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Application of Geo-Spatial Technique in River Shifting Analysis of the Ghaghara River: Case Study from Bahraich to Ballia, Uttar Pradesh, India

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Abstract: ***The present Study evaluated the Spatio-temporal variation in term of river sifting analysis of the previous 43 years using Survey of India (SOI) toposheet on 1:50,000 scale and Satellite imageries were studied for the flood dynamics. In the study, the maximum migration of the River channel has recorded which is 7, 4.9, 6.5, 4.5 kilometers sifted with a rate of 464.9, 195, 184.8, 105.3 meter/year from 1975-1990, 1975-2000, 1975-2010, 1975-2018 respectively in direction NNE in its proximal part and SSW in the distal part. The spatio-temporal sinuosity of the channel has been measured which is 1.3, 1.3, 1.2, 1.2, and 1.3 for year 1975, 1990, 2000, 2010 and 2018, respectively. The dominance of sand and silt are prone to lateral erosion and further Sinuosity in the river occurs due to high discharge and sudden reduction in gradients as well as flow velocity. The analysis with respect of the abbreviation is very susceptible to identify the future migration. Due to irregular meandering, lateral shifting and the high sinuosity which is very sensitive to persistent floods and lateral erosion that causes major losses of property and living beings. It is suggested that the structure to protect the floods is essential for both of its bank.***

Keywords: Ghaghara River, Geo-spatial technique, Lateral sifting, Sinuosity Index, Lateral erosion, Flooding.

1. Introduction

There are many factors controlling the meandering channel morphology like discharge variability, sediment load, slopes, channel resistance, vegetation, bank stability by [1], [3]. The meander belt as the lateral distance between meanders within the reach [4]. The temporal sequence of the channel positions is evaluated using the geographic information system [5], [6]. Ghaghara River is notorious for their valley incision through lateral erosion occurs as an active hazard during low-discharge period, apart from flooding and stream bank erosion during high-discharge periods [11]. Lateral erosion was recognized during low discharge time period is an acute hazard between Bahraich and Ballia. The high discharge during monsoon season cause irregular meandering, lateral shifting triggers the flood in the Ghaghara River [8]. The occurrence of flooding is persistent in the eastern part of Uttar Pradesh, which is result of discharge of rivers such as Kuwana, Rapti, Chhoti Gandak, Ghaghara, and Great Gandak [11]. The erosion of the stream bank is considered to be caused by flooding, and erosion on sandy soils is higher than on silty soils [2].

2. Study area

The study area is starting from Bahraich to Ballia and geographically it lies between 25° 58'and 27° 15' N and 81° 25' and 84° 15' E. (Fig. 1) Ghaghara is a snow-fed river which originates near the Mapchachungo glacier (Mansarover Lake) from Tibet Himalaya and confluent in Ganga. It is Ganga's largest tributary by volume and its second largest by length. It is a dynamic river regarding their valley widening and lateral shifting through incision/erosion. Slope towards NW – SE direction. The river having irregular meandering, lateral shifting due to high discharge during monsoon triggers the flood in Ghaghara River.

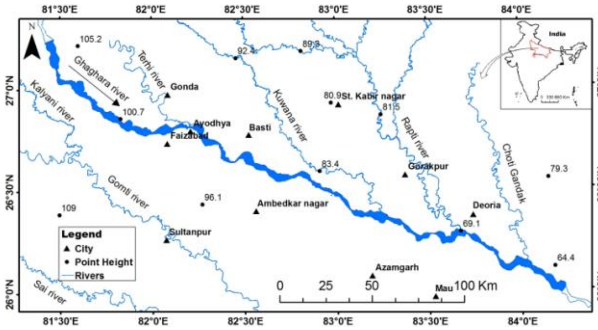

Figure 1: Location map of the Study area

3. Methodology

The study of Ghaghara River carried out using SOI topographical maps of 50,000 scale for the year 1975 and multi-date satellite imageries including, LANDSAT Thematic Mapper (TM) for the year 1990, LANDSAT-7 Enhanced Thematic Mapper Plus (ETM+) for the year 2000, LISS-3 for the year (2010) and Landsat-8 Operation land imager (OLI) for the year 2018 (Fig. 2) With the help of Arc GIS 10 software. (Table. 1)

