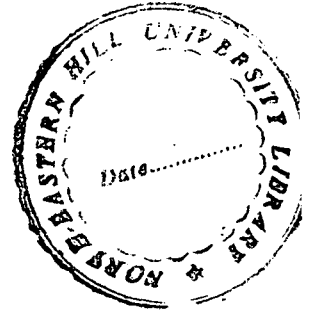


**CHANGING COURSE OF KAMENG RIVER IN  
THE LOWER REACHES**

**AMULYA CHANDRA DEBNATH**



**THESIS**

**SUBMITTED IN FULFILMENT OF THE REQUIREMENT OF THE DEGREE OF  
DOCTOR OF PHILOSOPHY IN GEOGRAPHY**

**DEPARTMENT OF GEOGRAPHY  
SCHOOL OF HUMAN AND ENVIRONMENT SCIENCES  
NORTH-EASTERN HILL UNIVERSITY  
SHILLONG-793022  
2007**

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**AMULYA CHANDRA DEBNATH**

**SUPERVISOR  
ZAHID HUSAIN QURESHI**

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**2007**

## DECLARATION

I, Amulya Chandra Debnath, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form the basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any University/ Institute.

This is being submitted to the North-Eastern Hill University for the degree of Doctor of Philosophy in Geography.



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Shillong, 16<sup>th</sup> March, 2007

Amulya Chandra Debnath

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**CHAPTER I**  
**INTRODUCTION**

# **CHAPTER I**

## **INTRODUCTION**

### **1.1 GENERAL**

Shifting of course by a river is a natural phenomenon. Usually rivers change their courses in the plain portion of a river valley however, it may also happen in the mountainous region particularly due to tectonic movements. Interestingly, the rivers have a tendency to shift their courses in the piedmont zone where they debouch on to the plains and that can lead to change of the course downstream. Shifting of river course can also take place in any stretch of the alluvial tract right up to the delta or confluence with any other river. In fact, shifting of course by a river is an integral part of the alluviation process in a river valley that is responsible for the formation of vast plains on the earth surface. In other words, rivers do shift their courses to catalyse alluviation process in the plains. When a river leaves its existing course and takes a new course to maintain its flow it is termed as shifting or change of course. Changes in the course of a river can be attributed to geologic, geomorphic, climatic and hydrologic factors or to human interference or combination of the two or more factors together as well. Significantly, course of a river is most liable to change during the extreme floods and tectonic movements in the river basin.

River is a natural concentrated flow of water in a channel along with solutes and sediments from land to larger water bodies. As a direct consequence of the running water, the structure and form of the land and its margin are altered through erosion, transportation and deposition by the river termed as 'fluvial processes' in the science of

geomorphology. Changes occur in the fluvial landforms with the changes in the discharge, sediment load and course of the river. The floods, particularly the flash floods, leave their distinct mark on the landforms. The sculpturing impact of the fluvial process of a river over its zone of migration is discernible to the hydrologists, geologists, geomorphologists and other earth scientists working both in the field and on remotely sensed data (aerial photographs and satellite imagery), of course more clearly on the later. An engineer is also interested in the fluvial processes and forms because not only it helps to design water resources development projects but also success of the projects largely depends on them.

Changes in the river course and floods have been affecting human civilisation from time immemorial as evident from the archaeological evidence of the river valley civilisations like-- Egypt along the Nile, Mesopotamia along the Tigris and Euphrates, Harappa along the Indus, and Chinese along the Hwang Ho. As both events destroy human settlements and developmental works they are considered 'natural hazards' too. Therefore, changing river courses and floods have attracted attention of man right from early times. Today earth scientists are especially concerned about it. Geomorphologists and Hydrologists pay special attention to such fluvial processes to deal with a number of fundamental and applied problems. The availability of remotely sensed data has given a great boost to the study of river dynamics, including migrating courses, floods, erosion, transportation and deposition (bank erosion, sand bars etc.) and many others. Invariably, changing courses and floods influence each other in carrying out the alluviation process and formation of the plains in the valleys. Both the processes are of great interest as they create lot of concern for man and environment, hence worth studying from different points of view by the geomorphologists and hydrologists.

The Kameng river has drawn attention of the earth scientists for its shifting courses and frequent and often disastrous floods, as is the case of many Himalayan rivers debouching on to the vast Indus-Ganga-Brahmaputra plains. Most of the Himalayan rivers have shown a tendency to shift their courses, and the triggering point of shift is invariably located in the piedmont zone. The problem is aggravated because the Himalayan rivers carry a huge amount of water and sediment from the basins lying in the young folded ranges of the Himalaya Mountain that are tectonically active and comprising mostly of the geologically weak rocks and fragile soils. Moreover, parts of the river basins, lying in the Lesser Himalaya Range and Siwaliks of comparatively recent origin, are susceptible to high erosion and landslide activity resulting in heavy sediment load in the rivers. Thus, the structure, landforms, tectonic activities and climatic elements, along with human interference in the basins of the Himalayan rivers enhance the complexity of the fluvial processes related with discharge, sediment load, erosion, deposition, floods, shifting courses etc. These dynamic fluvial processes attract attention of the earth scientists to carry out both fundamental and applied research to solve a number of academic and practical problems, because most of these fluvial processes and landforms do pose threat to man and his property. Many a times, the development is affected and thus necessitating incorporation of studies of such processes and forms in the planning process. In this context, the Kameng river basin, particularly its lower reaches, present an interesting case for study as it has experienced typical fluvial processes related with erosion, deposition, shifting of course and also the tectonic activities influencing the fluvial processes and landforms. Therefore, in the present Ph.D. research the problem of **'Changing Course of Kameng River in the Lower Reaches'** has been investigated.

## 1.2 STATEMENT OF THE PROBLEM

Shifting course and floods are natural behaviour of the rivers, which are related with the alluviation process responsible for formation of alluvial plains. It is also true in case of the Kameng river basin. Since shifting of river course and floods cause changes in the physical environment and affect man, both are worth studying as a natural process and also as a geohazard in a specific drainage basin. The lower reaches of the Kameng river have been subjected to several changes in its course due to various factors. As a result, a popular threat perception has gripped the people in which it is believed that next change in the course of Kameng river is going to affect a large inhabited tract including the site of the Tezpur University. Therefore, the changing courses of Kameng river have caught attention of the Geomorphologists, Hydrologists, Planners etc. in recent times

In the present study, changes in the course of the Kameng river have been identified and mapped. Pattern in changing course has also been ascertained. Causes responsible for the changes have been investigated. All these have been understood and explained in the light of geomorphologic, hydrological and tectonic data of the Kameng river basin. Geomorphic units of the study area have been demarcated. Data on rainfall, discharge and sediment transfer of the basin have also been collected and processed with the help of different techniques and models applicable in the study of the river dynamics. Suitable rainfall-runoff relationship has been developed where geomorphic information have also been incorporated. Attempt has been made to find out their relationship with the changing courses. After examining thoroughly the trend in migrating courses of the Kameng river forecast has been made about any change in the course in future, so that necessary precautions can be taken up by the planners and administrators to save life and property of the people living in the study area.

### **1.3 OBJECTIVES OF THE STUDY**

The following are the objectives of the study:

1. to identify, map and explain pattern and causes of changing course of the lower Kameng river,
2. to collect data on discharge and sediment for six months (especially during the monsoon period) and examine it for possible correlation, and
3. to suggest change in the course in the light of the findings of the present study.

### **1.4 RESEARCH QUESTIONS**

Following questions have been probed into in this Ph.D. research.

1. Usually the migrating courses of a river fill sediments in the valleys and have a certain pattern of migration; it is relevant to discern any recognisable pattern in the shifting courses of the Kameng river and its influence on the resultant alleviation in the basin.
2. Changes in the river course are caused by various factors, as such which are those factors that have been responsible for the changes of courses in the Kameng river.
3. Prognostication based on the results of the study is imperative on the part of the earth scientists, thus forecast has been made about what would be the most likely shift in the course, if any, in near future.
4. As discharge and sediment load have some relationship, and both influence the changing river course, the same has been tried to find out in case of the Kameng river.

## 1.5 STUDY AREA

The Kameng river basin is located within the Longitudes of  $91^{\circ} 58'$  to  $93^{\circ} 23'E$  and Latitudes of  $26^{\circ} 36'$  to  $27^{\circ} 59'N$  (Fig.1.1). The Kameng river and its tributaries originate from the snowfields of the Himalayan peaks and flow towards south to meet with the Brahmaputra river near Tezpur in Assam. The approximate area of the basin is 10,853 sq km. The major tributaries of the Kameng river are Pakke, Pappu, Pacha, Para, Waleng Bung, Wapriyang Bung, Pachuk, Bichom, Tenga, Mansari etc. The topography of the Kameng river basin is characterised by the snowfields, glaciers, steep slopes, sharp crests, deep valleys, river terraces, etc. At many places, the conditions are such that the slope forming materials are in a state of critical equilibrium, and any interference (natural or human) may trigger earth movements of varying extent. Climatic conditions vary from tropical in the plains to alpine in the high altitude.

In its lower reaches the Kameng river is popularly known as *Jia Bhareli*. The actual study area extends right from the foothills of the Himalaya Mountain to the confluence with the Brahmaputra covering an area of 1,089 sq. km. The major tributaries having confluence with the Kameng or Bhareli river within the study area are Pakke / Bardikrai, Namiri and Mansari. Except the isolated hillocks/inselbergs of peninsular shield (e.g., Tezpur) entire study area is characterised by fluvial landforms comprising of old and new alluvium and abandoned courses of the Kameng river. As a result of the changing courses and tectonic movements a number of terraces have been formed, the most notable is the Rangpara surface. Wetlands (*beels*) comprising of the ox bow lakes, back swamps, ponds etc. are commonly found in the study area. In fact, the study area is dominated by the landforms of fluvial origin but there are marked tectonic effects on the landforms also (e.g., graben etc.). While the inselbergs represent the peninsular shield.

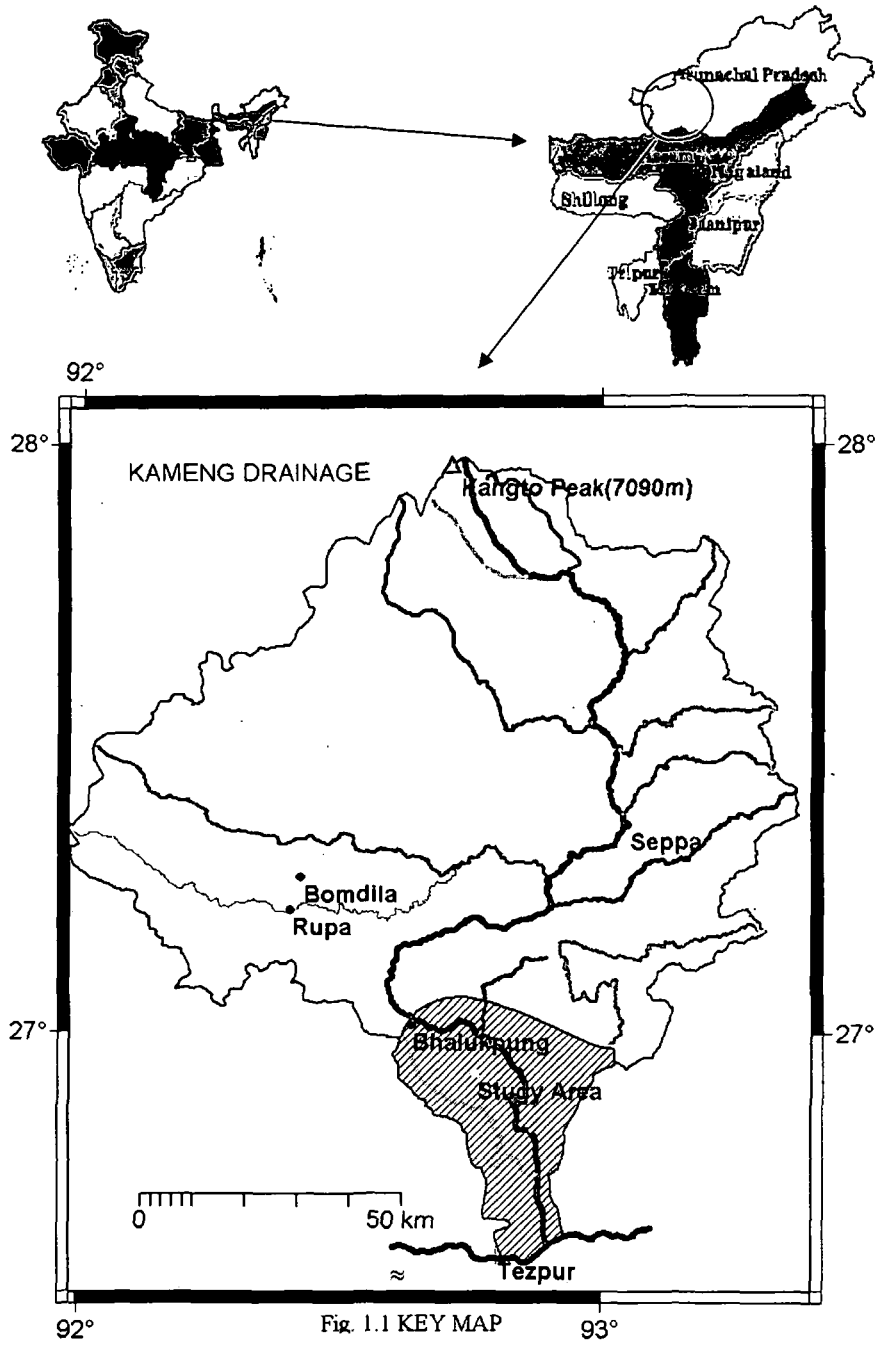


Fig. 1.1 KEY MAP

## **1.6 DATABASE**

### **1.6.1 Primary Data**

Following types of primary data were collected and used for the present study:

- (i) The changes in the river course of Kameng river were identified and mapped through multi-date remote sensing data and toposheets and then verified through field investigation by collecting geomorphologic and hydrological evidences.
- (ii) Geomorphic mapping of the study area has been done through the fieldwork and with the help of SOI toposheets and satellite imagery.
- (iii) Gauge, Discharge and Sediment site was established on the Kameng river to collect and analyse data on discharge and sediment load, and their relationship. GDS data has been collected for a period of 17 months from December 2004 to May 2006.
- (iv) Terrestrial photographs have been used to analyse and support the findings related with the research problem.
- (v) Oral traditions and written records were also used for extracting information on the courses of the Kameng river during the recent past of historic times.

### **1.6.2 Secondary Data**

Secondary data used for the present study are as follows:

- (i) Topographical information relevant to the study was extracted from the Survey of India toposheets and upgraded using multi-date satellite imagery.
- (ii) LANDSAT and LISS II and LISS III imagery of the Indian Remote Sensing Satellites (IRS I A to D, P4) covering the study area for the years 1989 to 2004 at suitable time interval were used for visual interpretation to identify changes in

the course of the Kameng river and demarcate geomorphic units in the study area.

- (iii) The historical gauge and discharge data from 1997 to 2003 were collected from the Central Water Commission having G&D Station at NT-Road crossing site over the river Kameng. Historical Gauge and discharge data for the same site were also collected from the Water Resources Department, Govt. of Assam, and Guwahati.
- (iv) Geological, Hydrological, Geomorphologic and stratigraphical maps and diagrams published in various GSI volumes and other publications have been used in the present study.
- (v) High Resolution Satellite Imagery laid over Digital Elevation Model by '*Google Earth*', which is made available on its website, were used to identify and interpret the changing courses of the river and different geomorphic and tectonic features of the study area.

## **1.7 METHODOLOGY**

Following methodology has been adopted for conducting the present study:

### **1.7.1 Delineation of the Basin**

The catchment area of the Kameng river basin was delineated from the Toposheets and updated using satellite imagery. Satellite imagery was also used for delineation of geomorphic features of the areas where Survey of India toposheets are not available or where the SOI did not survey.

The Survey of India Toposheets were available in 1:50,000 scale, whereas the Geological Survey of India maps were available in smaller scale. Non-geocoded satellite imagery of IRS series and LANDSAT were procured, which were processed to derive geocoded False Colour Composite outputs in its best representation at 1: 50,000 scales. However, the PANCHROMATIC data procured for the study area, had also been used to fuse the LISS III data deriving outputs at a scale of 1:10,000. These fused high-resolution images were used to derive detail surficial information for the critical areas of the study. Bringing all the source maps and imagery into GIS platform enabled easy overlaying to get output at the representative scale. For this purpose ILWIS 3.3 (Academic) developed by the ITC, Netherlands was used.

### **1.7.2 Study of the Changes in the Course**

The study on changing course of the Kameng river has been attempted by comparison of temporal maps and satellite imagery supported by geomorphic evidence. Digital image processing technique has been applied on the satellite imagery to enhance palaeo-courses of the river for an onscreen interpretation to reconstruct the old courses depicting shifting of courses and finding any pattern in it. These have been verified through ground truths and hydrogeomorphological evidences. Attempts have also been made to forecast the changes, if any, in the course based on the findings of the study and the sequence of geomorphic, hydrologic and tectonic changes in the study area. Historical records have also been taken into consideration for this purpose.

Several fieldworks were undertaken to identify different geomorphic features including the old courses of Kameng river in the study area and verify the geomorphic and geologic results derived through interpretation of the remotely sensed data. Different

features identified on the satellite imagery were verified through field checks and terrestrial photographs were also taken to support such results.

### **1.7.3. Geology**

Geologic features were extracted from the geological maps and different literature of the G.S.I. in the background of the satellite imagery. These features were further analysed and compared with the geomorphological findings through the spatial analysis of the geomorphology of the river using ILWIS 3.3 Academic software. The findings thus helped in establishing the shifting course of the Kameng river in chronological order. Geological information also facilitated understanding of the formation of the raised older alluvium surfaces, the graben and its edges, demarcation of the major lineaments, the rise of the boulder-gravel ridge and their relationship with the changing course of the river and the associated alluviation of the valley.

### **1.7.4 Discharge and Sediment Analysis**

Appreciating the role of the discharge and sediment on the work of a river, the discharge and sediment load of the river was measured for a short period of 17 months from December 2004 to May 2006 to examine possible relationship between these two parameters, and their relationship with the changing courses. The collected discharge and sediment data were processed and analysed to get the discharge pattern and sediment load distribution throughout the studied period. Then it was analysed along with the secondary data of preceding years to develop possible relationship of discharge with river dynamics. A Geomorphological Instantaneous Unit Hydrograph (GIUH) has been developed using mathematical model that enabled the use of historical data on maximum rainfall as input to the GIUH to develop a flood hydrograph suitable for hydraulic design.

## **1.8 ORGANISATION OF THE THESIS**

The entire Ph.D. Thesis has been organised in six chapters. The First Chapter is introduction to the thesis in which concept of changing courses of rivers, statement of the problem, objectives, research questions, database and methodology have been given. The relevant literature on changing course of rivers, fluvial processes, floods, sediment load, discharge etc has been incorporated in the Second Chapter as Review of Literature.

The Third Chapter is devoted to the discussion on various characteristics of the Kameng drainage basin as a whole in general and the study area, the Lower Kameng Basin, in particular. While Fourth Chapter is crux of the Ph.D. Thesis where changing courses of the Kameng River have been discussed and the pattern of changing courses have been identified. Causes responsible for the changes in the course have also been explained. The Fifth Chapter deals with the analysis of discharge and sediment data, relationship between them and their relationship, if any, with the changing course of the Kameng river. Attempt has also been made to develop Geomorphological Instantaneous Unit Hydrograph for the Kameng river. The conclusions and findings derived from the study have been given in the Sixth Chapter. It also includes limitations of the study and clues for further research work in future on related aspects.

**CHAPTER II**  
**REVIEW OF LITERATURE**

## **CHAPTER II**

### **REVIEW OF LITERATURE**

#### **2.1 INTRODUCTION**

Understanding the causes involved in bringing changes in the course and occurrence of floods in a river requires an appreciation of fluvial processes that operate over time and space in a river basin. Moreover, to study them the geomorphic, geologic, tectonic, and climatic (and cultural as well) histories of a drainage basin have to be taken into consideration. In fact, complex processes and factors are involved in the functioning of the geomorphic and hydrologic phenomena. Both the phenomena have been influencing man from time immemorial, as such attracted the scientists to study their nature, characteristic, magnitude, intensity, frequency, extent etc. not only to understand them but also to find out solutions and mitigate their hazardous affects on man.

The deciphering and remodelling of the changes in river courses result from skilful and thorough understanding of the various processes involved. Analysis of the geomorphic evidences, remotely sensed data and terrestrial photographs is done to trace changes in the river courses over time and space. The constant process of alluviation buries almost all the previous evidences (except of the latest ones) of geomorphologic events on the surface making the task of identifying earlier fluvial works more difficult. However, with the availability of high resolution remote sensing data, GIS programmes, GPS and various tools of surface and subsurface surveys (like echo-sounding and radar) research on present and prior courses of rivers has become more scientific and interesting. However, such attempts on the Brahmaputra and its tributaries are very few.

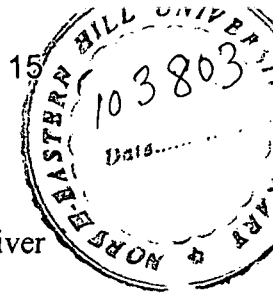
Development in space science has made it possible to collect the images of the earth surface from satellite and airborne platforms in different bands at various scales for desktop analysis providing a new horizon for analysis of geomorphologic, geologic and hydrologic evidences. The underlying layers of the earth's surface always have impact on the surficial development and leave its imprint on it in most of the cases. The satellite data once brought to the GIS platform on desktop can be processed with suitable techniques to search for such imprints of surficial development in order to gather geomorphologic evidences for reconstructing the complex changes in river courses.

It becomes interpretative if study of changing course of rivers is conducted in relation with discharge and sediment of the concerned river. This is because both are interrelated and influence each other as a part of the integrated fluvial process in a river basin. Truly, in this way the river basin act as a system whose various parts and functions are interrelated and interdependent and interconnected to carry out the ultimate processes of erosion, transportation and deposition in course of sculpturing the landforms. That also leads to creation of dynamic equilibrium between the process and form in a river basin. Interpretations revealing relations between the changing course and discharge and sediment load also become useful largely for river training works for long-term river basin planning and to explore water resources, thereby to save life and property as far as possible. Different approaches were adopted in isolation to develop hydraulic models depicting the river behaviour and flood. Therefore, the relevant literature has been reviewed in this Chapter, first to get theoretical insight into the problem and secondly to note the relevant empirical work on the topic of research. The review has been divided according to important points dealt with in the Ph.D. Thesis. Wherever required the literature has again been referred back in the following chapters.

## 2.2 FLUVIAL PROCESSES AND CHANGING COURSE OF RIVER

Migration of the course of a river and floods in its valley belong to the river dynamics. Shifting of a river course means that at a particular point of time and space a river abandons its original course and starts flowing along another course (Thornbury, 1954). It simply means taking a new route, other than the usual one, by a river in its journey. It is an indispensable part of the alluviation process responsible for formation of plains in the river valleys. Flood is an over bank flow of water from a river or lake that inundates the low lying areas. Though flood is a sudden and short duration event, it is strong enough to cause perceptible changes in the river basin. Leopold *et al.*, (1964) have mentioned that aggradation dominates degradation during the short-term floods and whatever sediments are removed by erosion not transported to long distance from its source. Calculations show that a large quantity of sediment transport is not possible even in bank-full floods. Butzer (1976) observed that sudden, strong and deep flow during floods bring more changes in shorter time rather than a normal flow of longer time and each flood contributes to the alluviation in the area. Actually, a variety of geomorphic, geologic, climatic and biotic factors influence changes in the course of a river and occurrence of floods in its valley. However, the major controls governing the behaviour of the river system in shorter time scale are sediment supply and flow regime (from immediately upstream), channel and valley morphology, and the nature of the volume of sediment supplied to the river from the adjacent slopes and undercut banks (Werritty, 1997).

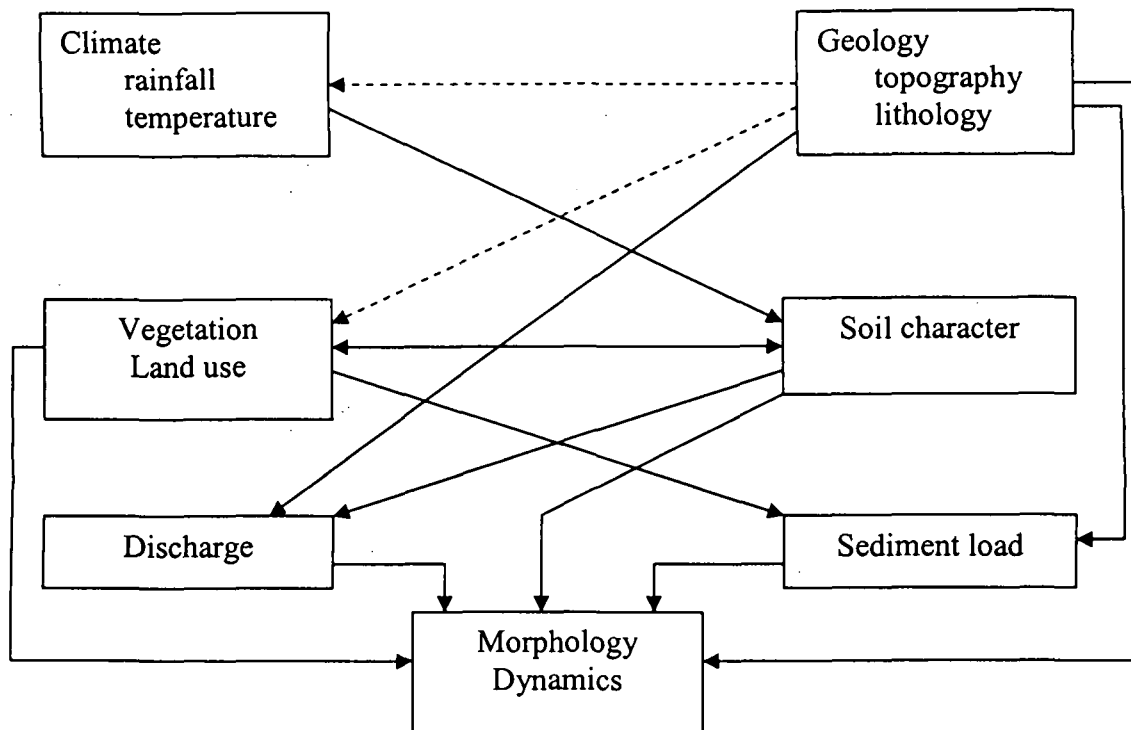
Streams are constantly adjusting and evolving in response to the sequence of normal flow and flood events. The inputs of water and sediment to the channel are not constant over time and space. Many problems of river management arise from the



inadequate prediction of sediment behaviour during floods. Part of this uncertainty stems from the complex nature of the drainage system and not having clear understanding of the link between runoff and sediment sources both within and outside river channel. Change in velocity, discharge and sediment load may cause changes in the course of a river. The changes may be slow or rapid, but it is a rule rather than exception that banks will erode, sediments will be deposited, and flood plains, islands, cuts and side channels will undergo modification (Schumm, 1977).

The interpretation of the past changes in river course depends on ability to explain and understand the present. This is simply an out come of the basic geomorphic concept 'present is the key to past' that is based on the *principle of uniformitarianism* propounded by Hutton. Thornbury (1954:16) has rightly worded this principle as '*The physical processes and laws that operate today operated throughout geologic time, although not necessarily always with the same intensity as now*'. Though the interpretation of changes in river courses is highly dependent on the experience and knowledge of the interpreter, the development in technologies led to availability of more precise and reliable data and thus made the effort of the interpreter easier. Further, such technological development is also helping in interpretation through interdisciplinary activities by educated researchers. The relics of the fluvial activity on the alluvial plains help in identifying the river courses of the past. This supported by terrestrial and historical information leads to successful extrapolation of the courses of a river of the past. If such cycles can be identified, future course of the river can also be predicted in time and space.

According to Morisawa (1985:1-2) "Rivers and river processes are one of the most important geomorphic systems operating on the earth's surface.... Fluvial processes may function by themselves or in conjunction with other geomorphic agents." River dynamics are an important part of the fluvial process. A few principles have to be kept in mind while studying mechanics by which rivers perform their functions of degradation, transportation and deposition. Three principles have been identified by Morisawa (1985:1-2). The first is '*the universality of change*'. It means that the material and forms of the dynamic earth are continuously modified by the forces of gravity, heat, orogeny and isostasy. Important to note that these modifications influence the activity of running water on the surface of the earth. This principle can easily be linked to the above-cited Hutton's principle of *uniformitarianism*. In this light the endogenetic and exogenetic processes (particularly the fluvial) operating in the Kameng river basin have to be analysed. The second principle is '*historical perspective*' since the change takes place over long, as well as short, periods. It means the actual state of the system at a given time or stage. In this context, the response of the Kameng river to past geologic, geomorphic, and climatic conditions has to be understood to trace the morphologic development up to present times. In the third principle, the rivers and their watersheds are considered as open systems. As such, each river basin is a complex system consisting of many components that undergo constant modification and interact with each other to give output in the form of discharge and sediment load (Fig. 2.1). This principle is directly reflected when the entire Kameng drainage basin is taken as one unit or system whose parts (i.e., various sections of the basin and stream) are interrelated and interdependent, e.g., events of the upper basin modify form and process in the lower reaches, particularly changes in the course.



**Fig. 2.1. Variable in a watershed affecting the dynamics and morphology of the fluvial system (From Morisawa and Vemuri 1975; cf. Morisawa, 1985:2).**

Morphometric analysis of the drainage network helps in understanding of both geomorphologic and hydrological characteristics of a drainage basin. The quantitative analysis of channel networks began with the classical work of Horton (1945). Strahler (1957) revised the Horton's scheme of stream ordering, referring to only the interconnections, and not the lengths, shapes or orientation of the links forming the network. Shreve (1966) led the way for a theoretical foundation of Horton's empirical laws and provided new perspectives for many other problems in fluvial geomorphology. Smart (1968, 1972) analysed the statistical properties of stream lengths and reviewed the channel networks.

### 2.3 DISCHARGE AND SEDIMENT LOAD

The stream flow representing the runoff is the most important data for hydrologic and fluvial geomorphic studies. The precipitation (particularly effective rainfall) is primarily responsible for the stream flow. An excessive peak discharge causes flood in a river. The probability of occurrence of high floods in a stream decides the design and life of the hydraulic structures. The stream flow is either measured directly by the standard methods or computed using empirical formula and statistical methods involving rainfall-runoff relationship. As rainfall varies over time and space, it is also necessary to have rainfall data for longer period representing the entire area for the measurement of the stream flow. The direct methods for stream flow measurement are (i) area-velocity methods, (ii) dilution techniques, (iii) volumetric method, (iv) electromagnetic methods, and (v) ultrasonic methods. The indirect methods for determination of stream flow are (i) hydraulic structures, and (ii) slope-area method.

The empirical rainfall-runoff relationships, developed for estimating runoff, are applicable to the ungauged river basins. The rational method (Mulvany, 1850), which is useful in estimating the peak discharge, is probably the simplest one in this regard. However, it only depicts the total and peak discharge, not the progress of discharge in relation to time. Development of hydrographs of extreme floods and its stages is essential for hydrologic design. Many empirical relationships for Flood-Peak-Area Relationship were developed by the early twentieth century, e.g., Dickens Formula (1865), English Formula (1884), Fuller's Formula (1914) etc.

The simplest and most successful of the rainfall-runoff formulations that describe the full hydrograph is the unit hydrograph (UH) concept introduced by Sherman (1932).

He defined the unit hydrograph as the hydrograph of direct runoff resulting from one unit depth of effective rainfall occurring uniformly over the basin and at a uniform rate for a specific duration. Determination of a unit hydrograph depends on the availability of the input and output data. Snyder (1938) developed the most commonly used synthetic unit hydrograph, which was later modified by Taylor and Schwartz (1952). Mockus (1957) introduced the concept of dimensionless unit hydrograph to form a basis for developing synthetic unit hydrographs.

Whereas, the computation of runoff hydrograph due to complex storm is simpler with instantaneous unit hydrograph (IUH) approach introduced by Clark (1945). He indicated the possibility of developing IUH by routing the time-area-concentration curve using a single element of linear reservoir storage. Nash (1957) considered the basin to be series of linear reservoirs and formulated the two-parameter IUH model. Dooge (1959) proposed the general theory of the unit hydrograph, whereas O'Donnell (1960) suggested the 'Fourier series expansion' for developing IUH.

Kirkby (1976) set the guidelines for formulation of Geomorphological Instantaneous Unit Hydrograph (GIUH) based on the width function (WF) of the basin, coupled with various routing procedures. His process considers hydraulic component comprising celerity and longitudinal diffusivity. These parameters can be determined from the geomorphic characteristics. Mesa and Mifflin (1986) and Naden (1992) also proposed similar formulations for GIUH.

Rodriguez-Iturbe and Valdes (1979) pioneered the probabilistic approach of GIUH, assuming a semi-markovian process for the time distribution. According to their

theory (R-V theory), IUH of a basin is interpreted as the probability distribution function (PDF) of the travel time that a drop of water, landing anywhere in the watershed, takes to reach the outlet. The time of travel in streams of given order is assumed to follow an exponential distribution. A triangular IUH would reasonably specify the peak and the time to peak. However, 'the characteristic velocity', which remains constant anywhere in the basin at a given time in the R-V GIUH, is difficult to estimate. Valdes *et al.*, (1979) suggested replacement of the characteristic velocity by an estimated peak velocity for any event in the basin.

Gupta *et al.*, (1980) generalised the R-V theory of GIUH by employing a kinematic theoretical framework for obtaining an explicit mathematical representation of the GIUH at the basin outlet. They set two examples to develop explicit formulae for IUH, analogous to solutions that Nash's linear reservoirs basin concept would have given considering the channels either in series or in parallel. Their theory provided good agreement for the basins of larger areas but underestimated the peak flow for a smaller basin that was later explained by a quasi-linear approximation.

Rodriguez-Iturbe *et al.*, (1982a) introduced the Geomorpho-Climatic Instantaneous Unit Hydrograph (GCIUH) where he eliminated the mean velocity parameter by introducing climatic dependency in terms of (i) kinematic wave parameters, (ii) intensity of rainfall, and (iii) basic basin geomorphological parameters. Since GCIUH depends on the climatic inputs, it departs from the linear assumption of the traditional theory. Rodriguez-Iturbe *et al.*, (1982b) evaluated the Nash model in relation to the Geomorpho-Climatic theory. To avoid the need to estimate prior effective rainfall, Hebson and Wood (1982) attempted to introduce the infiltration parameter in overland

and channel segments into the model. Such hydrograph could be estimated directly using total rainfall. Diaz-Granados *et al.*, (1984) also proposed a similar approach.

Cordova and Rodriguez-Iturbe (1983) developed a simple methodology for the estimation of flood probabilities, using Geomorpho-Climatic information. Kirshen and Bras (1983) analysed the effect of linear channel on GIUH. They solved the continuity and momentum equation using the boundary conditions of IUH and derived the response of individual channels. They also considered the effects of upstream and lateral inflow to the channels while deriving the basin's IUH and concluded the adopted methodology to be more accurate.

Gupta and Waymire (1983) reviewed the available methodologies and came with the fact that the incorporation of network geometry in terms of the Strahler's ordered channels was not appropriate. They formulated an alternative analytical approach that required the use of the path number classification for the purpose. Gupta and Mesa (1988) discussed the progress related to the need for a comprehensive quantitative theory of channel networks in three dimensions. Such model should reflect the components, which are in dynamic equilibrium with channel network.

Bras (1990) presented an excellent review of the works of earlier investigators related to the use of the geomorphological characteristics of the basin for hydrograph development. Snell and Sivapalan (1994) examined the three approaches for introducing geomorphology in deriving IUH. These approaches are: (1) Using the Horton's order ratios to derive analytical expressions for pathways parameters, (2) Extracting probabilities and lengths directly from Strahler's ordered network without using Horton's

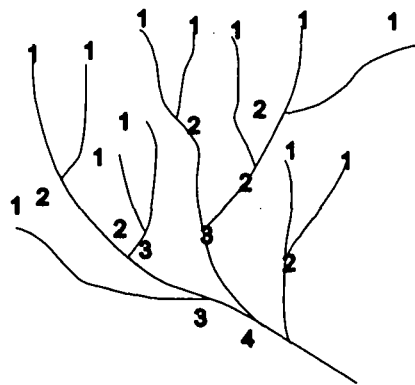
ordered ratios, and (3) Using contributing area-flow distance function extracted directly from the digital elevation model (DEM) without the assumptions of Strahler's stream ordering. The geomorphological dispersion coefficient derived from the area-distance function depicts the natural dispersion within the catchment.

Al-Turbak (1996) presented a Geomorpho-Climatic model with a physical based infiltration component. The model calculated the peak discharge and time to peak. He incorporated these outputs into an infiltration model for calculating the ponding time, and effective rainfall intensity along with its duration. The model predicts the peak discharges reasonably well for the events with detailed and accurate data. Franchini and O'Connell (1996) reviewed different formulations of GIUH and compared their performances with the original GIUH and width function based IUH (WFIUH). Based on a study carried out on four sub-basins, they concluded that the velocity parameter lacks physical interpretation unlike the hydraulic parameters of the WFIUH.

Panigrahy (2002) developed a computer model of Geomorphological Instantaneous Unit Hydrograph (GIUH) based on the theory proposed by Rodriguez-Iturbe and Valdes (1979) and its subsequent generalisation by Gupta *et al.*, (1980). It has been observed that the computer model developed by Panigrahy (2002) is suitable for determination of the GIUH of Kameng river. According to the theory, the unit input (unit depth of rainfall) comprises of an infinite number of small non-interacting drops of rainfall of uniform size falling instantaneously over the entire region. The travel time of a randomly chosen drop of water, from its starting point to the outlet, represents the instantaneous unit hydrograph (IUH) of the basin. The travel of a raindrop to the outlet is dependent on the geomorphological features of the basin.

The basin geomorphology plays an important role in the movement of rainwater from the overland region to channels (streams) and from the channels of lower order to the next higher order. Geomorphological laws are applied to simplify the explanations of these movements. However, the channel network is given hierarchical order according to the Strahler's scheme for applying the geomorphological laws as per the following rules.

- i) Channels that originate at a source (un-branched at the starting point) are termed as first order channels.
- ii) When two channels of order 'j' join, a channel of order 'j+1' is formed.
- iii) When two channels of different order join, the resulting channel at the downstream of the junction retains the higher of the orders of the two joining channels.
- iv) The order of the basin is the same as that of the highest order channel.



**Fig. 2.2. Strahler's ordering scheme applied to a fourth-order stream network**

Graphical representation of the ordering scheme for a sample of fourth order stream network is shown in Figure 2.2. Once the basin is ordered, the basic geomorphological features such as the number and average length of each order channel and average area of each order sub-basin are measured from the map. Subsequently, the

following geomorphological laws are used to estimate the geomorphological parameters of the basin.

**Laws of geomorphology:** According to the geomorphological laws, the ratio of number, average length of streams of one order to that of the next higher order, and the average area of sub-basins of one order to that of the next higher order tend to assume constant values. These ratios are termed as geomorphological ratios.

Let  $\Omega$  denote the order of the basin network. If  $N_i$  ( $i = 1, 2, 3, \dots, \Omega$ ) and  $L_{ji}$  ( $i = 1, 2, 3, \dots, \Omega$  and  $j = 1, 2, 3, \dots, N_i$ ) represent the number of streams of order  $i$  and the length of the  $j^{\text{th}}$  stream of order  $i$  respectively, then the mean stream length of order  $i$  is given as follows.

$$\bar{L}_i = \frac{1}{N_i} \sum_{j=1}^{N_i} L_{ji} \quad \dots 2.1$$

The law of stream numbers is mathematically expressed as follows.

$$\frac{N_{i-1}}{N_i} = R_B \quad i = 1, 2, \dots, \Omega \quad \dots 2.2$$

where,  $R_B$  = bifurcation ratio, which varies from 3 to 5 for natural basins.

The law of stream lengths is mathematically expressed as follows.

$$\frac{\bar{L}_i}{\bar{L}_{i-1}} = R_L \quad i = 1, 2, \dots, \Omega \quad \dots 2.3$$

where,  $R_L$  = stream length ratio, which ranges from 1.5 to 3 for natural basins.

The law of basin areas, proposed by Schumm (Smart, 1972), is given as follows.

$$\frac{\bar{A}_i}{\bar{A}_{i-1}} = R_A \quad i = 1, 2, \dots, \Omega \quad \dots 2.4$$

where,  $R_A$  = area ratio, which ranges from 3 to 6 for most of the basins; and  $\bar{A}_i$  = mean area of sub-basin of order  $i$ , which can be calculated as follows.

$$\bar{A}_i = \frac{1}{N_i} \sum_{j=1}^{N_i} A_{ji} \quad i=1, 2, \dots, \Omega \quad \dots 2.5$$

where,  $A_{ji}$  = area of the overland region that drains into  $j^{\text{th}}$  stream of order  $i$ .

