation in upper catchment areas added sediment sources to the drainage prevailing and the effect is observed in the lower basin as siltation and sedimentation in the river course led to flooding, bleaching of embankments and siltation in the flood plain. The siltation or sand casting in lower basin due to flood causes deforestation too, as the existing forest coverage including agro-based forest are damaged by submergence by flood and then by the sediments after flood, lowering the water table. The observation of Dihiri, Nepali Khuti, Ratuwa and Kachukhona are good example of deforestation and flood consequences.

LAND USE PLANNING AND SUSTAINABLE DEVELOPMENT:

Information on land use and land cover change has an important role to play on planning of regional development plans. The land use pattern of a region is an important aspect of the sustainable development of the region, thus it is an important subject in regional planning. The planning and management task is hampered due to insufficient information on rates of land cover and land use change (Kotoky, Bezbaruah, Baruah and Sharma (2003). Land use and land cover of the Jiadhal is controlled by the environmental geomorphology mainly the fluvial actions under high intensity rainfall. The study area is also suffering from climate change as the intensity of rain and temperature is changing rapidly which is affecting the region. The Socio-economy of the region is depending on the primary activity mainly agriculture. The main problem of the entire Jiadhal basin is the fluvial geomorphological response to flood, erosion, siltation, sedimentation and channel migration. Such phenomenon ruins not only the land use and land cover in the Jiadhal river basin but also on environmental geomorphology.

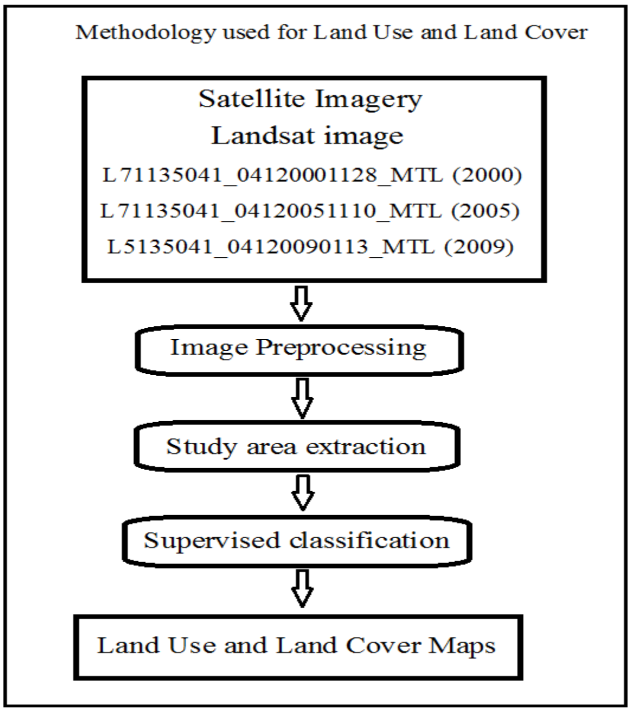


Fig. 4.6: Methodology Flow Chart for the analysis of Land Use and Land Cover

The basin have tremendous fertile alluvium soils suitable for agriculture, but the seasonal flooding and siltation discourages cultivators to practice large scale agriculture for livelihood. The basin shows that the share of dense forest has a mean fall of 20.62 Km^2/year and comparatively the degraded forest has raised 10.40 Km^2/year during the observation period of 2000 to 2009. Accordingly the share of rural development area is decreased 21.57 Km^2/year in contrast to the same an increase in fallow land and wetland compiles 19.3121.57 Km^2/year. The statistics of the area clearly indicated that the environment and land use pattern of the Jiadhal river basin was highly influenced by the flood and its consequences during recent years. The planning for the stability of social as well as economic development of the region the main importance is gained by the flood management. The scope of activities for the sustainable development includes management of infrastructural or non-infrastructural plan to stabilize the river banks so they remain free from embankment bleaching and flood. The main factors that aggravate the embankment failure are-

- Siltation led river bed rising
- Improper maintenance of embankment
- Erosion of embankment by river current
- Use of substandard construction material
- Use for temporary road communication
- Use for temporary shelter during flood
- antisocial elements damaging of embankment by for quick relief

- Accumulation of rain water due absence or inadequate cross drainage facility etc.

The causes of the embankment failures are the trigger on which planners and the planning should concentrate to have a sustainable solution. The situation of the basin itself indicates that the management of flood is possible only if both the states of Arunachal Pradesh and Assam took collective initiatives for its conservation and management. As the river is flowing from the hilly tracks of Arunachal from where it carries the sediment loads and deposits in the river course causes the raising river bed. The conservation is only possible with integrated watershed management programmes. Thus the situation and solution of the Jiadhal river basin problems could be mainly to Upper basin and the Lower basin area for planning and implementation of management programmes to make the region sustainable.

LAND USE PLANNING FOR UPPER JIADHAL RIVER BASIN

The upper Jiadhal basin is a hilly terrain occupied by the Arunachal Himalayas with and altitude variation of 150 to 1400 meters of height and composed of lofty mountain ranges which are dissected by numerous drainage systems prevailing in the region. The physiography of the upper basin determines the landuse and land cover of the basin. Another factor affecting the land use and land cover in the upper Jiadhal basin is its inaccessibility, as there is no a road or routes to communicate the interior of the upper catchment areas. Inaccessibility to the interior makes the upper basin free form human disturbances and very less settlement is observed in the upper jiadhal basins which are mainly seasonal settlements. The river itself in the winters is the route to the upper reaches of the basin through the narrow gorges to Tin-suti (tri-junction) which is narrow depressed terrace in the river valley. Physiographically the Upper Jiadhal basin could be divided on the basis of the relief features of the region into five divisions as (i) River Terrace-1, (ii) Terrace-2, (iii) Terrace-3, (iv) Rough mountain terrain and (v) Mountain peaks. The purpose of the delineation of the physiographic divisions are to analyze the land use plan of the upper Jiadhal basin.

The Terrace-1 occupies 22.38 sq.km consist only 6% of the total area of the upper basin (Fig 4.7 & Table 4.7). The area is low lying composed of debris deposition mainly drought by the river on the top layer and the hard rock as its bed. It has boulders and pebbles of different magnitude accompanied with coarse to find grained sand deposits along the river side. The terrace-1 is subjected to submerge in water in peak flow during the rainy season and thus remains less vegetative cover occupied by grassland and shrubs. This area is dominated by debris and rock slides from the numerous tributaries to the main river. The tributaries are associated with fault lines and the lithology of the Siwaliks is fragile and composed of conglomerates and thus the hill slopes are prone to erosion mainly by fluvial action. The second terrace (terrace-2) ranges in the elevation of 200 to 250 meters and is occupied by dense forest with tall trees and under growing scrubs and grasses (Fig 4.7 & Table 4.7). This area is prone to deforestation by human activities in winter season in the name of agro-forestry and shifting cultivation. Terrace 2 occupies 53.06 sq.km 14% of the total area of the upper drainage basin. It is associated with tall grassland types of vegetation with less developed trees (Fig 4.7)

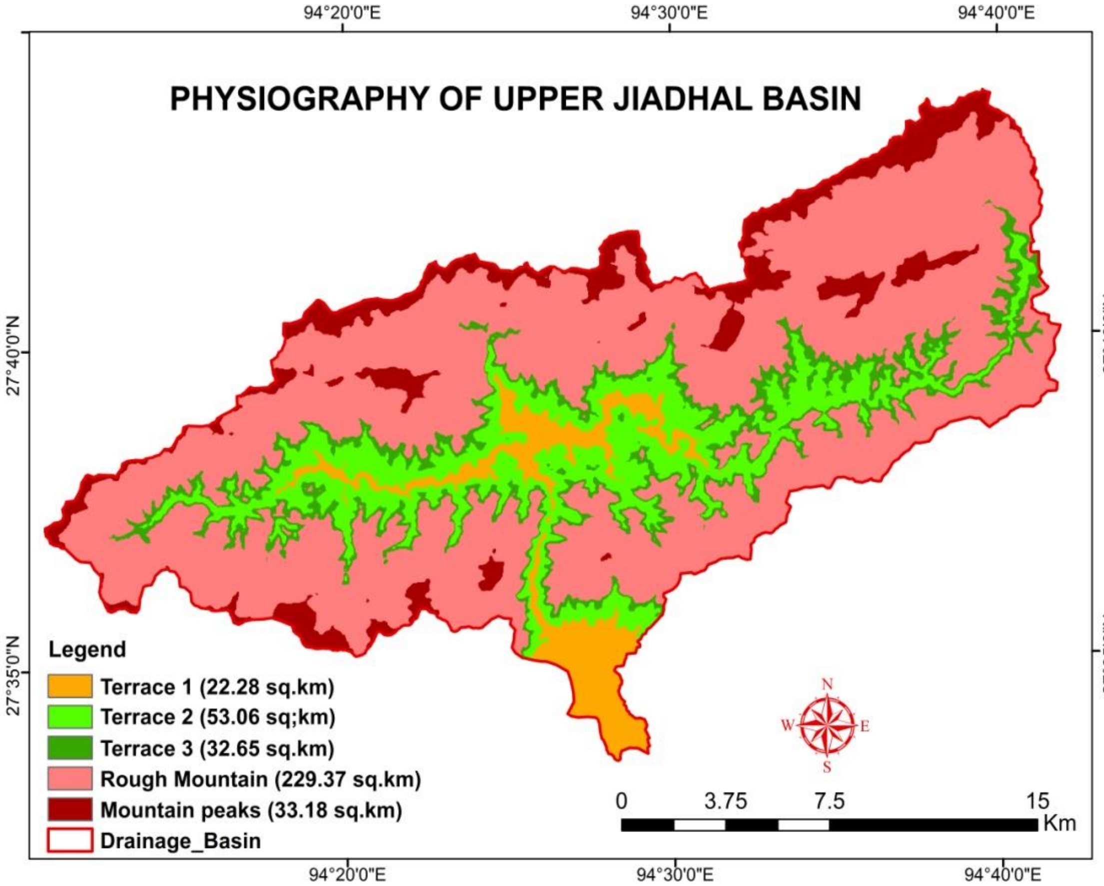


Fig 4.7 : Shows Physiographic divisions of Upper Jiadhal River Basin

Table 4.7 : Geographical characteristics of physiography divisions of Upper Jiadhal River Basin

Physiography	Shape_Length	Shape_Area	Area (Sq.km)	% of Area
Terrace1	104583.89	22282208.20	22.28	6
Terrace2	338043.06	53062711.91	53.06	14
Terrace3	514755.26	32646348.10	32.65	9
Mountain	440489.26	229366469.73	229.37	62
Mountain Peaks	184347.51	33180653.12	33.18	9
Total	1582218.97	370538391.06	370.54	100

Sources: Map parameters ArcGIS10.1.

The river terrace 3 is a narrow zone associated with steep slope gradient is a transit zone is dominated by free face slopes along with debris deposition in the foot accompanied by undulating hills. The rough mountains occupies 229.37 sq.km comprises 62% of the total area of the basin which is mainly associated with undulating and rough mountain ranges (Fig 4.7). In comparison with other divisions, it had the highest share of natural vegetation. The vegetation types are higher grasses scrubs and young plants with low developed trees. The undulating low gradient slope is mostly exploited by deforestation in the name of agro-forestry and the rest due to lumbering in the winters, and thus prone to deforestation. The highest elevation of the mountain peak is free from human intervention but the limbering activities hampers the hill peaks also result for the degradation. From the land use land cover analysis it is clear that the forest cover of the upper basin was decreased at the rate of 11.60 km^2/year during 2000 to 2009 and still continues. Considerably the share of degraded forest cover is increased at the rate of 13.83 km^2/year during 2000 to 2009 and the trend is still on (Table 4.7).

Conservation Plans:

The conservation of the forest is the first step in the planning of the natural land cover of the upper Jiadhal basin. The region is inaccessible in most of the days and proper sustainability of the region would be possible if it will be thoroughly connected with road network. The area is free from government surveillance due to its strategic situation. The agencies like forest are unable to reach and monitor the ground truth of the interior forest coverage, which is found to be in degradation according to the studies carried out. The indigenous people have has started management of their properties but in reachable areas are reachable in winters by the river itself, so the road communication would provide security not only to the forest up there but also the prospects of agro-forestry and horticulture. The roads will permit establishment of settlements and without settlement the region has no proper ownership to maintain and conserve. The degraded forest areas could be turned into agro forestry and plantation crops could be flourished like orange, pineapples, bananas, cane, bamboo even aracanut and other products, which will not only stable the hill slope but also strengthen socio-economy of the region. Presently the forest product is only in use, due to settlement increases the scope of cropping pattern and cropping choice may bring sustainable development of the upper basin area.

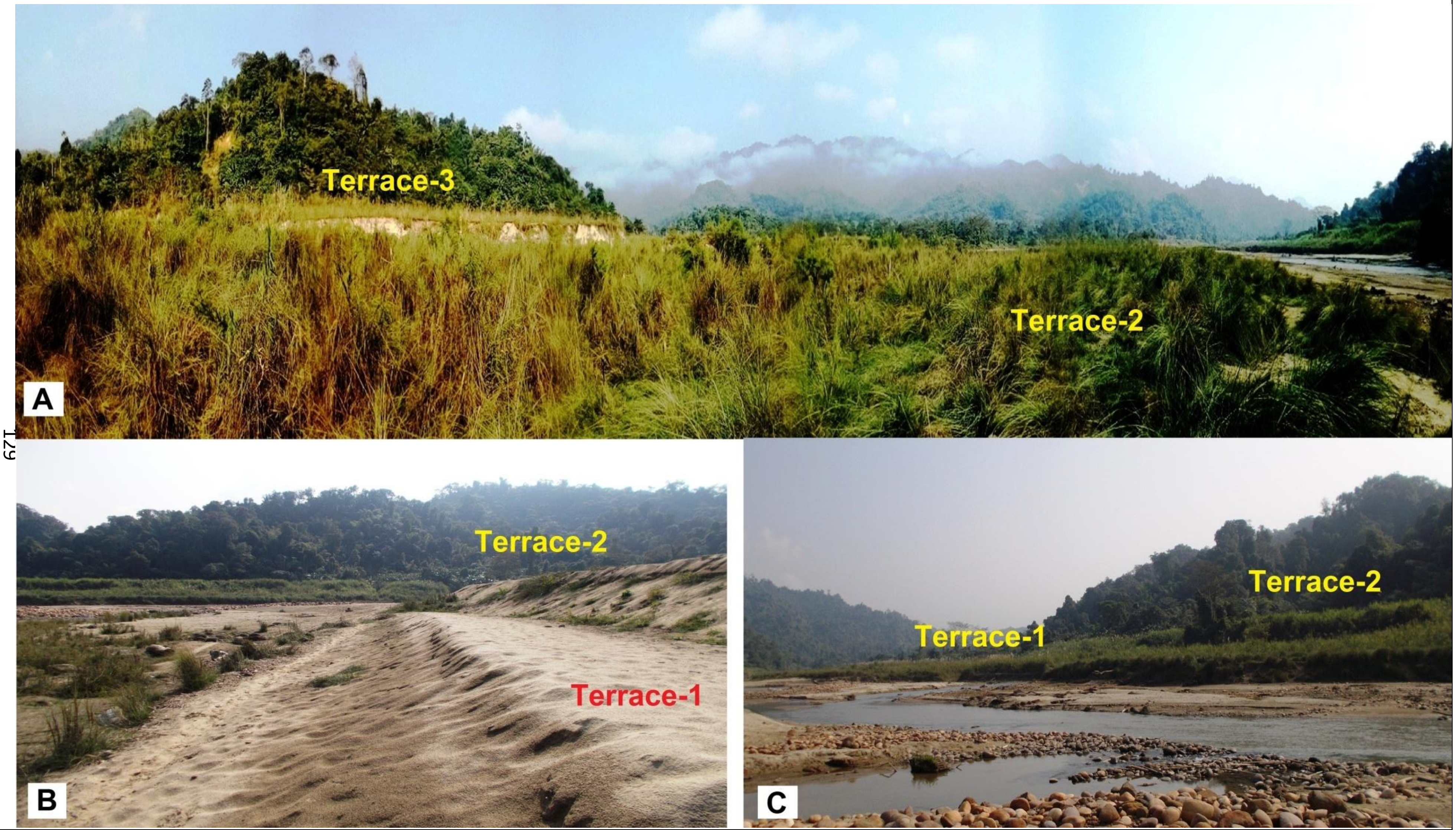


Plate. 4.3: a) Terraces in Tin-Suti area Jiadhal with terrace-2 & 3 as first is within river course and narrow, b) Right bank of Sido full of sand deposits and little grasses, c) Right bank of Siri with low grasses in terrace 1 and higher grasses in terrace-2.

LAND USE PLANNING FOR LOWER JIADHAL RIVER BASIN

Land use is an important aspect of environmental geography particularly relevant to environment, agriculture and economic as well as social geography of a region. A land use of the region explains the trend of human intervention on the environmental settings for their living. The natural environment plays a vital role in the socio-economy of the region and the land use is the primary sector that effect on the environment of the region (Goswami, 2003). The natural calamities found in the region are understood by monitoring the land use trend of the region. The region experiences natural calamities like flood, drought, landslide and erosion or land degradation. The Land Use is concern to the practices of the human that exist due to the interaction of man and natural environment.

The physiography of the lower Jiadhal basin is an extensive featureless plain mainly composed of the alluvial deposits by the different drainage system prevailing there. The natural phenomenon is still active in the region and hampers the most land use as well as the land cover of the region. The region is associated with the low lying depressions composite of wetland and swamps which remains water logged throughout the year. The trends of land use and land cove since 2000-2009 has observed that the wetland and swamps have been increased from 60.42 sq.km in 2000 to 127.14 sq.km till 2009. Whereas the Rural area decreased from 605.21 sq.km to 423.79 sq.km till 2009 is the factor representing the flood and siltation has influence the land use and land cover of the basin. The population in the surveyed villages has adopted different alternate livelihood other then agriculture which is the primary activity of the region mainly due to flood and its consequences. The socio-economy of the region is drastically hampered by the perennial flooding of Jiadhal river system. The region receives tremendous rainfall and the terrain of the plain remains water logged even it doesn’t have direct influence to river flow. The river course of Jiadhal is in higher elevation than the flood plains beside the river which make it vulnerable and prone to bleaching. The tributaries namely Na-nadi, Kumotia and Sampara often get connected due to the problem of water logging in the fields. A day rainfall is enough for water logging and it remains for 2 to 3 days in some areas, damaging the crops and even livelihood. The average flood level observed in the Dihiri, Ratuwa and Kachukhona in the right bank and Bordoloni Kalita gaon, Konch gaon and Boruapothar in left bank is 4.7 feet from the ground level and went up to 7.3 feet particularly in the year 1997, 2002 and 2007 (Annual Report Amasure, 2007). The ground level of the entire affected flood plain are raised due to siltation and sedimentation ruining the agricultural crops, livestock and even infrastructures including rail, road, culverts, bridges, settlements and granaries. The study of occupational structure in the selected village helped justifying the trend of the shift from primary agriculture to other alternate livelihood options available in rural areas. These villages were the worst affected observed as 671 households with 3225 populations (Census, 2011). Among the total 1848 working population 896 (48% of the total working population) were main worker comprising 703 (38% of the total working population) personal engaged in cultivation (agriculture). The marginal workers share found higher than main worker which reflects the agriculture popularity is decreased mainly due to its unsustainablility. The marginal worker shares 52% of the total working population 922 out of which cultivator (industrial) has largest occupant sharing 44% of the total working population. Followed by the Agricultural labourers (Industrial) and other industrial workers the rural scenario did not permit much alternative for livelihood. The marginal workers are mainly engage in construction works and agricultural labourers (industrial) who are in daily wages on modern technologies like tractors, power tractors etc. in agro-sector and construction works only.

Problems and Causes of Land use and Land cover change:

The Jiadhal river is the main factors among the rest social and cultural problems in the lower basin. The river brought large quantity of silt and sediment in peak season which raises the river course to a shallow depth. The increasing water volume with new sediments in rainy season get overflowed from the river banks by bleaching the earthen embankments due to low passage and lower slope gradient. The bleaching of river bank is associated with huge siltation in the flood plain which has lower bench mark then the river course. The water logging in the agricultural field added another hydrological characteristic to the earthen embankment for erosion. The excess use of earthen embankment as means of transportation and even shelter in flood situation weakens the share strength of the embankment and prone to degrade. The siltation brought by the flood not only damaged the crops but also ruined other like fisheries, wetland, swamps, and buildings too. The response of the villages surveyed recorded as 10 to 20 cm of silt each year in regular flood and in the extreme deposits up to 2 to 3 feet at once in lower areas. The flood of Ratuwa, Kachukhona, Bordoloni kalita gaon, Konch gaon, Maj gaon have experienced such extreme flood. The agricultural field, fisheries, swamps and depression were submerged by the siltation and sand casting. The residential houses were submerged even though they prefer to build in a raised platform at an average height of 3 to 4 feet above the ground level. The standing crops and orchards are dried up due to siltation and its renovation took 5 to 7 years and in between it faces the same problem again.

Conservation Plan:

Land use and land cover of the lower Jiadhal basin need to be conserved mainly from the natural floods and its consequences that make the basin vulnerable. The management plan for through environmental geomorphology of the lower jiadhal basin involved a permanent solution to river embankment bleaching.

Agriable Land: The region has ample scope of agriculture, as the soil is bring renewed with new fertile alluvium in each flood span. The sand casting or siltation is a major problem degrading the agriable land to fallow land. The maintenance of the embankments ensures low flood risk and bleaching which boost the cultivators for agricultural renovation.

Water logging : The water logging is another issue and is probably because of less drainage to let the logged water out from the field. The agriable land is under water just on rainfall, and proper ventilation of the unwanted water to stream would be a better option. Otherwise the wetlands, depression and swamps should be turned into mini reservoir which could hold the unwanted water in the field for longtime. The renewed reservoir would help the water table in winter too for irrigation purpose and the agriculture would be boosting.

Wetland and Swamp: The wetland conservation is to be done for biodiversity as well as for the industry sector to gain some economic benefits. The local species of fishes have ample scope and the population has tradition to have fishing as their part of livelihood. But due to submergence of fisheries and flood flashing their production the population get losing their interest on pisciculture too. Thus the remained wetland and swamps could be conserved and transform into fish rearing plots with government and public participation so that the production would grant a livelihood to the inhabitants.

Culturable Land: The land use pattern under cultural land includes the rural settlement and agroforestry associated with the settlement area which is mainly of standing crops and plantation of fruits, bamboo and groves of sericulture. The rural settlement areas have the trend of planting different types of banana and bamboo surrounding the cultural areas to prevent it from natural calamities including flood and storms. These plants are the most reliable and necessary plants among others and used for preparing remedial against flood.

Sand and Silt: The Jiadhal River course natural hazards in the basin and the main reason are the flood effects of sand and silt deposition in the river bed which causes the river bed sallower. The rising river bed due to huge siltation is a problem of the jiadhal basin in one end but in other, it is great natural resources of the region. The proper utilization of the same with inoperative management system could redefine the adversity to privilege. The sand and silt brought by the river in rainy season could be easily excavated with proper management. Excavation works for the river channel deepening which restrain the channel depth and flow restricting the embankment bleaching.

REFERENCES

Boruah, J.K. (2000): Geomorphic study of lower Subansiri basin, Assam, Suodhganga.net, http://hdl.handle.net/10603/61665, pp-9-160.

Burley. M. (1961): Land Use and Land utilization, online library. wiley.com. Http://doi.org/10.1111/j.0033-0124.1961.136_18x.

Cengiz, A. E. (2013): Impacts of Improper Land Uses in Cites on the Natural Environment and Ecological Landscape Planning. ADVANCE IN Landscape Architecture (et.al), DOI:10.5772/55755.

Clawson. M and Stewart. C.L. (1965): Land Use Information,Natural Resource Journal, Baltimore: The Johnes Hopkines Press. pp-359.

Goswami, D. C. (2003): Interlinking of Indian River: The Plan and its Implication, Proceedings of the National Seminar on Linking the Major Rivers of India: Possibilities and Apprehensions, Organised by AsSam Science Society, April 29, 2003, Guwahati pp. 38-45.

Kanianska. R. (2016): Agriculture and its Impact on Land-Use, Environment, and Ecosystem Services, Landscape Ecology-The influence of Land Use and Anthropogenic Impacts of Landscape Creation (et.al.) DOI: 10.5772/63719.

Kesari, G.K., DasGupta, G., Reddy, B.V.R. and Prakash, H.S.M. (2009): Geology And Mineral Resources Of Assam, GSI, 30 Part IV Vol 2(i) Assam. pp-8-51.

Knap, A.H and Ivan, R (2016): Environment exposes due to Natural Disasters, Rev Environ Health, HHS, Public Access, NIHMS793214 doi-10.1515/reveh-2016-0010.

Kotoky, P., Bezbaruah, J. and Sarma, J.N. (2003): Erosion activity on Majuli – the largest river island of the world; Current Science, Vol.84, No. 7.

Lombi, P. (2015): Shifting cultivation in the foothills-a case study of West Siang district, Arunachal Pradesh, Dutta, C.K. et. al, Biodiversity of North East India, Kiran Prakashan, Dhemaji, ISBN: 9789382746850 pp- 187-198.

Mohammad. N (1992): Socio-Economic Dimension of Agriculture, New Dimensions in Agricultural Geography(et.al), Comncept's International Series in Geography, New Delhi. Vol. 3,No.4 pp-20-22.

Patnaik, S. K. (1993): Hydrogeomorphologic characterization of Sankh head water catchment (Doctoral thesis) Shodhganga @ INFLIBNET/10603/20985 loded on 22-July-2014. pp 113.

Rawat, M.S., (2011): Environmental Geomorphology and Watershed Management. Concept Publishing Company Pvt. Ltd. New Delhi, pp.-1-286.

CHAPTER-5

GEOGRAPHICAL APPRAISAL OF HEADWATERS OF THE JIADHAL RIVER BASIN

INTRODUCTION

This chapter focuses on the headwater areas which control the environmental geomorphology of the Jiadhal River Basin. The headwater zone has the highest elevation with unique slope gradient and thus is comparatively fragile to degradation by nature as well as human-induced or climatic change. The remoteness of these areas can also mean they are overlooked, or passively addresses in management and policy, despite their role of providing ecosystem / environmental services locally and further downstream (Ariza et al.,2013). Headwaters provide many vital environmental, social and economic services (water, timber, peat, grazing land, locally aesthetic, cultural, recreational, educational, hazard mitigation), which are being impacted by climatic and global changes and need international policy actions focused on sustainable management (Cost, 2019). These are the main sediment source region of the river basin, and the Jiadhal discharges a great amount of sediment in the lower basin area. Thus it is prior concern to understand the headwater environment to make the stability of the basin. The headwater's environmental services were studied to understand their importance in the basin and the degradation of the area is observed for strategic planning and management of headwater areas of the study area. Headwaters experience a number of disturbance regimes. Often these disturbances are intense, but infrequent, such as mass wasting events that accompany high precipitation events. Wet soils can lead to slope failures which run into headwaters. Moreover, sediments (rock and wood) stored in headwaters can be mobilized during higher flows and lead to debris torrents of materials down the small channels to where the material is deposited where gradients are lower or continues down larger streams into which materials are delivered. Headwaters are often the source of sediment supplies to downstream, shaping the possible configurations of downstream channel structures depending in part of the transport capacity of the source streams, grain size distributions and slopes, as above.

GEOGRAPHICAL ANALYSIS OF THE HEADWATERS

Headwaters are the part of watersheds furthest from the river's end point. These parts of the watersheds are critical since they are the main areas that the water is produced. If headwater streams have been disturbed or altered due to human activities such as deforestation, inappropriate forestry practices, urbanization or agriculture, this can harm several ecosystem services substantially especially water quality downstream (Cost, 2019). The headwater has major impact on both the sustainable development of the headwater region as well as those who live downstream (Haigh, 2010). Headwater control aims to promote ground, better integrated and more self-sustainable development in headwater environment. It is constituted upon three principles: First, it recognizes that headwaters are vulnerable habitats much threatened by environmental change, both climatic and more directly anthropogenic, such as the anthropogenic degradation of forest, biodiversity, ecosystem health, waters and soils, and the demanding effects of air pollution, agriculture and economic development. Second, it focus on management plan of the watershed by different measures including water management, soil conservation, landslide mitigation, land reclamation, pollution control, forest engineering, bioengineering, applied environment education and action-oriented community participation programmes for community welfare. Finally, it emphasizes the practical application of holistic integrated environmental management, both in its biophysical and social components (Krecek, et.al, 2017).

Structure of Headwater areas of Upper Jiadhal Basin

The upper catchment of Jiadhal river basin is dominated by high hills and undulating terrain comprising the Siwaliks range of Arunachal Himalayas, range from 200 to 1400 meters above mean sea level. The region is very less populated and has a very rich biodiversity. The human intervention in the region is the real threat for the sustainability of the region as well as the geomorphological processes. The region receives tremendous rainfall throughout the year and mainly during the summer season concerned mainly as monsoon season. The topography of the region creates an interesting phenomenon in the region, which distinct the river basin as individual micro climatic zone. The relief features act as a mini climatic divide and it composites a unique own climate system. Mainly the central upper basin region is an elongated river valley surrounded with lofty mountain ranges which restrict the influence from northern part and even the local wind system from the southern plains. This is a unique combination of climate and the geo-hydrology of the region, regulating the geomorphological and hydrological phenomenon in the region. The region experience local precipitation system in supplementary to the monsoonal regime, which influence the quantity of rainfall in local places and produces a peak flow in the rainy days. The peak flow in the stream accompanied with heavy sediment load which is being eroded from the source regions of the hill slopes of the upper catchment areas, mainly composed of fragile conglomerates of Lower Siwalik range of Subansiri and Kimin formation. The topography of the upper catchment is hilly terrain with lofty mountain ranges, which make it a unique physiographical situation. The drained river system namely Sido, Sika and Siri from there different directions of west, north and east respectively flows to join in a junction locally termed as tin-shuti (meeting point of three river) to form Jia river. Each river has its own characteristics on stream flow, sediment load carrying capacity as well as erosional power and landform developments along their courses.

Table 5.1: Stream number of the Upper Jiadhal Basin

Catchment	Symbol used	Stream order (U)							
		1st	2nd	3rd	4th	5^{th}	6th	7th	Total
Sido Catchment	4	169	38	9	1	0	0	0	217
Sika Catchment	5	77	16	4	2	1	0	0	100
Siri Catchment	5	193	74	16	2	1	0	0	286
Jia-Up Catchment	6	64	16	1	0	0	1	0	82
Upper Jiadhal Basin		503	144	30	5	2	1	0	685

Source : Map attribute table (ArcGIS 10.1)

.

Sido River: The river originates in the north west portion of the river basin and flowing easterly, the highest elevation of the river is 1300 m. above mean sea level along the eastern mountain barrier of the Subansiri river system. Locally the area is termed as Mandir hills or Subansiri line and have the lofty ridges in the extreme upper reach of the river system. The main course of the river is natural springs mainly seeping from the slippery and free faces of the mountain slopes. The composition of the existing landmass of the Subansiri or the Siwaliks is an established fact. The climatic factor responding the stream flow in the gullies and valleys of the catchment, the precipitation intensity is high as the catchment has good vegetation cover. The slope gradient is higher in the upper slopes as well as the fault lines followed by streams. Sido is fourth order stream having 169 first order, 38 second order, and 9 third order stream with a total of 217 streams occupying 106.62 sq.km of area (Table 5.1).

Sika River : Sika on other hand is a smaller northern catchment between hill ranges and share water divide with Subansiri basin towards the north. It is an undulating stream catchment with mainly two streams of forth order the Taka and Sika originating from the lofty mountain ranges and join from opposite direction to join the Tinshuti as Sika. It has 77 first order, 16 second order, 4 third order and 2 fourth order stream projecting it as fifth (5^{th}) order stream comprising total 100 streams with an aerial extension of 46.96 sq.km (Table 5.1). The surrounding hills act as local climatic divide and mainly associated with local temperature inversion phenomena over the mountain valleys.

Siri River : Siri is fifth order stream and it has the largest catchment flowing from east to join Tinshuti to form Jia. The stream originates at an elevation of 1000 meters as Rite (local name). The stream is structurally controlled along the deep gorges to flow with 193 first order, 74 second order, 16 third order and 2 forth order stream with a total of 286 streams occupying 172.66 sq.km of area (Table 5.1).

Plate. 5.1: Observation point of Upper Jiadhal headwater (a) Sido with boulders pebbles and fine sand, (b) Sika river has more boulders then fine sand, (c) Siri Gorge point free from boulders and (d) Siri Middle line is contributes debris with fine to course grained sand and boulders).

Jia- Up River : Jia is the sixth (6^{th}) order stream and is a originating from the tri-junction (Tinshuti) of Sido, Sika and Siri rivers. The stream is dominated by structural morphology as it flows thoroughly over gorges bisecting the lofty mountain range to extensive plain of Dhemaji. It has an aerial extension of 34.17 sq.km with 64 first, 16 second and one third order stream comprising 82 total streams (Table 5.1).

LULC of Headwater Catchment of Upper Jiadhal Basin.

The Land Use and Land Cover of the headwater clearly indicate the environmental condition of the water source region. On the basis of the observation made with the help of Google Earth images and multispectral Landsat images to identify the classification. The dense forest occupies 134.97 sq.km of the total area of the headwater catchment areas followed by degraded forest cover comprising 6.67sq.km it reflects the water source areas which are well covered with natural vegetation and natural as well as anthropological interference for its degradation.

