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RESEARCH ARTICLE

GEOMORPHOLOGY AND ITS DIFFERENT PARAMETERS IN THE FLOOD PRONE LOWER GANDAK PLAIN

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Abstract

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The physical appearance of any area is the outcome of geomorphological interactions between endogenic and exogenic processes. Endogenic processes are very slow while the exogenic are quite obviously observable operating at or from above the surface of the area. They may be included like – wind, fluvial, glacio-fluvial, glacier, permafrost, karst etc. They sculpture the concerned area and people use the same for their own needs. Land use may be seen in two ways – natural or human induced use of land. The Lower Gandak Plain is characterized by flooding in the monsoon period when torrential rain associated with glacier melt water occupy the low lying area in the region. But this huge amount of water is brought by numerous tributaries of Gandak from upper Himalayan catchment. Therefore, enormous water from Himalayan catchment is to be drained through the Lower Gandak Plain. The Gandak flood plain is highly populated and anthropogenic activities are prominent. So, most of the areas have human sign and less as natural. Flooding is, therefore, more due to anthropogenic factors. Hence, an attempt has been made here to (i) evaluate the geomorphological characteristics, (ii) elaborate the flood plain forming processes on the basis of planforms, and (iii) explain various geomorphological parameters in the Lower Gandak Plain. This study is expected to help in systematic and integrated plan preparation for overall development of the Lower Gandak Plain on the basis of detail characteristics of the area explained.

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Introduction:-

Flood is a natural process by which great hardship and sufferings are caused to affected people and their pets, cattle and other domesticated animals. Area becomes inhospitable and widespread health related unhygienic conditions are resulted. Many of the infrastructures developed by human beings are destroyed, crops damaged, houses gets collapsed. It is resulted into disaster and cause many deaths and drowning. Overall, entire area is affected by one way or the other. Britannica defines flood as "high-water stage in which water overflows its natural or artificial banks onto normally dry land, such as a river inundating its flood plain". NIDM explains "floods are caused due to heavy rainfall and the inadequate capacity of river to carry the high flood discharge". India is a land of monsoonal rain confined into about four months from June to September (JJAS). During this period, almost 80 percent of the

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total annual rainfall is received. It is the time when the temperature is also very high and huge amount of water by Himalayan snow melt is also added. This increases the water availability to be drained off. The result is that, food becomes inevitable. In general, flood is caused by intense rainfall, reducing carrying capacity of the river by depositing sediment, landslide and damming of the river course, cyclonic disturbances, chocking of urban drainage system etc. Sometimes, people residing in the embankment area used to cut it to get rid of flood, causing the surrounding area to submerge. All of these actions are sculpturing the surface, which is a continuous process, and a variety of geomorphological processes are observed.

Objectives:-

The objectives of this study are to (i) evaluate the geomorphological characteristics, (ii) elaborate the flood plain forming processes on the basis of planforms and (iii) explain various geomorphological parameters in Lower Gandak flood plain.

Data Source and Methodology:-

This study is based on secondary data collected from various sources. Important among them are numerous reports prepared by Ganga Flood Control Commission (GFCC), National Institute of Disaster Management (NIDM), Census of India (2001 and 2011), numerous research papers published in journals, and open sources available online. Different information collected are referred at appropriate places and analyzed statistically and graphically. Planforms images are collected from the Google Map satellite imageries and interpreted as an overall flood plain processes.