The approach to develop the GIUH is described by Panigrahy (2002). He considered basin (B) as a natural unit and assumed that the direct runoff produced by the basin is from its storage and net effective rainfall, i.e., losses due to evaporation, infiltration etc. have already been taken care of. The continuity equation for B, at any instant  $t$  ( $>0$ ) becomes,

$$\frac{d S_B(t)}{dt} = - Q_B(t) + i_B(t) \quad (t > 0) \quad \dots 2.6$$

where,

$S_B(t)$  = volume of water in storage within the basin;

$Q_B(t)$  = outflow from the basin; and

$i_B(t)$  = inflow into the basin, i.e., rainfall at time  $t$ .

Since the total flow at time  $t$  is composed of the contribution from all drops that were injected between times 0 and  $t$ , the ordinate of the hydrograph at time  $t$  is represented as follows.

$$Q_B(t) = \int_0^t h(t-\tau) i(\tau) d\tau \quad \dots 2.7$$

where  $i(\tau)$  = rainfall intensity at time ' $\tau$ ' ( $\tau > 0$ )

$t$  = time to reach a drop to outlet,  $t > \tau$

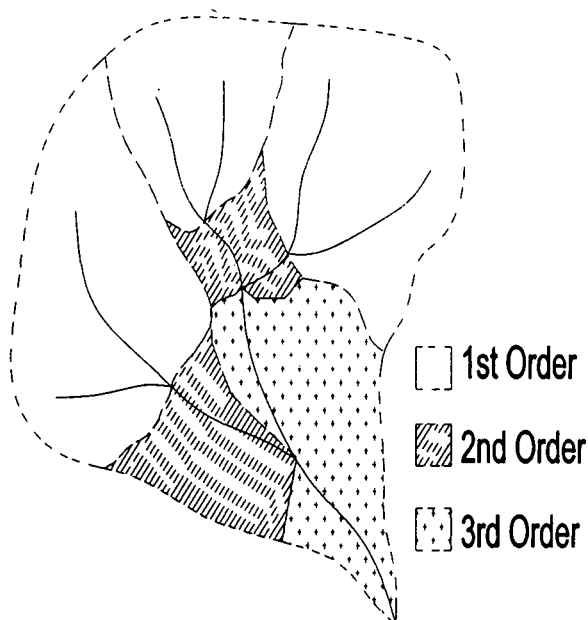
$h$  = ordinate of the hydrograph

Eq. (2.7) is the linear convolution transformation between the input and the output.

Figure 2.3 shows an example of the basin area draining directly into a channel of order 'i'. The mean holding time of the IUH can be estimated as the first moment of  $h(t)$ , and mathematically expressed as follows.

$$K_B = \frac{\int_0^{\infty} t h(t) dt}{\int_0^{\infty} h(t) dt} = \frac{\int_0^{\infty} t h(t) dt}{1} = \int_0^{\infty} t h(t) dt \quad \dots 2.8$$

The net effective rainfall intensity at any instant  $t$ , i.e.,  $I(t)$ , can be estimated by subtracting the average infiltration rate,  $I_f(t)$ , from the rainfall intensity,  $I_r(t)$ , i.e.,  $I(t) = I_r(t) - I_f(t)$ .



**Fig. 2.3. Basin area draining directly into channels of different order**

Sediment load in a river is any material transported by it in the form of dissolved, suspended and bed load. The sedimentation process consists of three phases (i) Origin of sediment, (2) Transportation of sediments, and (iii) Deposition of sediment in riverbed, flood plain, or larger water bodies. Sediments, irrespective of its origin, are therefore responsible for rise in river bed, decline in the bed slope/gradient and water bearing ability, increase in the tendency of shifting of river course. Hence, estimation of sediment load of a river is necessary for successive preventive adaptive measures to be taken up for securing life and property. The two methods used for this purpose are (i) Empirical equations, and (ii) Sediment sampling at site. The most common empirical relationship adopted nowadays for assessing the sediment yield from a basin is Universal Soil Loss Equation (Wischmeier and Smith, 1978). However, the direct measurement through *in-situ* sediment sampling in the concerned river yields to actual results, which may in turn be used to correlate the output with the catchment parameters to develop empirical equations.

## 2.4 FLOODS

Floods in Brahmaputra river and its tributaries have been studied by a number of scientists. Goswami (1982) studied floods of the Brahmaputra river. Shukla (1989) conducted a geoenvironmental study on parts of Sonitpur and Nagaon districts of Assam and suggested that long term steps such as construction of reservoirs on the catchment area should be taken up to mitigate the flood problem being faced in the study area. Bora (1993) examined the fluvio-sedimentary environment of the Assam section of the river Kameng known as Jia Bhareli. Gupta and Reddy (1993) prepared an inventory of landslides in Kameng river basin.

Husain (1994) examined the role of floods in sculpturing the desert landforms in the light of the field study on the 1979's flood in the Luni river system of the Thar Desert. Minor and major geomorphic changes brought by such short but vigorous floods in the arid and semi arid environments are of considerable interest in comparison to usual cyclic seasonal and normal floods of the humid environment. Raina *et al.*, (1996) mapped geology of the Nargum Ri – Dirang belt in western part of the Kameng Basin. The geology of a few villages in the Kameng basin was surveyed by Mishra and Goswami (2001) and they found that the area is characterized dominantly by Quaternary sediments with a few outcrop of granite gneiss. Five morphologic units including erosional and depositional surfaces were identified. Kalita *et al.*, (2001) conducted a study of the bank line migration of the Kundil river located in the eastern part of Assam and Arunachal Pradesh using multi-date satellite data to identify the stable reaches of the river over a period of 35 years. Three types of bank line migrations were identified; these are: (a) straightening of the river courses by meander cut-off, (b) Lateral migration, and (c) progressive changes of meander bends. Among these, the lateral migration of the bank line is most commonly observed type in the river. Husain (2002) studied the Geocology of Kameng Himalaya to find out changes occurring in the biophysical environment with changes in altitude, which have influence on the pattern and process of human adaptation.

Studies have also been conducted on the floods induced by the bursting of the lakes created by blockage of the river water due to huge landslides in Fiji islands, China, New Zealand and Canada leading to spectacular changes in courses of rivers. Most of these events were related with active tectonics. Rahiman (2006) studied the Rhine river basin and found that failure of steep slopes due to retreat of snowline resulted in

impoundment of the water in the course of the Gail river due to landslide in 1348 A.D. which pushed it southwards by one kilometre. He also studied the palaeo Nayua-Waidina river (Rahiman, 2006) of Fiji and found that the huge landslide obstructed the flow of the river for several thousands of years and ultimately separated the rivers to flow as two independent rivers. The earthquake of June 1, 1786 A.D. triggered a large landslide that dammed the Dadu River in the southwestern China creating a huge lake, the failure of which resulted in flash floods causing 100,000 deaths ([www.cat.inist.fr](http://www.cat.inist.fr)).

The Canadian rivers bear number of evidences of occurrences of huge landslides triggered by tectonics, specifically due to glacial activity and subsequent climatic changes. The Peace river and its tributaries are occupying a basin once covered by Laurentide ice sheet. Subsequent up-drainage advance of the ice sheet triggered landslides, many of which dammed the corresponding rivers. Failure of the lakes led to extreme floods and changes in landforms down the stream (Lu and Cruden, 2000).

Selting *et al.*, (2001) studied the historic Mission Debris flow in the Rattlesnake canyon above Santa Barbara. He concluded that failure of a landslide dam was sufficient to set off the Mission Debris flow, which deposited  $10.9 \text{ km}^3$  of debris around Santa Barbara during Late Holocene. Garde *et al.*, (2004) also found similar happenings 5400 years ago in the Marsyandi river of the Central Himalaya in Nepal that redefined the morphology of the basin. Green Lake of New Zealand bears the largest documented occurrence of such landslides on the earth. Hencox *et al.*, (1994a and 1994b) found that the landslide occurred due to glacial recession after the end of the last glaciations. Withdrawal of the lateral support from the very steep eroded mountain slope triggered the collapse of 1500 m high mountain ridge leading to obstruction of the 9 km long hunter valley.

## 2.5 EXAMPLES OF THE CHANGING COURSE OF RIVERS

Shifting of course and floods are common features of a river essential for formation of alluvial plains. As such, examples of changes in river courses are also plenty throughout the world. There are ample evidences in the world about the migrating courses of the rivers and the devastating floods, details of which are mentioned in the Fourth Chapter.

Shifting courses of the Missouri river have been traced dating back to the Late Tertiary and Early Quaternary periods during which the river started flowing almost in opposite direction, i.e., from northwest to southeast. The Missouri river along with a number of streams used to drain into the Arctic Ocean before the Pliocene period. Subsequently its course changed eastwards to Hudson Bay, and finally to southeastwards to join the Mississippi as its tributary (Wayne *et al.*, 1991).

In 1952, because of a downpour of 22 cm of rain in 24 hours in the catchment area of Lyn river, the runoff became far greater than could be carried away through the existing channels. It led to the formation of a new course, which tore its way down the hillside, as a raging cataract, and burst through the little town of Devon before rejoining the original course (Holmes, 1965). Mesopotamia was greatly affected by recurring floods of the Tigris river until 1954. A deep canal was dug from the Tigris river to a low lying area, which saved Iraq from the fury of the great flood of 1957, otherwise it would have resulted into catastrophe (Thair, 2006).

Although Chinese civilization originated in the Hwang Ho river basin, it has the most recorded changes in its course throughout the development of the civilisation.

Records indicate that from 602 B.C. to present the course of the river made at least five major large-scale changes in direction and its levees were breached more than 1,500 times. During 1194 A. D., a devastating flood redirected the river to takeover the drainage course of the Huai river basin, south of the Hwang Ho river, to flow for the next 700 years through it. The Hwang Ho, popularly known as Yellow River or 'river of sorrow', adopted its present course in 1897 ([www.users.ox.ac.uk](http://www.users.ox.ac.uk)).

Interestingly, a number of cases and extensive shifts in the courses of rivers have also taken place in the Indian Subcontinent. Wadia (1919) mentioned changes in the courses of a number of rivers of North India. He wrote, "There are both physical and historical grounds for the belief that the Jamuna during early historic times discharged into the Indus system, through the now neglected bed of the Saraswati river...." While Krishnan (1954) pointed out changes in the courses of the Indus, Ganga and Brahmaputra rivers in the plains during the historic and prehistoric times. He mentioned, "The history of the Saraswati is exceedingly interesting. The withdrawal of the waters from the Sutlej, and possibly from the Jamuna, dried up the Saraswati that was once a great river that flowed through Bikaner, Bahawalpur and Sind.... All the Himalayan rivers that debouch into the plains of northern India, show ample evidence of building deltas in which their courses change very frequently". In this case, the courses of the Kosi and Teesta rivers are specifically mentioned.

One of the largest shifts of a river were traced with the help of satellite imagery and verified through the fieldwork about the Vedic Saraswati by Ghose, Kar and Husain (1979, 1980) of the Central Arid Zone Research Institute, Jodhpur. They are pioneer to discover that the Saraswati river used to flow from the Himalaya Mountains to the Rann

of Kuchchh across the Thar Desert. They traced the buried courses of the river for the first time south of the present dry bed of the Ghaggar. In fact, about five prior courses of the Saraswati were identified which clearly depicts that before meeting the Indus river it used to drain independently to the Rann of Kuchchh, and the last independent course was through the now known courses of the Raini-Wahinda-Hakra. Subsequently due to advancing aridity, mild tectonic movements, and instability in the Siwaliks the river changed its course and finally fanned out to reach the Indus river. The Sutlej river as northern tributary used to contribute water to the Saraswati river. The Luni from the Aravalli Range was also a tributary to the Saraswati river.

Probably the Yamuna river used to flow in to the Saraswati. According to Ahmed (1984) the Yamuna river was part of Saraswati drainage system in Pre-Mahabharata times. The up warping of the Aravalli region due to neotectonics resulted in capture of the Yamuna river by the Ganga drainage system (Saifuddin and Iqbaluddin, 1999). Actually, on the Yamuna-Sutlej water divide the Indus-Ganga-Brahmaputra plains attain highest elevation of 275 m above mean sea level between Sahranpur, Ambala and Ludhiana in the Punjab. This tract is thus the present water divide, to east lies the Ganga river system, and to the west lies the Indus river system. There exists much evidence to prove that this was not the old water-parting. Actually, the courses of many of the rivers of the plains have undergone great alterations ([www.en.wikipedia.org](http://www.en.wikipedia.org)).

Most of the great Punjab Rivers have frequently shifted their courses. In the time of Akbar, the Chenab and Jhelum joined the Indus at Uch, instead of at Mithankot, almost 100 km downstream, as at present. Multan was then situated on the Ravi, now it is 60 km from the confluence of that river with the Chenab. About 250 years ago the Beas deserted

its old bed, which can still be recognised between Montgomery and Multan, and joined the Sutlej near Ferozepur several hundred kilometres upstream ([www.en.wikipedia.org](http://www.en.wikipedia.org))

The records of the third century B.C. show that the Indus flowed more than 130 km to the east of its present course through the now practically dry bed of a deserted channel to the Rann of Kuchchh, which was then a gulf of the Arabian Sea. The westward shift of the Indus is thus a very pronounced phenomenon for which different causes have been suggested. Either the present dry river bed to the east of Sind known as the eastern Nara is the old bed of the Indus or, more probable, the channel of the Sind portion of the Sutlej after the river had deserted it. While Ghose, Kar and Husain (1979, 1980) considered it as the last independent course of the Saraswati. The famous cities of Mohenjo Daro, situated on the Indus in Sind, and Harappa, located on one of its affluent in the Punjab, were probably abandoned at a much earlier date due to the vagaries of the shifting rivers and also to their recurring flood deposits, which eventually buried them.

The sluggish Arun river, after passing through the Mahabharata range, enters into the piedmont zone, below the Chatra gorge, to be known as the Kosi river. However, due to non-availability of sufficient space for passing through degradation and aggradation stages the river drops its sediments on the plain choking its own path and shifts its course directing to some dead old courses. When the lower area is raised, another diversion takes place in a comparatively lower tract, while flowing from there to its junction with the Ganga within a short reach of 75 kilometres. It used to flow near Purnea two centuries ago. It is notoriously shifting its course very frequently to flow through the present main braided channel, 96 kilometres to the west (Holmes, 1965, Ahmed, 1976 and Ahmed, 1985). Whereas Shillingford (1895) had noted that the Kosi oscillated from the

Brahmaputra to about the Ganga-Gandak confluence during the pre-historic and historic times, though it is doubted by many authorities.

The Son river of the central India is the largest southern tributaries of the Ganga river. The river had been notorious for its changing courses in the past, as it is traceable from several old beds on its east, but now it has been tamed squarely with the anicut at Dehri, and now more so with the Indrapuri Barrage, a few km upstream. ([www.en.wikipedia.org/wiki/Rivers\\_of\\_India](http://www.en.wikipedia.org/wiki/Rivers_of_India))

The Teesta river earlier flowed southward through Dinajpur and joined the Ganga through the Punarbhaba river prior to 1787. Following a major tectonic movement, it has gradually shifted towards east to discharge ultimately in to the river Brahmaputra in a southeasterly course. It significantly augmented the discharge of water and sediment into the Brahmaputra forcing it to shift its course towards west. The Teesta, after changing its old course, became a tributary of the Brahmaputra in 1787 (Ghulam Kibria, 1981).

Great changes have likewise taken place in Bengal and in the Gangetic delta since 1750; and hundreds of square kilometres of the delta have become habitable since then. The Brahmaputra flowed through the old course past Mymensingh, west of Dacca, to the Bay of Bengal through the Meghna. Gradually it shifted to the west flowing through the drainage course of other rivers to join ultimately with the Ganga. The structural movement of two uplifted blocks radically changed the course of old Brahmaputra. The Teesta is responsible for changing the old course of Brahmaputra to its present course. The Brahmaputra changed its course from Bahadurabad to the confluence with the Ganga near Aricha by 1820 (Ghulam Kibria, 1981).

Similarly, the rivers originating from the eastern Himalaya Mountain, for example, the Manas, Aie, Puthimari, Pagladiya, Subansiri etc. have also shifted their courses from their respective piedmont zones when they debouch into the Brahmaputra plains. Where closely spaced streams discharged from a mountainous region across a piedmont, their deposits may eventually coalesce to form a piedmont alluvial plain (Holmes 1965).

Regional drainage patterns suggest that an ancestral Tsangpo-Irrawaddy river was captured by the Brahmaputra network due to efficient headward cutting; this was likely caused by the river system's confinement within topography established by the tectonics of the Eastern Syntaxis (Koons, 1995). Brookfield (1998) suggested that this capture occurred a few million years ago. The Tsangpo river passes through a high gorge in Namcha Barwa, to drop its bed level up to two kilometres within a reach of 100 km with almost 7 km of relief on either flank that cuts N-S across the axis of the Eastern Syntaxis of the High Himalaya. Terraces of lacustrine sediments were discovered, high on the flanks of the upper Tsangpo, at about 3100 and 3500 m altitude (200 and 600 m higher than the river) deposited during 1200 – 1600 B.C. and 8800 – 9800 B.C., respectively. The terraces stop at a zone of thick glacial moraine, cut by the Tsangpo, which suggests that both were formed in the lakes behind two ice dams of 240 m and 680 m deep, respectively. About 830 km<sup>3</sup>, and the lower some 80 km<sup>3</sup> water accumulated behind the ice dams. Breaching of the dams caused the largest recorded erosive events in recent Earth history, forming the gorge below. Each flood discharge would have been between 1 and 5 million cubic metres per second, equivalent 3 to 15 times the maximum flood discharge of the Amazon (Montgomery, 2004).

Viswanathan and Chakravarti (1977) in their study found that the Kameng debouches from the Himalaya through a dissected piedmont plain and is restricted within a narrow valley wall. Tak and Mehta (1981) conducted a study on the photogeomorphic study of the Kameng basin and divided the basin into six geomorphic units.

However, some researchers have conducted studies on different hydrogeological and fluviomorphological aspects of the Kameng river, but the complete spectrum of changes in the course of Kameng river has neither been revealed yet nor its influence on the alluviation of the valley and formation of landforms has been studied. It has been observed during the last decade that the river course is undergoing rapid modifications. As such, a study should essentially be conducted to investigate the changes in the river course to bring out an up to date scenario. Moreover, such fluvial problems need regular updated studies. That is why study of changing course of the Kameng river has been done in the present Ph.D. research.

## **CHAPTER III**

# **THE KAMENG DRAINAGE BASIN**

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### **THE KAMENG DRAINAGE BASIN**

#### **3.1 GENERAL**

As the study area pertains to the lower reaches of the Kameng river basin, it is imperative to discuss about the basin as a whole in general. This is because a drainage basin functions as a system. Hence, it has to be discussed from holistic point of view. According to Morisawa (1985) rivers and their watersheds should be considered as an open system. Thus the river basins are complex system comprising of interacting components which constantly bring modifications. Therefore, the details of the study area, that is, the Lower Kameng Basin can only be seen in the background of the Kameng Basin as a whole. This is because of its functional and areal relationships with the entire drainage system. Whatever is happening in the upper reaches in terms of input, losses, discharge, sediment load influences the middle reaches, and in turn the lower reaches. Moreover, such description follows the 'whole to the part approach'. Therefore, in the beginning different aspects of Kameng drainage basin as a whole have been described, most of which is based on information from secondary sources. It is followed by a detailed account of the study area, that is, the lower reaches of Kameng river, which is mainly based on primary data collected through fieldwork. However, information collected from secondary sources has also been used wherever necessary. Discussion on geomorphic, geological, hydrological, climatic and other aspects mentioned in this Chapter is basic information, as it will be referred back in the subsequent Chapters wherever needed. In the following lines, the study area has been described in background of the Kameng river basin as a whole.

### 3.2 LOCATION AND EXTENT

The Kameng river is one of the many river systems which originate from the snowfields of the Greater Himalaya Mountain Range. It means the river has its catchment within the three parallel ranges of the Himalaya Mountain, unlike the antecedent rivers whose catchments extend far beyond the Greater Himalayan Range right up to the southern slopes of the Tibet Plateau. The Kameng is one the major right bank tributaries of the mighty Brahmaputra river which is an antecedent river.

In fact, the Kameng river originates from the snowfields of the Kangto Massif (7090 m) and its catchment extends over the different ranges of the Kameng Himalaya, lying at the international border with Bhutan and Tibet as a part of the Eastern Himalaya Mountain. The Manas drainage basin lies in the west (whose upper part is known as Tawang river), and the Subansiri drainage basin is in the east. The Kameng river along with its tributaries flows towards south to merge with the river Brahmaputra at present about 9 km east of Tezpur town in Assam (Fig. 3.1, and Fig. 3.2). The Kameng river is popularly known as Jia Bhareli in its lower reaches, i.e., after debouching into the plains, which is the actual study area of the present research (Plate 1, 2 and 3). The river enters the alluvial plains just near Bhalukpong in Arunachal Pradesh. From Bhalukpong, it first flows to the east-southeast between two boulder ridges and then turns sharply to the south and flows more or less in a straight course right up to its confluence with the Brahmaputra river.

The total area of the Kameng river basin is 10,853 sq km extending between longitudes  $91^{\circ}58'$  and  $93^{\circ}23'$  east, and latitudes  $26^{\circ}36'$  and  $27^{\circ}59'$  north. The river basin comprises areas of the West Kameng and East Kameng districts of Arunachal Pradesh and Sonitpur district of Assam. The Survey of India Toposheets **83A** 2,3,4,5,6,7,8,9,10,11,12,13,14,15,16; **83B** 9,10,13,14; **83E** 1,2,3,4,6,7,8; **83F** 1 cover the Kameng drainage basin. However, the Toposheets **78M** 16; **83B** 5; **83F** 2 were also used for understanding the drainage divide and behaviour of the tributaries originating from the divide. Though the study area belong to the lower reaches of Kameng river lying in the plains, for the sake of convenience and systems analysis the entire Kameng drainage basin has been taken into consideration. This helps in understanding the basin as a whole and the developments in its lower reaches where migration of its courses and occurrence of floods are common phenomena. Actually, detailed study in a part of a drainage basin, particularly in the lower reaches, cannot be undertaken properly unless various aspects of the whole basin are not taken in to account. The use of satellite imagery along with the toposheets had an added advantage in understanding the morphology of the basin as a whole. Such database helps in developing geomorphology-runoff relationship of the basin for predicting flood peaks and time to peak flood.

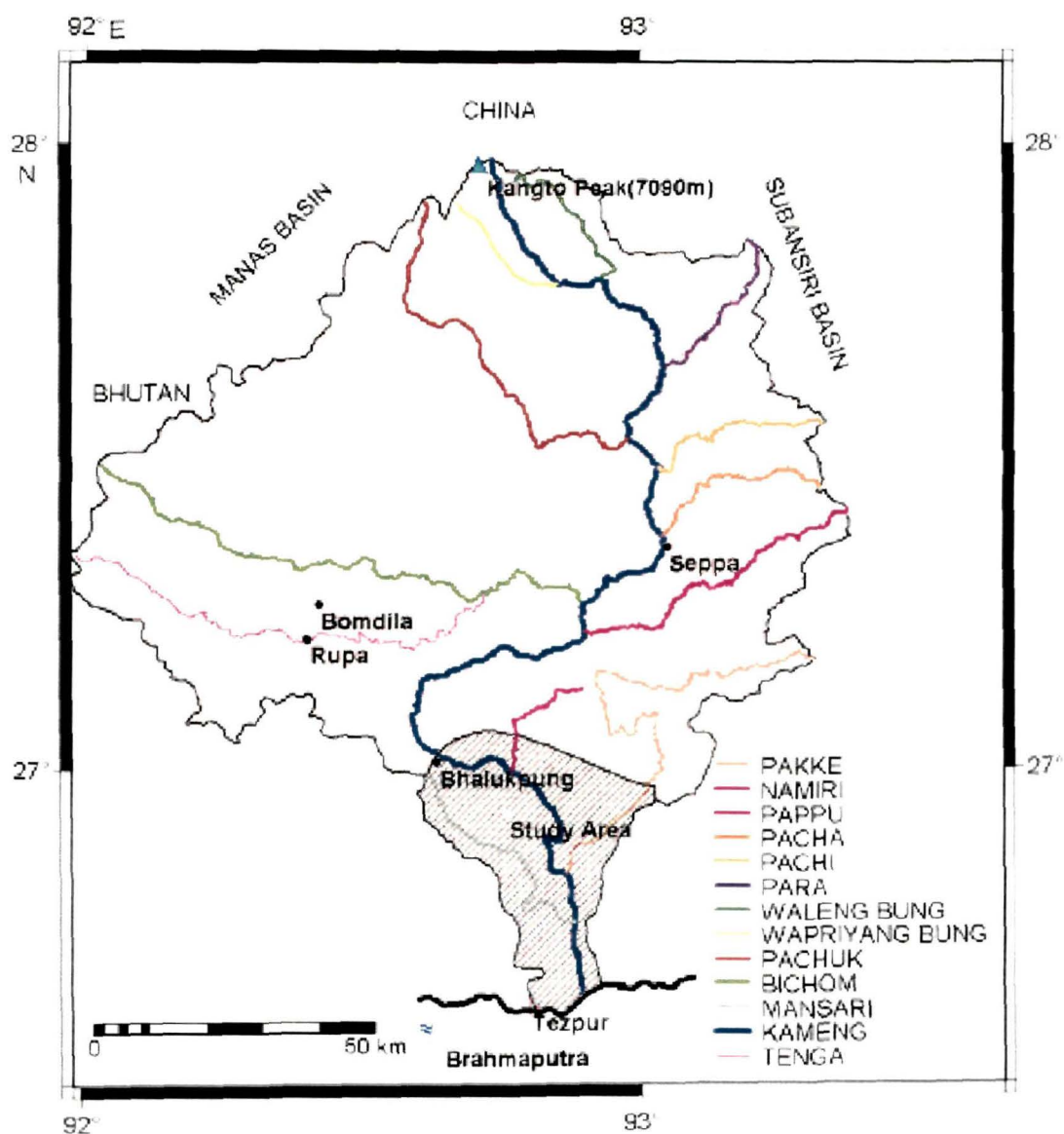
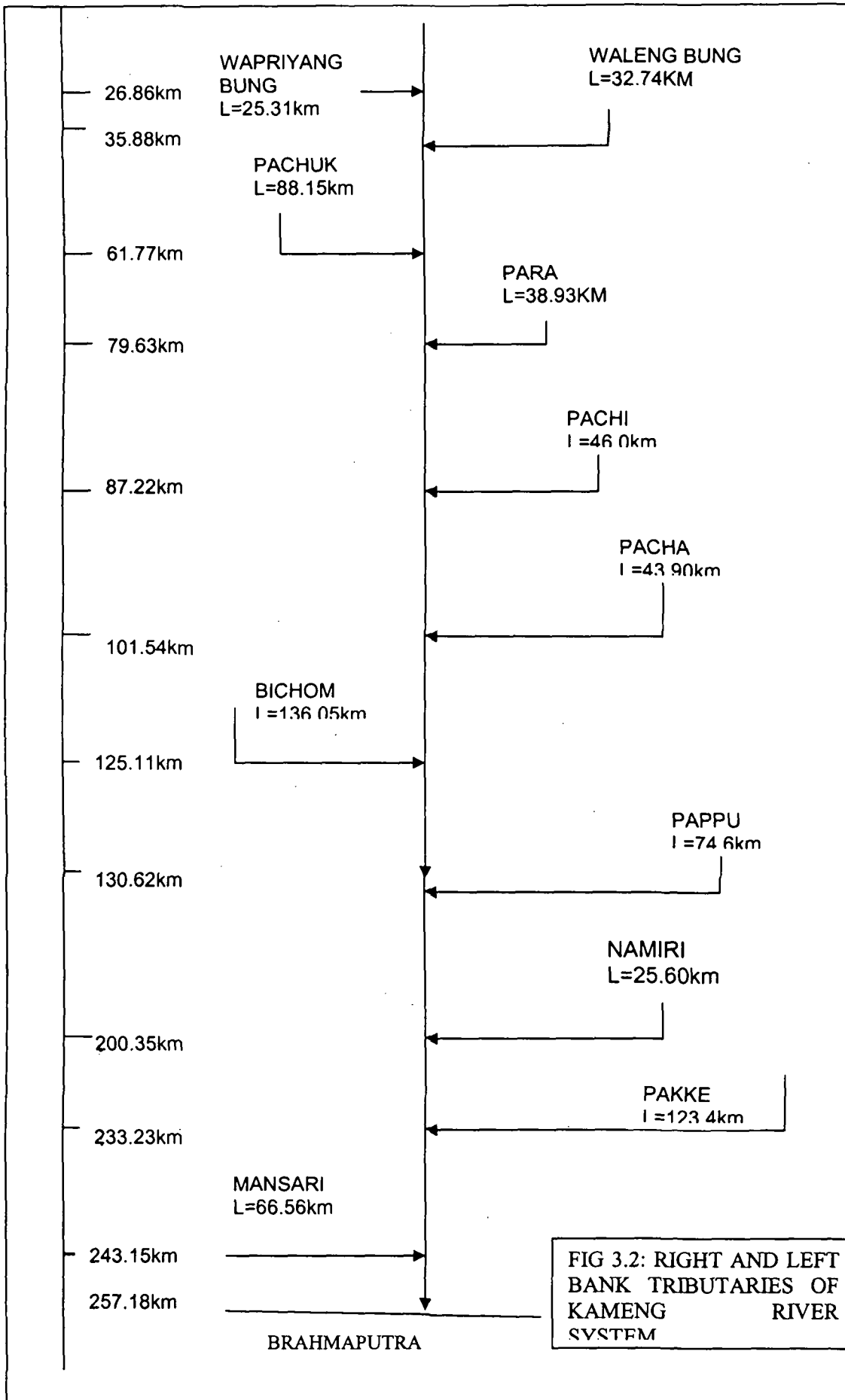


FIG 3.1 KAMENG DRAINAGE BASIN

**KAMENG**



**FIG 3.2: RIGHT AND LEFT BANK TRIBUTARIES OF KAMENG RIVER SYSTEM**

### 3.3 PHYSIOGRAPHY OF THE KAMENG RIVER BASIN

The evidences of coexistence of diverse topographical, geological, hydrological and neotectonic activity could be observed in the Kameng basin and that makes it an ideal case of understanding fluvial geomorphology and the river and its behaviour. These components have decisive impact on origin and development of landforms and the river course in its mountainous regime and as well as the alluvial regime. The topographical or terrestrial information of a basin is usually expressed through its morphometric characteristics. Morphometric analysis deals with quantitative description of basin geometry through the relationships like bifurcation ratio, drainage density, texture ratio etc. The terrestrial features of the Kameng basin have been extracted from the Survey of India Toposheets subsequently updated by satellite imagery which was used to calculate the morphometric relationships qualifying the basin. The mathematical definition of the morphometric parameters has been given in Table 3.1, and different morphometric characteristics derived from morphometric analysis of the Kameng river basin have been shown in Table 3.2.

**Table 3.1. Definition of morphometric parameters**

PARAMETERS	DEFINITION
<i>Area</i>	$A$
<i>Perimeter</i>	$P$
<i>Stream length</i>	$L$
No of streams of order $u$	$N_u$
Basin length	$L_b$
Bifurcation ratio ( $R_b$ )	$R_b = N_u / N_{u+1}$
Drainage density ( $D_d$ )	$D_d = L/A$
Stream frequency ( $F_u$ )	$F_u = N/A$
Texture ratio ( $T$ )	$T = N_1/P$
Form factor ( $R_f$ )	$R_f = A/(L_b)^2$
Circularity ratio ( $R_c$ )	$R_c = 4\pi A/P^2$
Elongation ratio ( $R_e$ )	$R_e = (2/L_b) * \sqrt{A/\pi}$
Compactness coefficient ( $C$ )	$C = P/(2\sqrt{\pi A})$

**Table 3.2. Morphometric Characteristics of Kameng River Basin**

(a)	Total basin area	10,853 sq. km
(b)	Catchment perimeter	615.00 Km
(c)	Length of the river	257.18 km
	(i) Length within Arunachal Pradesh	183.36km
	(ii) Length within Assam	73.82 km
(d)	Gradient along channel bed	0.0289m/m
(e)	Number of 1 <sup>st</sup> order streams	32080
(f)	Number of 2 <sup>nd</sup> order streams	6819
(g)	Number of 3 <sup>rd</sup> order streams	1563
(h)	Number of 4 <sup>th</sup> order streams	355
(i)	Number of 5 <sup>th</sup> order streams	79
(j)	Number of 6 <sup>th</sup> order streams	16
(k)	Number of 7 <sup>th</sup> order streams	4
(l)	Number of 8 <sup>th</sup> order streams	2
(m)	Number of 9 <sup>th</sup> order stream	1
(n)	Basin length	152.59km
(o)	Bifurcation ratio	4.70
(p)	Drainage density	0.0322 km/ha
(q)	Stream frequency	0.0377 no/ha
(r)	Texture ratio	0.052 no/m
(s)	Form factor	0.466
(t)	Circularity ratio	0.361
(u)	Elongation ratio	0.770
(v)	Compactness coefficient	1.665

The data has been derived from the SOI toposheets of 1:50,000 scale, and updated with the help of IRS LISS III, PANCHROMATIC and LANDSAT data. The morphometric parameters suggest that the Kameng basin is having bifurcation ratio, drainage density and stream frequency in moderate range. The Shape factor, Texture ratio, Form factor, Circularity ratio, Elongation ratio and Compactness coefficient suggest that the basin is more or less elongated approaching towards an oval shape. Brief morphometric analysis of some significant tributaries in relation to the Kameng basin as a whole have also been discussed in the stream morphology section of this Chapter to appreciate the nature and characteristics of the sub-basins and its possible contribution to causes leading to changes in Kameng river course.

Though the river has large number of tributaries, the names of a few major tributaries along with their catchment areas are shown in Table 3.3.

**Table 3.3 Major tributaries of the river Kameng**

Name of Tributary	Significant Sub-tributary	Area (Ha)	Perimeter (km)
Pakke		67987.84	178.96
Namiri		21697.13	77.70
Pappu		63315.06	135.86
Pacha		29247.33	86.32
Pachi		35574.49	99.24
Para		27497.00	85.50
Waleng Bung		19967.20	76.30
Wapriyang Bung		18817.32	73.37
Pachuk		120486.78	190.64
Bichom		392153.65	338.46
	<i>Gang</i>	135541.91	217.20
	<i>Tenga</i>	107817.85	220.82
	<i>Kuvu Nala</i>	29377.34	77.26
Mansari		26401.71	92.54

The drainage pattern of the Lower Kameng river system and its adjoining rivers systems of the study area are shown in Fig. 3.3. The adjoining river systems are also shown, the pattern of which have been discussed in the Chapter IV in relation to the changing course of the Kameng river in its lower reaches.

### 3.3.1 The Mountainous Regime of the Kameng River Basin

The Kameng river flows right from the highest Kangto peak at 7090 m altitude to the confluence with Brahmaputra at 59 m for a length of 257.18 km. The Himalayan drainage area of Kameng and its tributaries are grouped into three zones (GSI, 1977).

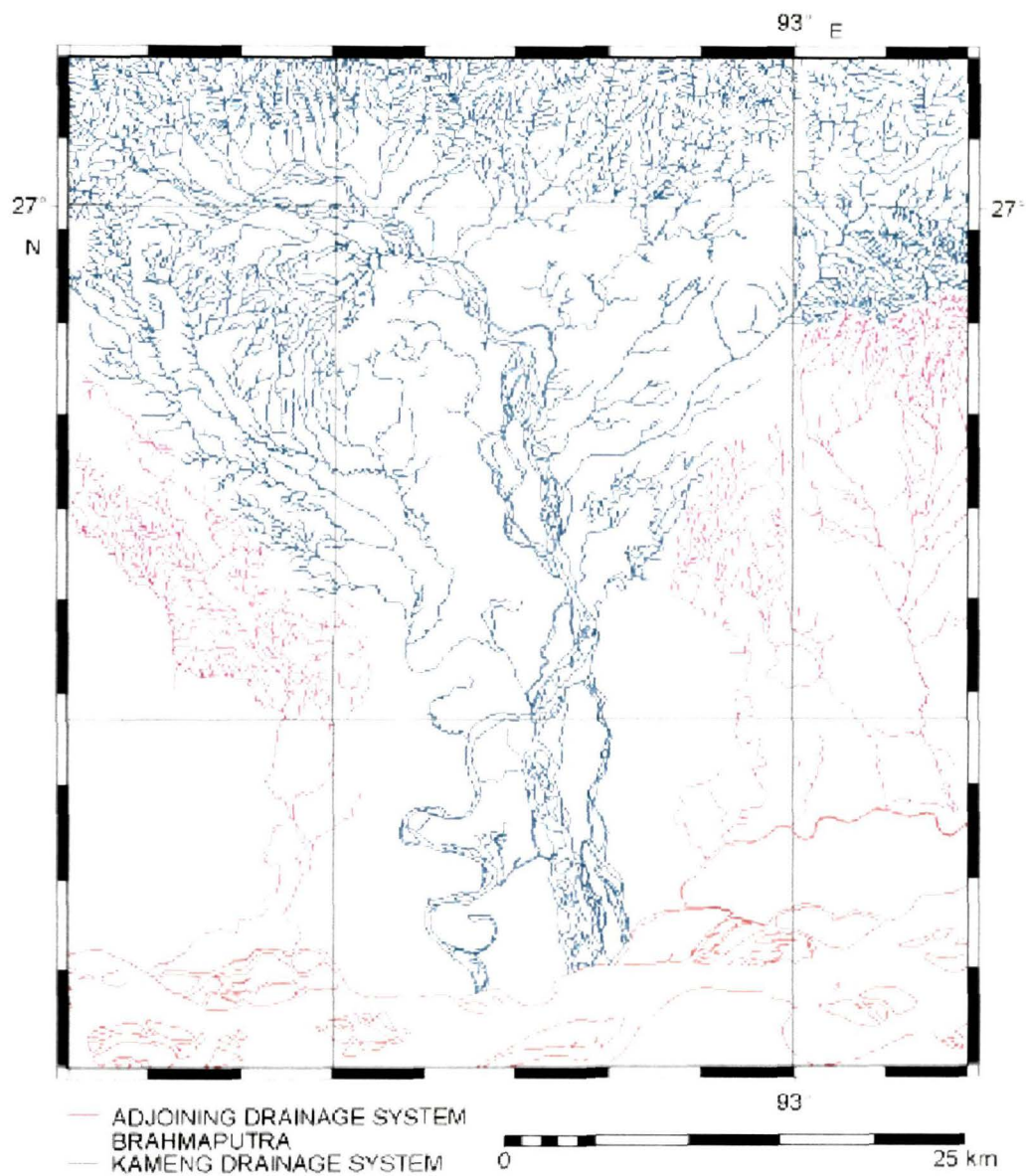


FIG 3 3 DRAINAGE MAP OF LOWER KAMENG BASIN AND ITS ADJOINING RIVER SYSTEM

- (i) **The northern zone;** high mountains corresponds to the southern part of the Great Himalaya Range with the peaks- Gorichen (6,558m), Kangto (7,090m), Chomo (6,937m), Neyegi Kangstang (7,047m), Takpa Siri (6655m) and others. The precipitation (rainfall as well as snowfall) in this zone is about 300 cm and the climate is Temperate to Alpine. A few unnamed glaciers also exist in this zone as evident from satellite imagery on the extreme north of the basin in the vicinity of the Kangto massif.
- (ii) **The middle zone;** about 60 km wide attaining height up to 4,877 m. Snow peaks are common. Rainfall reaches 300 to 400 cm.
- (iii) **The outer zone or southern zone;** the hilly area about 26 km broad, the general height being about 2,400 m though it may attain 3,040 m. The climate is humid Tropical and Temperate with rainfall exceeding 300 cm.

### 3.3.2 The Alluvial Regime of the Kameng River Basin

The alluvial regime of the basin comprises of older alluvium to recent alluvium in the active flood plain with distinguished features having imprint of the fluvial process during Pleistocene and Holocene epochs. Along the river near Tezpur, some hills crop out of the alluvium near Bhomoraguri, whose summits range from 90 m to 140 m above mean sea level. The weather is dry and cool from the middle of November till the end of February. The temperature begins to rise from the end of March but the showers experienced in April reduce it. The analysis conducted for the rainfall data of IMD for the period 1971 to 1999 reveals that the average rainfall at Tezpur was 183.5 cm. The GSI analysed rainfall data during 1929-50 and observed that the average rainfall at Balipara was 218 cm and at Borpukhuri it was 217 cm. This indicates that as the foothills are approached the rainfall increases.

### 3.3.3 Stream Morphology

The Kameng River receives many tributaries on both banks. Most of the tributaries are having confluence with the Kameng in its mountainous reach, except Pakke and Mansari. The mountainous tributaries are flowing through the young folded Himalaya Mountain having records of prominent landslides. However, these tributaries carry the debris and sediment generated from the upper basin that has insignificant influence on river dynamic in the lower reaches. In general dendritic type of drainage system is observed in the basin.

