CHAPTER I
INTRODUCTION

1.1 Statement of the problem

Encompassing hydrologic, geomorphic, ecological, environmental and socio-economic significances, the rivers and their processes are dynamic entities. The dynamic nature of fluvial process is best expressed in its diverse manifestations of morphology, flow pattern, morphology and forms developed in time and over space in various geo-environmental conditions.

The rivers and their processes are dynamic and are found to vary in intensity and magnitudes in different climatic regions and also along gradients of temperature, precipitation, altitude and seasonality. While flowing they are constantly cutting, scouring, transporting, depositing and networking the landscape. As a landscape development process, it is so wide spread for which it is regarded as “normal process” (Bloom, 1998), but due to its constant and slow moving nature its effects are not always apparent even at the river’s edge. Its curved and aboundond courses, point bars, sandbars, levees, ox-bow lakes etc. clearly indicate how river is dynamic and how it carries out perpetual efforts to modify the landscape. The flow in a river affects the channel variables like water discharge, sediment discharge, channel width, channel depth, flow velocity, channel gradient, sediment size, wetted perimeter, hydraulic radius etc. The flow variability and resultant channel changes also depend on these variables (Leopold, Wolman and Miller, 1964).

Generally, water and sediment discharge are the principal determinants of the dimensions of a stream channel expressed in terms of its width, depth, meandering wavelength and gradient. Physical characteristics of stream channels such as width/depth ratio and channel pattern like straight, meandering and braided are highly affected by flow and sediment load. Changes in stream morphology within a few years indicate changes in water and sediment discharge. Width/depth ratio always increases with bank erosion and with higher coarse loads. Short term channel changes take place in response to relatively high magnitude flood events, whilst long term changes over a sequence of
events may reflect fundamental alteration in discharge and sediment load (Osterkamp, 2006). In fact, stream channels are highly variable in response to various climatic conditions. Moreover, frequent incidence of channel changes and bank failure is experienced in the case of less cohesive bank materials. The stream channels with higher energy flowing through less consolidated bank materials are most dynamic and sensitive.

Flow in a river channel has been nature’s way of conveying water on the earth’s surface from upstream to downstream. Men living adjacent to river have always been blessed by the type of flows under control and plagued by their destructive force when out of control. It has therefore, been a subject of constant study. Thus, characteristics of river flows are of importance to everyone dealing with water resources. Several types of flows confined to the river channels have been recognized by hydrologists. These include laminar flow and turbulent flow; uniform and non-uniform flow; steady and unsteady flow; and tranquil flow, rapid flow and ultra rapid flow. Values of Reynolds’s numbers (Re) can generally be used to recognize the type of flow in the river channels. In a river channel flow disturbances are commonly present in such magnitude that laminar or uniform type of flow is rarely found, but change of flows from one type to another type is very much common (Morisawa, 1968).

Thus, flow variability of both spatial and temporal is a common character in every river. In rivers, extreme flows of both high and low flows are highly essential for maintaining physical and biological characteristics. The physical properties of flow variability which include volume, magnitude, velocity, etc. have always strong geomorphological and environmental consequences at local as well as regional scales. Frequently occurring extreme high and low flow regimes may bring catastrophic change over a long term established fluvio-geomorphic regime of the river (Naiman et.al, 2008).

The available past records reveal that flow variability, earth movement and resultant channel changes including channel shifting are causally linked, as many of the river valleys of the world have already experienced major shifting of channel courses either during extreme high flow regime or immediately after the tectonic movements of high intensity. Shifting of channel course is a natural phenomenon and every river has a tendency to shift its channel course when it debouches into the plains and continues up
to its downstream. In a river valley shifting of channel course is an integral part of the alluviation process which becomes one of the major causes to the formation of extensive flood plains. Flood plains are perhaps the most common of fluvial features which are integral part of the river valleys. In fact, to expedite the fluvial action over the plains, rivers do change their courses. Thus to maintain its natural flow regimes as well as capability of doing its all functions naturally, a river sometimes abandons its existing course and develops a new course. This natural process of changing courses in a river profile is known as channel shifting. Though geological, geomorphological, hydrological and climatic factors primarily govern this process, presently, the role of human interference also cannot be ignored (Devnath, 2007). It is true that the study on flow variability and channel changes has got great impetus and also well established and recognized recently by different scholars from various fields.