Table 1: Specification of the satellite data sets used

Satellite/ Toposheet	*Data source/ Sensor*	*Band*	*Resolution*	*Date*
Toposheet	Survey of India	-	50,000 scale	1975
Landsat-TM	TM	7	30 m	1990
Landsat-7	ETM+	8	30 m	2000
Resourcesat-I	LISS-3	4	23.5 m	2010
Landsat-8	OLI	11	30 m	2018

4. Result and Discussion

4.1. Analysis of sinuosity parameters

Rivers with a sinuosity index 1.3 shows the sinuous in nature and 1.5 are lead to meandering nature [4] (Table.2). The sinuosity index calculated for all identified sections for monitoring the channel Sinuosity parameters of the river using the procedure of 1 [4] following equation for each reach.

SI = Cl/Vl

The sinuosity has been measured of the river. The total distance of selected segments of the river is 403 km was divided into 10 equal sections. The computed value of the sinuosity index of the river segments for the year 1975, 1990, 2000, 2010 and 2018 is 1.3, 1.3, 1.2, 1.2, and 1.3, respectively. (Table. 3) During 1975, and 1990, the river was high sinuous. In year 2000 and 2010 the sinuosity parameters decreased sharply while again it increased during 2018 (Fig. 3)

Table 2: Classification of the Sinuosity Index and channel pattern based on [4]

Number of channels	*Ratio*	*Channel Pattern*
Single channel	< 1	Straight
Wandering channel	1 -1.3	Low sinuous
Braided channel	1.3-1.5	High sinuous
Anastomosing channel	>1.5	Meandering

