CHAPTER - II

CHAPTER TWO

PREVIOUS WORK

Geologists and Geomorphologists have carried out extensive work on various fluvio-geomorphological parameters of the Ganges as well as other major rivers of the world. Some of the important references are discussed below:

- Singh et al. 2007[88] studied the sediment characteristics and transportation dynamics process of the Ganges. From the studies related to the textural properties, grain size characteristics and transportation dynamics of the river sediments, it was seen that the sediments originating from the Himalayan orogenic belt, the Northern Indian craton and the Ganga alluvial plain regions shows the predominance of fine to very fine sand, medium to fine sand and very fine sand to clay. Downstream, the textural variations are much complex and show strong influence of the lateral sediment inputs by the other tributaries whereas the Himalayan base shows a very sharp gravel-sand transition.

- Goswami et al. 1999[29] carried out the studies for the Subansiri river in Assam, in which bankline changes due to erosion and various other fluvial changes had been taken into consideration. It was seen that the channel had became wider during the period 1970-1990. Other fluvial changes such as increase in the amount of mid-channel bars whereas decrease in the number of point-bars during 1920-1990 was also observed. These variations were responsible for bringing about changes in the channel pattern. The study also showed that the river channel seemed to have made a remarkable change from a meandering pattern in 1920 towards a braiding pattern by 1990.

- Various anthropogenic activities are also responsible in bringing about channel changes. Studies carried out by Liqian et al. 2007[49] for the Jianli reach area in the middle Yangtze river, using 1:100,000 channel distribution maps from 1951, 1961 and 1975 and 1:25,000 navigation charts from 1981 and 1997 showed that due to the constraint of levees along the river banks the channel had undergone minor widening and frequent bank failure due to susceptible bank structure and increased water discharge.
- According to Gregory 2006[31], human activities such as channelization, dam construction, diversion and other geo-engineering works also leads to changes in the channel pattern as well as other geomorphological changes. Apart from these activities, deforestation, intensive agriculture, building and constructions, urbanization etc. also results in channel changes.
- Sarma and Phukan 2004[75] carried out studies on the evolution and geomorphological changes of the Majuli island of the Brahmaputra river. According to the earlier official data the island covered an area of about 1255 km^2 in the year 1901. After this in connection to the above data, work carried out by using historical reports, SOI maps of 1917, 1966-1972 and satellite images of 1996 and 2001 showed that Dihing, one of the major Brahmaputra tributary which once flowed almost parallel and very close to the main river has shown migration as well as changes in the geomorphological features which resulted due to an extreme flood event that occurred in 1950, which eventually diverted part of the flow of the Brahmaputra through the channel of Dihing by about 190 km upstream of its confluence. When these two rivers joined, the in between land area formed the Majuli island. Initially this island was made up of a cluster of 15 small and big islands. Further studies carried out by superimposing the bank-lines of 1917, 1966-1972, 1996 and 2001 showed that the rate

of bank-line shift is not uniform at all the places and migration leading to erosion is dominant on the southern bank. The area of the island showed considerable amount of shrinkage and changes in the length and width. Increase in the amount of erosion upto 1.77 km^2 from 1917 to 1972, 1.84 km^2 from 1972-1996 and 6.42 km^2 from 1996-2001 was observed. It has been found that amount of erosion has increased whereas the drainage density and stream frequency has decreased.

- According to Kale 2002[41], fluvio-geomorphological studies of the Gangetic river includes hydrology of monsoonal rivers, forms and processes in alluvial channels, causes of avulsion, channel migration pattern, dynamics of suspended sediment load and the geomorphic effects of floods on rivers. Studies have shown that the Himalayan rivers exhibit an extreme dynamic behavior with a large variability in discharge and sediment load transportation. High magnitude earthquakes and landslides are also common in this region which triggers the river behavior, thus showing frequent changes in shape, size and channel position. In contrast to this the peninsular rivers show less amount of such variability.

- From the studies carried out by Sharma 1997[79], Ganges carries highest silt load then any other river of the world and the deposition of this transported silt material (alluvium) results in the formation of large river deltas. Ganges is thus the largest river delta in the world. It approximately extends 400 km from North to South and 320 km from East to West. Since the main river channel carries lot of sediment load, the water is highly turbid in nature. However the tributaries of the main channel which are spring fed are very clear whereas the snow fed ones are highly turbid. The spring fed tributaries are clear because they come from the clean underground sources from the low or moderate altitudes whereas the snow fed streams are a resultant from the melting to the other. At some places the shift has been slow, gradual and continuous whereas in the other parts it is very rapid.

