CHAPTER-I

INTRODUCTION

1.1 General

The present study will focus to summarize the situational analysis of downstream areas of Teesta sub basin of greater Brahmaputra basin. The situational analysis contains changes of the hydrological regime, conditions of the local people and their coping strategies and adaptation practices in the hazard prone area of Lower Teesta River Basin, which is a part of India. Consequently, the present study includes a summary of historical trends and stresses and identification of major issues that require attention through regional policies, cooperation and action.

The sub-Himalayan West Bengal being situated from the southern margin of Himalaya and dissected by the snow peak dependent rivers has always been liable to floods. The reasons for high floods are excessive and intensive rainfall within small duration in small catchments and continuous rainfall of several days in bigger catchments during monsoon. The simultaneous melting of snow accumulated on high mountains and rainfall in lower catchments often caused floods of devastating nature. (Kusari A.M. et al. 1981; Ramaswamy C. 1987; Sarkar S., 2004; Sanyal C.C., 1969, 1970) The River Teesta has a typical mixed hydrological regime (Starkel L. & Basu S., 2000), fed by snow, ice and groundwater which receives the most energy from extreme continuous rain that repeats every 20 to 50 years (Starkel L., 1972, Sarkar S., 2004b). These, along with sudden bursting of water storage in the upper catchment caused by heavy landslide that blocked river channel, released unbelievable volume of water through the river Teesta in 1968 and caused unprecedented devastation (Sen S., 1968). In the last two centuries such extreme floods were recorded in 1899, 1950 and 1968. Every year at the mountain edge the discharge may reach 3000 to 5000cumecs, the water table rising to 5 to 6 meters above mean water level. But in 2nd October 1968 due to intense storms and glacial lake outburst (Bandyopadhyay et al., 2014) the water level in Teesta bazaar rose to 26m above normal and discharge was calculated at 18,500cumecs whereas Jalpaiguri about 50km downstream of the mountain front , the discharge reached 19,800cumecs, and part of the town was flooded (Starkel, L. et al., 2008).

However, **i**n the context of the evolution and behavior of surface drainage network and evaluation of ground water potential, the frequency of discharge is especially important in an understanding of the hydraulic geometry of river systems and how the width, depth and velocity of natural rivers change in a downstream direction (Leopold and Madcock, 1953). A major emphasis on fluvial dynamics or hydro-morphological change of a river basin is very normal and is a natural process over a time period. Naturally, a river changes her characteristics frequently but from time to time and these changes occur alongside human interference as well as natural flow of a river. On the whole bank erosion, runoff over the basin, change of ground water level, discharge in river course through damming, embanking, diversion of water through canal system, land use change, deforestation, climate change and change of discharge directionality etc. all together and individually have an impact on the morphology of the river basin. At the same time hydrological and geomorphologic processes like runoff, soil erosion, river sedimentation, changing river flow characteristics , impacts of dam and reservoirs within the basin are factors, which control the land use and land cover changes of a river basin and its surroundings (Garde, 2005; Mohd et al., 2013).

1.2 Review of the Related Literature

Snow peak dependent river basin has the important geomorphologic features in the alluvial river systems. They have existed in a complex geometry. Their processes of fluvial dynamics and changing hydrological character with related causes is an important part of the research work and at the same time , utilization of different resources surrounding the river as well as their life sustaining processes and problems related human activity and influences are also of keen interest in this research work.

Till today, limited peripheral research work has been conducted on the core area of behavioral changes of hydrological character of the River Teesta. Some notable research work and research papers have been published on the hydrological regime of the Teesta but there is a wide gap in studying the *Impact of Hydrological Changes and Adaptation practices by the Rural Poor and Vulnerable People in the Lower Teesta River Basin of West Bengal, India.* Therefore, an attempt has been taken up by the present investigator to fill this gap. In this context, the following literatures have been studied which exhibits a few major and marginal instances of the work taken under study. In the present literature review related to this study have been discussed. The concepts of fluvial dynamics, flood, livelihood, critical moment, adaptation strategies and reviews related to these topics have been presented below:

1.2.1 Concept of Hydrological character

1. A recent study by Mullick, Babel, and Perret, 2010 conducted in the Teesta river basin describes that, environmental flow is essentially required for the sustenance of the river itself as well as for the whole ecosystem, including the poor‘s livelihoods which are largely shaped by the river flow especially in a country like India. However, in the period of 2001 – 2006 (post-barrage-2), the dry season (December – March) mean flow is to be observed only 80 m whereas mean January, February and March flow is observed to be only 40, 24 and 57 m3s-1 respectively. All these values are quite below from the environmental flow requirement.
2. Akhter, S et.al.(2019) using multi-temporal Landsat images data with GIS, spatial autocorrelation index and an autoregressive integrated moving average (ARIMA) model have analyzed that the temporal changes in channel shifting rates were mostly affected by high sedimentation in the river flow path, whereas the spatial changes along the channel reaches were primarily controlled by the differences of river bank, as demonstrated by the various bar area formations. The relationship between the bar area and the braided index exhibits a strong positive correlation (R^2 = 0.96, p<0.01), while a moderate correlation occurs (R2 = 0.50; p<0.05) between the sinuosity index and time, suggesting a high rate of sedimentation and changing the flow of the river affected by the channel banks.