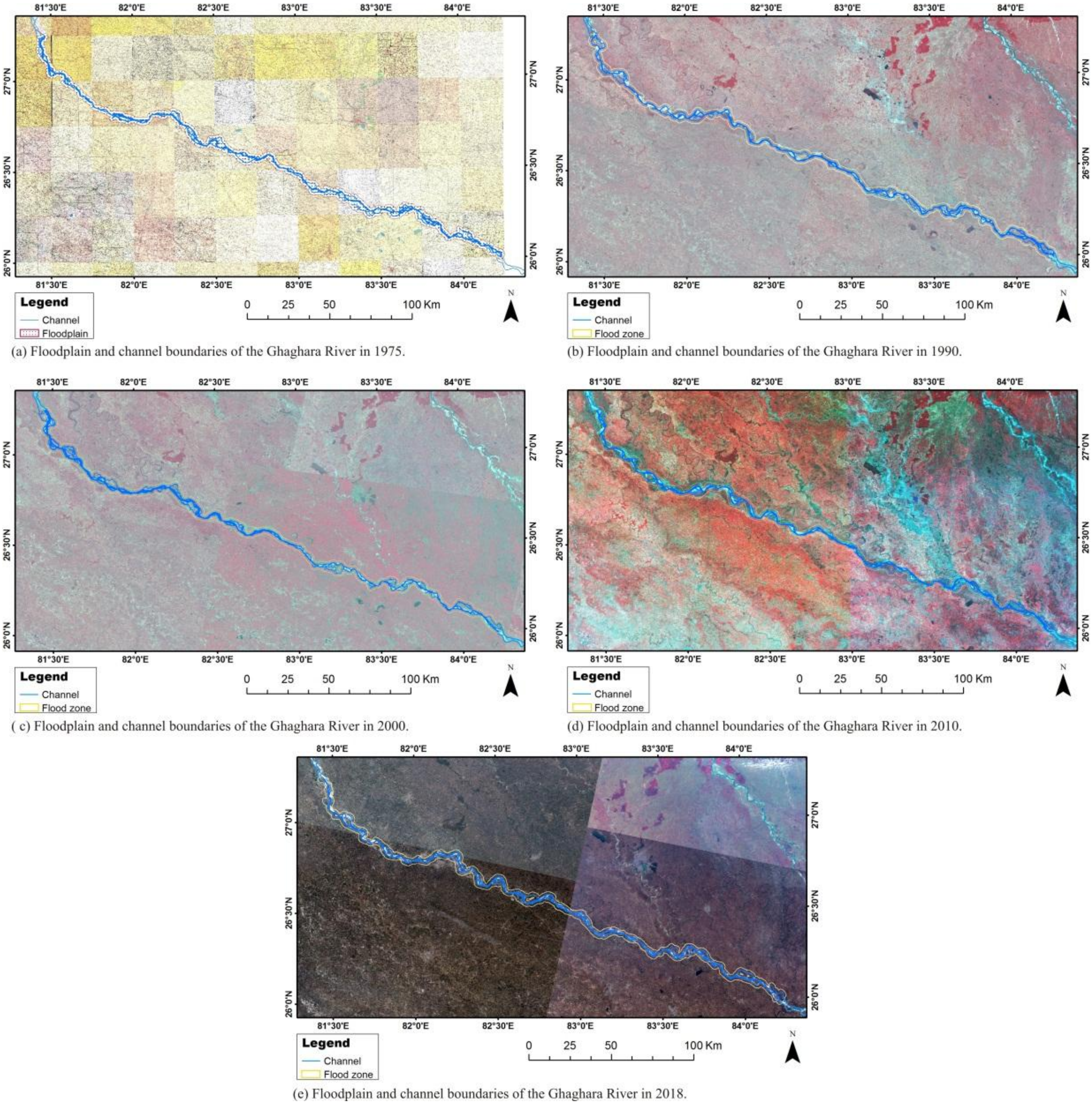

Figure 2: Floodplain and channel boundaries of the Ghaghara River. (a) 1975, (b) 1990, (c) 2000, (d) 2010, (e) 2018. (a) Floodplain and channel boundaries of the Ghaghara River in 1975. (b) Floodplain and channel boundaries of the Ghaghara River in 1990. (c) Floodplain and channel boundaries of the Ghaghara River in 2000. (d) Floodplain and channel boundaries of the Ghaghara River in 2010. (e) Floodplain and channel boundaries of the Ghaghara River in 2018

Table 3: Sinuosity analyses of Ghaghara River from 1975 to 2018

River Segments	*Sinuosity Index*				
	1975	*1990*	*2000*	*2010*	*2018*
1	1.4	1.5	1.3	1.2	1.2
2	1.2	1.2	1.2	1.2	1.3
3	1.2	1.4	1.1	1.2	1.2
4	1.3	1.4	1.2	1.4	1.4
5	1.2	1.2	1.3	1.3	1.4
6	1.3	1.1	1.2	1.2	1.3
7	1.2	1.3	1.2	1.2	1.2
8	1.3	1.3	1.3	1.3	1.2
9	1.2	1.2	1.2	1.2	1.4
10	1.3	1.2	1.1	1.2	1.2
Avg.	1.3	1.3	1.2	1.2	1.3

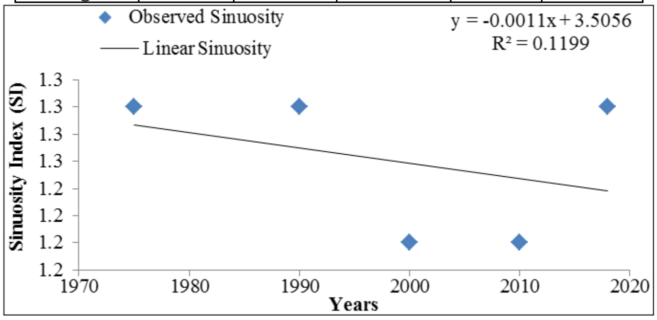

Figure 3: Spatio-temporal Sinuosity of the Ghaghara River

4.2. Analysis of channel shifting

The shifting measurements using the transect method given by [7].

1) The first step is specifying the origin channel; the main channel of 1975 was considered the origin channel.
2) The second step was to divide the flood plain into transects. The floodplain of 1975 was divided into transects of 40.3 km length each.
3) The third step was to overlay the center line of the low flow channel of all years and the floodplain transects in ArcGIS.
4) The fourth step was the changes in the position of the intersection of the main channel center line with floodplain transects in ArcGIS for all the periods and the direction of channel migration.
5) Migration rate is the outcome of dividing the migration distance by the number of years between various images the topographic map (1975). Fig 4.