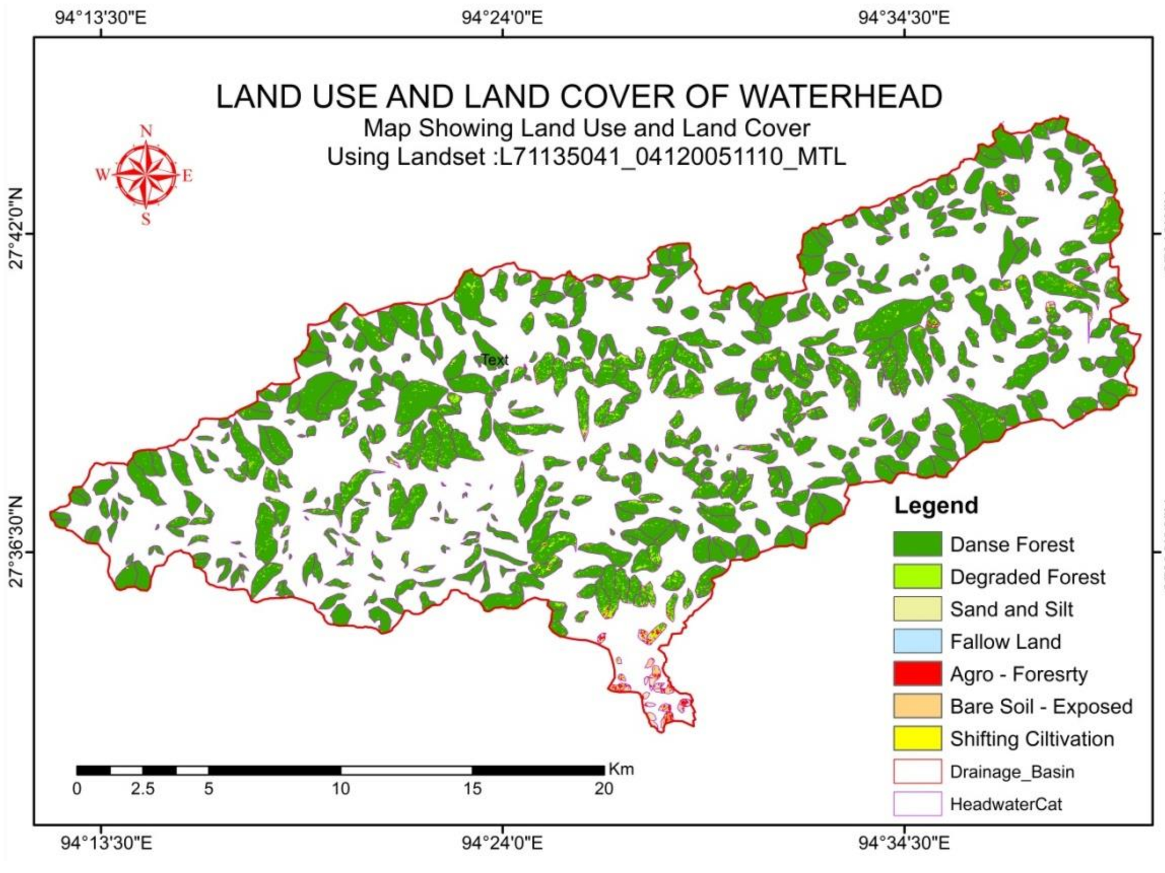


Fig. 5.1: Showing Land Use and Land Cover of Headwater Catchments of the study area.

The land cover of sand- silt and bare soil- exposed rocks occupies 1.23 sq.km comprising the sediment yield areas of the catchment. Deforestation activities in the upper catchment in the form of timber works, agroforestry and shifting cultivation degrade the headwater areas and the result is the increasing sediment load in the main stream. The southern areas of the upper Jiadhal basin comprises 1.15 sq.km of areas of the headwater on agro-forestry and 0.59 sq.km on shifting and fallow land together.

Table 5.2 : Land Use and Land Cover of Headwater Catchments

Classification	Jia	Sido	Sika	Siri	Total
Dense Forest	9.93	36.26	17.84	70.94	134.97
Degraded Forest	1.41	1.67	0.66	2.92	6.67
Sand and Silt	0.40	0.02	0.00	0.32	0.74
Fallow Land	0.25	0.08	0.00	0.04	0.37
Agro-Forestry	0.64	0.00	0.05	0.46	1.15
Bare Soil-Exposed	0.47	0.00	0.00	0.02	0.49
Shifting Cultivation	0.08	0.08	0.04	0.02	0.22

Source: Map attributes

<u>Vegetation Distribution in the Headwaters of Upper Jiadhal Basin</u>

The vegetative cover of the headwaters indicated that the forest has greater role in water recharge of the headwater catchments. As per the field survey the upper and middle catchments have an average density of 2.5 trees per 20 meters with heavy undergrowth. The lower catchment occupy by open scrub with lowest tree density of 1 tree per 20 meters of area. The catchments with high vegetation or dense forest are moist and the lower tree concentration comprises open scrub area with grassland. The vegetation canopy varies with locality, the trees in higher ridges has 6 meters of radius whereas the valleys have highest canopy of 4 meters of radius. The tree canopy in the open scrub area has 2 meters of radius. Thus the upper ridges are well covered and the valley parts have moderate coverage mainly influence by deforestation made by human population.

Table 5.3 :Vegetation cover of the Headwater Catchments of the Jiadhal Basin

Area (20 Sq.m.)	1st	2nd	3rd	Total	Ave	Forest Canopy (in m radius)	Forest Density	Vegetation type	Remarks
Upper Catchment	2.5	1.5	1	5	1.7	6	High	Dense Forest	Moist and heavy undergrowth
Middle Catchment	2.5	1	0.5	4	1.3	5	Medium	Degraded Forest	Moist and heavy undergrowth
Lower Catchment	1	0.5	0	1.5	0.5	2	Low	Open Scrub	Dry and low undergrowth

Source: Map attributes and field observation

<u>Soil Properties of Headwater areas of Upper Jiadhal Basin</u>

Soil geography of the headwater catchments is under the impact of the environmental geomorphology of the region. The geology belong to Siwaliks of Himalaya and thus composed of gray-sand stone, dolomites and conglomerates.

Table 5.4: Soil Properties of Headwater Catchment in the Upper Jiadhal Basin

Soil Profile of the Upper Catchment	Jia Catchment				Sido Catchment			
Observation	1	2	3	Ave	1	2	3	Ave
Soil Depth (f)	2	1.5	0.5	1.33	2.2	2	0.8	1.66
Soil Texture (%)	70	40	50	53.33	60	70	80	70
Soil Types	Loam				Sandy Loam			
Soil Profile of the Upper Catchment	**Sika Catchment**				**Siri Catchment**			
Observation	1	2	3	Ave	1	2	3	Ave
Soil Depth (f)	1.8	1.2	0.6	1.2	2.5	2.7	1.8	2.33
Soil Texture (%)	40	70	60	56.66	40	80	90	70
Soil Types	Loam				Silty Loam			

Source: Field observation

The vegetation cover of the region reflects that the soil thickness is well developed in the region. The headwater catchment of Siri has recorded highest soil thickness of 2.7 feet depth with an average depth of 1.8 feet of soil mainly composed of Silty loam with 70% silt and 30% sandy soil in average. The lowest soil depth is observed in Sika catchment as the region is highly consist of rough terrain and mainly composed of fragmented sand stone mixed with conglomerates and dolomite. The soil thickness ranged 0.6 to 1.8 feet of depth, composed of loam. The Sido headwater areas comprise 0.8 to 2.2 feet of soil depth and mainly compose of sandy loam. Whereas Jia headwater catchment has soil depth ranging from 0.5 to 2 feet and mainly composed of loam. The soil is prone to erosion due to vegetation loss and fragile lithology and thus contributes huge amount of silt to the drainage runoff.

ENVIRONMENT AND DEVELOPMENT IN THE HEADWATER CATCHMENTS OF THE JIADHAL RIVER BASIN

Development of headwaters could be of different forms, it may be originated from natural water reserves like natural springs and aquifers or snow cover. It is characterized by surface flow of accumulated water as runoff with fluvial processes and activities. Headwater streams are the main streams of the catchment which dominates its environmental geomorphology, it may be flowing through the year or might dried up occasionally (Richardson, 2019). Headwater is a unique geographical unit with significant resistibility of the environment system influencing the water budget of the streams. One defining characteristic of headwater streams is that these main water house which determines the biodiversity of the region (Rhoads & Herricks, 1996). Further Cushing, et al., (2006) illustrates that about 80% of total stream length of the world are associated with headwater streams. Its environmental importance is being discussed under the following paragraphs.

Rainfall in Headwater Areas: The chapter focuses to highlight the role that a headwater plays in the environment and development of Jiadhal River Basin. The headwater is the sources of the first water contributing the stream runoff. Rainfall regulates the characteristics of headwater ecosystems, providing hydrological connectivity (Freeman et al., 2007) in the entire basin area. Intensity of rainfall determines stream property, as lower rainfall could reduce the stream flow and even completely dry-up during summer. Robinson (2017) classified such streams with greater than 10 days of zero discharge as intermittent runoff or intermittent flashy stream. Such variability is responsible for typical environmental development in the headwaters. The amount of precipitation received, the amount of water transferred further downstream and the rate of sediment load it carries, the landform, vegetation cover and the surface or the ground water alternation are some of the important aspects in catchment hydrology as well as erosion processes involved in the headwaters. Patnaik (1993) studied headwater areas have great variance in water budget and mainly due to less rainfall in winters, probably by the influence to deforestation, global climatic change etc. The inversion of temperature in mountain valley contributes local precipitation in form of due, fog, mist and drizzle in the upper catchment areas. Thus the water supply to the ground water keeps replenished naturally. The rainfall intensity increases in summer and mostly from the month of April to August of each year. The monsoon wind system is responsible for the climatic phenomenon of the basin. The lofty mountain act as barriers to rain bearing clouds from the south and south east and causes orographic rainfall in the hills as well as in the lower basin too.

Erosion in Headwater Areas: The surface runoff is characterized with geographical factors like climate, vegetation, relief and topography. The upper catchment area is a hilly terrain and have distinct environmental characteristic. The mountain slopes are prone to water erosion in combination with a number of other denudation processes, such as weathering of soil rocks, debris falls, landslides, creep, soli erosion and some others. Its rate depends not only on energy of water flowing upon slopes but on other processes providing loosening and thus preparing rock materials to be washing out and removing by water (

Mandych, 1992). The fragile lithology of Siwaliks and the geological structures like fault and cracks induces large erosion in the headwater.

Soils in Headwater Catchments: The extremely dissected high relief drainage basins may exhibit a high flood potential even given low rainfall input. The irregular distribution of rainfall does not promote vegetation or soil development and therefore the resulting greater magnitude of surface flow leads to the formation of rills or gullies on hill slopes (Patnaik. 1993). The intense soil erosion may lead to loss of top soil, decrease the infiltration or moisture capacity, soil fertility and also inhibit vegetation growth (Nyssen, 2006). Various types of soil erosion were evident within the catchment, predominantly sheet erosion, gully erosion, rill erosion, river bank erosion and landslides are found in the upper Jiadhal basin.

Relief and Headwaters: Structural variation due to differences in geology, surrounding vegetation, slopes, contributing areas and others can be important contributors to species sorting by environmental filters. Relief and topography can affect the size, specific gravity, shape and even the surface roughness of exposed soil parts in headwaters. Headwaters can be colluvial, i.e., their flows are not competent to move the largest of the deposit in the channel, providing highly heterogeneous channels (Patnaik. 1993). Slope gradient of the headwater determines its properties of soil depth, vegetation cover and surface runoff, lower the gradient lesser the erosion and more prone to slides and with steeper slope gradient. Headwater of Jiadhal have high slope gradient and thus prone to erosion.

Aquifer in Headwater Areas: Headwater is the store house of water with variation ranging from long-term water storage to short term or fast storm event subsurface flow is observed (Hofmann, 2018). Geomorphology or geology determines the hydrological properties of headwater catchments which control the infiltration of ground water, surface flow, and residence times of water throughout surface (Alexander, 2007). It is mainly influenced by the precipitation received, vegetation cover and the local relief and structure to set the infiltration rate to ground water or aquifers. Jiadhal headwaters have reach vegetation and the stream follows the fault lines, thus it receives maximum input of surface flow from the subsurface water.

Ecology of Headwaters: Headwater streams are characterized by high connectivity with their surroundings. Shad provided by forest canopy or even shrub-level vegetation can moderate stream heating to maintain cooler conditions than elsewhere. The headwater with greater undergrowth contributes more on aquifer recharge then low under cover as the time taken of surface runoff in influenced by under growth vegetation. On the other hand cross-ecosystem resource subsidies in the forms of leaf litter, seeds, terrestrial invertebrates and others can dominate the basal resource base of such debris-based streams (Graça, 2001).

Environmental Threat in the Headwaters: Headwaters have relatively small contributing areas, hence small amounts of groundwater storage, streams that have perennial flow in an average year may be vulnerable to loss of surface flow in a drier than average year (Hewlett, 1970). The Jiadhal headwater is perennial but the increasing pressure on forest and land; the indigenous population is entering the interior headwater for exploitation of forest resources. This exploration led to increase deforestation in the name of settlement, agriculture, horticulture, agroforestry and in infrastructural development, which would decrease the forest coverage affecting the headwaters. Global climate change in another alarming factor, the uncertain rainfall and its intensity induces vulnerability to headwater of Jiadhal. Low rainfall would shrink the headwater as well as the torrential rainfall often denudes to large extent to failure. The increasing erosion increases the sediment load of the river and it ruins the downstream while peak flow by flash flood and siltation.

ENVIRONMENTAL SERVICES OF HEADWATER CATCHMENTS

Headwaters are water recharge areas in mountains or uplands, crucial for freshwater resources. Thus, headwaters control and regulate runoff genesis and delivery, water resources recharge, water quality, and a good number of ecosystem services, which strongly influence the downstream environmental security and human well-being. Headwater provides series of benefits and services to human societies, generally termed as ecosystem or environmental services. These services may be in separated or integrated forms. In general the environmental services could be classified by Gorucu (2017) as follows.

1. **Provisioning services**: Materials that environment provide such as food, water, wood, grass, medicinal plants and other raw materials etc.
2. **Regulating services**: Services that environment provides regulators such as landforms development, soil and air quality, carbon storage, rainfall, flood, erosion and disease control etc.
3. **Supporting services**: Services that environment provide sustained space such as habitat, biodiversity of flora and fauna, nutrient cycling etc
4. **Cultural services**: Services that environment provide humanity, quality such as recreation, aesthetic value, spiritual inspiration and so mental health etc.

On the other hand it provides many important ecological functions to downstream system and can be classified to three major categories (Morley, 2011).:

1. **Hydrologic** : Including a) provide a source of water, b) influence the timing and response of water, c) allows for direst interactions at the groundwater- surface water interface,
2. **Chemical** : includes a) initially characterizes the chemistry and quality of water entering streams, b) important source of nutrients
3. **Biological** : includes a) are characterized as areas of high productivity, b) Increase local and regional biodiversity, c) increases ecosystem stability.

Provisioning Services of Headwater: In this section classification of environmental services (Gorucu, 2017) have been discussed in respect to Upper Jiadhal headwaters. The headwaters of Jiadhal are found to be active on supply fresh water, replenish ground water, support biodiversity, and provide resources, store, transform and transport huge sediment load as well (Ken and Brent, 2011). The Jiadhal basin experience warm and humid climate in summer and cold and dry in winter responding the water supply to the catchment. The rainfall intensity is not regular through the year; it receives heavy rainfall during summer in the month of April to August ranging to 500 to 700 mm and even 1000 mm in rainy seasons. The winter is cold and rainfall is occasionally occurring in the upper reaches of the catchment areas due to local climatic factors. Thus the water supply to the basin is continues with a fluctuating range to seasonal difference. It provokes flood hazards in the lower reaches and let huge deposition of silts and sediments. The upper basin has 98 % land cover under forest comprising 52% of dense forest and 46% of degraded forest (LULC 2009) which fulfill the basic requirement of the indigenous population inhabited the region. The main forest product is timbers, firewood, bamboo, cane, toko leaves, various medicinal plants, orchids for day to day life. The wild fruits, birds, animals and fishes have ethnic importance in tribal population living the region. The most common species of forest products are categorized on the basis of its physical properties as.

Regulating Services of Headwaters: The headwaters are the sensitive zone with tremendous natural mountain aquifer or ground water. Seepage of natural springs from the structural faults accumulates surface runoff from the subsurface water reserve. The soil characteristic of the headwater determines the percolation of surface runoff to enrich ground aquifers of the mountain, which are streaming out as natural springs initiating the stream flow in winters. Thus the stream runoff is lower in winter than in summer due to high precipitation. The vegetative coverage of the headwater catchments plays a vital role in water supply. The headwater catchment with more vegetative coverage allows infiltration to aquifers than areas having bare exposed rock. On the other hand the supply of sediment is more on bare exposed rocks then the catchments having vegetative coverage (Patnaik, 1993). The bare and exposed soil occupies mainly the headwater areas recorded highest in the year 2009 of 2.80 sq.km about 1% of the upper Jiadhal basin (LULC, 2009). This reflects the headwater catchments are intact to nature but the deforestation in the region triggers its sustainability.

Table 5.5 :The floristic composition is given below

Species level	Common name	Scientific name	Species level	Common name	Scientific name
Top Storey	Hollock	Terminalia Myriocarpa	Lowers storey	Boramthuri	Talauma hodgsonii
	Jutuli	Altingia excelsa		Selling	Sepium baccatum
	Amari	amoora wallichii		Poreng	Olea dioica
	Borpat	Ailanthus grandis		Morhal	Vatica lancafolia
	Gonsoro	Cinnamomum ceciodaphnae	Ground cover	Tita tenga	Citrus spp.
	Sopa	Magnolia spp.		Kaupat	Phrynium imbricatum
	Bogi-poma	Chikrasia tablaris		Kologoch	Musa spp.
	Dhuna	Canarium resiniferum		Bonposola	Sarauja panduana
	Bohera	Terminalia belerica		Bhat	Clerodendron infortunatum
	Khokan	Duabanga grandiflora		Bihlongoni	Pteris guadrisurita
	Hillika	Terminalia chebula		Jeng	Calamus erectus
	Simul	Bombax ceiba		Ekra	Erianthus revanas
	Udal	Sterculia villosa		Dhopatia	Clerodendron viscosum
Middle storey	Hinguri	Castanopsis indica	Bamboo	Kako Bans	Dendrocalamus hamiltonii
	Urium	Bischofia javanica		Bijuli Bans	Bambusapallida
	Moj	Albizia lucida		Bojal Bans	Pseudostrachyumpolymorphum
	Jamuk	Syzygium cumunii	Cane	Lejaibet	Calamus floribundus
	Banderdima	Dysoxylum binectiferum		Raidang Bet	Calamus flagellum
	Nahar	Mesua ferrea	Palm	Toko palm	Livistona jenkensii
	Outenga	Dillenia indica			
	Pichola	Kydia calycina			

Sources : Department of Forest, Arunachal Pradesh, http://arunachalforests.gov.in/pasighat_forest_division.html

<u>Supporting Services</u>: The human intervention is low in the headwater regions of the study area. Though it is not free from human intervention mainly because it provides a wide range of essential environmental services that have been benefited the regions environment as well as socio-economy of the basin. The Timber works in headwater catchment is the main problem for the deforestation and related issue of soil loss and increase of sediment load in the river. The upper catchment areas are prone to erosion due to vegetation loss and structural difference of the lithological composition. The conservation of the land resources in the headwaters is a strategic management plan with combination of the environmental and geomorphological study. To find solution to the problems of stream sediment load the landform of the upper catchment areas were segregated as debris slope, debris fan, landslide prone, rockslide prone, and regolith deposits so to that each areas of the upper catchment may be planned under watershed management plan.

Cultural Services: The inhabitants of the headwater region of Jiadhal river system are indigenous tribal population of West Siang district of Arunachal Pradesh. They are Galo in particular and have rich tradition with headwater environment for their livelihood too. The traditional shifting cultivation called jhum in Galo dialect it termed as Mo-Di-Rikh (hill agriculture) or Tump Rikh (dry field) and they indigenously use the headwater streams for the irrigation purpose of the agricultural plots in the hill slopes. According to tribal believes and customary laws the headwater are always their propriety, as they provide them water shelter, forest resources as well as fish for their wellbeing (Lombi, 2015). The forest provides many services to the inhabitants, traditionally they have made huts from the available forest raw materials like cane- bamboo, timber, toko leaves as building materials and firewood, food and shelter, fish and wild animals for hunting etc. The over use of forest resources is a concern to the inhabitants of the area, they have to move remote places to collect their necessities as the easily reached areas are already utilized and have low productivity, thus exploration into deep forest for necessary items are prevails. This practice brings vulnerability to headwater region of Jiadhal river system too due to increasing pressure of exploration and exploitation.

Status of Headwaters: Today, most headwaters are threatened by human development and activities, even those formerly at the margins of socio-economic activity. The threat like over use of natural resources, disruptive land-use changes, global climate change or pollution seriously degrading the environment as well as the headwater regions. Therefore, a serious concern of headwater conservation is evolved as a burning issue in present context. Headwater catchments must be properly managed with an integrated focus on water and its overarching role, avoiding biased sectoral approaches toward other resources, goods and services (forestry, livestock, recreational, agriculture). In the Upper jiadhal region the trend of forest cover is decreasing due to various factors, some are natural and others anthropogenic. The degradation of headwater environment could render hazardous impact on human society. It become a threat and needed to taken care for the sustainable development of the entire river basin.

Headwaters and Natural Hazards: The shrinking of headwater due to known as well as unknown issues makes it vulnerable for its sustainability. Headwaters have high potential of resource development, so are prone to exploitation disturbing the natural environmental. The human activities in headwater regions can have dramatic effects on both the environmental and socio-political stability of areas downstream (Křeček and Haigh, 2017). Headwater environments are threatened by environmental changes due to human action including forest decline, deforestation, land degradation, deteriorating water quality and the damaging effects of air pollution, agriculture, road construction, excessive exploitation of natural resources, overuse of forest, mismanagement of environment, tourist development and mining etc. Global climatic change is another important issue related to decline precipitation intensity to enrich headwater zones. Ownership of the land an important aspect which restricts the proper management of the headwater, the Forest Rights Acts (2006) overrides the 1920 Indian Forest Act, allowing tribal communities and forest dwellers to use the forest land for generations. The Jiadhal watershed experiences such issues as the exploitation in headwater areas is normal according to indigenous inhabitants, but the consequences are observed beyond political boundaries in the lower basin areas due to flood and siltation. Lumbering in the headwater is a burning issue in the region mainly for collection of building materials and even for commercial purposes. The timber demand in the market increases its exploitation leading to forest degradation. It is practiced more in illegal form than legal with proper permission from the government authority. Apart from human induced threat natural calamities also renders headwater catchments mainly due to landslide, soil erosion, flash flood, torrential rain, structural weakness of the topography etc.

GENERAL GEOMORPHOLOGY OF HEADWATER CATCHMENTS

The Upper Jiadhal basin is hilly terrain associated with the Himalayan geomorphology with altitude ranging from 60 meters to 1460 meters of height above msl. The upper reach has rich vegetation cover and composed of relatively coarser and loose sandstones prone to denudation processes. The basin is divided into five physiographic divisions on the basis of landform and elevation. The areas with elevation more than 1000 meters above mean sea level (msl.) termed as Peak and composites 5.23 sq.km (1.43%). High Mountainous region comprises 60.76 sq.km (16.40%) of the total upper basin area with elevation 100-1000 meters above msl. The Mountainous region (400-700 m) comprises the largest physiographical region extending 138.02 sq.km (37.25%) of the area. It is dominated by degraded slope with high to low degraded forest coverage due to deforestation activities. Highlands occupies 121.80 sq.km (32.87%) are associated with residual hillocks and undulating topography with low elevation. Piedmont region comprise the river valley, gorges, river terraces and the foothill region stretching 44.70 sq.km (12.06%) of the upper Jiadhal basin.

Table 5.6: Physiography of Upper Jiadhal Basin

Physiography	Area (sq.km)	Elevation Range	Geomorphic Features
Piedmont region	44.70	60-200	Valley, Gorge, River Terraces
Highlands	121.80	200-400	Residual hillocks, undulating topography
Mountainous	138.02	400-700	Degraded slope, High to low Vegetation cover, Deforestation
High Mountainous	60.76	700-1000	Dense forest, low deforestation
Peak	5.28	1000-1460	Dense forest, low deforestation
Total	370.56		

Sources: Map attribute table (ArcGIS 10.1)

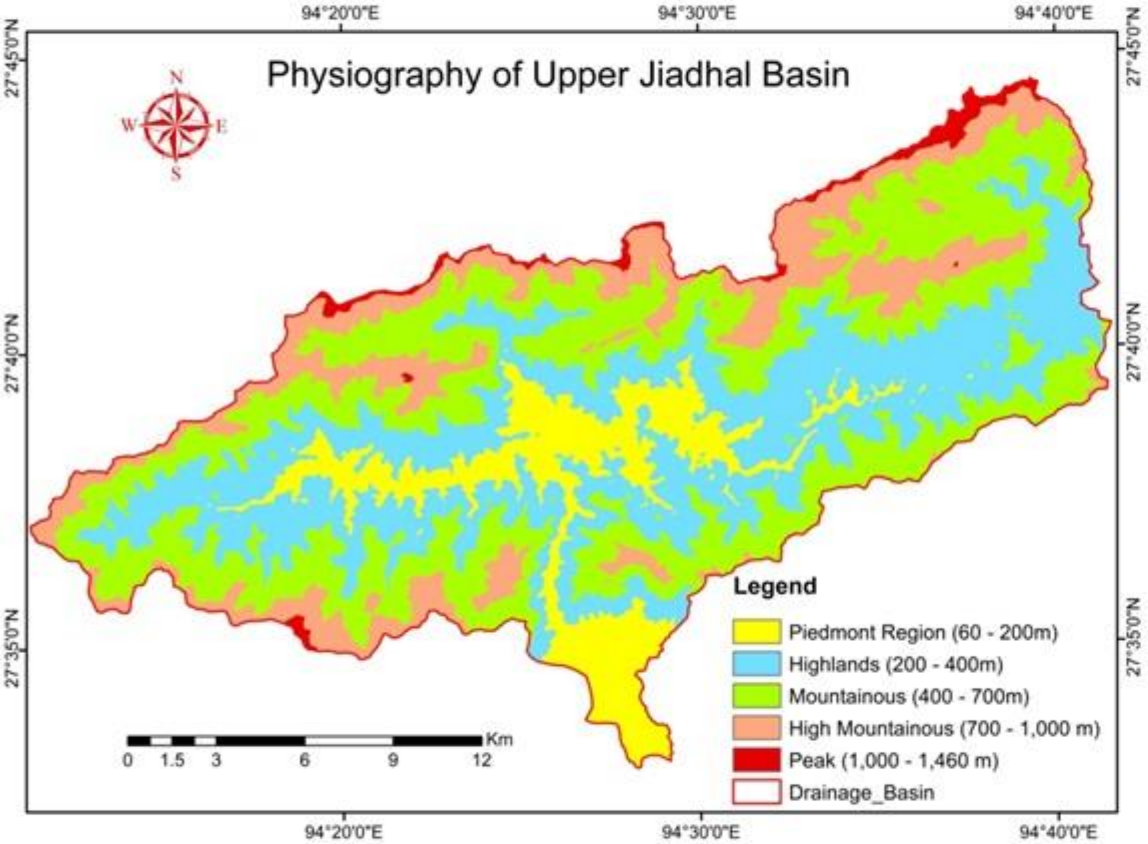


Fig 5.2: Physiography of Upper Jiadhal Basin Area

The physiography of headwaters in the basin reflects the nature of stream properties including the sediment sources of the stream. The headwater catchment is dominated in the mountainous region having elevation between 400-700 meters comprising 41%. The region is composed of unconsolidated sand stone strata and thus prone to erosion results increase of sediment supply to the river. Among the four main catchments Sika comprises 30.74 sq.km followed by Sido than Sika and least in Jia catchment. The mountainous region occupies 204 headwater catchments mainly concentrates Siri catchment.

Table 5.7: Catchment wise Headwater Physiography (Area in sq.km)

Physiography	Elevation Range	Jia	Sido	Sika	Siri	TOTAL
Piedmont Region	60-200	3.76	1.86	0.74	3.44	9.81
Highlands	200-400	4.77	13.28	2.02	27.27	47.35
Mountainous	400-700	3.58	16.14	8.46	30.74	58.92
High Mountainous	700-1000	1.04	6.62	6.76	11.46	25.87
Peak	1000-1460	0	0.10	0.61	1.78	2.49
Total		13.15	38.01	18.59	74.68	144.43

Sources: Map attribute table (ArcGIS)

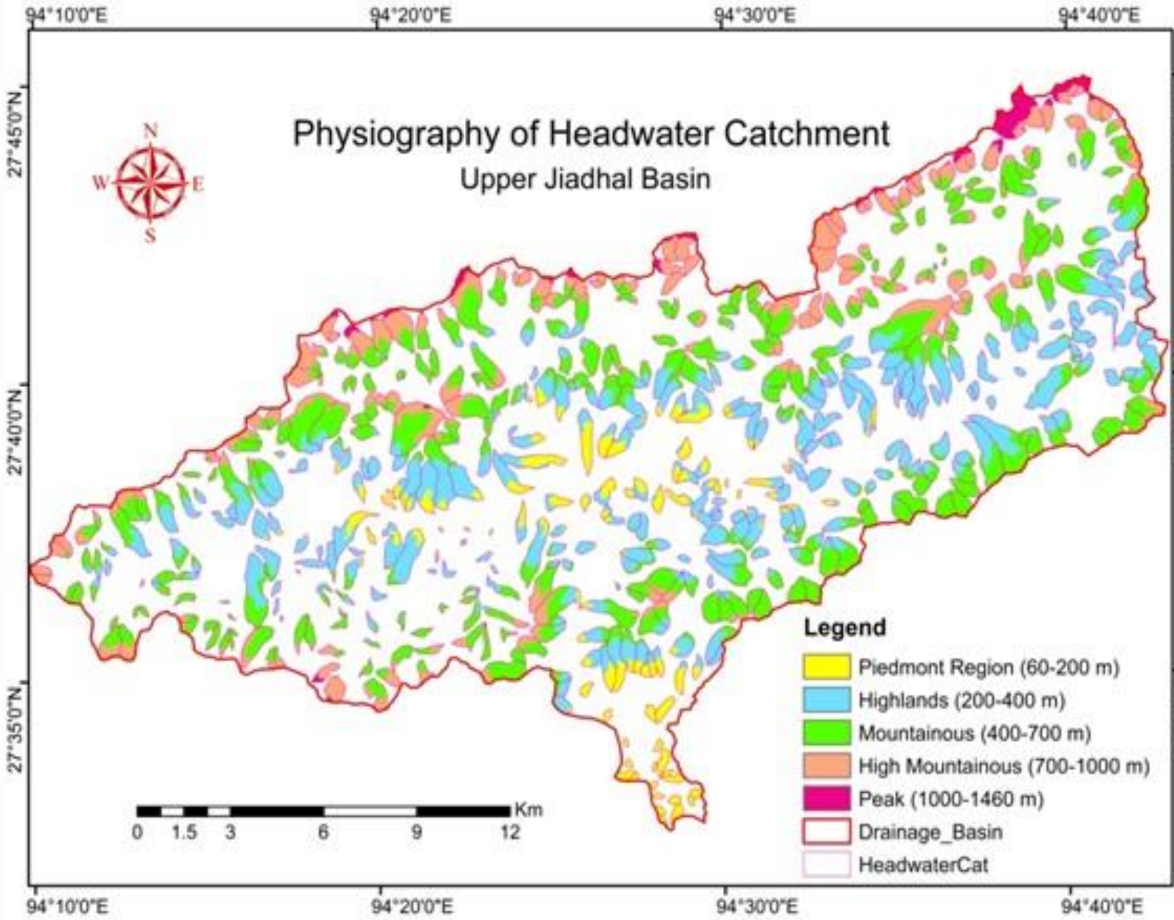


Fig 5.3: Map showing the physiography of the Headwater Catchments of Upper Jiadhal Basin.

The Highlands compiles the second dominating physiography consisting 47.35sq.km (33%) of the headwater area, with 145 dominating catchment. Siri and Sido has highest share of highland whereas Sika has lowest share with only 2.02 sq.km.

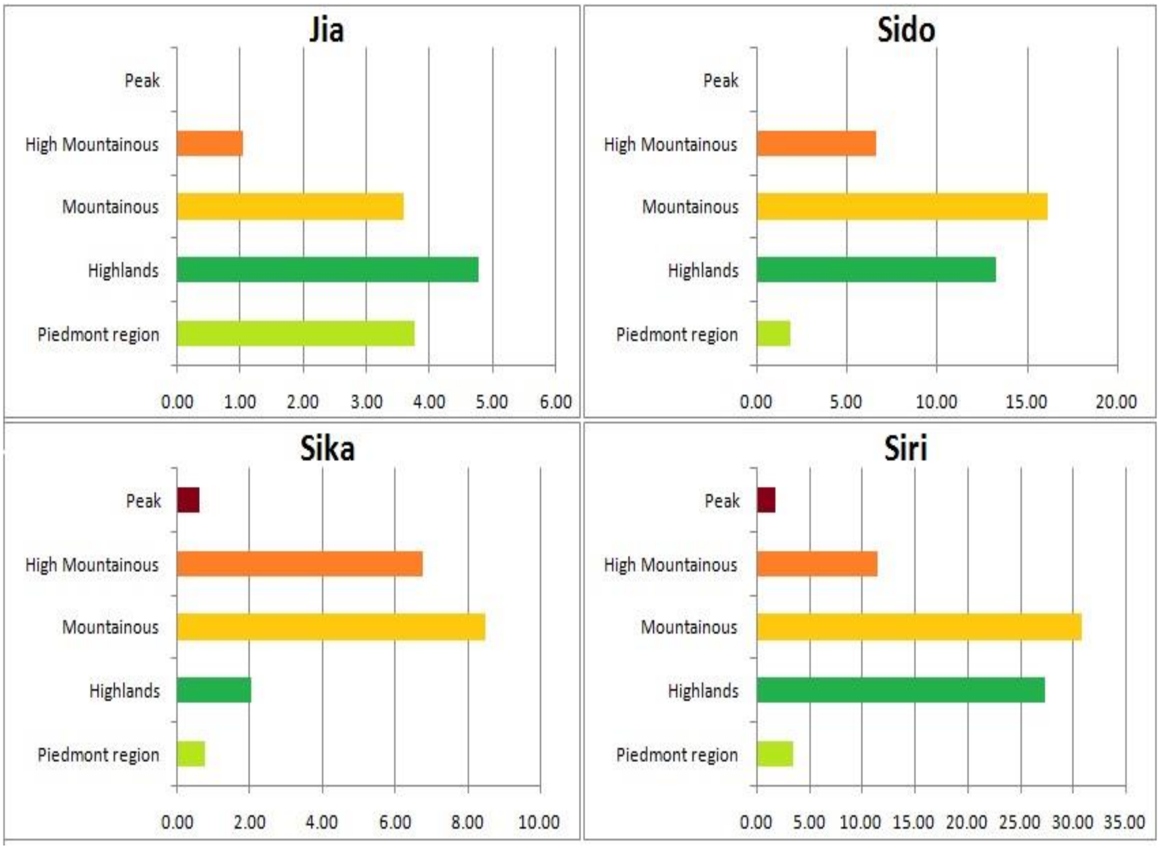


Fig 5.4: Graphical representation of Headwater Physiography

The High Mountainous region occupies 25.87 sq.km (18 %) consisting 89 headwater catchments. The region is fragile and thus prone to nature as well as human induced degradation thus produced large amount of sediment load to the stream flow. Piedmont region occupies 9.81 sq.km (7%) and comprises 50 headwater catchments mainly situated in the foothill areas. Sika has lowest share less than one sq.km of area and mainly concentrates on Jia, Siri and Sido with 3.76, 3.44 and 1.86 sq.km respectively. The Jia catchment does not have any peak areas, Sido and Sika has nominal areas but less than a square kilometer. Siri has 1.78 sq.km comprising only 6 headwater catchments is the highest water source of the entire catchment. The climatic condition of the basin determines the water supply to the headwater, it receives intensive rainfall and prone to fluvial processes of erosion. The rainfall induced gullies were predominant in headwater areas and are irregular in flow, as in summer the runoff increases inducing massive erosion and land slide contributing sediment to the stream flow. Structural properties of the physiography led the headwater streams powered by valley deepening process influencing amount of sediment supply to the surface runoff or stream flow.