1.2.2 Concept of human interventions

1. Downstream geomorphic and hydrological impacts of dams vary with the operational strategies of dams and the characteristics of downstream river channels. Studies of regulated rivers have revealed varying responses including narrowing of channel, channel widening, degradations or aggradations of river bed occurring at different temporal scale (William and Wolman, 1984; Xu, 1997).
2. The study of 35 dams on large rivers in the Western US that rivers with braided patterns tended to narrow following dam construction and meandering rivers experienced reduction in channel migration rate (Friedman et.al.1998).

3. To know about the complexity of hydrological and geomorphic result of rivers to human interventions, case studies of a river for which the data regarding pre and post dam condition are helpful. Understanding the fluvial dynamics in relation to human interventions i.e. dam construction can enhance our perceptive of the impacts of a dam on the downstream river reach. It is also essential to understand that the unregulated water and sediment regime as well as changes caused by flow regulation. Such understanding can provide opportunities to differentiate between natural and induced changes and has been adequately highlighted by Gordon, W. M. (1984)
4. The Teesta is one of the most dynamic river systems sustaining the local livelihood patterns of river bank people over a long time. However, there is an increasing concern regarding such a dynamic system, due to its channels being subjected to regular shifting and threatening human interventions i.e. engineering projects, which results in various socio-economic and environmental problems (Akhter, S et.al., 2019)
5. Downstream of a river is very much dependent upon midstream and upstream character itself. But floodplain and river channel have been dramatically altered by a number of human interventions or anthropogenic activities such as construction of a dam, sand mining and grazing, whereas channel incision and other fluvial processes have also led to changes in the natural character of a river. In this context Kusimi (2008) has identified Densu river basin of Ghana has come under serious threat from a number of man-made activities such as farming, salt mining, animal grazing, dam installation among others.
6. River bank failure and flood phenomenon is a very common feature at downstream of Farakka Barrage Ganges. From the study used by remote sensing images it is clear that bank failure has occurred because of soil stratification of the river bank, high load of sediment and difficulty of dredging and construction of Farakka Barrage as an obstruction to the natural river flow. So, Thakur et al., 2012 have emphasized that the estimated affected erosion areas have been subject to devastating nature of hazards every year.

1.2.3 Concept of flood

1. A Flash flood simulation model has been run to make an analysis of the flash flood in the region, based on the past rainfall events of the Teesta basin area. Some information has been generated on water discharge, peak discharge time and volume of discharge of

selected points, which are very helpful for this entire study. This kind of research is operational with highly scientific and contemporary methodologies with reliable satellite data products and with this process total loss of life and assets can be minimized; flood prediction and assessment can also be implied. The local administration can make use of the model and it will be the local residents of the region who will get the utmost advantage (Mandal, S. P., & Chakrabarty, A., 2016).

2. During monsoon season the flood is very common phenomenon in the downstream of River Teesta and consequently, local people residing in the surrounding areas of River Teesta have been experiencing massive damage to people and their properties. Due to this every year dynamic and complex nature of flooding, flood prediction, risk assessment and flood management is very much necessary to minimize the damage. In this regard, the Freidman test, Wilcoxon signed-rank test, Kruskal-Wallis test and Kolmogorov-Smirov test were applied by Talukdar, S., et.al. (2020) for the flood susceptibility modeling implied on Receiver Operating Characteristics curve (ROC) to determine the influence of the factors for flooding, which showed more than 800 sq.km area was predicted or more than 85% of area under the curve which indicate highly accurate flood models. Moreover, the policy makers will make use the model to get the maximum benefit for developing appropriate mitigation measures.
3. History of flood occurrences and inundation of the Sub-Himalayan Rivers, owing to its position at the foot of the hill and to the number of rivers which flow through it alongwith the Jalpaguri district have always been peculiarly liable to floods. This is evident from the disastrous flood in 1787, prior to which the Teesta River used to flow into the Ganges. After that, the Teesta River changed its course often due to sudden floods resulting from heavy rainfall in the hill areas. Serious flood episodes have been recorded in the years of 1881 and 1882 but the worst floods occurred in 1902 and 1906. From the past to the present era, the sudden increase in frequency of floods in the region has come as a surprise to everybody in Jalpaiguri (Gruning, J.F, 1911). But the causes of the flood have been changing in the present era, where human interventions have been closely associated with the flood.
4. The Teesta has fragile geology, multifaceted climate, ecosystems and socioeconomic conditions and is prone to regular landslides and floods similar to the other river basins of the Sub-Himalayan regions. These landslides in Himalaya sometimes are responsible for

floods and vice-versa due to its location. Catastrophic floods occur almost every year in the upper, middle and lower courses of River Teesta, mainly in Darjeeling and Jalpaiguri, while in the downstream of Bangladesh also the 1968 and 2015 floods were the most disastrous (Pal et al., 2016).

5. In downstream areas of River Teesta, many flood protection structures such as dykes and embankments are already damaged from previous monsoon floods along with the current back-to back floods i.e. 2016, 2017, 2019 and 2020 flood. While the normal recovery cycle after a disaster is 3-5 years, this is hampered due to this increased frequency of floods. The floods during monsoon cause heavy damage to the community, household infrastructures as well as causing further loss to lives and livelihoods of the people. In reality livelihood or income generating activities in and surrounding River Teesta have been severely affected each year (NAWG, 2020).