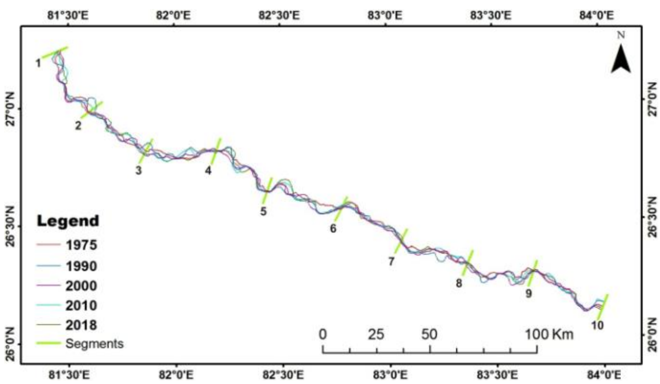

Figure 4: The cross section along the river showing Spatio-temporal River channel

4.3. Analysis of Migration rate from 1975 to 2018

Migration rate has measured for the year 1990, 2000, 2010, and 2018 after that compared with year 1975. The results of the river lateral shifting, migration rate and its direction (Fig. 5). The field survey concludes the meandering of the river cause lateral erosion (Fig. 10)

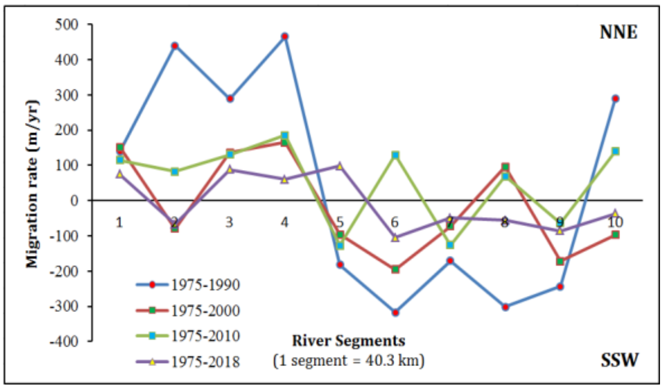

Figure 5: Migration rate of the Ghaghara River channel

4.3.1. Migration rate from 1975–1990

From the year 1975–1990, the lateral distance of the river for segment 1, 2, 3, 4, 10 is 2.1, 6.6, 4.3, 7, 4.3 km, it shifted with a rate of 139.7, 439.8, 288.9, 464.9, 289.3 m/year in the direction of ENE, NE, NNE, N, NE and for segments 5, 6, 7, 8, 9 the lateral distance measured is 2.7, 4.7, 2.6, 4.5, 3.7 km, it shifted with a rate of 182.1, 316.6, 171.1, 301.3, 243.7 m/year in direction SW, SW, SW, S, SE respectively. (Table 4) The river has maximum sifted 7 km with migration rate is measured 464.9 m/yr. The migration rate at sections 2, 3, 4, 6, 8, and 10 increased spatially except section, except 1, 5, 7, and 9 lower reaches. (Fig. 6)

Table 4: Shifting, measurement from 1975 to 1990

1975-1990			
River Segments	*Lateral distance (km)*	*Migration rate (m/year)*	*Direction*
1	2.1	139.7	ENE
2	6.6	439.8	NE
3	4.3	288.9	NNE
4	7	464.9	N
5	2.7	182.1	SW
6	4.7	316.6	SW
7	2.6	171.1	SW
8	4.5	301.3	S
9	3.7	243.7	SE
10	4.3	289.3	NE