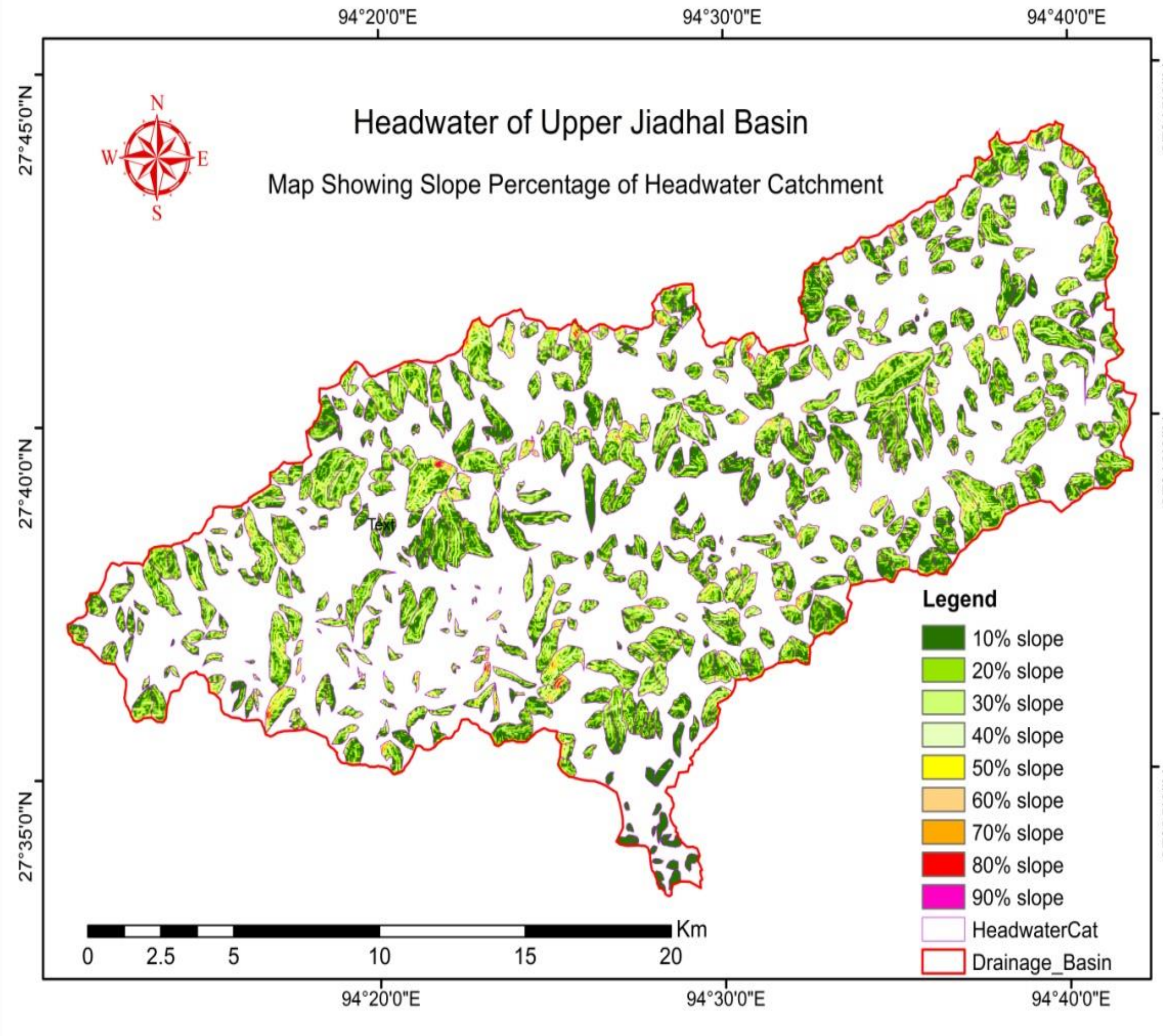


Fig 5.5: Showing Slope Percentage of Headwater Catchment (DEM extract)

Table 5.8: Slope (in %) characteristics of the Headwater catchments in the Upper Jiadhal basin.

Slope Percentage	Area	Area in %	Remarks
10	56.53	39.14	Gentle slope
20	49.73	34.43	Gentle slope
30	24.74	17.13	Medium slope
40	8.70	6.02	Medium slope
50	3.16	2.19	Steep slope
60	1.04	0.72	Steep slope
70	0.37	0.25	Very steep slope
80	0.13	0.09	Very steep slope
90	0.02	0.02	Vertical slope
TOTAL	144.43	100	

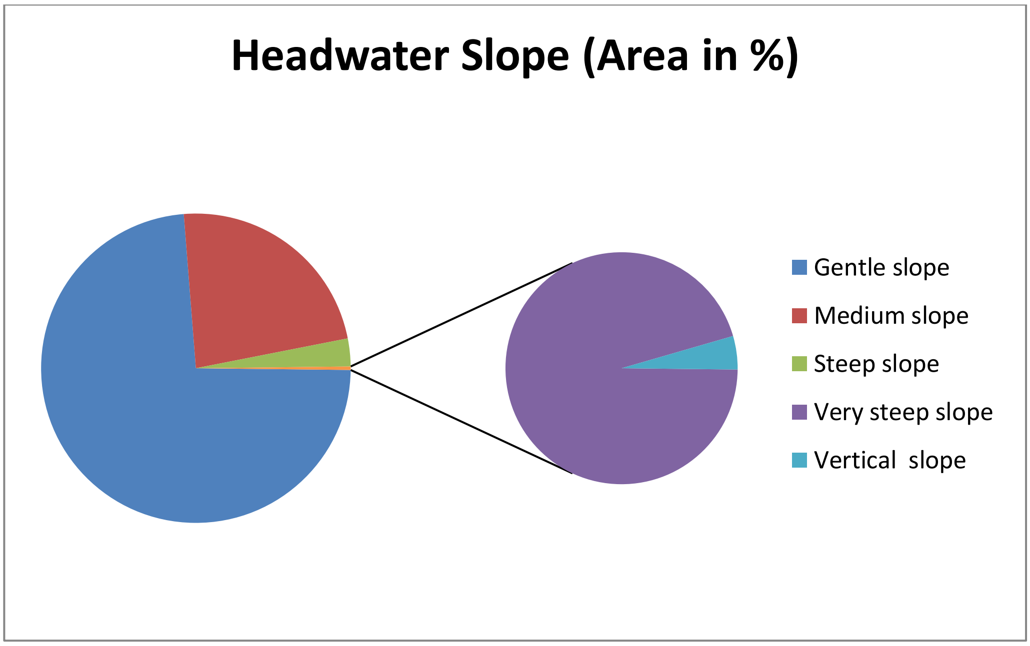


Fig 5.6: Graphical represent of Headwater Catchment Slope in Percentage of Upper Jiadhal Basin.

The headwater catchments are determined by the geomorphology of the region and the concentration varies a wide range, as the region is associated with high mountainous ranges and deep valleys. The slope percentage computed with the help of DEM file shows that the headwater catchment are concentrate mainly in gentle slope comprises 73.57% of 10-20% slope gradient. Moderate (30-40%) slope gradient compiling 23.16% is the associate with middle course of headwater catchment area. 50-60% slope gradient is steep slope comprising 2.91% of the area and very steep slope gradient (70-80%) comprise 0.34% of the area. The headwater area under vertical slope comprises only 0.02% of the total area. In catchment wise Jia headwater has steeper slope followed by Sido, Sika and Siri. The slope gradient has direct relation with stream flow properties including capacity of flow, erosion and degradation. The water supply is mainly rainfed associated with monsoon and local orographic rainfall, the vegetation coverage of the area added the infiltration of mountain aquifer led to perennial springs feeding the stream flow of the headwater catchments. The intensive rainfall due to cloud burst increases the surface runoff resulting mechanical process for intensive soil erosion adding stream load.

GENERAL HYDROLOGY OF HEADWATER CATCHMENTS

The Hydrology of the headwater catchment depends on its environmental situation as well as the geomorphology concerns to climatic condition and vegetation coverage. The vegetative coverage of a headwater determines the water components such as rainfall interception, soil moisture and infiltration rate of the soil to mountain aquifer and spring (Del Campo et al. 2014). The stream hydrology of the headwater catchment of the study area is different from the regular stream of low land or downstream valleys. On the basis of quantity of stream discharge a headwater streams may be categorized as perennial or intermittent and the headwater of jiadhal are composed of both. Hydrology is a structuring force in headwater streams as it influences the riparian vegetation, in stream biota and the biogeochemical processing. In general, headwater stream discharges are greatest during the summer and rainy seasons when local and monsoon regimes prevail and when evapotranspiration is at its lowest. The water quantity is low in the headwater and mainly feeded by natural springs from the mountain aquifers. The important morphometric parameters like average slope, drainage density, trend surface, vegetation coverage and soil characteristics form a set of basic characteristics of different hydro-geomorphologic units.

Rainfall in Headwater Region

The seasonal variation of rainfall in the upper catchment of Jiadhal basin determines the surface runoff of the stream. The July month recorded highest 727 mm in the year 2018 in foothill of Jiadhal river basin and heavy rainfall concentrates the month of April to September with intense cloud burst. Thus the rainfall in headwater region is estimated to be more than 1000 mm. Generally rainfall decreases October onwards, so the surface runoff of the stream decreases too. December is the driest month receiving less than 1 mm monthly rainfall except 2018 recorded of 13.60 mm.

Table 5.9: Rainfall in Jiadhal Basin area during 2015-2018

Years	2015		2016		2017		2018		2019	
Months	Quantity of Rainfall	Average Rainfall	Quantity of Rainfall	Average Rainfall	Quantity of Rainfall	Average Rainfall	Quantity of Rainfall	Average Rainfall	Quantity of Rainfall	Average Rainfall
J	Nil	Nil	Nil	Nil	19.00	0.63	0.00	0.00	28.78	0.96
F	83.90	2.80	34.40	1.15	61.34	2.04	22.90	0.76	52.12	1.74
M	26.57	0.89	6.11	0.20	70.67	2.36	103.80	3.46	86.97	2.90
A	314.35	10.48	248.29	8.28	213.73	7.12	42.70	1.42	246.94	8.23
M	458.82	15.29	138.30	4.61	321.29	10.71	58.80	1.96	247.46	8.25
J	688.22	22.94	255.71	8.52	622.35	20.75	417.00	13.90	392.21	13.07
J	401.85	13.40	669.10	22.30	722.39	24.08	727.13	24.24	546.43	18.21
A	638.53	21.28	178.61	5.95	518.82	17.29	375.68	12.52	546.22	18.21
S	166.60	5.55	166.60	5.55	602.60	20.09	324.01	10.80	353.73	11.79
O	82.55	2.75	82.55	2.75	408.43	13.61	59.69	1.99	143.12	4.77
N	0.00	0.00	0.00	0.00	8.85	0.30	87.69	2.92	18.87	0.63
D	0.65	0.02	0.65	0.02	0.65	0.02	13.60	0.45	24.06	0.80
Total	2862.04	238.50	1780.32	148.36	3570.12	297.51	2233.00	186.08	2686.91	223.91

Source: AWRMI, Basistha, Guwahati-29, Rain-Gauge Station-Dhemaji E&D Office.

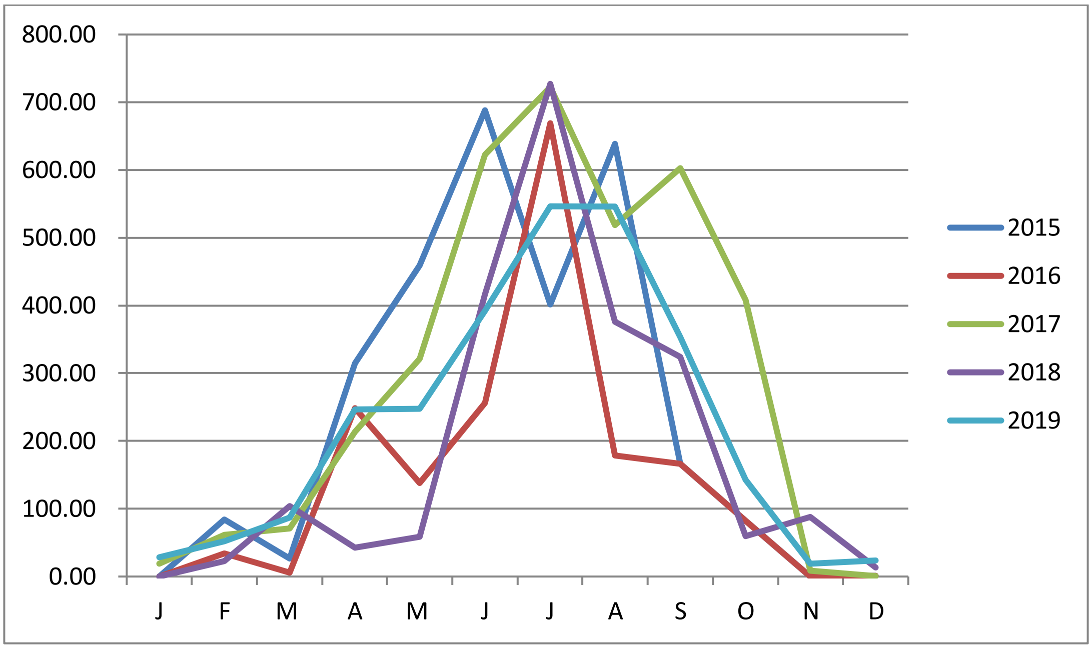


Fig. 5.7: Graphical representation on Rainfall during 2015-2018, Jiadhal river Basin (Rainfall in mm)

The graph reflects that the rainfall intensity is more in the months of June, July and August each year of the observation period. In the year 2017 September and October receives excessive rainfall comparative to early years, which consequent a flood in the lower Jiadhal basin. The duration of rainfall was longer and so the impact would be. The watershed has emerges as the logical unit for managing surface water and on support the management of ground water. The Jiadhal headwater has seasonal variation in water intake and responds variedly in different geographical conditions. One headwater stream of each catchment is taken for observation on the basis of its hydrological properties.

Geometry of upper Jiadhal headwater catchment

The discharge in headwaters regulates the environmental phenomenon of the upper catchment. A estimation of discharge was carried out in selected headwaters in dry season during January and February of 2017, the wet season data is estimated on the basis of the flood marks in the headwater. Sido, Shortcut (138) catchments have high elevation with more vegetative cover in higher ridges. The channel discharges rises to 0.01 m^3/sec in dry and 0.20 m^3/sec in wet season. Its seasonal discharge velocity ranges from is 0.23 m^3/sec to 0.61 m^3/sec in wet season. Sika catchment has highest elevation and considerably has low vegetative cover in higher ridges and the catchment have rough topography with rigid slope of bedrock in lowest depth. The headwater, Taka (178) has elevation range of 500-1200 meters above msl. The channel discharges rises to 0.01m/sec in dry and 0.16 m^3/sec in wet season. Its seasonal discharge velocity ranges from is 0.36 m^3/sec to 0.59 in wet season. Siri has most area occupied by highland; the catchment ranges an elevation of 400-1020 meters above msl.

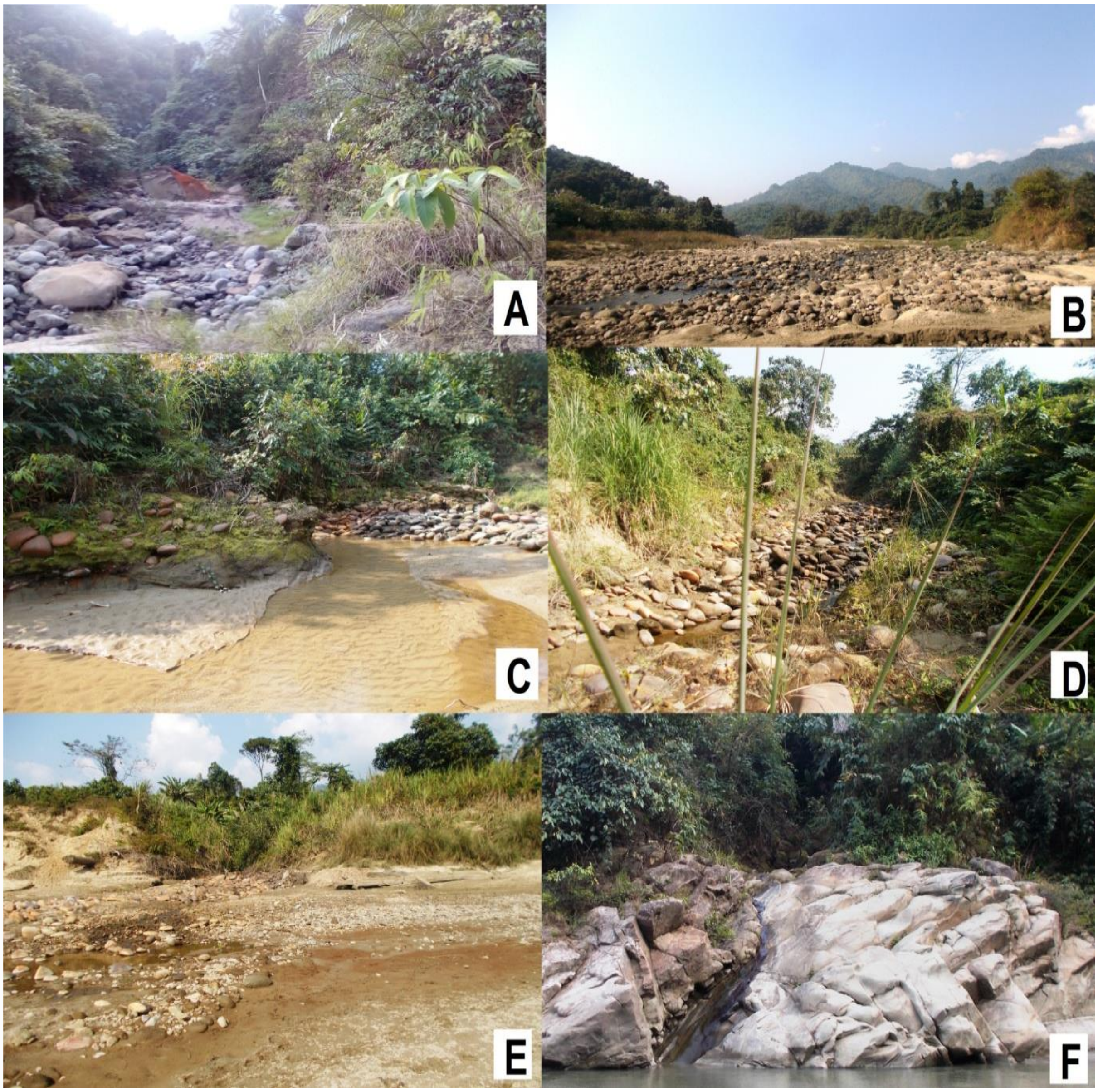


Plate. 5.2: Photographs of headwater in upper Jiadhal basin area; (a) Jia – up ; (b) Sika main stream, (c) Sido near shortcut; (d) Sika up stream; (e) Siri below gorge point and (f) Siri upper course.

Siri, Middle Line (284) is situated in the central part of catchment. The headwater catchment is highly fragile with great sediment source with a lowest discharge of 0.01m^3/sec in dry and 0.17 m^3/sec in wet season. Its seasonal discharge velocity ranges from is 0.22 m^3/sec to 0.65 m^3/sec in wet season. Jia headwater and Gorge point (479) on other hand is having high physiography connected with from high mountainous to low piedmont plains and gorges with an elevation range of 300-740 meters and originate from natural spring and contributes high channel properties to main stream. The headwater has 0.12m^3/sec in dry and 0.28 m^3/sec in wet season with great erosive power as the outlet has massive boulders and free from silt and sand, reflects its power of erosion and transportation. It is resumed that catchment with rich soil depth and vegetation has good discharge then that having less depth soil profile (Rawat, 2011.and Patnaik, 1993).

Table 5.10: Seasonal stream channel geometry of selected headwaters.

Season	Headwater, location, code.	Coordinates	Width (m)	Depth (m)	Area (m)	Discharge (m/sec)	Velocity (m/sec)	Hydraulic Radius (m)
Dry	Sido, Shortcut, 138	27°37"42' N and 94°23"17' E	0.36	0.15	0.05	0.01	0.23	0.08
Wet			0.73	0.45	0.33	0.20	0.61	0.20
Dry	Sika, Taka 178	27°40"42' N and 94°42"22' E	0.23	0.08	0.02	0.01	0.36	0.05
Wet			0.58	0.47	0.27	0.16	0.59	0.18
Dry	Siri, Middle Line, 284	27°65"05' N and 94°47"81'E	0.3	0.1	0.03	0.01	0.22	0.06
Wet			0.53	0.5	0.27	0.17	0.65	0.17
Dry	Jia, Gorge point, 479	27°35"57' N and 94°25"43'E	0.72	0.35	0.25	0.12	0.47	0.18
Wet			7.16	1.1	7.88	5.28	0.67	0.84

Source : Map attribute table and field observation. (January-February, 2017)

The headwater catchments are the genesis of stream flow and its impact are observed in the outlet of the catchment. The headwater contribution is as the outcome of the river course, the water volume, sediment load carried as well as deposited in the river course at the outlet. The water discharge in catchment outlet is the outcome of the headwater catchment. Siri outlet at confluence drained the highest share of water among the three tributaries of Upper Jiadhal Basin. Contributing 141.35 m^3/sec. and estimated to be draining out 3392.47 m^3/day to 51593.82 m^3/year of mean discharge. Followed by Sido outlet contributing 77.67 m^3/sec. of mean discharge draining 1864.18 m^3/day and an estimation of draining a total of 28351.04 m^3/year.

Table 5.11: Mean water discharge of the outlets in Upper Jiadhal Basin

Sl. No.	Headwater Outlets	Water Velocity (m/ sec.)	Water Discharge (m3/ sec.)	Water Discharge (m3/day.)	Water Discharge (m3/year)
1	Sido outlet	0.83	77.67	1864.18	28351.04
2	Sika Outlet	0.80	43.13	1035.22	15743.93
3	Siri Outlet	0.83	141.35	3392.47	51593.82
4	Jiadhal Mukh	0.96	290.75	6977.93	106122.72

Source: Field observations

Sika contributes the lowest, mainly due to smaller catchment area compiling mean discharge of 43.13 m^3/sec. and estimated to drain out 1,035.22 m^3/day and a total of 15,743.93 m^3/year. The confluence of the Sido, Sika and Siri at tri-junction (Tinshuti) projects the Jiadhal to piedmont areas at Jiadhal Mukh. At Jiadhal much the drainage disposes 290.75 m^3/sec. and estimated to be draining out 6,977.93 m^3/day and compute to 1,06,122.72 m^3/year of mean discharge with tedious amount of silt and sand in the extensive flood plain.

MORPHOMETRY OF HEADWATER STREAMS

The mountainous terrain of Jiadhal river basin is characterized by high erosion rate and tremendous river sediment fluxes during the monsoon season. The geomorphology of the upper basin plays an important role in the drainage system prevailing. The river valleys of each catchment is a depression surrounded by the mountains act as an centrifugal characteristic to all kind of water including ground water, surface runoff and rainfall to accumulate and for the stream flow. Morphometric analysis of the drainage basin deals the basin quantitative analysis of the basin to tackle the environmental as well as socio-economic aspects of the basin. Uses of modern techniques like remote sensing and geographic information system (GIS) to study in micro level about the geometry of the drainage basin and provides an insight to drainage and relief characteristics (Das and Mukherjee 2005; Meraj et al. 2015; Sanda et al. 2015 and Youssef et al. 2016).

Headwater Morphometry of Upper Jiadhal Basin

The headwater catchment of the upper Jiadhal basin occupies 144.62 sq.km of area with 503 first order streams and a total perimeter extension of 1158.73 km. The Siri catchment has the highest length if the headwater stream of 2.93 km followed by Sika and Sido catchment with 2.45 km and 2.35 km of stream length respectively. The physiography of the headwater areas represents with maximum elevation of 1460 meters in case of Siri with a average height of 800 meters. The Sika has highest elevation of 1200 meters with a average height of 670 meters. Sido has elevation of 1140 meters of spot height with an average height of 645 meters. On the other hand Jia catchment has a unique physiography with 1120 of highest elevation and 80 meters of lowest elevation extending from the headwater in mountain peak and the piedmont areas.

The ground water depends on the soil properties of the catchment including its texture, composition and profile development. Soil of the region is associated with sandstone and conglomerates accompanied by the structural perimeters of Himalayan mountain system. The structural discontinuity of Himalayan ranges perform as the weak zone of geomorphic hazard prone belt contributing the seeping zone of underground water and even prone to slides. . This structural joints or lineaments are associated with deep gorges or faults contributing huge sediment load to the stream flow composed of different magnitude of rocks, boulders, debris and sand. The morphology of the upper catchment determines the characteristic of the stream discharge, its volume, velocity, streams width and load carrying capacity. The stream channel is fill of large boulders which reflects the river is very turbulent in rainy season; the stream average widths in the middle course is 10 meters and during dry season it shrinks to 1 to 1.5 meters in few locations due to narrow passage and boulders lying obstruct the stream flow to minimum. The stream velocity increases with depth in such location and are free from bed siltation due to high turbulence.

Table 5.12: Headwater Catchment Attributes of Upper Jiadhal Basin

Headwater Perimeters	Jia Catchment				Sido Catchment				Grand Total
	Total	Max	Min	Ave	Total	Max	Min	Ave	
Number of 1st Order Stream	64				169				
Area occupied	14.31	0.96	0.02	0.49	36.75	1.84	0.01	0.93	
Perimeter	122.47	0.88	0.67	0.78	310.57	4.41	0.42	2.42	
Stream Length	30.91	1.85	0.02	0.94	94.06	2.35	0.02	1.19	
Contour Height		1020	80	550		1140	150	645	

Headwater Perimeters	Sika Catchment				Siri Catchment				Grand Total
	Total	Max	Min	Ave	Total	Max	Min	Ave	
Number of 1st Order Stream	77				193				503
Area occupied	18.72	1.52	0.01	0.765	74.84	2.54	0.01	1.275	144.62
Perimeter	145.32	6.03	0.39	3.21	580.37	7.35	0.6	3.975	1158.7
Stream Length	38.61	2.45	0.1	1.275	147.33	2.93	0.01	1.47	310.91
Contour Height		1200	140	670		1460	140	800	

Source: Map attributes table and field observation

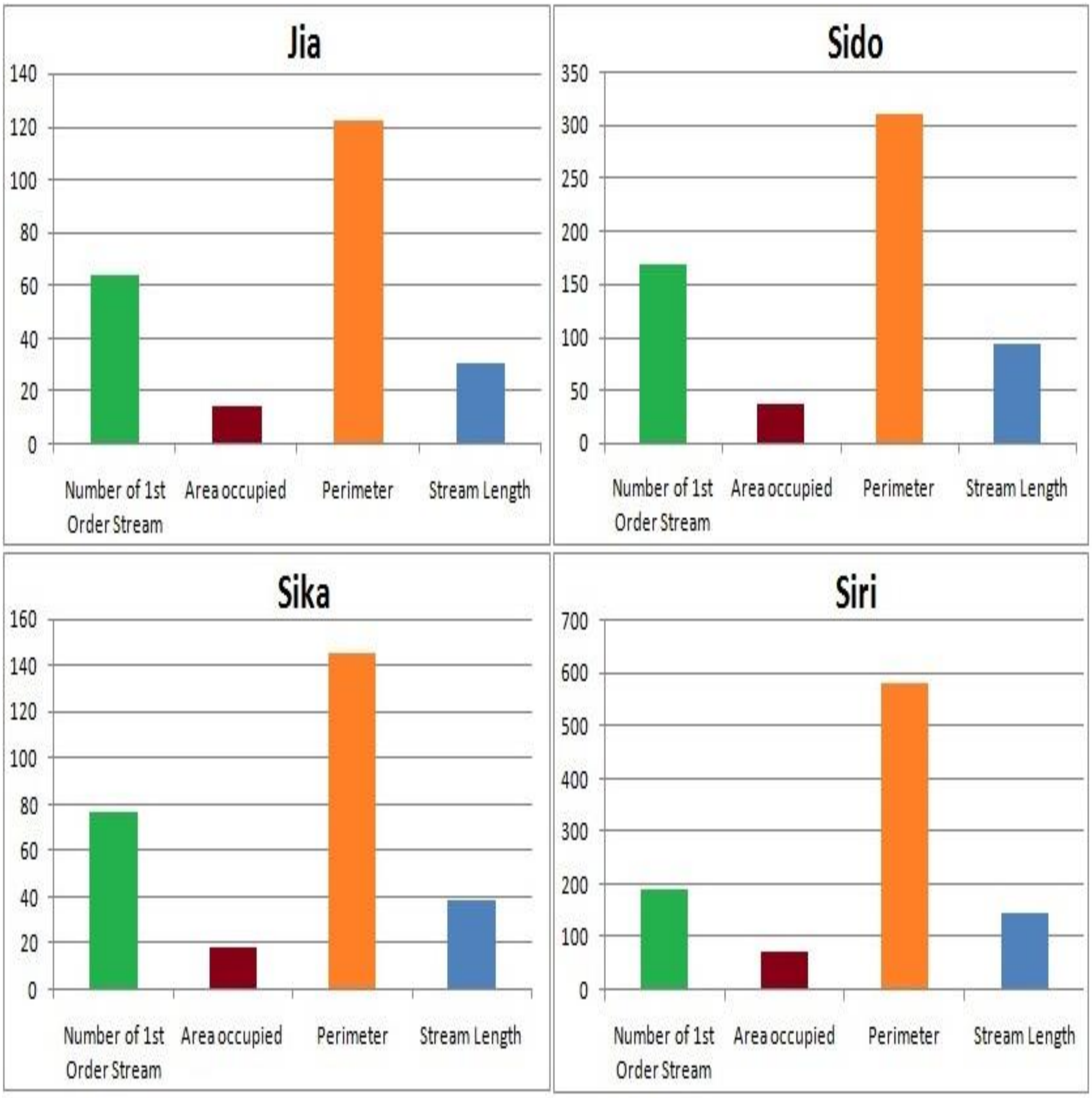


Fig. 5.8: Graphical presentation of headwater perimeters of Upper Jiadhal Basin.

The entire river bed is filled with course to find sand which remains shifting its course due to turbulence and the observation in the field reflects the sand deposit is more in Siri river course then Sido and Sika. Among them Sika has low sand deposit because of is gradient and dominated by rocky bed with 20-30 meters of stream width filled with boulder deposits. The Sika in lower section get divided into two channel due to presence of a hillock and thus its stream width extended to 40 meters whereas its headwater is narrow ranging 2-3 meters of width.

The stream of the first order is represented by the natural springs seeping out from the mountain aquifer and the natural vegetation has direct relation for its existence. The degradation of forest cover due to natural phenomenon like landslide, erosion and even by human induced activities as deforestation in the name of timber work, agro forestry and shifting cultivation in regional basis. The intensity of rainfall is fluctuating due to various geographical factors which led to unequal quantity of rainfall through the year. In summer the cloudburst in the upper catchment is common phenomenon resulting higher amount of precipitation led to increase of surface runoff. The degraded forest and the weaker section of structural fault lines are prone to erosion generative stream load. The land slide and rock slide is common in these fault lines adding sediment to the stream line. As the lithology is composed of sandstone and conglomerates deposits of tertiary and quaternary period the hill slope are highly fragile and prone to erosion. The sediment in the river bed is transported to the lower basin in peak flows increasing flood hazards in the piedmont and the extensive plain of the lower basin. The problem of siltation or sand casting in the river bed in the lower basin reduces the river depth. The shallow river course represents the vulnerable sites of flooding due to overflow of the water discharge in peak season bleaching the river banks and the embankments. The consequence of flood in the lower basin is observed in form of losses of firm land, loss of agricultural field, crops, livestock and even human life and properties.

ENVIRONMENTAL DEGRADATION IN THE HEADWATER CATCHMENTS

The environmental degradation in upper reaches of catchment areas is mainly due to mechanical erosion process dominated by fluvial action. The mountain environment is mostly ruined by the landslide associated with intense rainstorms or other catastrophic events with long return intervals, supplies materials to the fluvial system that may be removed during the intervals between instability events giving a steady-state landscape (Caine, 2004). The intensive rainfall during summer results severe soil loose and the process in upper reaches of the catchment decreases the soil depth. The consequence of it implies the low vegetative growth, reducing vegetative canopy over the fragile lithology of Siwaliks mainly compose of sand stone with structural characteristics. The geological structure and relief topography determines the effect of surface runoff, triggers the soil loose process affecting the forest ecology. The headwater catchment are the high ridges of the basin and are covered with rich vegetation, thus the ground water replenishment is active. Degradation in headwater is active in various forms like sheet erosion, gully erosion; river bank erosion and landslides etc are active in the Jiadhal basin too. (Ghimire, 2013) accompanied along the peak flow of the river system creating environmental hazards in the headwater area and also in the lower basin.