The tributary Mansari has its origin from the uplifted Balipara Boulder-Gravel Ridge (coalesced alluvial fan) near Bhalukpong from an altitude of 320 m only. It flows through nearly flat slope to have a confluence with the Kameng (Plate 18) at an aerial distance of 6.4 km downstream of the Bridge over the Kameng river on NH-52. It is flowing through an abandoned course of the Kameng as a misfit river from near Balipara. It is believed that the Mansari used to flow independently to have confluence with Brahmaputra along the abandoned course of Kameng during Late Quaternary, the remnants of which can be seen near Goroimari.

The Pakke or Pakhui is one of the most important tributaries of the Kameng, which is also known as Bardikrai in Assam. It originates from the water divide between the Kameng and Subansiri rivers and flows across the MBT and many more unrecognised cross faults. The trellis type of drainage pattern found in its upper reaches indicates the existence of such faults. Consequently it is responsible for carrying debris much more than its competence. The satellite imagery of the area indicates that once the river used to flow independently through the course of the present day Dikrai and shaped the landscape accordingly.

The Bichom is the largest tributary of the Kameng. It has large sub-tributaries like the Gang, the Bichum, the Tenga, each of which individually have large catchment areas. The Tenga and the parent river Bichom flow parallel south and north respectively to the Bomdila fault for a long distance. This part of the basin area has been subjected to huge landslides leading to mudflow several times in history causing substantial rise of the piedmont zone of the Kameng, as it is evident from the material of the alluvial fan (GSI, 1977).

**Table- 3.4 Morphometric characteristics of the major tributaries of the Kameng river**

<b>Sub Catchment</b>	<b>No. of 1st Order Streams</b>	<b>No. of 2nd Order Streams</b>	<b>Basin Length, km</b>	<b>Bifurcation Ratio</b>	<b>Drainage Density, km/ha</b>	<b>Stream Frequency, No./ha</b>	<b>Texture Ratio, No./m</b>	<b>Form Factor</b>	<b>Circularity Ratio</b>	<b>Elongation Ratio</b>	<b>Compactness coefficient</b>
<b>Pakke</b>	1845	432	58.36	4.27	0.027	0.035	0.010	0.200	0.267	0.504	1.936
<b>Namiri</b>	777	83	20.92	9.36	0.030	0.041	0.010	0.496	0.452	0.795	1.488
<b>Pappu</b>	2509	464	51.449	5.41	0.042	0.049	0.019	0.239	0.431	0.552	1.523
<b>Pacha</b>	1321	279	30.54	4.73	0.057	0.057	0.015	0.314	0.493	0.632	1.424
<b>Pachi</b>	1551	312	30.37	4.97	0.047	0.055	0.016	0.386	0.454	0.701	1.484
<b>Para</b>	1014	197	26.89	5.15	0.030	0.046	0.012	0.380	0.473	0.696	1.455
<b>Waleng Bung</b>	647	152	24.5	4.26	0.030	0.042	0.009	0.333	0.431	0.651	1.523
<b>Wapriyang</b>											
<b>Bung</b>	434	88	22.69	4.93	0.023	0.029	0.006	0.366	0.439	0.682	1.509
<b>Pachuk</b>	3431	780	58.42	4.40	0.040	0.037	0.018	0.353	0.417	0.670	1.549
<b>Bichom</b>	11439	2534	90.85	4.51	0.029	0.038	0.034	0.475	0.430	0.778	1.525
<i>Gang</i>	3158	739	59.91	4.27	0.027	0.030	0.015	0.378	0.361	0.693	1.664
<i>Tenga</i>	3772	723	73.59	5.22	0.032	0.044	0.017	0.199	0.278	0.503	1.897
<i>Kuvu Nala</i>	923	219	22.58	4.21	0.030	0.041	0.012	0.576	0.618	0.857	1.272
<b>Mansari</b>	234	59	37.63	3.97	0.017	0.012	0.003	0.186	0.387	0.487	1.607

The morphometric analysis of the tributaries of Kameng river as shown in Table 3.4 reveals that most of them have values close to the parent river Kameng. The bifurcation ratio is found to be as high as 9.36 in Namiri basin. The bifurcation ratio of the other tributaries ranges around 5, as is the case for the Kameng river where it is 4.70. The sluggish tributary Mansiri is flowing through almost a flat topography having confluence with the Kameng within the study area, due to which the morphometric parameters like bifurcation ratio, drainage density, stream frequency and texture ratio are found to be lowest as 3.97, 0.017 km/ha, 0.012 no./ ha and 0.003no./m. The rest of the tributaries, which are flowing through mountainous reach for a comparatively long distance, are having these values within a narrow range as 4.21 – 5.41, 0.023 – 0.057 km/ ha, 0.029 – 0.057 no./ ha and 0.006 – 0.034 no./m, which derive the values close to the parent river Kameng as 4.70, 0.032 km/ha, 0.038 no./ ha and 0.052no./m. However, the analysis of the shape factors indicates extreme values for the tributaries Pakke, Tenga and Mansari. The form factor, circularity ratio and elongation ratio of these tributaries respectively are as low as 0.200, 0.199, and 0.186; 0.267, 0.278 and 0.387; and 0.504, 0.503 and 0.487 indicating that these basins are elongated in shape. The values of rest of the tributaries are found to vary within 0.239 – 0.576, 0.361 – 0.618 and 0.552 – 0.857 and may be compared with the values of the Kameng river as 0.466, 0.361 and 0.770. This analysis as such has thrown light on the topography of the basins of the tributaries based on which inferences have also been drawn for the exploration of possible causes responsible for changing course of the Kameng river at its lower reaches.

### 3.4 GEOLOGY

The geology of Kameng Himalaya where the Kameng river basin lies can be studied as a part of the Eastern Himalaya. It has records of the most dramatic and visible geomorphic and geologic (endogenetic) forces related with the formation of the highest young folded mountain system in the world. The lofty Himalaya Mountain, which stretches over 2400 km from Nanga Parbat (8138 m) in the west to Namcha Barwa (7756 m) in the east (e.g., Le Fort, 1996), along the border between India and Tibet, are the result of an ongoing mountain orogeny. Generally, it is believed to be the result of a collision between two continental plates, best understood with the help of 'plate tectonic' hypothesis. There are views opposite to this belief as well discarding the collision theory, but for some limitations details of both are not discussed here. Undoubtedly, this immense mountain range was formed by huge tectonic forces and sculpted by unceasing denudation processes of weathering and erosion.

The evolution of the Himalaya Mountain has drawn attention of the scientists to understand its interesting orogeny. The MCT (Main Central Thrust) hanging wall of Himalaya has been the primary focus of geologists thus far (e.g., Hodges *et al.*, 1996; Coleman, 1998, Guillot, 1999). Most of the studies were conducted on the Western and Middle Himalaya. Comparatively the Eastern Himalaya including the Kameng Himalaya is less explored.

The earliest attempt to record geology of the Kameng drainage basin was made in 1883 by La Touche (1885), particularly on the Aka hills. Then information about geology came from the writings of Banerjee (1954a, 1954b), Balasundaram (1956), Rao (1972), followed by an important document by the GSI (1974). Jhingran (1981) also gave geological account of the Kameng Himalaya. Even then, entire Kameng Himalaya is yet to be explored. Based on this literature following account on geology of the Kameng drainage basin has been prepared. The rock types encountered from the Bhalukpong foot hills in the south to Tsela (Sela) in the north have been grouped successively as; (i) Tertiary or Siwaliks or Outer Himalaya, (ii) Lesser Himalayan Sediments, and (iii) The Central Crystalline or Greater Himalaya. The alluvium of the Quaternary has been described separately.

(i) *The Tertiary or Siwaliks or Outer Himalaya:* To the north of the Quaternary alluvium lies the Tertiaries in the Kameng river basin comprising mostly of the sedimentary rocks. Conglomerates are predominant in the Upper Siwaliks, which are common in the eastern parts of the basin. Apart from it there are hard and massive sandstone overlain by yellowish clayey siltstone, sands, pebbles and boulder beds. Interesting to mention are the white quartzitic sandstone near Tipi nullah (Plate 14), a few lenses of lignite and young rocks of river terraces. The strike trend of the rocks varies from NE-SW to NNE-SSW with regional moderate northward foliation bedding dips. The Tertiary rocks (Siwaliks) are over thrust in the north by a thin strip of Gondwanas comprising carbonaceous shale, micaceous and gritty sandstone.

(ii) *The Lesser Himalayan Sediments*: Real Himalayan characteristics of extensive thrust sheets (nappes) comprising of highly deformed and recrystallized unfossiliferous, crystalline and meta-sediment rocks. The Gondwana of Permian age are represented by sandstone and slaty shales. While pre-Permian unfossiliferous sediments of the Lesser Himalaya are locally called as Bichom Group comprising unfossiliferous white and purple quartzite, conglomerate, variegated shale sequence, grey silty phyllites, dolomites and dark shale as seen in the Tenga valley and lower reaches of the Bichom river in thrust contact with the Gondwanas in the south. The upper part of this group is noted further north in the Digen valley near Saleri below the metamorphites. A group of mica schists, quartzites and paragneisses are termed as Tenga Formation and are seen in tectonic contact with the Bichoms in the Tenga valley. The Bomdila Group comprising biotite gneiss, mica schists, graphitic schists and marble quartzites have a wide exposure around Bomdila and these overlie the Tenga formation. The Tsela Group comprising garnetiferous augen gneiss, muscovite-biotite and tourmaline granites, migmatites and pegmatites are exposed from north of Digen and continue beyond Tsela and are in tectonic contact with Bomdila Group schists near Dirang in the south (GSI, 1974).

(iii) *The Central Crystalline or the Greater Himalaya*: These are the highly metamorphosed pre-Cambrian rocks of the Greater Himalaya Range, hence called as 'central axis'. Some of the crystalline rocks occurring in the Lesser Himalaya are known as Tse La group and Bomdi La group according to their location. The most common rock types include gneiss, schist etc.

### 3.4.1 Brief orogen-scale description of the Himalaya Mountain

The MCT is one of five fault systems that formed during the evolution of Himalaya Mountain (Gansser, 1981; Pêcher, 1989; Schelling, 1992; Le Fort, 1996; Yin and Harrison, 2000). At their base, the Greater Himalayan Crystallines are thrust over the Lesser Himalaya along the MCT (Arita, 1983; Brunel and Kienast, 1986; Pêcher, 1989). Further south, the Main Boundary Thrust (MBT) separates the Lesser Himalaya from the Siwalik Formation (Valdiya, 1992; Meigs *et al.*, 1995). South of the MBT, the Main Frontal Thrust (MFT) typically defines the boundary between the Siwalik Formation and the northern Indo-Gangetic Plains (Mugnier *et al.*, 1999 and others). These crustal-scale faults are termed as the Main Himalayan Thrust (MHT) (Zhao *et al.*, 1993; Nelson *et al.*, 1996). A clearly identifiable ~50-km wide zone of predominately moderate earthquakes ( $5 \leq m_b \leq 6$ ), termed the Main Himalayan Seismic Zone, is located between the MCT and the MBT (Seeber *et al.*, 1981; Khattri and Tyagi, 1983; Valdiya, 1992; Pandey *et al.*, 1995; Kayal, 1996).

The Lesser Himalaya is mainly comprised of Gondwana sediments (Tripathi and Singh, 1987 and others) with granite intrusion. Most models proposed for the evolution of Himalaya assume the zone of plate convergence shifted progressively and temporally towards the foreland during the mountain building process. The Main Central Thrust (MCT) is thought to be active during the Miocene (Hodges *et al.*, 1996 and others). South of the MCT, the Late Miocene movement slip occurred along the Main Boundary Thrust (MBT) (Meigs *et al.*, 1995 and others), and presently, the Main Frontal Thrust (MFT) is active (e.g., Yeats *et al.*, 1992). Convergence is primarily accommodated by the youngest structures.

### **3.5 LANDFORMS OF THE ALLUVIAL REGIME**

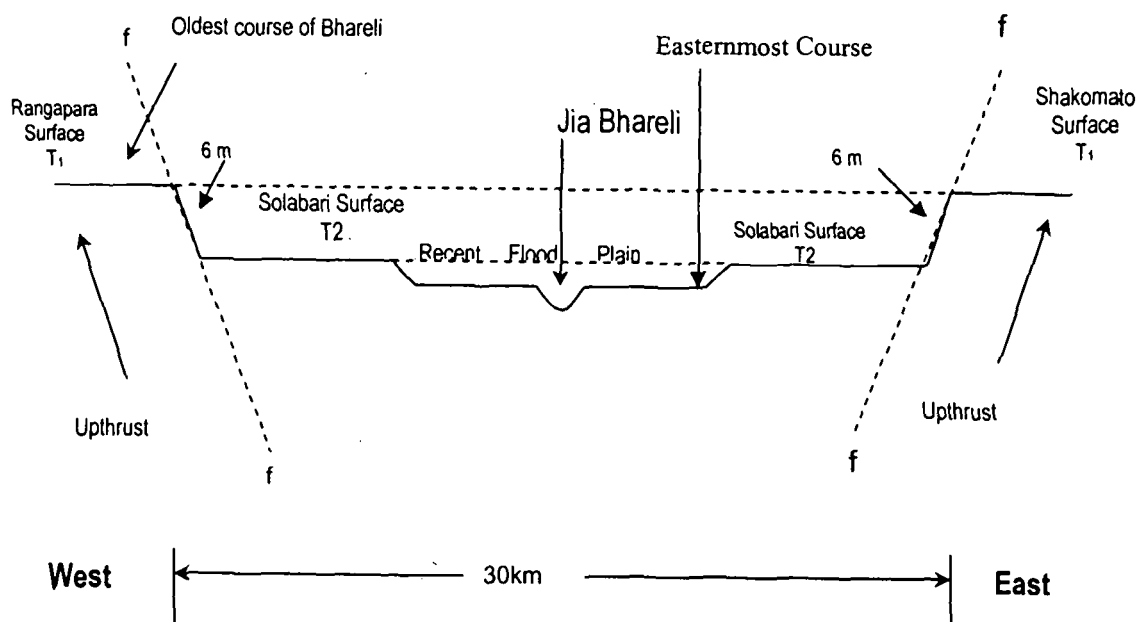
While flowing through the Outer Himalaya to the foothills, the Kameng river starts the alluviation process. The alluvial regime of the Kameng basin has been formed through intensive work of the river and its tributaries like Bichom, Pakke (Bardikrai), Mansari etc. The neotectonic activity is also guiding the work of the river right from the Siwaliks to the confluence with the Brahmaputra. The satellite imagery of the area shows clear imprint of the work of these rivers more specifically during the Holocene period. The area under the alluvial regime of the basin is covered by the Survey of India toposheets 83 B 9, 10, 13, 14 and 83 F 1, 2. The river might not have any contribution in formation of the Inselbergs and the Siwaliks, but their existence on the periphery of the alluvium certainly requires some explanation. As such, the landforms within the alluvial regime have been divided into a few major geomorphic units depending upon their sequence of origin along with brief mention of the role of these small hillocks belonging to the Indian Peninsular shield.

#### **3.5.1 Inselbergs and Siwaliks**

A chain of small hillocks along the right bank of the Brahmaputra namely Kaliabhomora, Agnigarh, Dhenukhana, Ouguri etc. are found protruding out of the Quaternary formations. These hillocks rise to height of about 100 m from the surrounding ground level and defined as Inselbergs (Tak and Mehta, 1981) having Pre-Cambrian origin. The hillocks are made up of granite and in isolated cases of quartzites. The outwash of the weathered granite material extends towards Tezpur and

responsible for filling up some part of the city and drainage channels extending to Dekargaon.

The Siwaliks were formed during the Plio-Pliocene, i.e., in the third phase of the Himalayan orogeny or uplift. The outer hills of Siwaliks of the Himalaya form the northern limit of the alluvial formations throughout the interface between the Indus-Ganga-Brahmaputra plains and the Himalaya Mountain. The Siwalik ranges extend from east to west with the peaks whose heights range from 387 m to 1,067 m. The southern front of the Siwalik range almost coincides with the 152 m contour. The southern most exposure of the Siwaliks is extended to near Potasali with altitude of 84 m (GSI, 1977) (Fig. 3.4, 3.5 and 3.6).



**Fig. 3.4 : Schematic Cross Profile of the Lower Reaches of the Kameng River (Bhareli)**

### **3.5.2 Alluvial Fans, Ridge, Surfaces and Terraces**

The alluvial fan deposits form the highest of the Quaternary surfaces of the basin, which is also known as 'Balipara Surface' in geological literature. This is also characterised by the highest degree of slope, relief and dissection. In places streams like Nam Sonai, Upar Sonai and Chotei have cut through this alluvial blanket and have exposed the underlying pre-Quaternary rocks with clear profile of the deposits. Clearly the coalesced alluvial fans have formed a terrace at the northern most extremity of the alluvial regime in the study area, as it is a common case wherever the Himalayan rivers debouch into the plains.

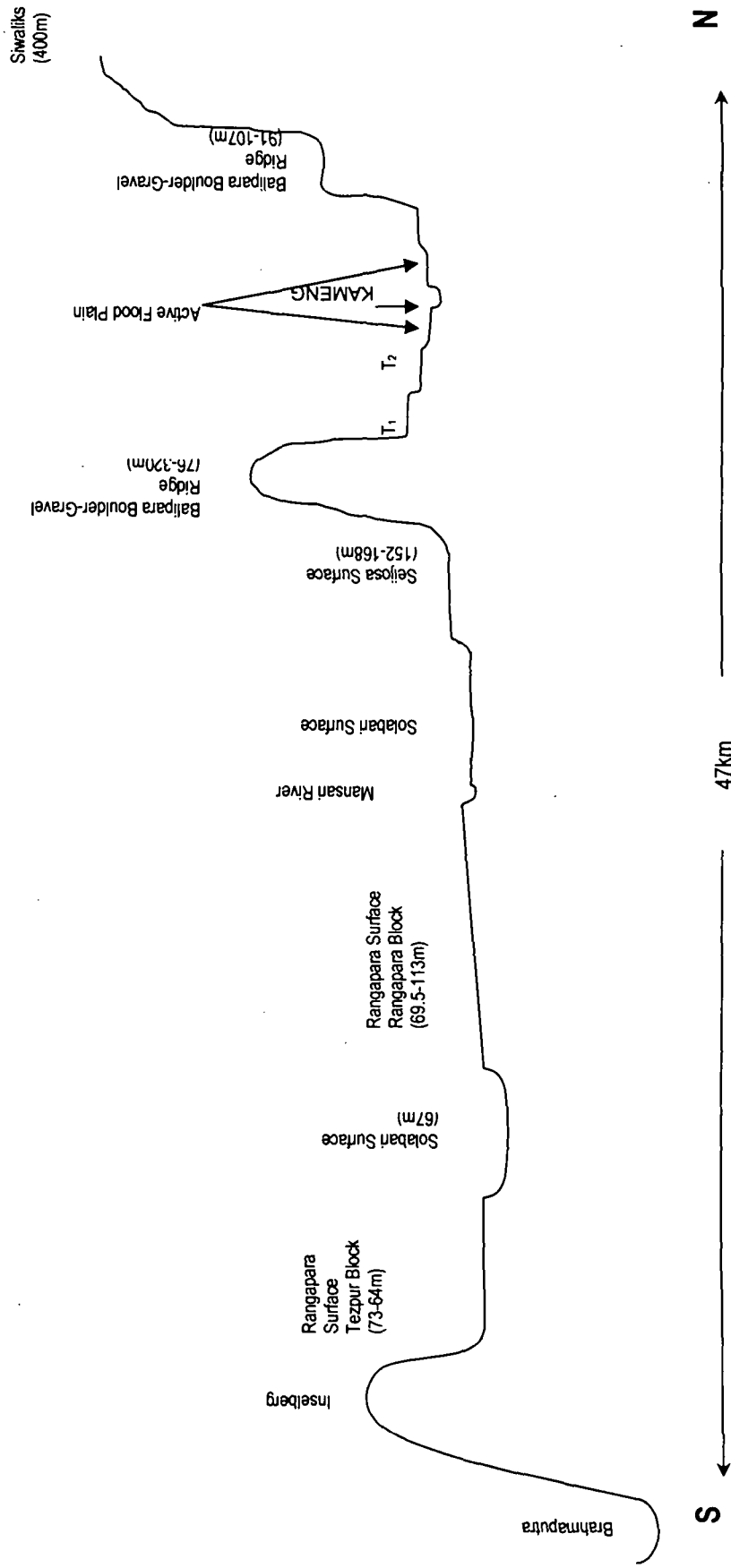


Fig. 3.5 Schematic Profile from Brahmaputra towards North through Tezpur

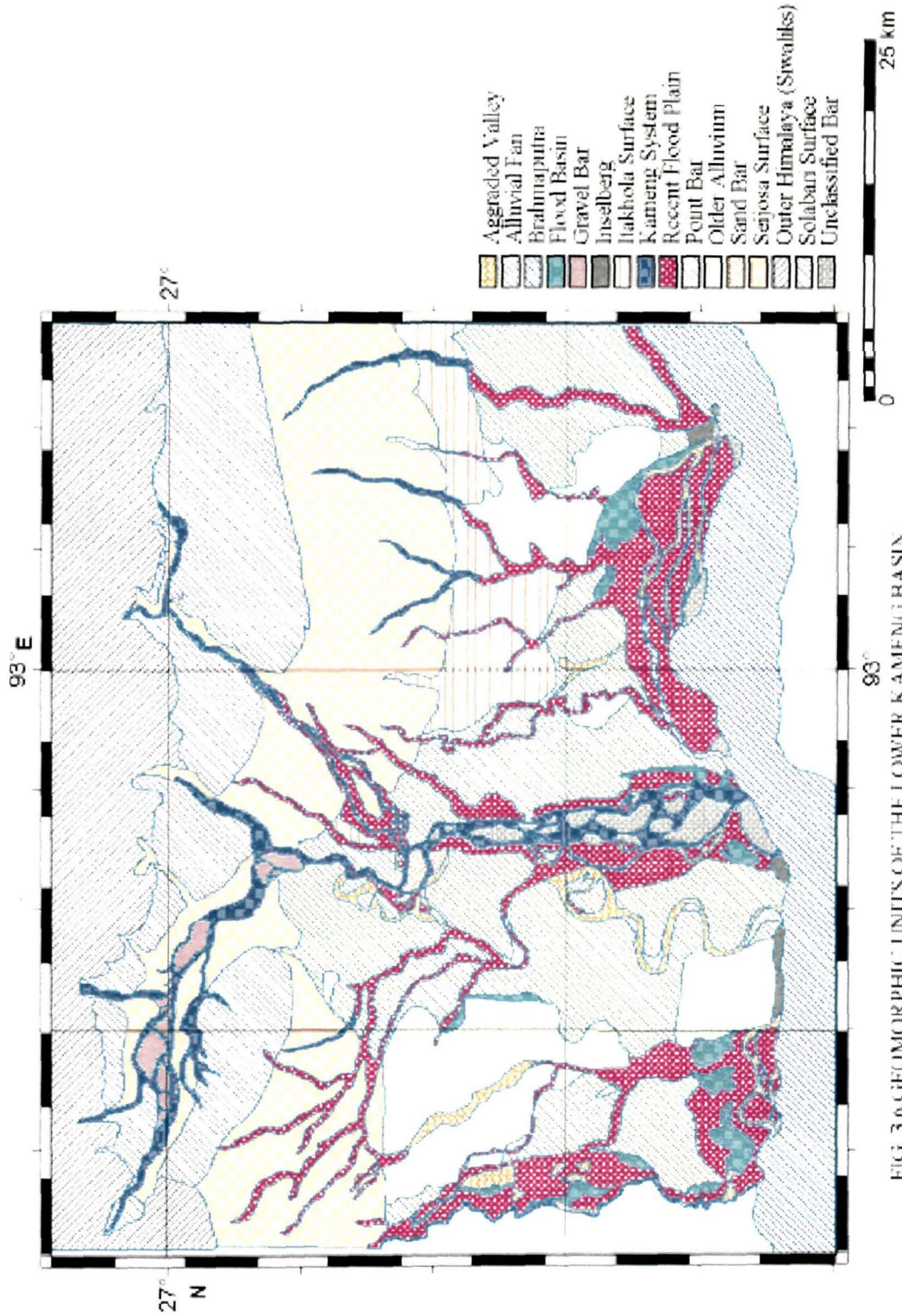


FIG 3 o GEOMORPHIC UNITS OF THE LOWER KAMENG BASIN

The alluvial fans formed by the Kameng river and its tributaries lie south of Siwalik range in between longitudes  $92^{\circ}38'E - 92^{\circ}48'E$  and latitudes  $26^{\circ}55'N - 27^{\circ}00'N$ , with maximum altitude of 320 m. This surface has a general southerly slope, which varies from place to place due to interference by later phases of erosion, deposition and faulting. The streams flowing through the surface have highly dissected and deeply incised the surface. It is resting with profound erosional unconformity on the terraced sediments of moderately northerly dipping Siwaliks. It comprises of semi-consolidated poorly sorted mixture of gravel, pebble, boulder, coarse sands and minor silts (Plate 12). All the sediments are coarser. The exposed 76 -107 m high valley walls of the surface suggest occurrence of mudflow carried by extraordinary high flood and dumped in the foothills. The boulders are unassorted mixture of quartzites, gneisses, slates etc. derived from Greater and / or Lesser Himalaya Ranges. Subsequently, due to tectonic movement the surface raised along with the rise of the Himalaya Mountain to achieve the present height. Henceforth, this highest part is referred as Balipara Boulder-Gravel Ridge in the Thesis.

Significant to mention here that a major fault is observed south of Jorhat township of Assam which swings westward of the town to reach south of Helem in Sonitpur district, where it turns suddenly West-North-West to continue in to the Himalaya (Barooah, 1981). The Brahmaputra river follows the fault to some distance as evident from its SEE-WWN course north of Kaziranga National Park. Moreover, the Digital Elevation Model (DEM) of the *Google Earth* website clearly shows that

the fault line enters the Himalaya near Bhalukpong where the Kameng river has taken a southeasterly course along the fault ripping apart the uplifted Alluvial Fan surface or the Balipara Boulder-Gravel Ridge. As such, the Kameng river has deeply cut the fan surface near Bhalukpong and further southeast exposing 122-152 m thick fan deposits. It has isolated the right bank fan surface from the left bank leaving the latter as a domal surface. The streams originating from the domal surface flows radially outwards to join the Kameng in north and Mansari in the south. East of longitude  $92^{\circ}50'E$  the fan surface reappears to continue up to  $93^{\circ}02'30''E$  longitude. In this stretch, it is confined between the Siwaliks in the north and the scarp faces of 152-168 m high Ridge from the gently sloping Seijosa surface in the south within latitudes  $26^{\circ}57'N$  -  $27^{\circ}00'N$  in the west and  $20^{\circ}53'N$  -  $26^{\circ}57'N$  in the east, running in an east-southeasterly direction. The surface has been highly dissected by the tributaries of the Kameng and adjoining rivers exposing 91-107 m of valley walls. The southern margin of this surface in between longitudes  $92^{\circ}38'E$  and  $92^{\circ}48'E$  is more or less straight. Similarly in the stretch bounded by longitudes  $92^{\circ}50'E$  -  $93^{\circ}03'E$  the south-southeastern margin of this fan surface shows scarp boundaries which may be due to simple erosion or faulting (GSI, 1977 and Tak and Mehta, 1981). This surface also corresponds to the Subankatha terrace identified in the Pagladiya basin and the Kukulong surface in the Manas basin.

### 3.5.3 Older Alluvium

The older alluvium was formed by the Kameng river system during the Pleistocene and Recent ages of the Quaternary period. The older alluvium appears as islands of various extents in the plains much above the present highest known flood level. Existence of the old alluvium in separate patches is due to its erosion by the courses of the Kameng and its tributaries. Such older alluvium is comparable with the older alluvium found in other basins of the Indus, Ganga and Brahmaputra. Medlicott (1865) correlated the sediments of the older alluvium with that of the Ganga basin.

The older alluvium of the valley, also known as Rangapara surface, has been subjected to peculiar weathering after its elevation from adjoining areas. The existence of an impervious clay layer at shallow depth resulted in low leaching to cause relative enrichment of iron compounds. The bulk of the sediments of the surface contain sandy clay. The ferruginous material originally contained in the sand clay got deposited due to poor leaching and subjected to oxidation over the surface. Generally it is composed of ferruginous silty-clay with fine sand lenses in its upper parts.

Such island type blocks of elevated ground are found distributed over the entire alluvium regime on the both banks of the Kameng covering an area of 250 sq km. There are three major blocks and two minor ones made up of this surface, well

developed around Rangapara (GSI, 1977). The gently rolling Rangapara Surface with the characteristic semi-lateritic weathering of the sediments can probably correspond to the Chapor Surface described from southwestern part of the Manas basin.

### 3.5.3.1 Right bank older alluvium surfaces

The right bank older alluvium surfaces are the remnants of the direct work of the Kameng river and its right bank tributaries, which can be divided in following blocks.

(i) *Garogaon Block*: It is located around Garogaon north of Rangapara surface covering an area 2.3 km by length and 1.1 km by width existing as an isolated island within Solabari and Seijosa surfaces. This block merges with Seijosa surface on its northern and the western boundaries with gentle slope.

(ii) *Rangapara Block*: This island of older alluvium is the most spectacular one after which the entire older alluvium of the Kameng basin is named. This surface is located around Rangapara township, the northern boundary of which merges with the Seijosa surface. The eastern edge (Plate 4) of the block is separated from the Solabari surface by a north south scarp face (about 6-9 m high) except for a short stretch between Phulbari and Adabari Tea Gardens. The block is deflected towards west by another East-West scarp face of one km length. The south-eastern and

southern part of the block stands above the adjoining Solabari surface by about 2- 4 m. The block has a gentle slope dipping towards west to merge with the Jia-Gabharu plain. Altitude of the Surface varies from 69.5 m in the south to 113 m in the north along the western boundary. The Rangapara block has been highly dissected by small secondary streams forming gullies that deeply incised the alluvium and exposed the Surface up to 6 to 10 m of depth.

The Rangapara block is slightly curved upward indicative of a slightly domal surface. Gravity and magnetic map has shown that the high anomaly around Rangapara is almost certainly a basement feature (G.S.I., 1977). Thus the basement uplift around Rangapara and north of Tezpur is reflected on the surface in the Older Alluvium Formation.

(iii) *Tezpur Block*: The entire Tezpur township is located on the older alluvium called Tezpur block stretching up to Dekargaon village in the north. In fact, it was continuation of the Rangapara block, now separated by the Solabari surface. This older alluvium is located within longitudes  $92^{\circ}44'E$  and  $92^{\circ}48'E$  and latitudes  $26^{\circ}37'15''N$  to  $26^{\circ}40'15''N$ . The northern side of this block is bounded by a narrow stretch of Solabari surface. The block abruptly ends at a 6 to 9 m scarp face on its eastern side to form right valley wall of the Mara Bhareli. This scarp face extends from Parwagaon in the north to Tezpur in the south. The southern boundary of this surface merges with the inselberg surface near Tezpur and the Brahmaputra river. Along the western boundary the top of the surface stands above the adjacent *beel*

complex surface by 4 to 5 m. Old map indicates that the *beel* complex was earlier course of the Brahmaputra. The southward shift of the Brahmaputra was responsible for formation of the *beel* complex. This surface is dissected and traversed by a number of nullahs or surface drainage channels that presently drains the surplus rainwater of the older alluvium. The surface slopes gently towards north from 73 m near Tezpur to 64 m near Diputa-Hatkholā.

### 3.5.3.2 Left bank older alluvium surfaces

A few older alluvium surfaces are standing high over the newer surfaces on the left bank of the Kameng as well. These surfaces were developed mostly by the east bank tributary Pakke, and adjoining rivers flowing directly to the Brahmaputra. The Pakke river earlier used to flow independently to the Brahmaputra and developed most of the landforms. The Ghiladhari and other small rivers, originating from the Outer Himalaya, were responsible for the formation of the landforms of Biswanath block further east of the present Dikrai basin. Following are the different blocks of the left bank older alluvium.

(i) *Korsontola Block*: The older alluvium of Korsontola block lies east of Jamuguri, on the left bank of the Kameng river. Along the Dikrai this surface is dissected to 5 to 6 m depth. The western boundary face of this older alluvium from the Jamuguri-Chutia road section to Bengaligaon exposes a scarp face of 4 to 5 m height and is fault bounded. In this block also the surface is highly dissected by the

small nullahs or secondary drainage channels that traverse north to south. The surface shows a gentle easterly slope.

(ii) *Chariali Block*: Though this surface does not have direct impact of work of the Kameng river, its existence in the eastern part of the basin requires description to elaborate its genesis. Entire Biswanath Chariali township sits on this surface. Elevations of this block varies from 76.2 m in the south, west and east to a maximum of 79.2 m along a north south line through the block near the eastern boundary. Generally higher elevations are on the west and the entire unit dips east beneath the overlapping Solabari Surface. An abrupt west-southwestern margin separates the low, flat, flood plain of the eastern part from the uneven highly dissected older alluvium. The entire western and southwestern margin is formed of a (?) series of fault(s) 12 km long (GSI, 1977). The eastern side of the fault up thrown, and the surface relief indicates a minimum throw side of 6.1 m having eastward tilt in parts. The antecedent nature of the Sadharu nullah attested to regional uplift in addition to eastward tilt.

#### **3.5.4 Seijosa Surface**

The high upland ground located south of the Alluvial Fan Surface is called as Seijosa surface separated by a fault scarp at the southern margin of the Uplifted Alluvial Fan Surface called the Balipara Boulder-Gravel Ridge. This surface is gently sloping southward to merge normally with the older alluvium surface. The

northern boundary (almost along  $26^{\circ}55'$  N) of this surface runs in a southeasterly direction between longitudes  $92^{\circ}38'$ E and  $92^{\circ}45'$  E, then running easterly up to  $92^{\circ}48'$ E. It is essentially an east-west trending landform. The north-south width of the landform varies considerably.

The Seijosa surface has the shape of a dissected fan with the apex located at the debouching point near Seijosa outpost. The fan spreads radially outwards into the plains. The transverse profiles of the surface indicate that they are convex upwards the sky, the degree of convexity gradually diminishes with the distance from the fan head. The radial profiles are concave to the sky reflecting diminishing slope with distance from the fan head. Surface slope instead of having a smooth exponential form, has the shape of a discontinuous curve formed by joining linear segments indicating discrete slope breaks. The slope break at the fan toe is very pronounced. This surface is essentially built by alluvial fan deposits and extensively eroded by the streams originating from the uplifted surface and within the Seijosa surface. Its stratification is crudely developed and the soil is uniformly oxidised. The sediments are more compact and consolidated than the uplifted Alluvial Fan Formation, apparently due to composition of finer particles.

### 3.5.5 Itakhola Surface

Seijosa Surface is fringed by an older flood plain. The remnants of this higher flood plain unrelated to the present streams are clearly discernible in the alluvial landscape and apparently considered to be the work of the Pakke river. The surface is extensively developed around Itakhola, east of Kameng and hence named accordingly. The Itakhola Surface is in essence a valley plain terrace, which persists as isolated remnants of varying sizes contained at a lower level by the Solabari and Recent Surface of the Kameng Basin. It has a general slope to the south and southeast. It is characterised by the presence of disturbed topsoil, chocolate brown in colour formed of medium to fine sands. It is composed of a bottom stratum of gravel, with very coarse to medium sand. The upper layers are found to be in cycles of medium to fine sand and silty clay. The chocolate colour of the top layer indicates an incipient phase of laterisation. Micro relief is of low order and secondary gullies are present. West of the Kameng River this Surface has been extensively eroded to be occupied by the comparatively recent Solabari Surface. The Itakhola Surface with its characteristic top chocolate brown coloured soil corresponds to the Sorbhog Surface of the Manas basin.

### 3.5.6 Solabari Surface

Southwards of the toe of the Itakola and Seijosa Surfaces, another dissected surface can be identified with wide expanse in between latitudes  $92^{\circ}44'N$  and  $93^{\circ}10'N$  covering an area of 512 sq km. This surface forms the valley wall for the

recent flood plain along the Kameng River system. The sediments of this landform are semi-consolidated and the stream density is medium to high with tortuous meandering incised streams dissecting the surface. It also exhibits numerous cut-offs and ox-bow lakes. The Mansari and Jorasor rivers that flow through the surface in their lower reaches have their valleys deeply incised in it. The banks as exposed are up to 8m high as seen near Charduar and further north. The right bank of the Mara Bhareli river is uniformly 5 to 6 m high in a reach of 29 km from Bamgaon in the north to Parwagaon in the south. Its altitude ranges from 69 m in the south to 91 m in the north.

The soil of this surface predominantly has sands and silts. Layers of pebbles, gravels and cobbles are also seen in the northern portion of the surface. The right bank of the Kameng exposes 5 to 6 m thick sediments. The sediments are found to be fine regionally from north to south down the older flood plain showing vertical inter-stratification of medium with fine sands. The entire surface on the right bank is also sculpted by meanders of the earlier Kameng river. Such features indicate that the surface has undergone repeated submergence and intermittent construction of levees during floods. The Solabari surface is bounded by a fault scarp on its eastern side forming the valley wall of the earlier Kameng river. The existence of *beels* near the fault scarp indicates a slight tilt of the surface towards east. The Solabari Surface occupies a position similar to that of the Hauli Surface of the Manas river basin.

### 3.5.7 Kuruwani surface or recent flood plain

The depositional part of the basin is the recent flood plain. Such depositional sediments are vastly available around Kuruwani and as such it is also known as Kuruwani surface. Such flood plain exists in a very narrow valley wall of the Seijosa surface confined to a stretch from 12.5 km south of Bhalukpong. The streams are typically braided and the sinuosity ratio of the channel is very low. Channel bars are the typical morphological elements. Top stratum deposits on the banks are characteristically absent. Top accretion in the channel bars is common. The bed load is essentially boulder-cobble-pebble-gravel.

Further down south from Ghoramari the valley walls retreat further with the formation of neo flood plains of the Kameng river which gradually open out near Khalihamari into a vast stretch having width of 2.5 km near Kuruwani on the right bank. In the stretch between Colderghat and Kuruwani-Hatbar line the flood plain shows lateral bars and levees (meander scrolls). Channel bars are the typical morphological elements throughout the reach. Channel fills are common on the left bank of the river in between Samdhara and Hatbar. In between Kuruwani and Bhomoraguri hill on the right bank, almost the entire area of the right bank is inundated during high flood. There is a prominent zone of *beel* complex formed by the back swamp west of Chiruwani Chapori, corresponding to the Kameng and the Brahmaputra. Except in the levees crest, which is about 0.2 km wide, the whole area morphologically belongs to channel fills and flood basins.

In between Gerugaon and Tezpur from the toe of the Rangapara Surface up to the *beel* complex of Barnakata *beel*, Bedalimari Doloni, and Barua Doloni the ground is extremely flat and is liable to inundation every year. This surface is confined between 67 m and 64 m contours. The stream density is low. East of Kameng river also this surface extends from Panpur to Nalbari. The *beel* complex of Barnakata *beel*, Bedalimari Doloni, and Barua Doloni between Gerugaon and Tezpur and the *beel* complex of Rangamari *beel*, Bonga *beel*, Hatachapari *beel* and Kaduman *beel* are extremely low lying areas below 64 m altitude and are rapidly being filled up by the present river systems. The satellite imagery of the area clearly shows that these *beels* are actually relicts of the stream channels of the Brahmaputra, which collect water behind the bank width of the river; they receive spill over floodwater from the Brahmaputra. East of the Kameng river the Brahmaputra used to flow past Panibharal, Ghiladhari Khuti, Domgaon, Kumargaon and Panpur. West of Tezpur the Brahmaputra river used to flow past Dagaon Pukhuria, Pithakhowa and Puthimari Chapori (GSI, 1977). Since 1894 the river shifted its channel southwards and it is possible to estimate that the north bank in the stretch Biswanath to Panpur has shifted by 6 km to the south of the 1894 disposition leaving relict channels to be occupied by *beels* and the smaller streams.

South of these *beel* complexes a zone of negative slope extends up to the present channel of the Brahmaputra river. This zone is about 1.5 to 2 km width and is confined towards the south by the north bank of the Brahmaputra river. This stretch

of negative slope is almost devoid of stream except for large tributaries that cut through this surface. Not infrequently the Brahmaputra overtops this surface during high flood stage and thus this zone is likely to be modified frequently. Bank failures also change its geometry constantly. This negative slope is due to presence of levee on the north bank of the Brahmaputra river.

The recent levees on the right bank of the river Kameng extends from Ghoramari in the north to Kaliabhomora hills in the south. The bottom stratum of the levee is cross bedded medium to fine sand and the top section of ripple cross laminated fine sand and silt. The multiple rhythms of ripple cross laminated by very fine sand and even bedded silty-clay units indicate multiple flood cycle sediments. The sediments vary from coarse sand to silty-clay with the increase of height of flood plain (GSI, 1977).

### 3.5.8 Chronology of the Alluvial Surfaces

The geomorphic succession of the alluvial surfaces as identified can be arranged in the chronological order as follows (Table 3.5).

