

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

**ABSTRACT**



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**THESIS**

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## ABSTRACT

### Introduction

Changing course of rivers is a natural phenomenon. 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. 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. 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. Geomorphic work carried out by the running water a river is 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.

The Kameng river has drawn attention 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. Both changing courses and floods of rivers pose threat to man and his civilisation, thus considered as geohazards. Many a times, the development is affected thus necessitating incorporation of studies of geohazards in the planning process. In this context, the Kameng river basin, particularly its lower reaches, present an interesting case for study. Therefore, in the present Ph.D. research the problem of '**Changing Course of Kameng River in the Lower Reaches**' has been investigated.

### **Objectives**

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.

### **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.

## **Database**

### **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.

## 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.
- (iii) The historical gauge and discharge data from 1997 to 2003 were collected from the Central Water Commission and Water Resources Department, Govt. of Assam.
- (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*', were also used for the study area.

## Methodology

Following methodology has been adopted for conducting the present study:

- (i) The catchment area of the Kameng river basin was delineated from the Toposheets (1:50,000) and updated using satellite imagery. Satellite imagery was also used for delineation of geomorphic features of the areas. 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 scale. 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.

(ii) 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 prior 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 geomorphologic, geologic and hydrologic evidences. Attempt has also been made to forecast the changes, if any, in the course based on the findings of the study.

(iii) 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.

(iv) Geologic information 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.

(v) 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. 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.

### **Summary**

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.

Present Ph.D. Thesis 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.

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. 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.

## 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:

### (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 alluvia 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.

## **(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.

### **(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.

#### (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 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.
- (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.

### **(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.

### **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.

### **Recommendation 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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