Water specially the river water is an important commodity and it is also a destructive as well as constructive force. On account of its destructive nature the river water during its extreme situations causes many hazards which include flood, drought, landslide, erosion, siltation etc. However, among all such hazards the floods have been the most common as well as disastrous natural hazards in terms of economic damage and human casualty including loss of animal life under fluvial environment. Excessive amount of rainfall due to a variety of atmospheric mechanisms normally creates the floods and associated hazards in most of the river basins. Of course, under various geo-environmental conditions the floods may also be generated through the mechanisms like ice-melt, storm surge event, catastrophic failure of both artificial and natural water reservoirs and dams, and landslides. Sometime, high sediment discharge as destructive force creates channel instability and causes floods and associated hazards. Due to the involvement of such a variety of causes, the assessment of impact of flood hazards on humans, ecosystem and natural resources and also their management has been very critical. Though the task of flood hazard assessment and management has always been under the domain of hydraulic engineering, presently fluvial-geomorphology has also been increasingly recognized as an important discipline to assess and manage flood hazards (Benito and Hudson, 2010). Consequently, many river basins have now been intensively modified, designed and planned for managing the extreme flow variability and meeting different societal needs. Even many rivers for severe manipulation have
now lost their natural character and behaviour and retained little of their original flow variability. No doubt, the human manipulation over the river flow regimes may provide many benefits to society but it also leads to frequent occurrence of channel shifting resulting in many associated hazards like landslides, bank-erosion, bank-migration, catastrophic floods and droughts (Naiman et.al, 2008). Thus, human interference is an important factor. The human actions sometimes modify the basin environment especially in terms of landuse landcover changes. Basin landscape change is thus a complex phenomenon and its associated hazards are both natural and man-made. Such hazards are often costly to people and society.

In a river system the spatio-temporal shifting of channel through bank erosion, flow variation and resultant geomorphic hazards constitutes an important theme of fluvio-geomorphic study. The three aspects, i.e flow variability, channel changes and associated geomorphic hazards are very closely correlated and among these the flow variation is the independent variable on which channel changes and associated hazards depend.

The main problems of the study area are the flow variation and resultant channel changes and associated hazards. The Noa-Mangaldoi river system is one of the important north bank river systems of the central Brahmaputra valley. Although the river system has five geomorphic units, viz. active flood plain, younger alluvial plain, older alluvial plain, piedmont plain and structural hills, but its major part i.e 63.75% (475 km²) falls under alluvial plain. The river system is conspicuously characterized by high degree of flow variability, frequent changes of channels and severity of geomorphic hazards including flood and bank erosion. The spatio-temporal changes of flow, channels and occurrence of geomorphic hazards are the products of the ongoing fluvial processes of the river system which is trying to adjust constantly with its delicate fluvial regime. The frequently changing flow regimes, especially the high flows and resultant hazards have been posing serious threats towards socio-economic development in the alluvial plain, which urgently needs some management strategies. Keeping all these points in mind a research topic entitled “Flow variability, channel changes and
associated hazards of Noa-Mangaldoi river system, Assam” has been taken for investigation.

1.2 Review of relevant works

The rain water that falls over the earth’s surface has been generally removed by infiltration, surface run-off through some rills, gullies and stream channels. The movement of water over the land surface without confining to distinctive channels is called over land flow. But this over land flow does not remain as run-off for long time. The surface flow after forming rills, gullies and rivulets turns into a river or stream. As a part of physical environment a river always plays a key role in sculpturing both natural and cultural landscape. Thus a river has always been considered as the life-line for the growth and development of human society.

Though empirical study on various aspects of river is quite recent, observations regarding its origin and growth had started many years ago, as our all major human civilizations grew on the river banks. Even in ancient period, some scholars of Greece, Roman and Egypt had made some observations towards landform development and modification by the river. Such contributions of ancient scholars have already been recognized and established in the history of geomorphological studies. The postulation “Egypt was the gift of Nile” which was made by great scholar Herodotus (485 BC-425 BC) based on his personal observation on depositional works of the River Nile and also the ideas offered by some other great scholars like Aristotle (384 BC – 322 BC), Strabo (54 BC – 25 BC) and Leonardo da Vinci (1450- 1519 AD) regarding erosional and depositional works of rivers and resultant landform development clearly indicate the indebtedness of present fluvio-geomorphical study to those old scholars of the ancient period (Husain, 2009).