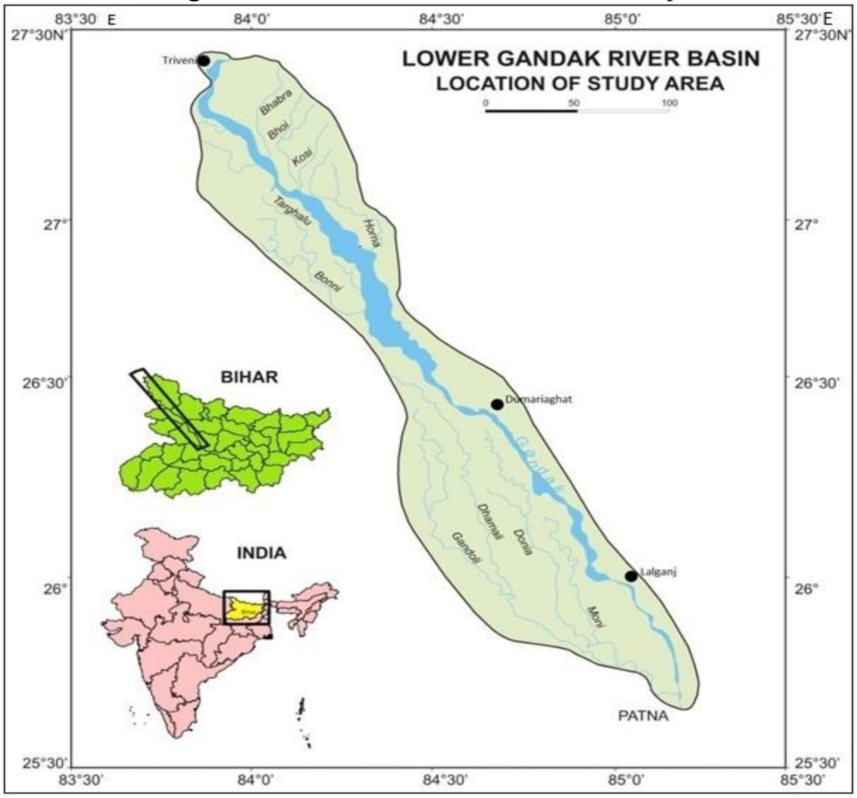
The Study Area

The area under study is a part of Indo-Gangetic plain. Based on the surface draining channel/ river network system, the area is denoted as a Lower Gandak River plain. For present study, Lower Gandak Plain falls below Valmikinagar Barrage at Triveni in WestChamparan. In the plain, many of the rivers are running almost parallel to each other following the general slope in a north-westerly to south-easterly direction. The Lower Gandak is also following the same trend and thus the area is almost elongated. A map of Lower Gandak River Basin is prepared with the help of Plate Nos. 11 and 12 of the Atlas of Soil and Land Use Survey (Figure 1). This Atlas was prepared by the Ministry of Agriculture, Government of India, published in 1988. Valmikinagar barrage determines the northern limit and in south the Ganges River forms its boundary. The Ghaghara river plain lies to the west and northwest and the BurhiGandak Plain to the east and southeast. The latitudinal extent of this area is 25º21’23”N to27º26’54”N and longitudinal expansion is 83º49’00’’E to 85º15’52”E. The complete area under study occupies 7620 km² out of which 968 km² lies in Uttar Pradesh and 6652 km² in Bihar. It covers parts of Maharajganj and Kushinagar districts of Uttar Pradesh and West Champaran, EastChamparan, Gopalganj, Siwan, Saran, Muzaffarpur and Vaishali districts of Bihar. It covers parts of Maharajganj and Kushinagar districts of Uttar Pradesh and West Champaran, East Champaran, Gopalganj, Siwan, Saran, Muzaffarpur, Samastipur and Vaishali districts of Bihar.

The Gandak River rises from an altitude of 7620 meter (CWPRS 2012) to the north of Dhaulagiri in Tibet near Nepal boundary. The geographical coordinate of the origin of the river is 29º18’N latitude and 83º58’E longitude. The Upper Himalayan catchment area of Gandak River is in Tibet and Nepal territory with an area of 38680 km². The lower catchment occupies over an area of 7620 km². By adding both catchments – upper and lower – the total area comes to 46200 km². The proportion comes out to be about one-fifth (20%) for lower catchment whereas the upper catchment is four-fifth (80%). The catchment up to Tribeni (West Champaran) is hilly while the area lying in India forms part of the Gangetic plains.

The river flows about 100 km in south-westerly direction in Nepal. This river receives many tributaries like the Mayangdi, the Bari and the Trisuli. The Gandak debouches into the plain at Tribeni in Nepal. After this, the river flows in a south-easterly direction and determines the demarcating boundary between Uttar Pradesh and Bihar. The Lower Gandak River finally joins with the Ganga River opposite Patna near Hajipur. The area lying in India is plain. The Gandak or the Great Gandak (Singh, 1971) is also known as the Narayani and Saligrami. From time immemorial, the River has also been called as Sapt-Gandaki. Its major seven tributaries are “Trisuli, Budhigandaki, Daraudi, Marsyangdi, Madi, Setigandaki and Kaligandaki” or the area prominently drained by seven Gandakas (ICIMOD 2017). It is supposed to be formed by seven main streams (NCAER 1964).

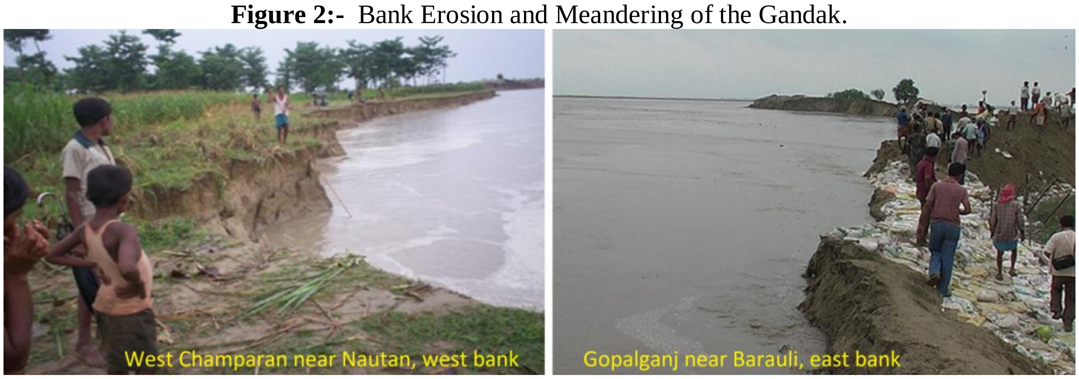
Figure 1:- The Lower Gandak River Basin Map.