1.2.4 Concept of critical moment

1. A very recent study of water scarcity and vegetation in Teesta river basin shows that overall vegetation and soil moisture content in downstream declined over the study period which has been correlated to the water scarcity. Difference between water supply and demand is determined by the existence of water scarcity. As a result, it is defined in relation to water needs for livelihoods. Overall vegetation has declined between year 1989 and year 2010. Soil moisture content is also recorded as turned down except in the 2000 image. It has found vegetation biomass and soil moisture content has been increased partly in natural harvested area than farmland but Teesta Barrage Project (TBP) boundary has not correlated with these changes. Grey floodplain soil area becomes greener than other types of soil. Disparity between supply and demand has been increased due to climate change, less water flow in Teesta River during dry season and high demand for irrigation, biodiversity and human consumption. Teesta River water is playing an important role to keep the balance in water supply in this region. Uneven water control in the upstream region can be a reason of massive damage downstream because supply of irrigation water for downstream crops is a matter of life and death (Sarker et al., 2011).
2. In the Himalayan Adaptation, Water and Resilience (HIAWARE) research ‗Critical climate-stress moments‘ has precisely illustrated where ‗critical moments‘, distinct when households, communities, and the dependent livelihood systems are especially vulnerable

to climate and weather-related risks and hazards, whereas these risks and hazards include floods, droughts, riverbank erosion, heat waves, cold spells, hail storms, and so on. The concept of critical moments can be introduced as an approach to vulnerability, aimed at overcoming several bottlenecks, particularly when it comes to bridging science and policy-making in transforming adaptation policy and plans into concrete actions at the right time. Critical moments are a combination of specific socio-economic and biophysical conditions, in which climate-stressors are particularly likely to be risky and adverse to a particular household or community and the systems they depend on. A _critical moment‘ may last days, weeks or even months, depending on the socioeconomic or and bio-physical drivers (Groot et al., 2017).

1.2.5 Concept of livelihood

1. Intense population and food production systems are always being sustained around the lower basin of a river at any scale. Due to the physiography at the downstream of a river, flood is a very common phenomenon. However, during monsoon the Himalayan river system at their lower course every year induces floods viz. in the Teesta river basin. Under this kind of variability, livelihood vulnerability at flood prone Teesta river basin is severe in nature each year. To estimate livelihood vulnerability due to behavioral change of hydrological regime, Hahn et.al. (2009) developed Livelihood Vulnerable Index (LVI) to assessed climate change vulnerability in the Mabote and Moma Districts of Mozambique. They surveyed 200 households in each district to collect data on socio-demographics, livelihoods, social networks, health, food and water security, natural disasters and climate variability. Data were aggregated using a composite index and differential vulnerabilities were compared. Results suggest that Moma may be more vulnerable in terms of water resources while Mabote may be more vulnerable in terms of socio-demographic structure. Moreover, it is hoped that the LVI will provide a useful tool for development planners to evaluate livelihood vulnerability to fluvial dynamics i.e. flood or climate change impacts in the communities in which they work and to develop programs and to take some adaptive strategies to strengthen the most vulnerable sectors.
2. The upstream, midstream and downstream of River Teesta represent different sets of vulnerabilities. There is no single critical moment for communities in the Teesta River basin. Rather, communities are experiencing series of critical moments that occur one

after another during different periods of the year, particularly during the monsoon. In the downstream areas, floods and riverbank erosion are the most overwhelming hazards and constitute critical climate-stress moments. The lives and livelihood systems are vulnerable after each large flood due to disruption of agricultural production, education, communication and sanitation facilities. Moreover, erratic rainfall, heavy gusty wind during monsoon, and drought, fog, cold waves, and heat waves during dry season altogether have large impact on the lives and livelihoods of the people of the study area. (Hassan, et al., 2021)

1.2.6 Concept of adaptation strategies

1. Community based adaptation to climate change is a participation process to make local people aware of climate change risk and build up capability to disaster management through networking with local government and vulnerable communities, as well as get together in one single platform for collective decision making. In order to access the implication of the comprehensive disaster management strategy, it should undertake research on the different regions in combination to generalize community based adaptation of the whole Teesta basin area of Bangladesh. Government and non-government initiatives should undertake action for promoting water harvesting activities against water scarcity. Village Disaster Management Committee (VDMC) group members should take initiatives with the help of local administration to increase their ability to enhance the efficiency and effectiveness of climate change risk management. Chain of command from the top to bottom level should be maintained strictly in all circumstances. So, it will be helpful for taking action against disaster challenges (Karim, M. R., & Thiel, A., 2017).
2. Agriculture is vital to South Asia‘s growth prospects, as about 70% of the population live in the rural areas. Most of the rural poor depend primarily on agriculture for their livelihoods (IFAD, 2007). However, agriculture in the region is extremely at risk to climate change, mostly in the form of change in intensity of rainfall events, and the break cycles of monsoon combined with increased risk of critical temperatures being experienced at more frequent intervals. In fact, as reported by the International Fund for Agricultural Development (IFAD), crop yield decrease of 30% in the region by the mid-21st Century, with the most dramatic negative impacts expected in arid zones and flood

affected areas. Considering these negative impacts of climate change on agriculture, a sustainable approach to adapt to climate change is crucial. A _climate smart agriculture' (CSA) initiative was proposed to sustainably cope with the negative effects of climate change.