**Table 3.5 Chronology of the Alluvial Surfaces**

<i>Processes</i>	<i>Flood Plain</i>	<i>Piedmont Plain</i>
Depositional Regime	Kuruwani Surface	Recent alluvial fan surface in the streams
Partially erosive Regime	Solabari Surface	Seijosa Surface
Erosive Regime	Itakhola Surface Rangapara Surface	Balipara Surface
		(GSI, 1977)

This chronological order of the different geomorphic surfaces is based on (1) their relative height, (2) type of soil formation, (3) type of sediments forming the surface, (4) degree of oxidation undergone by sediments, (5) nature of the drainage pattern, and (6) nature of the streams. This chronological order of surfaces has been utilised in identifying informal stratigraphic formations which share the same locality names (Table 3.6), both in the flood plains and piedmont plains.

**Table 3.6 Stratigraphy of the Lower Kameng Basin**

<i>Flood Plain</i>	<i>Piedmont Plain</i>
Kuruwani formation	Recent gravel bar deposits
Solabari formation	Seijosa formation
Itakhola formation	?
Rangapara formation	Balipara formation
? Siwalik Group	Siwalik Group
Granitoid gneisses of the inselberg of Tezpur, Singri, Bhomoraguri hills and Biswanath granitoid gneisses	

(GSI, 1977)

### 3.5.9 The Bhareli graben

The structural features noted in the Kameng alluvial basin can be accounted for if one assumes a major fault at depth which extends to the surface in the form of two or more secondary echelon faults. The following observations are significant and support the above statement. (i) Changes in the stream courses of the Kameng, Dikrai-Bor Dikrai and other streams. (ii) The western and southwestern side of the Charali Block is terminated by a fault with west side downthrown. The eastern side

of the Rangapara and Tezpur blocks are terminated by a fault with eastern side downthrown. Similarly the southern side of the Balipara block (uplifted alluvial fan) is terminated by a fault with southern side downthrown. This again could be related to a subsidence trough (truncated to the north) passing between Charali and Rangapara blocks. (iii) The profiles of both the Rangapara and Charali blocks indicate a curved surface (upwards) suggestive of a domal uplift. This is proved by geophysical data (G.S.I., 1977) indicating uplift of the basement directly below the Rangapara Surface. Thus all evidence suggests the presence of a "Zone of Weakness" passing between the Rangapara and Charali blocks and the Kameng flows through a Graben (GSI, 1977). The graben needs more elaboration and refers the above mentioned Figure where the graben is well depicted between two faults.

### **3.6 CLIMATE**

The great variation in altitude of the Kameng basin governs the climatic variation within short distances with contrasts in temperature and rainfall between the sheltered valleys, foothills and the mountain tops. Based on altitude, the three bioclimatic belts of the Kameng river basin are: Tropical up to 1800 m; Temperate between 1800 m and 3500 m; and Alpine above 3500 m. Within the Tropical zone it is Hot and Humid Tropical up to 900 m, and Wet Sub-Tropical Between 900 m to 1800 m. The area between 1800 m and 2900 m has Wet and Cold Temperate climate, while between 2900 m to 3500 m it is Dry and Cold Temperate. The snow line in winter is around 2750 m, whereas during summer it goes higher around 5500 m.

The basin experiences pre-monsoon showers from the end of March to May. The monsoon proper lasts from June to September. Snowfall is common in the winter in the higher altitudes with sporadic rains in the lower altitudes. June and July are the wettest months of the year. The areas above the altitude of 1500 m generally experience snow fall. Glaciers are observed above the altitude of 4000 m. No large moraine fields or terraces have been recognised in the Lower Himalaya so far (GSI, 1977).

The climate of the study area, i.e., the Lower Kameng Basin, is devoid of climatic extremities associated with the upper Kameng basin and it is almost similar to rest of the Brahmaputra valley. Winter, summer or pre-monsoon, monsoon and post-monsoon are the four distinct seasons in a year. Winter starts by late November and continues till February. This period is characterized by cool weather with frequent morning fog, with or without occasional localized thunderstorms. Temperature remains usually above 12<sup>0</sup> C. During the winters the average monthly temperature varies from 14<sup>0</sup> C to 16<sup>0</sup> C and the average diurnal ranges do not exceed 5.5<sup>0</sup> C. Cold spells are infrequent and of short duration. The minimum temperature goes down to 7<sup>0</sup> C. The total rainfall during this period is less than 7.5 cm. The average monthly relative humidity varies from 84% to 91%. The influence of western disturbances, weakened by the time they reach the Eastern Himalaya, can be seen in the Kameng river basin. Under its influence, the higher altitude zone gets snowfall, while the lower zone receives precipitation in the form of rainfall.

Pre-monsoon or summer season starts from the beginning of March and continues up to the mid or late May and is characterised by rapid rise of temperature and frequent rains. The mornings are cool, pleasant with mild winds, but afternoons in a non-rainy day are fairly hot. This is due to the wide range of diurnal temperature variation. From the mid-April onwards rainfall is generally associated with thunder storms.

Monsoon is the longest season in the basin extending from the first week of June to the end of September and sometimes to the mid of October. Besides rain, the monsoon weather is characterized by high atmospheric humidity, low temperature variation and prolonged rainy days. The average monthly temperature varies from  $21^{\circ}\text{C}$  to  $28^{\circ}\text{C}$ . The average relative humidity during these months remains high. The mean annual monsoon rainfall varies from 145 cm to 188 cm. Number of rainy days in a month is 18 to 20 from June to August.

Post-monsoon or autumn season is brief and is characterized by progressively fair weather with morning fogs of short duration. The average monthly temperature varies from  $20^{\circ}\text{C}$  to  $24^{\circ}\text{C}$ . Rainfall is very scanty, but humidity remains high.

### 3.7 VEGETATION

The natural vegetation of the Kameng Drainage Basin can be divided in three distinct belts governed by the altitude- Tropical up to 1800 m, Temperate 1800 m to 3500 m, and Alpine between 3500 m to 5500 m. Each zone has its typical vegetation specific to its climate, as it is the most dominant determinant on the biotic realm of the mountain including the Himalaya. Altitude governs the climate and in turn climate governs the biotic world in the mountain. That's why within a short distance great variations occur in the climate and biotic regime of the mountains.

Vegetation pattern and its distribution over a basin influence its geo-hydrological regime. The climate and soil of the basin have a great influence on the vegetation pattern in the mountainous region. The forest type ranges from tropical evergreen in the foothills through temperate evergreen in the middle ranges to the conifers in the higher elevations. The most part of the catchment area lies in the wet belt of high rainfall to the tune of 400 cm per annum leading to high runoff in the streams of the Kameng River system.

The vegetation pattern in the study area resembles to rest of the Brahmaputra valley. Tropical evergreen forest dominates the northern region, while deciduous forests grow along the bank of the river. The species grown in forest areas located on the piedmont zone are Bansum (*Phoebe goalparendia*), Mekahi (*Phoebe booferiana*), Khakan (*Duabanga sonnerationdes*), Gamari (*Gmolina arborea*), Nahar

(*Mesua ferra*), Bhola Sopa (*Morus laevigata*), Tita Sopa (*Michelia champace*), Bhelu (*Terramelia nudiflora*), Jutuli (*Altingia excelya*), Gonsori (*Cinnamomum cecidodapana*) and miscellaneous species. Large tracts of once luxuriant forest like Chariduar Reserved Forest have degraded to scrubland and are under encroachment and deforestation.

The wetlands formed in natural depressions within the flood plain are locally known as *beels*. Growth of water hyacinth is normally observed in these *beels*. Generally *rabi* crops are cultivated on the periphery of these wetlands. Mainly *Boro* paddy is grown when water level recedes during the dry winter season. Tall grasses grow over the low lying swampy areas as well as on the river islands where water table is very shallow.

Most of the rural built up areas are located on the older alluvium and levees of the old courses of the Kameng. The older alluvium, the Itakhola surface and the areas of Seijosa surface, that is where drainability is high, are the most preferred places for tea cultivation, hence most of the Tea Gardens are found there. The agricultural crops of such areas have gradually been replaced by tea cultivation. Other horticultural crops like areca nut, coconut, medicinal and fruits plantations are grown on the higher surfaces of adjoining areas of levees where the built up areas also exist. Bhalukpung, Seijusa, are some of the places dominated by such plantation.

Most of the study area has been brought under agricultural crop cultivation except the few reserved forests and the sand bars of the river. The Solabari surface and recent flood plains are most preferred sites for growing rice as such areas are dominated by availability of plenty of water and fertile level lands. However, the soil of the newer alluvium surface supports growth of a host of crops. Paddy is the main staple crop grown during the *Kharif* season. Paddy crop is generally grown during three seasons known as Autumn rice, Winter rice and Summer rice. Winter paddy (*Sali* paddy) is the main crop in the study area. The improved varieties of *Sali* paddy grown are Pusa, Soket-4, Massori, Pankaj, Ranjit etc. Early *Ahu* paddy, *Boro* paddy, wheat, mustard and sesame are the main crops cultivated during the *Rabi* season. Other preferred *rabi* crops grown in the study area are pulses, oil seeds, fibre crops, tuber crops, *Boro* paddy and scattered early *Ahu* paddy. Apart from these a variety of vegetables are also grown in all the seasons, particularly during the *kharif* season.

## **CHAPTER IV**

# **CHANGING COURSE OF THE KAMENG RIVER**

## **CHAPTER IV**

### **CHANGING COURSE OF THE KAMENG RIVER**

#### **4.1 INTRODUCTION**

Shifting of course is a natural tendency of the rivers and it is a universal phenomenon. Without shifting of course by the rivers it is impossible to imagine formation of vast alluvial plains on the surface of the earth. In fact, it is an inbuilt mechanism in the alluviation process of the valleys. Despite knowing the fact that changing courses of rivers are associated with the alluviation process in the valleys it is interesting to reveal such changes not only to understand the work of rivers and resultant landforms but to save the life and property affected by such changes considered hazards along with the floods. That is why, shifting courses of rivers have invited attention of the scientists right from early times as man and his civilisation has been affected by them. Interest of the scientists has got a boost with the arrival of remotely sensed data, for it contains a mine of information on the alluviation process in a valley including the changing courses of rivers responsible for it. This has inspired the earth scientists the world over to study and reveal changing courses of the rivers and predict such changes in future that may affect life and property. Such studies also make it possible to explain formation of different landforms in the valley as the studies reveal geomorphic history of the valley. Moreover, the prior or buried courses of rivers act as good aquifer with high water bearing capacity to be tapped for various purposes. In the present Chapter IV, shifting courses of the Kameng river have been identified, traced and mapped. Pattern in the changing courses has been revealed and based on which forecast about any changes in future has been made. Causes of the shifting courses have also been explained.

There are numerous examples of shifting courses of rivers in the world, both in the past and present, which are worth studying from various points of view. It would be appropriate to mention some examples of changing courses of the Himalayan rivers because the Kameng river is a part of it. This will not only help in understanding what has happened in the other Himalayan rivers which drain the northern part of the Indian Subcontinent but it will also be compared wherever required when dealing with the shifting course of the Kameng river.

#### **4.2 SHIFTING COURSES OF THE HIMALAYAN RIVERS**

It is worth mentioning that a number of shifts, sometimes extensive, in the courses of rivers have taken place in the Indian Subcontinent, particularly in the courses of the Himalayan rivers. Though books on prehistory and history of India contain some references here and there, it would be appropriate to start with references from the books on geology of India. Wadia (1919) mentioned changes in the course of the rivers of north India. On physical and historical grounds he believed that the Jamuna during early historic times discharged into the Indus system, through the now neglected bed of the Saraswati river....” Krishnan (1954) also recorded changes in the courses of the Indus, Ganga and Brahmaputra rivers in the plains during the historic and prehistoric times. He mentioned, “The history of the Saraswati is exceedingly interesting. The withdrawal of the waters from the Sutlej, and possibly from the Jamuna, dried up the Saraswati that was once a great river that flowed through Bikaner, Bahawalpur and Sind.... All the Himalayan rivers that debouch into the plains of northern India, show ample evidence of building deltas in which their courses change very frequently”. Examples of the Kosi and Teesta rivers were specifically mentioned.

The Vedic Saraswati river used to drain independently to Rann of Kuchchh across the Thar Desert, whose lower course from Pachpadra to Rann of Kuchchh is now occupied by the Luni river as a misfit river. Another Vedic river- the Drasdwati was a tributary to it. The last of its independent course was through the now known courses of the Raini-Wahinda-Hakra (Ghose, *et al.*, 1979, 1980, and Kar and Ghose, 1984). The Sutlej river was also joining the Saraswati. The decrease in rainfall in commensuration with the advancing aridity in its catchment area reduced the discharge in the river. Mild tectonic activity and instability in the Siwaliks further disturbed the course of the river. The Yamuna river used to flow into the Saraswati during Pre-Mahabharata times (Ahmed, 1984). It was captured by the Ganga due to upwarping of the Aravalli region (Saifuddin and Iqbaluddin, 1999).

The Saraswati originated from the Bandapunch massif of the Himalaya descending through Adibadri, Bhavanipur and Balchapur in the foothills to enter the plains (Valdiya, 1996, Kalyanaraman, 1999). Due to increase of rainfall and subsequent break up of glaciers, the Saraswati had flowed as a great river for 2000 years (between 6000 and 4000 B.C.) leading to the rise of Vedic civilization along its courses. It was obliterated in a short span of geological time through a combination of destructive natural events. During 4000 B.C., the neotectonism and climate change in the form of end of wet climate and the onset of aridity led to changes in the course of the Saraswati. Later-day meteorological and pollen analysis research about palaeoclimates of the area (Valdiya, 1996, Ramaswamy, 1968, Wilhelmy, 1999, Clausen, *et al.*, 1999 and Street-Parrot, 1990), oxygen isotopic studies (Divakar, 1990), thermoluminescent (TL) dating (Jain *et al.*, 1999) of wind-borne and river-borne sands in the Thar desert region, radiocarbon dating of lake-bed deposits (Hashimi, *et al.*, 1995) and archaeological evidences

(Rajaram, 1999 and Kosambi, 1996) have all indicated that during early to middle Pleistocene epoch this region had enjoyed wetter climate, heavy rainfall and even recurring floods and that increase in aridity commenced by mid-Holocene (5000–3000 BC) only. The remnants of the affluent proto-historic cities of pre-Harappa (Kalibangan, Pilibangan) and Harappa (Mahenjo Daro) indicate that the essential requirement for the development of such a civilisation like sufficient water for agriculture and domestic use, navigable water for transport and business was available.

Peter Clift of the University of Aberdeen, Scotland and Jerzy Blusztajn of the Woods Hole Oceanographic Institution reconstructed the erosional discharge from the Indus River over the past 30 million years and found that the source of those sediments changed 5 million years ago. Earlier it was from the northern mountains, then it came from the erosion of the rising Himalaya. The change is caused by a rerouting of the major rivers of the Punjab region into the Indus river. Previously these rivers flowed east and joined the Ganga river system before reaching the Bay of Bengal, east of the Indian Subcontinent ([www.physorg.com](http://www.physorg.com)). The records of the third century B.C. show that the Indus flowed more than 130 km to the east of its present course, through the now practically dry bed of a deserted channel, to the Rann of Kuchchh that was then a gulf of the Arabian Sea. Later the river changed its course towards west.

Most of the great Punjab Rivers have frequently shifted their courses. In the time of Akbar, the Chenab and Jhelum joined the Indus at Uch, instead of at Mithankot, almost 100 km downstream, as at present. Multan was then situated on the Ravi, now it is 60 km from the confluence of that river with the Chenab. About 250 years ago the Beas deserted

its old bed, which can still be recognised between Montgomery and Multan, and joined the Sutlej near Ferozpur several hundred kilometres upstream ([www.en.wikipedia.org](http://www.en.wikipedia.org))

The records of the third century B.C. show that the Indus flowed more than 130 km to the east of its present course through the now practically dry bed of a deserted channel to the Rann of Kuchchh, which was then a gulf of the Arabian Sea. The westward shift of the Indus is thus a very pronounced phenomenon for which different causes have been suggested. Either the present dry river bed to the east of Sind known as the eastern Nara is the old bed of the Indus or, more probable, the channel of the Sind portion of the Sutlej after the river had deserted it. While Ghose, Kar and Husain (1979, 1980) considered it as the last independent course of the Saraswati. The famous cities of Mohenjo Daro, situated on the Indus in Sind, and Harappa, located on one of its affluent in the Punjab, were probably abandoned at a much earlier date due to the vagaries of the shifting rivers and also to their recurring flood deposits, which eventually buried them.

Another example is of the river Kosi. It is also known as the Sapt-Kosi, because it is fed by the union of seven rivers, and is the most powerful left bank tributary of the Ganga. By the time that the Kosi reaches the foot of its alluvial fan most of its gravel and coarser sand has been deposited, and from there to its junction with the Ganga the river follows a short meandering curved course. The Kosi is notorious for its frequent and often disastrous floods, some of which have altered the course of the river. Two centuries ago, it flowed near Purnea, but now the main braided channel lies westwards at a distance of 96 km (Holmes, 1965 and Ahmed, 1976). Surprisingly, a number of westward curved courses of the Kosi can easily be seen between the piedmont zone and the confluence with the Ganga river, as if the north bank levee of the Ganga does not allow its notorious

tributary to meet for a long distance. Actually the Himalayan rivers while entering into the low gradient plains greatly lose their competence and capacity in turn deposit the debris in the piedmont zone that usually obstructs the path of the river. Usually alluvial fans are formed by such deposits. Coalescence of more than fans can form terraces.

The Teesta river earlier flowed southward through Dinajpur and joined the Ganga through the Punarbhaba river prior to 1787. Following a major tectonic movement, it has gradually shifted towards east to discharge ultimately in to the river Brahmaputra in a southeasterly course. It significantly augmented the discharge of water and sediment into the Brahmaputra forcing it to shift its course towards west. The Teesta, after changing its old course, became a tributary of the Brahmaputra in 1787 (Ghulam Kibria, 1981).

Great changes have likewise taken place in Bengal and in the Gangetic delta since 1750; and hundreds of square kilometres of the delta have become habitable since then. The Brahmaputra flowed through the old course past Mymensingh, west of Dacca, to the Bay of Bengal through the Meghna. Gradually it shifted to the west flowing through the drainage course of other rivers to join ultimately with the Ganga. The structural movement of two uplifted blocks radically changed the course of old Brahmaputra. The Teesta is responsible for changing the old course of Brahmaputra to its present course. The Brahmaputra changed its course from Bahadurabad to the confluence with the Ganga near Aricha by 1820 (Ghulam Kibria, 1981).

Similarly, the rivers originating from the Eastern Himalaya Mountain, for example, the Manas, Aie, Puthimari, Pagladiya, Dihang, Dibang, Tidding, Lohit, Buri Dihing, Subansiri etc. have also shifted their courses from their respective piedmont zones when they debouch into the Brahmaputra plains.

Shifting of course of the Subansiri river has been identified by Prasad et al., (1981). After comparing the course surveyed in 1918-19, photographed in 1951 and surveyed in 1971 they found that the course has shifted from east to west and again it is moving towards east. During the 1951 devastating flood the river migrated westward by 600 to 700 m south of Pathalipam Tea Estate, attempting as if to straightening of the course in comparison to previous circuitous southeasterly course. In 1971 it again shifted westward but this time by 3.6 km. Based on the erosion taking place on the east bank and reverting of the course by 200 to 300 m they assumed that the river is swinging back to its easterly course.

Specific pattern in the shifting courses of the north-bank tributaries of the Brahmaputra was observed by Taher (1986). The migration of the rivers in Jonai-Dhemaji region is towards west, from the Subansiri river to Pagladiya river is eastward, while from the Manas river to Sonkosh river is again westwards. Such migration of river course takes place partly or wholly after every high flood by a few metres or a few km. He attributed the heavy sediment transfer from the young Himalaya by the steep gradient rivers, and deposition of it onto the plains as cause of the changing course of the rivers.

Likewise, there are many examples of changing courses of the Himalayan rivers in particular and the rivers of the Indian Subcontinent in general. This is mainly due to typical configuration of the relief features (the mountains, plateaus and plains), heavy precipitation (both in the form of snow and rain), annual floods (sometimes very severe and flash), and last but not the least, the active tectonic movements due to its structural instability of the Indian shield in general and the Himalaya Mountain in particular. Spread and retreat of ice sheets and glaciers in the Himalaya Mountain during the Quaternary glacial periods might also have been responsible for it.

### 4.3 ALLUVIATION OF THE BRAHMAPUTRA VALLEY

Before coming to the actual changing course of the river Kameng it would be necessary to give an account of the nature and characteristics of the basement and alluviation of the entire Brahmaputra valley. This is because the entire ramped valley of the Brahmaputra in Assam is one geomorphic unit and the Kameng basin is one of its parts. Therefore, whatever happened in the Kameng river basin has to be seen as a part of the happenings in the Brahmaputra valley. Moreover, the Kameng river is one of many tributaries of the Brahmaputra river, of course, an interesting tributary from geomorphologic, geologic and hydrologic point of view.

Studies conducted by the scientists on the alluvial deposits of the Brahmaputra river basin in the light of the neotectonic activity threw certain light on the morphogenetic process actively involved in the formation of valley and the alluvium of the basin. The Neotectonics, especially the Pleistocene and Holocene (Quaternary) crustal rising, as well as the intense erosional and depositional fluvial processes are believed to be responsible for the development of present complex landscape of the Brahmaputra river basin. The Quaternary terraces and discordant drainage patterns are regarded as the evidence of Neotectonic movements in the entire Brahmaputra river basin. The role of periodic influences of related structural movements plus the mosaic of exogenetic geomorphic processes mainly expressed in the atmosphere's gross fabric and associate humid, alternating humid-arid and glacial environments (Mukhopadhyay, 1995).

First of all the basement of the Brahmaputra valley in Assam is discussed, for the alluviation has taken place on the basement whose form, lithology and structure have direct or indirect relationship with the fluvial processes and landforms. The Brahmaputra

valley is a part of the Indus-Ganga-Brahmaputra Foredeep (IGBF) which occupies 7,70,000 sq. km. area covering a large portion of Sind, Northern Rajasthan, almost whole of Punjab, UP, Bihar and part of Assam. The width of the plains is about 500 km in the west and 150 km in the east. The IGBF is constituted by low-lying flood plains, extensive alluvial flats with transverse lineaments and faults indicating neotectonism in the foredeep (Nakata, 1997; Ghosh *et al.*, 1989, Qureshy, 2005). The platform rock formation of the Peninsular India or the Archaean or Gondwana basement of the Brahmaputra valley is overlain by the alluvium brought by the rivers from the Himalayan Mountain, Patkai Range, Naga Hills and Meghalaya – Mikir Plateau. Undoubtedly, a major contribution to it has come from the Himalayan rivers and the study pertains to the one of the major north bank tributaries of the Brahmaputra river.

Although, the Brahmaputra is flowing towards west, the depth to the floor of the basement from the alluvial surface suggests variation in sediment deposits from the lowest in the west to the highest in the east. The basement is under thick cover of sediments ranging from the Cretaceous to Recent. The depth to the sediment at Disangmukh (eastern part of valley) has been found up to 3800 m below the surface, of which the Recent and Pleistocene sediment deposits cover 1000 m. The sediments appear to be thickening towards the Subansiri river to a depth of 5000 m. The slope of the basement monotonously increases towards north at an angle of 4 to 5 degrees (80 m per km). In contrast, it dips steeply south of Jorhat covered by thick pile of sediments, e.g., 7000 m near the Naga Hills. The depth of the basement is 1000 m at Tezpur dipping at a slope of 3 per cent towards north. The estimated depth to basement at Rangapara is 2500 m. However, near Tangla and Udalguri, the basement has an anticlinal structure. The basement has a steep slope towards west of Jakhalabandha, on the southern side of the

Brahmaputra, whereas from Nagaon it slopes north, while the alluvial cover is found to be only 340 m thick near Guwahati (Barooah *et al.*, 1981).

The zone of faults extending from east through south of Jorhat trends westwards and follows the course of Brahmaputra to some extent. It takes a sudden WNW turn south of Helem in Sonitpur district. Thus, the fault zone can be traced from Helem extending to Bhalukpong and further continuing to the foothills of the Himalaya Mountain (Plate 5). The Brahmaputra valley has strong tectonic influence although the work of the river and its tributaries is responsible for formation different fluvial landforms in the valley. Faults with small to large down throw can also be seen in the valley, which are probably responsible for guiding many of the river courses (Barooah *et al.*, 1981). Here it would be worthwhile to mention a few major lineaments of the North East India (Table 4.1). Out of these, the Bomdila lineament is affecting the alluvial fans and Siwaliks in the study area.

**Table 4.1 Major lineaments of the North East India**

<b>Thrust</b>	<b>Direction</b>	<b>Area affected</b>
Mishimi Thrust	NW	Equivalent of MCT, separates Naga Lusai mountain area from the Mishimi block
Lohit Thrust	NW	Cuts across Lohit – Dihang rivers and Greater Himalaya within Mishimi block
North Lakhimpur Lineament	NW	Present day flood plains, alluvial fans, Siwaliks and Lesser Himalaya
Bomdila Lineament	WNW ESE	Alluvial Fans and Siwaliks
Dihang Lineament	NE	Continuation of MCT, abuts against Lohit Thrust
Sankosh Lineament	N-S	Within Greater Himalaya
Yadong Gulu Lineament	NE	Within Greater Himalaya
Kanchenjunga Lineament	NE	Present flood plains, Alluvial fans, Siwaliks, Lesser Himalaya and Greater Himalaya

*Source: Ghosh et al., 1989.*

Higher surfaces of the old alluvium known by different names such as “terrace deposits”, “unstratified drifts”, “older or high level alluvium” or “red bank soils” are found quite extensively in the Brahmaputra valley and in the Barak valley as well. These are most preferred sites of tea cultivation. Undoubtedly, they have been deposited by different rivers in their basins under the alluviation process. These can be taken as old flood plains, which are now much higher in altitude than the present active flood plain even in extreme cases. These older alluvium surfaces have been identified as depositional terraces of Pleistocene – Holocene times that happened due to changing climate and sea levels and subsequent tectonic upheaval (Mukerji, 1963 and Evans, 1964). Tak and Mehta (1981) considered existence of two older alluvial terraces in the form of Rangapara Surface and Solabari Surface in the Lower Kameng basin as evidence of two periods of rejuvenation, first due to tectonic uplift and the second due to lowering of the local base level of the river. For the later southward movement of the Brahmaputra course might be responsible, as the second terrace is within the graben and was formed after its origin. Older alluvium is also seen in the Ganga plains at about 51- 15 m above the present day active channel.

Discussion on shifting of courses of rivers can definitely be started with the formation of these raised surfaces of the older alluvium. This is because, it can easily be assumed that alluviation reached at certain stage in which such extensive alluvium was deposited, which are now much higher than the present bed of the river which deposited them and dissected at many places after they were raised or eroded away when the rivers which deposited them shifted their courses. Whatever shifts took place before formation of these alluvial surfaces in the process of alluviation of the valley are buried much below it hence not traceable by both human eyes and remotely sensed data. Therefore, the

discussion on shifting courses of the Kameng river has to begin with the oldest course of the river associated with these older alluvial surfaces. Definitely, the older alluvium and changing position of the courses of river belong to the Quaternary period, mostly the Holocene.

The earliest reference to this older alluvium was given by Medlicott (1865). Allen (1905) indicated existence of older alluvium in the Brahmaputra valley. These older alluvium are normally preserved on the raised surfaces and found in a highly dissected profile. Rising above the highest flood level, older alluvium passes through the weathering process leading to continuous wet and dry soil condition in humid areas developing semi-lateritic to lateritic soil. *Chapar* surface from the southwestern part of the Manas basin is also described as the older alluvium. Such surfaces show many relicts and a few active drainages, ponds lakes etc., for most part, it is made up of silty, clayey silt with fine sandy inter-beds. The active river channels on this surface are mostly of entrenched meandering underfit type.

Exposures of older alluvium are identified as *Chapor* and *Kukulong* formations near the Archaeans located at south bank of the Brahmaputra river. Older alluvium formations are also identified as river terraces close to the Himalayan foothills on the north bank of the Brahmaputra river. The alluvial deposits on the north bank of the Brahmaputra are geophysically indicated to occur on prominent depressions of the Tertiaries. The formations in the depression are indicated to dip towards north while the ground slopes down from north to south. This dip in the basement is indicative of the existence of the thrust zone related to the uplift of the Himalaya, which was subsequently filled up by the sediment brought by the Himalayan rivers till the north south ground slope attained level during the Pleistocene times (Barooah and Bhattacharya, 1981).

#### 4.4 CHANGING COURSE OF THE KAMENG RIVER

In the above background, now the changing course of the Kameng river in its lower reaches will be discussed. The Kameng river has also changed its course many a times during the Quaternary era. The study of the structure of the valley and ongoing fluvial geomorphic processes essentially give clue for the changing course in the late Pleistocene and Holocene periods and the factors responsible for the changes. Therefore, the structural characteristics, neotectonics and the geomorphic processes active in the Kameng river basin as a part of the entire Brahmaputra river basin have been studied and discussed in the present Chapter. The changing courses of the Kameng river have been discussed subsequently in chronological order. The events responsible for the changes and the factors associated with the changes have also been discussed in the same order.

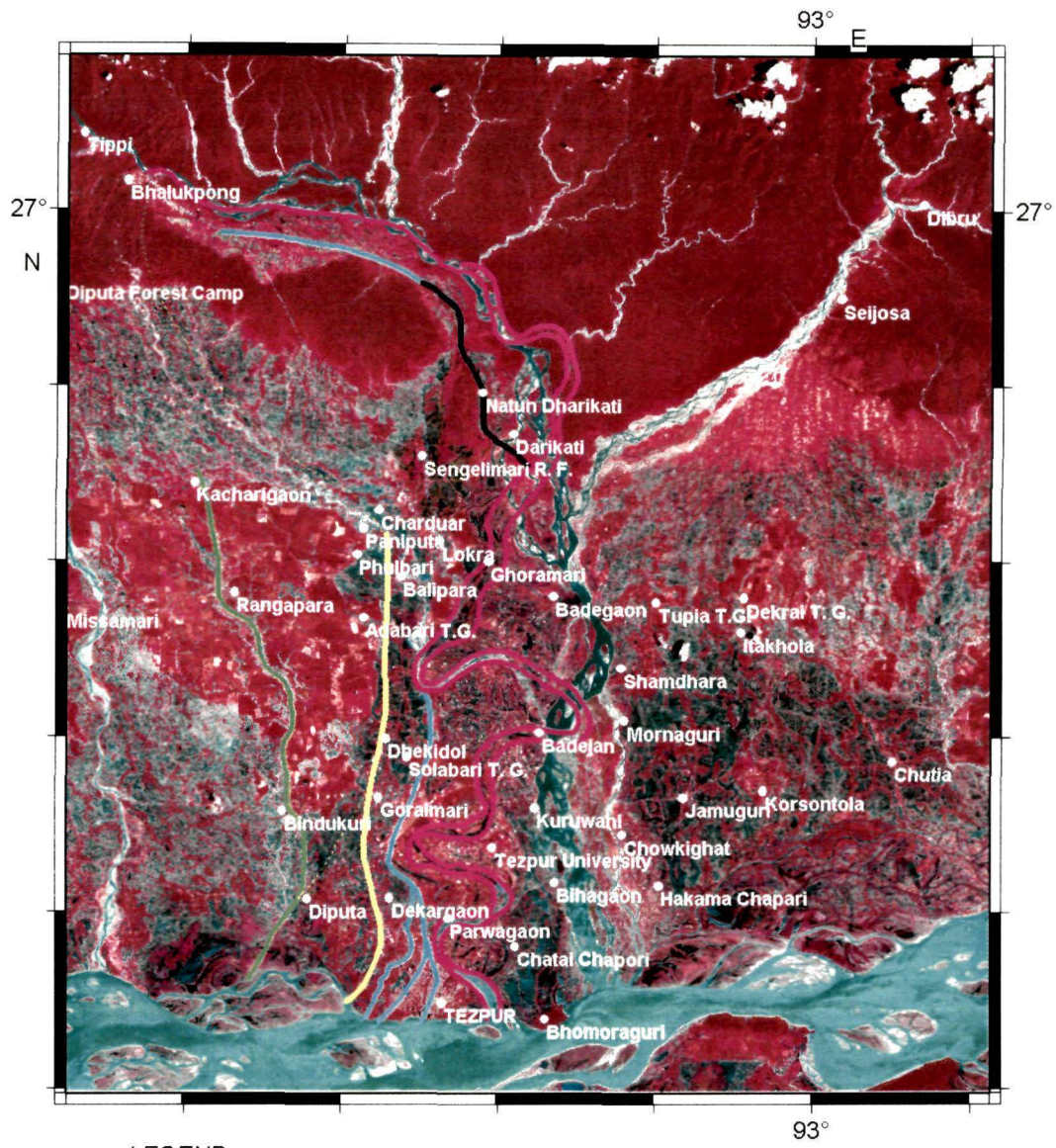
A river changes its course after debouching from the mountainous region into the plains right from its piedmont zone up to its confluence. It is a continuous process in geological time scale and has also been happening in case of the lower reaches of the Kameng river. However, continuous alluviation buries the surficial evidence of changes in the long past. The research study has been conducted along with the earliest traceable course of the Lower Kameng river which are supported by geomorphological evidences. Altogether six prior courses of the Kameng river in its lower reaches have been identified, distinctly showing changes in the course.

The **oldest course** (Fig. 4.1 and 4.2) of the Kameng river in its lower reaches has been identified from Bhalukpong that ran straight towards south through the Kacharigaon, Rangapara, Nagapathar, Bindukuri and Arimora Chapori and met the

Brahmaputra river about 10 km west of Tezpur town. The remnants of the oldest course can clearly be seen on the raised Rangapara surface (older alluvium), which is now occupied by the Diputanala as a misfit stream (Plate 6). Since a river frequently changes its course, especially in the piedmont zone, the Mara Diputanala, a tributary of the Jia Ghabharu river might have also occupied this old course of Kameng at some point of time after the Kameng shifted towards east.

The **first change** in the course came in the form of an eastward diversion near Diputa Forest Camp approximately 6 kilometres south of Bhalukpong, in the northwest corner of the study area. First it flowed southeastward along south of Bogijuli village and north of Paniputa up to Charduar (now the Mansari river flows in this course as a misfit river) then ran almost parallel to the oldest course to meet the Brahmaputra river near Da Parbatia village 5 km east of the oldest course. From Charduar to the confluence with the Brahmaputra, this course existed on the eastern margin of the raised Rangapara surface (the margin itself is the western boundary of the graben). However, a branch from this course diverted towards west from Goraimari and joined the oldest course near Diputa village (see Fig. 4.1 and 4.2).

The **second shift** in the course of the Kameng river took place right at Bhalukpong from where the river flowed almost eastwards for a short distance of 5 km from Bhalukpong through Balipara Reserved Forest then turned southeastwards to reach Charduar and from there it followed the second course in the downstream to reach to the Brahmaputra river (see Fig. 4.1 and 4.2). Remnants of the third course can be seen clearly across the Boulder-Gravel Ridge (Plate 8).



LEGEND

- 1st(oldest) COURSE
- 1st(oldest) COURSE-Eroded
- 2nd COURSE
- 2nd COURSE- Eroded
- 3rd COURSE
- 3rd COURSE-Eroded
- 4th COURSE
- 4th COURSE-Eroded
- 5th COURSE
- 6th COURSE



FIG. 4.1 PRIOR COURSES OF KAMENG RIVER IN ITS LOWER REACHES

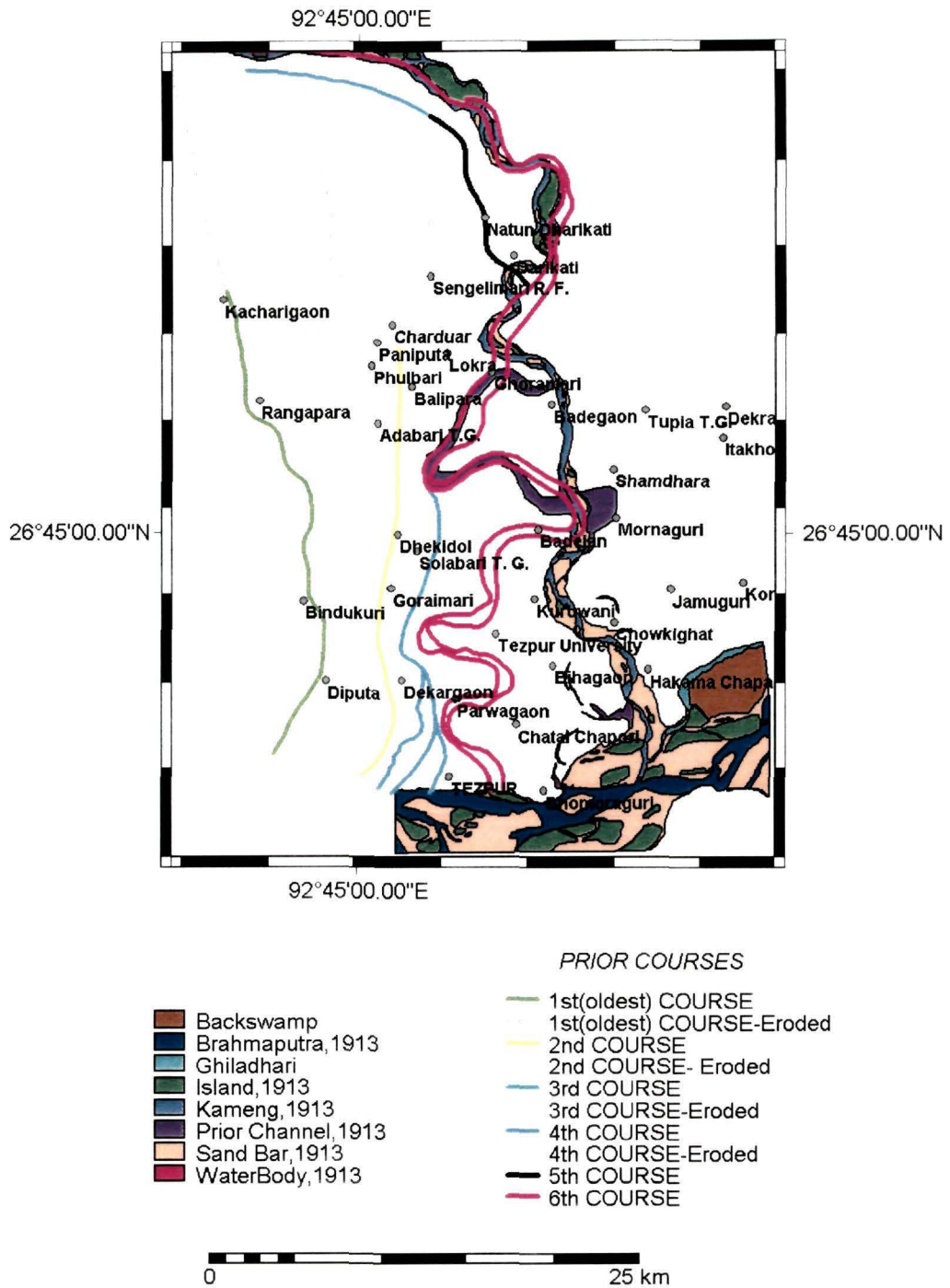


FIG. 4.2 SHIFTING COURSES OF THE LOWER KAMENG RIVER (FROM THE OLDEST TO 1913)