The inaccessibility to the upper Jiadhal Basin is the big hurdle in assessment, thus GIS, satellite imageries, Google earth-Pro, DEM and topographical sheets were used to understand the environmental degradation of the headwater catchments. Field observation in winter is conducted for ground features of the headwater regions. Considering the characteristics of stream flow selection of watershed was done for analysis. The headwaters of Jiadhal river are mainly originated from natural springs and have low flow in winter and maximum went dry, only seepages could be traced in the foothill. The selected streams have water flow throughout the year with high variable range. The rainfall increases the stream flow to peak in summer and reduced to seepage in winter. This phenomenon represents that the stream flow in headwater is very erosive as the river bed is filled with boulders and the upstream with regolith deposits due to intensive slope failure. The Vegetative cover on the other hand plays an important role in slope stability reducing the surface runoff and increasing the possibility of infiltration to enrich mountain aquifers. Ansari (2003) mentioned that the main factor affecting vegetation cover is the soil depth and soil depth is determined by soil erosion. Higher soil erosion leads to a) low percentage of vegetative cover, b) lower species richness of vegetation, c) Lower forest canopy and d) lower soil strength prone to erosion, further rescuing forest ecology (Anderson and Herlocker, 1973).

Discussion: The environmental assessment of the selected headwaters is carried out with online Google earth image and to hey a real picture the year 2012 and 2019 was selected to evaluate the changes. The upper Jiadhal basin is prone to tectonic activities led to fragile topography with weak zones of fault lines associated with drainage system. Thus a local torrential rain causes huge erosion along the fault lines and particularly in Jia, Gorge point and the Sido, Shortcut headwater catchment. The Jia catchment (479), which is an old degraded fault line, has low stream runoff during dry season and the increase in surface runoff in wet season accelerates the erosive power ultimately. During January, 2012 the catchment has fine green tone representing low scrub and grasses in the upper areas which is eroded and exposed to stream flow in November of year 2019. On the other hand the Sido, Shortcut headwater catchment (138), has defined new eroded stream valley during January, 2012 along the stream line and the re-generation of vegetation is observed with more bright tone in exposed soil, reflects that he valley deepening is active and new areas are eroded. This explains the environmental changes in the headwater are not only natural but also anthropogenic in nature mainly due to cutting of trees for timbers and collection of bamboo and cane from the stream sides.

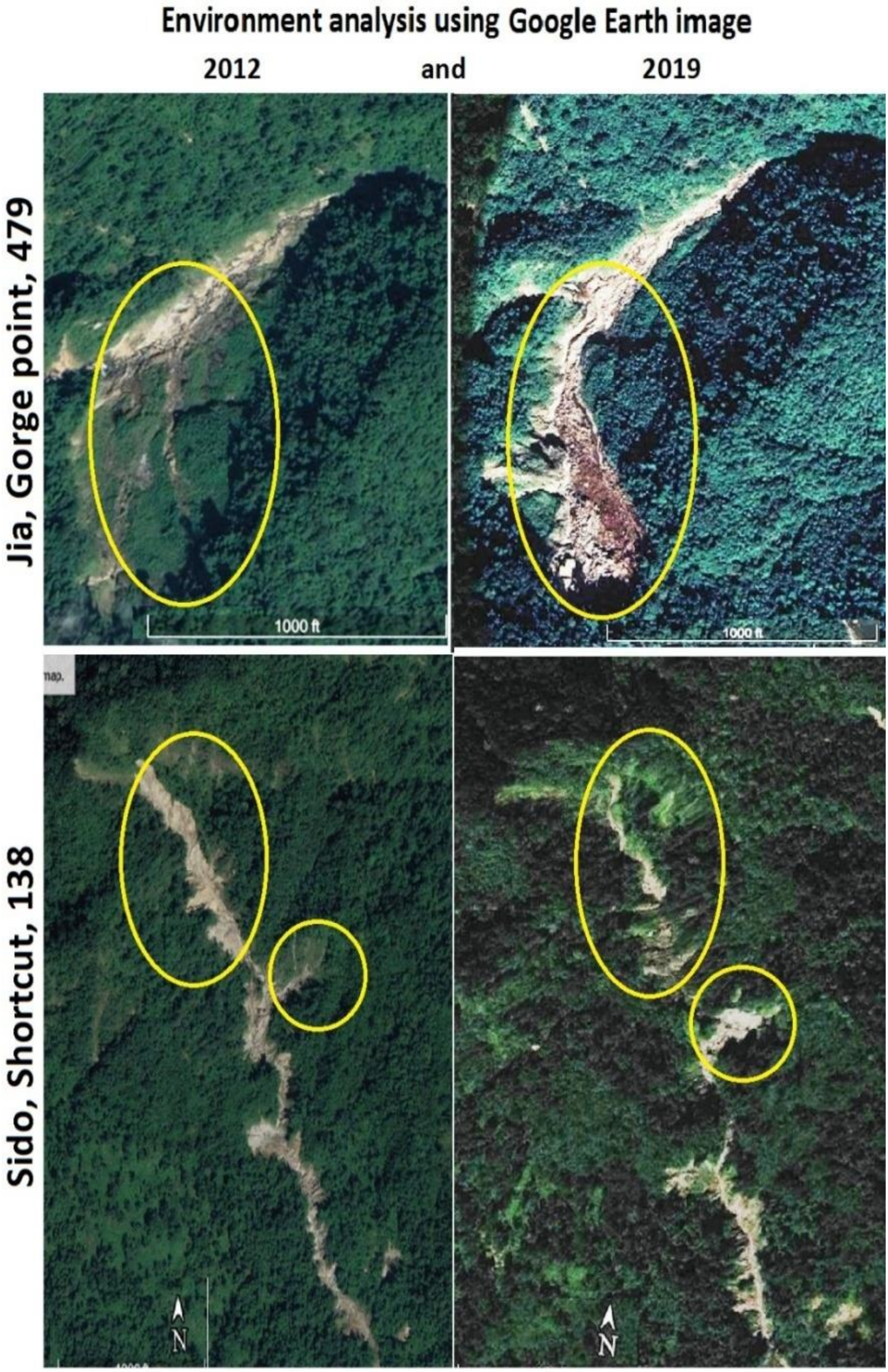


Plate. 5.3: Jia and Sido headwater (Google Earth image of January, 2012 and November, 2019)

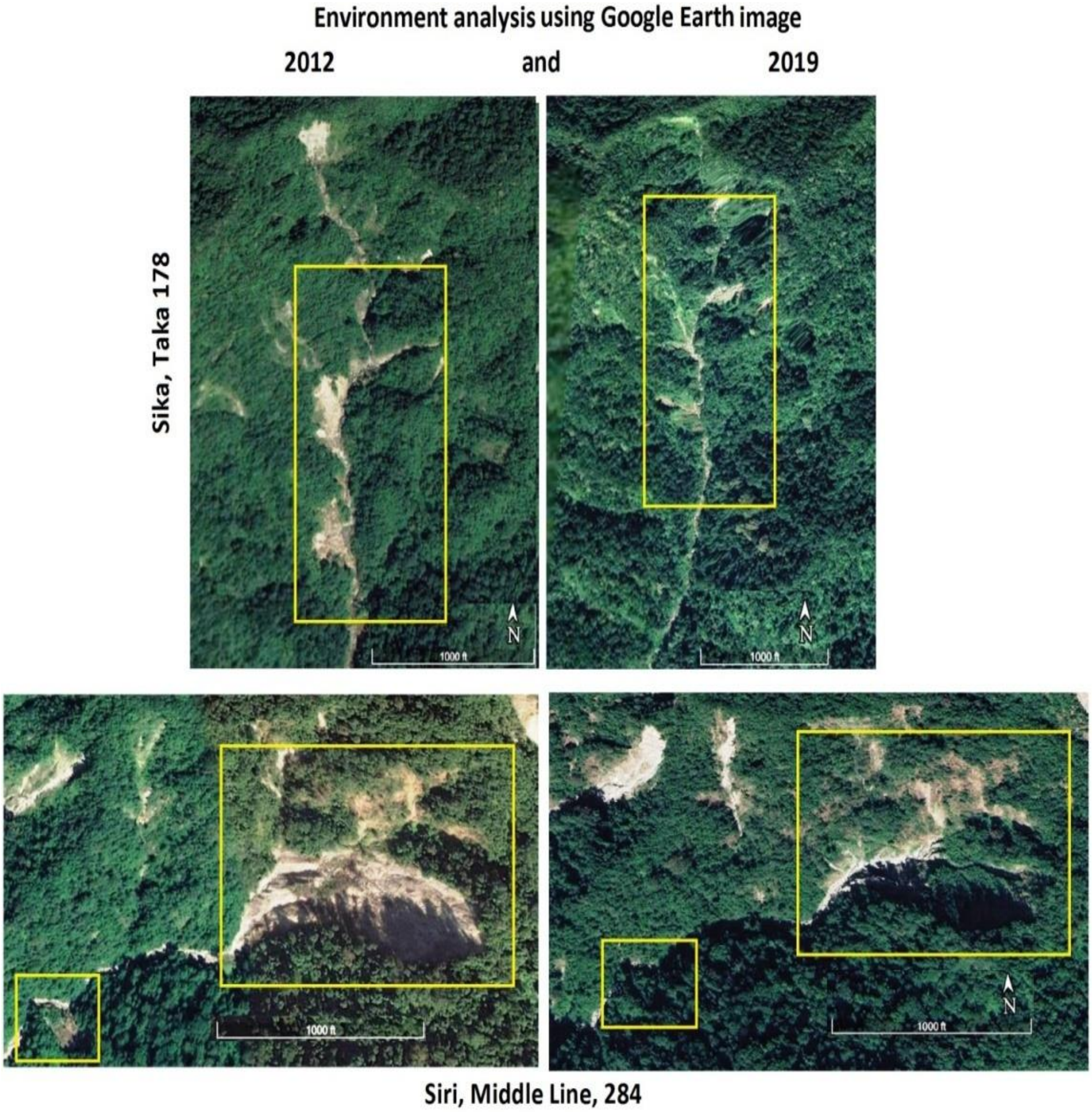


Plate. 5.4: Sika and Siri headwaters (Google Earth image of January, 2012 and November, 2019)

The Sika, Taka headwater catchments (178), is erosive in January 2012 and the catchment rejuvenates the vegetative cover and the reason behind is low larger tree in the river side of the watershed till November 2019. The scar erodes all the top soil and the stream valley is free from fine sediments only boulders lay longitudinally along the stream course with less water discharge in dry season. The Siri, Middle line watershed catchment (284), is explored extensively as the areas is bare exposed in patches which indicate it is human induced degradation and the areas is rejuvenated vegetation till, November, 2019. This indicates the watershed is left untouched during the time span as there was no suitable large size tree left. The natural fault lines are with the bare soil thus it assumed that the flat land has good quality of tree which was cleared up before January 2012.

(a) 

(b) 

Plate. 5.5: Headwater outlet (a) Jia, Gorge point, 479 and (b) Siri, Middle line, 284.

A time span of seven years is not enough to rejuvenate a natural forest cover in jiadhal watershed region and thus it is serious concern to think for the conservation of the headwaters from degradation. The consequence of headwater degradation is visible if we observe the stream deposits in the lower reaches. The Siri, Middle line watershed catchment, 284 and the Jia, Gorge point catchment 479 (Plate. 5.5) has tremendous debris and boulders deposits and in comparison of large boulders it is free from fine sediment and silt deposits. This indicates the headwater peak flow is turbulent and energetic that all fine sediments are discharge to the main stream.

HEADWATERS AND SUSTAINABLE DEVELOPMENT.

The sustainable development of the headwater catchment is the product of a joint process of management of the environmental and geomorphological elements active in the region. The Jiadhal as situated in monsoon climate is receiving intensive rainfall in the summer season on an average of 350 mm annual rainfall (Hazarika, 2015). The topography of the upper basin is mountainous characterized by Siwaliks composition of lithology detonated by sand stone. The structural, fault lines and joints dissect the mountainous region with numerous channels following deep gorges. These structural characteristics of the terrain make it fragile to erosion. The elevated ridges have rich vegetation coverage but the intensive rainfall causes risk to soil degradation. Thus the soil and forest coverage of the headwater catchment plays vital role in its sustainability.

The climate change, deforestation, soil erosion, irregular rainfall, cloud burst and slope failure are the threat for the environmental sustainability of the upper headwater catchments. The rapid deforestation in the headwater catchment of the region leads to shrink in the stream water discharge throughout the year. The seasonal discharge of the headwater reflects that the natural springs and mountain aquifer are in fluctuation and thus headwater stream does not have stream runoff throughout the year. The forest cover is decreasing with alarming rate reducing the water infiltration to mountain aquifers, which lead the stream to be dried up in winters due to less rainfall or direct supply of water. Vegetative cover of the headwater catchment adds water to the ground reducing the surface runoff, the bare soil or rock without vegetation are prone to erosion (Patniak, 1993).

The headwater geomorphic condition determines the sustainability of the water source. The slope failure and soil erosion in the headwater generates sediment load to the stream flow reducing the porous soil and exposing the bed rock to surface. During intense rainfall, these regions allows rapid surface runoff and increases stream load due to wash of the unconsolidated weathered materials downstream. This process results mass wasting affecting the channel slope as well as the channel bed due to deposition of boulders in the course.

Measures for sustainability of headwater catchments includes, measures for reduction of soil erosion, landslide events, regulate surface runoff, reduce stream load, increase infiltration to ground water or mountain aquifer, increase vegetation coverage and to enrich natural springs. Li, Tianchi, (2004) worked on landslide mitigation in China suggest bio-engineering and planting vegetation in the risk prone areas with necessary structural engineering including retaining walls, gabions, spur dikes and removal of debris from the channel bed for regular slow of the stream. Rawat (2011) worked in Nana Kosi (Kumaun Himalaya) watershed suggested that the headwaters needed to be replenished the bare slope and the regolith deposit with local vegetation (scrubs, bushes, fodder plants that grew faster), use of local materials for preparation of check- dams and retaining walls so that the channel bed get clear for regular runoff. The stream bank erosion should be checked by vegetal cover. The role of forest cover in flood control has been reported particularly by higher frequency (lower extremity) rainfalls because of the limited retention capacity in watersheds (Willis, 2002). In contrast, Versini (2013) highlighted impacts of deforestation on the growth of impervious areas and more rapid hydrological responses to rainstorms. Jiadhal upper headwater catchment has the characteristic of rich vegetation enriching the ground water and on another end degraded forest cover threatening the environmental hazards.

The Key Area for Sustainable Development of Headwaters: Headwater degradation is a matter not only concern to environmental geography it has various subjects including meteorology, forestry, agriculture, fisheries, hydrology, geology, landscape ecology, community, business firms, government policies and various Government and Non-Government agencies of both the state of Arunachal Pradesh and Assam. The concept of sustainable plan and strategies needed a serious concern of each stakeholder and thus it would be interdisciplinary and multidimensional programme. The headwater is directly related to hydrology of a river system and related issues like soil erosion, forest degradation, desertification climate change and most dominantly the natural calamities and hazards. The headwater catchments of Upper Jiadhal basin situated in the West Siang district of Arunachal Pradesh and is mostly forested region with less population concentration. Thus in practical it is free from human intervention such as infrastructural development, agricultural activities and major land landscaping. The downstream of Jiadhal flows to extensive low land of Dhemaji district of Assam, which experience worst affect in the form of flood and siltation by the river. Therefore any development plans of the headwater region should involve both the side for the sustainability of entire river basin. Joint venture projects on headwater could solve the problem for all the stakeholders and few sectors to be taken care in such planning are as follows.

1. Increased awareness on the significance of ecosystems goods and services to all stakeholders of the headwaters and downstream
2. Understand and manage of ecosystem services, water resources and biodiversity of headwaters to ensure sustainability
3. Improved understanding and management climate change by increased biomass, biodiversity and bio-economic diversity
4. Improved understanding and management of human impacts on headwaters

5. Empower and use the local communities as key stakeholder in the socio-economic development from the headwater environments
6. Headwater management through innovative land-use practises, structural engineering, hydrological modelling etc.
7. Regenerate degraded fresh water source regions
8. Sustainable water and soil conservation in the headwaters as well as in the downstream areas,
9. Plan formulation and implementation of natural hazard mitigation programme.
10. Evaluation of integrated benefits (downstream impacts), and ecosystem services (especially drinking water supply and flood risks).

Beneficial objectives of headwater management: Headwater conservation and management are to sustain a water budget and environmental balance in the region. Its aim could be listed as (Conserving Carolina.org.),

1. To establish conservation of the fresh water towers and harvesting of clean drinking water,
2. To support healthy environment and encourage forest ecology and diversities,
3. To ensure and restore forest habitat for flora and fauna of the headwater by introducing conservation plans for them,
4. To protect and improve the water quality and quantity by rescuing headwater degradation by nature as well as anthropogenic activities,
5. To support forest-related economic development in local communities to strengthen headwater forest coverage,
6. To ensure slope failure and check the sediment sources for the stream,
7. To ensure and aware each stakeholders, and integrate them to manage for the sustainability of conservation program.

Measures for headwater management: These sectors of headwater development and management could be triggered by interdisciplinary programmes and linking headwater with other schemes and programmes from other stakeholders. Afforestation programmes in the watershed and reduction of desertification in collaboration of community and forest resource and environment ministry would be preferable target. The soil degradation, erosion, landslide which are responsible for sediment load in the stream and watershed should be framed to innovative technologies with forest, agriculture, horticulture departments with collaboration of local communities. Community level participation is necessary for headwater conservation and redirecting the benefit of conservation to income source is a winning strategy. The afforestation in vulnerable region would enrich vegetative cover as well as could benefit economic gain to land owners by simply modifying the species of medicinal and economic values. The cardamom plantation in hill slopes nearer to stream line would solve the soil erosion and increase infiltration to ground water. Converting bare and degraded land into agro forestry could replenish the reverine ecosystem and fulfil the need of forest product of the community as well. Slope failure is the sources of sediment load in the headwater stream and it could be checked with involvement of geological landscaping, forestry and hydrological engineering in micro level, target to stabilise hill slopes and re-generation of mountain aquifer to enrich ground water infiltration.

Headwater failure is directly or indirectly related to slope failure in the catchment area involves stream sediment yield and stream flow magnitudes, forest canopy and subsurface water budget. Thus, slope stability is a major step towards management of headwater sustainability and few measures applicable in Jiadhal river basin are Cook & King (1983), Hutchinson (1977) and White & Franks (1978).

1. **Surface Protection Measures**: The simplest and most effective measure to stabilizing bare soil surface of the headwater is to introduce vegetation or mulches. it stabilize the slope failure and reduce sediment yield to the stream flow. Native plants are preferred most as its development and grow faster in due to favourable environmental factors.
2. **Site analysis**: To ensure re-vegetation of degraded slopes it is necessary to understand the local climate, geology, soil profile and moisture of the area, so that it may be planned and execute in proper way. The selection of plant species in case of imported plants could be possible too by such observations, e.g.- adaptation of bamboo groves, cardamom groves etc.
3. **Contour Walling and filter strips**: To prevent soil creep and mass wasting introduction of walling and filter strip may adopt. Walling of filter strips works to break the slope into short segments so that the velocity of surface slow is reduced, which stabilises the slope and grass coverage helps to water infiltration to groundwater replenishment too. It is more structural landscaping by preparing stares or steps following contour lines associated with vegetation plantation to reduce surface runoff.
4. **Brush Layering**: The brush layering involves laying of tree branches and logs horizontally against the slope to restrict the erosional force over the slope. The accumulation of debris on the obstacles created by horizontal barriers, stabilize the soil creep naturally. Such locally available raw materials uses are termed to be cost effective management too.

5. **Mechanical Treatment**: it is a structural engineering and landscaping techniques adopted to manage slope failure by construction of steps, terraces and small barriers or check dams across sensitive areas. The terraces and check dams regulates the toe losing mechanism of slope and help to re-generate vegetative coverage in the vulnerable areas. Raw material used could be collected locally like boulders, tree logs and bamboo for the construction in headwater region could be economical too.
6. **Engineering and Structural measures**: Construction of structural barriers against vulnerable slope is costly but sustainable measures against slope failure. Retaining walls, piling walls, culverts and bridges etc are most common structural engineering used for slope management. Steel and aluminium binding wire net could be used for boulder staking to reduce the foot loose phenomena in the slope. Concrete retaining wall is applicable in vulnerable drainage side and along roadways.
7. **Bio-mass and bio-netting**: The use of biomass and bio-degradable nets and carpets covering the slope is an innovative method. It increases the slope shear strength and terrain the loose debris to develop vegetative growth, which further supports the slope strength.
8. **Vegetation cover**: Most appropriate measures against slope failure is afforestation, mainly local species over the slope, The vegetation canopy and undergrowth rescues the slope failure if it protect the surface from direst impact from heat as well as rainfall, which also reduces surface runoff and accelerate infiltration. The high colonial species of plants could be used to retain slope failure. The bamboo and cardamom grove plantation in river valleys is a great example.
9. **Habitat conservation**: The headwater are the safest habitat of wild flora and fauna, its degradation act as force to push them to migrate to other region, with more vulnerability. So to ensure wild life habitat, measures taken should be of plantation fruit and flower bearing trees and plants in the upper catchment. Involving local inhabitants for its security and implementation of plan and projects in the headwaters.
10. **Ensure participant involvement**: Each plan and programmes should be an integrated one and a third party should engage to monitor and review the outcome of the conservation plan. Thus the flow of conservation plan prevails to attain the sustainable development of the headwater. Research and investigation should be promoted for evaluation headwater, both before and after the projects implementations.

REFERENCES

Alexander,R. B. Boyer, E.W, Smith, R.A, Moore, R.B (2007): The Role of Headwater Streams in Downstream Water Quality, https://doi.org/10.1111/j.1752-1688.2007.00005.x) (26 January 2007).

Anderson, G. D, and Herlocker, D.J (1973): Soil Factors Affecting the Distribution of the Vegetation Types and Their Utilization by Wild Animals in Ngorongoro Crater, Tanzania, J*ournal of Ecology*, Vol. 61, No. 3 (Nov., 1973), pp. 627-651 (25 pages).

Ansari, A,S (2003): Influence of Forest on Environment,The XII World Forestry Congress, Quebec City, Canada. 1018-B2, http://www.fao.org/3/XII/1018-B2.htm

Ariza, C., Maselli, D. and Kohler, T. (2013): Mountains: Our Life. Our Future. Progress and Prospective on Sustainable Mountain Development from Rio 1992 to Rio 2012 and Beyond. Swiss Agency for Development and Cooperation (SDC), Centre for Development and Environment, Bern, Switzerland.

Cook, M.J., and King, J.G. (1983): Construction cost and erosion control effectiveness of filter windrows on fill slopes. US Dept. of Agriculture Forest Service. Research Note INT-335, Intermountain Foest and Range Experiments Station, Ogden, Utah. 5 p.

COST, (2019): Smart management of headwater catchments, COST, European corporation in Science and Technology, COST Association AISBL, office @ cost.eu, www.cost.eu.

Cushing. C.E, Cummins, K.W. and Minshal,G.W (2006): River and Stream Ecosyatems of the World,: With a New Introduction, University of California Press, pp-832

Das AK, Mukherjee, S. (2005): Drainage morphometry using satellite data and GIS in Raigad district, Maharashtra. J Indian Soc Remote Sens 65:577–586.

Del Compo, A., Fernandes, T. and Molina, A. (2014): Hydrology-oriented(adaptive) Silviculture in semiarid pine plantation: How much can be modified the water cycle through forest management? Eur, J. For. Res., 113:879-894.

Freeman, M. C., Pringle, C. M. & Jackson, C. R. (2007) Hydrologic connectivity and the contribution of stream headwaters to ecological integrity at region scales. J. Am. Water Resour. Assoc. 43, 5–14.

Ghimire, S. K. , Higaki, D. and Bhattarai ,T. P., (2013). Estimation of Soil Erosion Ratesand Eroded Sediment in a Degraded Catchment of the Siwalik Hills, Nepal, *Land* 2013, *2*, 370-391; doi:10.3390/land2030370 (www.mdpi.com/journal/land/)pp-370-391.

Graça, M.A.S.; Ferreira, R.C.F.; Coimbra, C.N.(2001): Litter processing along a stream gradient: The role of invertebrates and decomposers. J. N. Am. Benthol. Soc. 2001, 20, 408–420.

Gorucu, O, (2017): Headwater Catchments : Foundation Pillars for Ecosystem Services. Křeček & Haigh at al, Ecosystem Services of Headwater Catchments https://www.springer.com/gp/book/9783319579450(accessed on 31 August 2019).

Haigh, M. (2010): Headwater control: An agenda for the future. In: Zlatic, M. (ed),Global change: Challenge for soil management. Advance in GeoEcology,41:1-12.

Hazarika, A (2018): An Anthropological Impact Assessment of Flood: A Case Study Of Dhemaji Development Block Assam, PhD Thesis, https://shodhganga.inflibnet.ac.in/handle/10603/288152.

Hewlett, J.D.; Nutter, W.L. (1970): The varying source area of streamflow from upland basins. In Proceedings of the Symposium on Interdisciplinary Aspects of Watershed Management, Bozeman, MT, USA, 3–6 August 1970; ASCE: New York, NY, USA; pp. 65–83.

Hofmann.H, Cartwright, I, Morgenstern, U. (2018):Estimating retention potential of headwater catchment using Tritium time series, Journal of Hydrology Volume 561, June 2018, Pages 557-572.

Hutchinson, J.N. (1977): Assesment of the effectiveness of corrective measures in relation to geological condition and types of slope movement. Bull. Int. Assoc. Eng, Geol.,16,pp 131-155.

Ken, F. and Brent, J., (2011): Headwater system- what are they and what do they do? EPA, Office of Research and Development National Exposure Research Laboratory, Ecological Exposure Research Division. ppp.1-25.

Krecek, J., Haigh, M., Hofer, Th., Kubin, E., Promper, C. (2017): Ecosystem Services of Headwater Catchments, free preview, https://www.springer.com/gp/book/9783319579450 (accessed on 31 August 2019).

Krecek, J., Haigh, M., Hofer, T., Kubin, E. and Promper, C. (2017): Ecosystem Services of Headwater Catchments. Springer Netherlands. [ISBN 978-93-81891-36-0].

Lombi, P., (2015): Shifting cultivation in the foothills-a case study of West Siang district, Arunachal Pradesh, Dutta, C.K. et. al, Biodiversity of North East India, Kiran Prakashan, Dhemaji, ISBN: 9789382746850 pp- 187-198.

Mandych, A. F.(1992): Water Erosion and ediment Yield in Mountain Areas: Natural Preconditions (Krecek and Haigh et al.)pp-148-154.

Meraj, G., Romshoo, S.A., Yousuf, A.R., Altaf, S., and Altaf, F. (2015): Assessing the influence of watershed characteristics on the flood vulnerability of Jhelum basin in Kashmir Himalaya. Nat Hazards 77(1):153–175.

Morley, T.R., Reeve, A.S., Calhoun A.J.K. (2011): The role of headwater wastelands in altering stream flow and chemistry in a Maine, USA catchment. Journal of the American Water Research Association. http://onlinelibrary.wiley.com/doi/: 10.1111/j.1752-1688.2011.00219.x (accessed on 30 August 2019).

Nyssen, J.; Poesen, J.; Deckers, J.(2006): Land degradation and soil and water conservation in tropical highlands, mekelle, ethiopia. *Soil Tillage Res.* 2006, *103*, 197–202.

Patnaik, S. K. (1993) : Hydrogeomorphologic characterization of Sankh head water catchment (Doctoral thesis) Shodhganga @ INFLIBNET/10603/20985 loded on 22-July-2014. pp 113.

Rawat, M.S., (2011): Environmental Geomorphology and Watershed Management. Concept Publishing Company Pvt. Ltd. New Delhi, pp.-1-286.

Rhoads, E. L. & Herricks, E. E. (1996): Naturalization of headwater streams in Illinois. In: River Channel Restoration: Guiding Principles for Sustainable Projects (ed. by A. Brookes & F. D. Shields Jr), 331–367. John Wiley & Sons, Chichester, West Sussex, UK.

Richardson, Douglas; Castree, Noel; Goodchild, Michael F.; Liu, Weidong; Marston, Richard A., eds. (2017). "Landforms & Physiography". International Encyclopedia of Geography, 15 Volume Set: People, the Earth, Environment & Technology. Wiley-Blackwell. pp. 3979–3980. ISBN 978-0470659632. Retrieved 2019-09-06.

Robinson, M and Ward, R.(2017): Hydrology, Principles and processes, IWA Publishing Alliance House, London, p-399.

Sanda. R., Danut P, Loan, F., Luliu V, Sorin, F. (2015): Application of landslide hazard scenarios at annual scale in the Niraj River basin (Transylvania Depression, Romania). Nat Hazards 77(3):1573–1592.

Versin, P.A., Velasco, M., Cabello, A. and Sempere-Torres, D. (2013): Hydrological impact of forest fire and climate change in a Medetarranean basin. Narural Hazards, pp:609-628.

Willis, K.G. (2002): Benefit and costs of forest to water supply and water quantity. coted by Krecek J and Palan L et al. Environmental Services in Mountain Catchment by the Acid Atmospheric Deposition, CPC, pp-169-181.

White, C.A, and Franks, A.L. (1978): Demonstration of erosion and sediment control technology, Lake Tahoe Region of California, State Water Resource Control Board, Final Report. 393 pp.

Youssef, A.M, Sefry, S.A, Pradhan, B and Alfadail, E.A. (2016): Analysis on causes of flash flood in Jeddah city (Kingdom of Saudi Arabia) of 2009 and 2011 using multi-sensor remote sensing data and GIS. Geomat Nat Hazards Risk 7(3):1018–1042.

CHAPTER-6

INTEGRATED WATERSHED MANAGEMENT AND PROSPECTS OF SUSTAINABLE DEVELOPMENT

INTRODUCTION

A watershed is a topographically delineated area that is drained by a stream system; it is also a hydrological unit, a biophysical unit and a holistic ecosystem in terms of the materials, energy, and information that flow through it (Wang, 2016). Watershed management is a continuous process involving the management of natural as well as social aspects of a geographical unit. The interaction of human over the natural environment is the main force behind these innovative concepts of natural resource management. Integrated Watershed Management is one of the products of the man-nature relationship. The watershed management is the consequences of the continuous observation and empirical analysis of the natural phenomenon occurring in a geographical unit in spite of the diversities in respect of the environmental geomorphology, integrated watershed management builds upon the foundational principles of watershed management to integrate various social, technical and institutional dimensions, as well as conservation, social and economic objectives (German, 2007).

The research works conducted to understand the integrated watersheds management to highlight its fundamental functionaries and issues in respect of the study area and to propose the integrated management strategy for study area for the sustainable development. Water is an important and integral part of the watershed including human and agriculture activities. Therefore, management of water is necessary for the well-being of the watershed. The development of the watershed depends upon the productive use of the natural resources comprising soil, water, forest, ecosystem etc. to get more yields and better income and employment opportunities. The watershed development is an integrated part of the development of the region in respect of biodiversity, natural-environment as well as the socio-economy of the region. The basic idea over the management is to deal with the problems occur in the area whether it may be uncertainty and uneven rainfall over the year and uneven availability of sufficient water resources all over the region. The impact of the running water over the watershed may varies with the intensity and geomorphology of the region causing different magnitude of consequences of positive to negative impacts. Watershed development means, incorporates the ultimate or optimal use of land, water, plants and animals as well as conservation of natural resources within the geographical unit by human being. Watershed management tries to maintain the balance between the natural resources on the one hand and human being on the other with a concerned plan to cope with the diversities within. It includes the natural calamities, land use/ land cover, landslides, soil erosion as well as agricultural output, which also provides a wider range of allied activities like horticulture, sericulture, dairy, fisheries and agroforestry which owes the economy of the region. Integrated watershed management triggers to curve an integrated plan to sustain and enhance watershed functions that provide the goods, services and values desired by the community affected by a watershed boundary (Rawat, 2014). The management is complex, including components within the watershed (e.g., upstream, midstream, downstream) and even beyond involving human and natural sectors.

INTEGRATED WATERSHED MANAGEMENT PROGRAMME (IWMP):

The Integrated Watershed Management Programme aims the prevention of soil erosion, regeneration of vegetation cover, implementation of rain water harvesting and recharging of ground water table. The integrated watershed management program includes all government agencies under one common programme to address all these problems and improve the quality of environment as well as socio-economy of the region. IWMP was launched in the year 2009-10 with the objective of introduce a area based integrated plan including Integrated Wastelands Development Programme (IWDP), Desert Development Programme (DDP) and Drought Prone Areas Programme (DDAP) Hanumantha Rao (1994), in one umbrella. Other schemes under it include Integrated Wastelands Development Programme (IWDP) and the National Watershed Development Project for Rain fed Areas (NWDPRA) under 'Hariyali Guidelines'. The environment and human development were brought together for sustainable development planning during 2006 by the National Rain fed Area Authority. For sustainable development various aspects were identified including watershed development, soil & water conservation and efficient water management (WBDC, 2015). United Nations Convention to Combat Desertification (UNCCD). (2-13 September, 2019, New Delhi): Indian Prime Minister Mr. Narendra Modi addressed the high level segment of UNCCD COP-14 for undertaking water conservation activities to 'Restore land to Sustain Life' the conation of the convention. The major highlights are to improve the lives of the populations affected by desertification and land degradation and to improve the affected ecosystems, to mitigate the effects of drought and to mobilize sufficient resources to achieve the Sustainable Development Goals to be achieved during 2018-2030.

Objectives of Watershed Management:

According to Gunasekaran (2014) and Alagundagi, (2018) the objectives of an ideal watershed management are as follows -

1) Balanced use of natural resources and livelihood by watershed approach and efficient watershed management by mobilizing social capital. 2) Target to regeneration of degraded forest land through afforestation , horticulture and agro-forestry, 3) To improve land capacity and site conditions through proper watershed plan, 4) Restoring ecological balance by harnessing, conservation and developing natural resources, 5) Resource development usage will be planned to promote farming and allied activities, to promote local livelihoods, to ensure resource conservation and regeneration, 6) Increasing income-generating activities in the rural areas, 7) Creating sustainable water resources and to have sustainable source of income for the rural community by conserving water. 8) Promotion of people's participation in all the stages of the watershed development activities, 9) Establish and manage inter disciplinary plan and projects involving each stakeholders of the watershed, 10) Promoting over all development of rural areas and its sustainability.