3. Having relevance of livelihoods in hazard prone area of Lower Teesta River Basin and elsewhere can be regarded as adaptive strategies to fluvial dynamics i.e. floods and climate variability. Smallholder and subsistence system especially those located in marginal environments, areas of high rate of rainfall or high risks of natural hazards i.e. flood, are often characterized by livelihood strategies that that have been evolved (i) to reduce overall vulnerability to climate shocks known as *adaptive strategies*, and (ii) to manage their impacts ex-post known as *coping strategies*. The distinction between these two categories is however frequently blurred. What starts as coping strategies in exceptional years can become adaptations for households or whole communities later (Morton, J. F., 2007).

1.3 Research Problem

At downstream river basin by fluvial dynamics of River Teesta to action the process every year floods and sedimentation somehow modifies basin topography, surface water condition and layout of the river itself. Swift changes of these hydrological characters are leading to the problems of land use re-forms that are already affecting the lives and the livelihoods of rural communities living in the downstream river basin areas where the local people have been coping with or adapting to change in their own ways for decades. This study will focus its activities in different sites of the Lower Teesta River basin representing a range of hydrological conditions, socio-economic contexts and coping adaptation practices. To address the research problem this study may contribute to enhancing the adaptive capacities and water resilience of the poor and vulnerable people living in the flood plains of the Lower Teesta River basin.

1.4 Study Area

Teesta, the mighty river of North Bengal originates the Pahunri (or Teesta Kangse) glaciers of North Sikkim at an altitude of 6200m and is formed by the union of two streams viz. Lachen and Lachung at Chungthung in Sikkim (DoIW-GoWB, 2020). It enters West Bengal at Rangpo and upto Mechi, it forms the boundary between West Bengal and Sikkim. Two of its tributaries, Great-Rangeet and Rammam also serve as the natural boundary between the two States. The river finally outfalls into Brahmaputra in Rangpur district of Bangladesh. The total length of this river is 309 km. out of which 103 km. is situated within Sikkim and 121 km. in West Bengal. The total catchment area of this river Sub-basin is 10,053 sq. km. (DoIW-GoWB, 2020) At downstream of the mountain front, the river Teesta flows on the left margin of the fan taking only three tributaries i.e. the Lish, Ghish and Chel in its upper portion, which superimpose fine over bank deposits over the bars in the wide Teesta channel (Starkel, L. et.al., 2008). The older fan surface 8 to 15m high extending from the mountain margin is dissected by a 4 to 6 km wide braided channel, which continues above 200 km down to the river Brahmaputra, The present day Teesta fan extends south of Jalpaiguri, which was modeled by the shifting nature of the river. A great flood in 1787 caused the avulsion of the river Teesta over the fan surface to the east, causing it to join the Brahmaputra instead of the Ganga (Sen S., 1968).

Teesta basin is home to around 30 million people, 2% in Sikkim, 27% in West Bengal; and 71% in northwest Bangladesh of which 78% are rural and 22% urban. Sikkim is mountainous with very low population density; whereas West Bengal has a mix of low hills and plains, and in Bangladesh the terrain is almost flat (Syed, A. et al., 2017). A large barrage on Teesta diverts water for mainly irrigation purposes is constructed at Gajoldoba (under Jalpaiguri district) in India. For the analysis, the basin was divided into three areas defined by elevation: upstream (>1,500m masl); mid-stream (500m - 1,500m masl); and downstream plains or floodplains (<500m masl). The present investigator has taken only the downstream section of India.

Table1.1: Distribution of catchment area of Teesta River basin.

River Basin	Catchment area (sq.km)				
	Tibet	Sikkim	West Bengal	Bangladesh	Total (sq.km)
Teesta	29	7000	3012	12	10053

Source: Annual flood report-2019, Irrigation & waterways directorate, Govt. of West Bengal

Table1.2: Location of the study River basin.

Basin Section	Elevation	Country	State/District
Upstream (High elevation)	>1,500m masl	India	North Sikkim
			West Sikkim
Mid-stream (Mid-hills)	500m-1,500m masl	India	West Sikkim
			East Sikkim
			South Sikkim
			Kalimpong sub-division, Darjeeling, West Bengal
Downstream (plains) STUDY AREA	**<500m masl**	**India**	**Jalpaiguri, Koch Bihar; West Bengal**
		Bangladesh	Rangpur, Nilphamari, Lalmonirhat

Enhanced and Improved from HI-AWARE, 2017

Previously River Teesta had a narrow but deep channel but due to construction of barrage at Gajoldoba in India the sedimentation rate has increased. In general, large dams are effective to reducing peak discharges in flood period and increasing low discharges during dry periods (Ma et al., 2012). Whenever, the fluvial dynamics of an alluvial stream is impeding by anthropogenic construction such as a barrage or a dam, the stream tends to adjust to a new equilibrium condition by aggradations, degradation or by changing its planform. Such changes may be local or may extend over a long reach over time (Khan, 2001). Himalayan glacier melt increases due to climate change, trigger the high erosion rate and as a result sedimentation has been increased. Due to lack of dredging the situation got aggravate. The monsoons brings about a very hazardously high level of water flow, leading to massive flooding in the downstream of Teesta basin area, particularly in the chars and surrounding low lying villages where local peoples are very much use to with every year flood phenomenon.