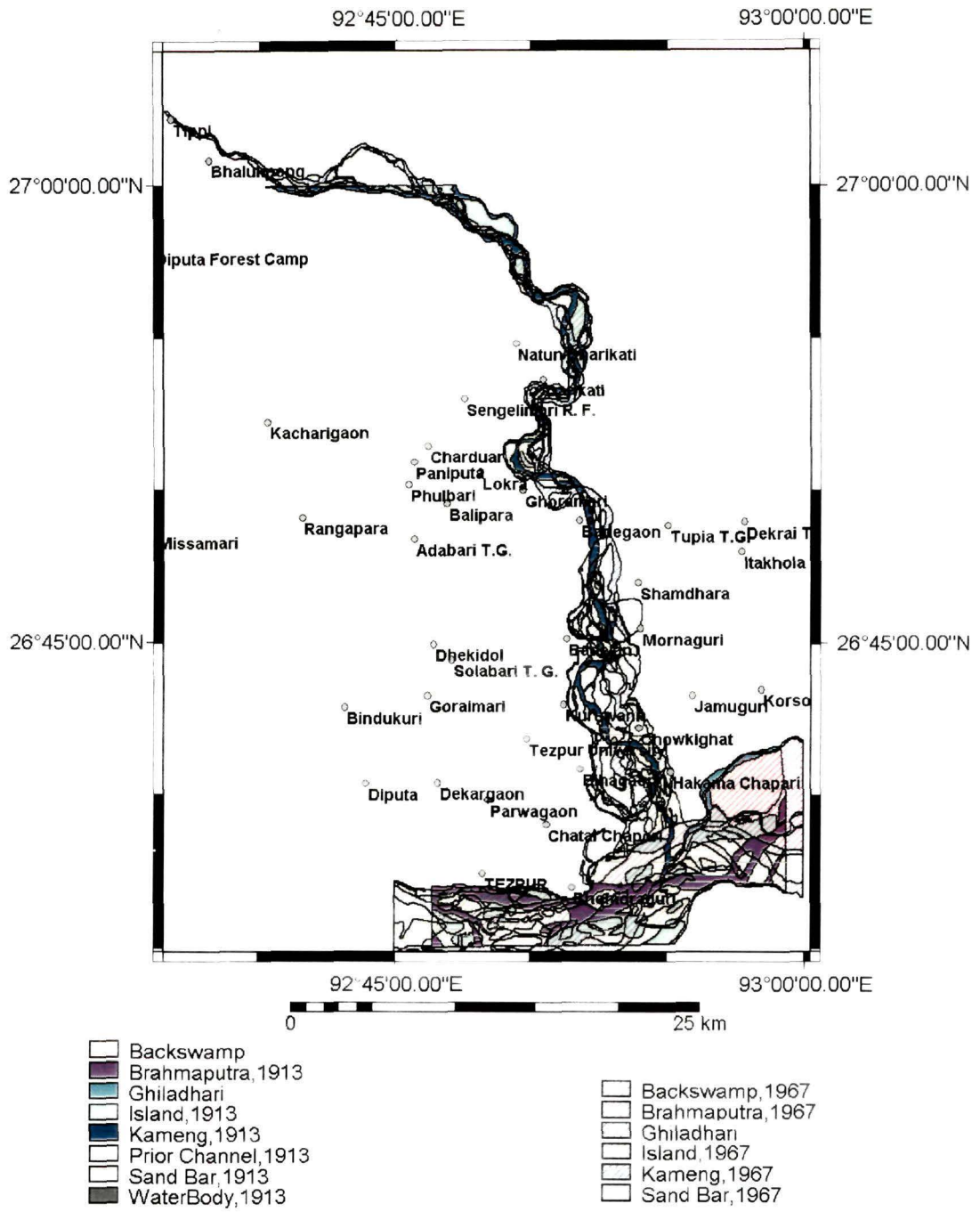


FIG. 4.3 SHIFTING COURSES OF LOWER KAMENG RIVER, 1913 AND 1964

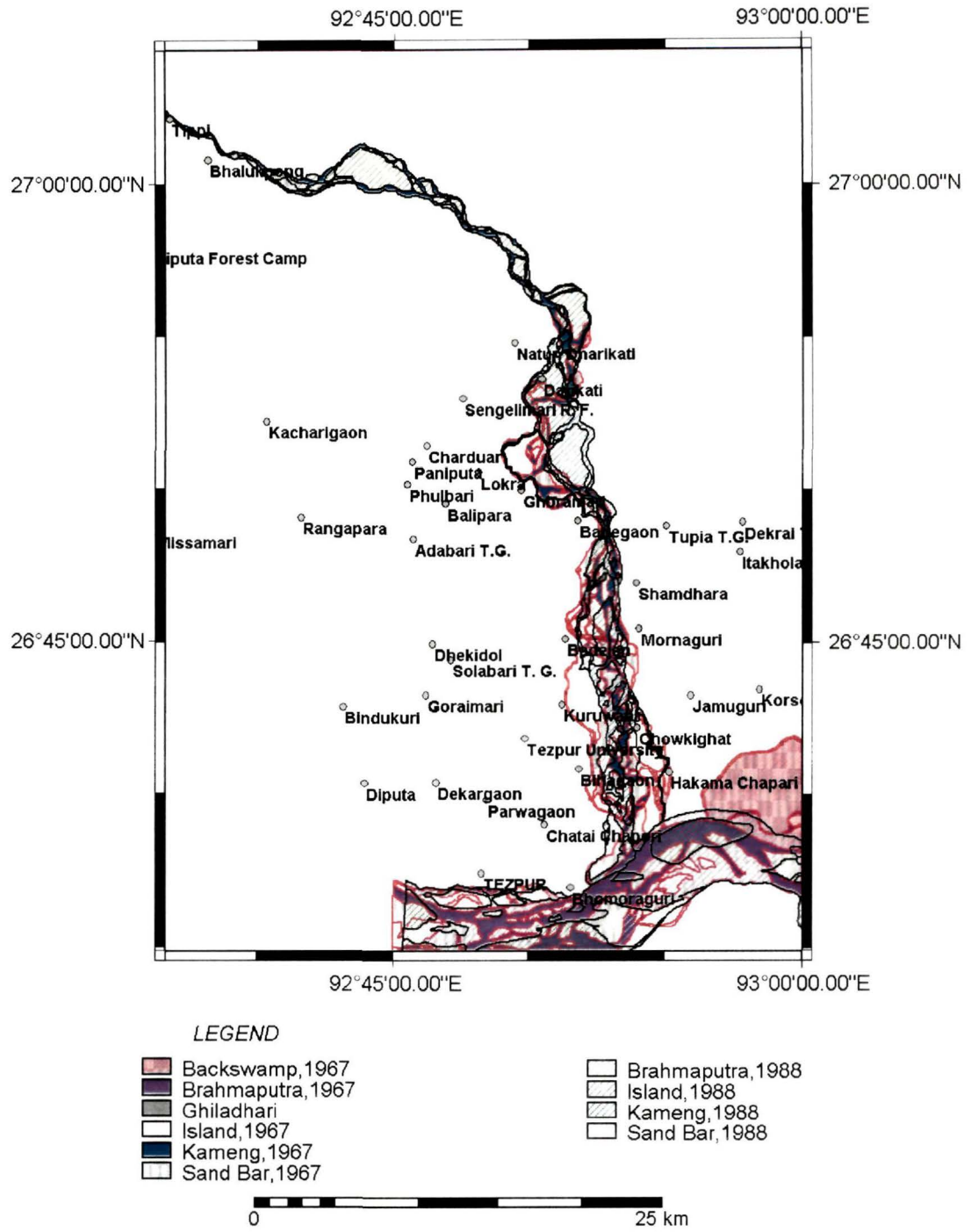


FIG. 4.4 SHIFTING COURSES OF LOWER KAMENG RIVER, 1964 AND 1988

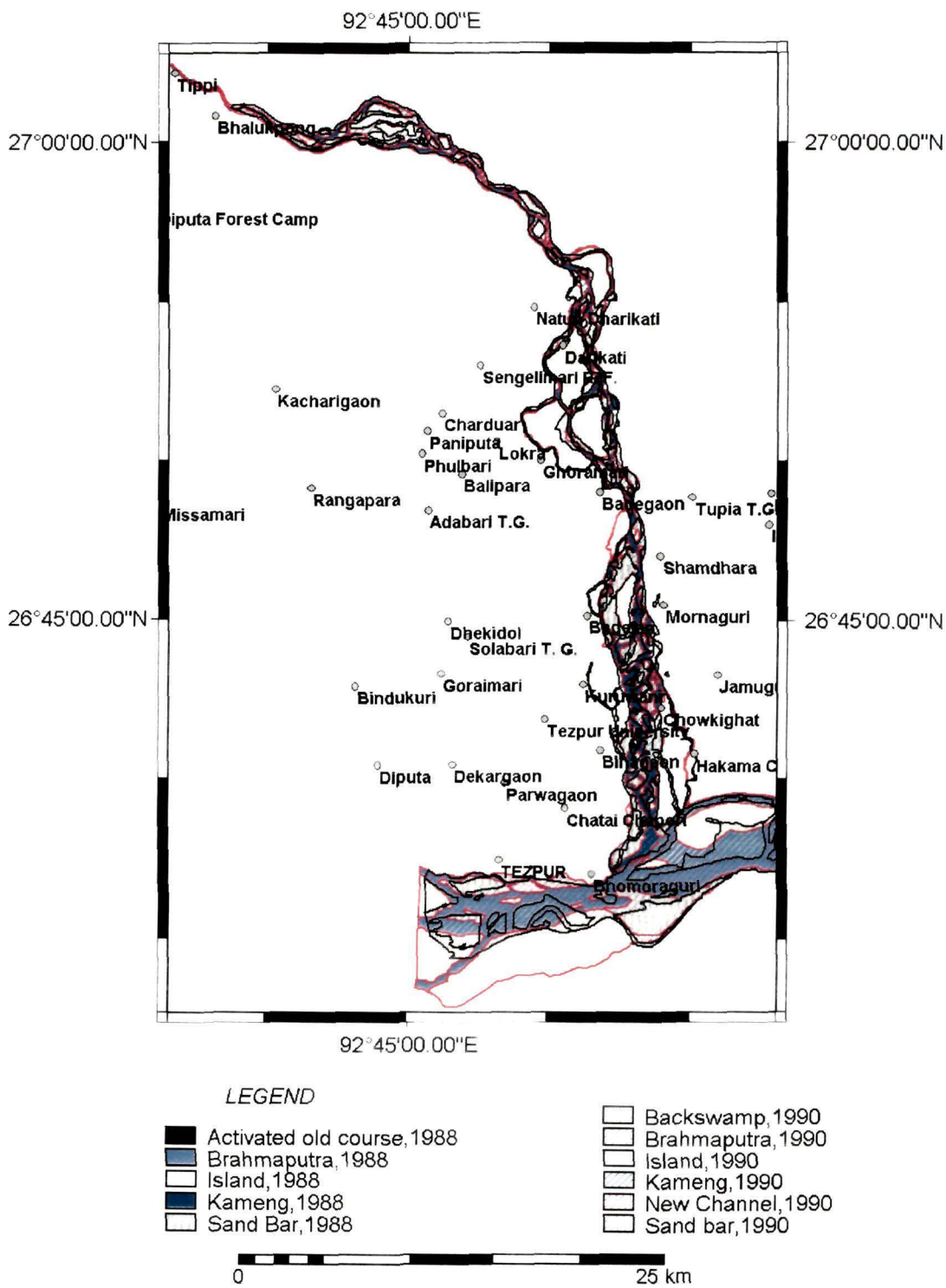
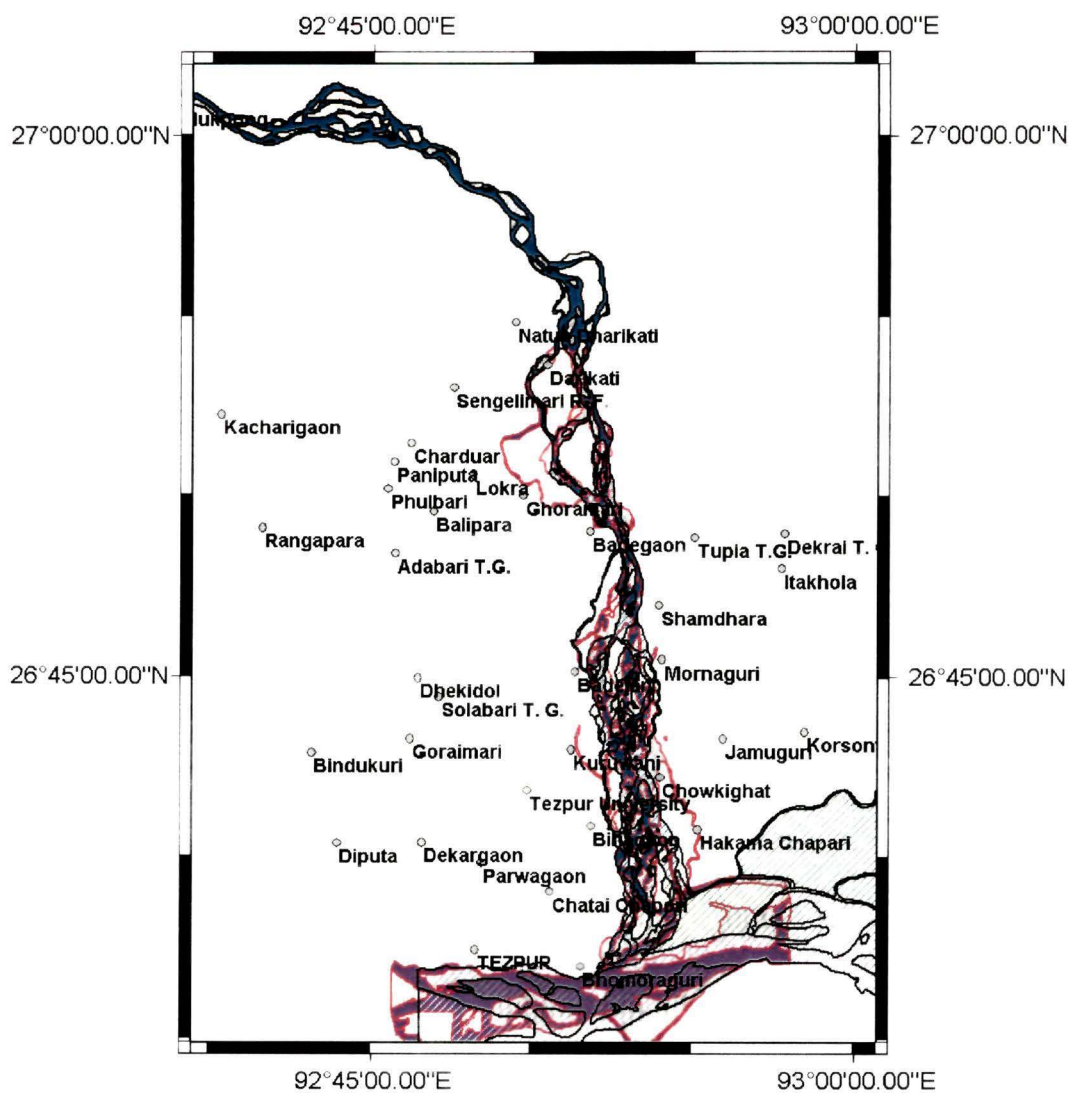


FIG. 4.5 SHIFTING COURSES OF THE LOWER KAMENG RIVER, 1988 AND 1990

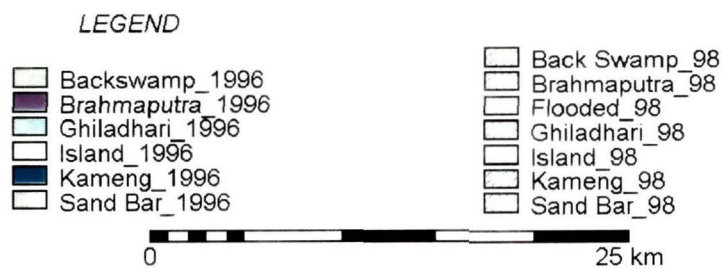
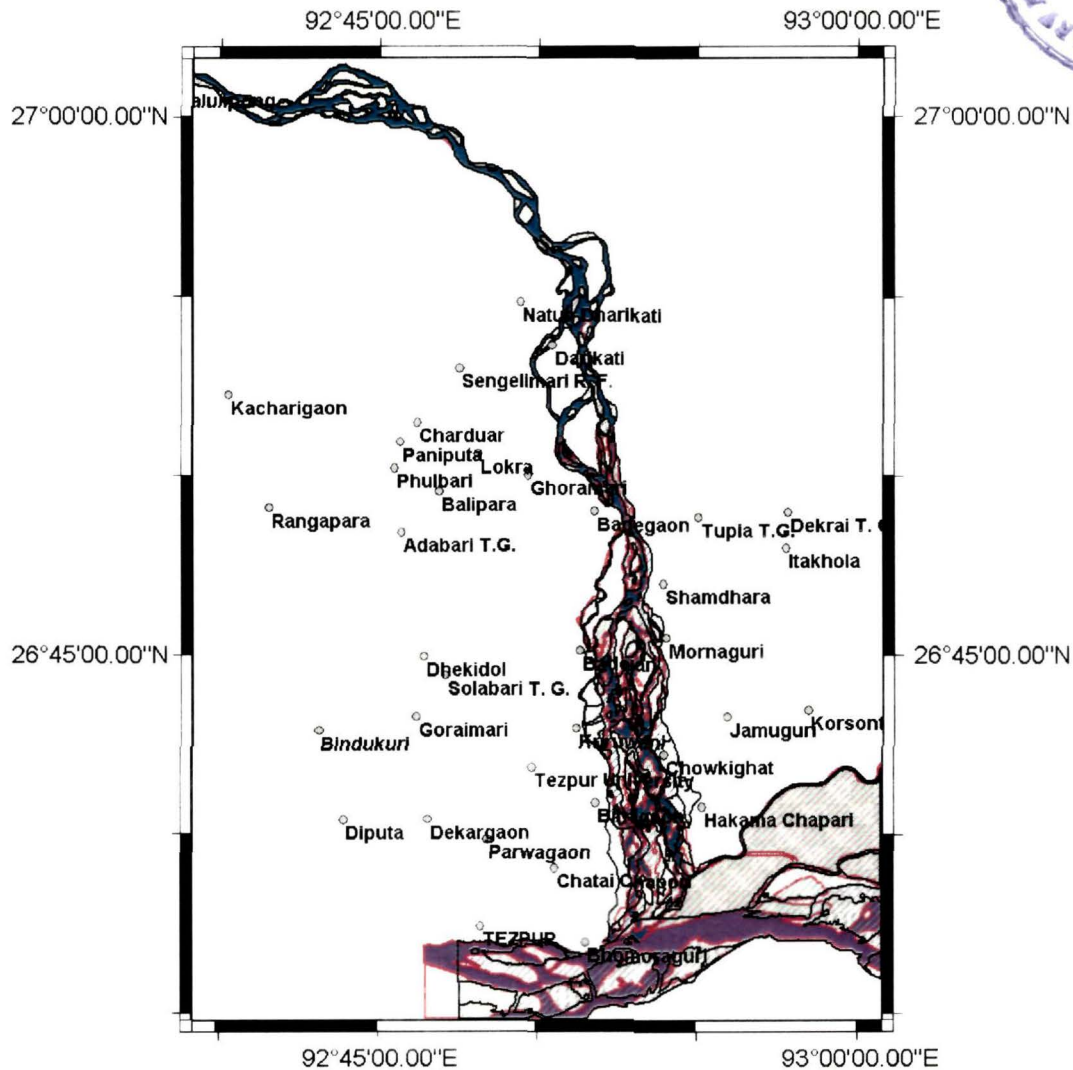


LEGEND

- |                   |                   |
|-------------------|-------------------|
| Backswamp, 1990   | Backswamp, 1996   |
| Brahmaputra, 1990 | Brahmaputra, 1996 |
| Island, 1990      | Ghiladhari, 1996  |
| Kameng, 1990      | Island, 1996      |
| New Channel, 1990 | Kameng, 1996      |
| Sand bar, 1990    | Sand Bar, 1996    |
| Waterbody, 1990   |                   |



FIG. 4.6 SHIFTING COURSES OF LOWER KAMENG RIVER, 1990 AND 1996



**FIG. 4.7 SHIFTING COURSES OF LOWER KAMENG RIVER, 1996 AND 1998**

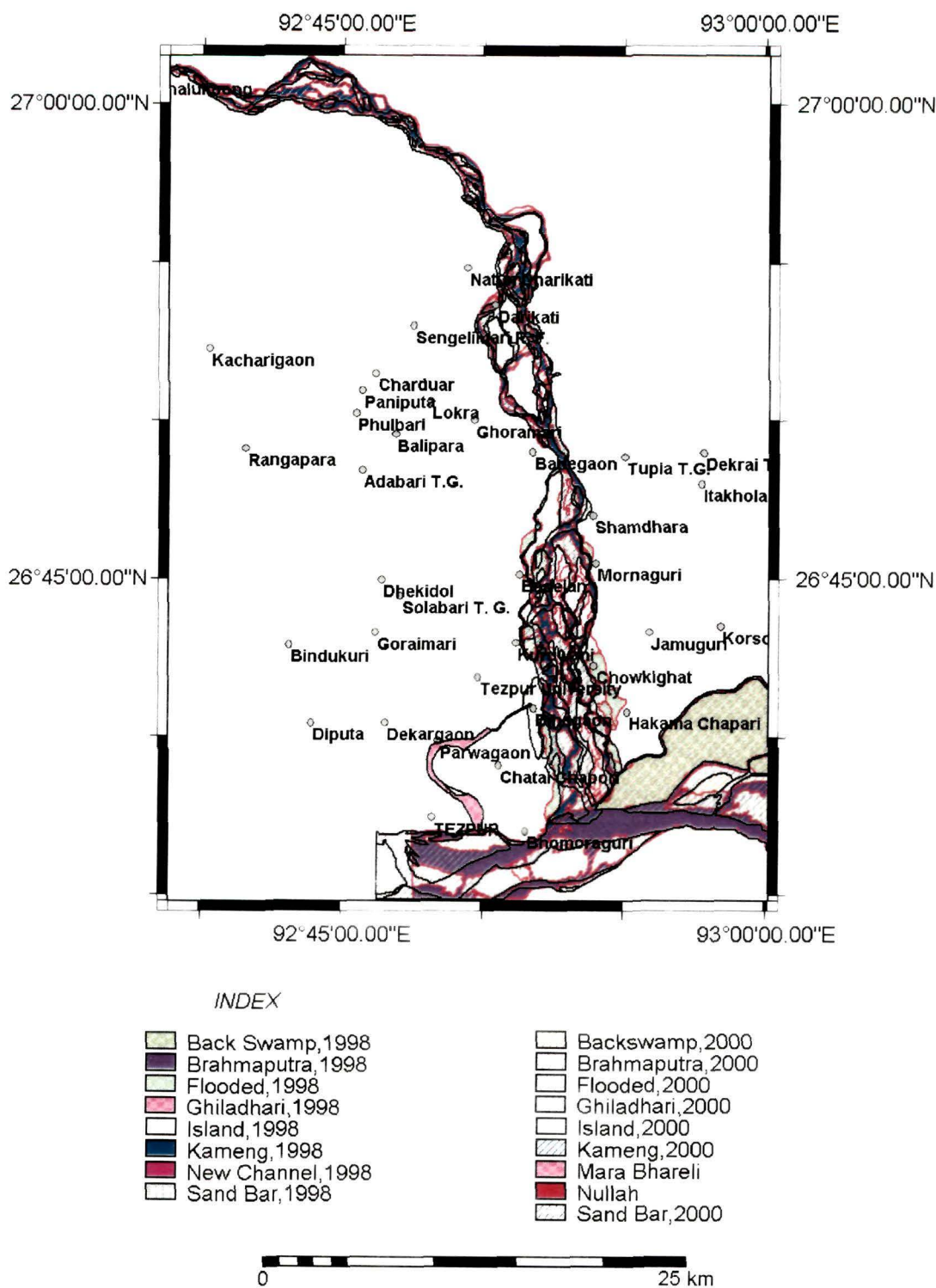
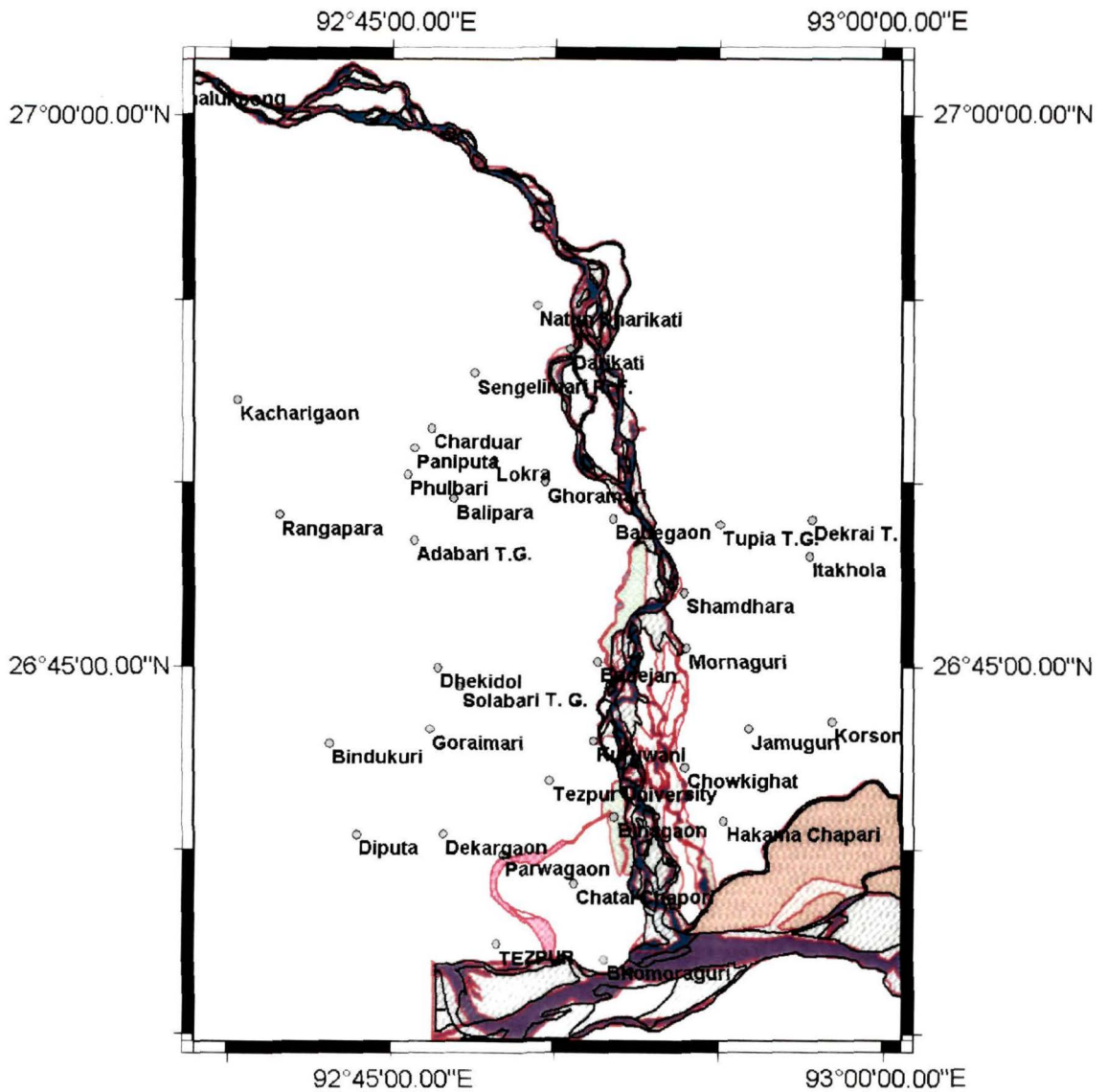


FIG. 4.8 SHIFTING COURSES OF LOWER KAMENG RIVER, 1998 AND 2000



*INDEX*














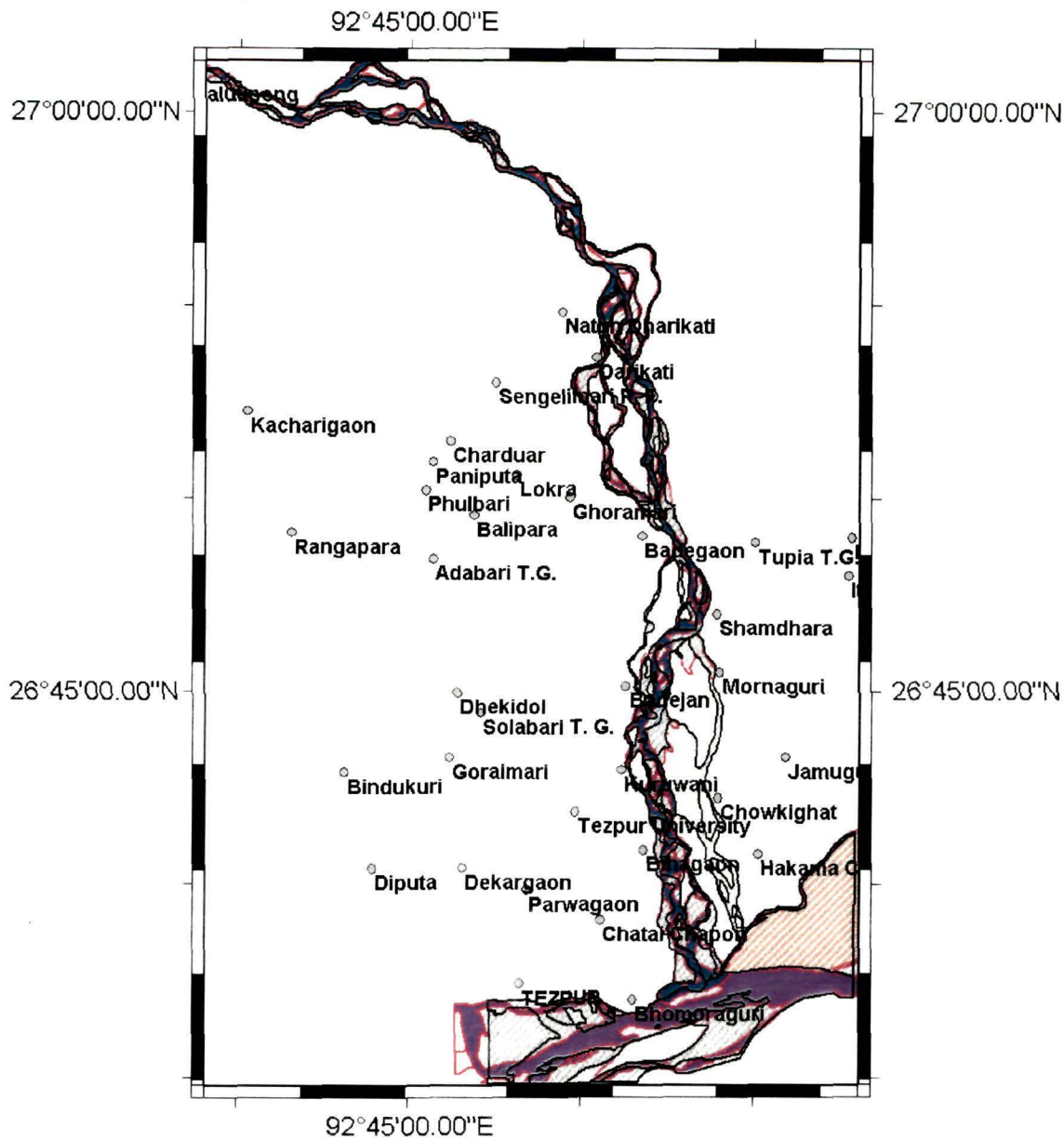
 Backswamp, 2000	 Backswamp, 2002
 Brahmaputra, 2000	 Brahmaputra, 2002
 Flooded, 2000	 Flooded, 2002
 Island, 2000	 Island, 2002
 Kameng_00	 Kameng, 2002
 Mara Bhareli	 Sand Bar, 2002
 Sand Bar, 2000	



FIG. 4.9 SHIFTING COURSES OF LOWER KAMENG RIVER, 2000 AND 2002



INDEX

- |                   |                   |
|-------------------|-------------------|
| Backswamp, 2002   | BackSwamp, 2003   |
| Brahmaputra, 2002 | Brahmaputra, 2003 |
| Flooded, 2002     | Flooded, 2003     |
| Island, 2002      | Island, 2003      |
| Kameng, 2002      | Kameng, 2003      |
| Sand Bar, 2002    | Sand bar, 2003    |



FIG. 4.10 SHIFTING COURSES OF LOWER KAMENG RIVER, 2002 AND 2003

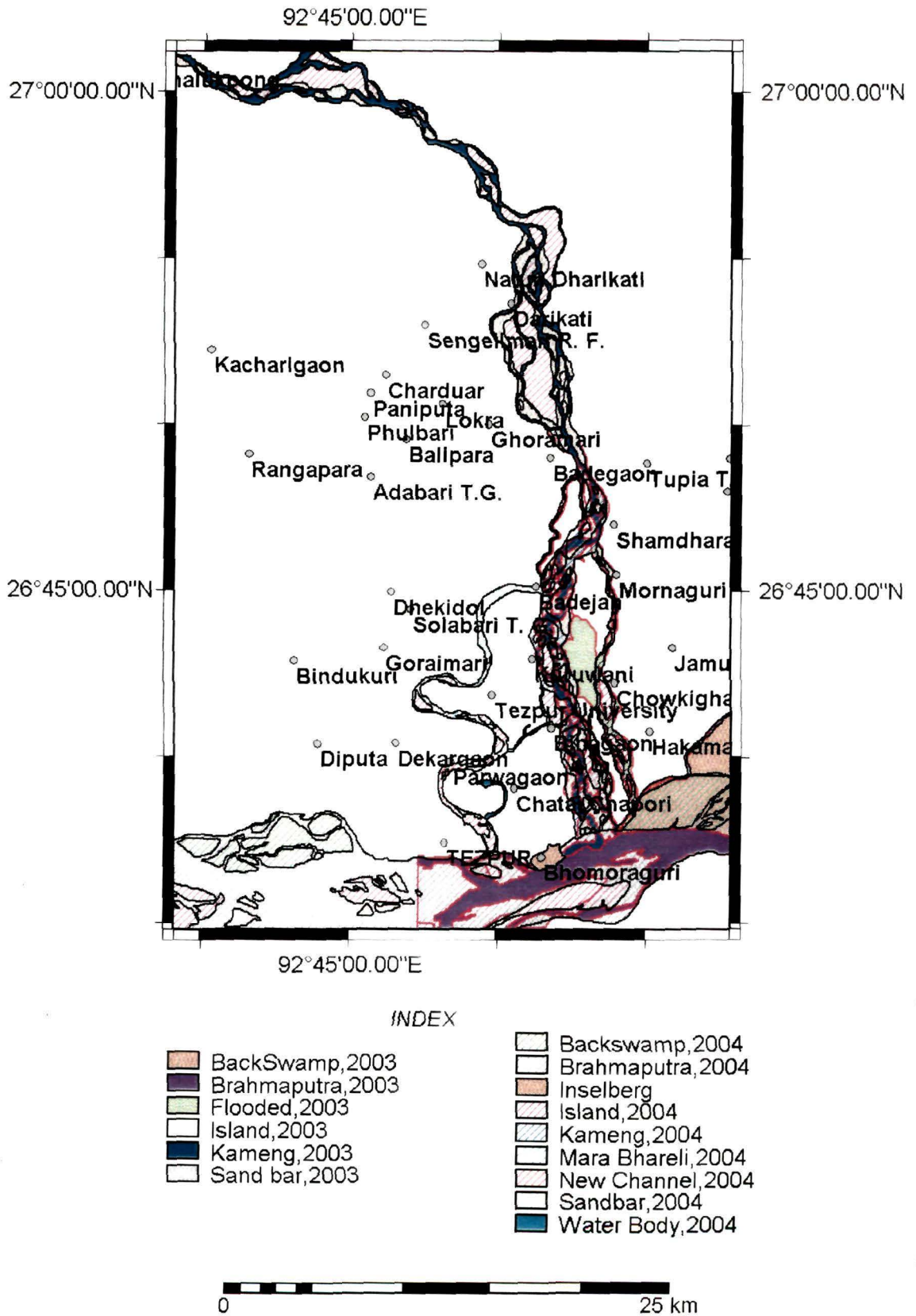


FIG. 4.11 SHIFTING COURSES OF LOWER KAMENG RIVER, 2003 AND 2004

During the existence of the first three courses of the Kameng river, the Balipara Boulder-Gravel Ridge (alluvial fan or terrace) was not at its present height and orientation or probably it did not exist at all. The formation of the Ridge actually obstructed the earlier courses and controlled the flow and direction of the subsequent courses of the Kameng river. Thus, the Balipara Boulder-Gravel Ridge may be considered as an imposing landform in the study area owing its origin to both fluvial and tectonic processes (Plate 7). The Ridge now has definite control on the course of the Kameng when it comes out of the Himalaya Mountain, as such on changing course as well.

The **third change** in the course of the Kameng river took place from a point southeast of Bhalukpong and the river followed the northern curvature of the Balipara Boulder-Gravel Ridge (evident from terrace number one on the northern slopes) to come out on the eastern margin of the Ridge (see Fig. 4.1 and 4.2 and Plates 7 and 9). Then this course ran straight southwards via present Sengelimari Reserved Forest and Lokra aligning almost parallel to the second and third courses to meet the Brahmaputra further eastwards through the Tezpur town (Plate 16). Of course, it had a few branching before meeting the Brahmaputra river. These few branching channels are responsible for formation of many of the channel lines existing over the Tezpur block of the older alluvium.

The point of change in the course of the Kameng then shifted on the eastern margin of the Balipara Boulder-Gravel Ridge and **fourth time changed** course passed through the present Natun Darikati and Darikati settlements (see Fig. 4.1 and 4.2). From Darikati to Brahmaputra the clear surficial evidence of this course has almost been

obliterated by the later courses of the Kameng river. As it is evident from the highly complex traces of the Kameng river in the tract lying between the fourth and the present course of the Bhareli alias Kameng river.

The point of the next and **fifth shift** of the Kameng river was again Bhalukpong from where the course ran eastwards almost along the present course and parallel to the fourth course up to Baithabhanga from where it was a circuitous route full of meanders up to the Brahmaputra river (see Fig. 4.1 and 4.2). Interestingly, from Baithabhanga downwards the course is known as Mara Bhareli (Dead Bhareli or Kameng). The oldest course of the Kameng river and subsequent five changes in course as discussed above have been superimposed over the satellite imagery of the year 2004 and shown in Figures 4.1 and 4.2.

Some other sources of information on the river courses have also been used to find out any change in the course of the Kameng. In this context, worth mentioning is the stone inscriptions displayed at the Bhomoraguri hill on the north bank of the Brahmaputra river near Kalibhomora Bridge. It indicates that a meandering course (Fig. 4.12) of the Bhareli existed in the year 1616 A.D. and its confluence with the Brahmaputra was near the Bhairabi temple of Tezpur (Sarma, 2001; see Plate 15). The Kameng river changed its meandering course to a more or less straight braided one before 1824 (Viswanathan, *et al.*, 1977). A large-scale map published by Survey of India in 1892 shows the lower reaches of the Kameng river as almost straight one. However, the meandering course from the piedmont to Dharikati was active up to 1892. An earthen embankment was constructed during first decade of Twentieth Century to close the mouth of the Mara Bhareli. Till then the entire meandering course (Mara Bhareli) used to carry floodwater from the Kameng or Jia Bhareli.

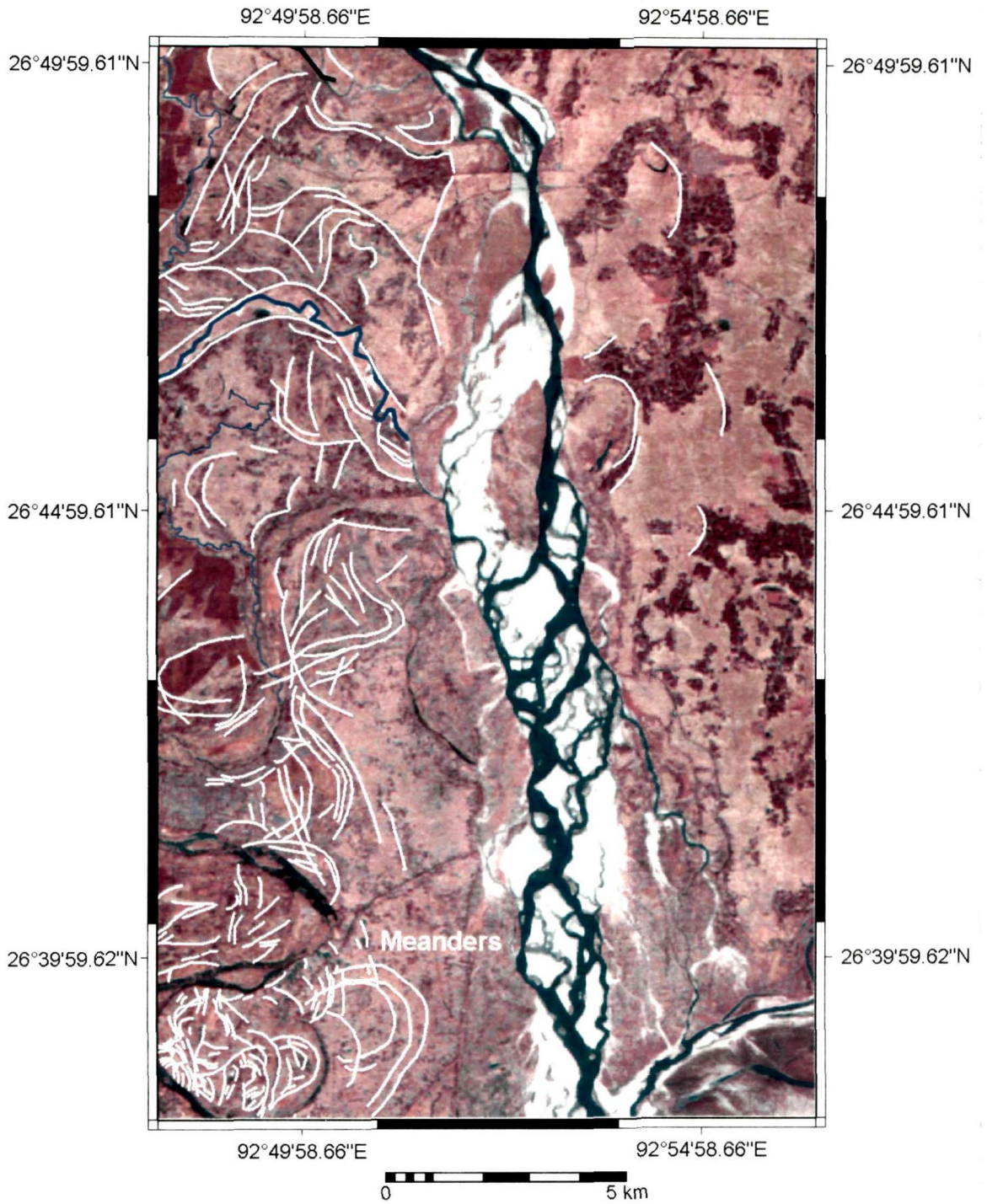


Fig.4.12 MEANDERS OF THE OLD COURSES OF THE KAMENG RIVER

The river recorded its earliest known easternmost shift during 1824 and 1913 as evident from the SOI toposheet, 1934 (surveyed in 1913), to meet the Brahmaputra at a location 12.5 km east of Tezpur town. This was the **sixth change** in the course of the river (see Fig. 4.2). The course of the river has been traced 700 m west of the present course at the National Highway bridge site. The existence of curved *beels* (ox bow lakes) on both banks on the map indicates that the river had two more swings engulfing the right bank area up to Bhomoraguri hills whereas the Chowkighat and other nearby villages were also under water. There was no existence of the villages known as Gataimari and Laltapu in the year 1913.