Following the Hortonian revolution in geomorphology (1945), the landform studies have undergone a step ahead. There was a major shift of spatial and temporal dimension in landform investigation. The earlier macro-level and long temporal studies were removed by newer micro-level and short temporal investigation, wherein the mechanisms of processes involved in landform modification can easily be understood.
During subsequent period, a considerable number of scholars have come forward and undertaken various fluvial research works. In this regard, contributions made by Hoyt and Longbein (1955), Schumm and Lichty (1963), Leopold (1969), Strahlar (1975), Lewing, (1978), Morisawa (1985), Lambert and Walling (1987) and some others are remarkable.

Flow variation and channel changes of both spatial and temporal in a river and also the occurrences of floods in its valley come under the study of river dynamics. The spatio-temporal variation of flow magnitude has always been guided by the two elements of channel regime- the water movement and the sediment transport. In fact, the channel parameters like flow discharge, sediment discharge, width, depth, velocity, hydraulic radius, wetted perimeter, width depth ratio, channel pattern have their combine effect on the channel morphology and hydrologic flows of water and sediments. All these have caused varying flow types, magnitudes occasionally intensified leading to devastating floods. The rivers have to adjust to an array of discharges including high magnitude flood and exhibit various channel forms and morphologies.

In recent years a considerable number of fluvial research works have been done on changes in channel morphology, channel pattern, shifting of channels and also on flooding pattern, flood hazards, flood plain formation and morphology throughout the world. Leopold and Wolman (1957) studied about flood and formation of floodplain and identified vertical accretion and lateral migration of river in its valley as the two main responsible processes.

Gilbert (1877) was the first who tried to correlate the fluvial mechanics with fluvial geomorphology. This was his great contribution towards the field of fluvial geomorphology. But, it is only after the middle part of 20th century that study on rivers and river basins received due importance from hydrologic, hydraulic and fluvial geomorphic points of view. Many studies on forms and processes of river basins and channels were carried out by Leopold and Maddock (1953), Thornbury, (1954), Leopold and Wolman (1957), Chorley, (1969), Gregory (1977), Knighton (1984). However, from fluvial-geomorphological view point, the river basin study received true direction only after the work of Leopold, Wolman and Millar (1964). In their work they not only
included the aspects like floodplain morphology, spatio-temporal changes of channel morphology but also discussed some of the very critically dynamic aspects of river hydrology and hydraulic geometry. Some more empirical works have been presented regarding fluvial system by Doornkamp and King (1971), Bloom (1979).

The scientific works carried out by Vogel et.al (1995), Sear et.al (1999), Smakhtin (2001), Charlton (2008), Maitre and Colvin (2008), Naiman et.al (2008), Sen and Neidzielski (2010), and Bouhrissa et.al (2013) towards river flow regime are found to provide great momentum to subsequent researchers and also have helped the present study. Charlton (2008) had made some empirical studies on various hydrological aspects by giving special emphasis on the characteristics of different flow regimes, flood frequency-magnitude relationships and channel forming flows including the flow processes within the channel.

The analysis of statistical characteristics of river flow variability carried out by Sen and Neidzielski (2010) found various degrees of temporal intermittency of river flow time series. Thus, the higher values of kurtosis and skewness they found clearly support the occurrence of more intermittent flow pattern in the mountainous and hilly areas. Smakhtin (2001) discussed various methods of low flow estimation from streamflow time series which include flow-duration curves and frequency analysis of extreme low flow events.

In stream flow analysis by dividing flow regimes into annual flow regime, high flow regime, low flow regime, stream flow variation regime and sediment transport capacity regime carried out by Milhous (2014) and estimation of ground water contribution to river hydrographs and derivation of relationship between overland flow, inter flow and base flow by Misstear et.al (2009) have also been under consideration in the present study.

The contributions made by Leopold and Wolman (1957), Schumm (1963), Langbein and Leopold (1964), Morisawa (1968), Maddock (1970), Lyons and Beschta (1983), Parker (1993), Legg and Olson, (2014), Luquian et.al (2007), Howard (2008) relating to investigation of channel pattern, channel morphology and channel dynamics are remarkable. Channel cross-section and channel pattern are mainly controlled by the
discharge and load provided by the drainage basin was observed by Leopold and Wolman (1957).