- Work carried out using remote sensing techniques and field data by Mitra et al. 2005[54] have shown that Sarda one of the major rivers of Ganges has also undergone frequent channel changes in the recent times. It was inferred that the channel avulsions take place over a period of 10^1-10^2 years and the unidirectional lateral migration of the river is due to the tectonic activities of the late Holocene. Floods are also the major reasons which aggravate the channel avulsion process.

- From the studies carried out using remote sensing data of the year 2001 and 2004, SOI maps of the year 1934 and 1972 and GIS techniques by Sarma et al. 2007[76] the authors found that the river flows in a meandering pattern for about 220 km and the bank-line changes are mainly due to the river erosion process and two types of changes had been observed: alteration of the direction of flow due to neck cut-off and gradual change of the meanders resulting into lateral, rotational and other types of movements of the meander bends. Amount of erosion and deposition was also estimated by the authors and it was seen that during 1934-1972 erosion was higher then deposition, during 1972-2001 deposition was higher then erosion and again during 2001 to 2004 increase in the amount of erosion was seen.

- Studies carried out using Landsat MSS and TM remote sensing data by Jain and Ahmad 1993[37] it was found that there is a sudden change in the flow direction from West to East up to Varanasi and after that the shifting was not that significant. Maximum shift in the mid channel was about 4.55 km and the maximum shift in the left and the right banks was 4.6 km and 4.8 km respectively. According to the authors the shift was mainly in response to flooding, meandering and tectonic activities.

- In other similar type of studies by Philip et al.1989[66] in the middle Ganga basin lying around Monghyr in Bihar state it was observed that both, the main channel of the Ganges as well tributary Burhi Gandak had shifted from North to South by about 20 km and 30 km respectively.
- Studies on the channel changes and various fluvio-geomorphological changes of the Ganga river in Bihar state by Muley et al. 2006[57], Arya et al. 2009[4] and Arya et al. 2009[5] for the year 2000 and 2004 using remote sensing data, IRS 1D LISS III and RESOURCESAT-1 (IRS-P6) LISS III respectively, and SOI topographical maps as the reference maps on 1:250,000 scale for the whole stretch of the Ganga river covering Bihar has shown that the river has very prominently shifted at few locations such as Patna and Bhagalpur whereas it has undergone shifting in its course to a lager or smaller extent at various other locations throughout its course in Bihar.
- Bajpai 1989[6] studied the central Gangetic terrain of Kanpur-Unnao region, Uttar-Pradesh using Landsat images and it was inferred that the Ganges has migrated towards the Southern direction in that region.
- Studies by Pati et al. 2008[64] on the Ganga river shifting around the flood prone Allahabad city located on the Western banks of the Ganga river using historical SOI maps, and annual to monthly pre- and post-monsoon IRS 1D data and GPS measurements showed that the Western bank of the river has shown variable shift in its course. It was also found that the area between Rasoolabad and Govindpur is a point bar region which shows maximum deposition in the Western bank and erosion in the Eastern bank. The maximum shift was observed to be the ESE of Govindpur area with an average Easterly gradient whereas the minimum shift was observed ENE of Baghara area with a Westerly gradient. The Ganga river course in this region is controlled by Allahabad fault but the annual spatio-temporal shifting of the Western bank is mainly

controlled by the annual floods whereas the temporal shifting is related to the neo-tectonic activities.

- The satellite images show that there are many major as well as minor faults along and across the Ganga river and in addition to this there are also subsurface faults present near the course of the Ganga river. According to Singh 1996[85] on the basis of different geomorphic features and fluvio-geomorphical processes, it was concluded that the latest migration of the Ganga river course took place in the middle-late Holocene period. The shift direction was mainly in the West and East directions and at some places the shifting is controlled by the presence of sub-surface structures as well as sediment discharge Srivastava and Singh 1999[97].