The river slightly shifted towards west during 1913 and 1964 (Fig. 4.3) near its confluence with the Brahmaputra converting some of the river bed areas into its flood plain where villages like Gataimari and Laltepu have come up, on the then right bank and left bank, respectively. The meander located north of the Railway bridge further eroded towards south and took a course to flow nearly 1 km north of the railway line. The confluence of the tributary Mansari shortened almost 2 km by the shift of the active channel of the lower Kameng river towards west near Badejan. During this period, the Kameng left a branch channel around the village Gataimari located south of the confluence of Mansari and moved about 2 km eastward near Gataimari and engulfed the Chowkighat village located on the right bank, and as a result the confluence of the Kameng with the Brahmaputra shifted 3.5 km west of its previous confluence. These shifts can merely be stated as changes of active channels within its flood plain as a natural behaviour of river in its lower reaches.

Interestingly, the Kameng river took more or less a straight course in 1988 (Fig. 4.4) as evident from LANDSAT satellite data. The portion of the river upstream of the Railway bridge got straightened from its earlier western course, and engulfed partially the Gataimari village while the Chowkighat village resurfaced. The confluence of river with the Brahmaputra further shifted slightly westwards. The westward shifting confluence of the Kameng with the Brahmaputra river is not as significant as the eastward shift from the oldest known confluence lying west of present Tezpur town. Moreover, the slight westward movement of the confluence point from the eastern most course of the Kameng is also negligible, i.e., measuring a few kilometres only.

Satellite data of the years 1990, 1996 and 1998 indicate that the river continued its westward shift slowly engulfing entire Gataimari village and most part of the Bihiagaon area to have a confluence with the Brahmaputra at the base of the Bhomoraguri hills. The floodwater as over bank flow entered a trench joining the lower part of the Mara Bhareli. Oral tradition of the local old people of Panchmile area reveals that this trench was constructed during the Nineteenth Century for collection of earth to construct a road from Tezpur to the bank of Kameng near Bihiagaon to develop communication link from Tezpur to the river bank and Chowkighat on the left bank. Hence, the trench was not a work of the Kameng river, means it was not a natural phenomenon, instead such flow has human influence. The confluence of the Kameng river with the Brahmaputra shifted marginally towards east during 2000. The changes of the course of the Kameng river of 1990, 1996, 1998, 2000, 2002, 2003 and 2004 have been shown in Figures 4.5, 4.6, 4.7, 4.8, 4.9, 4.10 and 4.11, respectively. The courses of the previous years have also been shown on the maps for appreciation of the changes in river course.

The Kameng river did not show any significant shift in subsequent years, though its confluence marginally shifted towards east in 2004. However, an offshoot of the river on its right bank opened in the year 2005 and started flowing towards its old easternmost course. The oral tradition of the local people suggests that a road was constructed joining Tezpur with the bank of Kameng river to provide road communication facility during first part of Twentieth Century. A trench along the road was dug for collection earth required for the road construction for a length of three kilometres approximately. This trench started carrying rainwater from its own catchment and got enlarged in due course of time. It started carrying the floodwaters of the Kameng river from 2003. The offshoot of the river that came out in 2005 joined the trench, enlarged it and thus connected the Kameng river with its old meandering course of the Mara Bhareli. The trench is carrying at present substantial percentage of discharge of the parent river throughout the year (Plate 17).

It can be easily imagined that the tributaries like the Mansari, Bardikrai, Nameri etc. in the study area were meeting the Kameng river at different places along with changes in its course. In this way, the tributaries also changed their own courses. Not only that, the migrating courses of the Kameng river also ran over the courses of its tributaries at many places, thus superimposing its own course across the course of its tributaries. The surficial expression of the material deposited in course of alluviation in the study area exhibit a very complex pattern that can only explained by such developments. On the other hand, it also happened that the secondary drainage system originating from the raised Boulder-Gravel Ridge started flowing by occupying the abandoned course of the Kameng river. The misfit Mansari river and Diputa Nala are the

best examples of it. The development of paleo-meanders (see Fig. 4.12) along the fifth and sixth courses of the Kameng is also contribution of such several changes of courses.

#### **4.4 PATTERN IN THE CHANGING COURSES**

A definite pattern in the changing courses of the Kameng is easily discernible by looking at the direction in which courses have migrated and also by considering the sequence of the shifting courses. The pattern in the changing courses of the Kameng river has definitely been from west to east. It means the oldest course was in the western side of the study area. While the successive shifts in the course were towards the east. Because of this eastward movement of the course, the sixth and last shifted course lies in the easternmost side of the study area (see Fig. 4.2).

Because of the gradual west to east migration of the course the confluence of the Kameng with Brahmaputra river also shifted from west to east. There is distance of 22.5 km between the westernmost and the easternmost confluences (Fig. 4.14). However, there has been westward oscillation of the channels and the confluences moved between 3.5 km and 5.5 km from the easternmost confluence; while the present confluence is at 4 km away. Therefore, the confluence of the westernmost and the oldest traceable course with the Brahmaputra exists 18.5 km west of the present confluence of the river (Jia Bhareli). Though after reaching to the easternmost limit of shift the channels of the Kameng has begun a westward movement by a few km, there is no evidence that the pattern of shifting courses has reversed. It means that the course has now stabilised in the centre of the graben through which the Kameng river is flowing now. Therefore, a few westward movements in the active channels of the river should not be considered as precursor to westward pattern of change of the course of Kameng. This is because such channel migrations are within the active flood plain of the Kameng river. Presence of the immediate higher terrace and levee on the west bank also restricts westward movement of

the course of Kameng river. Moreover, the course of Kameng has aligned in the centre of the graben after filling it to a levelled flood plain.

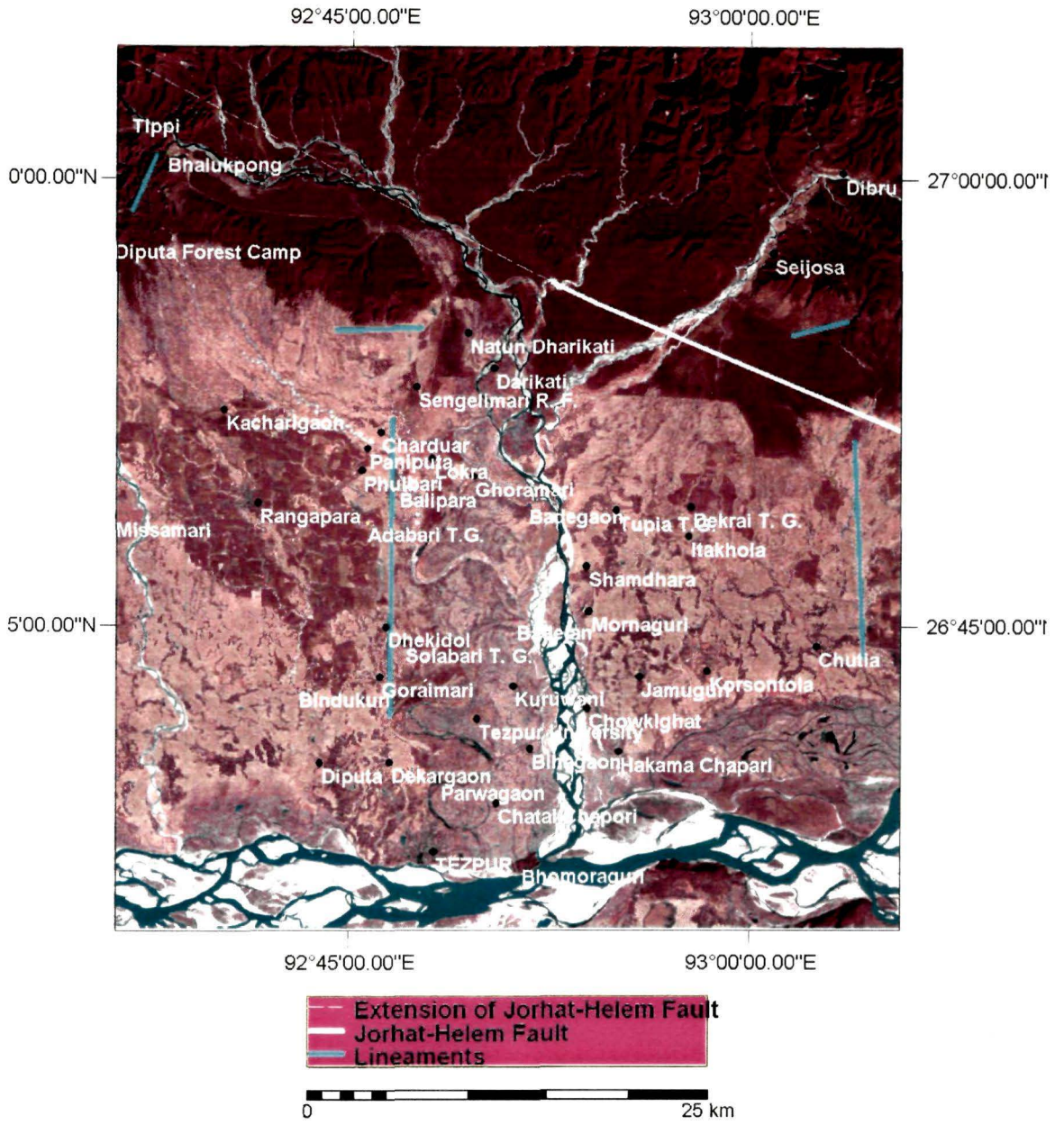
#### 4.5 CAUSES RESPONSIBLE FOR SHIFTING OF THE COURSES

The major cause behind the changing course of the Kameng river is fluvio-tectonic in which lineaments (faults etc.) and uplift of the older alluvium and formation of gravel ridge are important. A few significant observations definitely indicate that the study area is tectonically active that has been influencing fluvial processes and landforms. However, role of climate in it can not be ruled out.

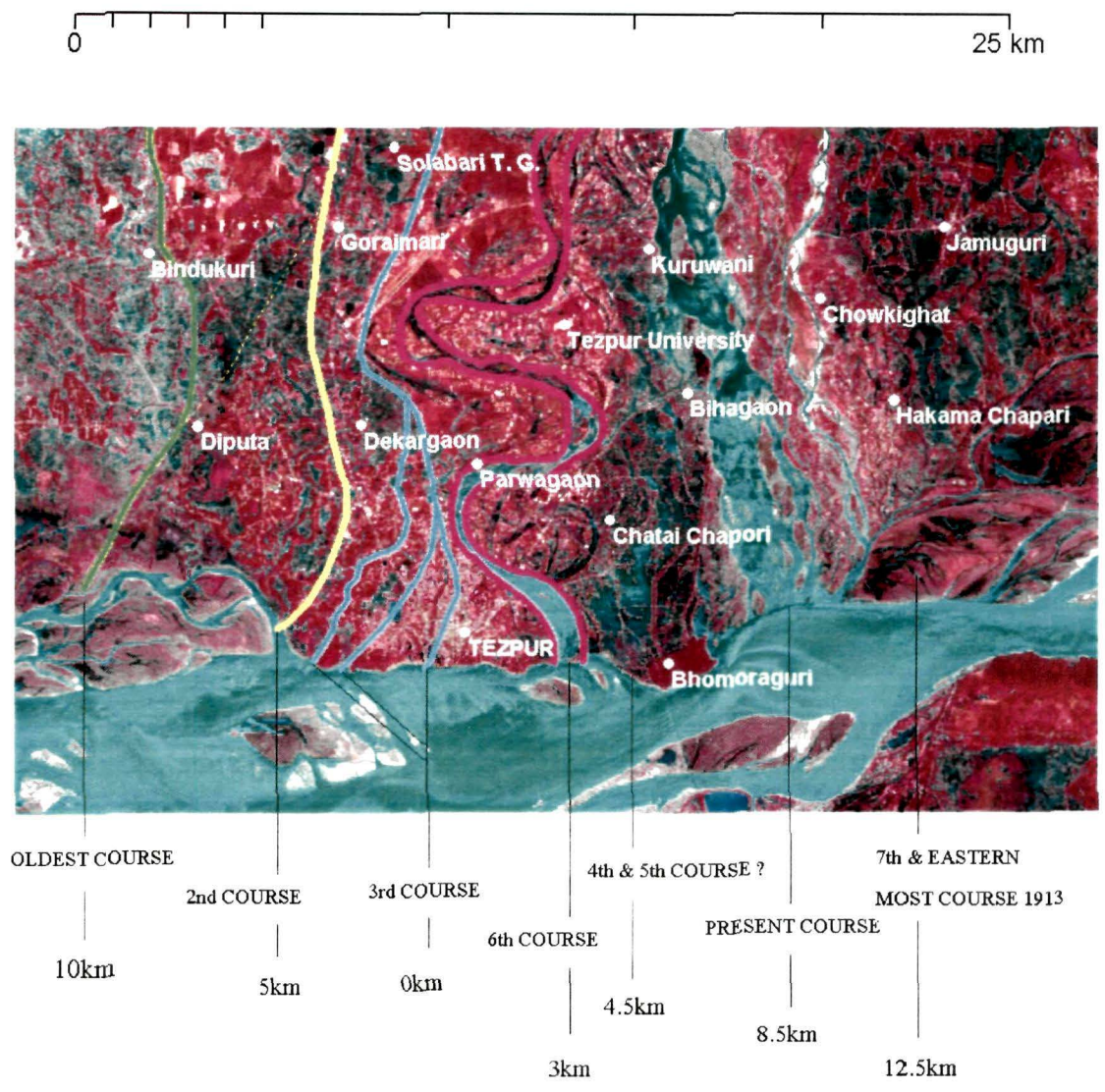
During the Himalayan Orogeny, the upheaval of the Himalaya initiated in the Late Eocene – Oligocene times. The renewed intensive folding and overthrusting related to the development on the Main Boundary Thrust (MBT) caused the upheaval of the Siwaliks and sedimentary basins formed in the early Pliocene. Consequently, silt, clay and sand beds with debris from lesser and greater Himalaya were deposited below the foothills over the sedimentary basins responsible for formation of the alluvium (Wirthmann, 1994). The rise of the Mahabharat range of Nepal in late Pliocene to Pleistocene is an excellent example. The Mahabharata Range is still in a state of rigorous uplift by at least 400 m since the end of the lacustrine sedimentation in the Kathmandu basin 19,000 years ago (Boesh *et al.*, 1977). Uplift of such a ridge of the Siwaliks along a northsouth fault located in the northwest corner of the study area, during early Holocene period, changed the general slope at that place forcing the Kameng river to abandon its oldest course (via Rangapara) and flow towards east leading to the **first change** of its course.

The emergence of MFF (Main Frontal Fault) modified the initial tectonic setting of the alluvial fans as it happened in the lineaments controlling the Brahmaputra, Sharda, Gandak and Kosi fans. Hence, sediments are undeformed in the alluvial plain. In other areas, inclined graben type setting is expected with tilting towards west and east (Ghose, 1994). The contemporary formation of such a graben also guided the Kameng river course from Charduar, as a result it took a southerly course and the river flowed along the westernmost edge of the graben. This course also eroded the Rangapara surface at many places. It appears that the second course lies on its eastern edge that happens to be the western wall of the graben also.

The major drainage systems issuing from the Himalayan source have greatly influenced the erosion, sediment transfer and deposition, i.e., dispersal of sediments along the faults. Movements along strike slip – cum – normal faults have contributed in altering drainage and depositional systems because of tectonic slopes. The existence of the EW Bomdila fault also guided the Bichom river and its tributary Tenga to flow almost along a straight course. The Rupa settlement located in the Tenga valley came up over terraces formed apparently due to lacustrine sediment deposition. The satellite data of the areas indicates occurrence of several huge landslides which might have dammed the river in most of the cases. Accumulation of huge quantity of water behind the dams and subsequent dam burst caused several mega floods in the river during which the floodwater carried the debris containing gneisses and slates through a process of transportation and deposition over the river bed to form terraces and subsequent erosion and ultimately to carry to the alluvial fans in the piedmont. Formation of terraces in the some parts of the Tenga valley and Bichom valley can be clearly seen in satellite imagery.



**FIG 4.14 DISTANCE OF THE CONFLUENCE OF THE PRIOR AND PRESENT COURSES OF THE KAMENG RIVER**



Occurrence of landslides has been noticed in many parts of the world due to debutress of the tectonically steep slopes after the withdrawal of the ice-sheets or retreating of the snow line, e.g., a huge landslide took place in Green Lake, New Zealand. Mega landslides did occur in the Tenga valley near Rupa (Plate 10 and 11), which might have impounded its waters. It is believed that the snowline during the Quaternary glacial ages was as at lower altitude about 1400 m in the Eastern Himalaya (including the Kameng Himalaya). The retreating snowline in the post-glacial period during the Holocene subsequently increased discharge in the rivers. Because of increased discharge in the Tenga river the dam got burst to cause flood and debris flow. This put pressure on the geometry of the river through increased energy of the hydro-geomorphic regime. Consequently, the debris was deposited in phases in the piedmont zone that forced the Kameng river to change its course. The exposed terraces on the left bank of the river upstream of Bhalukpong (where it is flowing through a gorge), substantiates occurrence of such mega-floods. Borthakur (1968) has also observed that a severe winter with heavy snowfall followed by a warm rain summer may invariably may result in high floods in the Kameng river, which might have changed its fluvial regime.

The first of such events occurred during the early Holocene. This is substantiated by the resemblance of the component material of the Balipara Boulder-Gravel Ridge with the material of the Lesser Himalaya (GSI, 1977). This was the beginning of the formation of the Balipara Boulder-Gravel Ridge, which blocked the second course of the river. The existence of a northsouth trending ridge of the Siwaliks along a minor fault also forced the river to take an easterly route leading to the **second shift** of the river and establishment of its third course. This shift was more of a fluvial geomorphic event induced by climate change, instead of purely tectonic like in the previous case.

The occurrence of the second large landslide in Rupa area led to another high sediment load condition in the river. This was supported by continuous uplift of the Balipara Boulder-Gravel Ridge, which caused **third change** in the course to follow the easternmost boundary of the Balipara Boulder-Gravel Ridge up to its extremity (Plate 9). This shift can be attributed to fluvio-tectonic factors. In the lower reaches, this fourth course was further deflected eastward to flow through the Tezpur town. The materials eroded by the Kameng from Balipara Boulder-Gravel Ridge were deposited in and around Sengelimara Reserved forest as higher level terraces.

The development of the Jorhat-Helem fault up to the Himalayan foothills prompted **fourth shift** of the river towards east to follow its fifth identified course. Its evidence downstream of Darikati is completely obliterated by the work of the river in the later periods. Two terraces developed on the north of the Balipara Boulder-Gravel Ridge are the remnants of the abandoned courses of the river (Plate 7, 9 and 13). The strengthening of the fault helped in development of the terraces downstream of Bhalukpong and the river further shifted towards east (the **fifth change**) to establish its sixth course and flow in a meandering course downstream of Badejan, now known as Mara Bhareli. Both the shifts were caused by the tectonic factor.

In present time, a high flood event occurred on 5<sup>th</sup> July, 2005 in the Pakke valley. The flood might have been caused due to burst of a landslide dam formed across its hilly course. Subsequently a large quantity of water and sediment was carried to the Kameng river. It may be correlated with the opening of an offshoot on the right bank of the Kameng near Kuruwani village, which joined the Mara Bhareli through a man-made trench dug long before for road construction. Occurrence of such severe flood between

1616 A.D. and 1824 A.D. might have forced the river to abandon its circuitous course for a straight braided course and caused its **sixth shift** and formation of the seventh course of the river. This happened to be the last recognisable and significant shift and the establishment of the eastern most course of the Kameng river too. The last change in the course of the Kameng has definitely been brought about by the fluvial factor.

#### 4.6 PROGNOSTICS

Now the Kameng river is flowing through the graben that has restrained the river to shift its course beyond eastern and western boundary of the graben. Existence of levees on the right bank from Ghoramari up to the Kaliabhomora hills restrains the Kameng river from any westward shift now. Therefore, it appears without doubt that there is going to be no major westward change of the Kameng river for the time being. The Kameng river merely changed its channels during 1892-2004 A.D. within its recent flood plain, neither from east to west nor from west to east. This phenomenon is likely to continue within the identified zone of channel migration that should not be treated as shifting of river course.

The stability of the present course is directly due to given fluvio-tectonic conditions of the study area and climatic conditions of the basin as a whole. On the basis of the findings of the present study, it can be easily said that in near future there is not going to be any major change in the course of the Kameng river. This observation contradicts the general threat perception that the site of the Tezpur University is going to be overtaken by the Jia Bhareli or Kameng river. This is because the river is now flowing through the centre of the graben having almost in a straight stabilised course. However, during floods the river water may follow some of its abandoned nearby courses as a

natural tendency of a river in the flood plains, as it has happened in the recent times in the lower course of the Mara Bhareli.

In the context of relative stability of the present braided course of the Kameng river (Jia Bhareli) it would be worthwhile to mention that the river is flowing nowadays in relatively steeper gradient in comparison to its prior courses, some which were circuitous and full of big meanders. The increased gradient is due to two reasons. First, the present braided course lies in the centre of the graben, thus facilitating unhindered straight flow of the river water. Secondly, it is believed that the Brahmaputra has shifted slightly southward, thus lowering the local base level of the Kameng river. Geomorphic evidence to this effect is clearly seen on the satellite imagery and in the field as well, particularly to the east of the present course. It can be concluded without doubt that in the normal given conditions a braided river by its nature itself has less chance to change its course than a meandering river. By normal condition is meant absence of occurrence of exceptional floods, climate change, tectonic movement, etc. Of course, migration of channels within the active flood plain is possible in the case of a braided river, and that is happening in the present course of the Kameng river. Therefore, on the basis of such scientific facts it can be said that there is going to be no major change in the course of Kameng river, and thus any fear psychosis attached with it must be given up by the people, administrators, planners and scientists as well.

\*\*\*\*\*

**CHAPTER V**  
**DISCHARGE AND SEDIMENT ANALYSIS**

## CHAPTER V

### DISCHARGE AND SEDIMENT ANALYSIS

#### 5.1 INTRODUCTION

The discharge and sediment load of a river determines the magnitude of the work of the river. Discharge is governed by rainfall-runoff relationship of the basin. Flood means a very high stage of river discharge leading to over bank flow. Normal floods are one that occur frequently/regularly/yearly causing inundation of the active flood plains. Whereas exceptional floods are irregular ones that occur at long interval of time causing submergence of a very large area. The condition of a river may be favourable for change of its course due to other factors, but the event of such change is normally timed with the unusually high peak discharge and excessive sediment load.

Floods of a river are studied to assess the occurrence of floods, especially probability of occurrence of the rarely high flood events. Such studies are of great relevance to the understanding of the fluvial processes and resultant landforms. It is crucial in the analysis of the changes in the course of a river. It also helps to design hydraulic structures, and to explore the ways to minimize the loss of life and property in flood events. The life and size of the hydraulic structures like embankments, dams, barrages etc. are designed based on estimation of floods. The determination of precise rainfall-runoff relationship can also help in flood forecasting to enable hazard management. Therefore, development rainfall-runoff relationship for a basin has great significance both from fundamental and applied points of view.

Adequate and well-distributed rainfall data of a river basin is required to develop rainfall-runoff relationship. Since the catching area of a raingauge is very small compared to the aerial extent of a storm, it is obvious that to get a representative picture of a storm over a catchment raingauges should be installed in the area as large as possible. However, economic considerations, topography and accessibility restrict the number of gauges to be maintained. The World Meteorological Organisation recommends one station for 100-250 sq km in ideal condition and one station for 250 – 1000 sq km as acceptable in the mountainous regions of Temperate, Mediterranean and Tropical zones. Rainfall data for Kameng basin is very scanty and that too available for a short period. Analysis of such data may not be able to show the extreme values and dependence on such values for hydrologic structures may result in disaster. It is also appropriate in such cases of ungauged basins to adopt a method, which is independent of rainfall data like Geomorphological Instantaneous Unit Hydrograph (GIUH).

Sediment is defined as fragmental material transported by, suspended in or deposited by water or air. The sediment carrying capacity of a river is closely related with flood discharge. The surface runoff, which causes stream flow, is also the cause in many situations and agent for transporting upslope sediment to the streams in the basin. The trends of shifting of river courses are promoted by deposition of sediment on its bed. Such deposition changes the channel hydraulics and thereby changes the direction of flow. The river water as such abandons its previous course and flows along the highest slope available within its reach.

Appreciating the role of the discharge and sediment of the river, an attempt is also made in this study to measure the sediment load of the river and correlate with the

discharge. The detailed discharge and sediment analysis conducted during the study period is discussed in the present Chapter. Since, the study is conducted for a short period it will not be wise to forecast floods. Therefore, another attempt is also made to develop a Geomorphological Instantaneous Unit Hydrograph (GIUH). The historical maximum rainfall data may be used in the GIUH as input to develop a flood hydrograph, which is also useful for hydrologic design.

## 5.2 GAUGE, DISCHARGE AND SEDIMENT DATA COLLECTION

Selection of proper method for measurement of discharge and sediment load depends upon availability of infrastructure. Use of sensitive equipments may lead to accurate measurement. A host of parameters are responsible in such complex operation. Velocity of flow varies across the section and along the depth of flow, whereas, depth of flow in the section varies in an irregular fashion. Concentration of sediment also varies with the variation of velocity. A method that presents the accurate idea of the water level, variations of the stream depths over the cross-section, and the velocity and sediment concentration variation within the cross-sectional area can be adopted as the best method. The stream may be divided into small elemental areas over the whole cross section to measure the velocity, discharge and sediment concentration and integrate them to obtain the overall discharge and sediment flow rate of the stream. However, due to the limitations to achieve this, most methods of flow measurement aim at an approximation of the area – velocity integration.

The Kameng is a braided river in its lower reaches with no straight reach and stable riverbank available near confluence with the Brahmaputra. The *in-situ* discharge and sediment concentration measurement in such areas requires ship mounted

sophisticated and costly equipments not yet available in the region. The straight reach between the Railway Bridge and the Road Bridge over the river have been found to be the only relatively suitable site for the purpose and being used by various organisations working in this field as per their need. The Central Water Commission (CWC), Govt. of India, is also maintaining a gauge site on the same location. The Water Resources Department, Govt. of Assam, and The Brahmaputra Board also make use the same site as and when needed. However, one more tributary viz., Mansari, of the Kameng has its confluence with the Kameng downstream of the CWC gauge site. The impact of the discharge and sediment load of the Mansari, having a basin area of 264 sq km, could not be overlooked on the working strength of the Kameng in its lower reaches during initiation of the study. Therefore, two gauge, discharge and sediment (GDS) sites were established with the help of CWC, one at the NT – Road crossing site of Kameng river and the other over the tributary Mansari at a location 3 km upstream of its confluence with the Kameng.

The Area – Velocity method has been considered the most suitable method for measuring the discharge in large streams. The measurement of flow area is done simultaneously with the measurement of velocities. As such, this method has been applied to measure the discharge at both the sites. The velocity was measured with digital cup counter current meter. Float method was also used to measure velocity in certain circumstances. The current meter used to lower from the road bridge with the help of Bridge Outfit to measure the depth to the riverbed, depth to the water surface level, depth to the 0.6 of depth of flow where the velocity is also measured. The velocity of flow of water at a depth of 60% of the depth from the surface across the vertical section is considered to represent the average velocity.

The width of the Kameng river at the GDS site was 500 m. The section was divided in 25 m reaches where velocity and discharge was measured separately. Similarly, the width of the section at the GDS site of Mansari was 53 m, which was divided in 3 m reaches and measurements were taken for the each independent section. The procedure followed by Central Water Commission was also adopted for calculation of all outputs for achieving uniformity with the historical data. Collection of data started from 11.11.2004 in the Mansari and 01.01.2005 in the Kameng river and continued until 31.05.2006.

Similarly water samples were collected at 0.6D of every section referred above for both the rivers for analysis of Coarse ( $>0.2\text{mm}$ ), Medium ( $0.075\text{mm} - 0.2\text{mm}$ ) and Fine ( $< 0.075\text{mm}$ ) sediments. Punjab Type sediment samplers were used for collection of water samples in both the GDS sites. Water samples were collected at 0.6 D at every section. The samples then were mixed in a bucket, stirred uniformly to make it homogenous and one litre of the mixer was extracted. This one litre of water sample was allowed to pass through sieves of 212 micron and 106 micron-sizes respectively to extract coarse and medium sediments. The rest of the water was allowed to pass through a filter paper of size one placed on a funnel mounted on a beaker. Thus, the fine particles were trapped on the filter paper. These samples thus were dried over a stove and pan. The dried samples were thus weighted and its concentration per litre was calculated. This experiment was conducted daily in two individual Silt Analysis Laboratories established solely for the purpose at the two GDS sites. Data was collected at 08.00 am every day at the two sites. Necessary labor was also hired and technical support was taken from the CWC.

### 5.3 DISCHARGE ANALYSIS

Study of the hydrology of a river requires long historical data. Since the river Kameng did not have continuous historical data for the last thirty years attempts have been made to make the scanty available data representative of the river hydraulics. The discharge data of the river was measured along with the sediment load for the period from 01.01.2004 to 31.05.2006 comprising one monsoon season. Historical data as available with the CWC and Water Resources Department, Govt. of Assam were collected. The period and type of data collected are:

- (i) CWC (Gauge data) for the period from February 1997 to October 2003.
- (ii) WRD (Gauge and Discharge) data for the period from January 1997 to December 2001 with missing data for several days and month.

It is also necessary to analyse the available secondary data to develop hydrograph for the period from 1997 to 2003. The primary data collected through personal supervision requires analysis and comparison with the output of the secondary data. This will help in the attempt to extrapolate the output to past storm events.

#### 5.3.1 Stage – Discharge Relationship

The measurement of flow data of everyday for a long period is literally not possible from economic point of view. Further, due to high velocity sometimes it became impossible to measure the flow data with the available resources. The Kameng river is also having several possible breach points upstream of the GDS site that makes it impossible to measure the actual flood discharge. Hence, discharges occurring between the periods of measurement are determined from already developed stage – discharge relationships, where the stage is the water surface elevation above a selected arbitrary or datum plane. The stage – discharge relationship is in principle developed by measuring

the stage simultaneously with each measurement of discharge and plotting the same against the measured discharge. Thus, if the stage is known, discharge can be obtained from the already developed relationship.

The primary aim of all direct discharge measurements stands at preparing a stage–discharge relationship or rating curve. The measured value of discharges when plotted against the corresponding stages gives relationship that represents the integrated effect of a wide range of channel and flow parameters. If the relationship for a gauging section is constant and does not change with time, it is treated as permanent. Only subsequent gauge data is required, in such case, for development of hydrographs. An attempt has been made to develop a stage-discharge relationship using the measured data following standard procedure and validated with the data collected from other organisations.

#### **5.3.1.1 Selection of gauge site**

Regardless of the type of gauge employed, the GDS site should conform to the following requirements:

- (1) It should be located upstream of the desired site but within the range of influence of control,
- (2) The support to the gauges should be immovable and rigid so that the elevation of the datum is unlikely to change,
- (3) It should be located in a reach where, greatest range of fluctuation in the stage occurs,
- (4) It should be well-protected spot. Its destruction by floating debris or ice should be improbable,
- (5) The gauge site should be easily accessible,

- (6) It should not be located upstream so near to the confluence with another stream that it is affected by backwater from that stream, and
- (7) The gauge should also not be located within the influence of the backwater of a Dam or Hydroelectric plant.

In the Indian Subcontinent where the flood period is well defined during the monsoon months, the bed rugosity and water surface slope conditions are different during the two periods of monsoon and nonmonsoon months. Under such conditions, it would be desirable to develop stage-discharge rating curves for monsoon and nonmonsoon months separately.

The stage-discharge relation curves are primarily intended for interpolation, and their extrapolation beyond the highest recorded high water or lowest recorded low water can be subject to risk and indefinite errors. Physical factors like over bank spills at high stages, shifts in controls at very low and very high stages, changes of rugosity coefficients at different stages, etc. materially affect the nature of the relationship at the extreme ends and must be taken into account in the extrapolations.

#### **5.3.1.2 Analysis of stage-discharge relationship**

The most common methods for the extension of stage-discharge curves are: (i) Steven's method, (ii) logarithmic method, and (iii)  $\sqrt{S}/n$  method. If the cross-section of a stream at the site of a gauge is, or approximates to, a uniform section to which one can roughly fit a segment of a circle, parabola, rectangle or trapezoid, then the logarithmic method is more suitable (Subramanya, 1984). The discharge can be expressed as:

$$Q = C(G - G_0)^n \quad 5.1$$

Where  $Q$  = Discharge

$G$  = Gauge height

$G_0$  = Gauge height corresponding to zero discharge

$C, n$  is constants for any particular station

The developed equation requires test of correlation using standard statistical methods. To, apply correlation techniques, the equation can be expressed in logarithmic form to convert into an equation of straight line as

$$\log Q = \log C + n \log (G - G_0) \quad 5.2$$

This is an equation of straight line whose slope is  $n$  and whose intercept with the discharge axis is  $\log C$ . The value of  $G_0$  for the GDS site is observed to be 67m.

Coefficients of this relationship may be determined by least square method as:

$$n = \frac{N[\sum (\log Q)\{\log(G - G_0)\}] - [\sum \log(G - G_0)][\sum \log Q]}{N[\sum \{\log(G - G_0)^2\}] - [\sum \log(G - G_0)]^2} \quad 5.3$$

$$\log C = \frac{(\sum \log Q) - n[\sum \{\log(G - G_0)\}]}{N} \quad 5.4$$

The correlation coefficient ( $r$ ) is a measure of linear association between two variables independent of units, the value of which lies between  $\pm 1$ . The relationship is perfect when its value is 1, whereas, the relationship is reverse when it is  $-1$ . As such, the gauge – discharge relation may be adopted when ‘ $r$ ’ reasonably approaches  $+1$ . Mathematically correlation coefficient may be defined as:

$$r = \frac{Cov.(x, y)}{\sigma_x \sigma_y} \quad 5.5$$

where,

$Cov. (x,y)$  = Covariance of x, y.

$\sigma_x$  = Standard deviation of x

$\sigma_y$  = Standard deviation of y

Including the definition of the covariance and standard deviations in terms of the two variables, the equation 5.5 can be simplified as

$$r = \frac{\frac{1}{N} \sum_{i=1}^N X_i Y_i - \overline{XY}}{\sqrt{\frac{1}{N} \sum_{i=1}^N X_i^2 - (\overline{X})^2} \sqrt{\frac{1}{N} \sum_{i=1}^N Y_i^2 - (\overline{Y})^2}} \quad 5.6$$

Following this procedure, attempts have been made to determine the empirical relationship between stage and discharge separately for monsoon and non-monsoon seasons for every year against which stage and discharge data were available. The intention for developing the relationship was to examine whether the GDS site can be considered to be an ideal site having appropriate stage-discharge relationship. If an appropriate relationship is developed, discharge data may be generated by extrapolating to other years where only gauge data is available. The relationship for different years is shown in Table 5.1.

The correlation coefficient developed for the years 1997, 1998, 1999, 2000, 2001 and 2005 indicates that only the stage-discharge relationship for rainy days of 1997 and 1998 and nonmonsoon days for 1998 approaches 1 and can be adopted for extrapolation for only these few years. The poor relationship thus found indicates that the GDS site is not in conformity with the conditions stated in 5.3.1.1. In such a situation, when stage does not have suitable relationship with the discharge, it is necessary to measure the discharge everyday using suitable method.

**Table 5.1 Stage- Discharge Relationship in Kameng River, 1997-2005**

Year	Monsoon (15 <sup>th</sup> May – 15 <sup>th</sup> October)		Non-monsoon (16 <sup>th</sup> October – 14 <sup>th</sup> May)	
		Correlation coefficient		Correlation coefficient
1997	$Q=11.00162(G-67)^{2.22406}$	0.816	$Q=327.092(G-67)^{2.51467}$	0.111
1998	$Q=2.732754(G-67)^{2.88975}$	0.960	$Q=1.061342(G-67)^{3.23306}$	0.996
1999	$Q=261.3995(G-67)^{0.75387}$	0.413	$Q=0.42925(G-67)^{3.54021}$	0.840
2000	$Q=1253.035(G-67)^{0.01583}$	0.421	$Q=5.9306(G-67)^{2.19708}$	0.547
2001	$Q=16.51367(G-67)^{1.89575}$	0.578	$Q=413.6208(G-67)^{-0.16693}$	-0.050
2005	$Q=0.002138(G-67)^{5.98484}$	0.612	$Q=0.000174(G-67)^{6.83754}$	0.759

### 5.3.2 Discharge in River

The hydrologists working in Brahmaputra valley observed that the monsoon period in this area is much longer than other parts of the country. Though the normal monsoon appears in the region in the 1<sup>st</sup> week of June, there are instances of an early arrival of monsoonal rains, e.g., monsoon rain started on 27<sup>th</sup> of May in the year 2006. In addition to that, the pre-monsoon rainfall also leads to substantial precipitation in the month of May. As such, the CWC recognised a longer monsoon period, i.e., start on 15<sup>th</sup> of May and withdrawal on 15<sup>th</sup> of October. The present study also adopted the convention of CWC for monsoon and nonmonsoon periods to facilitate easy secondary data inflow and outflow, and accordingly analyses have also been carried out in section 5.3.1.

Thus, the monsoon is spread over a period of 5 months during which 65 per cent of the total annual rainfall precipitates. Out of this quantity, 70 per cent is discharged as surface runoff and the rest accounts for abstractions like evapotranspiration, surface retention and deep percolation etc. The maximum daily rainfall of 10.44 cm was recorded on 18.08.1969 in 1971 at Bindukuri Tea Garden (GSI, 1977). The Kameng drainage basin has good drainage efficiency. The existence of water bodies in the basin is almost insignificant except a few swampy areas on its downstream. The river originates from snowfields and descends to its confluence within a very short distance of 242 km along its channel bed. The slope of the river channel bed varies from 0.21 m/m near its origin to 0.0009m/m near confluence with the Brahmaputra with an average of 0.0289m/m. The time of concentration is computed as 17.78 hours in section 5.3.4. This short time of concentration of the river along with its high slope indicates that most of the surface runoff is transported rapidly to the main drainage channel of the tributaries including the numerous ephemeral channels causing flash flood on most occasions. The water level at the GDS site usually remains below 77 m during non-monsoon season with minimum fluctuation. The highest flood of 5548 cumec was recorded in July 1969 (GSI, 1977). The water level starts rising by the end of April. The highest water level in a year may attain at any day between mid-June and mid-August. The hydrographs of the river indicate that besides a primary peak water level, there exists number of secondary peak water levels of appreciable magnitude in the period between mid-June and mid-October, depending upon the depth and distribution of rainfall. The highest discharge recorded during the study period was 4863 cumec on 26<sup>th</sup> September 2005 followed by 4818 cumec, 4816 cumec and 4803 cumec on 27<sup>th</sup> September 2005, 24<sup>th</sup> August 2005 and 25<sup>th</sup> August 2005, respectively.

The discharge data of the years 1997, 1998, 1999, 2000, 2001, 2005 and 2006 were drawn against time and shown in Figure 5.2. The discharge was directly measured during the study period. The discharge data shown by CWC were the result of conversion from gauge data using a standard factor. The data collection site has been found to be not in conformity with the specified standards indicated in section 5.3.1.1. The difference in peak discharges of the study period in comparison with the previous years as shown in Fig. 5.2 also substantiates the findings. The Gauge and Discharge site of the Kameng river at NT Road Crossing as shown in Figure 5.1 also visualizes the unconformity with an ideal site.