During the monsoon India opens all the gates of their Gojaldoba barrage, which causes massive floods. In low lying villages of Jalpaiguri and Koch Bihar surroundings of downstream Teesta, frequent floods devastate the poor and vulnerable local people, demolishing their homes, cultivated land and precious assets every year. Climate change scenarios also suggest an increase in extreme rainfall coupled with the melting of the Himalayans will contribute to a greater frequency of flash floods (World Bank, 2014) in the lower Teesta river basin.

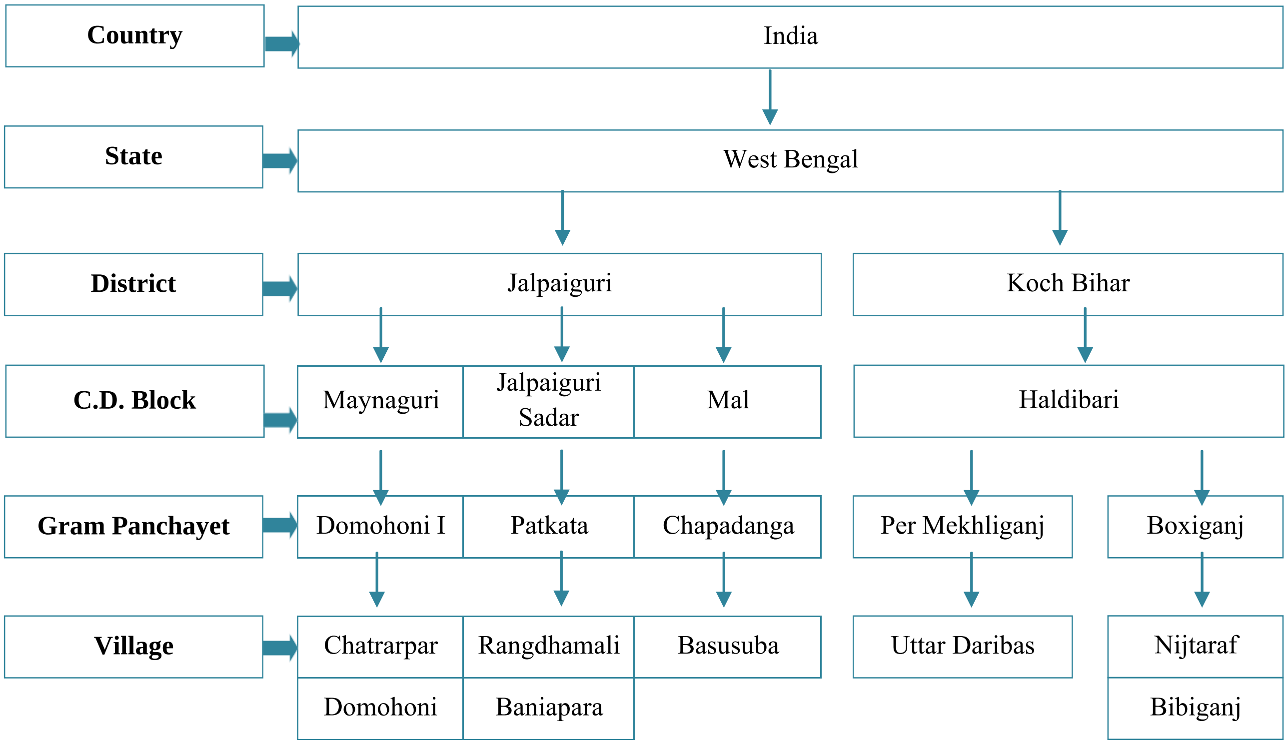

Figure1.1: Selection of study area.

Table1.3: Brief of the study area

Sl. No.	District	Village	Total area	Total Population	Total Household	Surveyed HHs (10% has taken)
1		Rangdhamali	207.1	1139	263	26
2		Baniapara	173.3	1069	252	25
3	Jalpaiguri	Basusuba	621.8	2515	530	53
4		Chatrar par	301.6	1893	433	43
5		Domohoni-I	273.2	1507	368	37
6		Bibiganj	144	423	105	11
7	Koch Bihar	Uttar Daribas	118.4	264	61	6
8		Nijtaraf	713.5	2448	565	57
					N_1=2577	**N_2=258**