Activities Undertaken under IMPS:

Few essential activities in integrated watershed management programme includes, 1). Soil and moisture conservation like terracing, bunding, trenching, vegetative barriers and drainage line treatment, 2) Planning of different kinds of plants pasture development, 3) Increasing and regenerating non-forest and degraded land, 4) Promoting agro-forestry and horticulture, 5) Fuel wood and fodder conservation, 6) Creating awareness and training extensions, 7) Encouraging people's participation through community organization, 8) Capacity building, 9) Development of water harvesting structure, 10) Development and conservation of common property.

Expected Outcomes of the IWMP:

Reduction of Soil Erosion: The environmental stability as well as socio-economy of the geographical region would sustain by reduction of soil erosion. Measures included structural engineering's as, Check Dam, Gully Plug, and intelligent landscaping by Contour Bund, Bori Bund, and Afforestation etc. Enriches Ground Water Level: Environmental planning in regards to watershed, agriculture and hydrology generation benefits the of ground water level and reduces degradation processes.. Measures undertaken to, headwater management, afforestation rejuvenate degraded land etc.

Control Surface Water and Stream Flow: Stream flow and surface water management reduce the venerability of slope failures, bleaching, flood and water logging. Measures undertaken are retaining wall, porcupine, spours and embankments.

Surface Water Runoff Reduction: The afforestation and agricultural measures influence the top soil erosion and improves infiltration of water to aquifers. Measures include agricultural management like contour, mix farming and multiple cropping etc.
Crop Diversification, Cropping Intensity, Change in Land Use Pattern and Agricultural Productivity: This has been one of the major objectives to develop the ecology while offering sustainable livelihood opportunities to the relevant communities. Multiple options like agriculture, fisheries, horticulture, sericulture and animal husbandry etc. are projected to improve the productivity and stabilize the socio-economy too.
Increase in employment and reduction in migration: The project resulted in an increase in local employment for marginalized communities and this further resulted in reduced migration to other areas for employment. Poverty alleviation and improved standard of living: With regular income generated through direct and indirect involvement in the project. Alternate occupational opportunity apart from agriculture is providing scope to livelihood. Measures adopted are food security, women empowerment, entrepreneurship development etc. which activities not only support the poor but also improved standard of living.

Governments Initiatives in Jiadhal River Basin

The Jiadhal River basin have divergent physiography and topography which affect the plan preparation, thus its sustainability could be maintain with different plans and projects for each areas 'The Upper Basin and the Lower Basin'. The upper basin is dominated by mountainous terrain and needs a serious concern to water, land, soil and forest conservation including landslide, surface runoff, deforestation, desertification and social benefit to ensure sustainability. Whereas the lower Jiadhal basin is an extensive low flat land except the foothill region in the northern belt. The major concern of IMPS in lower basin would be the flood control measures, rainwater harvesting, landscaping, irrigation, agriculture, horticulture and socio-economic benefit of the inhabitants. Thus vast stakeholders are involved in the entire watershed and each should be involved for a sustainable integrated watershed management plan some of the programmes are described as follows -.

I. Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREG): The MGNREGA, 2005 guaranteed 100 days of work for the unskilled rural population under government development plans. This programme provides employment opportunities to those people who demand for employment. The integration of two schemes provide ample scope for IMPS as the watershed works like soil and water resource conservation were taken up under this MGNREGA. Activities undertaken under the MGNREGA with collaboration of IWMP in the Jiadhal River basin are as follows:

- Water Harvesting
- Soil Conservation
- Irrigation
- Flood Protection
- Afforestation and
- Plantation, etc.

II. Rashtriya Krishi Vikas Yojana (RKVY): This programme was launched in the RKVY, 11th plan (2007-08) against a backdrop of faltering. To spur growth in the agriculture and allied activities, and preparation of the agriculture plans for the districts and the states based on agro-climatic conditions as well as availability of technology and natural resources and their activities are mixed with the IMPS as, Structural measures for water harvesting structure such as check dams, nala bunds, ponds, tanks etc, Entrepreneurship development through agriculture and allied activities, Innovative agricultural measures for rainwater management through bunding, counter bunding, trenching, land leveling, mulching etc.

III. Assam Agricultural Competitiveness Project: A World Bank aided project was started in the year 2005-2015 in order to increase the productivity and stimulate the agricultural economy of Assam through providing market access to the targeted farmers and community people (Borthakur, 1998). Reviver report by Oblitas (2016) in Implementation Completion Report (ICR), highlighted that sectors for activities include Rural and Urban Roads and Highways (60%), general agriculture, fishing and forestry (11%), irrigation and drainage (10%), agricultural extension and research (10%), agro-industry, marketing and trade (9%) of total USD276,830,000. The productivity is increasing with major gain in paddy, mustard, cauliflower and cabbage, and on the other hand there is five-fold increases is observed in milk and fish production.

IV. National Afforestation Programme (NAP): Ministry of Environment and Forest (MoEF) during the ninth five year plan sponsored four central schemes namely, Integrated Afforestation and Eco-Development Project, AOFFPS, NTFPS and ASTRPS. To restore regeneration of the degraded forest by afforestation and encourage ecological security to meet the fuel wood, fodder and other needs of the rural population. It target mass involvement of rural population to upgrade forest cover of the country by various schemes of funding, awareness and training etc.

V. Van Dhan Scheme: The Van Dhan Scheme initiated in 14th April, 2018 by Ministry of Tribal Affairs and the Tribal Cooperative Marketing Development Federation of India (TRIFED) to improve tribal population income through value addition of forest products and their popularity. Targeted to encourage indigenous technologies of forest conservation in modern innovation of resource development including tamarind, mahua flower, mahua seed, hill broom, chironjee, honey, sal seed, sal leaves, bamboo split, myrobalan, mango, aonla, tez patta, cardamom, black pepper, turmeric, dry ginger, cinnamon, coffee, tea etc.

VI. Green Skill Development Programme (GSDP): The ministry of Environment, Forest and Climate Change, Government of India planned a vocational training programme focus on mechanical/technical skill rather than ‘soft’ or ‘green’ skills with conation “Green Skill India-Save Environment Today for Better Tomorrow”. Green Skill contributes to preserving or restoring environment quality for sustainable future and increase enhance generate employability in protection of ecosystem, biodiversity for sustainable development by 2021.

VII. Assam State Disaster Management Authority (ASDMA): Disaster Management Act 2005 provides that there shall be a Disaster Management Plan for every state. Units of State level disaster management force, authority are responding regularly for the awareness, training and preparedness of the common citizen of the region. Also performs for the implementation and emergency operations for rescue and rehabilitation in natural as well as artificial deserters. District level units are developed with combination of both government and non-government organizations for the wide spread of programmes.

RIVER BASIN AS A GEOGRAPHICAL UNIT FOR SUSTAINABLE DEVELOPMENT:

A River Basin is often termed as watershed, represents a geographical region or an area that is drained by a drainage system comprising numerous smaller upstream catchments and having a common outlet. Watershed being a natural hydrological unit, it responds most effectively to various engineering, biological and cultural treatments (Satapathy, 2003). The terrestrial surface runoff of the catchment as well as the underground water of the basin is characterized to have a particular accumulation and flow directions. River basin is thus become a spatial unit with a homogeneous ecological identity triggered by the topography, geomorphology, geology, environment conditions including climatic elements, vegetation, natural resources and environmental hazards. A Basin is an integrated feature for the phenomenon prevailing in the region and thus could consider being a suitable area for implementation of development plans as well as environmental conservation for sustainable development (Strahler, 1964). A river basin is unique geo-physical unit which has a distinct hydrological characteristics including precipitation which influence land use activities that affect climate, landforms, soil and vegetation which impact on natural distribution of water within the region. Apart from the natural phenomenon occurring in the region the human intervention is the greatest element beside the alternation occurred in the river basin. As human activities such as deforestation, construction works and landscaping, urbanization and agricultural practices, can alter the slope of land and channel form; pave over or compact soils; remove vegetation; and have many other effects accelerating the natural processes of denudation. This elements and disturbances in the nature triggers phenomenon like soil erosion, landslide, mass-wasting and leads to major issues related to flood in foothill plains. Environment impacts may also have a direct or indirect cost for different sectors of the economy, including tourism and services generated by biodiversity include climate change, global warming, loss of biodiversity, impaired energy cycles, food crisis etc. and (Hassan, 2013). River basin is thus a development unit in which all the natural resources like vegetative coverage, soil, water, geomorphology and land use, and socio-economy are in harmony there by facilitating adoption of holistic approach to problem solving. It is considered to be the ideal unit for analysis and management of natural resources planning for sustainable development (Steiner, 2000).

The Integrated River Basin Management (IRBM) focused on developing the basins water for all the different users, both upstream and downstream, including the environment itself as well as the different drivers of change. It acknowledges the nexus between water, energy, food, and ecosystem issues, and helps to develop a better understanding of upstream-downstream linkages as well as the linkages between natural resources management and sustainable livelihoods. At the river basin level, there are strong linkages between upstream activities and processes, downstream water availability, geomorphology, and dependent ecosystems - a dam built upstream to provide drinking and irrigation water may result in loss of fishermen’s livelihoods downstream or of silt to fertilize fields. Riskless clearance of land for farming without measures focused on water retention may result in reduced infiltration, increase risk of flooding, and drying of the springs that provide drinking water in the watershed. The integrated nature of water resources is inherent in a river basin. The changing pattern of provision and needs in both the natural world and human society as a river wends its way from source to sea epitomize the concept of connectivity, continuity, and change. The soil, vegetation and water are the basic resources of a drainage basin, and could be managed collectively and in an integrated way for the sustainable development of the entire basin. The hydrology-geomorphology of the basin triggers elements like terrain, slope gradient and nature of soil cover, land use-land cover, climate, socio-economic and legal aspects etc. which controls the natural phenomenon active in the region.

Environmental problems in Upper and Lower Jiadhal Basin

The environmental problems are mainly related to the natural phenomenon prevailing in the earth surface including weathering, soil erosion, mass-wasting as well as the sand and silt deposition or siltation. The Upper Jiadhal Basin is mountainous region with structural differences and highly dissected topography pronounced in literal erosional activities mainly fluvial in action. The rate of denudation i.e. weathering , soil-erosion as well as mass-wasting is more due to various factors like steepness of the slope, undulating terrain, physiography, vegetative coverage, climatic condition, surface runoff and human intervention too (Table 6.1).

Table 6.1 : Factors controlling the environmental geomorphology of Upper Jiadhal river basin

Climatic factors	Temperature	Jiadhal basin temperature varies from 11-24 ^{o}C in winter and 15-37 ^{o}C in summer, high temperature increase the rate of endothermic chemical reaction lading exfoliation -weathering
	Precipitation	It receives an annual rainfall of 250 to 350 cm with intensive precipitation above 1000 cm during rainy season, high precipitation increases the availability of surface runoff – high surface runoff- higher the soil erosion
Biotic factors	Vegetation cover	A dense forest canopy protects the soil from direct impact of running water to be washed. Vegetation consumes surface runoff to infiltrate into ground water replenishment which reduces the velocity of surface flow.

Geomorphic factors	Land surface stability	Slope characteristics the upper basin including steepness, composition, structural and sear strength also responsible for the intensity of weathering and soil erosion. Slope instability and the faulting are the sediment source areas in the basin.
Geological factors	Rock types	Upper course is composed of fragile rock due to presence of thrust and joints of Himalayan structures which determines the state of its stability, rock hardness and sear strength varies with stability of the slope. Dominating rock types are sandstone, gneiss, dolomite and conglomerates.
	Rock texture	Rock texture implies the sear strength of the rocks. The composition –structural characteristics of the rock layer. e.g. conglomerates are imperceptibly bonded and prone to erosion
	Rock feasibility	Gneiss and sandstone is the main composition with frequent structural properties like fault, joint, fracture, grain boundaries promote weathering penetration especially in crystalline rocks
	Climatic change	Variation of climate and vegetation with time to time affects the balance of weathering and erosion.
	Tectonic change	The study area is situated in Earthquake Zone-V, affects land surface stability- and the period availability of weathering penetration.
Anthropogenic factor	Deforestation	Deforestation by agro-forestry, lumbering, agricultural land use, and ill use of natural space creates weaker zones for easy access to erosion and mass-wasting.

Source: after Boruah, 2000

.

The most important elements of geomorphological hazard in the upper Jiadhal basin is the anthropogenic activities. The magnitude is less as the hilly track is inaccessible throughout the year and because of very less population living there. But the effect of the human intervention is today only in a stage of hazard and if not checked thoroughly it could be a disaster in near future. The main human activity in the upper course of Jiadhal river basin is deforestation in the name of forest product collection, agriculture, lumbering and soil erosion (Table 6.2).

Plate. 6.1: Deforestation due to lumbering activities in river sides

The tribes of Arunachal Pradesh are very thinly populated in the upper basin of the Jiadhal river which have comparatively less influenced in the area such as clearance of forest for jhumming or shifting cultivation. But the practice of agro-forestry and collection of forest product are the traditional activities of the tribes and did affect the biodiversity as well as the environment issues like soil erosion. The lumbering activity is widely practiced in the upper Jiadhal basin both legally and illegally. The indigenous people have the right to their land or territories and how to develop the resources according to their needs, UNDRIP (Article 32(i)) explored their native land or forest, for domestic and community uses, but today the industrialization influenced for large scale lumbering ruining the forest sustainability. This practice of lumbering degrade the forest ecology and the genesis of various environmental issues including the hazards to soil and slope stability. The upper Jiadhal Basin is a hilly terrain and concerned to the environmental degradation due to human intervention. The human activities like clearance of forest coverage in respect of timber business or for farming as jhumming; the top soil is exposed to agents of degradation mainly due to the running water. The surface running water acts for the disintegration of the surface material and transportation of the same loosened and disintegrated materials downstream flowed. This is the genesis of the sediment loads of the Jiadhal river system. The unproductive and unstable hill slope and slope failures are is responsible for the increasing sediment load of the jiadhal river system in the rainy season. The hill slope is weakened by the geological factors of the terrain and due to the effect of deforestation made by humans.

Table 6.2 : Agriculture - Lumbering and soil erosion calendar (after Rambabu et.el. 1978)

Months	Agricultural Activities	Lumbering	Erosion Problem
January	Jungle cutting	Jungle cutting and logging to river sides	Displacement and loss of soil material
February	Burning	as above	as above
March	Clearing of hill slopes or jhum land	Transportation to downstream with first rain through the rivers	Down hill & scatting - movement of debris
April	Clearing continuous showing begin	Transportation through the river to downstream	Soil erosion as above wash due to rain
May	Showing and weeding	as above	Heavy soil wash with sheet and overland flow
June	Weeding	end-	Heavy soil wash
July	Weeding		as above
August	Occasional weeding	-	Crops root exposed
September	Harvesting		Mass appear soil erosion slow down
October	Harvesting		Soil erosion very much reduced
November	Fallow	Approach to upstream	Slow erosion
December	Fallow	Jungle cutting and logging to river sides	Displacement of lose of soil material

WATERSHED AND SUB-WATERSHEDS IN THE JIADHAL RIVER BASIN

The environmental sustainability of watershed is possible only through an integral management processes in consideration of all the factors dominating the watershed. The geomorphological phenomenon determines the characteristics of the watershed and is an important element in environmental geomorphology and watershed management programmes. Watershed management involves protection of land against all forms of degradation, restoration of degraded land, sediment flow control, pollutants control, and prevention of floods, etc.

(Speed, 2016). The Jiadhal Basin area has vast heterogeneity regarding the geomorphological characteristics of the watersheds or the sub-watersheds of the basin. There is a big difference in terms of environmental geomorphology of the Upper basin and the Lower Jiadhal Basin. The silent features of environmental geomorphology and basin characteristics are briefly described as follows -

The Upper Jiadhal Basin is occupied by the rough and lofty mountain ranges with deep down cut valleys with different magnitude of landforms associated with the dynamic fluvial action of a river system during the youth stage of its life span. The rivers are mainly rainfed and the water is naturally occur from springs which are prone to dried up during winters. The rainfall intensity determines the perennial flow, as the rainfall in summer and monsoon season is more. Thus the river system is activated in the upper basin even by a small surface runoff. The unavailability of rain water in winters reduces the stream flow to null in many initial streams in the headwater catchments of the basin. The irregular stream flow of the headwater is responsible for the high degradation in the headwater areas and the upper catchment in comparison to the lower basin areas. The Upper basin is accompanied by four sub-watersheds and dominated by dense forest cover with less human interference in respect of human habitation but other human activities are prevailing to degrade the environmental geomorphology of the watersheds. The table.6.2 below illustrates the environmental as well as geomorphological characteristics of the watersheds and the aspects of management plan to be implemented for the sustainable development of the region. The major concern in the upper basin is the topography and difficult accessibility to upper reaches, as there is no transport facility. Only manual tracking along the river in winter season is the mode of transportation. Therefore the upper reaches are settlement free from human habitation and the agroforestry and lumbering activities are practiced extensively in accessible areas. Apart from the geological and geomorphological characteristics of the basin the deforestation is the prime concern led to issues regarding the activation of sediment source areas, massive landslides, soil erosion, slope failures and subsequent sediment loads in the river which is the cause of frequent floods in the lower basin. The region receives heavy rainfall during summer and cloud burst is common phenomenon, increasing the river flow during rainy season, and in dry season the water level reduces to nominal. The range of water level is extreme which ranges 15-16 meters of height as the recorded data of the Water Resource Department of Dhemaji, Assam.

The management of sub-watershed in upper Jiadhal basin is mainly influenced by the physiography and land use and land cover (Table 6.3). The largest sub-watershed is Siri with 176 sq.km of aerial extension and the altitude ranges from 100-1400 and above covering 47% of the Upper Jiadhal basin area. The catchment mainly composite of 5% piedmont, 37% highlands, 41% mountainous, 15% high mountainous and 2% Peak with 42% dense forest cover and 57% degraded forest cover which is mainly due to anthropogenic activities. The degraded forest cover are the main sediment source region porn to loose of top soil due to erosion, land slide and footloose phenomenon.

Table 6.3: The Geographic characteristics and Watershed Management attributes of the Sub Watersheds of the Upper Jiadhal Basin

Name of the Sub-Watershed	Area in Sq. km	Environmental aspects	Physiography in Percentage	Area in %	Landuse and land cover	Range of Altitude (m)	Aspects of Management planning
Sido	111	High Intensity rainfall, Cloud Burst, Deforestation, Landslide, Soil erosion, Sediment source region, exposed river slopes	Piedmont (5), Highlands (35) Mountainous (42), High Mountainous(17)	30	Dense Forest-69, Degraded Forest-30,	60-1000	Slope reclamation measures, Afforestation in degraded areas, Agro-forestry
Sika	49		Piedmont (4), Highlands (11) Mountainous (46), High Mountainous(36), Peak (3)	13	Dense Forest-69, Degraded Forest-31, Bare exposed-1.	60-1400	Engineering structure to retain foot loose of slopes, Headwater treatment
Siri	176		Piedmont (5), Highlands (37) Mountainous (41), High Mountainous(15),	47	Dense Forest-42, Degraded Forest-57,	100-1400	Headwater treatment, Slope reclamation, afforestation in degraded areas,

			Peak (2)				Agro-forestry, Horticulture, check dams to control sediment supply
Jia	35		Piedmont (29), Highlands (36) Mountainous (27), High Mountainous(8)	9	Dense Forest-20, Degraded Forest-59, Sand-Silt-2, Rural Dev-1, Fallow Land-6, Net Sown-9, Wetland-1 and Waterbody-1.	50-900	Slope reclamation measures, Afforestation in degraded areas, Geo-netting of exposed slope

The measures recommended are Headwater treatment, Slope reclamation, afforestation in degraded areas, Agro-forestry, Horticulture, check dams to control sediment supply as it is the highest sediment source of the river system. The second largest sub-watershed is Sido with 111 sq.km 30% of the upper Jiadhal watershed. It consist piedmont (5%), highlands (35%) mountainous (42%) and high mountainous (17%) with 69% of area covered by dense forest and rest 30% is degraded forest. Slope reclamation measures, afforestation in degraded areas, agro-forestry are some suitable measures for the Sido sub-watershed. Follower by Sika sub-watershed with 49 sq.km and is only 13% of the upper Jiadhal watershed. It has occupied by 36% of high mountainous area followed by 46% highlands compiling it a highly elevated part of the basin with steep free face and V shaped valleys. Sika has only 3% area under peak and 4% of piedmont areas with an elevation range of 60 to1400 meters. The land cover is dominated by dense forest cover compiling 69% followed by degraded forest cover of 31% and bare soil exposed on only 1% of the total sub-basin areas. The measures proposed for its stability is engineering structures to retain footloose phenomenon of the slope to reduce the soil erosion. The degraded forest cover and the valleys need reclamation of headwater treatment to reduce large sediment loosing phenomenon. The Jia up catchment posses 35 sq.km and only 9% area of the watershed and mainly has high relief alteration comprising piedmont (29%), highlands (36%) mountainous (27%), high mountainous (8%). Of which 20 % is dense forest, 59% degraded forest, 2 % is covered by sand-silt, 6% is fallow land, 9% is net sown and only 1% of rural dev. area, wetland and water body. It is to southern part of the drainage basin and highly prone to peak flow in rainy season and thus prone to massive erosional due to high velocity as well as heavy sediment load. The aspect of management plan are slope reclamation measures, afforestation in degraded areas, geo-netting of exposed slope to retain sediment loose and landslides.

The Lower Jiadhal River Basin is associated with piedmont areas and flood plain produced by the active drainage system. The river course is associated with siltation problem due to low slope gradient. The elevation generally ranges from 50 to 250 meters from msl and towards the north the altitude rises to 800 meters along the Arunachal Himalayas. It is compiled of numerous drainage system which is interlinked in many cases and comparatively five major sub-watershed has delineated. The river course is turbulent in the upper basin and flows through a deep gorge to the extensive plain. It is sallow in the plains and often flowing above the altitude of adjoining areas or the flood plains in the northern part of the lower basin. River braiding is common phenomenon during dry and in wet season river shifting due to failure or bleaching of embankment is common. The low lying areas of the lower basin are always remained water logged and have permanent wetland or swamps. During wet season the water level of the river as well as the agricultural fields get affected, which ruins the agricultural yields greatly. The socio-economy of this area is greatly influenced by the natural calamities flood hazards in the watershed, including high rate of siltation and sedimentation, soil erosion, water logging, fluctuating water table and floods.

The environmental geomorphology of the lower basin is mainly dominated by the extensive flood plain with gentle slope gradient. The composition is mainly old and new alluvium, with feature less flat topography. The main characteristics of river course of the lower basin is siltation, sedimentation, sallow river depth, bank erosion, embankment bleaching, unstable river course, river shifting, flood, water logging and fluctuating water table. The Jiadhal lower watershed is the most affected watershed accompanied by perennial floods and siltation problems thus, the measures for watershed management is the need of the area for sustainable development of the study area. Thus its management is mainly triggered the flood hazard management measures, structural measures- embankment and river bank, wetland management, maintenance of river flow, drainage interlink management, rain and surface water harvesting, agricultural development, control top soil erosion, river resource utilization-sand quarry promotion, landscaping of residential areas and improvement of transport communication.

Table 6.4: The Geographic characteristics and Watershed Management attributes of the Sub-Watershed of the Lower Jiadhal Basin.
(Source : Map work and detailed field observation)

Name of the Sub-Watershed	Areas (Km^2)	Environmental aspects	Physiography in Percentage	Area in %	Landuse and land cover in Percentage	Range of Altitude (m)	Aspects of Management planning
Na-Nadi	192	Flood, Water logging, Fluctuating water table	Piedmont (6), Highlands (2) rest is plain ranging from 50-250 meters	13	Dense forest -2, Degraded forest-22, Bare soil-exposed -4, Rural Dev-14, Fallow land-28, Net Sown-28 and Wetland-1.	50-800	Flood management, Structural measures-Embankment and river bank, Wetland Management, Rain or Surface water harvesting
Koran	266	Water logging, Bank erosion	The topography is more or less homogenous with loss range of altitude ranging from 50 to 250 meters.	18	Bare soil-exposed-10,Rural Dev-33, Fallow land-18, Net Sown-3 , Wetland-5 and Water body-2	50-250	Wetland Management, Agricultural development, control top soil erosion, river bank protection measures, surface water harvesting
Charikaria	228	Flood, Water logging, Fluctuating water table,		15	Sand-Silt-4, Bare soil-exposed -17, Rural Dev-34, Fallow land-14, Net Sown-18, Wetland-11 and Water body-4.	50-200	Wetland Management, Agricultural development, control top soil erosion, river bank protection measures, surface water harvesting

Chila	169	Water logging, Fluctuating water table, seasonal drying		11	Sand-Silt-3, Bare soil-exposed -20, Rural Dev-20, Fallow land-10, Net Sown-16, Wetland-22 and Water body-9.	50-200	Improve stream flow, Wetland management, Flood management, Improving transport facilities
Jiadhal	626	Siltation, Sedimentation, Sallow river depth, Bank erosion, Embankment bleaching, Unstable river course, River shifting, Flood, Water logging, Fluctuating water table		42	Sand -Silt-2, Bare soil-exposed -15, Rural Dev-32, Fallow land-14, Net Sown-25, Wetland-8 and Water body-3.	30-250	Flood management, Structural measures-Embankment and river bank, Wetland Management, Maintenance of river flow, Drainage interlink management, Rain or Surface water harvesting, Agricultural development, Control top soil erosion, River resource utilization-sand quarry promotion, Landscaping of residential areas, Improving Transport facilities,

The Jiadhal sub-watershed is the largest of all with 626 sq.km of aerial extension and covers 42% of the lower Jiadhal basin (Table 6.4). Dominating land use is the rural development areas comprising 32%, and net-sown area of 25% followed by bare soil-exposed of 15% and fallow land of 14% of the Jiadhal sub-watershed. It has 8% areas covered by wetland and 3% of area by water body thus the most demanding aspect of management are flood management, structural measures- embankment and river bank, wetland management, maintenance of river flow, drainage interlink management, rain or surface water harvesting, agricultural development, control top soil erosion, river resource utilization-sand quarry promotion, landscaping of residential areas, improving transport facilities. Koran sub-watershed is the second largest with 266 sq.km of extension covering 18% area of the lower basin. Rural development areas cover 33 % of area, followed by fallow land with 18% and bare soil-exposed of 10% with prior management aspects are wetland management, agricultural development, control top soil erosion, river bank protection measures, surface water harvesting. Charikaria extended 228 sq.km comprises 15% of the lower watershed area with 34% area under rural development area, 18% by net-sown area followed by 17% of area under bare soil-exposed. It consist 11% of area under wetland and 4% under water body so most dominating aspect of watershed management are wetland management, agricultural development, control top soil erosion, river bank protection measures, surface water harvesting. Na- Nadi sun-watershed in the northern part is extended 192 sq.km and covers 13% of the lower watershed. It has relief variance and 6% is piedmont areas with elevation of 500 m above msl and 2% highlands elevated to 800 m above msl. It has 22% degraded forest and 2% of dense forest cover along the northern terrain and plains down consist of 28% areas each under net-sown and fallow land and 14% of rural developed area. The main aspect of management is flood management, structural measures- embankment and river bank, as water logging is the trigger to be managed by wetland management, rain or surface water harvesting measures. Chila sub-catchment comprises 169 sq.km and 11% area of the lower Jiadhal watershed and mainly dominated by wetland extending 22% of the sub-basin followed by 20% of rural development area. Thus the main aspects for watershed management concentrates on improve stream flow, wetland management, flood management, improving transport facilities as to cope with flood like situation due to water logging (Table 6.4).

THE PLANNING STRATEGY FOR INTEGRATED WATERSHED MANAGEMENT IN THE JIADHAL RIVER BASIN

The strategy for Integrated Watershed Management in Jiadhal river basin is based on the characteristics of environmental geomorphology of the river basin. The basin has vast diversity in terms of physiography and thus it is divided into upper and lower Jiadhal basin. The upper basin is situated mainly in West Siang district of Arunachal Pradesh and the lower basin lies in the Dhemaji district of Assam. The environment and environmental problems of both the basins are different but interrelated. Thus Integrated Watershed Management with collaboration of both the state is the prior concern to cope up with natural hazards including land and water degradation and accelerated soil erosion, flood, siltation and sedimentation. Integrated watershed management includes the integration of many scattered programs of soil conservation, afforestation, minor irrigation, crop production, tree plantation, fodder development and other development activities into a well prepared watershed project. These are mainly based on climate, land, water and plant resources on the one hand and man and animal resources on the other. It offers hope for bringing about sustained natural resources development. Environment and Socio-economic development is prior concern too. It also provides solution to many environmental problems like soil erosion, siltation, improper land use, lowering ground water table drying up of springs, mass wasting etc. (CWC, 2004). The strategies recommended being effectively implemented to have effective programme for addressing the problem of flood in the country, the following. (CWC Guidelines, 2011)- i) Scientific Assessment of Flood Prone Area, ii) Integrated Basin Management Approach, iii) Construction of Dams and reservoirs with adequate Flood Cushion, iv) Drainage Improvements, v) Strengthening of Organizations, vi) Public-Private Partnership Concepts, vii) Inventory of Works completed by State, viii) Provision for adequate funds for maintenance of existing works. ix) Procedural Reforms, x) Application of New Technologies, xi) Emergency Action Plans.

Measures for flood management and erosion control:

According to the scenario of the Jiadhal river basin the main, problem in lower basin is the flood and erosion of the river bank and the phenomenal issues like siltation and sand casting. Thus the basic trigger for the sustainable development of the region requires the management and control over soil erosion, massive land degradation due to bank erosion, flood and its other affects. Different measures have been adopted for the management of the flood situation and to reduce the flood/erosion losses and protect the flood plains. On the basin of their work, it may be classified under Non-Structural and Structural, the non-structural methods to mitigate the flood damages are as under CWC (2011):

1. Flood Plain Zoning;
2. Flood Forecasting and Flood Warning;
3. Flood Proofing; and
4. Living with Floods**.**

On the other hand the structural measures includes engineering measures for flood management/erosion control are classified into long-term and short term measures, which bring stability to the flood prone areas by reducing flood flows and the flood levels are:

1. Creation of reservoir to accommodate excess water logging
2. River course deepening to generate firm channel flow
3. Sand and gravels quarry in river course to increase river depth
4. Diversion of flood waters to other basins to manage high discharge
5. Construction of flood embankments reduces bleaching
6. Construction of spurs, groynes, studs etc. restrict river bank erosion
7. Construction of bank revetment along with launching apron attain sustainability
8. RCC porcupines in the form of screens, spurs, etc. reduce flow impact in banks and
9. Vetivers, Newwebs, geo-bags etc as well as natural vegetations
10. Preparedness to flood and after flood impacts including transport and communication.

PROPOSED PLANNING STRATEGY FOR UPPER BASIN MANAGEMENT:

The upper basin area is mainly dominated by the mountains mainly associated with geomorphic processes and resultant landforms. The drainage in the upper basin are not perennial as the streams are mainly associated to natural springs and which went dried up in season of less rainfall. The situation could be basically categorized on the basis of its nature of land strata, landform and river morphology concerns to each river system prevailing.

1. The Sido Sub-Watershed: This sub-watershed is associated with deep valleys with steep side walls accompanied with series of fault lines and liniments. These areas are also the sediment source in the watershed, which reflects its fragile condition and thus the sediment load in the river is more. Up to 6 kilometers above the tri-junction the river deposits is dominated by sand bars, pebbles and grabbles associated with big boulders, which reflects that the lower course of Sido is associated with broad river course. The upper course of Sido is narrow and deep valley associate with vertical side walls and the practice of river deepening is active in this section. The tributaries to Sido are natural springs and associated with deep free fault lines bisecting the mountain ranges.

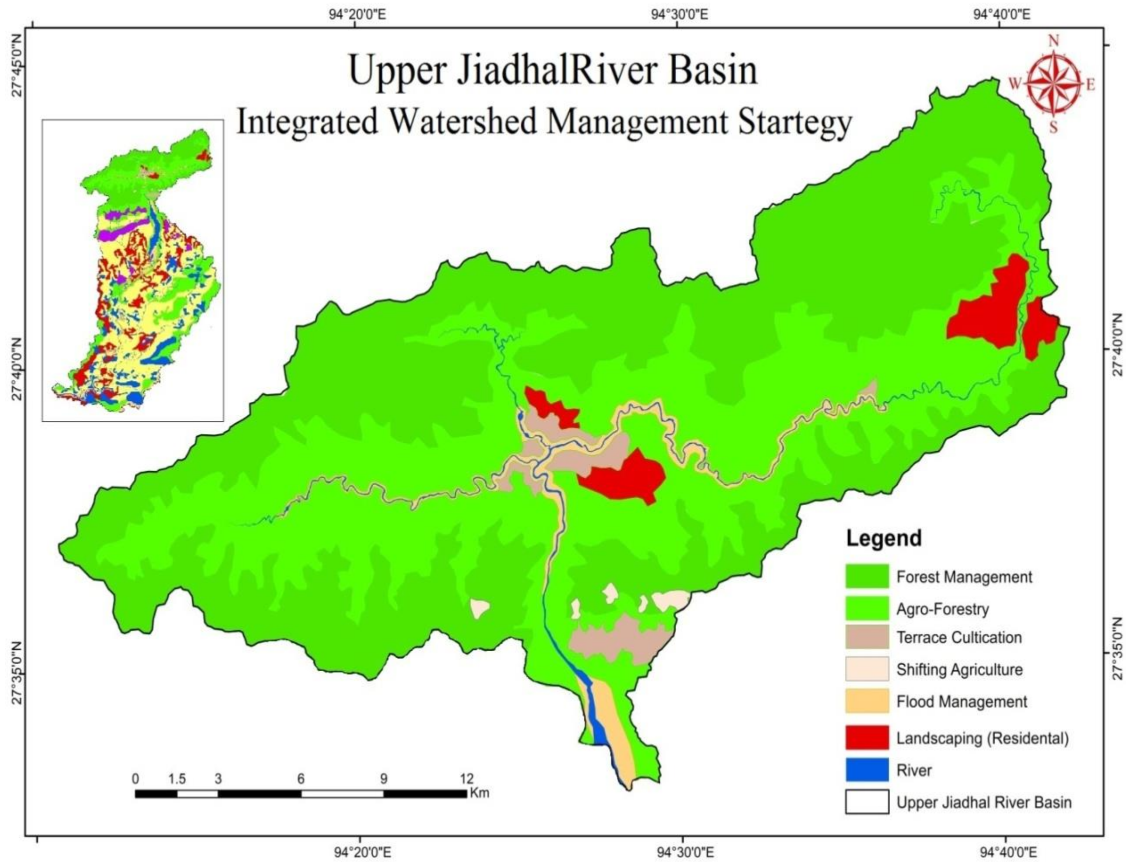


Fig. 6.1: Integrated Watershed Management strategy for Upper Jiadhal River Basin

Management Plans: The vegetative coverage plays an important role in the stability of the slope as well as controlling erosion of river course. The deforestation in the name of agro-forestry and lumbering decreasing the vegetative coverage of the area, which led the soil exposed to external forces for extensive erosion associate massive landslides and mass wasting. The side walls of the fault lines are prone to erosion thus the weaker structures should be accompanied by spours and check dams so the toes loss phenomenon could be checked. Terrace and contour plantation will sustain the slopes from mass-wasting and low sediment discharge due to rich vegetative coverage. The tributaries contributing much more sediment have been identified and mini- watershed management plans could be the best option for its sustainability.