Changing Course of Gandak River

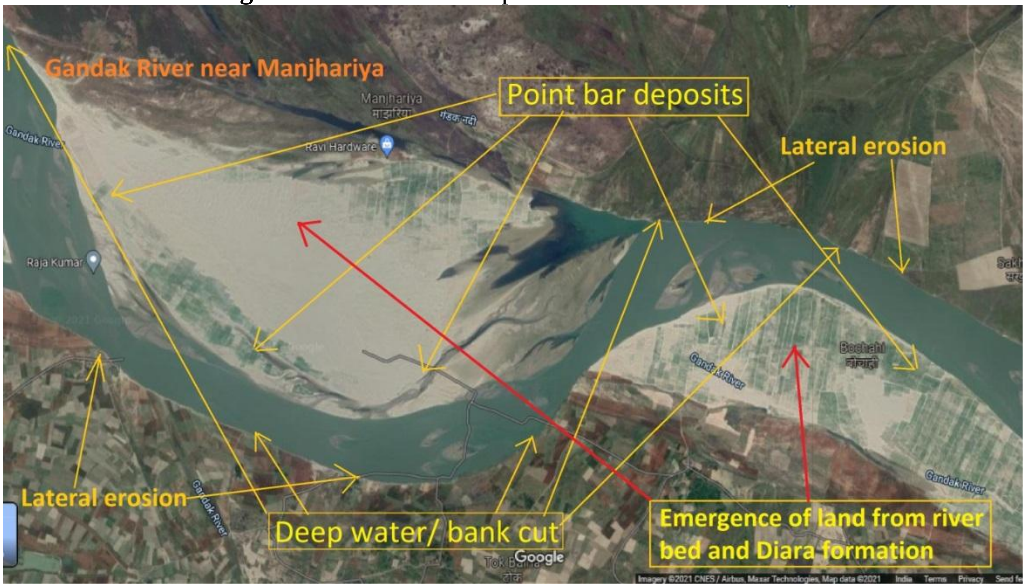
The river has been changing its course since time immemorial (Das 1968, Wells & Dorr 1987 and Prasad 2000) but it has been embanked from both sides since long time, mainly after independence of the country. Its changing behavior is still maintained today but within the two embankments. It has also breached the embankments occasionally and created great flood fury outside the embanked area. The main cause of channel/ river shift is huge siltation by the flood water during rainy season. The siltation process is a regular affair in the embankment area (Prasad 2002). The process of plain formation is constantly taking place. The flow hitting the bank erodes and bank materials and carving particularly in the plain areas (Figure 2). The carved out material is deposited to the other. This deposition is known as point bar. Since the river is very huge and wide, the other bank is not visible in the camera picture frame. Hence, a snapshot from the Google Map is taken (Figure 3) to explain the behavior of the Gandak along a meander in Gopalganj district near Manjhariya. The same is very clearly observed all along the course of the Gandak River. In this way, meandering is initiated. The pools and refills (Prasad 2008) are generally created and can be seen very easily across the river. This sort of action of the running water leads to the formation of meanders in the plain. It is well accepted and universally seen along all the rivers of the world in fluvial flood plains.

Figure 2:- Bank Erosion and Meandering of the Gandak.



Source: Photograph clicked by second author.

Figure 3:- Erosion and Deposition Process at Meander.



Due to frequently changing river course and emergence of land from river bed, chars or diara land is formed. Mostly, it is found between marginal embankments and the present course of the river. It used to extend around 10 km of stretch. The creation of these diaras is an interesting example of soil/plain formation. The diarais characterized by a heap of sand and fertile soil deposited by the flowing river water. The rise in the level of water in the river during high flow inundates diara. The inundation leads to the deposition of loads associated with the flow. Therefore, diara is on making every year depending upon the flow of the river and accompanied (sand, silt or clay) loads. The soil of such *diara*is,sometimes, extremely fertile and produces bumper *rabi*crops.But if the river course changes and the area is occupied by river, fertility of the soil is affected drastically by the deposit of coarse grained sediment, it becomes barren. Although *diara* lands are constantly being destroyed and re-formed as the river sways from side to side, diara area is subjected to submergence every year during monsoon period.

General Characteristics and Geomorphological Parameters

The Gandak River basin is enclosed by the Kosi River basin in the east and Tsangpo River system in the north. To the west, it is bounded by the Ghaghra River basin while to the south it merges with the Ganga River basin of which, it is a tributary. Out of the top-10 peaks of the world, three are located in its catchment area. They are Dhaulagiri (8167 meter, 7^{th} highest), Manaslu (8163 meter, 8^{th} highest) and Annapurna (8091 meter, 10^{th} highest). This river drains the feet of these mountain and collects water (snow-melt as well as rainfall) from about 38680 square km in Nepal Himalayan zone before entering the plain at the boundary of India (Uttar Pradesh and Bihar) and Nepal. This area is known as upper catchment of the Gandak River. The lower catchment has an area of 7620 km². The general information about the Gandak River can be seen from Table 1.

Table 1:- Gandak River Basin Characteristics and Geomorphological Parameters.

Parameters	**Gandak River**
Total length (km)	625
Total catchments area (km²)	46200
Plains area/ Upland ratio	1:5.07
Channel width and depth ratio	133
Sinuosity*	1.0- 1.93
Braid-channel ratio*	1.33- 5.38

The entire area falls under ten districts (two districts of Uttar Pradesh and eight districts of Bihar). Out of the total lower catchment 12.70 percent area is in Uttar Pradesh (968 km²) and the remaining area (87.30 percent) is in Bihar (6652 km²). When river is at its bankfull stage, channel width and depth ratio is calculated by dividing the width by average depth of the channel. In case of Gandak, it is a depth of one unit at a width of 133 units. For example, if the river is 133 meter wide, its depth is one meter. Sinuosity index represents the relationship between stream length and valley length. Stream length is point to point straight distance of a river while valley length is the measurement of length along the deepest bed of the channel. When the value is one or near to one, it is straight channel but with increasing value, it represents more and more meandering. With respect to the Gandak River, it is 1.00 to 1.93. Braiding channel index is calculated by dividing total channel length in a particular segment of the river reach by its total length of the main active channel. Braid-channel ratio for the Gandak River is 1.33 to 5.38.