Source: District Census Handbook of India, 2011

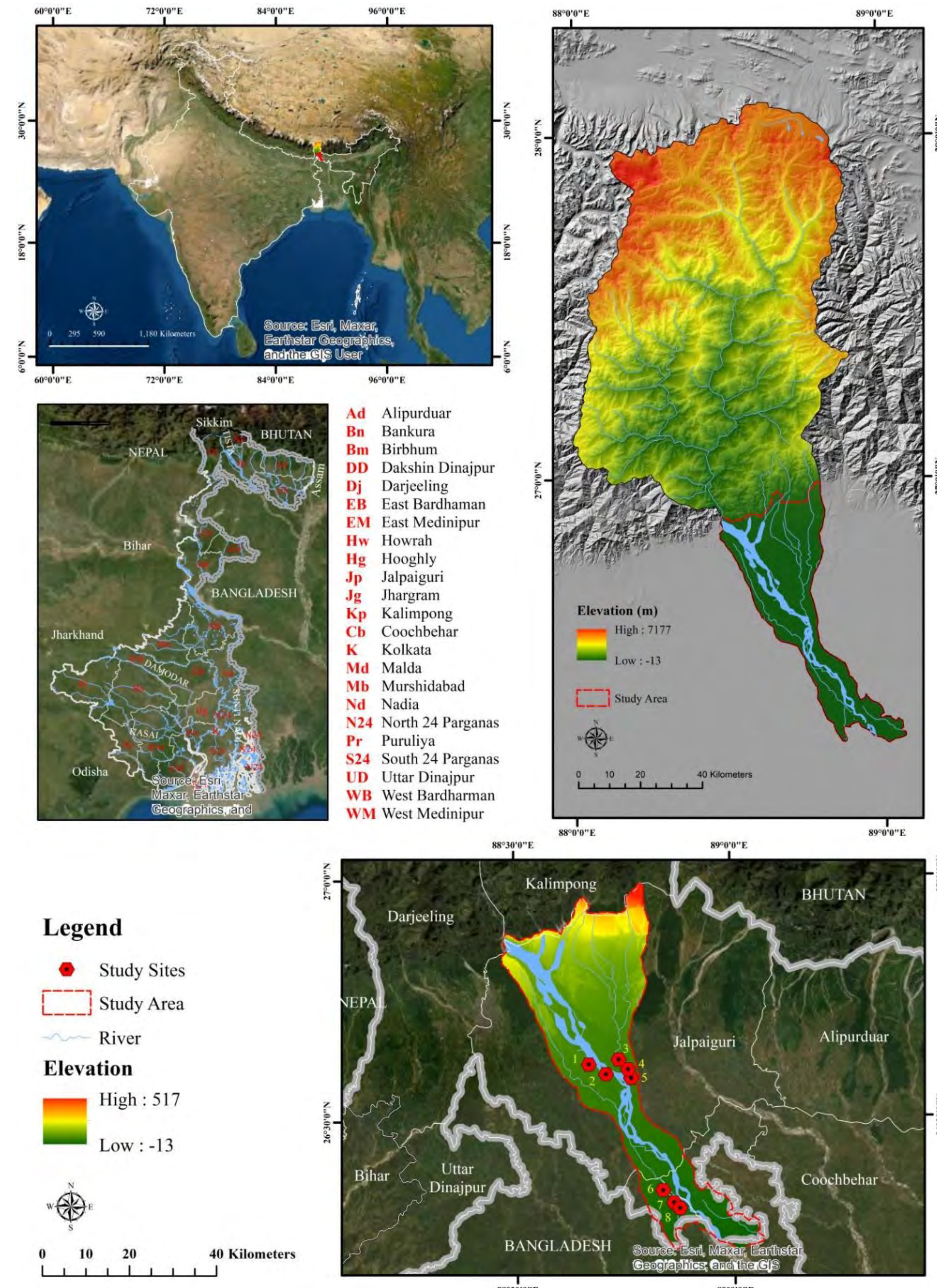

Figure1.2: Location map of the Study area.

1.5 Objectives

1. To find out the hydrological character of the river as well as the basin as a whole.
2. To study the physical and socio-economic conditions leading to vulnerability by changing hydrological character.
3. To assess the emerging problems of flood occurrences and associated resulting risk on agricultural system of the basin.
4. To assess the local people‘s perception to changes of hydrological character.
5. To study adaptation practices at various scales by local people and decision-makers.

1.6 Hypothesis

1. Anthropogenic activities have direct impact on the hydrological character of the basin.
2. Variability of hydrological regime and rising flood occurrences has impact on livelihood and land use pattern in particular agriculture.
3. Adaptation practices at various scales by local people and decision-makers are reassembling to changes of hydrological character.

1.7 Database

To conducting a research work authentic database has a significant role to establish the concrete conclusion. Primary and secondary sources of data both will be used in this study. For *primary sources of data* it should be collected directly from the field through conducting field survey including expert observations by questionnaire, focus group discussions with the community, participatory rural appraisal and key informant interviews with local leaders, representatives of administrative bodies, government and non-government organizations. To evaluate the hydrological behavior of the river at different sites different morphometric techniques would be used to measure in field, length and width of segments of embankments would also be measure. Whereas published data from different government and non-government organizations should be undertaken as *secondary sources of data* in this thesis.

At the side of Expert judgement as primary data collection in this study the data has also been collected from various secondary sources i.e. District Census Handbook (2011), Annual flood report (2010-2020) of DoIW-GoWB, Well monitoring ground water data from State Water Investigation Department, GoWB;, 40 years rainfall and temperature data collected from Indian Meteorological Department, GoI;, Water discharge data at different period composed from Central Water Commission are mostly consulted to used and different relevant books, journals and papers are also referred to review and analyzed. The map thus prepared through Arc GIS which made a height to the research paper.