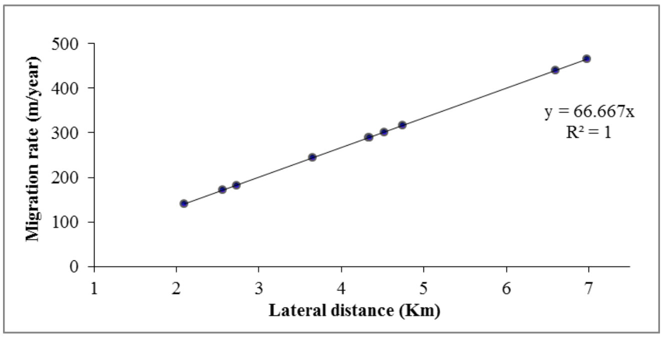

Figure 6: Graph showing Migration rate from 1975 to 1990

4.3.2. Migration rate from 1975–2000

From the year 1975–2000, the lateral distance of the river for segment 1, 3, 4, 8 is 3.8, 3.4, 4.1, 2.4 km it shifted with a rate of 151.1, 136.7, 165.5, 95.6 m/year in the direction of E, NNE, NNW, NNW and for segments 2, 5, 6, 7, 9, 10 the lateral distance observed 2, 2.4, 4.9, 4.9, 1.8, 4.3, 2.4 km, it shifted with a rate of 79.2, 95.9, 195, 72.9, 172.6, 96.9 m/year in direction SW, SW, SSW, SSW, SSW, SW respectively. (Table 5) The maximum sifting of river is 4.9 km with migration rate 195 m/yr. (Fig. 7)

Table 5: Shifting, measurement from 1975 to 2000

1975-2000			
River Segments	*Lateral distance (km)*	*Migration rate (m/year)*	*Direction*
1	3.8	151.1	E
2	2	79.2	SW
3	3.4	136.7	NNE
4	4.1	165.5	NNW
5	2.4	95.9	SW
6	4.9	195	SSW
7	1.8	72.9	SSW
8	2.4	95.6	NNW
9	4.3	172.6	SSW
10	2.4	96.9	SW

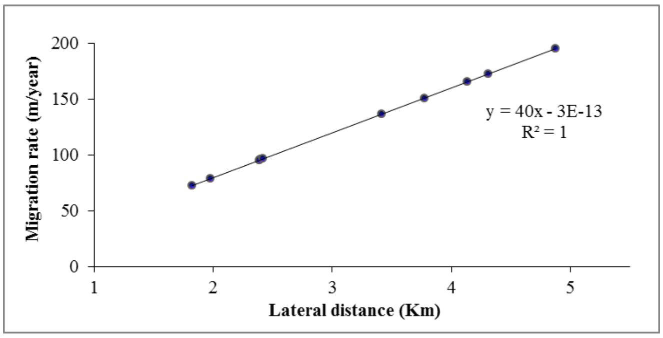

Figure 7: Graph showing Migration rate from 1975 to 2000

4.3.3. Migration rate from 1975–2010

From the year 1975–2010, the lateral distance of the river segment 1, 2, 3, 4, 6, 8, 10 is 4, 2.9, 4.6, 6.5, 4.5, 2.4, 4.9 km, it shifted with rate 115, 82.5, 130.2, 184.8, 129.7, 69.7, 139.6 m/year in direction ENE, NE, NE, NNE, ENE, NE, NE and for segments 5, 7, 9, the lateral distance calculated 4.5, 4, 2.2 km, it shifted with rate 127.9, 126.7, 63.5 m/year in direction SSW, SSW, SSE respectively. (Table 6) The maximum sifting of river is 6.5 km with migration rate184.8 km/yr. (Fig. 8)

Table 6: Shifting, measurement from 1975 to 2010

1975-2010			
River Segments	*Lateral distance (km)*	*Migration rate (m/year)*	*Direction*
1	4	115	ENE
2	2.9	82.5	NE
3	4.6	130.2	NE
4	6.5	184.8	NNE
5	4.5	127.9	SSW
6	4.5	129.7	ENE
7	4.4	126.7	SSW
8	2.4	69.7	NE
9	2.2	63.5	SSE
10	4.9	139.6	NE