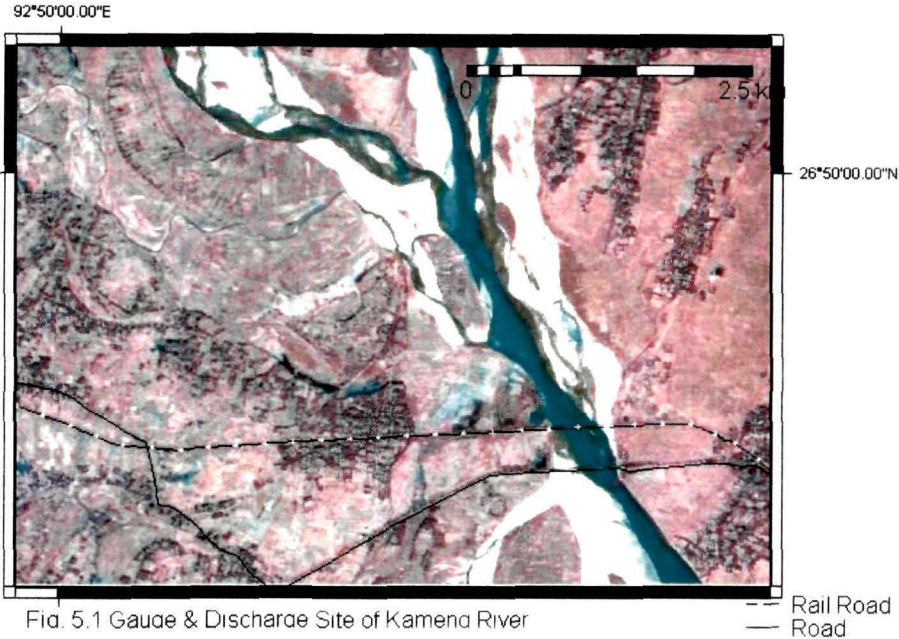


Fig. 5.1 Gauge & Discharge Site of Kamena River

### DISCHARGE VS. TIME CURVES OF KAMENG RIVER AT NT Rd. X-Ing

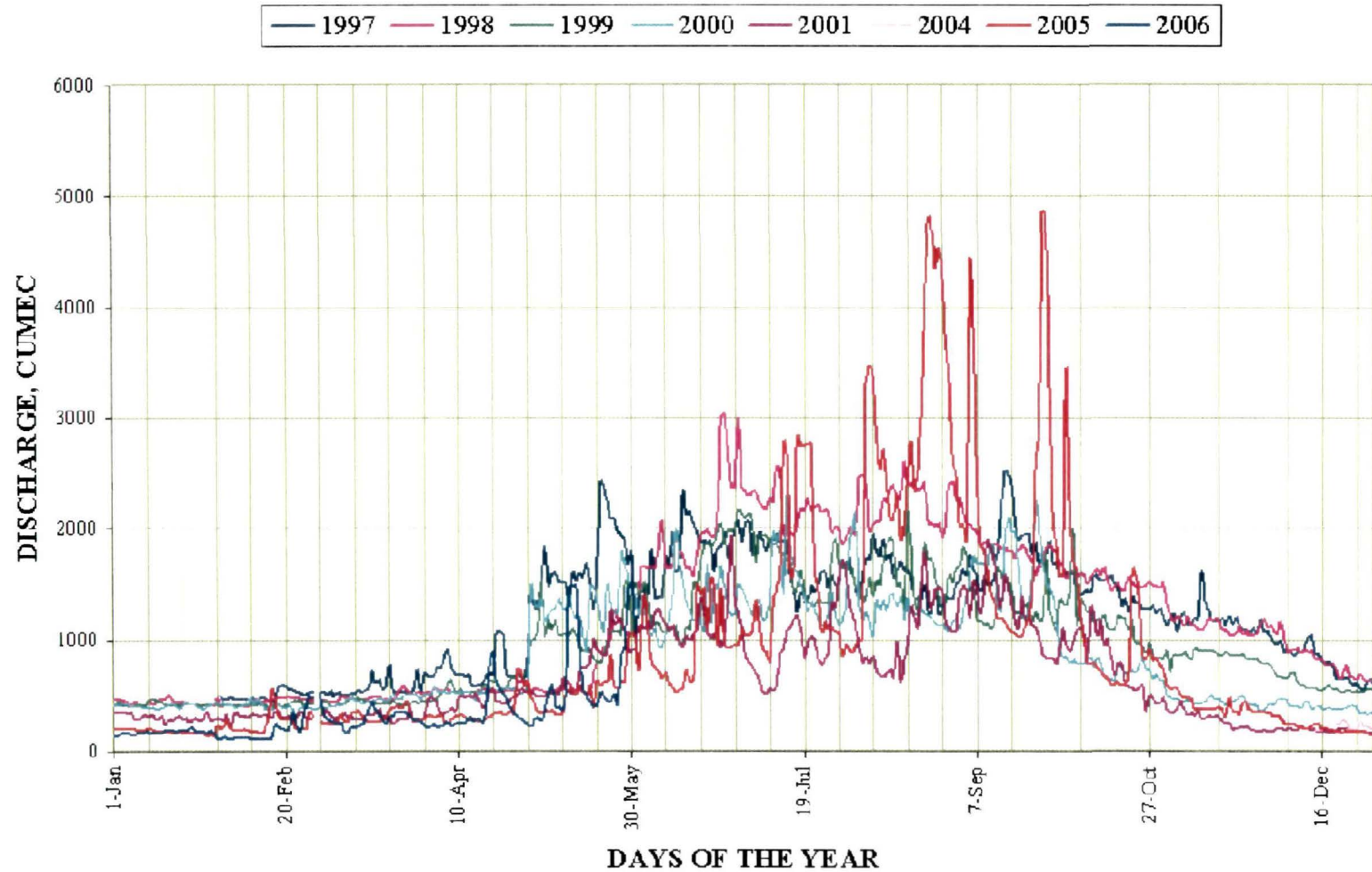


Fig. 5.2 Discharge of Kameng River during 1997 to 2006

### 5.3.3 Flood Events

Rivers in the alluvial plains normally spill over their banks several times in a year causing floods. It is a common feature and also essential for the river to accommodate its water flowing in excess to its carrying capacity during rainy days on its flood plain. However, it is the extreme floods, which occur rarely, cause misery to the people and are responsible for the losses of many types. A few of the flood events of the world have been discussed here, which are also used for describing the floods of the Kameng river.

As discussed in Chapter II, the Yellow river of China breached its levees 1500 times from 602 B.C. causing severe misery to the people, hence called as the 'Sorrow of China'. The principal problem of the Yellow River is the silt deposit caused by exceptionally high sediment load. The average annual silt run-off of the river is 1,920 million tonnes, with an average of 4.4 per cent by weight. The slope of the river on alluvial plain is steep, in comparison to other rivers, varying from 1: 2,400 to 1: 10870, with an average of 1: 6000. Under these circumstances, the rate of aggradation of the riverbed has been 1 to 1.3 cm a year on the average that increases potential flood threat year after year.

The Kosi river is notorious for its capricious nature. Due to its shifting courses, the river has ruined an area of 7,770 sq km of land in Bihar and 1,295 sq km of land in Nepal by sand deposition. During its shifting of courses, many settlements were wiped out and heavy losses of property, cattle and even human life were inflicted. Its catchment area is 59, 279 sq km. Average annual total runoff as measured at Barakshetra in the Himalayan Gorge is 53,040 million cubic meters of which 81 per cent is contributed during June to October. The annual maximum discharge varies from 5700 to 24300

cumec. The river is subject to sudden spate, sometimes rising over 9 m in 24 hours in the Himalayan Gorge. Its annual sediment load at Triveni is 11,84,14,700 cubic meters with a concentration of 0.24 per cent. The maximum observed concentration is 0.47 per cent recorded during the unprecedented high flood of 24300 cumec in 1954. The flood and sediment characteristics of the Kosi river in comparison to other rivers of the world are shown in the Table 5.2. Average annual sediment yield of the Kosi river is 20.08 Ha-m/100km<sup>2</sup>, with an average annual silt load of 11858 ha-m. Therefore, it can be said the Kosi transports the highest sediment among the rivers compared in the Table 5.2.

There are plenty of examples of flood events occurring due to dam burst. A river course may be entrapped temporarily by huge soil mass or debris coming down from uphill slopes due to landslide. An artificial lake is formed in the upstream of such dam. While reaching critical point the dam bursts allowing the trapped water to gush and reach the confluence within a very short time causing an unusually large flood with immense destructive power.

The river Siang (as the Brahmaputra called in Arunachal Himalaya) experienced an unprecedented flash flood on 11<sup>th</sup> June 2000, which was a hot sunny day in the area. The water level suddenly rose to 20-30 m in places. The rise of water level recorded in Yingkiang 12.2 m within an hour. Twenty six people were killed, 2000 missing and fifteen important bridges were washed away during this mega-flood event. Later on, China confirmed that it all happened due to a dam burst. In fact, a 60 m high and 2.5 km wide size dam was formed over the river Tsangpo due to a landslide occurred on 9<sup>th</sup> April 2000. The landslide was described as the biggest one in Asia and the third biggest in the

world. The dam was created within a matter of eight minutes only ([www.dailyexcelsior.com](http://www.dailyexcelsior.com), [www.daily.axom.faithweb.com](http://www.daily.axom.faithweb.com) ). It shows that for two months, the water of Tsangpo was impounded and when the threshold reached the dam burst released exceptional amount of water within no time leading to mega-flood of such high magnitude. Similar mega-flood phenomenon was also recorded in the Indus river during the same time.

Though such events can rarely be seen, it is not unprecedented and did occur several times in the past in the same river. The Brahmaputra river at its full spate hurtles into the plains of Bangladesh, loaded with debris at a rate of around 70000 cumec. Although, it is but a third of the river Amazon, the Brahmaputra has to carry the water through a gorge only a few hundred meters in width. The gorge lies downstream of a west to east stretch with lower gradients, falling around 1 km in 300 km, which suggests some dramatic incision begins at the junction of the two sections. While searching for solutions, the geomorphologists found evidences of lacustrine sediment terraces 200 m and 600 m above the river water level, the origin of which was traced back from two different ages of the Holocene. The event has been discussed elaborately in the section 2.3. The terraces suggest formation of lakes behind two ice dams, breaching of which caused the largest recorded erosive events in recent Earth history, and explains the gorge below allowing these to be called as mega flood events (Montgomery, 2004).

The river Kameng also has histories of such major floods. The discussion in section 4.5 indicates occurrence of huge flood events due to dam break in the Tenga river, a major tributary of the Bichom river that itself a tributary of the Kameng. The Pakke river is a major left bank tributary of the Kameng. Its catchment area falls within the Siwaliks and Lesser Himalaya sheared by many fault zones including the MBT

covered by vegetation and Siwalik deposits. As such, drainage pattern is mainly trellis type along with dendritic type as seen in the region. The geomorphic and geologic conditions of the region itself indicate that it is a potential area of landslide waiting to occur at appropriate time, particularly during seismic activities. Remote sensing data also indicate that the piedmont zone had a rapid rise due to deposition of debris leading to formation of a high alluvial cone. The remote sensing data show traces of major shifting of course of Kameng in the piedmont zone. Remote sensing data also reveal that in the past the Pakke river used to flow independently to discharge into the Brahmaputra. In this way, it has been responsible for alluviation of the Itakhola, Sotea, Majuligarh and Jamuguri region. The present day small misfit rivers like, Dikrai, Bogijuli etc. are remnants of the old Pakke river.

On 5<sup>th</sup> July 2005, a flash flood occurred in the Pakke river causing extensive damage in the area. Huge chunks of boulders, trees and debris brought down by the river from the upstream, choked the barrage located in the foothills, completely changing its course to flow along its old course across the road connecting Seijousa with Tezpur. The flood killed many people and damaged extensively the irrigation project and washed away many of its gates and canals. The cause of the flash flood was attributed to the heavy down pour in the upper catchment. However, satellite data of subsequent dates indicate that probably a dam formation took place due to huge landslide at a location 9.5 km upstream of the barrage, and flash flood can be attributed to the dam burst after reaching the critical point. Similar flood events have also been reported in the river Puthimari, Aie, Manas etc. all of which are north bank tributaries of the Brahmaputra.

The embankments constructed a century back along both the banks in the lower reaches of Kameng (Jia Bhareli) contained flood waters for many years. However, the

embankments reduced the area of the active flood plain, limiting the area of the depositional regime of the river. Thus, it also sped up the process of riverbed sedimentation leading to accelerated rise of the riverbed. Since the embankments weakened in due course of time they started giving up due to the attack by flood waters with full vigour with increased tendency of channel changes from 1996 A.D. Many villages located on its right bank, were consumed by the river during the floods of 2000 to 2005 A.D. Immediately after the flood of 5<sup>th</sup> July 2005, an offshoot was opened on the right bank and activated one old channel to release some of its water to the lower part of the Mara Bhareli through a man-made trench. This event caused fear psychosis among the people that the river is again going to change its course and that may wash away large tract of land including the site of the Tezpur University. Therefore, it became, essential to develop some mechanism through which flood of such nature may be forecasted to build up efficient hazard preparedness programmes for safety of the land and population. Constant monitoring of the sensitive upper catchment area through satellite imagery may also help in clearing of any obstruction, if any, occurred on the river courses.

#### **5.3.4 Development of GIUH**

Though it is important to develop a proper rainfall-runoff relationship, the paucity of rainfall data representing the basin forced to develop alternative relationship. As discussed in the Chapter II, it was clearly understood that development of a Geomorphological Instantaneous Unit Hydrograph (GIUH) is possible which is proved to reflect the response of rainfall on the catchment. Panigrahy (2002) developed a computer model of Geomorphological Instantaneous Unit Hydrograph based on the theory proposed by Rodriguez-Iturbe and Valdes (1979) and its subsequent generalisation by Gupta *et al.*, (1980). This computer model has also been used to develop the GIUH of the

Kameng river basin. The procedure of developing the model have been discussed elaborately in Chapter II for understanding the processes involved to get acceptable output. The procedure for use of the Computer Model is also detailed in the subsequent section, which may also be used for development of unit hydrographs of any other duration.

### **5.3.5. GIUH of Kameng River Basin**

The final GIUH equation consists of a series of exponential functions. However, once the required parameters are estimated, systematic programming can be done to arrive at the final equation. The GIUH computer model developed by Panigrahy (2002) is found to be suitable even for 12<sup>th</sup> order basins. Considering his suggested steps for using the model following sub-sections were used to develop the general form of GIUH model for the Kameng basin.

#### ***Estimation of geomorphological parameters***

The model requires the geomorphological data of the basin for estimating the initial and transitional probabilities. The topographical information of the Kameng River basin was extracted from the Survey of India Toposheets and subsequently upgraded using satellite imagery. The Integrated Land and Water Information System (ILWIS 3.3 Academic), a GIS and Remote Sensing software developed by ITC, Netherlands was used for analysis of the spatial data.

The streams of different orders, areas under streams of different orders, catchment and sub-catchment boundaries have been delineated and digitised. Using Strahler's stream ordering scheme, the stream network was ordered in separate layers as needed.

Separate layers were created for different orders of streams and sub-catchment areas. All streams of the same order for the individual catchments were put into the layer designated for that order. Similarly, all sub-catchments of the same order were put into the layer designated for that sub-catchment. The number and length of streams of different orders, area of the sub-basins of different orders, area draining directly to streams of different orders, and bifurcation, length and area ratios were calculated. These parameters have been used to prepare the input file for the model.

### ***Development of Kameng GIUH model***

The data extracted from the previously mentioned exercise have been put into the GIUH computer model as input to establish the Geomorphological Instantaneous Unit Hydrograph. The requisite coefficients were calculated and the model subsequently uses the established coefficients to estimate the direct runoff hydrograph for different sets of rainfall data.

The input data for the model as derived from topographical analysis are detailed below. The measurements have been taken for the catchment area of the Kameng basin from which it is draining through the GDS site located at NT road crossing. As such, it excludes the lower part along with the Mansari sub-basin.

1. The number and length of streams of different order and area covered by respective streams as derived from the analysis are shown in Table 5.2.
2. Length of the Kameng river from its origin up to the GDS site = 242260 m
3. Average slope of the river = 0.0289689
4. Time of concentration as derived from the model = 17.78 hours

5. Bifurcation ratio,  $R_B = 3.18$   
 6. Length ratio,  $R_L = 2.10$   
 7. Area ratio,  $R_A = 3.86$

**Table 5.2 Stream length and area parameters of Kameng river basin**

Order	No. of Streams	Length of Streams (km)	Area (sq. km)	Average length	Average area
1	32080	23928.67	6665.2261	0.745906	0.207769
2	6819	5382.72	8062.4138	0.789371	1.182345
3	1563	2595.21	8927.0864	1.660403	5.711508
4	355	1400.9	9438.1409	3.946197	26.58631
5	79	747.85	9682.6296	9.466456	122.5649
6	16	463.83	9919.9948	28.98938	619.9997
7	4	95.21	9974.6697	23.8025	2493.667
8	2	135.25	10026.537	67.625	5013.268
9	1	169.73	10193.747	169.73	10193.75

The GIUH thus developed is shown in Fig. 5.3. Using the GIUH, the 1 hour, 2 hour, 3 hour and 4 hour Unit hydrographs for the basin have been developed and shown in Fig. 5.4.

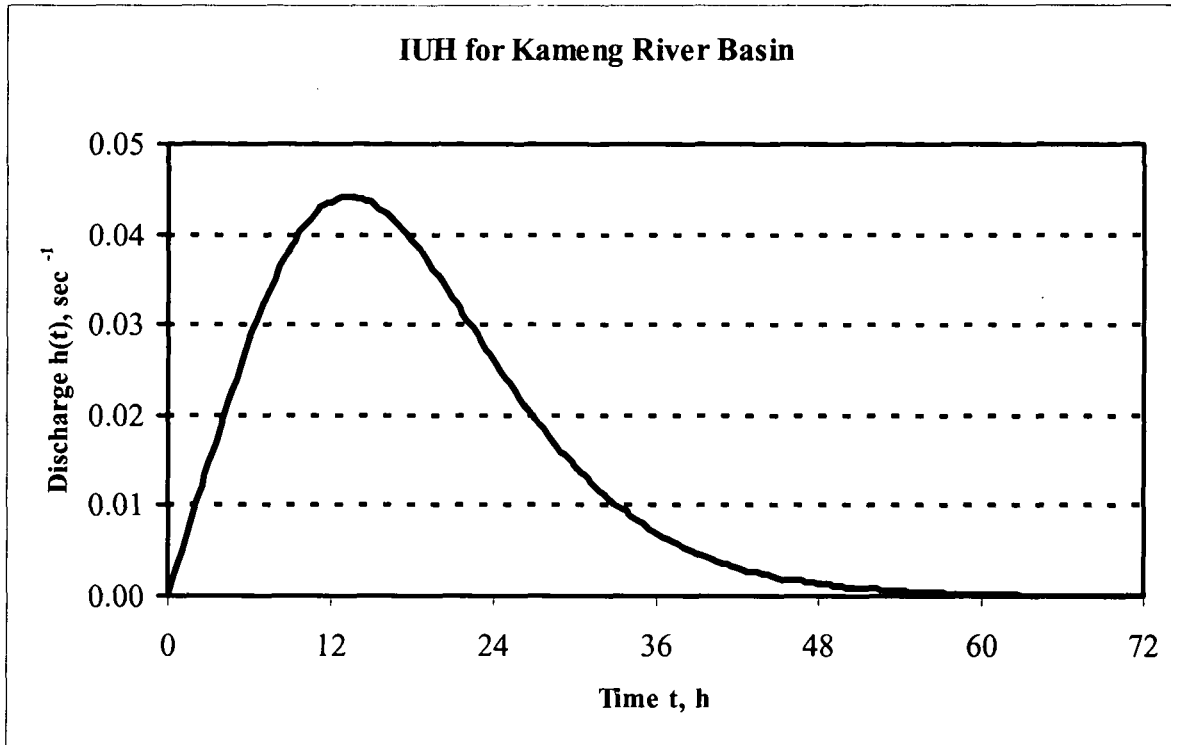


Fig. 5.3 The Geomorphological Instantaneous Unit Hydrograph of the Kameng River Basin

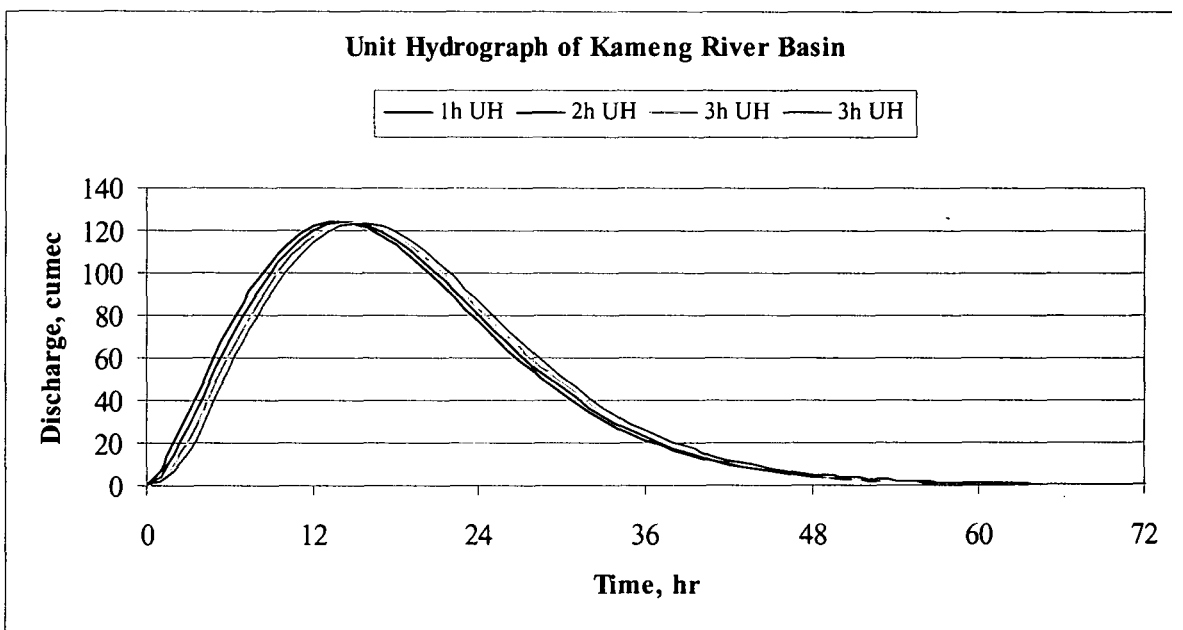


Fig. 5.4 The 1, 2, 3 and 4 hour unit hydrographs of the Kameng River Basin

#### 5.4 SEDIMENT ANALYSIS

Sediment analysis of a river generally is understood as the analysis of sediment in all of its form. Since Kameng river is changing its channels and courses several times as can be traced during the Holocene period, analysis of all of its causes should invariably be studied, particularly in relation to the sediment analysis. It is an established fact that the rivers like Huang Ho, the Kosi etc. had changed their courses because of high sediment load. Though, an in-depth investigation on the fluvial geomorphology of the Kameng was made and explained in the Chapter III, the sediment load of the river should also be verified for any of its possible role in changing the course of the river. The comparison of the sediment load with other such rivers will give a vivid picture of its role played in the Kameng.

Since most of the Kameng river and its tributaries are flowing through the loose and tectonically active Lesser Himalaya and Siwaliks, the river obviously carries high sediment load and debris to the piedmont zone and as well as to the flood plain. But the erosion products are moved down the slope in a discontinuous process and some of it will only move from one location to other depending upon the competence and carrying capacity of the river during high flood. The competence of river also varies from year to year and flood to flood leading to heterogeneous movement of the erosion particles. There is no rational method for quantification of the spatial and temporal movements of erosion products. Only the concentrated storages in lakes and reservoirs are amenable to analysis. The ultimate coastline is along the coastlines in the sea. The assessment of sediment in bed load or the distribution and transport of suspended load is still largely grass work (Raudkivi, 1979).

Movement of bed load sediment is a function of bed shear stress, turbulence intensity, and grain size and grain size distribution. Grain size and its distribution govern the structure of bed surface. The shear stress required to move a specific particle is also a function of its piling position and location. A physically based relationship for this process would have to account for the amount of sediment in motion, local grain size and grain size distribution, turbulence characteristics of flow, i.e., the size of the systems, and stress field at the bed in terms of bulk flow parameters. The sediment forms into transverse ridges, ripples and dunes. The entrainment and ordering of particles is dominated by the flow structure and by the stress field at the bed. An enormous amount of research effort is required to establish the physical links for entrainment between fluid flow and bed composed of a mixture of grain sizes (Raudkivi, 1979).

Spreading of suspended matter may rise from (i) scattering due to random molecular (Brownian) motion of fluid, (ii) gradient diffusion of turbulence or velocity or (iii) convection by currents in the cross section. Brownian motion is in significance only with colloidal particle sizes. The descriptions of suspension are almost entirely in terms of gradient diffusion of turbulence. Little progress has been made with quantitative studies of such diffusion. Numerical models were developed for solving a variety of sediment flow condition using the existing nascent development of underlying sediment flow physics that may result in arbitrary outputs in absence of lack of measured data (Raudkivi, 1979).

The development of research in sediment analysis so far indicates requirement of long term data to develop some statistical relationship. The empirical relationships of discharge versus sediment flow are also in a nascent stage. As such, an attempt was made

in this study to throw light on the sediment carrying status of the Kameng for a short period of 17 months.

The maximum observed sediment load carried by the river during the study period was 91,019.38 tonnes per day against a discharge of 2,765 cumec only on 20<sup>th</sup> July 2005. The maximum discharge observed for the Kameng during study period was 4,863 cumec on 26<sup>th</sup> September 2005, with sediment load of 41,176 tonnes/ day. The total sediment load of the year 2005 was observed as 23,59,004 tonnes against total runoff of 2.505 million Ha-m. The observed discharge versus the sediment load of different sizes has been shown in Figure 5.5 for the year 2005. A comparison of the yield of runoff and sediment load of the river Kameng with some rivers of the world are shown in Table 5.3. The analysis indicates that the sediment carried by the Kameng river does not increase with the increase in discharge. It supports the statement of Butzer (1976) that sudden, strong and deep flow during floods bring more changes in shorter time rather than a normal flow of longer time and each flood contributes to the alluviation in the area. The comparison of the yield of runoff and sediment load of the river Kameng with some rivers of the world in Table 5.3 reveals that present routine sediment load of the Kameng river is much less than the other major rivers of the world which are known for changing their courses due to high sediment load.

**Table 5.3 Comparison of sediment load of the Kameng river with some rivers  
of the world**

Sl. No	Item	Kameng at NT-Rd crossing (as on 2005)	Kosi at Barakshe-tra	Mahanadi at Hirakud	Sutlej at Bhakra Dam	Colorado at Hoover Dam	Nile at Aswan Dam
1	2	3	4	5	6	7	8
1	Catchment area, km <sup>2</sup>	10,194	59,052	83,398	56,876	432,528	1,605,793
2	Average annual rainfall, cms	183 (at Tezpur)	152	167	114	25	---
3	Average annual runoff, million Ha-m	2.505	5.278	4.258	1.976	1.853	8.153
4	Average annual silt load, Ha-m	131.0558	11858	3161	2421	16923	6531
5	Average annual sediment yield, Ha-m/ 100km <sup>2</sup>	1.2856	20.08	4.245	4.292	3.911	0.405
6	Average annual silt concentration as % of Run-off	0.0052	0.22	0.083	0.122	0.91	0.08

Source: Compiled from different sources.

OBSERVED SEDIMENT AND DISCHARGE AGAINST DAYS OF THE YEAR, 2005

Coarse Sediment Medium Sediment Fine Sediment Total Sediment Discharge

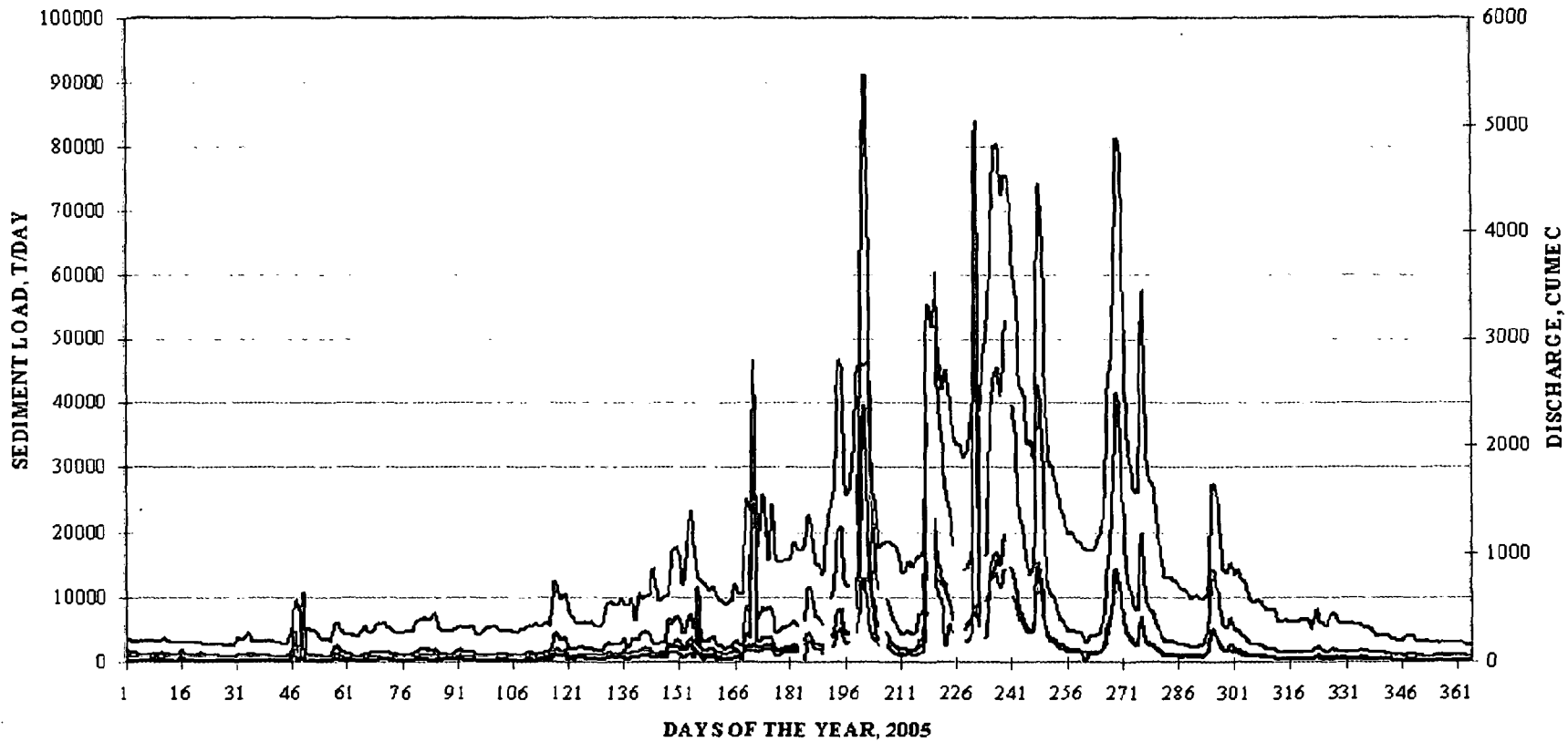


Fig. 5.5 Discharge and Sediment Load of Different sizes of Kameng River

## 5. 5 FLOODS AND SEDIMENT LOAD

The correlation coefficient determined for the Stage and Discharge data of the Kameng river for the years 1997, 1998, 1999, 2000, 2001 and 2005 shows large deviation from unity except for the years 1997 and 1998. This indicates the present gauge site is not fulfilling entirely the suggested conditions for development of such relationships. As the Kameng is a braided river right from the piedmont zone up to the confluence with the Brahmaputra, it is essential to measure the discharge directly at any location in between.

The highest discharge recorded during the study period was 4,863 cumec on 26<sup>th</sup> September 2005. It was followed by 4,818 cumec, 4,816 cumec and 4,803 cumec on 27<sup>th</sup> September 2005, 24<sup>th</sup> August 2005 and 25<sup>th</sup> August 2005, respectively. The GSI has recorded highest flood of 5,548 cumec in 1969. It means that the recorded highest are lower than the figure of the 1969 indicating a decline in the peak discharge over the years.

The poor correlation of stage and discharge necessitates development of an alternative technique to calculate design discharge from rainfall data for possible structural measures. As such, a computer model of *Geomorphological Instantaneous Unit Hydrograph* has been developed for the basin using the geomorphic parameters extracted from the data on the entire Kameng Basin. The 1-hr, 2-hr, 3-hr and 4-hr unit hydrographs were also developed from the same model. Incorporating the rainfall data of the basin, the developed unit hydrographs may be used for computing peak discharge of the river to be used for design of hydraulic structures over the Kameng river.

## **5.6 ROLE OF DISCHARGE AND SEDIMENT ON CHANGING COURSE OF KAMENG RIVER**

Though role of discharge and sediment on changing course of the Kameng river can not be attempted in reality, for data for the discharge and sediment are not available for the entire period for which shifting of course of Kameng has been traced. This is simply due to incompatibility of two sets of data in terms of time. Moreover, no major shift in the course has taken place during the period for which discharge and sediment data are available. Even then, some points can be discussed in this regard.

The discharge and sediment analysis of the Kameng river reveals that the normal annual discharge and sediment load of the river has contribution in shifting of its active channel through routine aggradation and degradation and helping in overall alluviation of the active flood plain confined to the present Kuruwani surface. For example, it happened recently in 2005 when a channel was formed on the right bank of the Kameng river in the wake of a flash flood. The geometry of the riverbed is not sufficient in containing the peak flow water levels leading to spill over causing flood.

Thus, it substantiates the findings of the previous Chapter that the changes of the landforms over upper catchment due to tectonic and geomorphological reasons have been playing dominant role in shifting courses of the river. The occurrence of landslide in the Himalaya Mountain throughout the Holocene caused damming of its rivers several times. The Kameng river experienced unusually high devastating extreme flood due to subsequent breach of the Dam formation. The floodwater also carried the debris deposited on its bed subsequently to the piedmont zone in phases with unusually high sediment concentration, which was deposited on the plains. Occurrence of such high

magnitude flood in its tributary Pakke on 5<sup>th</sup> July 2005 also indicates that certain upper catchment areas are susceptible to major landslides and they are lying still in dormant stage. Some of the landslides occurring in remote areas may also remain unnoticed but they may lead to high sediment production in the parent river at times.

Erosion of the Balipara Boulder-Gravel Ridge and part of the piedmont sediment is continuing due to high slope and unconsolidated material, and as such, possibilities of sudden spurt of increase in sediment load in the river may not entirely be ruled out. The increase of human interference in the vulnerable upper catchment also triggers minor and major landslides, which may increase sediment load and thus leading to deposition of huge sediment over the flood plain of the lower Kameng river basin. Since the lower Kameng basin is in depositional state increase in riverbed level may also be expected leading to frequent changes in its channels. However, the present study on the changes of the river course of Kameng invariably confirms that the river has stabilised at the centre of the graben and changes of the active channel may occur only within its recent flood plain, i.e., the Kuruwani surface. Moreover, almost continuous levee on the right bank also restricts the river to its existing course.

**CHAPTER VI**  
**SUMMARY AND CONCLUSION**

## CHAPTER VI

### SUMMARY AND CONCLUSION

#### 6.1 GENERAL

Present Ph.D. Dissertation entitled 'Changing Course of Kameng River in the Lower Reaches' pertains to changes in the course of the Kameng river during the late Quaternary period; pattern of the changes; the geomorphologic, tectonic, climatic and hydrologic causes responsible for the changes; and analysis of the discharge, floods and sediment load in the river. This study clearly reveals that the Kameng river has definitely changed its course six times on its alluvial plain during the Late Pleistocene and Holocene epochs. The shifting of the course could be observed from the piedmont zone near Bhalukpong to its confluence with the Brahmaputra. In fact, shifting of courses of the Kameng river and its tributaries is the absolute cause of the alluviation process responsible for the formation of the plains in the study area. The sediments comprise of both younger and older alluvium. Rangapara Surface of the right bank in the west is considered as the oldest alluvium of the study area, which now exists as uplifted terrace.

Formation of the fluvial landforms in the Lower Kameng river basin, observed as interesting landscape on the remote sensing data, has been attributed to the changes in the course of the river and its discharge and sediment load during the short geological history. In fact, changes in the course of the Kameng river and occurrence of floods in its valley have very distinct impact on the landforms of the lower basin. Of course, the tectonic movements have left their indelible mark on these landforms, e.g. the raised older alluvial terrace and the boulder-gravel ridge, and formation of graben and faults.

The Kameng river basin as a whole extends from the Himalaya Mountain to the flood plains of the Brahmaputra river. Most of the upper catchment lies in the Lesser Himalaya and the Siwaliks which are tectonically active and comprise mostly of the geologically weak rocks and fragile soils. In the upper catchment have occurred huge landslides several times during the Holocene, which produced heavy sediment load in the rivers of the Kameng drainage system to be carried down towards the lower reaches and were deposited especially in the piedmont zone and that triggered many of the changes in the course of the river. Most of these dynamic fluvial processes and landforms pose threat to man and his property. As a result, changing course and floods of the river have attracted attention of the scientists. The availability of remotely sensed data from 1989 onwards has facilitated study on the Kameng river dynamics, including its migrating courses and floods. The vast plains of the basin owe their origin to sediment filling done by the shifting courses of Kameng river and its flood. Therefore, as such the study is fundamental in nature explaining the dynamic fluvial processes operating in the Kameng river basin. On the other hand, the study is of applied nature as well since it deals with how the in-depth understanding of the fluvial processes (changing course, floods, discharge, sediment load etc) can help in mitigating the hazards related with these processes. Not only the study has helped in understanding the origin and development of different landforms, especially of fluvial and tectonic origin, but also how to deal with the hazardous events of changes in the course and floods of the Kameng river and its tributaries that affect man and his development. The results of the present study are surely going to form an integral part of the planning and development of the study area, particularly the hydraulic structures and location of human settlements. Thus, it can easily be said that basically the study is fundamental in nature but it has applied implications as well.

## 6. 2 SUMMARY

Entire study has been organised into six chapters. The introduction to the Ph.D. dissertation is presented in the First Chapter in which objectives of the study, research questions, study area, database and methodology have been discussed. In the Second Chapter, relevant literature has been reviewed for getting an insight into different theoretical aspects of the research problem and present examples of changing courses of rivers and floods in different rivers of the world and Indian Peninsula. The causes, importance, and inferences of shifting course of the rivers have also been discussed in this Chapter that are supported by evidences found by different scientists.

Various aspects of the Kameng river basin have been described in the Third Chapter. As the development over the upper catchment is responsible for the changing course of a river in the lower reaches, the entire drainage basin has been taken as a single unit for discussion. It includes description about the origin of the Kameng river, its size, shape and morphometric characteristics. Then details of the Lower Kameng River Basin have been given to highlight the geomorphological personality of the study area that has predominantly been sculpted by the changing courses of the river.

The Fourth Chapter is the core of the present dissertation. As a background to this chapter, shifting courses of the Himalayan rivers have been discussed with suitable examples. The reasons behind such shifting of courses have been minutely seen to draw references for the shifting courses of the Kameng river. Alluviation history of the Brahmaputra valley including the lower Kameng basin has also been given. The seven prior courses of the Kameng river were identified and traced from the satellite imagery and verified through the extensive field checks in the study area. For this purpose

toposheets and published literature were also consulted. In tracing the changing courses of the Kameng river maps and toposheets of 1892 onwards were of significant help. Whereas, satellite imagery used for this work belonged to period from 1989 to 2004. The migrating river courses were arranged in chronological order based on their trend of change. That helped in finding out pattern of changes in the course. Causes responsible for the changes were investigated and explained accordingly. On the basis of pattern of changing courses the likely changes in future have been prognosticated. The geomorphic, hydrologic, climatic and tectonic causes responsible for shifting of the course have been explained in the light of various geomorphic, geologic and hydrologic evidences.

Data on the discharge and sediment load of the Kameng river, as measured at GDS sites and also collected from the secondary sources, were analysed and discussed elaborately in the Fifth Chapter. Rainfall-runoff relationship was developed using computer based statistical method. It has also been tried to develop possible relationship of rainfall-runoff with the river dynamics- changing course and floods. Since the discharge and sediment data were collected for a short period it can not be used for flood forecast for want of further information. To fill the gap a Geomorphological Instantaneous Unit Hydrograph (GIUH) was developed, which is also useful for hydraulic design. The rainfall corresponding to the magnitude of the past floods may also be appreciated using this model.

The Sixth Chapter includes summary, major findings and conclusions of the Ph.D. research. Difficulties faced in carrying out the present study and clues for further research on the related topics have also been mentioned in this chapter.

The Kameng river is one of the many river systems which originate from the snow fields of the Greater Himalaya Mountain Range. The Kameng is one of the major right bank tributaries of the mighty river Brahmaputra. The total area of the Kameng river basin is 10,853 sq km extending between longitudes  $91^{\circ}58'$  and  $93^{\circ}23'$  east, and latitudes  $26^{\circ}36'$  and  $27^{\circ}59'$  north. Altitudinally the Kameng river basin extends from the highest Kangto peak with altitude 7090 m to its confluence with the Brahmaputra river at about 60 m. The alluvial regime of the basin comprises of older alluvium to recent alluvium with distinct features having imprint of the fluvial processes operated during the Pleistocene and Holocene epochs of the Quaternary. The Bichom river is the largest tributary having confluence with the Kameng river in the mountainous regime, while the Mansari and Pakke are the main tributaries having confluence within the alluvial regime.