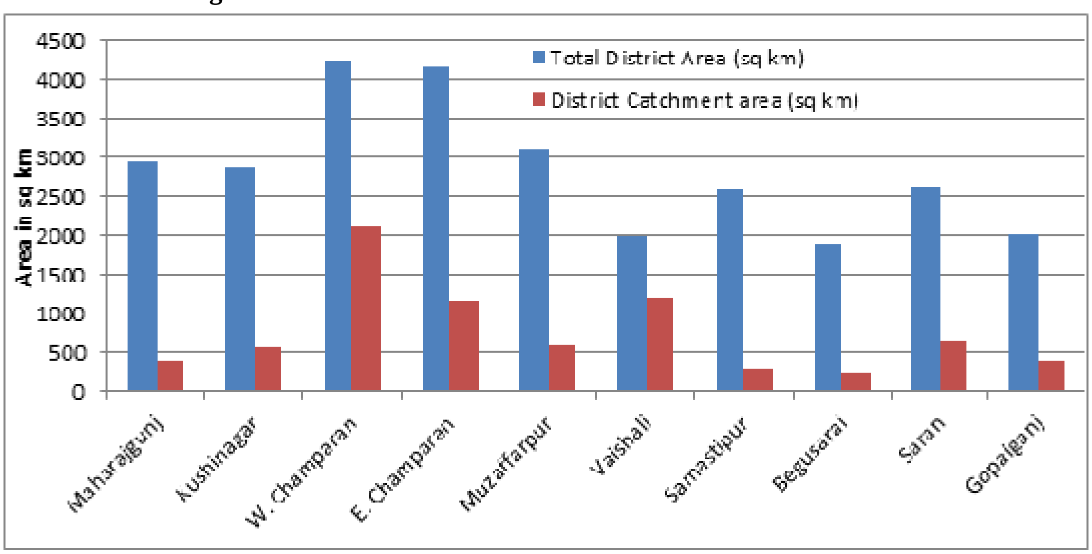
District-wise Area of Lower Gandak Plain

The geographical area of different districts is varying considerably. Therefore, the percentage calculated (Table 2) in column 5th shows the percentage of the district area falling in the Lower Gandak catchment. Rest of the area of the districts is outside of the Lower Gandak Plain. Depending upon the location of the river and general slope of the area, the percentage of area is also varying greatly. Far southeastern districts like Samastipur and Begusarai, which are extending beyond the confluence point, have lesser area under Gandak catchment. The Gandak River confluences with the Ganges, greater area of Vaishali district is in its catchment. Table 2 is very clear and self-explanatory and the diagrammatic presentation of the same in Figure 4 presents a complete picture of the same. The largest area of the Gandak Plain lays in West Champaran constituting 27.56 percent followed by Vaishali (15.75 percent) and East Champaran (15.09 percent) respectively. These three districts encompass 57.8 percent of the entire area. Remaining nine districts occupy only 42.2 percent. The district-wise distribution of the area is very clearly presented in Table 2.

Table 2:- District-wise Distribution of Lower Gandak Catchment Area.

State	Districts	Total area of the district (km^2)	Catchment area in district (km²)	% of catchment area in district	Catchment % in district.
	Maharajgunj	2951	400	13.55	05.25
U.P.	Kushinagar	2874	568	19.76	07.45
	Total	**5825**	**968**	**16.62**	**12.70**
Bihar	W. Champaran	4250	2100	49.41	27.56
	E. Champaran	4155	1150	27.68	15.09
	Muzaffarpur	3123	600	19.21	07.87
	Vaishali	1995	1200	60.15	15.75
	Samastipur	2579	300	11.63	03.94
	Begusarai	1889	250	13.23	03.28
	Saran	2624	650	24.77	08.53
	Gopalganj	2009	402	20.00	05.28
	Total	**22624**	**6652**	**29.40**	**87.30**
Grand Total		**28449**	**7620**	**26.78**	**100.00**

Figure 4:- District-wise Area Distribution in Lower Gandak Basin.



Left Bank Tributaries

Manor, Kanua, Rahua and other minor streams draining the low hills south of Triveni form a combined stream known as Bhabsa and it joins with Gandak at Pathkhauli. Baghi also originates from the low hills southeast of Triveni, drains into Gandak a little downstream to Bagaha. Harha also originates in the low hills and outfalls into Gandak at Balna (Table 3). Dhanauti was a spill channel of Gandak but due to construction of embankment, spilling has stopped and it is almost a dead channel now, which used to fall out into BurhiGandak at Pakri Deal. Baya and Ghaghra are two other small streams in this basin on the left bank. Samhotti joins Baya five kilometers downstream of its off-take. Samhotti carries the drainage of a large area in the south of East Champaran district. Presently due to siltation at several places and upheaval of its bed due to the 1934 earthquake, the drainage is badly affected and water remains stagnant in Baya-Ghaghra valley.

Table 3:- Tributaries of the Lower Gandak River System.