- According to Sinha 2005[91] and Sinha et al. 2005[93] the river Ganga as well as all other major tributaries like the Yamuna, the Sone, the Ghaghara, the Kosi, the Gandak, etc. draining the Gangetic plains show a remarkable geomorphic diversity and thus this has consequently characterized the rivers to be dominantly aggradational in the Eastern Gangetic plains (EGP) and degradational in the Western Gangetic plains (WGP). Stream power and sediment supply are the two main primary factors which governs the aggradation or degradation of a river system and which are in turn controlled by catchment parameters such as rainfall and regional tectonics. Also, it has been found that processes such as aggradation as well as degradation play a major role in fluvio-geomorphological processes such as channel migration and flooding. The rivers draining the Western plains are characterized by higher stream power and low sediment supply which results in degradation whereas the rivers draining the Eastern Gangetic plains have lower stream power and higher sediment supply which results in aggradation. Such diversity may also exist because of climatic and tectonic variance.

- Studies by Roy and Sinha 2005[74] on the geomorphological processes of the Gangetic plains in Uttar-Pradesh have shown that the confluence of the Ganga-Ramganga-Garra rivers have shifted upstream as well as downstream in last 30 years in response of river capture, local cut-offs and aggradation.

- Extensive work has been carried out by many workers on the Kosi migration. Studies by Sinha 2009[94] have shown a dominant Westward movement by about 150 km in last 200 years, mainly due to the sediment in the braided stream, active tectonics, bed level rise and excessive flooding.

- From the studies carried out by Sinha 2009[94], unlike the previously showing Westward shift, in a more recent event, Kosi river on 18th August 2008 showed a very prominent migration in the Eastward direction about 120 km which was the highest then any other single avulsive movement ever recorded since historical times. It was found that this avulsion was triggered by a breach in the Eastern afflux bund of the Kosi at Kusaha, 12 km upstream of the Kosi barrage. This channel reoccupied one of the palaeochannels and 80-85% of flow was diverted in this new channel, but because of its initial low carrying capacity water started overflowing by about 15-20 km wide and 150 km in length and this new course did not join back with the main Kosi channel neither did it drain in the Ganga river channel due to which it remained water-logged for around 4 months, and this was a mega avulsion rather then a regular flood.

- Gandak, has also shown shifting over its megafan surface from West to East over a distance of around 80 km in past 5000 years Mohindra et.al. 1992[55]. The reason behind this unidirectional shifting was related to the slow Eastward neotectonic tilting of the Gandak megafan in the Eastern Gangetic plains. Many smaller river such as Burhi-Gandak, kamala-Balan, and Baghmati have also shown significant shift in their banklines Sinha et al. 2005[92].

- In order to understand the weathering process of the Ganga alluvial fan, studies by Singh et al. 2005[86] on the geochemistry of the Ganga alluvial plain weathering products, transported by the Gomti river, a tributary of Ganga, it was found that the Ganga alluvial fan has undergone chemical weathering up to a moderate level and the weathering products have also shown an incomplete alteration in the alluvial sequence comprised of Himalayan sediments.
- Luminescence chronological studies by Shrivastava et al. 2003[81] have shown an incision around 20 m of late quaternary sediments forming the vast upland terrace (T_2). The incised Ganga river valley shows presence of two terraces: the river valley terrace (T_1) and the present day flood-plain terrace (T_0). From the studies it was found that T_1 showed the presence of meander-scars, ox-bow lakes which suggests that meandering was prevalent in the past whereas the present day river flows on T_0 which shows a braided nature which suggested that the river Ganga had experienced atleast two phases of tectonic adjustments (1) incision and (2) channel metamorphosis from meandering to braided pattern. Optical dating studies had shown the phase of incision to be < 6 and 4 Ka whereas T_2 underwent differential erosion due to tectonic activities which also resulted in the channel incision.
- Extensive work has been carried out by different workers around the Ganges in Uttar-Pradesh. Around Kanpur city, it was observed that the Ganga river has shown a major channel shift which is governed by the fluvial dynamics of the river Harijan et al. 2003[35]. Presence of two major geomorphic zones associated with two major episodes of changes in the sedimentation pattern was clearly visible. It was seen that in the Eastern part the Ganga river showed presence of overlapped palaeochannels which suggests that the younger flood-plains are surrounded by the older ones. From the previous studies by Singh 1996, the latest river migration that took place was in the

North-East direction in the middle-late Holocene period accompanied by decrease in the water discharge and increase in sedimentation due to various climatic changes.