Langbein and Leopold (1966) had made the inference that meandering pattern is more stable than straight reach and it is the interplay of two fundamental processes of erosion and deposition. Such stability involves a delicate adjustment between planimetric geometry and the hydraulic factors of depth, velocity and local slope.

The character of a stream channel has always been guided by the type of material transported as well as mode of its transport was observed by Schumm (1963). The increasing trend of flows with timber harvesting and road building expansion and resultant changes in channel pattern were studied by Lyons and Beschta (1983) when they analysed the relation between watershed factors and channel morphology of the Middle Fork Willamette River of Cascades Mountains.

Parker (1993) in his observation had considered the meander migration, avulsion and meander cut-off as the main mechanisms of lateral channel change on the floodplain of Santa Cruz River. Channel expansion, bend migration and channel avulsions were also found as the major processes of channel migration across floodplains and the contributions of these processes were considered to create distinct channel patterns in the study of Western Washington by Legg and Olson (2014).

The reduction of channel capacity, channel stability and effect in hydraulic geometry downstream due to the construction of levees and revetment on the middle Yangtze River were noticed by Luqian et.al (2007). Such observations have been kept in mind as empirical bases for the present study.

Sediment transport and sedimentation at certain locations along the river course are some of the very important aspects of a river which have morphological effects on the fluvio-geomorphic environment. In this respect a good number of works have already been done by Klimec (1974), Macklin (1985), Reinec and Singh (1980), Magillian (1985), Howard (1992). However, among them identification of fluvial-depositional landforms in a chronological order and also the classification of fluvial deposits and bank deposits into three major groups- channel deposits, bank deposits and flood plain deposits by Reinec and Singh (1980) are really very important.
Considering various global environmental crisis, recently equal stress has been given on aspects like fluvio-geomorphic hazards, their causes, impact, mitigation and management. Outstanding works in this field have been done by Sargent (1992), Knox (1999), Hirschboeck et.al (2000) and Whittle and Medd (2012). Sargent (1992) who studied impacts of flooding in Rockhampton, Australia gave more stress on preparation of flood maps, while Knox (1999) investigated the causes and impacts of palaeo floods of upper Mississippi River Valley.

By nature the extreme floods are always rare and to characterize and evaluate the frequency as well as maximum potentiality of these floods in the context of long term history of the river, the gauged records from a single river are inadequate as mentioned by Hirschboeck et.al (2000), while analyzing the causes of floods in their paper “Hydroclimatology of Meteorologic Floods”.


Recently, in India many research works have been done on various aspects of rivers and river basins by many scholars. Though the contributions of earth scientists towards fluvial research have been emerging but studies on fluvial forms and processes primarily came from hydraulic Engineers. Some of the important earth scientists who contributed lot during last 2-3 decades include Coleman (1969), Mukharji (1976), Goswami (1985), Mutreja (1986), Reddy, (1986), Bristow (1987), Garg (1987), Kale (1990), Singh (1998), Singh and Dubey (2000), and Sarma (2005).

Mutreja (1986), Reddy (1986) and Garg (1987) in their works on hydrology used various statistics in hydrologic analysis especially for high and low flows including hydrograph analysis. All these provide a scientific base for the present study.
Kale (1998; 1999; 2003; 2008) analyzed the long-term flood series of some major rivers (Ganga, Narmada, Tapti, Godavari, Krishna, Mahanadi and Kaveri) and came to the conclusion that variability in flood magnitude is strongly linked to the long period variations in the monsoon rainfall. Besides, Goswami (1998) and Seth (1998) have also examined and analyzed the floods of many Indian rivers and also suggested probable measures and strategies for managing flood hazard.

Some more systematic investigations have been conducted in recent years to evaluate the bank line change, flow pattern and landuse-landcover change using multi data topographical maps and satellite images by Colman (1969), Chitale (1977), Thomas and Sharma (1998), Sarma (2003), Sarma (2005), Rana et.al (2009), Kavitha and Ganesh, (2009), Rymbai and Jha, (2011). All these studies have arrived at common conclusions that the Ganga-Brahmaputra river system with dense networking of many tributaries has the migratory tendencies resulting in development of abandoned channels in the forms of cut-off, swamps, marshes etc.