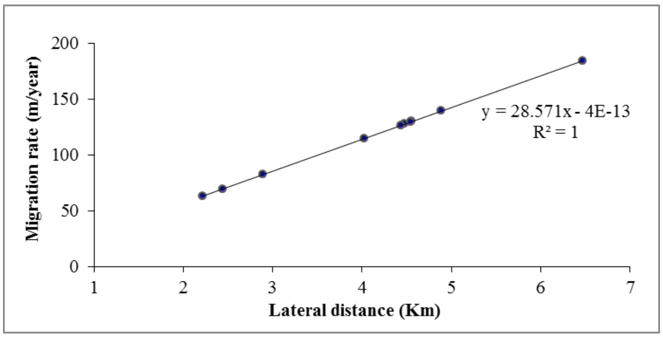

Figure 8: Graph showing Migration rate from 1975 to 2010

4.3.4. Migration rate from 1975–2018

From the year 1975–2018, the lateral distance of the river segment 1, 3, 4, 5 is 3.2, 3.8, 2.6, 4.2 km, it shifted with rate 74.9, 87.7, 59.6, 98.2 m/year in direction ENE, NE, NE, ENE and for segments 2, 6, 7, 8, 9, 10 the lateral distance measured 2.9, 4.5, 2.1, 2.4, 3.7, 1.6 km, it shifted with a rate of 67.3, 105.3, 49.7, 57, 85.8, 36.8 m/year in direction SW, SW, SW, SE, SE, SW respectively. (Table 7) The lateral distance of the river is calculated 4.5 km with a rate of 105.3 m/yr. (Fig. 9)

Table 7: Shifting, measurement from 1975 to 2018

1975-2000			
River Segments	*Lateral distance (km)*	*Migration rate (m/year)*	*Direction*
1	3.2	74.9	ENE
2	2.9	67.3	SW
3	3.8	87.7	NE
4	2.6	59.6	NE
5	4.2	98.2	ENE
6	4.5	105.3	SW
7	2.1	49.7	SW
8	2.4	57.0	SE
9	3.7	85.8	SE
10	1.6	36.8	SW

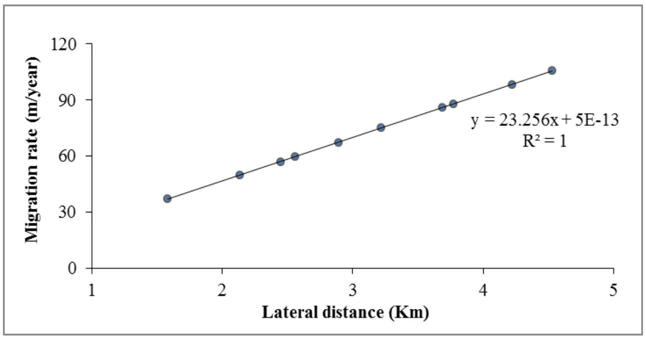

Figure 9: Graph showing Migration rate from 1975 to 2018

4.4. Delineation of meander belt

The channel belt relates to the areas where the channel was a ctive. According to this definition, channel delineation depends on locating the areas which were occupied by the river during the previous years. As the river in the study stretch is braided, the channel belt includes both active and abounded channels. The channel belts were delineated manually by drawing simple polygons covering the channel belt in the years 1975, 1990, 2000, 2010 and 2018. The polygons (channel belts) were overlaid and merged together to get the overall channel belt. (Fig. 10) Show the channel belt in various years and (Fig. 11) show the meander belt of the Ghaghara River in the study area. The overall belt widths were measured in all the sections and the width varied from 1 km to about 3.5 km with an average value of about 2 km. The delineation of the meander belt is important as it has a direct impact on the planning of flood protection works.