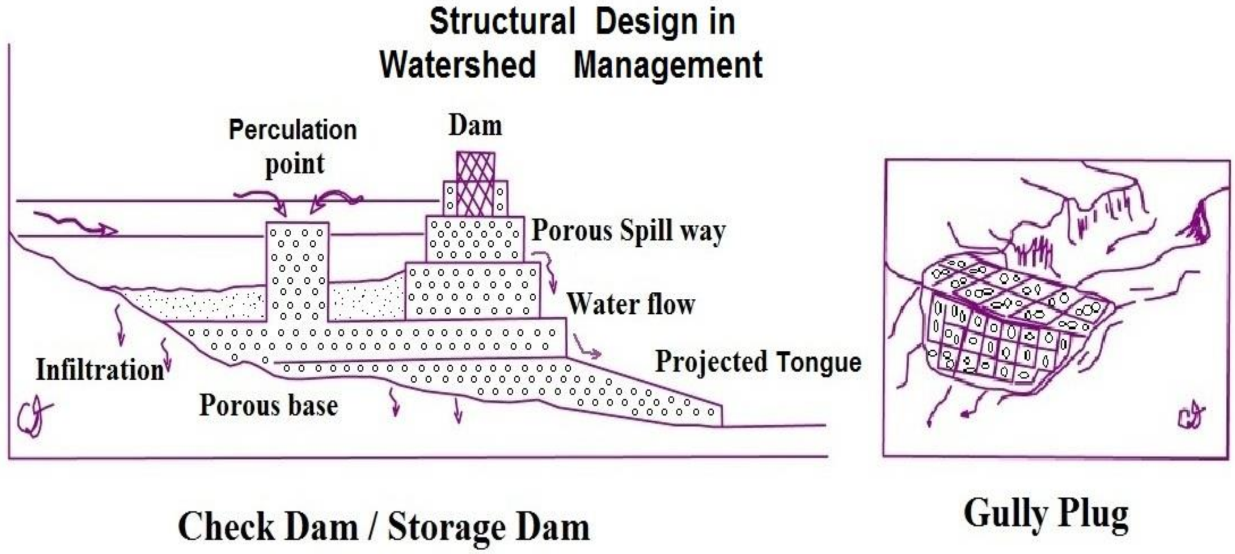


Fig. 6.2: Structural design in watershed management after Valdiya (2004) and CWC (2011)

2. The Sika Sub-Watershed: The sub-watershed is characterized by the narrow stream channel in the upper course and associated with rocky river bed, which reflects that the Sika sub-watershed has potential of high sediment yield due to fragile mountain system. The river course of the Sika is free from fine grained sand deposits mainly with boulders and big sized grabbles and low sand along the river bed. Thus, Sika is a contributor of course sediment load to the main stream.

Management Plans: The fragile structure of the mountain system in the upstream part of Sika sub-watershed is the most vulnerable and high sediment source area and prone to erosion mainly in the south facing slope of the basin. The Check dames would regulate the down cutting of the Sika, while the foot loose problem of the slope could be checked. The Sika is free from fine sediment load so the river produces less suspended load. The structure of check dam (Valdiya, 2004) is considered appropriate for upper catchment areas with structural innovation of percolation point, porous spill way and projected tongue would make it sustainable from siltation and foot erosion.

3. The Siri Sub-Watershed: This sub-watershed of upper Jiadhal River basin is the longest and largest tributary of the tri-junction to form Jiadhal. It is associated with tremendous fine sand deposit along the river bed as well as the side of the meander points through the river system up its upper ridges areas where it flows along deep gorges with less width and depositional features. The tributaries to Siri is accompanied to Joints and Fault lines in the mountain system yielding great amount of sediment load ranging from fine sand and silt to boulder to the main stream. The steep and free faced side wall reflects that the river deepening is extremely pronounced in this section. The terraces along the river course reflects that the river is turbulent as well as erosive so its river course get modified in times due to the characteristics of the geological structure of the area.

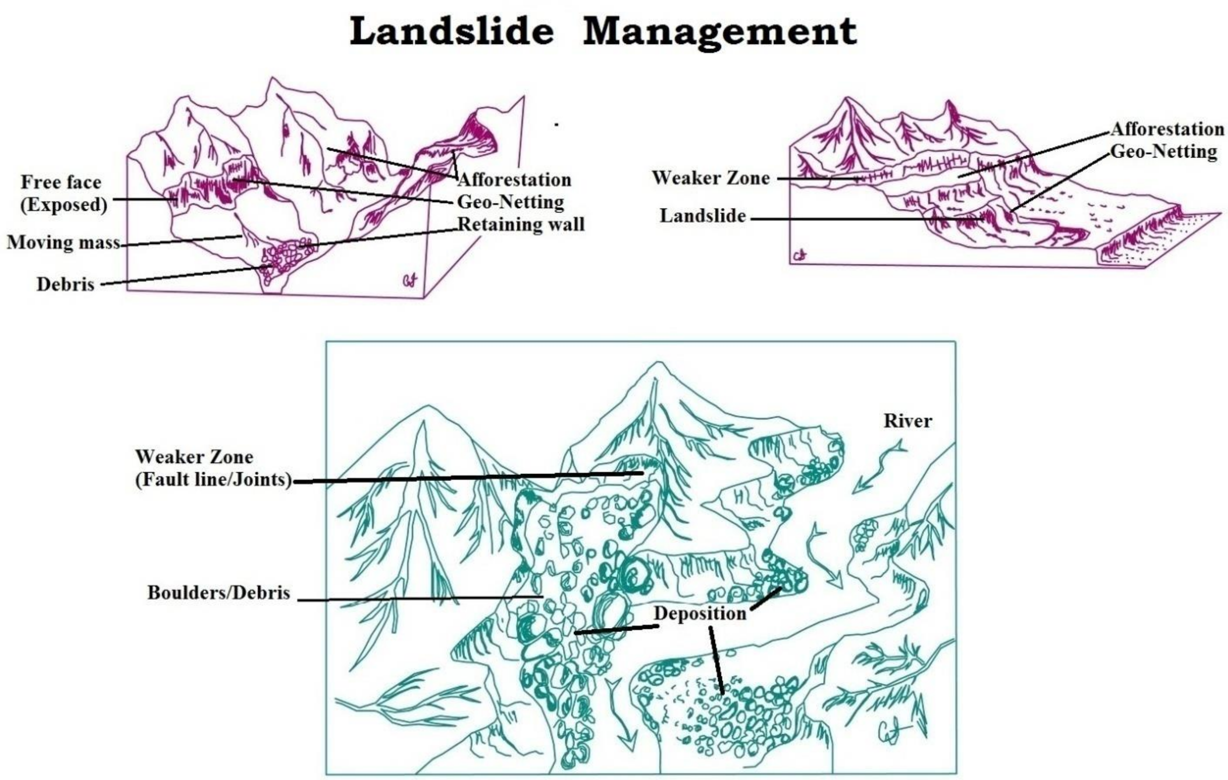


Fig. 6.3: Landslide management after Valdiya (2004).

Management Plans: Siri basin is associated with larger basin area and thus contributing the highest sediment loads to the main stream. The river gorges of Siri are free faced with less vegetation coverage yielding great sediment loads. The land use in the lower terraces of the basin should be managed so that even in submergence in water in rainy days the soil didn't erode. The river meanders and point bars along the river course have tremendous fine sand deposits are vulnerable to erosion in peak flow. Check dams with boulders across the river could manage the siltation of the river bed and check the sediment load flow (Fig 6.3). Forest conservation, agroforestry are the basic measures to control the environmental geomorphology of the upper Jiadhal basin. Landscaping includes residential areas, but as the entire basin is free from human settlement, these sites are projected to be suitable for settlement in regards to its accessibility from either side of the basin (Fig. 6.1).

4. The Jia Upper Sub-Watershed: This sub-watershed is located south of the tri-junction which is associated with deep gorges and narrow river width ranging 12-15 meters. The river sides are steep side wall and are free from vegetative coverage and composed of large sedimentary rocks. The vertical side has rich coating of mosses and grasses which keep the soil unexposed to external elements, but the natural structure of faults and weathering is pronounced and the slopes are prone to mass wasting, landslide and rock fall.

Management Plans: The Slope failure and soil the resulted erosion is common in upper Jia, as the river is a trance-mountain, it flows through a narrow and deep gorge across the southernmost range of Arunachal Himalayas. The mountain is composed of large sedimentary blocks and associated with conglomerates. The tributaries to Jia cuts deep gorges to reach the main stream and produces high sediment load in form of big to small boulders, conglomerates and course to fine sand. Deforestation in the upper catchment should check to improve surface runoff and infiltration of water to ground aquifers. Slope treatment in the gorges could be possible from geo- netting and retreating walls in vulnerable sites to erosion. Series of check dam could reduce the stream sediment flow and raise the stream depth, which will restrict the stream sediment and foot loose phenomenon in the river banks.

PROPOSED PLANNING STRATEGY FOR LOWER JIADHAL BASIN MANAGEMENT:

Among the earlier proposed management techniques for conservation of flood and soil erosion in lower basin particularly the flood plains, the structural measures are found to be effective for longer durability. The most popularly used structural designs are the flood embankment, spurs, bank revetment, and structural compositions like porcupines and dikes along the triggered areas. Considering environmental geomorphological and land use land cover analysis, the management plan evolved for lower Jiadhal basin is as follows (Fig. 6.3).

I. Forest Management: The category of management plan includes the afforestation of the degraded forest cover, and to retain the natural vegetation compiling the sustainability of soil, slope and forest ecology. The resources from forest are collected occasionally, and would be continued too, thus the species should be preserved and replenished in the natural habitat so that the biodiversity would sustain. Local people participation in Public Private Partnership should be encouraged in ground level so that the need of forest management is understood by the local population and work for it by their will. Indigenous knowledge of forest based industries should be supported for socio-economic growth through forest replenishment (Fig. 6.3).

II. Agro Forestry: The plan includes the replenished of degrades bare land, sand and silt casted land along the river course which are unproductive, into agroforestry. This will be benefiting both environmental geomorphology of the basin and the socio-economy of the basin too. As the lower basin is favorable for sericulture, so plantation of plant species fit for sericulture would solve the problem. Horticulture is another option which not only enriches the environment but also sustains the economy of the population inhabiting the area.

III. Agricultural Development: The share of fallow land is increasing, which ruined the interest of agriculture in larger scale. Proper innovative plan should be initiated in agriculture to use the land resource to its ultimate, to boost the economy of the basin area. Fluctuating water table and unpredictable monsoon are the hurdles in irrigating agricultural fields which cause seasonal unemployment of arable land. Drainage linking programmes could solve the problem of irrigation and agricultural land could be benefited.

IV. Flood Management: Permanent solution to flood problem is the construction of structural measures for longer durability. Earthen embankments as suggested by CWC (2011), and RWD, Dhemaji could solve the problem if the top of the embankment are concerted to metallic road. Small structural measures to retain river course and bank erosion should be adopted. River deepening by authorized and systematic quarrying of sand resources from the river bed is beneficial both for the smooth river flow and in the landscaping of the adjacent low lands. Proper road transport to the river side for heavy trucks and loaders is the only requirement along the enablement in selective sites of sand quarry (Fig. 6.3).

V. Rain Water Harvesting: The solution to fluctuating water level for agricultural purposes and soil conservation could be resolved by rain water harvesting is headwaters of the lower basin. The integrated watershed management programmes would solve to problem if it is correlated to alternate occupations for local inhabitants as fish and poultry farming, so that the local population could get economic benefit of it too (Fig. 6.3).

VI. Wetland Management: The water logging in low lying areas always ruined the arable land as well as settlement areas during heavy rainfall in the lower basin area. The wetland management programme could solve the issue for the biodiversity of the basin. The wetland should be treated and renovated so that they accommodate the excess surface runoff, and could be used for economic as well as ecological benefits too.

VII. Landscaping (Residential): The range of elevation of the lower Jiadhal basin is very low, as agricultural and even residential areas are below the river bed, which creates the water logging phenomena in rainy season. Such areas could be renovated to raised land by landscaping, and the government schemes of rural road connectivity could be benefited by aborting innovative plans considering the river deepening as well as landscaping of vulnerable sites (Fig. 6.3).

Some of the specific vulnerable sites are considered for field survey and strategic plan development in the lower Jiadhal basin and the outcome are discuss with their problem and management plans are as follows.

1. The braded channels in piedmont areas is the real target areas affecting worst at time of peak flow with huge sediment loads in Jiadhal watershed. The meandering of river on the other hand creates multiple weaker sections in the river courses due to undulating relief or elevation of the ground. The Jiadhal is flowing considerably in a regular river course till its middle course and the area concerns the flood Zone II, which is more prone to flooding and its effects and main areas for flood management. The river course before the Railway track is considered as the piedmont areas of the Jiadhal river system and is frequently triggered by huge siltation which thus the water get over flowed from its regular course to adjacent plains towards its left (east) bleaching the embalmment each year. The problem could be solved by structural measures like construction of embankment and spurs along the river to retain the peak flow within the river courses. The construction of spurs, porcupines and dikes within the river bank would restrict the bank erosion and redirect the velocity of the river flow towards its central course and the river flow straightly within the embankments.

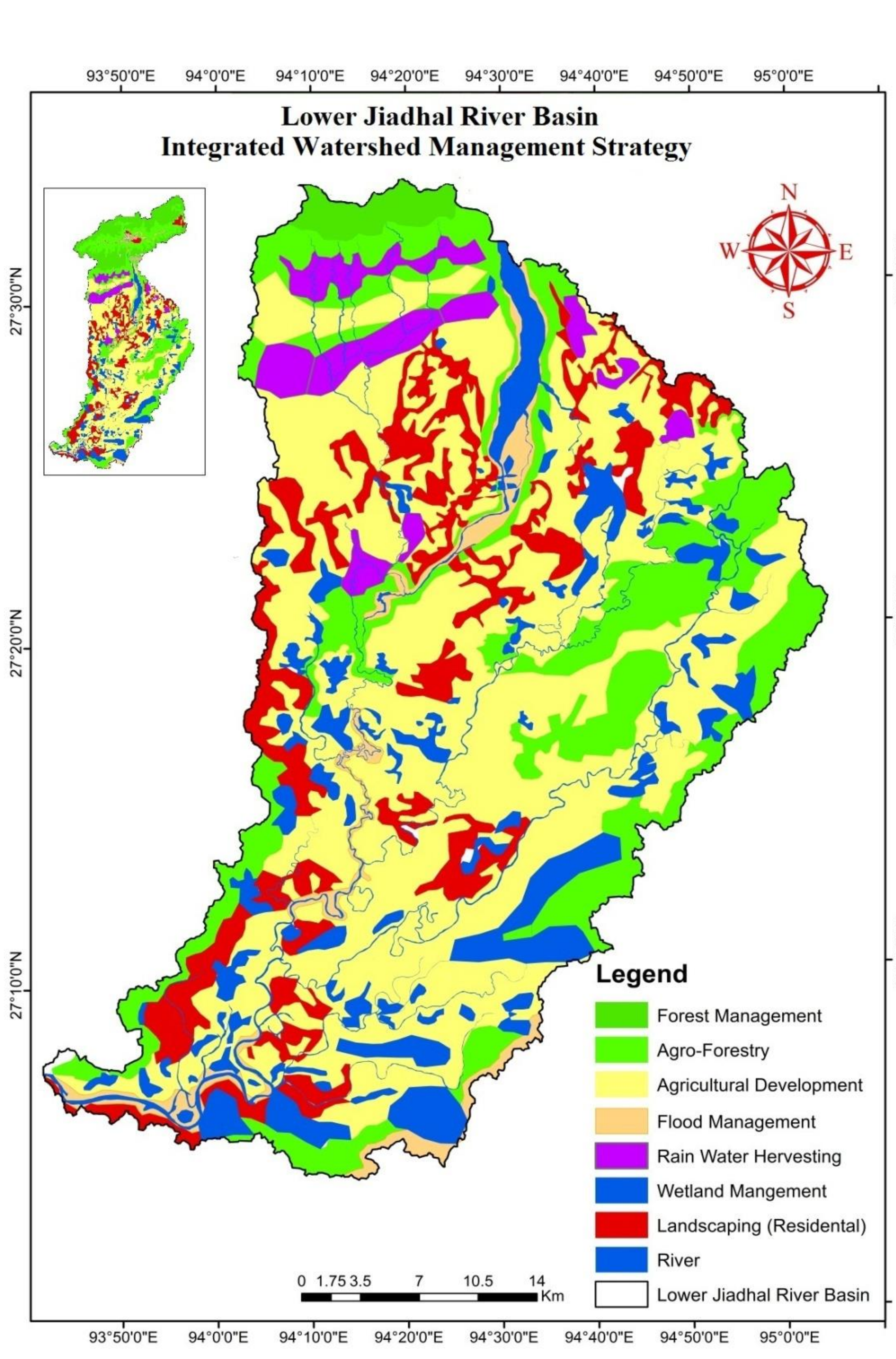


Fig. 6.4 : Watershed Management strategy of Lower Jiadhal River Basin.

The sand resource in Jiadhal is an asset and its excavation would solve the problem of river shallowness and landscaping of the residential areas. The flood plain has lower relief and remains waterlogged, so landscaping, wetland management and rain or surface water harvesting are the standing measures for sustainability of water level for agricultural development and socio-economy of the watershed.

Management Plans: Free flow of river water in a particular river course would retain the peak flow within the channel. Thus the bank should be supported by structural engineering with solid and permanent structures like series of crates and gabions to retain the slope of the river bank. Revet mattress is rectangular mattress made with hexagonal double twisted steel wire mesh, where the depth is small in proportion to its length and width could be used to retains the side slope of the river intact and free from erosion (CWC, 2011). Erosion control mat either bio-degradable or non degradable type provides immediate erosion control and high moisture content to establish vegetation. It creates hospitable conditions for plant invasion and establishment which provide extra strength against erosional forces (CWC, 2011). Series of spurs could be constructed either normal to flow direction or at angle pointing towards upward side or down side of the flow. The spurs pointing upward side of flow repels the flow away from the bank and is known as repelling or deflecting spurs used to retain the erosive side of the meander. The Spurs pointing down side attracts the flow towards the bank and is known as attracting spur could used to retain the river in its own course by restricting the stream flow to one desired direction. The degraded, exposed and sand casted land cover and land use could be transplanted by afforestation (Forest conservation) particularly by agro-forestry. The low lying areas having water logging problems should accompanied by Wetland management programmes. Plantation Species need to be choosing for forest cover increase as well as for biodiversity development. The fruit bearing plants plantation would increase the availability of fodder for wild animals and birds too. The plant species encourages the indigenous silk industries could benefit the socio-economy of the region. Horticulture plants and standing crops like aracanut, beetle leaves, black piper, tea and coffee as well as vegetables are grown locally could be encourages in larger extent for the income generation of the indigenous population for their sustainability in flood plain.

Plate. 6.2: No.1RCC Bridge (Jiadhal Bridge), at NH15 and No.1 Railway Bridge in different discharges during peak flow and after bleaching discharges decreases.

2. The Middle course below railway bridge to Na-nadi tributary. The area is characterized by high peak flow and bulging of river water due to narrow passages in the RCC Bridge points. The No.1RCC Bridge (Jiadhal Bridge), at NH15 is sallow due to depositional activities of the river system, the height of the bridge is ranged from 1.4 to 2.8 meters, with a an average height of 2.1 meters in dry season. The length of the bridge is only 200 meters. The water discharge in the river is less and sallow on dry season, but as the intensity of rain increases its flow also increases in accelerating rate in monsoonal or summer rainy season. The river course before the bridges accommodates more water than the bridge bottom and thus its passage and velocity influence the river characteristics to become turbulent after passing the No.1 RCC Bridge and directly encounter the embankment in front along Ratuwa and Nepali Khuti village. The river embankments encounter high water discharges and due to a meander towards the right. The right embankment is safer than the left embankment which encounters the direct impact of the stream flow. Siltation and sedimentation of river bed is affecting river depth and the embankments are vulnerable in peak flow to bleaching and creating flood.

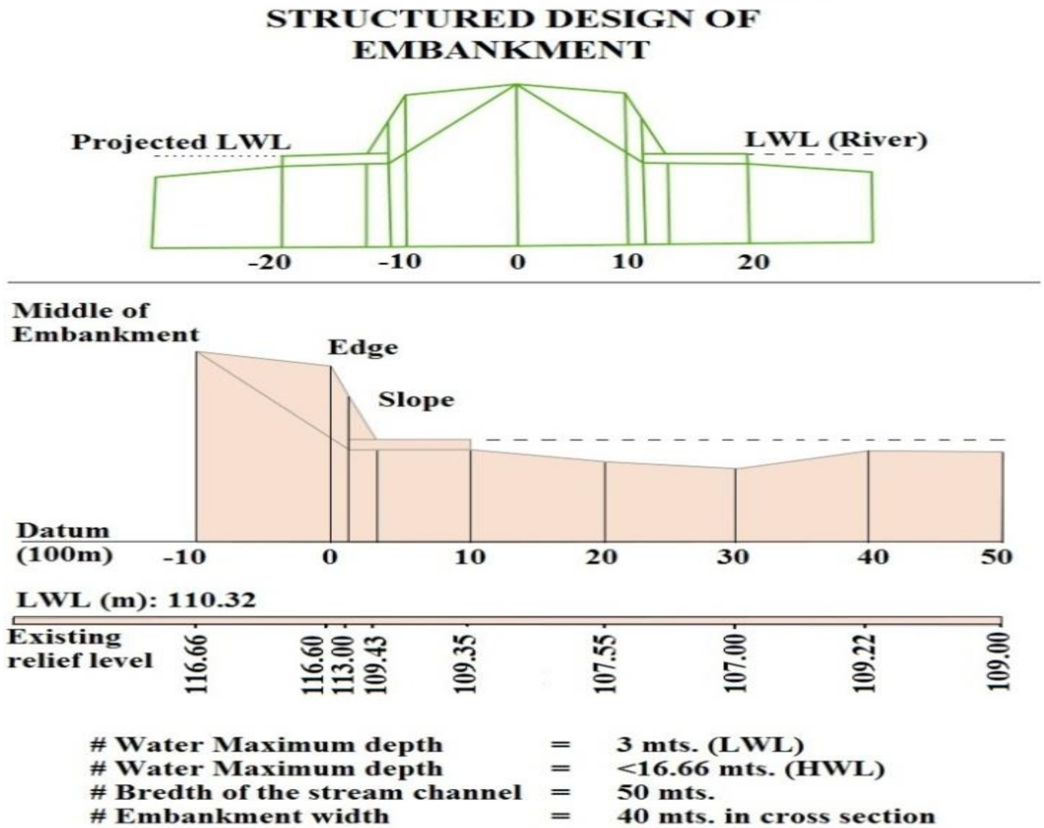


Fig. 6.5: Structured design of embankment, Water Resource Department, Dhemaji, 2017.

Management Plans: Sediment management in river basins to maintain the stream flow and reduce erosion and bleaching, measures taken for sediment management are sand quarry in dry season and deepening the river bed to channelize stream flow are practiced in the lower basin river course Natural Levees and embankment are the real structural design fit for the middle course, as the river meandering and braiding of channels make the river course widened. The sedimentation along the river bed sallow the depth of stream channel and during peak flow it get over flooded and river water flowed to adjacent flood plains. Thus a natural levees or an embankment would solve the problem of river bleaching. The river deepening is another important factor of flood management, during winter or dry season the sand and stone quarry should be practiced judiciously along the river course to maintain the river depth. The infrastructural requirement of road to excavation sites of sand in the river.

Plate. 6.3: Measures taken in Jiadhal river for stable embankment.

a) Boulders and metallic binding wires are used for embankment construction; b) Left bank to railway bridge; c) Right bank down to RCC bridge No.1; d) Deepest point of abundant river bed; e) Shifted Jiadhal river 2019; f) Jiadhal river bed exposed for sand quarry

Road link to quarrying should be permanent so that it cannot hamper the embankment and the river bank while quarrying in the river bed. The triggered zones should be identified by analyzing previous records and necessary measures should be taken for its mitigation and flood management programmes for the sustainability of the region. Afforestation along the embankment with local vegetation would strengthen the embankment as well as the river banks from erosion. The agriable land should be treated with agricultural innovations including interlinking of drainages to have free flow and relocate excess stream flow. The sand resources of the river bed should be excavated and used for landscaping in the rural development areas. The consequences of sand quarrying would be both for river deepening and landscaping of vulnerable areas. Awareness and training on flood preparedness, emergencies and rescue operation trainings, after sock management trainings and relief and rehabilitation programmes should be organized. Supporting unit of national and state disaster management forces, medical, nursing, police, education, food security, portable water, food and shelter for all should have a backup plan for any situation in any circumstances at vulnerable areas.

3. The No.3 RCC Bridge along Bordoloni to Ghilamara road is another critical area in the Middle course of Jiadhal river. The flooding in the year 2017 responded worst, as the river course got diverted to leftward by bleaching the embankment near Gohaingaon in front of the Jungle Block village. The middle course of the river is prone to lateral erosion and features like meandering and braiding of channel are the common phenomenon. The bridges over the river are the sensitive part of the river system, as the bridges are mostly constructed in the location with minimum channel width. It restricts the flow of river in peak seasons to pass through it with a condition of narrow pass in comparison of the river main course. The water logging in front of the bridges creates a temporary blockage of stream flow towards the main stream across the bridge. The velocity increases due to less width in the bridge point, the river bed erosion got activated resulted turbulence and eddies in the river channel. This created huge deposition of silt and sand in the front of the river channel reducing the channel depth restricting the river flow. The consequent of the bleaching make the actual river dried up due to huge siltation made by the river in above the No.3 RCC Bridge, and the river water retrieve backward along the river course to the new bleaching point. Embankment are used for transportation as well as for temporary shelter at flood situations which increases its vulnerability

Management Plans: Such phenomenon could be controlled if the river depth is maintained regularly i.e. each winter the river bed should open for sand quarry as that the landscaping in required places are done as well as the channel deepening is also occurred. Structure design recommended by water resource Department Dhemaji (Fig-6.5) is adoptable and proper metallic road should be included beside the bridges for the sand quarries so that the embankment is not used for transportation purpose. Further embankment itself is a road if the top of the embankment is generated to be a roadway. The embankment should have permanent road communication system for the sand quarry as the heavy vehicles (Turks, Tractors and Dumper etc.) would be trafficking and could damage the embankment if it is not according to planned infrastructure. A communicable embalmment with sliding metallic road to river side could solve the problem of embankment damage due to traffics of sand quarry.

4. Confluences of tributary to mainstream are other vulnerable sites with alarming cases of lower Jiadhal river course. The water quantity get added to the mainstream increases the pressure of the stream flow and in peak seasons due to heavy rainfall the confluence get water logged. The water logging and siltation produces a situation of low stream flow and water level got raised creating bleaching over embankments. The problem could be undertaken by wetland management, which will not only solve the water logging but also stable the aquatics biodiversity as well as socio-economy by fish rearing by the inhabitants. The agricultural development would be influenced by the balance in water level as in winters it is usually sallow and could provide an ample scope for the agriable fallow lands.

Management Plans: The confluences of tributaries are vulnerable because of bi-directional flow of water, impacting the river bank to erode resulting meanders. The structural engineering on both side of the river bank and embankment could solve the problem. Along with the embankment of the main stream spurs and dikes on the river course to retain the added discharge of tributary into the mainstream is necessary. The water discharge remained within the river course accelerates the river deepening process and the channel flow continues without logging due to siltation. Such infrastructure is mainly needed in Na-Nadi confluence as the depth of tributary is less than the mainstream, but in rainy season the whole area remains water logged by rainwater which is another vulnerable factor. The water logging mainly due to rainfall in low-lying areas could be solved by re-establishing the natural reservoirs i.e. the swamps, ditches and mini reservoirs. Wetland management is another option for the accommodation of surface water logging which creates a flood like situation even due to heavy rainfall.

Plate. 6.4: No.3 RCC Bridge, (a) Stream flow deflected by sedimentation and flow redirected backward; (b) abounded river due to bleaching; (c|) Redirected flow bleaches the embankment; (d) Bleaching point and embankment restored; (e) the bleaching point is 30 meters, and (f) Embankment used for temporary shelter.

Surface water harvesting or rain water harvesting in proper form should be implemented to solve the problem of water logging in agricultural fields and damages the soil quality and crops too. Adoption of pisciculture to accelerate water conservation and also to generate an alternate livelihood for the flood plain dwellers would be fruitful and important technique.

All above the discussed measures the vital role in planning and management is played by the techniques and measures adopted for the assessment of environmental and social impacts of the area. The planners should undergo such impact assessment analysis to module a suitable strategic plan for the sustainability of the watershed. The common hurdles in between are lack of transparency and public awareness and participation in the decision making process, as long term planning is not done as per the requirement of the basin. A thorough cumulative environmental impact assessment needed to be carried out over the river basin to estimate the carrying capacity of the river system and to provide adequate safeguard the environmental consequences both up and downstream areas. The short term projects to mitigate flood hazards are also important in respect to the availability of the economy for such plans; the investigation of environmental geomorphology could provide the base for such planning and implementation. The integrated watershed management approach for the river based on the principles of soil and water conservation as well as sustainable development needs to be adopted. Proper assessment of various hazards such as flood, erosion, sedimentation, channel migration based on their impact and vulnerability, empowering of local population, employment generation and improved public private partnership programmes are very much essential for this purpose. As a long term strategy for resource utilization and hazard management, a judicious use of structural and non structural measures need to be undertaken. The challenge before the public decision makers in Jiadhal river basin includes the interstate coordination of plan and management within Assam and Arunachal Pradesh for the quest of sustainable development of environment and socio- economy of the region.

REFERENCES

Alagundagi, A. N., (2018). A study of watershed development in north karnataka with special reference to Vijayapura and Gulbarga district, (Ph.D Thesis), sudhganga, pp- 11-48 (accessed on 15/10/2018).

Borthakur, B.C. (1998): Sustainability in crop production: The challenges in North East India. National seminar on Management strategies of North Eastern Hills Ecosystem. ICAR, Research complex for NEHR, Umiam -8-10th August 1998, pp- 57.

CWC,2004: Handbook design of flood protection, anti erosion measures and river training works, CWC, Patna, 2004 pp-1-72.

CWC, 2011: Handbook for Design of Flood Protection, Anti Erosion Measures & River Training Works, Government of India, CWC Handbook, New Delhi , 9-5 pp 104.

German L, Mansoor H, Alemu G, Mazebgia W, Amede T, Stroud A(2007), Participatory integrated watershed management: evolution of concept and methods in an ecoregional program of the eastern African highlands, Agric Syst 94:189-204.

Gunasekaran. S, (2014), Planning and strategies of watershed management projects – an analytical study in Dindigul district, Tamilnadu (Thesis), The Gandhigram Rural Institute – Deemed University, Tamil Nadu, pp -1-203.

Hassan, (2013): Watershed characterization and management planning in Wular catchment,(Ph.D Thesis),University of Kashmir, Srinagar, Shodhganga : a reservoir of Indian theses @ INFLIBNET,http://hdl.handle.net/10603/191345. pp.01-203

Oblitas, K.R.A. (2016): Assam Agricultural Competitiveness Project, Implementation Completion Report (ICR) Review. Independent Evaluation Group (IEG). http://documents. worldbank.org, pp 01-26 (assessed on 09/09/2019).

Rawat, M.S., (2011): Environmental Geomorphology and Watershed Management. Concept Publishing Company Pvt. Ltd. New Delhi, pp.-1-286.

Rawat, M.S., (2014): Prospects of Water Resources Management of sustainable Development in Nagaland. North East India, International Journal of Developmental Studies and Research, V. L. Media Solution Vol. 3 No.2, pp.—123-145.

Satapathy, K.K. (2003): Watershed Based Farming Systems As Alternative to Shifting Cultivation in North Eastern Region. Journal of agriculture Engineering ,Vol 40 (1), pp-41-48.

Speed, R., Tickner, D., Naiman, R., Lei, G (2016): River restoration: a strategic approach to planning and management, CC BY-SA 3.0 IGO [7112] 202 p., illus.

Steiner, F., Marruffo, J., and Holm, M. (2000). A Watershed at a Watershed: The Potential for Environmentally Sensitive Area Protection in the Upper San Pedro Drainage Basin (Mexico and USA) . Landscape and Urban Planning. 49(3-4), 129-148.

Strahler, A. N. (1956). "Quantitative slope analysis." *Bull. Geol. Soc. Am.* 67: 571-596.

United Nations Convention to Combat Desertification (UNCCD). (2-13 September, 2019, New Delhi): Restore land to Sustain Life, https:// www.unccd.int/conventionconferance-parties-cop/cop14-1-13september-new-delhi-india (assessed on 09/09/2019)

Valdiya, K.S. (2004): Geology, Environment and Society, University Press (India) pvt.ltd. Hydrabad, p-226.

Wang, G Mang, S, 2016, Integrated watershed management : evolution, development and emerging trends, Journal of Forest Research, oct2016, Vol-27, issie5, pp 967-994.

WBDC (2015): Integrated Watershed Management Programme, https://www.mapsofindia.com/government-of-india/integrated-watershed management-programme. html (assessed on 08/09/2019).