Coleman (1969) in his study on channel process and sedimentation of Brahmaputra river concluded that rate of rise and fall of river stage, composition of bank materials, major active channels and their number and position during flood, bed structure, movement of bedforms and bank slumping intensity are the major causative factors of bankline migration. The river training works, especially the construction of bundh across and near the river course was identified by Thomas and Sharma (1998) as the major cause of channel shift resulting in frequent flood havoc in the Ravi river, Punjab.

After every major flood events some dramatic change in the channel morphology occurred especially in the lower reach due to channel avulsion and cut-offs. This was observed by Rana et.al (2009) during their scientific investigation on nature of channel shifting of river Rapti. While analyzing the nature of channel migration of river Diana of Sub-Himalayan range, Chakraborty and Mukhopadhyay (2014) found that the moderating effects of human interventions are equally responsible in channel dynamics like the natural processes.
The evaluation of geomorphic effectiveness of high magnitude floods carried out by Kale (2002) for calculating average unit stream power at a cross-section has been established as a major step towards enriching fluvial geomorphology. As per his calculation, the value of average unit stream power for some major Indian rivers varies between 322 \( \text{w} \text{m}^2 \) on Godavari and less than 10 \( \text{w} \text{m}^2 \) on Brahmaputra. Low width-depth ratio and relatively higher channel gradient of Godavari have been the cause for higher value of average unit stream power.

Not only by scholars from various fields but a number of institutions have also carried out investigations on the Indian rivers. The Geological Survey of India (GIS) (1977) has carried out a detailed investigation on fluvial processes, forms and geology of some major tributaries of Brahmaputra. The Brahmaputra Board, Govt. of India has been regularly investigating the flood and erosion problem of the Brahmaputra river and has prepared the master plans for Brahmaputra and its major tributaries. The preparation of methodology for flood plain zonation of Indian rivers by the Ministry of Water Resources, New Delhi (1999) and also its suggestions regarding flood plain and flood hazard management which have been later on supported by Indian National Committee on Irrigation and Drainage (INCID, 1993) is also very important. Besides, the North-Eastern Council (1990) studied various aspects of the river Brahmaputra which covers geology, hydrology, bank erosion, siltation problems together with preparation of flood prone area map including management task.

Goswami (1985) and Sarma (2005) had analysed relation between flow discharge and sediment discharge of river Brahmaputra. Sarma’s (2005) analysis clearly indicates that higher rate of flow and sediment discharge occurs for a small fraction of time for years with single peaked floods as compared to multiple peaked ones. Regarding geomorphology of Brahmaputra River, Goswami’s contributions (1982, 1985, and 1998) which include a wide range of aspects ranging from suspended sediment transport, valley aggradations, basin denudation to flood hazard and flood plain management in the valley are outstanding.

A systematic analysis on flow pattern, sediment transport, pattern of channel migration and its impact on people living on flood plain of the Jia Bharali river made by Bora (1990) provides baseline information for the present research work. Duarah (1999)
made a systematic investigation towards fluvio-sedimentary environment of the lower reaches of Pagladiya and Puthimari rivers. In this study the stress was given on channel morphology, channel dynamics and various aspects of sediments. The study reveals that both the rivers bring down huge sediments from the Himalayan range during every monsoon and raise the river bed downstream through siltation which, in turn encourage recurrence of floods and make the channel more unstable. Das (2000) who carried out a major work on fluvial processes operating in the flood plains of Subansiri river including their impact on arable land, clearly pointed out the role of bank erosion in the flood severity through breaches in the embankments.

A good work to observe sequential changes of channel morphology of the Subansiri river covering a span of 70 years was carried out by Goswami et.al (2007). The nature of channel change was found varied. Four different types of channel changes that they traced are, the development of (i) neck cut-off (ii) bar (iii) anabrances and (iv) new meandering bend. Such investigation has provided a true direction to the present study.

Other notable works regarding Brahmaputra and its major tributaries which have already been carried out include Bora and Bhattacharya (1997), Roy (2000), Sharma (2003), Bora (2003), Bhattacharya (2005), Kotoky et.al (2005), Bhattacharjee (2008), Sarma (2008), Bhattacharjee and Barman, (2011), Kar (2012), and Lahiri and Sinha (2012).

Barman (2011) has done a good work regarding flood plain formation and management of lower Brahmaputra valley covering the entire tributary basins. Kar (2012) in his work “The Brahmaputra: Flood and its Preventive Measures” had not only made a comparative analysis of morphometric behaviours of Brahmaputra with the major rivers of the world but also carried out a critical analysis of flood characteristics including various suggestive measures for flood and associated hazard management.