S. No.	River	Direction	Origin	Outfall at	River Condition
1.	Bhabsa	L	16 km east of Triveni	Patkhauli	Live channel
2.	Harha	L	5 km south east of Bagaha	Balna	Live channel
3.	Mahi	R	Village BalnaMasrakh	Hajipur	Live channel
4.	Gandaki	R	Village Karnia	Sitalpur	Dried up/silted up
5.	Ghogri	R	Near Ramkola Factory	Bishambharpur	Dried up/silted up
6.	Kakara	R	Near Bajahia	2 km u/s of Sonepur bridge	Dried up/silted up

Right Bank Tributaries

Mahi, Kakara, Gandaki, Dhamati and Ghogri are the important tributaries of the right bank of Gandak. Mahi takes off at Rajapatti Railway station from the local chaurs and outfalls into Gandak about a kilometer downstream of Sonepur Bridge. Kakara originates from Hardiachaurs and meets Gandak, about 100 meter upstream of Sonepur Bridge. Gandaki originates near Karnia, 154 km stone of Saran Embankment and joins Gandak near Hirapur. Ghori a small drainage channel takes off near Parsauni and joins Gandki near Sitalpur. Except Mahi and Gandaki all other channels have almost silted up. Details of different tributaries of the Gandak River have already been presented in Table 3.

River Reaches

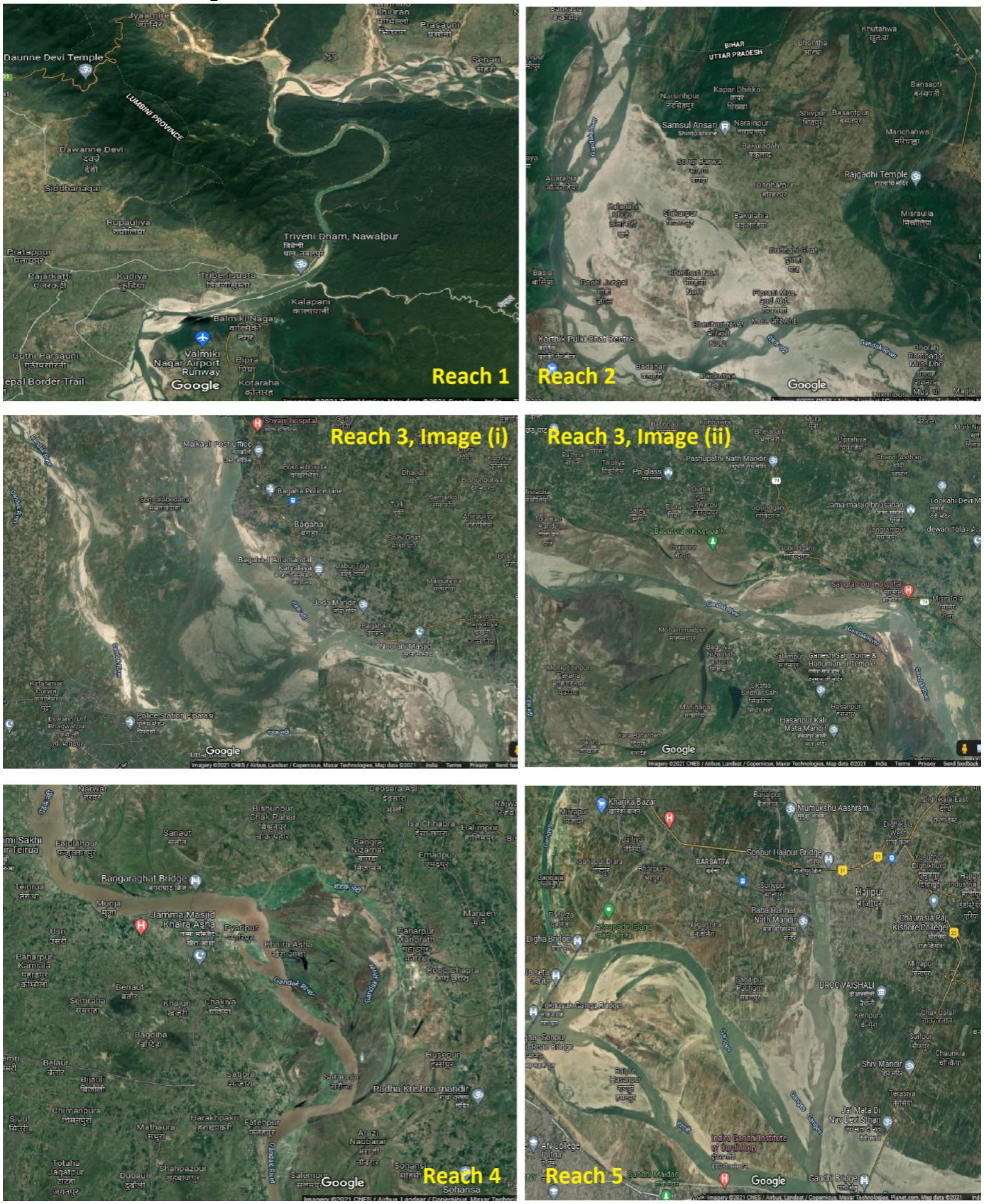
River reach is defined as a section of river stretch where there is similarity in geomorphological and physical conditions in terms of river morphology, discharge, bed material/ geology, river load, and overall behavior of the river. To study the changes in the river reach, and finally grouping the stretch in uniform one reach, a distance of half a km is taken to ascertain the similarity or dissimilarity. The study is conducted and various parameters mentioned above are analyzed.