CHAPTER-7

SUMMARY AND CONCLUSION

The study area "Jiadhal River Basin" is a river basin in Dhemaji district of Assam, originating from the Arunachal Himalayas of Kangku circle of West Siang district of Arunachal Pradesh. Jiadhal covers an area of 1851.43 km^2 having latitudinal and longitudinal extensions of 27° 08' N to 27° 45' N and 94° 15' N to 94° 38' E respectively. Out of its total basin area, Arunachal Pradesh occupies 370.63 km^2 i.e. 20 % of the total basin area and rest 1480.80 km^2 i.e. 80 % of the basin area drains in the state of Assam, north east India. The major problems prevails in the Jiadhal Basin is the massive flood hazards and their related problems including soil erosion, landslide, sedimentation in lower basin, siltation in flood basin, and the related socio-economic aspects regarding loss of properties and life every year particularly during the monsoon months.

The study area consist of basically two geomorphological divisions, first the Upper Jiadhal River basin which is situated in the hilly track of Arunachal Himalayas, in the West Siang District, and another in the extensive flood plain of Dhemaji, North Lakhimpur and Majuli district of Assam. The river is a venture of three streams namely Siri, Sika and Sido and enters the plains of Assam and named as Kumotia or Jiadhal and subsequently flow to Subansiri River. The lower basin covered by the floodplains produce by its tributaries Na-nadi, Sonpara, Kaoran and Charikuria and Cila or Chiloni. The river carries heavy silt and sediment load from the catchment area during the rainy season responsible for the sand casting in the plains. Sand casting in the river led the river bed rising to sallow depth which is the main cause of embankment bleaching and flood in the lower basin. A trend of record was traced as the left embankment up to the railway line was breached more than **16 times** in the years of 1984, 1987, 1988, 1990, 1992, 1996, 1997, 1998, 2007, 2008, 2010,2012,2017 and 2019 on the other hand the right bank was breached **25 times** remarkably in 1983, 1985, 1988, 1990, 1991, 1996, 1997 and 2007.

The study region 'The Jiadhal River Basin' is an important part of the Subansiri River Basin and occupies a vulnerable geographical unit with lots of natural characteristics of the Brahmaputra flood plain. About 81.11 % of the study area is covered by flat land between 50-200 meters above mean sea level mainly concentrate by agricultural lands, settlements, swamp and wetlands comprising the environmental diversity and socio-economy of the region. Flood and siltation issue of the region creates havoc each year and its intensity varies with duration of its occurrence. The flood occurring in the month of June and July has highest effects. The major problems were found in the study region which are as follows-

1. Forest degradation
2. Soil degradation
3. Landslides
4. The massive flood hazards
5. High rate of siltation and sedimentation
6. The problems related socio-economic aspects regarding loss of properties and life
7. The other environmental and ecological problems

The main cause of the flood Hazards in the region is the monsoonal climatic regime. During the monsoonal regime the region receives heavy rainfall in the hill segment as well as in the plains. The lower basin has low gradient and almost flat plain with low lying depressions. These lowlands are even below the elevation of the Jiadhal river bed so the area is prone to water logging and remains wet through the year. The composition of the flood plain is such that the water table is nearer to the surface but shrinks to 10 to 12 feet below in winter season. In rainy season the plains receives tremendous rainfall of 150-250 mm daily which are logged within the land without draining out to an outlet or river system. This is mainly due to inadequate gradient of slope of Jiadhal lower basin to drain out the surface runoff to rivers. The river embankment is not permanent and mainly constructed by earthwork, by raising the soil from the river bed with support of plastic bags to protect it from erosion. The embankments are even degraded with time by various factors including natural and artificial too. The Jiadhal brings tremendous sediment load and frequently changes its course of flow due to siltation and over flow of the water to adjacent plains and a local accumulation and damming situation prevails within the river course. This led the shifting of channel flow and affects the weaker section of the embankment to erosion.

The Jiadhal River basin is agro-based economic zone and thus the land cover has the greater impact in the socio-economy of the population of the region. The physiography of the region is dominating **the land cover and land use** as well. The Upper Jiadhal basin which is a hilly terrain has the highest concentration of natural forest cover and low human settlement. The main problem of the upper Jiadhal basin is its inaccessibility, as there is no communication route or roadways to its interior. The river itself is the route in winter by manual trekking. The indigenous practice of timber collection and various forest products from the interior in winter make the interior upper catchment explored by human. The most vulnerability brings the timber industries and the lumbering activity in the interior of upper catchment, resulting its degradation if natural forest. The prominent land covers identified are dense forest, degraded forest, sand – silt, wetland-swamps and water bodies. Rural development areas, net-sown areas, fallow land and bare soil-exposed as important land use type of the basin. The dense forest occupies 381.70 sq. km comprising 20.61% share of the total land cover of Jiadhal basin in the year 2000 and mostly concentrates in the upper basin. The highest extension of degraded forest is recorded in the year 2009 comprising 217.58 sq. km. (11.75%) of the total area coverage. Sand – silt dominated areas share is recorded highest in the year 2000 with 47.12 sq. km. comprising 2.54% of the total area. Bare soil- exposed occupies highest share 274.06 sq.km 14.8% of the total area in the year 2000. In the year 2009 wetland – swamp records the highest extension of 127.72 sq. km comprising 6.9% the basin area.

Water bodies occupy 62.72 sq. km in the year 2000 comprising 3.39% of the basin area. Net-sown area of the basin recorded 366.96 sq. km in 2009 with 19.08% of the basin area excluding the tilled and exposed soil. Fallow land extension is recorded highest in the year 2009, with 198.95 sq. km comprising 10.7% of the total area of the basin. The Rural development area composition 697.64 sq. km (2005) is the highest record with 37.7% of the total basin area.

Changes in land use and land cover is observed and the results shows that the forest areas are drastically degraded and in negative trend as a result degraded forest in positive trend. The Dense forest cover of the basin is recorded in decreasing trend as it recorded 381.70 km^2 in 2000 and loose 13.64 km^2 till 2005 and reduces to 196.12 km^2 with 171.94 km^2 decreases during 2005-09. The rate of decrease was 2.73 km^2/year during 2000-2005 and increases to 42.99 km^2/year during 2005-2009. On the other contrast the degraded forest cover has increased from 123.99 to 217.58 km^2 with an increase of 111.52 km^2 since 2000 to 2009. The rate of change is 3.59 sq.km/year during 2000-2005 and increases to 27.88 km^2/year during 2005-2009. Wetland and Swamp area is in increasing trend as it is records 61.94 km^2 in 2000, 61.01 km^2 in 2005 and 127.72 km^2 in 2009. With reference to Sand and Silt the impact of flood in rainy days is traced and found in negative trend, as during 2000 it covers 47.12 km^2 is sand caster while in 2005 it record 38.01 km^2 and in 2009 it decreases to 27.42 km^2. Rural development areas is in positive trend in the period 2000-2005 with an increase of 79.01 km^2

from 618.63 to 697.64 km^2 , but again fall in the period 2005-2009 to 424.49km^2 thus comparatively it is in negative trend. Particularly during 2000-2005 its rate if increase is recorded 15.80 km^2/year and during 2005-2009 it decreasing rate goes 68.29 km^2 /year. It is mainly due to increase in degraded forest, fallow land and wetland in flood consequences.

The impact of land use changes is observed the characteristics of environmental geomorphology of the basin. The Upper Jiadhal basin have low population concentration and though have less impact on land use changes due to human activities, but the practices of landownership and protection, if property is greatly affecting the region. They use to clear the natural vegetation in name of agro-forestry and plants horticulture crops. The part it not yet explored for human settlement but the approach is from the indigenous population of Arunachal Pradesh. The scenario of the lower Jiadhal basin is different; it is totally based on agro-economy. The main influence if its change is the natural hazards like floods, erosion and siltation. The flood creates havoc to the agricultural population of Jiadhal plain, as it is hazardous phenomena ruining the agriculture, fisheries, individual properties even life. The siltation is the main problem apart from flash flood of the area studied. The river course shifting is a major problem for the agriculture and which submerges a huge plot of cultivable land into desert like sand deposits. Dulung Kan has the high aerial extension of 323.5 hectares with 161.8 hectares of net sown area and 122.2 hectare of current fallow land. Out of 115 main working populations, main worker is 88 against 122 marginal worker (industrial) population reflects the agriculture is no longer remain the lifeline of the village. Dihiri Chapori has 297.2 ha. land area comprising 117 ha of net sown area, 86.2 ha. of current fallow and 23 ha. of culturable west land is perennially affected by flood. Dihiri Panitula has 148.6 ha of net sown area and 123.9 ha of current fallow with only 32 cultivators out of 219 main working population and 126 marginal worker. Whereas the No. I Kachukhona has 138.4 ha. comprising 40 ha net sown area, 44 ha fallow land including current fallow with, only 5 main workers and 177 marginal workers out of 182 main working population of the village. The occupational structure shows a clear picture of the socio-economy of the population and the impact of the land use pattern. The marginal working population includes the Cultivators (industrial) the population engage in cash crop cultivation, Agricultural Labourers of daily wagers and seasonal agricultural labourers and Household Industrial worker composite population adopt cottage industries as their livelihood including weaving, carpentry, constriction workers etc.

Environmental consequences of agricultural activities is less in Upper Jiadhal Basin as the basin is free from human settlement, but human intervention of in the natural ecology of the Upper Jiadhal basin led to the degradation of the natural vegetation coverage. Lumbering in the name of agroforestry is prominent in the upper basin. The need and intensity of acquiring timber from the natural forest region with less care led the degradation of the forest ecology and simultaneously the geomorphological processes get activated in accelerating rate due to access to weaker section of the lithology. Natural landslide, soil erosion and forest fire in form of shifting cultivation are the other factors affecting environment degradation on the upper Jiadhal basin.

The Lower Jiadhal Basin consists of piedmont hills and an extensive flood plain with low and uniform elevation, with increasing number of settlement more land is acquired for increasing demand of agricultural land led the clearance to natural forest into agriable land. The land use and land coverage of the lower Jiadhal river basin is more or less in vulnerable situation due to the increasing population pressure and well as from the natural phenomenon of flooding and siltation or sand casting by the river system.

The consequences of environmental hazards are reflected by the land loss of the villages due to flood and siltation. In 150 villages surveyed 23 villages are situated within 2 km buffer zone with 1569 household and 8881 population affected by flood and siltation out of 2388 households and 13590 population. The land loss statistics within 2 km buffer zone shows 510 (72%) household loss 2 bighas, 157 (22%) loss upto 6 bighas and 31(4.4%) losses 8 bighas and 8 (1.1%) losses 10 and more than 10 bighas of land in flood. The land loss of 4 km buffer zone is rated second with 231 (65%) household loss 2 bighas, 81(23%) loss upto 6 bighas and 20 (5.7%) losses 8 bighas and 8 (3.1%) losses 10 and 10 (2.8%) more than 10 bighas of land in flood consequences. The 6 km buffer zone is less affected by flood even though it has recorded the land loss of, 69 (67%) household loss 2 bighas, 14 (14%) loss upto 6 bighas and 12(12%) losses 8 bighas and 8 (7.8%) losses 10 and 10+ bighas of land. The 8 km buffer zone is free from worst flood affects with 12 household loss 2 bighas and 3 households' losses 6 bighas of land. The villages within 4 km buffer zone is more affected by flood siltation.

The headwater has major impact on both the sustainable development of the headwater region as well as those who live downstream. The upper catchment of Jiadhal river basin is dominated by high reliefs and undulating terrain comprising the Siwaliks range of Arunachal Himalayas, which ranged from 200 to 1400 meters above mean sea level. The region is very less populated and has a very rich biodiversity. The region experience local precipitation system in supplementary to the monsoonal regime, which influence the quantity of rainfall in locality and produces a peak flow in the rainy days. Sido is fourth order stream having 169 first order, 38 second order, and 9 third order stream with a total of 217 streams occupying 106.62 sq.km of area. Sika has 77 first order, 16 second order, 4 third order and 2 fourth order stream projecting it as fifth (5^{th}) order stream comprising total 100 streams with an aerial extension of 46.96 sq.km. Siri comprises 193 first order, 74 second order, 16 third order and 2 forth order stream with a total of 286 streams occupying 172.66 sq.km of area. Jia-Up is sixth order stream and has aerial extension of 34.17 sq.km with 64 first, 16 second and one third order stream comprising 82 total streams. The vegetative coverage of the headwater indicated that the region has much contribution to water recharge of the headwater catchment. The upper and middle catchments have an average density of 2.5 trees per 20 meters with heavy undergrowth. The lower catchment occupy by open scrub with lowest tree density of 1 tree per 20 meters of area. The vegetation canopy varies with locality, the trees in higher ridges has 6 meters of radius whereas the valleys have highest canopy of 4 meters of radius. The tree canopy in the open scrub area has 2 meters of radius. The vegetation coverage of the region reflects that the soil thickness is well developed in the region. The headwater catchment of Siri has observed highest soil thickness of 2.7 feet depth with an average depth of 1.8 feet of soil mainly composed of Silty loam with 70% silt and 30% sandy soil in average. Sika soil thickness ranged 0.6 to 1.8 feet of depth, composed of loam. Sido headwater areas comprise 0.8 to 2.2 feet of soil depth and mainly compose of sandy loam. Whereas Jia headwater catchment has soil depth ranging from 0.5 to 2 feet and mainly composed of loam. The soil is prone to erosion due to vegetation loss and fragile lithology and thus contributes huge amount of silt to the drainage runoff.

Environmental Services of Headwater Catchment of Jiadhal is found to be active on supply fresh water, replenish ground water, support biodiversity, provide resources to entire basin. The upper basin has 98 % land cover under forest comprising 52% of dense forest and 46% of degraded forest (LULC, 2009) which fulfill the basic requirement of the indigenous population inhabited the region. The main forest product is timbers, firewood, bamboo, cane, toko leaves, various medicinal plants, orchids for day to day life. The wild fruits, birds, animals and fishes have ethnic importance in tribal population living the region. The stream runoff is lower in winter than in summer due to high precipitation triggers the regulating services. The headwater catchment with more vegetative coverage allows infiltration to aquifers than areas having bare exposed rock. Headwater cultural services covers the traditional practices of the indigenous population of Arunachal (Galo tribe) for using it acquire raw materials for house made of available forest raw materials like cane- bamboo, timber, toko leaves as building materials and firewood, food and shelter, fish and wild animals for hunting etc.

The physiography of headwaters of the basin reflects the nature of stream properties including the sediment sources of the stream. The headwater catchment is dominated in the mountainous region having elevation between 400-700 meters compiling 41%. The Highlands (200-400 m) compiles the second dominating physiography consisting 47.35 sq.km (33%) of the headwater area, with 145 dominating catchments. Siri and Sido has highest share of highland whereas Sika has lowest share only 2.02 sq.km. The High Mountainous region occupies 25.87 sq.km (18 %) consisting 89 headwater catchments. Piedmont region occupies 9.81 sq.km (7%) and comprises 50 headwater catchment mainly situated in the foothill areas. Siri has 1.78 sq.km comprising only 6 headwater catchments is the highest water source of the entire catchment. In general, headwater stream discharges are greatest during the summer and rainy seasons when local and monsoon regimes prevail and when evapotranspiration is at its lowest. The seasonal variation of rainfall in the upper catchment of Jiadhal basin determines the surface runoff of the stream. The July month recorded highest 727 mm in the year 2018 in foothill of Jiadhal river basin and heavy rainfall concentrates the month of April to September with intense cloud burst.

The discharge in headwater regulates the environmental phenomenon of the upper catchment. The water discharge in catchment outlet is the outcome of the headwater catchment. Siri outlet at confluence drained the highest share of water among the three tributaries of Upper Jiadhal Basin. Contributing 141.35 m^3/sec. and estimated to be draining out 3392.47 m^3/day to 51593.82 m^3/year of mean discharge. Followed by Sido outlet contributing 77.67 m^3/sec. of mean discharge draining 1864.18 m^3/day and an estimation of draining a total of 28351.04 m^3/year. Sika contributes the lowest, mainly due to smaller catchment area compiling mean discharge of 43.13 m^3/sec. and estimated to drain out 1035.22 m^3/day and a total of 15743.93 m^3/year. The confluence of the Sido, Sika and Siri at tri-junction (Tinshuti) projects the Jiadhal to piedmont areas at Jiadhal Mukh. At Jiadhal much the drainage disposes 290.75 m^3/sec. and estimated to be draining out 6977.93 m^3/day and compute to 10,61,22.72 m^3/year of mean discharge with tedious amount of silt and sand in the extensive flood plain.

The environmental assessment of the selected headwaters is carried out with online Google earth image and to hey a real picture the year 2012 and 2019 was selected to evaluate the changes. The Jia catchment (479), which is an old degraded fault line, has low stream runoff during dry season and the increase in surface runoff in wet season accelerates the erosive power ultimately. During January, 2012 the catchment has fine green tone representing low scrub and grasses in the upper areas which is eroded and exposed to stream flow in November of year 2019. On the other hand the Sido, Shortcut headwater catchment (138), has defined new eroded stream valley during January, 2012 along the stream line and the re-generation of vegetation is observed with more bright tone in exposed soil, reflects that he valley deepening is active and new areas are eroded. This explains the environmental changes in the headwater are not only natural but also anthropogenic in nature mainly due to cutting of trees for timbers and collection of bamboo and cane from the stream sides. The Siri, Middle line watershed catchment (284), is explored extensively as the areas is bare exposed in patches which indicate it is human induced degradation and the areas is rejuvenated vegetation till, November, 2019. This indicates the watershed is left untouched during the time span as there was no suitable large size tree left.

The sustainable development of the headwater catchment is the product of a joint process of management of the environmental and geomorphological elements active in the region. Measures for sustainability of headwater catchment includes, measures for reduction of soil erosion, landslide events, regulate surface runoff, reduce stream load, increase infiltration to ground water or mountain aquifer, increase vegetation coverage and to enrich natural springs.

Watershed management is a continuous process involving the management of land, water, environment and other resources as well as socio-economy of development. Integrated Watershed Management is one of the products of the man-nature relationship. It is the process of creating and implementing plans, programs and projects for sustainable development of a geographical unit within a watershed boundary including its services for the community development. The environmental sustainability of watershed is possible only through an integral management processes in consideration of all the factors dominating the watershed.

The Upper Jiadhal Basin is occupied by the rough and lofty mountain ranges with deep down cut valleys with different magnitude of landforms associated with the dynamic fluvial action of a river system during the youth stage of its life span. The rivers are mainly rainfed and the water is naturally occur from springs which are prone to dried up during winters. The major concern in the upper basin is the topography and difficult accessibility to upper reaches, as there is no transport facility. Deforestation is the prime concern led to issues regarding the activation of sediment source areas, massive landslides, soil erosion, slope failures and subsequent sediment loads in the river which is the cause of frequent floods in the lower basin.

The Lower Jiadhal River Basin is associated with piedmont areas and flood plain produced by the active drainage system. The river course is associated with siltation problem due to low slope gradient. The river course is turbulent in the upper basin and flows through a deep gorge to the extensive plain. It is sallow in the plains and often flowing above the altitude of adjoining areas or the flood plains in the northern part of the lower basin. River braiding is common phenomenon during dry and in wet season river shifting due to failure or bleaching of embankment is common. The low lying areas of the lower basin are always remained water logged and have permanent wetland or swamps. The socio-economy of this area is greatly influenced by the natural calamities flood hazards in the watershed, including high rate of siltation and sedimentation, soil erosion, water logging, fluctuating water table and floods.

Integrated Watershed Management with collaboration of both the state is the prior concern to cope up with natural hazards including land and water degradation and accelerated soil erosion, flood, siltation and sedimentation. It includes the integration of many stakeholders like soil conservation, afforestation, minor irrigation, crop production, tree plantation, fodder development and other development activities including human development for economic sustainability within an aerial extent of watershed. The sustainable development of the region requires the management and control over soil erosion, massive land degradation due to bank erosion, flood and its other affects.

On the basin of their work, it may be classified under non-structural and structural, the non-structural methods to mitigate the flood damages and structural measures are found to be appropriate in Lower Jiadhal basin along with the other measures. It includes (i) Creation of reservoir to accommodate excess water logging, (ii) River course deepening to generate firm channel flow, (iii) Sand and gravels quarry in river course to increase river depth, (iv) Diversion of flood waters to other basins to manage high discharge, (v) Construction of flood embankments reduces bleaching, (vi) Construction of spurs, groynes, studs etc. restrict river bank erosion, (vii) Construction of bank revetment along with launching apron attain sustainability, (viii) RCC porcupines in the form of screens, spurs, etc. reduce flow impact in banks, (ix) Vetivers, Newwebs, geo-bags etc as well as natural vegetations and (x) Preparedness to flood and after flood impacts including transport and communication.

Considering environmental geomorphological and land use land cover analysis, the management plan evolved for lower Jiadhal basin includes forest management, Agroforestry in vulnerable areas, Agricultural development for decreasing fallow agricultural land, Flood management for the river bank erosion and river flow, Rainwater harvesting for stable water level, Wetland management for control water logging problem and landscaping (residential) for infrastructural development and river deepening by sand quarry in river bed during dry season.

Few vulnerable sites are considered for field survey and strategic plan development in the lower Jiadhal basin and the outcome are discussed as, The Middle course below railway bridge to Na-nadi tributary. The area is characterized by high peak flow and bulging of river water due to narrow passages in the RCC Bridge points. The No.1RCC Bridge (Jiadhal Bridge), at NH15 is sallow due to depositional activities of the river system, the height of the bridge is ranged from 1.4 to 2.8 meters, with a an average height of 2.1 meters in dry season. The length of the bridge is only 200 meters. The river deepening is important factor of flood management, during winter or dry season the sand and stone quarry should be practiced judiciously along the river course to maintain the river depth. The infrastructural requirement of road to excavation sites of sand in the river. Road link to quarrying should be permanent so that it cannot hamper the embankment and the river bank while quarrying in the river bed.

The No.3 RCC Bridge along Bordoloni to Ghilamara road is another critical area in the Middle course of Jiadhal river. The flooding in the year 2017 responded worst, as the river course got diverted to leftward by bleaching the embankment near Gohaingaon in front of the Jungle Block village. The embankment should have permanent road communication system for the sand quarry as the heavy vehicles (Turks. Tractors, Dumper etc.) would be trafficking and could damage the embankment if it is not according to planned infrastructure.

Confluences of Na-Nadi to mainstream and the low lying wetlands are other vulnerable sites with alarming cases of lower Jiadhal river course. The structural engineering on both side of the river bank and embankment could solve the problem. The problem could be undertaken by wetland management, which will not only solve the water logging but also stable the aquatics biodiversity as well as socio-economy by fish rearing by the inhabitants.

All above the discussed measures the vital role in planning and management is played by the techniques and measures adopted for the assessment of environmental and social impacts of the area. The planners should undergo such impact assessment analysis to module a suitable strategic plan for the sustainability of the watershed. The common hurdles in between are lack of transparency and public awareness and participation in the decision making process, as long term planning is not done as per the requirement of the basin. A thorough cumulative environmental impact assessment needed to be carried out over the river basin to estimate the carrying capacity of the river system and to provide adequate safeguard to the downstream. The short term projects to mitigate flood hazards are also important in respect to the availability of the economy for such plans; the investigation of environmental geomorphology could provide the base for such planning and implementation. The integrated watershed management approach for the river based on the principles of soil and water conservation as well as sustainable development needs to be adopted. Proper assessment of various hazards such as flood, erosion, sedimentation, channel migration based on their impact and vulnerability, empowering of local population, employment generation and improved public private partnership programmes are very much essential for this purpose. As a long term strategy for resource utilization and hazard management, a judicious use of structural and non structural measures need to be undertaken. The challenge before the public decision makers in Jiadhal river basin includes the interstate coordination of plan and management within Assam and Arunachal Pradesh for the quest of sustainable development of environment and socio-economy of the region.

Findings

- ✓ The upper Jiadhal river basin is prone to degradation, forest exploration, landslide, soil erosion.
- ✓ The Siri sub-watershed is highest sediment source followed by Sido and Sika.
- ✓ Sika Sub-watershed has high typography do free from fine sediment deposits in the river course.
- ✓ Vegetation cover influence the headwater of the watershed, less vegetation prone to erosion and larger surface flow in rainy season led to mass wasting.
- ✓ Springs have fluctuating surface flow during seasons, likely to dry op during winters.
- ✓ Vegetation in Headwater help to aquifer replenishment, as seepages is observed in fault lines.
- ✓ Siltation and sedimentation of river bed in lower Jiadhal river basin led the river bed rising even flow above the flood plain.
- ✓ Sallow river depth responsible for frequent shifting of channel of the river.

- ✓ The water table of southern part of lower Jiadhal river basin is stable, as rivers have more surface flow due to new tributaries.
- ✓ The earthen embankment is prone to bleaching, due to foot loosing phenomenon in the river side.
- ✓ Embankments are often used for transport purposes, so prone to erosion.
- ✓ Narrow passage of water in RCC Bridges (No.1 and No. 3) led natural damming of river water in peak season, led to accelerate stream capacities beyond the bridges.
- ✓ Sand quarry in river bed is beneficial for both river bed deepening and landscape development in winter season to accommodate new sediment and river flow in forthcoming peak season.
- ✓ Wetlands are not managed led to water logging in agricultural fields as well as residential areas.
- ✓ Drainages in lower Jiadhal basin often overflow from its bank and captures the lowlands to waterlog.
- ✓ Transport facility is less in the lower Jiadhal River basin across and along the river side's.
- ✓ Agriculture is the main occupation both upper and lower Jiadhal river basin.
- ✓ Increasing fallow land and sand casted land is an alarming issue of agricultural sustainability.
- ✓ Phobia of flood led the inhabitant of lower Jiadhal river basin to have less interest for large scale agriculture.
- ✓ Alternate occupation apart from agriculture is demanded in the area, which is less in opportunity in rural scenario of Assam.

Suggestion

- ✓ Forest conservation, afforestation of degraded forest cover for economic benefit like agro forestry could balance the environmental geomorphology as well as the social needs of the upper Jiadhal river basin.
- ✓ Structural designs could be adopted to reduce sediment flow and soil erosion in the headwater.
- ✓ Agro forestry should be boosted in vulnerable sites to reduce surface flow and conserve soil erosion as well as to increase infiltration.
- ✓ Structural measures of flood management in lower river basin is recommended to have sustainable river flow to reduce frequent shifting of river and river bank erosion.

- ✓ Sand quarry could be authorized in river bed to river depth and flow.
- ✓ Plantation of trees along the embankment is an alternative to boost agro-forestry as well as sustainability of the earthen embankment.
- ✓ Road transportation should accompanied to embankment, in selected sites for communication and also for sand quarry from the river bed.
- ✓ Wetland management should be implemented to overcome water logging in lower Jiadhal river basin.
- ✓ Linkage of drainage system in lower basin should be accompanied with structural measures, so the overflow to agricultural fields could control in peak season.
- ✓ The road transportation facilities along with drainage could solve the water logging problem for the lower Jiadhal basin area.
- ✓ Rain water harvesting and wet land management could solve the increasing fallow land in the lower Jiadhal river basin.
- ✓ Agroforestry in the degraded land along river side could stabilize to soil conservation of the lower basin.

BIBLIOGRAPHY

Abriak, N.E, Pajany, Y M, Proulhac, N and Tivard, P. (2015): Beneficial use of dredged sediments in road engineering, methodological guide, CD2E, Ecoles des Mines de Douai https://sednet.org pp-8-10(accessed on 31 August 2019)

Acharjee, S and Mili, N.: The Importance of Geomorphology in Understanding Natural Hazards with Special Reference to Hazards of The Dhansiri River Basin in The Golaghat District of Assam, India, www.academia.edu (assessed on 31Aug2019).

Acharya, S.K. and Saha, P. (2013): Age and Tectono-Megmatic satting of Abor Volcanics, Siang Window, Eastern Himalayan Syntaxial Area, India. Journal of Applied Geochemestry, Vol. 15, No. 2. pp.170-192.

Alagundagi, A. N., (2018). A study of watershed development in north karnataka with special reference to Vijayapura and Gulbarga district, (Ph.D Thesis), sudhganga, pp-11-48 (accessed on 15/10/2018).

Alexander,R. B. Boyer, E.W, Smith, R.A, Moore, R.B (2007): The Role of Headwater Streams in Downstream Water Quality, https://doi.org/10.1111/j.1752-1688.2007.00005.x) (26 January 2007).

Alvarenga, L. A, Mello, C. R, Colombo, (2016): Hydrological responses to climate changes in a headwater watershed, Cienc. agrotec. vol.40 no.6 Lavras Nov./Dec. 2016, S1413-70542016000600647 (accessed on 02/09/2019).

Anderson, G. D, and Herlocker, D.J (1973): Soil Factors Affecting the Distribution of the Vegetation Types and Their Utilization by Wild Animals in Ngorongoro Crater, Tanzania, J*ournal of Ecology*, Vol. 61, No. 3 (Nov., 1973), pp. 627-651 (25 pages).

Ansari, A,S (2003): Influence of Forest on Environment,The XII World Forestry Congress, Quebec City, Canada. 1018-B2, http://www.fao.org/3/XII/1018-B2.htm

Ariza, C., Maselli, D. and Kohler, T. (2013): Mountains: Our Life. Our Future. Progress and Prospective on Sustainable Mountain Development from Rio 1992 to Rio 2012 and Beyond. Swiss Agency for Development and Cooperation (SDC), Centre for Development and Environment, Bern, Switzerland.

Ashaolu, A. B, Patrick L., Owen, Lewis A., Sharma, Milap C. and Finkel, Robert C.(2001): Natural and human-induced land sliding in the Garhwal Himalaya of northern India, Geomorphology, Vol. 40, pp. 21-35.

Barrow, C. J (1998): River Basin Planning and Development: A Critical Review. WorldDevelopment, researchgate.net/publication/22247473726(1)(1):171-186 · January 1998 *with*753 Reads.

Bartarya, S.K, (1991): Watershed Management strategies in Central Himalaya: The Ganla river basin, Kumaun, India. Land Use Policy, Vol.8, No.3, pp.177-191.

Batis, I.,& Ahmed, S.A., (2014): Evaluation of Morphometric Parameters – A comparative study from Cartosat DEM, SRTM and SOI Toposheet in Karabayyanahalli sub-watershed, Karnataka, International Journal of Research (IJR) Vol-1, Issue-11, ISSN 2348-6848, pp-679-688.

Biswas, S.P.(2015): An Overview on the Threats of Aquatic Ecosystem in Upper Brahmaputra Basin, IUCN,River of Life, Proce. of International Symposium on River Biodiversity: Ganga-Brahmaputra-Meghna River System, pp.46-53.

Bebarta. K.C, (2004). Forest Resources and Sustainable Development, Principle, Perspectives and Practice, Concept publishing com. New Delhi, ISBN-8180698954, pp-436.

Bello, I.E., Adzandeh, A., & Rilwani, M.I. (2014): Geoinfromatics characterisation of Brainage system within Muya watershed in the Upper Niger Drainage basin, Nigeria, International Journal of Research in Earth & Environmental Sciences, (https://www.academia.edu) Vol.2.No.3 pp.18-36.

Bhuvan: Indian Geo-Platform of ISRO/NRSC, bhuvan.nrsc.gov.in(ISRO), https://bhuvan-app3.nrsc.gov.in/data / download/index.php.

Bloom, A.L. (1979): Geomorphology: A systematic analysis of Late Cenozoic landforms. Prentice Hall of India, Pvt. Ltd., New Delhi, pp. 16-170

Briney, A (2020): "Geography of the Ganges River." ThoughtCo, Feb. 11, 2020, thoughtco.com/ganges-river-and-geography-1434474.
Brmudoi, A. (2015): From Crisis Management to Mitigation Jia Dhal Basin, Dhemaji, conference paper, Research Gate. e-publication, https://www. researchgate.net/ publication/287999393 .
Bora, A.K. and Goswami. D.C, 2016: Thesis: Jia bharali river of Assam a study in fluvial geomorphology, Shodhganga @ INFLIBNET link: http:// hdl.handle.net/10603/69153.
Borbora, M and Post, M, (2008): Quest of a Script, North East Indian Linguistics, ResearchGate: DOI: 10.1017/UPO9788175968431.017, pp. 255-270.
Borthakur, B.C. (1998): Sustainability in crop production: The challenges in North East India. National seminar on Management strategies of North Eastern Hills Ecosystem. ICAR, Research complex for NEHR, Umiam -8-10th August 1998, pp- 57.
Boruah, J.K.(2000): Geomorphic study of lower Subansiri basin, Assam, Suodhganga.net, http://hdl.handle.net/10603/61665, pp-9-160.
Burley. M. (1961): Land Use and Land utilization, online library. wiley.com. Http://doi.org/10.1111/j.0033-0124.1961.136_18x.
Burton, I., Kates, R.W., (1964): The perception of natural hazards in resource management. Nat. Resour. J. 3, 412– 441.
Caine, N. (2004): Mechanical and chemical denudation in mountain system, Owens, Philip & Slaymarker, Olav (ed.) Mountain Geomorphology, Edward Arnoid Pub. ltd, pp 132-152.
Cengiz, A. E. (2013): Impacts of Improper Land Uses in Cites on the Natural Environment and Ecological Landscape Planning. ADVANCE IN Landscape Architecture (et.al), DOI:10.5772/55755.
Chakrabarti, B.K (2000): Geology of the Himalayan Belt, Deformation, Metamorphism , Stratigraphy, ELSEVIER, ISBN: 978-0-12-802021-0, pp-145-248.
Chennaiah. C. H, H. Dutta and S. K. Dutta. (1998): Remote sensing application for sustainable development of land resources- A case study of Pasighat area. Perspectives for Planning and Development in North East India, GB Pant Institute of Himalayan Environment & Development, Almora India. Pp.32-39.
Chorley, R.J. (2019): Spatial Analysis in Geomorphology (et.al), Routledge, Taylors & Francis Group, New York. p374,pp. 3-16.
Chorley, R.J. (1965): Introduction to Geomorphological Hydrology (ed.) Methun Landon, pp. 1-316.
Chorley, R.J. (1967): Water Earth and Man. Methun Landon, pp. 1-193.
Choudhury, S. and Sen, N. 1977. On a collection of fish from Arunachal Pradesh with some new records. Newsletter Zoological Survey of India, 3(4): 217-223
Clarke, J.I. (1966): “Morphometry from maps.” In Essays in Geomorphology, edited by G.H. Dury, 235-274. American Elsevier Publication. New York.
Clawson. M and Stewart. C.L. (1965): Land Use Information,Natural Resource Journal, Baltimore: The Johnes Hopkines Press. pp-359.
Crevennaa, A. B., Rodríguez, V.T., Sorani, V., Frame, D. and Ortiz, M.A. (2005): “Geomorphometric Analysis for Characterizing Landforms in Morelos State, Mexico.” *Geomorphology* 67: 407–422.
Coggin Brown. J (1912): A geological reconnaissance through the Dihing valley being the geological result og the Abor Expedition. Rec. GSI. Vol-42, pp-232-264.
Cook, M.J., and King, J.G. (1983): Construction cost and erosion control effectiveness of filter windrows on fill slopes. US Dept. of Agriculture Forest Service. Research Note INT-335, Intermountain Foest and Range Experiments Station, Ogden, Utah. 5 p.
COST, (2019): Smart management of headwater catchments, COST, European corporation in Science and Technology, COST Association AISBL, office @ cost.eu, www.cost.eu.
Cowie, R. M., John, F. K, Kelsey R. Dailey, Mark W. Williams Taylor J. Mills, Noah, P. M. (2017): Sources of stream flow along a headwater catchment elevational gradient, Journal of Hydrology 549 pp-167-178https://www.researchgate.net/publication.