Keeping all the above mentioned works in mind carried out by different scholars at different times on various themes of river research, the present study has been carried out to deal with the flow variability, channel changes and associated hazards of Noa-Mangaldoi river system, Assam.
1.3 The study area

The Noa-Mangaldoi river system is located in between 91°56′ E and 92°05′ E longitudes and 26°21′ and to 26°58′ N latitudes. The rivers Noa and Mangaldoi originate from the sub-Himalayan ranges of Bhutan at an elevation of 1750 m and traverse for about 103 km from north to south to finally meet with the Brahmaputra River at an elevation of 50 m above the mean sea level. The river system covers a total area of 745 sq. km out of which about 94 km² (12%) lies in the sub-Himalayan tract of Bhutan and remaining 651 km² (87.38%) lies in the Brahmaputra valley of Assam.

The river system takes a fern-like elongated shape with characteristic hill slope in the Bhutan Himalayas, alluvial fans and cones in the foothill belt, alluvial plain with interfluves in middle and flood plain in the lower part extending upto the confluence with the Brahmaputra. The fluvial regime is highly dynamic characterized by high variability of flows, frequent channel changes and associated geomorphic hazards, especially flood and bank erosion.

1.4 Objectives

The research problem has the following objectives:

1. to analyse the variability of water flows and sediment flows and their relationship with basin and channel parameters.

2. to analyse the pattern and processes of channel changes of the Noa and Mongaldoi rivers at spatio-temporal scale.

3. to identify the major geomorphic hazards of the river system and assess their impacts on the fluvial environment and socio-economic life of the inhabitants.

4. to evaluate the causes of genesis of the geomorphic hazards and suggest some strategies for their management.

1.5 Hypotheses

The following hypotheses have been formulated in the present study:
1. The Noa-Mangaldoi river system is characterized by high degree of channel changes and bank erosion in comparison of severe flood occurrence, and hence channel shifting and bank erosion appear to be the dominant geomorphic hazards of the river.
Figure 1.1: Locational map of the study area
2. The natural factors in general exhibit their distinct dominance as compared to the non-natural factors in causing flow variability, channel changes and geomorphic hazards in the fluvial regime of the river system.

3. The lower reaches of the Noa and Mangaldoi rivers have undergone frequent changes of channels and high incidence of flood events which occur exclusively due to flood and erosion intensifying human-induced factors.

1.6 Methodology and database

Any geomorphological investigation always needs a careful, correct and systematic interpretation of information gathered from various sources. It is, therefore decided to take up the deductive reasoning approach as the methodological base for the present study. Under such methodology some existing models or laws and facts have been verified in the study area. Data used in this study are both primary and secondary. The primary data are generated from the field survey; whereas, the secondary data on various aspects have been collected from different offices of State and Central Governments.

In order to make the study more systematic the study has been organized in three successive stages. In the initial stage the research problem has been formulated. For this purpose, relevant literature from journals, newspapers, research papers, Encyclopedia, Britannica, data from internet, pre-field observations at suitable locations, personal experience, own perception and imaginations and discussion with supervisor and direct interviews with local people of the study area have been utilized to formulate the research problem.