The morphometric analysis of the tributaries of Kameng river and its major tributaries shows that most of the morphometric parameters of the tributaries have values close to the parent river Kameng. The bifurcation ratio of the other tributaries ranges around 5 as is the case for the Kameng river where it is 4.70. The sluggish tributary Mansiri is flowing through almost a flat topography having confluence with the Kameng within the study area, due to which the morphometric parameters like bifurcation ratio, drainage density, stream frequency and texture ratio are found to be lowest as 3.97, 0.017 km/ha, 0.012 no./ ha and 0.003no./m. The rest of the tributaries, which are flowing through mountainous reach for a comparatively long distances, are having these values within a narrow range as 4.21 – 5.41, 0.023 – 0.057 km/ ha, 0.029 – 0.057 no./ ha and 0.006 – 0.034 no./m, which derive the values close to the parent river Kameng as 4.70, 0.032 km/ha, 0.038 no./ ha and 0.052no./m. However, the analysis of the shape factors indicates extreme values for the tributaries like the Pakke, Tenga and Mansari. The form

factor, circularity ratio and elongation ratio of these tributaries respectively are as low as 0.200, 0.199, and 0.186; 0.267, 0.278 and 0.387; and 0.504, 0.503 and 0.487 indicating that these basins are elongated in shape. The values of rest of the tributaries are found to vary within 0.239 – 0.576, 0.361 – 0.618 and 0.552 – 0.857 and may be compared with the values of the Kameng river as 0.466, 0.361 and 0.770. This analysis as such has thrown light on the topography of the basins of the tributaries based on which inferences have also been drawn for the exploration of possible causes responsible for changing course of the Kameng river in its lower reaches.

Presence of the Main Central Thrust, Main Boundary Thrust and Main Frontal Thrust in the Kameng river basin depicts the entire process of orogen of the Himalaya Mountain. The alluvial regime of the Kameng basin has been formed through intensive work of the river and its tributaries like Bichom, Tenga, Pakke (Bardikrai), Mansari etc. The neotectonic activity has also guided the work of the river. The landforms within the alluvial regime have been divided into major geomorphic units of Alluvial Fan, Older Alluvium Surface, Seijosa Surface, Itakhola Surface, Solabari Surface and Recent Alluvium in the flood plains with existence of small hillocks/inselbergs of the Indian Peninsular shield on its southern periphery, particularly near Tezpur. The Kameng river is flowing through a graben having eastern margin along the fault scarp of the western margin of Biswanath Chariali and western margin along the eastern scarp face of the Rangapara Surface. Existence of the two older alluvial terraces in the form of Rangapara Surface and Solabari Surface is indication of two periods of rejuvenation in the study area for which formation of graben by upheaval of two older alluvium blocks (the Rangapara in the west and Itakhola in the east) and lowering of the local base level due to southward shift of the course of the Brahmaputra river are responsible.

The Kameng river changed its course several times during the Quaternary period specifically during the late Pleistocene and Holocene epochs. The neotectonics, especially the Pleistocene and Holocene (Quaternary) crustal rising, as well as the intense erosional and depositional fluvial processes are responsible for the development of landforms of the Kameng river basin. The study area comprises of several faults. One such fault zone has been traced right from south of Jorhat through Helem extending to Rangapara and further continuing to the foothills of the Himalaya Mountain. Further, the Tenga and Bichom rivers are also flowing parallel to the Bomdila Fault for a long distance before joining together to discharge in to the Kameng river in its mountainous regime.

Six prior courses of the Kameng river in its lower reaches could be identified, beginning from the late Pleistocene. The oldest course among them has been traced from Bhalukpong that ran straight towards south through Rangapara to meet the Brahmaputra river about 10 km west of Tezpur town. Formation of the older alluvium, known as the Rangapara Surface is attributed to work of this course. Interesting neotectonic activity followed subsequent to that period setting very good examples of geomorphologic and geologic factors together leading to shifting of river courses in the Brahmaputra valley, including that of the Kameng river. These developments led to the further rise of the Siwaliks, formation of the Helem–Rangapara-Bhalukpong fault, formation of the Older Alluvium of Rangapara and Itakhola and its uplift due to upheaval of western and eastern flanks of the graben, Balipara Boulder-Gravel Ridge etc. Further, the weak zones of Greater and Lesser Himalaya, specifically along the fault zones, also experienced huge landslides causing subsequent dam formation on the tributaries leading to mega floods and mudflow conditions downstream. Repeated occurrence of such events during the

Holocene period exerted lot of pressure on the lower reaches of the Kameng river and these are responsible for the formation of the present landscape of the basin, particularly the Boulder-Gravel Ridge and shifting courses of the Kameng river.

Buckling down to the changes in the fluvial geomorphologic and tectonic environment of the basin, the Kameng river recorded first change in its course to take a eastward shift from a point 6 km downstream of Bhalukpong to flow in a course now occupied as a misfit stream by the present day Mansari up to Charduar then in southward direction parallel to the scarp face of the Rangapara surface to meet the Brahmaputra at a location 5 km east of the oldest course. However, the river shifted its course for the second time from Bhalukpong itself for a short distance of 5 km through Balipara Reserved Forest up to Charduar and then continued to flow downstream in the second course to reach the Brahmaputra river. The continued changes in the fluvial condition of the basin prompted the river to shift for the third time and the course followed the northern curvature of the Balipara Boulder-Gravel Ridge to come out on its eastern margin. Then this course ran straight southwards almost parallel to its previous course to meet the Brahmaputra further eastwards, i.e., now through the Tezpur town. The fourth change of the course could be traced for a short distance in the piedmont zone below which the surficial evidence of the course have almost been erased by the subsequent courses. The fifth shift is the most prominent one that begun from Bhalukpong almost along the present course up to Baithabhanga from where it took a circuitous route, known as the Mara Bhareli, to have confluence with the Brahmaputra, now east of Tezpur town. The alignment of the course of the Kameng almost in the centre of the graben was gradual, not sudden. It was the next shift and establishment of the new course that occupied more or less centre of the graben.

Interpretation of the toposheets available from the year 1913 and the satellite imageries from 1989 onwards has revealed perceptible evidences of the changes in the course of the Kameng river. The river recorded its earliest known easternmost shift during 1824 - 1913 to meet the Brahmaputra now at a location 12.5 km east of Tezpur town. This was the sixth change in the course of the river. Whereas there occurred subsequent changes but in its channels only, i.e., within its recent flood plains, unlike the previous ones where the entire route of the river got changed. During the period from 1913 to 2004, the river course oscillated from left to right of the existing course indicating formation of a straight but braided course. This shifting of river channel is recorded specifically from below the piedmont zone right up to its confluence with the Brahmaputra. During this process many villages came up and many were erased from the map because of the erosion and deposition in the active flood plain of the river. The tributaries like Mansari, Pakke (Bardikrai), Nameri etc. in the study area were having their respective confluences at different locations with changing course of the Kameng river, and thus changes have occurred in their own courses as well which are not described in much detail here as focus is on the Kameng river itself. But they did contribute along with the Kameng to the fluvial processes, particularly to the alluviation process in the study area.

All the changes in the course and channel of the Kameng have occurred under the influence of geomorphic, geologic and some extent climatic factors, however, there are instances in recent years where channels migration has taken place due to human interference in the flood plain. For example, to provide a link between Tezpur and the right bank of the Kameng river (Jia Bhareli) a road was constructed for which a trench was dug to collect earth. This trench started carrying rainwater from its own catchment

and got enlarged in due course of time. But it so happened that the trench started carrying the floodwaters of the Kameng river from 2003. In the following year, i.e., 2004, an offshoot of the Kameng river joined this trench to enlarge so much so that it has now connected the Kameng river with its old meandering course, known as the Mara Bhareli. At present, the trench carries substantial quantity of water contributed by the parent river- the Jia Bhareli.

The natural fluvial processes associated with the river water are responsible for bringing changes in the landforms of the valley. As such, river hydrology plays a pivotal role in carrying out the changes in the river courses and in the fluvial landforms as well. In this way, geomorphology and hydrology are mingled in studying the fluvial processes and landforms in a river valley. Therefore, Gauge, Discharge and Sediment monitoring station was established over the Kameng river to collect the corresponding data with the intention of doing analysis of fluvial processes, for which secondary data was also collected from different sources. The highest discharge recorded during the study period was 4863 cumec on 26<sup>th</sup> September 2005 followed by 4818 cumec, 4816 cumec and 4803 cumec on 27<sup>th</sup> September 2005, 24<sup>th</sup> August 2005 and 25<sup>th</sup> August 2005, respectively.

Gauge and discharge relationships were also drawn using suitable method for several years independently for monsoon and non-monsoon seasons with the help of both primary and secondary data. The correlation drawn show that stage and discharge does not have suitable relationship indicating that the GDS site is not fulfilling the standard requirements. It is also obvious because the present course of the Kameng river is braided one right from the piedmont zone up to its confluence with the Brahmaputra and does not have any straight single channel in between. This necessitates direct measurement of

Discharge everyday using any of the standard methods. Such situation necessitated derivation of an alternative method to determine design peak discharge as a response of the catchment to precipitation for the purpose of construction of hydraulic structures.

Since the Kameng river basin doesn't have suitable distribution of rain gauges the Geomorphological Instantaneous Unit Hydrograph (GIUH) serves reasonably well in such basins for determining peak discharge. As the geomorphologic parameters play an important role in determining discharge from a river basin they used in development of GIUH. Accordingly, a GIUH of the Kameng river has been developed using a computer based GIS model.

The intensity of the floods in the Kameng river have been found to be within moderate range during the study period. It is believed that shifting of river courses usually occurs during the extreme high flood events. Incidences of high flood events have been recorded in the Pakke river during the recent past. On 5<sup>th</sup> July 2005, a flash flood occurred in the Pakke river and brought down huge chunks of boulders, trees and debris from the upstream that choked the river course and forced the river to completely change its course in the piedmont zone and start flowing along one of its abandoned courses. Occurrence of such high magnitude flood may trigger huge landslides in the mountainous regime of a river basin to generate unusually high sediment load in the rivers, and that causes prominent changes in the fluvial processes and landforms down the stream, particularly in the piedmont zone where usually lies the triggering point of shift in the course of the river. The analysis of the normal sediment load collected through the GDS site for the study period reveals that the maximum observed sediment load carried by the river was 91,019.38 tonnes per day against a discharge of 2,765 cumec only on 20<sup>th</sup> July

2005. Whereas, the maximum discharge in the Kameng river was 4,863 cumec on 26<sup>th</sup> September 2005, with sediment load of 41,176 tonnes/ day. The total sediment load of the year 2005 was observed as 23,59,004 tonnes against total runoff of 2.505 million Ha-m. The comparison of the yield of runoff and sediment load of the river Kameng with some rivers of the world reveals that present sediment load of the Kameng river is much less than the other major rivers of the world. As such a direct relationship between the discharge (along with sediment load) and changing course could not be established. Moreover, whatever prior courses of the Kameng river have been identified they belong to earlier times for which discharge data is not available. On the other hand, no prominent shift has taken place in the course of the Kameng river during the period of data collection on the discharge and sediment load.

### 6.3 MAJOR FINDINGS

The Ph.D. research has been conducted with an aim to identify the changes in the course of the Kameng river and find out causes of changes. To strengthen understanding of the fluvial processes, especially those related with the changing course of river, the discharge, floods, and sediment load have also been analysed. Major findings have been derived from the present research on changing course of the Kameng river in its lower reaches, which are as follows:

#### 6.3.1 Changing Course

- (1) Altogether **seven** prior courses of the Kameng river in its lower reaches have been identified, clearly showing changes in the course of the river in its alluvial regime from the piedmont zone to the confluence with the Brahmaputra river- the local base level of the river Kameng.

- (2) The **oldest course** of the Kameng river has been traced from Bhalukpong that ran straight towards south through the Rangapara and met the Brahmaputra river about 10 km west of Tezpur town. The remnants of the oldest course can clearly be seen on the raised Rangapara Surface (old alluvial terrace) which is now occupied by the Diputanala as a misfit stream.
- (3) The **first change** in the course came in the form of an eastward diversion near Diputa Forest in the northwest corner of the study area. First it flowed southeastward up to Charduar (now the Mansari flows in this course as a misfit river) then ran almost parallel to the oldest course but in the downstream swung towards east to meet the Brahmaputra river 5 km east of the oldest course, but still west of Tezpur town. From Charduar to the confluence with the Brahmaputra, this course existed on the eastern margin of the raised Rangapara Surface (the margin itself is the western boundary of the graben). However, a branch from this course diverted towards west from Goraimari and joined the oldest course.
- (4) The **second shift** in the course of the Kameng river took place right at Bhalukpong from where the river flowed almost eastwards for a short distance then turned southeastwards to reach Charduar and from there it followed the second course in the downstream.
- (5) During the existence of these three courses of the Kameng river, the Balipara Boulder-Gravel Ridge (terrace or alluvial fan) was not at its present height and orientation or it did not exist. In later times, sediment, including the boulders, gravels sand etc., was deposited and the Ridge was formed probably due to tectonic uplift. Subsequently, the Ridge actually obstructed earlier courses and controlled the flow and direction of the subsequent courses of the Kameng river. However, the courses of the Kameng and the secondary rivers have eroded the Ridge.

- (6) The **third change** in the course of the Kameng river took place from a point southeast of Bhalukpong and the river followed the northern curvature of the Balipara Boulder-Gravel Ridge (evident from terrace number one on the northern slopes) to come out on the eastern margin of the ridge. Then this course ran straight southwards via present Sengelimari Reserved Forest and Lokra aligning almost parallel to the second and third courses to meet the Brahmaputra further eastwards, i.e., through the Tezpur town now. Of course, it had a few branching before meeting the Brahmaputra river.
- (7) The point of change in the course of the Kameng then shifted on the eastern margin of the Balipara Boulder-Gravel Ridge and the **fourth time changed** course passed through the present Natun Darikati and Darikati settlements. From Darikati to Brahmaputra the clear surficial evidence of this course have almost been erased by the fluvial processes of the Kameng river in later times. As it is evident from the highly complex traces of meanders in the courses of the Kameng the tract lying between the fourth and the present course of the Kameng alias Jia Bhareli.
- (8) The point of the next and **fifth shift** of the Kameng river was again Bhalukpong from where the course ran eastwards almost along the present course and parallel to the fourth course (but little northward) up to Baithabhanga from where it was a circuitous route full of meanders up to the Brahmaputra river. Interestingly, from Baithabhanga downwards the course is known as the Mara Bhareli (Dead Bhareli).
- (9) Historical records indicate that a meandering course of the Bhareli existed in the year 1616 A.D. when its confluence with the Brahmaputra was near Bhairabi temple of Tezpur. GSI indicated that the river changed its meandering course to a braided course before 1824, and a map by SOI in 1892 also does not show this meandering course. It means that it was abandoned by the river, hence known as Mara Bhareli.

- (10) The river recorded its earliest known easternmost shift during 1824 and 1913 as evident from the SOI toposheet of 1934 (surveyed in 1913) to meet the Brahmaputra now at a location 12.5 km in the east of Tezpur town. This was the **sixth change** in the course of the river. The existence of curved *beels* (ox bow lakes) on both banks in the toposheet indicates that the river had two more swings engulfing the right bank area up to Bhomoraguri hills and that rendered Chowkighat and other nearby villages below water. Interestingly, there was no existence of the villages known as Gataimari and Laltepu in the year 1913.
- (11) Establishment of the seventh course was the beginning of the alignment of the river in the centre of the graben and thus the course got stabilised. This clearly shows that after the formation of the graben the Kameng river gradually shifted towards the centre of it, instead of a sudden drastic change in its course in the wake of a tectonic activity which is otherwise is not possible on the surface/landscape as the river faces resistance from its own older alluvial material and landforms which are subjected to erosion in the event of migration of its courses.
- (12) The Kameng river slightly shifted towards west during 1913 and 1964 converting some of the river bed areas into its flood plain where villages like Gataimari and Laltepu had come up on the then right bank and left bank, respectively. On the right bank the river shifted westward near Badejan, while eastward shift on the left bank near Kuruwani engulfed Chowkighat village and as a result the confluence with the Brahmaputra shifted 3.5 km west of the eastern most confluence. These shifts can merely be stated as changes of active channels within its active flood plain as a natural behaviour of river in its lower reaches, particularly because of its braiding nature.

- (13) However, the river took more or less straight course in 1988 as evident from LANDSAT satellite data. The portion of the river upstream of the Railway Bridge straightened in comparison to its earlier western course. The river downstream of the bridge partially engulfed Gataimari village on the right bank, while Chowkighat village resurfaced on the left bank.
- (14) It has been revealed from the satellite data of the years 1990, 1996, 1998 and 2000 that the river continued its westward shift slowly engulfing entire Gataimari village and most part of the Bihiagaon area to have a confluence with the Brahmaputra now at the base of the Bhomoraguri hills. The floodwaters as over bank flow entered a man-made trench and joined the lower part of the Mara Bhareli. Oral tradition of the old people of Panchmile area reveals that the trench was dug during the nineteenth century for collection of earth to construct a road from Tezpur to the bank of the Kameng near Bihiagaon to develop communication link from Tezpur to the river bank and Chowkighat on the left bank of the river.
- (15) The river did not show any significant shift in subsequent period. However, an offshoot of the river on its right bank got activated and started flowing towards the old easternmost course.
- (16) It can be easily imagined and inferred that the various tributaries in the study area were meeting the changing courses of the Kameng river accordingly at different places in the study area and together all have contributed to alleviation of the valley.

### **6.3.2 Discharge, Floods and Sediment Load**

- (16) The correlation coefficient determined for the Stage and Discharge data of the Kameng river for the years 1997, 1998, 1999, 2000, 2001 and 2005 shows large deviation from unity except for the years 1997 and 1998. This indicates the present gauge site is not fulfilling entirely the suggested conditions for development of such

relationships. As the Kameng is a braided river right from the piedmont zone to the confluence with the Brahmaputra, it is essential to measure the discharge directly at any location in between.

- (17) The highest discharge recorded during the study period was 4,863 cumec on 26<sup>th</sup> September 2005. It was followed by 4,818 cumec, 4,816 cumec and 4,803 cumec on 27<sup>th</sup> September 2005, 24<sup>th</sup> August 2005 and 25<sup>th</sup> August 2005, respectively. The GSI has recorded highest flood of 5,548 cumec in 1969. It means that the recorded highest are lower than the figure of the 1969 indicating a decline in the peak discharge over the years.
- (18) The poor correlation of stage and discharge necessitates development of an alternative technique to calculate design discharge from rainfall data for possible structural measures. As such, a computer model of *Geomorphological Instantaneous Unit Hydrograph* has been developed for the basin using the geomorphic parameters extracted from the data on the entire Kameng Basin. The 1-hr, 2-hr, 3-hr and 4-hr unit hydrographs were also developed from the same model.
- (19) The maximum observed sediment load carried by the river during the study period from December 2004 to May 2006 was 91,019 tonnes per day against a discharge of 2,765 cumec only on 20<sup>th</sup> July 2005. Whereas, the observed sediment load on the day of maximum discharge of 4863 cumec was 41,176 tonnes per day on 26<sup>th</sup> September 2005. The total sediment load of the year 2005 was observed as 23,59,004 tonnes against total runoff of 2.505 million Ha-m.
- (20) The comparison of the yield of runoff and sediment load of the river Kameng with some rivers of the world reveals that present sediment load of the Kameng river is much less than the other major rivers of the world which are known for changing their courses due to high sediment load.

### 6.3.3 Pattern of the Changing Courses

- (21) A definite pattern of the changing course of the Kameng is easily discernible by looking at the trend of the shifting of the course.
- (22) The pattern of changing course of the Kameng river has definitely been from west to east. The distance between the confluence of the oldest and western most course with the Brahmaputra and confluence of the easternmost course is 22.5 km, and that indicates the total span of shift or zone of changing courses.
- (23) Though after reaching to the easternmost limit of shift the course of the Kameng has again moved westward by a few km, there is no evidence that the pattern of shifting courses has reversed. It means that the course has now got stabilised in the centre of the graben through which the Kameng river is flowing now.
- (24) However, a few westward movements in the active channel of the river should not be considered as precursor to westward change of the course of Kameng. This is because such channel migrations are within the active flood plain of the Kameng river. The immediate higher terrace and existence of levee also restrict westward movement of the course. Moreover, the course of Kameng has aligned in the centre of the graben after filling it to a levelled flood plain.

### 6.3.4 Causes

- (25) The major cause behind the changing course of the Kameng river is tectonic in which lineaments (faults etc.) and uplift of the older alluvium and formation of gravel ridge are important. A few significant observations indicate that the study area is tectonically active. Apart from it geomorphic and partially climatic factors have also caused changes in the course of Kameng river.

- (26) Uplift of a ridge of the Siwaliks along a north-south fault located in the northwest corner of the study area, during early Holocene period, changed the general slope at that place forcing the Kameng river to abandon its oldest course (via Rangapara) and flow towards east leading to the **first change** of its course.
- (27) The contemporary formation of a graben also guided the river course from Charduar, as a result it took a southerly course and the river flowed along the westernmost edge of the graben. This course also eroded the Rangapara surface, hence it appears that the second course lies on the eastern edge of it.
- (28) Occurrence of a huge landslide in the Rupa valley during the early Holocene period substantially increased sediment load in the river, the debris of which was deposited over the alluvial fan surface. This was the beginning of the formation of the Balipara Boulder-Gravel Ridge, which blocked the second course of the river.
- (29) The existence of a north-south trending ridge of the Siwaliks along the fault also forced the river to take an easterly route leading to the **second shift** of the river and establishment of its third course.
- (30) There might have occurred several landslides subsequently nearby to the site of the first occurrence due to tectonic and other reasons like debuttrressing of the surface after receding of the snowline in post glacial period, one or two of which can be clearly identified from the satellite imagery provided by the Google Earth.
- (31) The occurrence of the second large landslide in Rupa area led to another high sediment load condition in the river. This was supported by continuous uplift of the Balipara Boulder-Gravel Ridge, which caused **third change** in the course to follow the easternmost boundary of the Balipara Boulder-Gravel Ridge up to its extremity. In the lower reaches, the fourth course was further deflected eastward to flow through the Tezpur town. The materials eroded by the Kameng from Balipara

Boulder-Gravel Ridge were deposited in and around Sengelimara Reserved forest as higher level terraces.

- (32) The development of the Jorhat-Helem fault up to the Himalayan foothills prompted the **fourth shift** of the river towards east to follow its fifth identified course. Its evidence downstream of Darikati is completely obliterated by the work of the river in the later periods. Two terraces developed on the north of the Balipara Boulder-Gravel Ridge are the remnants of the abandoned course of the river.
- (33) The strengthening of the fault helped in development of the terraces downstream of Bhalukpong and the river further shifted towards east (the **fifth change**) to establish its sixth course and flow in a meandering course downstream of Badejan, now known as Mara Bhareli.
- (34) The retreating snowline during the Holocene period was also putting pressure on the geometry of the river motivating it to change its course and dimension. The occurrence of severe landslides in the basin of the tributaries Tenga and Pakke causing mud flow and earthflow with sudden increase in discharge led to mega floods on several occasions. The exposed terraces on the left bank of the river upstream of Bhalukpong (where it is flowing through a gorge), substantiates occurrence of such mega-floods. Occurrence of such severe flood after 1616 A.D. and before 1824 A.D. might have forced the river to abandon its circuitous course for a straight braided course.
- (35) Since more than one causes are responsible for the changes in the course of Kameng river it can be stated that most of the time a combination of causes have been active in bringing changes in the course. Whereas, sometimes single factor has also been effective. For example, the third shift was caused by a combination of geomorphic, geologic and partly climatic factors while the first change was due to tectonic factor

only. However, in recent years reactivation of Mara Bhareli has been due to human interference.

- (36) The Kameng river merely changed its channels during 1892-2004 A.D. within its recent flood plain, neither from east to west nor from west to east. This phenomenon is likely to continue within the identified zone of channel migration that should not be treated as shifting of river course.

### 6.3.5 Prognostics

- (37) On the basis of the findings of the present study it can easily be said that there is going to be no major change in the course of the Kameng river in near future.
- (38) The above finding contradicts the general threat perception that the site of the Tezpur University is going to be overtaken by the Kameng river in future.
- (39) This is because now the river is flowing through the centre of the graben having almost straight stabilised course.
- (40) Moreover, the present course is guided by the levee on the right bank and active flood plain is confined within the terrace walls of Solabari Surface.
- (41) However, during high floods the river water may follow some of its abandoned nearby courses as a natural tendency of a river in the flood plains, as it has happened in the recent times, which reactivated the lower course of the Mara Bhareli.
- (42) It is believed that a braided river has less tendency of migrate than a meandering river. Hence, in the given geomorphic, tectonic, climatic and hydrologic condition the Kameng river is most unlikely to shift its course significantly.

## 6.4 CONCLUSIONS

From the above findings following conclusions may be drawn that:

- (1) The Kameng river changed its course several times during the Late Pleistocene and Holocene epochs mainly due to exceptional geomorphic events and neotectonic activities. In the exceptional geomorphic events, mention may be made of occurrence of huge landslides in the upper catchment of the Kameng lying in the Greater and Lesser Himalaya that led to phenomenal increase in the sediment load in the river, and high energy geomorphic environment associated with extraordinary floods. The climatic factor was also partly responsible in the form of retreating snowline in post glacial age.
- (2) Contemporary changes of the course after 1824 A.D., as derived from the maps, satellite data and collateral morphological evidences, have been confined to the recent flood plain, most of which occupied the channels of the prior courses.
- (3) Minor encroachment to the adjoining Solabari surface has also been observed along the low bank areas due to natural tendency of river to erode its bank during the floods.
- (4) The reactivation of the lower portion of the Mara Bhareli is not due to any abrupt change in the natural behaviour of the river. But it is due to the entrapment of an east-west man made trench by the flood waters, which was dug across a prior course of the river active between 1824 and 1913 AD.
- (5) The opening of the latest offshoot channel from the left bank of the river south of Shamdhara village to meet the Brahmaputra at a distance of 2.5 km east of the present confluence suggests that there is channel shift towards east within its active flood plain only.

- (6) The popular threat perception to Tezpur University Campus from the regularly changing course of the Kameng river is totally unfounded. This is because firstly, the University is located on a higher surface than the recent flood plain, and secondly the present course of the Kameng is well established in the centre of the graben thus not having any chance to change its course on any sides. Both the factors dispel the popular threat perception as it does not have any scientific basis.
- (7) Definitely, alluviation in the study area has been brought about by the changing courses of the Kameng river and its past and present tributaries.
- (8) The *Geomorphological Instantaneous Unit Hydrograph* developed may be useful for Hydrologic design. This concept is particularly important for the rivers of northeast India as sufficient historical hydrological data is not available for most the rivers.
- (9) Once raingauges are installed in adequate number and well distributed over the basin, independent GIUH's may be developed for the tributaries for better response of rainfall to river hydraulics.
- (10) By considering the number (six) and extent (23 km) of changes in the course of the Kameng river, and the multiple factors responsible for it, it can be concluded that the present case is unique in the Brahmaputra valley and worth comparable with shifting courses of other Himalayan rivers.
- (11) It is also unique in terms of the geodiversity as the lower Kameng basin can boast of having distinct landforms of fluvial and tectonic origin including older alluvial terraces, the raised Boulder-Gravel Ridge, piedmont fans/terraces, prominent faults, typical meanders, the prior courses of Kameng and its tributaries and also of the Brahmaputra river, the graben, the inselbergs of the peninsular shield etc. It indicates complexity of the geomorphic processes and landforms within a very small area. That makes it an interesting and ideal field of study inviting attention of the geoscientists.

## 6.5 Limitations of Study

It is not wrong to say that a scientific research, however detailed it may be, covers all aspects related with it and there is no further scope of research on the topic. Completion of one research work only adds a link in the long chain of research devoted to finding the truth. Therefore, though the present Ph.D. research work has been completed in all respects (i.e., fulfilling all objectives and answering research questions) there are some limitations in terms of the points that could not be covered in the present work. In the view of the investigator following are the limitations of the present work.

The changing courses of the Kameng river in its lower reaches have been investigated with the help of both primary and secondary data. The primary data has been collected directly from the satellite imagery and through the fieldwork with limited resources available. Present study has given first hand information on the overall geomorphological, geological and hydrological processes operating in the Kameng river basin. However, a lone research like this may not be able to provide all the evidences required to prove changing courses and answer the geomorphic, hydrologic, climatic, and tectonic causes responsible for it. Moreover, each shifting course has to be established in stratigraphic context, even by using echo-sounding techniques. Availability of radarsat images can do miracle in revealing the subsurface features, especially the buried courses of rivers. Each of these aspects needs separate investigations with individual entity. However, it was very much interesting to conduct the present research within all the limitations. Many of the limitations are related with non-availability of requisite data base for the present dissertation. The major limitations that the investigator experienced during the study have been listed below:

1. The Kameng river basin is located in a high rainfall zone on the windward slopes of the Himalaya, as a result of which the fluvial processes are very active, hence obliterated almost all the surficial geomorphologic evidences of the early Quaternary period limiting present study only up to the late Quaternary and Holocene.
2. Complete sequential alluviation of the valley could not be reconstructed as it requires detailed stratigraphy of the alluvium deposited on the pre-Cambrian basement. This is said despite availability of plethora of literature generated through different geological investigations in the Brahmaputra valley as a whole and the Kameng drainage basin in particular.
3. At present the Kameng is a braided river right from the piedmont zone to the confluence with the Brahmaputra. As such, though the gauge data have been collected at the present GDS site located at NT road crossing point by different agencies, it doesn't really provide accurate discharge information on the river as a whole, for the reach it does not fulfil the requisite criteria. Therefore, the discharge data directly measured from the concerned site during the study could not be used to correlate with the secondary data and as such could not be extrapolated to compare the extreme storm events with the corresponding changes in the river course.
4. Detailed analysis of the deposited sediments in entire Kameng basin, especially in the lower reaches, require full infrastructural facilities. With the limited available facilities much desired work could not be done in this regard.
5. Interconnectedness among various factors of changing course could not be firmly established as a host of data on geomorphic, tectonic and climatic aspects of past and present times are still awaited.

## 6.6 Scope for Further Study

Present investigation on the changing course of the Kameng river is the maiden study on the basin which incorporates entire geomorphic, geologic and hydrologic processes in a holistic manner. Though the aim of the study was limited to changing course of the Kameng, it has also opened up several new aspects in course of present research that require a detailed scientific investigation on the points listed below.

1. A detailed geomorphologic investigation of the Balipara Boulder-Gravel Ridge is required to know its origin, development, the composition, depositional pattern, and subsequent erosion. Such investigations will be able to find out composition of the Balipara Boulder-Gravel Ridge revealing the actual erosional and depositional processes and the geomorphic environment in which they were developed. This is because, the Gravel Ridge is not only a prominent fluvial landform of the study area but a dominant one governing the courses of the rivers. In fact, the Ridge is a storehouse of geomorphic information, hence its detailed study will unearth many evidences relevant to understand fluvio-tectonic processes and landforms of the study area.
2. Number of scientists have mentioned about the existing Older Alluvium Surfaces in the Brahmaputra valley of Assam, but detailed geomorphic investigation of such surfaces and its proper correlation with other such surfaces around the world, particularly those of the Indus-Ganga-Brahmaputra Plains is still awaited. Such, investigations will help in knowing the depositional process that existed during the Quaternary period in the Brahmaputra valley of which the Kameng basin is a part. Not only the composition of such older alluvium surfaces needs thorough study but their location, height and sequence of deposition also demand in-depth investigation to understand them and unravel the pages of the earth's history of this part of world.

3. The course of the Kameng river in its lower reaches has transformed from a circuitous course to an almost straight braided course of the present times. However, tectonic reason has been attributed to it, but attempt on geomorphic and hydrologic factors responsible for it have not been made yet. To attempt it one problem comes in and that is related with obliteration of evidences by the erosion and deposition fluvial processes of the recent past. As such, the subsurface alluvial sediments of the lower reaches of the Kameng river basin deserve detail investigation for various fundamental and applied purposes.
4. Conducting studies for computation of flood design requires direct measurement of discharge and sediment for a continuous, longer representative period. Proper hydrological analysis may be conducted only after such data collection for construction of safe and economical hydraulic structures. Thus, collection of adequate hydrologic data is another need of the hour, not only for different geomorphic and hydrologic analyses but for applied hydrology as well.
5. For a clear understanding of the nature, characteristic and pattern of the changing course of the Kameng river (and for that matter in any other river also) a micro-relief map with half metre contour interval at large scale has to be prepared with modern tools and technology.
6. Interconnectedness among various geomorphic, geologic, climatic and hydrologic factors of the past and present has to be thoroughly investigated and revealed to understand formation of landforms of different origin in the area for the fundamental and applied purposes.

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[www.cat.inist.fr](http://www.cat.inist.fr)  
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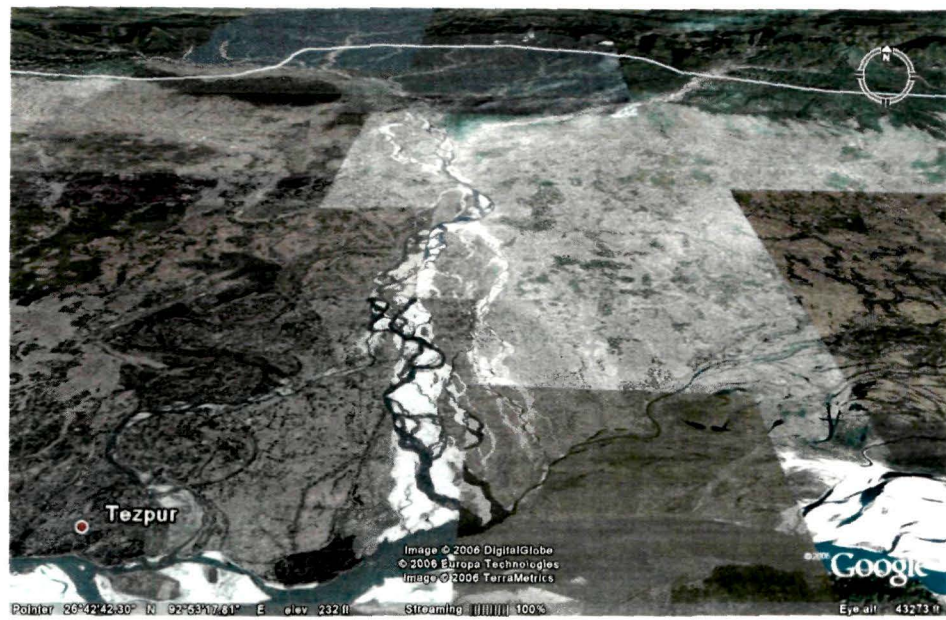
## PLATES

## PLATES



Plate 1 & 2. The Kameng river debouching into the plains





**Plate 3. The Study Area as viewed from South**



**Plate 4. The Eastern edge of Rangapara Surface**

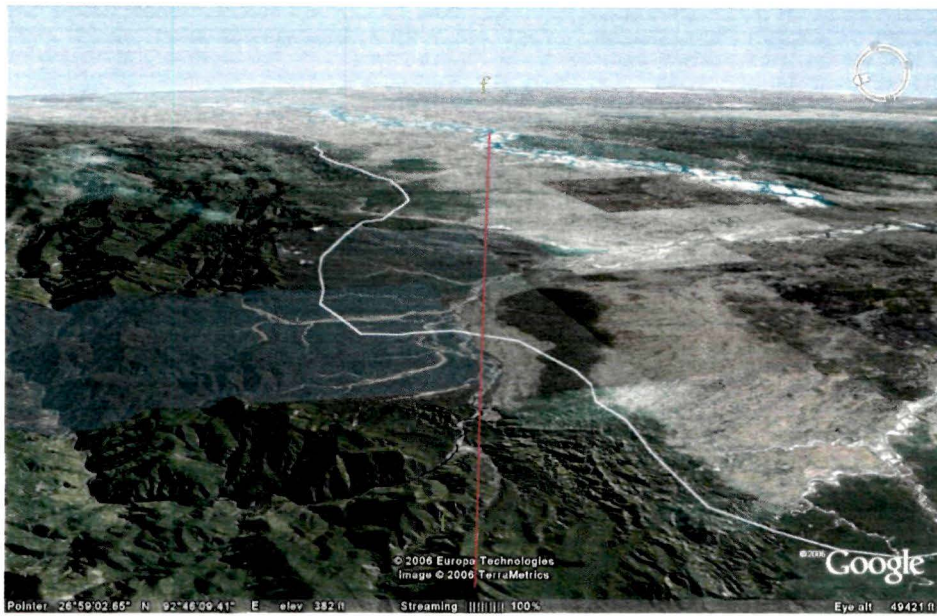


Plate 5. The Jorhat-Helem Fault extending up to Bhalukpong and beyond

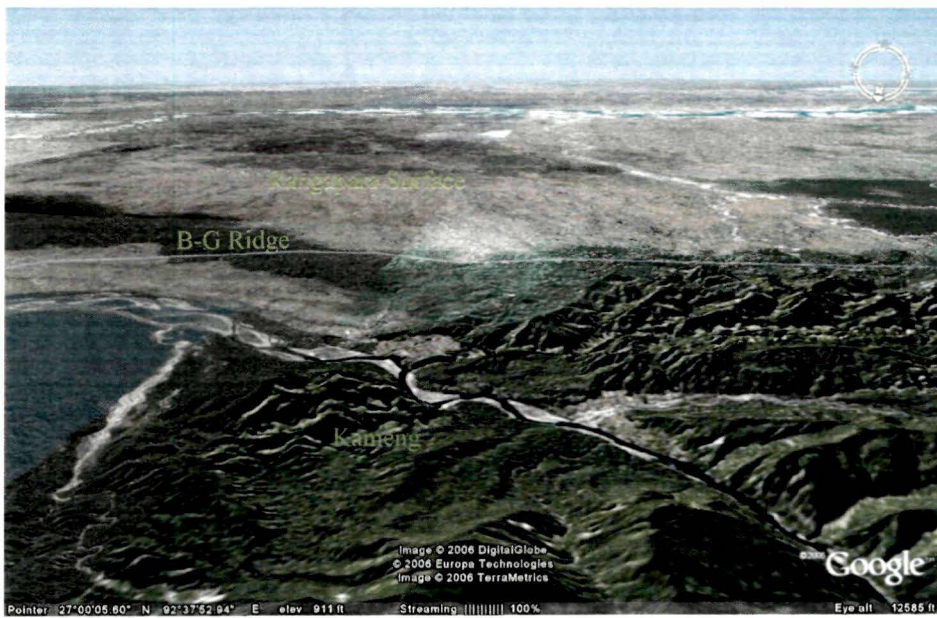


Plate 6. The Lower Kameng, B-G Ridge and Rangapara Surface

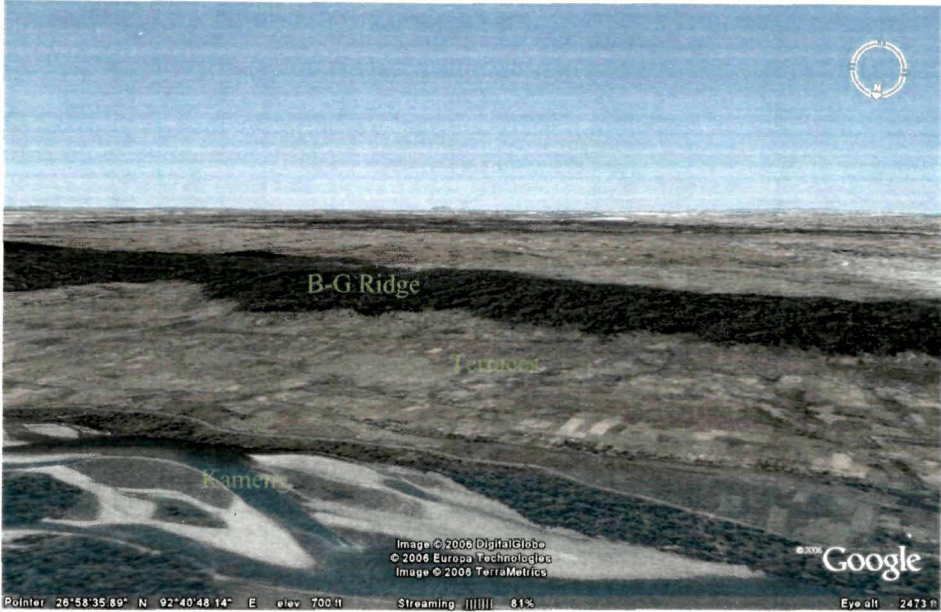


Plate 7. The Terraces on the northern slopes of the Boulder-Gravel Ridge



Plate 8. The gap in the Boulder-Gravel-Ridge showing the Third Course after the second shift



Plate 9. The 4<sup>th</sup>, 5<sup>th</sup> and 6<sup>th</sup> shifted courses and the present braided Kameng river



Plate 10. Site of the landslides in Rupa area



**Plate 11. The Tenga river terrace in Rupa valley**



**Plate 12. An exposed section of the Boulder-Gravel-Ridge**



**Plate 13. Fourth and Fifth courses represented by  $T_1$  and  $T_2$ , respectively**



**Plate 14. The gravel deposits underlain by sandstone cut by the river**



**Plate 15. Confluence of the Mara Bhareli with Brahmaputra near Bhairabi Temple during 17<sup>th</sup> Century**



**Plate 16. The confluence of the third shifted course with the Brahmaputra**



**Plate 17. Reactivated Mara Bhareli**



**Plate 18. Confluence of the Mansari with the Kameng river**

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