Table1.4: Datasets used for GIS mapping

Sl. No.	Data description	Purpose	Source	Resolution/ Scale
1	SRTM DEM	Contour	USGS	DEM 30 m x 30m
		Elevation Slope		
		Aspect Physiography		
		TRI		
2	Geology	Geology	Geological Survey of India	1:500,000
3	Drainage & Water Regime	Drainage Network		
		NDWI	Landsat	30m x 30m
		TWI		
		Stream Frequency	78 B/9, 78 B/10, 78 B/11, 78 B/15	1:50,000
		Drainage Density		
4	Climate	Annual rainfall average data for last 40 years	IMD	Point data
5	Soil	Soil type	FAO	
6	Vegetation	Natural Vegetation	78 B/9, 78 B/10, 78 B/11, 78 B/15	1:50,000
7	Satellite imagery	LULC	Landsat	30m x 30m

1.8 Methodology

The method used to developing this thesis includes a number review of available literature, and fieldwork in some selected vulnerable villages in the flood prone Teesta lower basin. The methodology of the present work is divided into three consecutive parts:

A. Pre-field work
B. Field work
C. Post-field work

A. Pre- field work

1. Review of available literature from different libraries and offices regarding the fluvial dynamics & Adaptation practices in the interview areas.
2. Collection of Topographical sheet from survey of India.
3. Collection of aerial photograph and satellite imageries of the study area from NRSA.
4. Collections of others map from the National library, District public library of Jalpaiguri, Department of Irrigation and Waterways, West Bengal, CWC, NATMO etc.
5. Collection of secondary data from different government and non-government organizations etc.

B. Field work

The fieldwork was limited to mainly expert observations, focus group discussions with the community, participatory rural appraisal and key informant interviews with local leaders, representatives of administrative bodies, government and non-government organizations to gather information on the local physical conditions and the impact of changing hydrological character and variability on people‘s lives, livelihoods and their adaptation practices.

PRA

For achievement of development objectives along with the aspects of human experience undergone as participants and local governance with Participatory Poverty Assessment (PPA) as common practice (Mohan & Stokke, 2000). In regard of this, Participatory Rural Appraisal (PRA) has become increasingly popular for participatory development (Mukherjee, 2001). It is very much important to know and understand the complication of socio-economic and ecological environment within which resource-poor and vulnerable farmers operates and their problems can then be resolved by collaborating with them according to their needs and priorities. As a methodology for adaptation practices in agricultural development Focused Group Discussions (FGDs) along with Farming system research (Chambers, 1994) were carried out in all the selected sites to develop field oriented results with the two objectives (Mukherjee, 2001) i.e. to assessing the value or quality of local agriculture and other needs of vulnerable rural poor and also to assessing the practicability of development needs and adaptation practices. For different community the 81 FGDs were conducted at several bases during 2019 to 2021, such as gender-disaggregated FGDs with men and women villagers and age-wide FGDs as well. With the help of Gram Panchayet and local leaders, on an average 10 to 15 key informant persons were randomly selected for each community based FGDs. For the PRA and FGDs, a survey schedule and a checklist was developed to gather information about impact of hydrological changes, human intervention on river, gender wise livelihood trends, land use-land cover (LULC) pattern, adaptation strategies and practices and identification of agro-hydrological relations.

C. Post-field work

1. Empirical and quantitative techniques of geomorphology have been applied according to the requirement.
2. Data collected from different sources has been analyzed by using appropriate statistical techniques wherever necessary.
3. Various relevant maps have been prepared using by geo-spatial techniques on the Remote Sensing and GIS platform. Quantitative and qualitative conclusions have been derived from systematic compilation processing and classification of information (generated by sample survey) and data.

To explain the methodology adopted for the present study, a flow chart has been prepared and shown in the *Figure No. 2* which provides an overview of the steps followed to complete this research work.