- Work done by Shukla and Raju 2008[82], has shown that the river Ganga has undergone prominent migration near Varanasi. From the borehole data it was found that during the late Quaternary, the Ganga river was not flowing in the present day location but was flowing in the Southern direction towards the peripheral craton, whereas now it flows along NW-SE tectonic lineament. The migration is believed to be in response to basin expansion resulted due to Himalayan tectonics in the middle Pleistocene period.

- Apart from the direct studies related to channel shifting and morphology, studies by Bhosle et al. 2009[12] have also been carried out to know and understand the tectonic and the sub-surface setting of the Gangetic basin so that its influence over the course of the river and river morphology can be studied and established in a better way. From their studies based on the interpretation from the digital elevation models, it was found that twelve active normal faults, transverse to the regional Ganga and Yamuna longitudinal faults are present. This data regarding the tectonic setting in the upper Gangetic plains can be helpful for further studies related to the channel shifting and river morphology.

- According to Sinha et al. 2005[92], the Gangetic basin is traversed by several transverse and oblique sub-surface faults and the seismic data have shown that many faults are neotectonically active. The present models of the Himalayan seismotectonics have shown Westward decrease in the crustal shortening and uplift rate along the Himalayan Frontal Thrust (HFT). The presence of longitudinal and transverse faults along with the basement configuration of the Gangetic plains has been thought to influence the fluvial processes and sedimentation.

- According to kale 2002[41] all Indian rivers show certain specific fluvio-geomorphological characteristics since they undergo large seasonal variations in flow as well as in the amount of sediment carrying capacity. The major aspects of studies in Indian as well as Gangetic river fluvio-geomorphology includes hydrology of monsoonal rivers, forms and processes in alluvial channels, causes of avulsion, channel migration pattern, dynamics of suspended sediment load and the geomorphic effects of floods on rivers. Studies have shown that the Himalayan rivers exhibit an acute dynamic behavior with a large variability in discharge and sediment load transportation. High magnitude earthquakes and landslides are also common in this region which triggers the river behavior, thus showing frequent changes in shape, size and channel position. In contrast to this the Peninsular rivers show less amount of such variabilities.
- Work carried out by Sinha and Jain 1998[90] has shown that primarily three distinct types of fluvial systems can be identified in the Gangetic basin, each showing different characteristics depending on its source area. These are mountain fed, foot-hills fed (Baghmati) and plains fed (Burhi-Gandak). The Ganga, Gandak and the Kosi are the mountain fed rivers which are generally multi-channel, braided systems characterized by high discharge and sedimentation than compared to that of the single and sinuous channel i.e. foot-hills or plains fed. The mountain fed rivers transfer a large quantity of sediment load from their higher relief catchments to the plains and consequently form large depositional areas usually termed as "megafans". According to Sinha et al. 2005[92] the processes controlling the valley formation and filling in the Gangetic plains are highly variable in space and it has been found that near the Himalayan front both tectonic as well as climatic factors play an important role in the valley formation and incision whereas in contrast the Western and Southern Gangetic

plains are mainly controlled by climatic factors since tectonic activity in these regions is very less.

- Jain and Sinha 2005[38] have studied that in Bihar, large amount of channel migration has been seen in the main Ganga channel as well as in its tributaries with a difference in scale and frequency. North Bihar rivers such as the Kosi, the Gandak as well as other smaller tributaries like the Burhi Gandak, the Baghmati and the Kamala Balan have shown channel migration which is basically in response to neotectonic activities and sedimentological re-adjustments. The rivers draining the Uttar-Pradesh region are much less dynamic then the rivers draining the Bihar region. Rivers like the Ghaghara, the Rapti and the Sarda have shown channel movements mainly attributed towards neotectonic activities and aggradation. High magnitude earth-quakes are also responsible for major fluvial changes. Active tectonics in a basin is an important factor influencing and controlling a fluvial system. Channel slope changes due to the tectonic deformation are also responsible for causing variations in the channel morphology and fluvial processes.