The second stage involves the collection of both primary and secondary data. For primary data and information field observations have been conducted. For ground water distribution and water table fluctuation, about 60 tube wells were surveyed and during March, 2014 and November, 2014 to represent pre and post monsoon respectively. The 60 wells have selected randomly covering the entire basin. Water samples were also collected from these sample wells and a chemical analysis is carried out at District Laboratory, Department of Public Health Engineering (PHE), Mangaldoi, to know whether water is suitable for domestic and irrigational purposes or not. Again, to deal with the causes and effects of fluvio-geomorphic hazards and also response and
adjustment with the hazards, data collections have been done through household survey. As per 2011 census, there are about 294 villages located in the basin out of which 215 villages are in the floodplain of which again as per Brahmaputra Board, 54 villages are located in the flood affected area. Giving more stress on these 54 villages, 15 villages have been selected randomly as sample villages considering upstream-downstream locations along with elevation and nearness to the channel as the bases for household survey using standard survey schedule and questionnaire. Direct interviews were held with concerned public and affected people during different times. The selected villages are Bar thekerabari, Chereng chapari, Monitari, Gerimari chapari, Niz-Rangamati, Bhaluk khowapara, Dariapara, Chamuapara, Medhi chapari, Outala, Barakala bagisa, Grandland bagisa, Puthimari gaon, Kowadonga and Kalita para. Among the villages Bar thekerabari, Chereng chapari, Monitari, Niz-Rangamati, Bhaluk khowapara are located in the downstream reach near the confluence with Brahmaputra at elevation ranging from 50m to 55 m. Gerimari Chapari, Chamuapara, Medhi Chapari are just few km. upstream from confluence but adjacent to Noa-Nadi and Mangaldoi river at elevation 55-60 m. The other villages like Outala, Barakala bagisa, Grandland bagisa, Puthimari gaon, Kowadonga and Kalita para are located in the middle reach having the elevations 60-80 m from mean sea level. The locations of all sample wells and sample villages are shown in the figure 1.2. Moreover, to collect the data for hydraulic geometry, intensive field survey have been conducted at three cross-sections, namely at Harisinga, N.T. Road crossing and Brahmaputra confluence point (Dastaki) to represent upstream, middle stream and downstream respectively. For analyzing temporal changes in channel morphology, cross-section data were collected from these three sections during April, 2013 and March, 2014.

The secondary data in regards to flood, channel changes and flood hazards have been made available from different departments including Water Resource Departments, Govt. of Assam; Brahmaputra Board, Govt. of Assam; Geological Survey of India, Govt. of India; Assam Remote Sensing Application Centre (ARSAC) Guwahati, Central Ground Water Board (CGWB), N.E. Region, Guwahati etc. The same data on population fronts have been collected from different Government offices including Block Development Offices, DC’s Offices, Panchyat Offices, Circle Offices etc. The details of the secondary data used for the present study are shown in the table 1.1.
Figure 1.2: Locations of sample villages and sample wells in the study area
### Table 1.1: Secondary data used in the study

<table>
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<tr>
<th>Data collected</th>
<th>Description of the data</th>
<th>Year</th>
<th>Source</th>
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<td>Survey of India</td>
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<td>SRTM image</td>
<td>Row 137 and Paths 42 Resolution- 90m</td>
<td>2000</td>
<td>Global Land Cover Facility (GLCF)</td>
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<td>Water level, flow discharge and sediment</td>
<td>At N.T.Road crossing Gauge-Discharge Site</td>
<td>1982-2011</td>
<td>Water Resource Department, Mangaldoi</td>
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<td>Data of Noa-Nadi</td>
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<td>Water level and flow discharge of Mangaldoi river</td>
<td>At Ramhari Gauge- Discharge Site</td>
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<td>Rainfall data</td>
<td>Four Rain gauge stations</td>
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<td>Ground water availability data</td>
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<td>Flood hazard data</td>
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<td>Noa-Nadi</td>
<td>1998</td>
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</tbody>
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The final stage deals with the processing of raw data by using standard and appropriate statistical and hydrological techniques. This stage also includes the analysis of processed data to make some meaningful conclusions. For the present study, from the topographical maps of Survey of India on the scale of 1: 50,000 (toposheets no. 78N/13, 78N/14, 78N/15, 83B/1, 83B/2, and 83B/3) the base map for the study area has been prepared with the help of ARC GIS 9.3 software. Based on the base map using the methods suggested by Horton (1945), Strahler (1964); Wolman (1957); Schumm (1977); Miller (1953); etc. the morphometric characteristics which include stream orders, stream numbers, stream length, bifurcation ratio, basin circulatory ratio, drainage...
density, drainage frequency, over land flow, sinuosity index, relief ratio etc. have been analysed to determine the basin morphometry and stage of development of the study area.

To study the flow variability, the collected hydrological data have been analysed using standard hydrological techniques which include the preparation of stage-discharge hydrographs, sediment rating curve, flow-duration curve, flow deviation pattern from the mean etc. For frequency analysis of high and low flows both the graphical (Plotting Position Method) and analytical methods (Log Pearson Type-III and Gumbel’s Extreme Value Distribution Method) have been used. Using D-Index the distribution best-fitted to the annual flow series of the river is found out and also recommended.