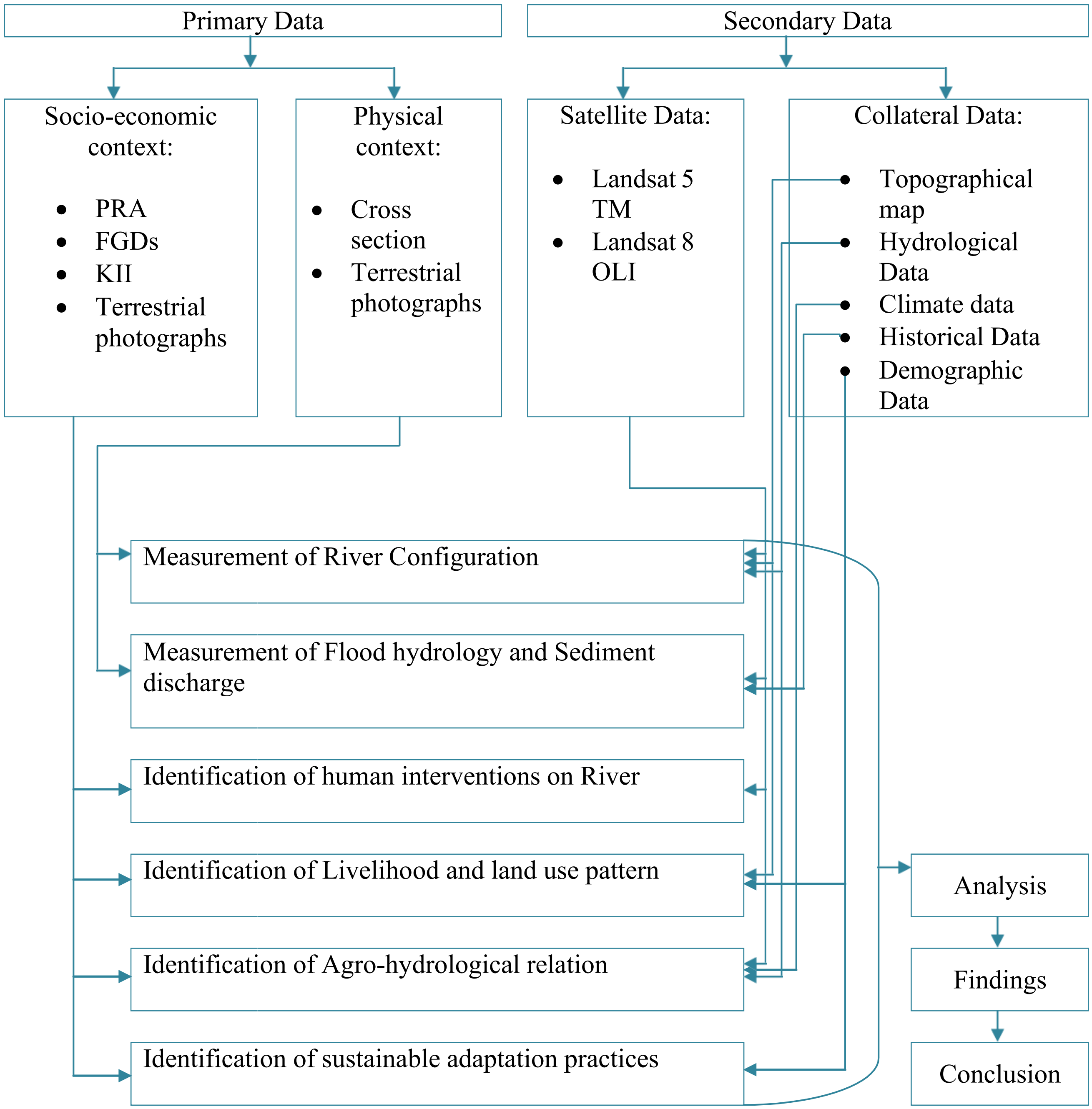

Figure1.3: Flow chart of Methodology of the present study.

Plate1.1: PRA at Patkata GP.

Plate1.2: KII at Nijtaraf Village.

Plate1.3: KII at Rangdhamali Village.

Plate1.4: Water collection at Basusuba Village.

Plate1.5: KII at Chatrarpar Village.

Plate1.6: Office visit at CWC, Jalpaiguri.

1.9 Organization of Chapters

The entire research work has been divided into the following tentative chapters:

CHAPTER-I: Introduction

CHAPTER-II: Physical and Cultural Setup of the Study Area

CHAPTER-III: Behavioral Changes of Hydrological Character

CHAPTER-IV: Flood Characteristics and Agricultural practices

CHAPTER-V: Changing Scenario of Livelihood and Land Use Pattern with Adaptation Practices

CHAPTER-VI: Summary**,** Recommendation and Conclusion

1.10 Limitation to Study

The researcher faced several problems during the present research which caused some limitations of this study. Among them concerned limitations are mentioned below.

I. The lacking of availability of secondary data about the water regime of the river basin and some demographic data of the char land settlers. Due to this lacking, the present study is not be up to the mark in certain cases and it depends on primary sources of data and also switch into other methodology to fulfill the present work.

II. Non-cooperation of the local leaders to provide the data and information about the char land settlements and livelihood as well.

1.11 Scope of the present research

Present research adopt a comparative, cross-scalar, transdisciplinary and integrative approach to look at short and long hydrological changes associated with its causes and impacts and to make a value added appraisals of the socio-economic importance coupled with adaptation practices of the river surrounding areas with some recommendations for sustainable management. The present context of this study will add new dimension to the further research work. For further integrative approach and plans on drainage hydrology, water-resource management and agro-economic development are going to be approved, the key stakeholders including practitioners, researchers and policy makers will have a basic framework provided by the changing hydrological condition and its influence and rationale. Additionally, the recommendations of this work on managing hydro-agrological resources will aid them in adding up while making decisions. The local people will gain a true understanding of the current state of irrigation practices, water consumption, land use change patterns, impacts both good and negative, etc. Moreover, it will show them how land use evolution is influenced by hydrological behaviour and how land use patterns should be connected to hydrological changes within the river basin. All of these will once again assist them in deciding how to interact with the dynamics of the hydrological system.

1.12 Conclusion

The study will produce a broad awareness of the area at a micro level, assisting academics and researcher in their efforts to learn more about the Teesta River and the area surround it. Planning for drainage hydrology, agro-economic development of the rural people will have a basic framework to know the changing hydrological characteristics and their impacts. People will gain a true understanding of the current state of river water use for different livelihood options. They will also be shown how the lives and patterns of riparian people are being influenced by factors such as hydrological changes. They will be able to adopt sustainable practices from the study regarding the present research. All of these will aid the locals in the downstream basin of Teesta River in making decisions regarding building construction as well as other economic and anthropogenic endeavors.

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