With this method, the GFCC (2004) has categorized lower Gandak River into five reaches (from serial no 2 to 6) shown in Table 4. Reach one mentioned in the table is in the Himalayan zone, which is known as upper reach or mountainous section. Just by looking at the table, it is quite obvious that these reaches are very distinct in terms of average slope as well as bed materials of the river. It is obvious to note that the change in the slope and bed materials is not abrupt but they change very gradually. Therefore, the categorization of the river reach into different groups by GFCC has more of an academic as well as engineering importance rather than only definitional importance.

Table 4:- Different Reaches of the Gandak River.

SI. No.	Name of the Reaches	Reach length (km)	Average bed slope	Bed materials
1.	River origin to Valmikinagar	365	5.70 meter/km	Boulder and shingle
2.	Valmikinagar to Patharwa Head works	12	0.57 meter/km	Shingle and sand
3.	Patharwa H/W to Chhitauni Rly. Station	28	0.30 meter/km	Average size 0.21 mm
4.	Chhitauni Rly. Station to Dumariaghat	122	0.23 meter/km	N.A.
5.	Dumariaghat to Hajipur	91	0.17 meter/km.	N.A.
6.	Hajipuar to confluence with Ganga	7	≤0.17 meter/km	N.A.

Figure 5:- Some Selected Views of Reaches of Lower Gandak River.



In Reach 1, river is debouching into plain at Tribeni, where three rivers are joining together, seen in the centre of the Figure 5. After leaving mountainous zone, river turns towards south-westerly direction and runs till the second Reach starts. Dekens(2007) rightly said, “the snake and the river don’t run straight”. Therefore, direction mentioned here is with respect to general description and not a specific hard fact. From the beginning of the second Reach, it takes a southerly direction and when it ends, it turns towards south-easterly direction. Almost for entire stretch of Reach three, it is running in similar direction with local departure as the river used to run. In Reach 4, it starts taking turn in southerly direction and in Reach 5, it is running in southerly direction before it confluences with the Ganga river at Hajipur, near Patna.

In the initial stage of entering the river in the plain shows single thread with meandering pattern. With decrease in slope in the plain, the large amount of sediment carried by river water is deposited and the widening of the river is very much apparent from the lower part of Reach one. As more sediment is deposited, the depth of water decreases and widening of the river is conspicuous. Lateral erosion is more and river starts its braiding pattern. Many of the branches and sub-branches of channels are taking offshoots and merging together and diverging continuously. This sort of pattern is obvious in second and third Reaches. Reach four is characterized by turning its channel to single or near to single thread. The meandering is regularly observed, even if, it is braiding pattern. Numerous meander cutoff channels are prominently seen from images. Many of them are detached from the main channel which we call oxbow lake, and many are still attached to it in tortuous turning. In the lower Reaches four and five, the amount of sediment reaching there is significantly reduced and less deposition is observed. That is why, the river becomes narrower in comparison to the upper reaches, and hence, single thread channel is the result. When the river is at spate, the braiding is almost completely submerged and huge single thread flowing river is visible.

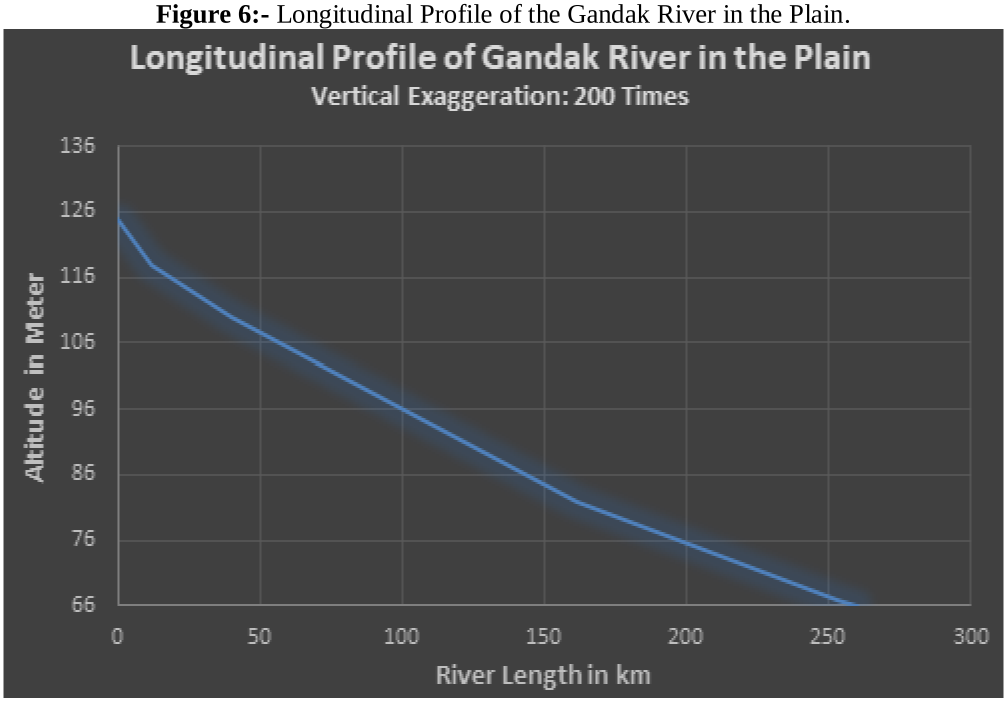
Longitudinal Profile of Gandak River in the Plain

Longitudinal profile is the plotting of river height against the distance measured along the river. Therefore, the plotting of height on vertical axis (y-axis) and distance on the horizontal axis (x-axis) on a graph paper provides the changes in altitude with distance travelled. Table 5 is extracted from the reach-wise information given in the GFC (2004) report (Table 4). The river length is measured from Valmiknagar Barrage and the river distance starts (0 km) from here. It is presented in column three. As per the reach division by GFCC, the height at different places is determined and it is given in the last column.