Cushing. C.E, Cummins, K.W. and Minshal,G.W (2006): River and Stream Ecosyatems of the World,: With a New Introduction, University of California Press, pp-832.

CWC, (2004) : Handbook design of flood protection, anti erosion measures and river training works, CWC, Patna, 2004 pp-1-72.

CWC (2011): Handbook for Design of Flood Protection, Anti Erosion Measures and River Training Works, GOI,CWC, New Delhi, 9-5.pp-104.

Das AK, Mukherjee, S. (2005): Drainage morphometry using satellite data and GIS in Raigad district, Maharashtra. J Indian Soc Remote Sens 65:577–586.

Das, P. J. (2012): Jiadhal River Catchment, Assam, India: Building community capacity for flash flood risk management, Aranyak (NGO) report on Case studies of flash flood risk management in the Himalayas.pp-24-30.

Dalai, T. K. (2001): Major ions stable isotopes Sr and Re in the headwaters of the Yamuna Implications to chemical weathering in the Himalaya, Shodhganga@INFLIBNET,http:// hdl.handle.net/ 10603/6076, xvii, 183p.

Damilola, A.E. (2016): The Osun Drainage Basin in the Western Lithoral Hyfrological Zone of Nigeria: A morphometric study. GEOGRAFIA, Malaysian Journal of society and Space. Vol-12, No-8, pp-71-88.

De Tapia, E.M. (2012): Silent hazards, invisible risks: Prehispanic erosion in the Teotihuacan Valley, Central Mexico. In: Copper J, Sheets P (eds) Surviving sudden environmental change: understanding hazards, mitigating impacts, avoiding disasters. University Press of Colorado, Boulder, pp 143–165.

Del Compo, A., Fernandes, T. and Molina, A. (2014): Hydrology-oriented(adaptive) Silviculture in semiarid pine plantation: How much can be modified the water cycle through forest management? Eur, J. For. Res., 113:879-894.

Devi, S. (2015): Geoenvironmental Characteristics of Eastern And Western Himalayas A Comparative Study Of Subansiri And Alaknanda River Basins, Shodhganga, http://hdl.handle.net/ 10603/135281.pp- 116.

Dikshit, K.R and Dikshit, J K. (2014): North-East India: Land, People and Economy, Advance in Asian Human-Environmental Research, Springer, New, York London, ISBN-978-94-007-7055-3(e-Book), pp. 800.

Dhital, M.R. (2015): Geology of the Nepal Himalaya: Regional perspective of the classic collided orogen, ResearchGate: DOI: 10.1007/978-3-319-02496-7.

Doula, M.K. and Sarris, A. (2016): Environment and Development Basic Principles, Human Activities, and Environmental Implications, ELSEVIER,https://doi.org/10.1016/B978-0-444-62733-9.00004-6. Pages 213-286.

Dudey, A. (1990): Environmental geomorphology: a study of Trans-Yamuna region, Inter-Indian publication, 1990, c 1986,ISBN: 8121002443, pp-59-64.

Dutta, C. K. (2020): Socio-Economic Sustainability of ST Population of Dholapara, Michamari, Bordoloni Development Block, Dhemaji, Assam, IJSRDV7I110023, Volume : 7, Issue : 11, pp-235-238.

Dutta, P (2013): Biometrical and Biochemical Evaluation of Indigenous Rice Cultivars of Dhemaji District of Assam. Ph.D thesis Shodhganga@INFLIBNET, http://hdl.handle.net/10603/32798, pp-213.

Earman, S., Campbell, A.R., Phillips, F.M., Newman, B.D.,(2006): Isotopic exchange between snow and atmospheric water vapor: Estimation of the snowmelt component of groundwater recharge in southwestern United States. J. Geophys. Res. 111, D09302. http://dx.doi.org/10.1029/ 2005 JD006470.

Ehrlich, P. R. and Mooney, H. A., (1983): Extinction, Substitution, and Ecosystem Services, BioScience, Vol. 33, No. 4 (Apr., 1983), pp. 248-254, University of California Press on behalf of the American Institute of Biological Sciences : http://www.jstor.org/stable/1309037 . (accessed on 24/09/2013 11.46)

Elsoghier, M. (2018): Morphometric Analysis of a selected drainage system in the northern part of the Western Desert of Egypt. International Journal in Physical and Applied Sciences Volume 5 Issue 08, ISSN: 2394-5710, pp-23-31.

FAO, (2006): The new generation of watershed management programmes and projects. FAO forestry Paper 150.Foof and Agriculture Organization of the United Nation, Rome.

Freeman, M. C., Pringle, C. M. & Jackson, C. R. (2007) Hydrologic connectivity and the contribution of stream headwaters to ecological integrity at region scales. J. Am. Water Resour. Assoc. 43, 5–14.

Furkumzuk, C. Rawat, M.S. 2012: Environment, Development and Prospects of Sustainable Development in Nagaland: Indian Journal of Environmental Studies, ISSN: 2278-8220 Vol-01, issue-01,september, 2012. pp 10-25

Fukushima, Y. The Role of Forest on the Hydrology of Headwater Wetlands, NATO Science Series: IV: Earth and Environmental Sciences book series (NAIV, volume 63) Environmental Role of Wetlands in Headwaters pp 17-47

Gares, P.A., Sherman, D.J., Nordstrom, K.F., (1994): Geomorphology and natural hazards. Geomorphology 10, 1– 18.

German L, Mansoor H, Alemu G, Mazebgia W, Amede T, Stroud A(2007), Participatory integrated watershed management: evolution of concept and methods in an ecoregional program of the eastern African highlands, Agric Syst 94:189-204.

Ghimire, S. K. , Higaki, D. and Bhattarai ,T. P., (2013). Estimation of Soil Erosion Ratesand Eroded Sediment in a Degraded Catchment of the Siwalik Hills, Nepal, *Land* 2013, *2*, 370-391; doi:10.3390/land2030370 (www.mdpi.com/journal/land/)pp-370-391.

Ghosh, A. M.N. (1956): Resent advance in geology and structure of eastern Himalayas, Proceeding 43rd Sess. Indian Sc. Congress, pt 2 pp85-99.

Graça, M.A.S.; Ferreira, R.C.F.; Coimbra, C.N.(2001): Litter processing along a stream gradient: The role of invertebrates and decomposers. J. N. Am. Benthol. Soc. 2001, 20, 408–420.

Gogoi, C., Goswami. D.C.,and Phukan. S.(2013): Flood risk zone mapping of the Subansiri sub-basin in Assam, India, International Journal of Geomatics and Geosciences, Volume 4 Issue, pp-2-13.

Gogoi, S and Chetia. B.C., (2011): Fuzzy role-based flood forecasting method of Jiadhal River Basin Dhemaji, Assam, India. International Journal of fuzzy Mathematics and System. www. ripublication.com , Vol.-1 No-1 pp. 59-71.

Gorucu, O, (2017): Headwater Catchments : Foundation Pillars for Ecosystem Services. Křeček & Haigh at al, Ecosystem Services of Headwater Catchments https://www.springer.com/gp/book /9783319579450 (accessed on 31 August 2019).

Goswami, D. C.(1972): Regional Flood Frequency Analysis of Brahmaputra Basin in North East India, Jr. of Inst, of Engineers (India), Vol. 77 pp. 564-617.

Goswami, D. C. (1982): Brahmaputra River, Assam, India: Suspended Sediment Transport, Valley Aggradations and Basin Denudation, Unpublished Ph.D. Thesis, The Jhon Hopkins University, Baltimore, USA Goswami. D. C., (1998): Fluvial Regime and Flood Hydrology of the Brahmaputra River, Assam, In: Flood studies in India, Lle, V.S. (ed). Memoir 41, Geographical Society of India, pp.-53-75.

Goswami, D. C. (1985): Brahmaputra River, Assam, India; Physiography, Basin Denudation and Channel Aggradations, Water Resources Research, Amex Geophys Union, Vol. 21, No. 7, pp. 959-978.

Goswami, D. C. (1988): Magnitude and Frequency of Fluvial Processes in the Brahmaputra Basin Assam: Geomorphology and Environment. Allahabad Geological Society, Allahabad, 203-211

Goswami, D. C. (1989): Stream Power, Bed form and Grain Size Relationship in Rivers; A Case Study from Brahmaputra River, Assam, Journal of Assam Science Society, Vol. 32, No. 1, pp. 31-37

.Goswami, D. C. (2003): Interlinking of Indian River: The Plan and its Implication, Proceedings of the National Seminar on Linking the Major Rivers of India: Possibilities and Apprehensions, Organised by AsSam Science Society, April 29, 2003, Guwahati pp. 38-45

Goudie, A. (1990): Geomorphological techniques, the British Geomorphological Research Group, Landon (2nd ed.) Unmin Hyman, pp. 1-570.
Gregory, K.G. and Walling, D.E. (1979): Drainage Basin: Form and Processes, Landon Arnold, pp. 1-200.
Gunasekaran. S, 2014, Planning and strategies of watershed management projects – an analytical study in Dindigul district, Tamilnadu (Thesis), The Gandhigram Rural Institute – Deemed University, Tamil Nadu, pp -1-203.
Guerr, A.J.T., and Marcal, M. D, S. (2005): Erosive Processes in Urban Areas in the Island of Maranhao-Brazil, Research Gate, Siciedade and Natureza, Uberlandia, Special Issue, pp-161-173.
Hassan, (2013): Watershed characterization and management planning in Wular catchment,(Ph.D Thesis),University of Kashmir, Srinagar, Shodhganga : a reservoir of Indian theses @ INFLIBNET,http://hdl.handle.net/10603/191345. pp.01-203
Hama, A. M, Sansone, A. Seitz, M, Stötter, J.,: Headwater Resources and Headwater Hazards: Perspectives from Environmental Education Case Study Galtür, Austria A.M., A., M. and J., Environmental Role of Wetlands in Headwaters, NATO Science Series: IV: (NAIV, volume 63) pp 181-202.
Haigh, M. (2010): Headwater control: An agenda for the future. In: Zlatic, M. (ed),Global change: Challenge for soil management. Advance in GeoEcology,41:1-12.
Hazarika, A (2018): An Anthropological Impact Assessment of Flood: A Case Study Of Dhemaji Development Block Assam, PhD Thesis, https://shodhganga.inflibnet. ac.in/handle/ 10603/288152.
Hewlett, J.D.; Nutter, W.L. (1970): The varying source area of stream flow from upland basins. In Proceedings of the Symposium on Interdisciplinary Aspects of Watershed Management, Bozeman, MT, USA, 3–6 August 1970; ASCE: New York, NY, USA; pp. 65–83.
Hofmann.H, Cartwright, I, Morgenstern, U. (2018): Estimating retention potential of headwater catchment using Tritium time series, Journal of Hydrology Volume 561, June 2018, Pages 557-572.
Horton, R.E. (1932): “Drainage basin characteristics”. Trans. Am. Geophysical Union 13: 350-361.
Horton, R.E. (1945): “Erosional development of streams and their drainage basins, hydrophysical approach to quantitative morphology.” Bull. Geol. Soc. Am. 56: No. 3,pp. 275-370.
Hutchinson, J.N. (1977): Assesment of the effectiveness of corrective measures in relation to geological condition and types of slope movement. Bull. Int. Assoc. Eng, Geol.,16,pp 131-155.
Jaiswal, (1997):Major areas, Watershed Management Development Programme, Panchayat Unnati, Newsletter, NIRD, Hyderabad, pp-27.
John, A.K. (2017): Determination of Flood Plain map and run-off computing (Case study of Eleyele Catchment Area), https://www.academia.edu/39509207.
Kanianska. R. (2016): Agriculture and its Impact on Land-Use, Environment, and Ecosystem Services, Landscape Ecology-The influence of Land Use and Anthropogenic Impacts of Landscape Creation (et.al.) DOI: 10.5772/63719.
Kar, M (2012): The Brahmaputra: Flood and Its Preventive Measures, Eastern book Publisher, ISBN-13-9788190781213 pp- 20-230.
Ken, F. and Brent, J., (2011): Headwater system- what are they and what do they do? EPA, Office of Research and Development National Exposure Research Laboratory, Ecological Exposure Research Division. ppp.1-25.
Kattelmann, (1987): Uncertainly in assessing Himalayan Watershed Resources. Mountain Research and Development, 7(3). Pp. 279-286.
Kesari, G.K., DasGupta, G. and Prakash, H.S.M. (2009): Geology and Mineral Resources of Assam, GSI, 30 Part IV Vol 2(i) Assam. pp.51.
Kesari, G.K., DasGupta, G. and Prakash, H.S.M. (2010): Geology And Mineral Resources Of Arunachal Pradesh, GSI, 30 Part IV Vol I(i) Arunachal Pradesh. pp.22-60.

Knap, A.H and Ivan, R (2016): Environment exposes due to Natural Disasters, Rev Environ Health, HHS, Public Access, NIHMS793214 doi-10.1515/reveh-2016-0010.

Konch, K. (2018): The Scenario of Crime in Dhemaji District of Assam: An Analytical Study, MSSV Journal of Humanities and Social Sciences, Vol. 3 N0. 1 [ISSN 2455-7706.

Konwar, S. 2017: Morphometric analysis of the Gai River Basin, NE Himalaya, India. IJAR Journal, http://dx.doi.org/10.21474/ijar01/4578, pp. 1-7.

Kotoky, P., Bezbaruah, J. and Sarma, J.N. (2003): Erosion activity on Majuli – the largest river island of the world; Current Science, Vol.84, No. 7.

Kubalikova, L (2013): Geomorphosite assessment for geotourism purposes. Czech Journal of Tourism,VERSITA, vol-2(2), 80-104. DOI: 10.2478/cjot-2013-0005, pp-80-104.

Krecek, J. and Haigh. J. (2006): Envrironmental role of wetlands in headwaters. Springer. [ISBN 978-1-4020-4226-3].

Krecek, J., Haigh**,** M**.,** Hofer**,** Th., Kubin**,** E., Promper**,** C. (2017): Ecosystem Services of Headwater Catchments, free preview, https://www.springer.com/gp/book /9783319579450(accessed on 31 August 2019).

Krecek, J., Haigh, M., Hofer, T., Kubin, E. and Promper, C. (2017): Ecosystem Services of Headwater Catchments. Springer Netherlands. [ISBN 978-93-81891-36-0].

Khakhlari, M. & Nandy, A., (2016): Morphometric Analysis of Barpani River Basin in Karbi Anglong District, Assam. IJSR, vol-6, No.-10, pp-238-249.

Lal, B. (1998): Sustainable resource management for soil and water conservation on hill ecosystem. National seminar on Management strategies of North Eastern Hills Ecosystem. ICAR, Research complex for NEHR, Umiam -8-10th August 1998, p-20.

Leopold, L. B. and Wolman, M. G.(1957), River channel patterns-braided, meandering and straight, USGS professional paper 282B Li, Tianchi. (2004): Mountain Hazards in China, Owens, Philip & Slaymarker, Olav (ed.) Mountain Geomorphology, Edward Arnoid Pub. ltd, pp 219-241.

Liebke, U., Antolie, B., and Appel, E. (2011) : Indication for clockwise rotation in the Siang window south of the eastern Himalayan syntaxis and new geochronological constraints for the area, Growth and Collapse of the Tibetan Plateau. GS, London, 353, 71-97. DOI: 10.1144/Sp353.5. 0305-8719/11.

Lombi, P., (2015): Shifting cultivation in the foothills-a case study of West Siang district, Arunachal Pradesh, Dutta, C.K. et. al, Biodiversity of North East India, Kiran Prakashan, Dhemaji, ISBN: 9789382746850 pp- 187-198.

Mandira, B. G. and Monimugdha, B.(2014): Impact of Flood and Siltation on Socio-Economy, Impact of Flood and Siltation on Socio-Economy A Case Study of Dhemaji Revenue Circle, District Dhemaji, Assam, Antrocom Online Journal of Anthropology 2014, Vol. 10. No. 2 – ISSN 1973 – 2880, pp.131-135.

Mandych, A. F.(1992): Water Erosion and ediment Yield in Mountain Areas: Natural Preconditions (Krecek and Haigh et al.)pp-148-154.

Mahan, B. (2012): Silk Industry among the Tai-Ahom of Assam, India as an Attraction of Tourist, International Journal of Scientific and Research Publications, Volume 2, Issue 12, ISSN 2250-3153, pp.4.

Meraj, G., Romshoo, S.A., Yousuf, A.R., Altaf, S., and Altaf, F. (2015): Assessing the influence of watershed characteristics on the flood vulnerability of Jhelum basin in Kashmir Himalaya. Nat Hazards 77(1):153–175.

Mc Glynn, B. L, McDonnell, J. J, Seibert. J, and Kendall C, (2004): Scale effects on headwater catchment runoff timing, flow sources, and groundwater-stream flow relations, Water Resources Research, American Geophysical Union, Vol 40-7, Article W07504; 14 p.

Mc Knight, T.L. and Hess, D. (2000): Physical Geography,Alandscape Appreciation,Virtual field trip edition, Prentice Hall,New Jerct,ISBN-0-13-020263-0, p604.

Meixner, T., (2016): Implications of projected climate change for groundwater recharge in the western United States. Journal of Hydrology. 534, 124–138. http://dx.doi.org/10.1016/ j.jhydrol.2015.12.027.

Mili, M. and Nandy, S., (2015): Degradation of Bio-Diversity in Honolgapara Gibbom Wild Life Sentury Jorhat District, Assam, Dutta, C.K. et. al, Biodiversity of North East India, Kiran Prakashan, Dhemaji, ISBN: 9789382746850 pp- 133-146.

Merritte. D. J (2010) : Landscapes on the edge, new horizon for research on Earth's Science, National Research Council, The Nation Academic Press, Washington, pp-164.

Mishra, A.K. and Gupta, S.K. (1998): Land and water resource management strategies for sustainable development of North Eastern Hill Ecosystem, National seminar on Management strategies of North Eastern Hills Ecosystem. ICAR, Research complex for NEHR, Umiam -8-10th August 1998, p-25.

Mishra, S.(1991), Perfornamce Apprisal of a Watershed Project in West Bengal-A Micro Level Study, *Indian Journal of Agricultural Economics, 46(3), 298-299.*

MOA. (1990): Watershed Atlas of India(1:1 million scale), All India Soil and Landuse Survey, Govt. of India, New Delhi.

Mohammad. N (1992): Socio-Economic Dimension of Agriculture, New Dimensions in Agricultural Geography(et.al), Comncept's International Series in Geography, New Delhi. Vol. 3,No.4 pp-20-22.

Morisawa, M. (1985): Rivers (Forms and Processes), Longman, London and New York.

Morley, T.R., Reeve, A.S., Calhoun A.J.K. (2011): The role of headwater wastelands in altering stream flow and chemistry in a Maine, USA catchment. Journal of the American Water Research Association. http://onlinelibrary.wiley.com/doi/: 10.1111/j.1752-1688.2011.00219.x (accessed on 30 August 2019).

MSME, (2014): State Profile of Arunachal Pradesh, GOI, Ministry of MSME, Itanagar, E.Mail:brmsme.itan@gmail.com.pp. 1-114.

North Eastern Council (NEC, 2013): Evaluation of NEC funded projects in Assam "controlling of Jiadhal River in Dhemaji district, Phase I"- November, 2013.

Nyssen, J.; Poesen, J.; Deckers, J.(2006): Land degradation and soil and water conservation in tropical highlands, mekelle, ethiopia. *Soil Tillage Res.* 2006, *103*, 197–202.

Oblitas, K.R.A. (2016): Assam Agricultural Competitiveness Project, Implementation Completion Report (ICR) Review. Independent Evaluation Group (IEG). http://documents. worldbank.org, pp 01-26 (assessed on 09/09/2019).

Offiong, V.E., Uzoezie, A.D & Umoh, R.J. (2018): Spatial Variation of Commercial land Use Rental Value in Southern Calabar, Cross River State, Nigeria-A Quantative Judgement for Planning Intervention, International Journal of Innovative research and Advance Studies(IJIRAS) Vol. 5. No. 1. pp-122-128 .

Oruonya, E.D., Ezekiel, B.B., Atiku. H.G.,Baba. E and Musa, N.I. (2015): Drainage Basin Morphometric Parameters of River Lamurde: Implication for Hydrologic and Geomorphic Processes, Journal of Agriculture and Ecology Research International, https://www.researchgate.net/publication/283341260, pp-1-12

Owens, N., Slaymarker, et al. (2004): Mountain Geomorphology, Edward Arnoid Pub. ltd, pp 313.

Ozdemir, H., & Bird, D.(2009) Evaluation of morphometric parameters pf drainage networks derived from topographical maps and DEM in point of floods. Environ Geol, (https://www.academia.edu) 56;1405-1415.

Parvati G (2014). Performance Management Watershed Programme in the District of Anatpuram of Andhra Pradesh. Ph.D Thesis.

Pahuja, S. and Goswami, D. (2006): A fluvial geomorphology perspective on the knowledge of the Brahmaputra; Background Paper No.3;August 2006: Development and Growth in North East India: The Natural Resources, Water and Environment Nexus, pp.87-90.

Pal, I., Singh, S., Walia, A. 2013, Flood Managemennt in Assam, India: A review of Brahmaputra Flood, 2012. International Journal of Scientific and Research Publication, Vol 3. Is. 10, Oct.2013, ISSN 22503153, pp 5.

Patnaik, S. K. (1993) : Hydrogeomorphologic characterization of Sankh head water catchment (Doctoral thesis) Shodhganga @ INFLIBNET/10603/20985 loded on 22-July-2014. pp 113.

Paul, A. G, Douglas, J.S, Karl, F.N. (1994): Geomorphology and Natural Hazards, Proceedings of the 25th Binghamton Symposium in Geomorphology, Held September,24–25, 1994 at SUNY, Binghamton, USA,1994, Pages 1-18.

Pradhan, B., Mansor, S., Pirasteh, S and Buchroithner, M.F (2011): Landslide hazard and risk analyses at a landslide prone catchment area using statistical based geospatial model. International Journal of Remote Sensing, Vol. 32, No. 14, pp-4075-4087.

Portenga, E.W, Bierman, P.R. (2011): Understanding Earth's eroding surface with 10 Be. GSA Today 21(8):4–10

Puncochar, P and Palan, L.(2017): Environmental security and headwater control in Brazil, Krecek-Haigh et al. Ecosystem Services of Headwater Catchments, pp-127-136.

Ramakrishnan, P.S. (1990): Agriculture system of the North Eastern Hill Region of India. In: Agro-ecology: Researching the ecological basis for sustainable agriculture.

Rao, K.V.S. (2000): Watersheds comprehensive development, B.S. Publications, Hydrabad ISBN:8178000040, PP-1-367.

Rastogi, R. A. and Sharma, T .C. (1976): Quantitative analysis of drainage basin characteristics. Journal of Soil and Water Conservation in India, Vol. 26, pp. 18–25.

Ravindra, M., (2013), Water Balance Drought Analysis and Watershed Development of the Anantpuram District Andhra Pradesh India, (Ph.D Thesis)

Rawat, M.S., (2010): Environment, Tribal culture and Resource management in Kiliki watershed of Zunheboto Hlls, Nagaland, Biodiversity to Biotechnology: Intellectual Property Rights (Kumar, A. & Sas, G. eds),. Narosa Publishing House, New Delhi, pp. 129-160.

Rawat, M.S., (2011): Environmental Geomorphology and Watershed Management. Concept Publishing Company Pvt. Ltd. New Delhi, pp.-1-286

Rawat, M.S., (2014): Prospects of Water Resources Management of sustainable Development in Nagaland. North East India, International Journal of Developmental Studies and Research, V. L. Media Solution Vol. 3 No.2, pp.—123-145.

Rawat, M.S, Furkumzuk, C. 2012: Environment, Development and Prospects of Sustainable Development in the Kiliki Watershed of Zunheboto District, Nagaland: Indian Journal of Environmental Studies, ISSN: 2278-8220 Vol-01, issue-01,september, 2012. pp-26-43.

Rhoads, E. L. & Herricks, E. E. (1996): Naturalization of headwater streams in Illinois. In: River Channel Restoration: Guiding Principles for Sustainable Projects (ed. by A. Brookes & F. D. Shields Jr), 331–367. John Wiley & Sons, Chichester, West Sussex, UK.

Riba. T and Borua, B (2015): Shrinking wetland of Assam:a geographical study of Bordoibaam wetland (Dutta, C.K. et.el) Biodiversity of North East India, Kiran Prakashan, Dhemaji, pp57-67.

Richardson, Douglas; Castree, Noel; Goodchild, Michael F.; Liu, Weidong; Marston, Richard A., eds. (2017). Landforms & Physiography. International Encyclopedia of Geography, 15 Volume Set: People, the Earth, Environment & Technology. Wiley-Blackwell. pp. 3979–3980. ISBN 978-0470659632. Retrieved 2019-09-06.

Robinson, M and Ward, R.(2017): Hydrology, Principles and processes, IWA Publishing Alliance House, London, p-399.

RVC(2017): Rural Volunteers Centre , Annual Flood report, Akajan, Dhemaji, riverbasinfriends@yahoo.co.in.

Sanda. R., Danut P, Loan, F., Luliu V, Sorin, F. (2015): Application of landslide hazard scenarios at annual scale in the Niraj River basin (Transylvania Depression, Romania). Nat Hazards 77(3):1573–1592.

Satapathy, K.K. (2003): Watershed Based Farming Systems As Alternative to Shifting Cultivation in North Eastern Region. Journal of agriculture Engineering ,Vol 40 (1), pp-41-48.
Scheidegger, A.E. (1994): Hazards: singularities in geomorphic systems, Geomorphology, Vol.10, 19–25.
Schumm S.A. (1963): A tentative classification of river channels, U.S. Geol. Survey Circular 477.
Schumm, S.A. (1968): River adjustment to altered hydrologic regimen – Murrumbidgee River and palaeochannels, AustraliaU.S. Geol. Surv. Prof. Pap. 598, pp. 65.
Sharada, V. N. et.al.(2005) { Sharda, V. N., & Ojasvi, P. R. (2005). Water harvesting through watershed management in different agro-ecological regions of India. *Indian journal of agricultural science*, *75*(12), 771-780
Sharma, U.C. and Mishra, A. K. (1998): Deforestation in North Eastern region of India and traditional wisdom in range management for resource and environment conservation. International symposium on agro-environmental Issues and future strategies: Towards 21st Century, May 25-30, 1998, University of Agriculture, Faisalabad, Pakistan.
Singh. V. and Sharma, M.L.(et)(1998): Mountain Ecosystem, A Scenario of Unsustainability, Indus publication com. New Delhi,, ISBN-8173870810, pp.-264.
Singh, V.P and Sharma, N.(2004): The Brahmaputra Basin Water Resources (Water Science and Technology Library Book 47) Kindle Edition, Springer; 2004 edition (9 March 2013)p-613.
Singh, Y.R., Singh, B.P., Devi, S.R. (2017): Source Rock Characterization, Digenesis and Depositional Environment of the Upper Disang Formation from Gelmoul Area of Manipur, NE India, Jour. Indian Association of Sedimentologists, Vol. 34, Nos. 1 & 2. (2017), pp. 1-7
Sinha, R.K., Kedia, D.K., and Kumari, A.(2015): Overview of Higher Vertebrates in the Ganges-Brahmaputra-Meghna River Basin: Their Status, Threats and Conservation, IUCN,River of Life, Proce. of International Symposium on River Biodiversity: Ganga-Brahmaputra-Meghna River System, pp.116-123.
Slaymaker, O. (1996). Introduction. In: Slaymaker, O. (Ed.), Geomorphic Hazards. Wiley, Chichester, pp. 1 –7.
Speed, R., Tickner, D., Naiman, R., Lei, G (2016): River restoration: a strategic approach to planning and management, CC BY-SA 3.0 IGO [7112] 202 p., illus.
Springgay. E.(2017): Headwater Catchments : Foundation Pillars for Ecosystem Services. Křeček & Haigh at al, Ecosystem Services of Headwater Catchments https://www.springer.com/gp /book /9783319579450 (accessed on 31 August 2019).
Stapathy, K.K. and Sonowal,D.K.(2003): Integrated Watershed Development – A Sustainable Approach for Resource Conservation and Management, http://www.kiran.nic.in/pdf/publications/ Watershed_Development.pdf, pp. 1-14.
Steiner, F., Marruffo, J., and Holm, M. (2000). A Watershed at a Watershed: The Potential for Environmentally Sensitive Area Protection in the Upper San Pedro Drainage Basin (Mexico and USA) . Landscape and Urban Planning. 49(3-4), 129-148.
.Strahler, A. N. (1950): Equilibrium theory of erosional slopes approached by frequency distribution analysis, Am. J. Sci., 248, No. 10, 673 696; No. 11, 800 814.
Strahler, A. N. (1956). “Quantitative slope analysis.” *Bull. Geol. Soc. Am*. 67: 571-596.
Strahler, A.N. (1964). Quantitative geomorphology of drainage basin and channel networks. In: V.T. Chow (ed.). Handbook of applied hydrology (4-76). New York: McGraw Hill Book.
Taha, M.M., Elbarbary, S.M., Naguib, D.M. and El-Shamy, A.Z., (2017): Flash flood hazard zonation based on basin morphometry using remote sensing and GIS techniques: A case study of Wadi Qena basin, Eastern Desert, Egypt, Elsevier, Remote Sensing Applications: Society and Environment, Vol-8, pp-157-167.
Teegalapalli, K and Datta, A, (2016): Shifting to settled cultivation: Changing practices among the *Adis* in Central Arunachal Pradesh, north-east India, Springer, doi: 10.1007/s13280-016-0765-x, Vol. 45(5): 602–612.

Thakur, P.K., Laha, C. And Aggarwal, S.P. (2011): River bank erosion hazard study of river Ganga, upstream of Farakka barrage using Remote Sensing and GIS; Natural Hazards doi 10.1007/s11069- 011- 9944- z.

Thiam, D. R. (2014): Property right , institutions and forest resource management in Developing countries, Scientific Research, Natural Resources, 2014,5,170-118

Thornbury, W. D., (1954): Principles of Geomorphology, New York, John Wiley & Sons, 618 pp

UNEP (2006): Environment and Disaster Risk Emerging Perspectives, ISBN: 978-92-807-2887-3 https://postconflict.unep.ch/publications/env_vulnerability.pdf, pp 1-34.

United Nations Convention to Combat Desertification (UNCCD). (2-13 September, 2019, New Delhi): Restore land to Sustain Life, https:// www.unccd.int/conventionconferance-parties-cop/cop14-1-13september-new-delhi-india (assessed on 09/09/2019).

USGS: USGS science for a change world, Earth Explorer, https://earthexplorer.usgs.gov

Varma, P. D. (2011). A Study of Watershed Development Programme in Sangamner Taluk- A Geographical Analysis. PhD Thesis.

Valdiya, K.S (1998), Dynamic Himalaya, University Press India p.ltd, Hyderabad pp-179.

Valdiya, K.S. (2004): Geology, Environment and Society, University Press (India) pvt.ltd. Hydrabad, p-226.

Valdiya, K.S. and Bartarya, S.K. (1991): Hydrological studies of springs in the catchment of Ganla river Kumaun Lesser Himalayas, India. Mountain Research and Development, Vol.11. pp-239-258.

Venkatesan, A. (2015): Geoinformatics in fluvial geomorphological study of Thoppaiyar sub basin Tamil Nadu India (Ph. D Theses),Shodhganga a reservoir of Indian theses, http://hdl.handle.net/10603/51184, pp- 86-98.

Versin, P.A., Velasco, M., Cabello, A. and Sempere-Torres, D. (2013): Hydrological impact of forest fire and climate change in a Medetarranean basin. Narural Hazards, pp:609-628.

Wang, G Mang, S, 2016, Integrated watershed management : evolution, development and emerging trends, Journal of Forest Research, oct2016, Vol-27, issie5, pp 967-994.

WBDC (2015): Integrated Watershed Management Programme, https://www.mapsofindia.com/ government-of-india/integrated-watershed management-programme. html (assessed on 08/09/2019).

WCED (1987): Our Common Future, the World Commission on Environment and Development, Sustainability, Oxford University Press, pp- 383.

Willis, K.G. (2002): Benefit and costs of forest to water supply and water quantity. coted by Krecek J and Palan L et al. Environmental Services in Mountain Catchment by the Acid Atmospheric Deposition, CPC, pp-169-181.

White, C.A, and Franks, A.L. (1978): Demonstration of erosion and sediment control technology, Lake Tahoe Region of California, State Water Resource Control Board, Final Report. 393 pp.

Youssef, A.M, Sefry, S.A, Pradhan, B and Alfadail, E.A. (2016): Analysis on causes of flash flood in Jeddah city (Kingdom of Saudi Arabia) of 2009 and 2011 using multi-sensor remote sensing data and GIS. Geomat Nat Hazards Risk 7(3):1018–1042.

Zahoor, Ul Hassan,2013: Watershed Characterization and Management Planning in Wular Catchment, University of Kashmir, Ph.D Thesis pp-3.

.

--**--