- Climatic conditions impart a very profound effect on the evolution of different landscapes. According to Sinha and Sarkar 2009[95], the Ganga alluvial plains exhibits a variety of fluvial environment ranging from piedmont fans to megafans to large valley fills and interfluves. Variable climatic and tectonic conditions have resulted in large spatial variability in the river hydrology, sediment transport and sedimentation characteristics. It has been seen that the region shows an Eastward increase in precipitation. According to the authors it has been observed that the modern day landscape is mainly controlled climatically then tectonically and such a geomorphic diversity has existed almost throughout the late Quaternary.

- From the studies carried out by Coleman 1969[19], apart from active tectonics, sedimentation also plays a very major role in river migration and instability. Rivers like the Brahmaputra and the Ganges discharge millions of cusecs of water during floods along with tons of suspended sediments. Heavy water discharge as well as deposition of the suspended sediments causes the rivers to be extremely unstable, showing a constant channel migration. It has been observed that both these rivers have occupied and abandoned numerous water courses. At many places the shifting is controlled by sub-surface faults and fractures. The most significant bankline changes take place during falling-river stage, when excess sediment is deposited as bars within the channel, causing a change in local flow direction.

- Burhi-Gandak is one of the major tributaries of the Ganges in the middle Ganga basin. The river is known to have an oscillatory character and has changed its course in recent times. From the delineation of fluvial palaeo features by Gupta 1993[32] using remote sensing data along with surface and subsurface data shows that the river has shifted from North to South over a distance of 30 km. It was also observed that the Burhi-Gandak river had a larger channel width and higher rate of water discharge then compared to the present day situation. By detailed study, a past link between the now Northerly flowing Baghmati and Burhi-Gandak rivers was detected and three distinct stages of river migration were identified.

- Work carried out by Buchroithner et al. 1991[15] for the Baghmati valley South of Kathmandu, using the 1971, 1977, 1984 and 1986 remote sensing images it was found the area showed no overall increase in the amount of erosion losses between the years 1971 and 1986. Only few local shifts in the terrain were detected.

- Similar work by Desai et al. 2006[20] on the river migration pattern and the estimation of erosion and deposition along the banks of the three major tributaries of the Brahmaputra river namely the Puthimari, the Pagladiya and the Jia-Bhareli have also been carried out. To study the changes in the flow pattern, two years data, over a span of six years (1998-2004) was considered. IRS-ID LISS III data was used for the year 1998 and RESOURCESAT-1 was used for the year 2004 and the comparative study was carried out with SOI maps. It was found the all the three tributaries showed distinct channel migration and changes in the fluvio-geomorphic parameters. Jia-Bhareli showed a distinct shift from East to West direction whereas the Puthimari showed a shifting in the East and South-East direction.

- Studies carried out by Desai et al. 2011[23] on the fluvial changes of the Ganges near Begusarai and Bhagalpur an over past 70 years, for the years 2000 and 2004 on 1:250,000 scale using IRS 1D and IRS P6 remote sensing data, showed that the regions near Bhagalpur have undergone prominent changes in the bank-lines as well as other fluvial parameters. The SOI maps of the year 1935-'36 were used as the base reference maps. It was observed that the river showed a shifting of about 1.5 to 6.5 km in the Northern as well as Southern direction. Also, Near Begusarai and Bishunpur the river has undergone prominent degradation as well as aggradation but the amount of degradation is much higher than aggradation, which suggests the widening of the river bed in this region. Near Bhagalpur the river shows dominant aggradation than compared to degradation, which indicates the shrinking of the river bed in this area.

- Similar work by Desai et al. 2008[21], on the fluvio-geomorphology of the Ganges and its comparison using SOI maps and IRS 1D LISS III pre-monsoon and post-monsoon data for the years 2000 and 2004 has also being carried out for the whole Ganga river stretch falling in Bihar. From the study it was seen that the river throughout its course at many different locations has undergone major as well as minor fluvial and bank-line shifting. The amount of change is not uniform and shows a temporal and spatial change. From the study it was also possible to locate the areas under major riverine changes and the areas under excessive erosion and deposition so that possible measures can be taken to prevent further aggradation and degradation.

- Work done by Desai et al. 2010[22], on the migratory pattern and the fluvial geomorphology of the Ganges near Bhagalpur have using SOI maps as base reference maps and IRS 1D and IRS P6 LISS III data have shown that the river in this region has undergone major changes in terms of bank-line shifting and the shift was calculated up to almost 6 km.