Table 5:- Length and Height along the Gandak River in the Plain.

Sl No.	Site	River length (km)	Altitude (meter)
1.	Valmikinagar	0	125
2.	Patharwa	12	118
3.	Chhitauni	40	110
4.	Dumariaghat	162	82
5.	Hajipur	253	67
6.	Confluence with Ganga	260	66

Figure 6:- Longitudinal Profile of the Gandak River in the Plain.



A longitudinal profile of the Lower Gandak River is prepared based on the Table 5 and illustrated through Figure 6. In general, when river is getting its origin in the higher altitude, the change in the slope is very abrupt. Even small amount of water available in high altitude with greater slope, river performs very high erosional work. It happens, because water is rushed very wildly. Erosive power is very high. Vertical erosion is prominent, river bed is very deep. The shape of the longitudinal profile is concave in mountainous reach. The same river, when it reaches to plain, the altitude is reduced. Relief is less, area is flat, and slope becomes very low. The widening of the channel is prominently observed. More and more sedimentation becomes the norm. Channel’s carrying capacity is reduced so, huge amount of sediment is deposited in the river bed. Therefore, the profile of the river is flat and almost straight line is noted. Change in the height is lowered per unit of the travelled distance along the river. That is why the gradual change in the slope is very prominent in the plain which is very much clear from the Figure 6.

Topography

The Lower Gandak River system extends from the Himalayan foothills in the north, to the river Ganga in the south. The topography, geology, vegetative cover, slope, utilization of land etc. in the upper Himalayan catchment play very decisive role in the lower catchment in terms of land and flood management. The sole problem of flood and land management lays in arresting the sediment charged water coming from the upper mountainous reach of the Lower Gandak River plain. This sediment loaded water is responsible for forming river plain in the lower part. The plain of the Gandak is in the formation stage since the beginning of upliftment of the Himalayas. It is still continuing and every year huge amount of sediment is deposited and the plain keeps on growing in the process. Therefore, the topography of the lower part is almost featureless plain with some exceptions. River channels, meanders, pools and refills, bhangra (old alluvium), khadar (new alluvium) are very clearly identifiable. The change in the river/ channel course, avulsion or cutoffs etc. is common in the plain.

The Himalaya is a young mountain and formed due to the plate movement, there is crushing effects in the rocks lying there. The rocks are soft, fragile, unconsolidated and sensitive to erosion (Prasad 2010). Human encroachment in the Himalayan delicate environment and ecosystem and their activities are increasing the yield of sediment in the flowing water of the rivers. Hence, sediment charged water brings enormous amount of load and the same is partly deposited and partly expelled to the Ganges. Deposition of sediment has created higher bed level of the rivers particularly where they are embanked. To get rid of the problems of sediment and flood in the plain, arresting the same in the upper catchment is the key measure. It could be done only through the judicious land use and their management upstream to Valmikinagar/Triveni.

The loads brought by the rivers forms inland deltas. This inland delta is known as mega-fan of the Gandak River. Since channel shift is very common with Gandak in its mega-fan area of the plain, numerous ponds, channels, lakes etc. are formed and with time, get integrated into fewer channels and thus, channel improves (Mohindra and Prakash, 1994). Several abandoned river courses or/ and large water bodies are locally known as maun, chaur, tal, pokhar etc. have deep beds with much water accumulation. Overall, the plain is flat and change in the slope is very gentle. In the north and northwest the slope is relatively steep as it happens with all rivers, when it debouches into the plain from the mountainous region. The average drop in height along the river is 59 meter in a distance of 260 km from Valmikinagar to the confluence of the Gandak with the Ganges (Table 5). It works out to be an average gradient of 23.08 cm/km.

Geology

The area occupied by the Gandak River system can be stratigraphically divided as conglomerates, sandstones and clays in its upper reaches, lignite, sandstones and clays in the middle reaches and grey and purplish sandstones silt and clay in the lower reaches. It is well known facts that the Siwalik range is very young whereas the northernmost part is the oldest one, but not more than 70 million years old. The surface rocks of the plain is the newest one and gets made/ evolved every year by the exogenetic forces primarily by running water and winds. The exposed rocks along the slope in the Himalayan areas are subject to great physical, chemical and biological weathering. This area experiences very heavy downpour in monsoon season. Hence, large amount of sediment is produced and deposited in the downstream leading to creation of new rocks.

Soil Characteristics

The Gandak River basin possesses mainly three types of soils. They are: (i) Terai soil (ii) Calcareous alluvial soil (iii) Alluvial soil.