For the study of pattern and processes of channel change, topographic maps, satellite imageries of different periods and historical evidences are used for measuring the rate of channel changes especially the horizontal movement of both Noa-nadi and Mangaldoi river. Topographical maps prepared by the Survey of India for the year 1968-69 at scale 1:50000 have been used to show the earliest bank-line and other important topographic features. For detecting the channel changes after 1968-69 for a span of 42 years, satellite imageries including landsat TM image having row 136 and paths 41, 42 with a resolution of 30 m for the year 1990 and 2010, downloaded from USGS have been used. All the topographic sheets have been mosaiced and georeferenced using software ARC GIS 9.3. Through image to image rectification process the topographical map and satellite imageries are matched with each other to avoid the distortion considering some permanent points like road crossing, railway crossing, tanks etc. by using software EARDAS imagine 9.2. Banklines for the three years (1968-69, 1990 and 2010) are digitized from the georeferenced toposheets and satellite imageries using ARC GIS 9.3 and then superimposed one on another. Taking 21 cross-sections in the channel of Noa-Nadi and 12 cross-sections in the channel of Mangaldoi, bank-line migration has been measured. The cross-sections have been taken randomly at distinct migration points. From the superimposed bank line layers of different years the migration pattern and the rate of erosion and deposition have been measured. By creating polygon layer in GIS software, erosion and deposition areas have also been estimated with the migration lines. Besides, the collected data of hydraulic parameters like mean depth, width, area, velocity, discharge, wetted perimeter and hydraulic-radius etc. the hydraulic geometry
relations are being established to observe the spatio-temporal changes in channel morphology.

For the preparation of flood hazard zonation map the multi-criteria evaluation method has been applied taking geomorphology, elevation, slope, rainfall, drainage density, landuse land cover and population density as flood hazard causing criteria. To encounter human response and their adjustments with flood and associated hazards more stress is given on data collected from direct field observation though data of secondary sources have also been incorporated. All these analysis have been represented in forms of maps, tables, graphs, charts, diagrams etc. to prepare the report in the form of thesis.

1.7 Organization of the study

The whole study has been organized into eight chapters. Chapter I incorporates the introduction of the problem and the basis of an orderly investigation of the problem in terms of review of previous work, objectives of the study, hypotheses, methodology and database along with the significance of the study. Chapter II deals with the physical and cultural elements of the study area. The elements include drainage system, relief, geology and geomorphology, climate, soils, natural vegetation, population and settlement characteristics, landuse and land cover, and finally the transport and communication. Chapter III seeks to analyse the drainage morphometry of the study area. It encompasses all the linear, areal and the relief aspects of drainage system.

Chapter IV describes the flow characteristics of both the high and low flows which include analysis of various hydrographs, frequency and probability analysis of flows. It also examines the spatio-temporal status of ground water in the study area. Chapter V analyses the pattern and processes of spatio-temporal channel change including changes in channel morphology in the drainage system. Analysis of channel hydraulic geometry also finds due position in this chapter. Flood and bank erosion as fluvio-geomorphic hazard, their causes, magnitudes and effects and identification of flood hazard zones are discussed and analysed in chapter VI. Chapter VII discusses the modes of human responses and adjustments towards fluvial hazards. Considering the gravity of the problem of hazards, some measures and management strategies are also incorporated in the chapter.
Chapter VIII carries the summary and conclusion of the entire study. Necessary relevant references are provided at the end while appendices are also added next to references.

1.8 Significance of the work

The significance of the study may be summarized as follows:

(a) From geomorphological, geological and hydrological points of view the study area has remained unexplored and untouched. This sort of study may provide a clear picture on flow, channel changes and flood characteristics.

(b) The frequent flooding and channel changes of the study area necessarily need a detailed investigation towards mitigating and solving such problem.

(c) Though natural factors are quite active for encouraging frequent floods and channel changes, but quite recently human activities through deforestation, river encroachment, channel manipulation as a result of faulty construction of sluice gate and agricultural practises etc. also cause recurring floods and channel changes.

(d) Due to recurring of floods and channel shift, flood affected areas under agriculture, forest and settlement are gradually increasing over the years. Thus this sort of study may be an effective step towards managing and mitigating such problems.

(e) The area under study has tremendous scope for agricultural, vegetational and other natural resources development. But due to lack of proper knowledge about hydrology, geology and underground water, these are still not properly explored. Hence, this sort of study may be highly significant.

(f) It may be a base work for researchers who intend to undergo further course in geomorphic studies. Thus, such studies may help the planners, land managers etc. to formulate strategies for further development, landuse and land resource management in the area.