Terai Soil

The Terai region is located at the southern margin of the Himalayas. It is characterized by unconsolidated and fragmented rock materials created at the latest orogeny of the Himalayas. The soils found here are composed of boulders, pebbles, gravels, sand and silt mixed with clay. This type of soils is found in the northern frontiers of the Lower Gangak Plain. They are distributed in the districts of Maharajganj, Kushinagar, West Champaran and East Champaran.

Calcareous Alluvial Soil

The calcareous alluvial soils have high content of calcium carbonate ($CaCO_3$). These soils are spread over some area of Kushinagar district in U.P. and East and West Champarans, Muzaffarpur, Saran and Samastipur districts in Bihar. These soils are light coloured and their texture varies from sandy loam to loam. The PH value of the soil is on the alkaline side (GFCC, 2004).

Alluvial Soil

The alluvial type of soils represents the vast tracts of riverine alluvium of the Gangetic plain. These soils are spread over both the sides of the river Gandak covering the districts of Kushinagar, in U.P. and Chapra, Siwan, Gopalganj, East Champaran, West Champaran, Muzaffarpur and Samastipur in Bihar. The colour of these soils ranges from pale grey, yellow to yellow-brown and dark grey. The texture is generally silty loam or silty clay loam. These soils respond very well to manures and fertilizers but need drainage facilities. The principal soil types found in various districts lying in the lower basin is presented in Table 6 (GFCC, 2004).

Table 6:- Soils in the Lower Gandak River Basin.

State	Districts	Type of Soil
Uttar Pradesh	Maharajganj	Calcareous Alluvial Soil
	Kushinagar	Calcareous alluvial Soil, Alluvial Soil
Bihar	W. Champaran	Terai Soil, Calcareous, Alluvial Soil
	E. Champaran	Terai Soil, Calcareous, Alluvial Soil
	Muzaffarpur	Calcareous alluvial Soil, Alluvial Soil
	Vaishali	Alluvial Soil
	Samastipur	Calcareous Alluvial Soil
	Begusarai	Alluvial Soil
	Saran	Calcareous Alluvial Soil
	Gopalganj	Alluvial Soil

Sediment Characteristics

The River Gandak, exhibits meandering tendency in the plain where slope becomes less. Due to lesser slope in the plain and great amount of water to be discharges from the channel, river tends to meander by eroding the channel by eddies effect at one side and depositing the eroded materials on the other side mentioned before (Figures 2, 3 and 5). This creates a loop in the running path of the channel. Therefore, the sediment plays great role in the meandering, channel shifting and braiding.

Huge amount of sediment brought from the upstream is deposited in the plain as well as in the bed of the river with reducing discharge in the lean season. Due to this, the channel is on the tendency to carve out a channel nearby the existing one. Sometimes, the shifting happens not only in the vicinity of the existing but also great departure is observed. The departure of about 4 to 5 km has been observed westward during last 50 years. This trend of westerly movement appears to be still continuing but within the two embankments of the Gandak. One of the main reasons for this extraordinary shift in its course has been attributed to the excessive silt charge. The causes of excess silt movement are mainly because of deforestation, uncontrolled cultivation on the Himalayan slopes, human encroachment in the virgin ecosystem and felling of forest etc. Besides, frequent landslides during monsoon also contribute considerably to the silt charge. The seriousness of silt problem in the basin deserves urgent attention towards taking suitable measures to minimize the silt load, which is mostly generated in the hilly catchments lying in Nepal.

Greater amount of deposition of sediment in the plain is also responsible for the breading pattern of the river. It happens because the deposition of sediments in the bed of the river causes the obstruction in the passage of the flow of water particularly in the lean season. Numerous islands like structures appear within the two banks of the river. The channels of the river bifurcates, diverges, goes apart, meets further downward side and thus it keeps on happening for a considerable distance (Figures 2, 3 and 5). This is braiding which is very common to those rivers which bring enormous sediments along with its water.

Conclusions:-

A general description of the study area – Lower Gandak flood plain has been presented in brief. The whole of the area is confined to the ten districts (two of UP and eight of Bihar). The northwestern districts possess little area under foothills. Rest of the area is completely flat plain with marginal change in the slope. The most of the Lower Gandak plain is made up of recent alluviums. On the basis of similarities or differences, river reaches are demarcated by GFCC which are five in number, there is gradual changes from one reach to another and thus, their characteristics changes as well. The changes could be seen in terms of slope, sized of materials deposited, width-depth ratio of the channels as well as in different channel geometry parameters. In the uppermost as well as in the lowermost reaches, river is relatively more stable in comparison to the middle reaches. The dynamism is caused by the loads of the river brought by running water especially during monsoon season. Though, meandering is visible all along its length, but braiding is conspicuous in the middle reaches because of more deposition of sediments. The upper mountainous catchment receives torrential rain and snow melt of Himalayan glaciers adds more water in the hot summer monsoon ultimately leading to flood fury and flood plain formation activities of the Gandak River. Sediment brought by the Gandak River is a big challenge in minimizing the flood loss. In fact, the primary problem of the Gandak River in the plain is to arrest the huge sediment in the upper Himalayan catchment, which comes under a foreign territory. A proper coordination and cooperation is the basic concern regarding solving/ minimizing the flood problems. Hence, the problem of the flood in the Gandak Plain is to be tackled in an integrated manner and not on a piece meal basis.

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