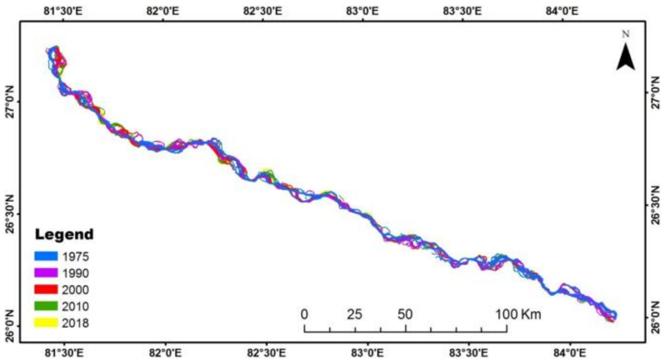

Figure 10: Channel belts of the Ghaghara River during the study period

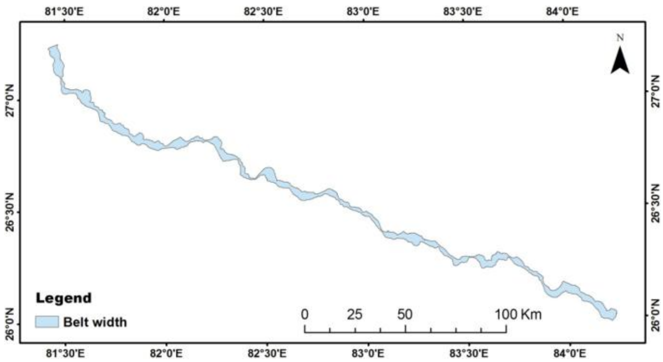

Figure 11: Meander belt of the Ghaghara River between Bahraich to Ballia

4.5. Flood effect along the Ghaghara River

The Ghaghara River having wide valley and Channel is narrow. The high discharge during monsoon season triggers the flood in Ghaghara River; Due to irregular meandering, lateral shifting and the high sinuosity nature that cause flood hazard. Places having high sinuosity and dominance of sand and silt are prone to lateral erosion whereas, high discharge is prone to flooding. [9]. The Spatio-temporal sifting analysis of the channel and field investigation help to identify the prone site that under more vulnerable to the flood. (Fig 12)

Figure 12: Vulnerable flood site along the Ghaghara River near Gorakhpur, Uttar Pradesh, India (Source : Google Earth)

4.6. Lateral erosion along the Ghaghara River

The measured sinuosity indexes and Sifting analysis reveal that the river increase the rate of erodibility may be accomplished through undercutting and slope destabilization leading to lateral erosion and susceptible to the floods along the channel due to bank instability. It became a disaster problem. The lateral erosion was identified as an independent fluvial hazard which operates during low discharge period [10]. The flood has extremely been destroying crops, Villages and property, which showing in the (Fig. 13, 14)

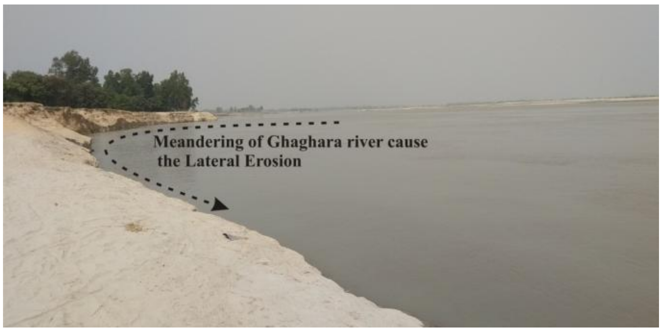

Figure 13: Showing meandering of the Ghaghara River near Maldha, Faizabad, Uttar Pradesh, India.

Figure 14: Lateral erosion of the Ghaghara River near Itahua Purab, Barabanki, Uttar Pradesh, India

4.7. Flood hazard zonation map

Flooding and lateral erosion in the Ghaghara are recognized as fluvial hazards. Showing lateral erosion operates during low-discharge period, Flood hazard zonation map clearly shows that under the study area the Ghaghara River is known to widen and flood its valley and the area along the river having the prone to flooding. Based on the flood plain (FP) mapping two zone constructed zone 1 and zone 2. Which is identified a lateral erosion zone and flood zone respectively. The flood plain in Zone 1 shows a higher loss in the agricultural land and soil than the settled areas while in Zone 2, the flood plain meanders according to the channel causing high record of flood inundated areas in the settled localities or villages than the agricultural domains. The observation of the differential flooding pattern may be because of gentle slope and high discharge during monsoon season contribute to the high pace of flood during monsoonal peaks. Thus, it can be concluded that within a short traverse of the Ghaghara River from Bahraich to Ballia the flooding impact can be observed differently due to the geomorphic landscape and this can be proved very effective with the aid of Geo-spatial technique (Fig 15, 16, 17) .

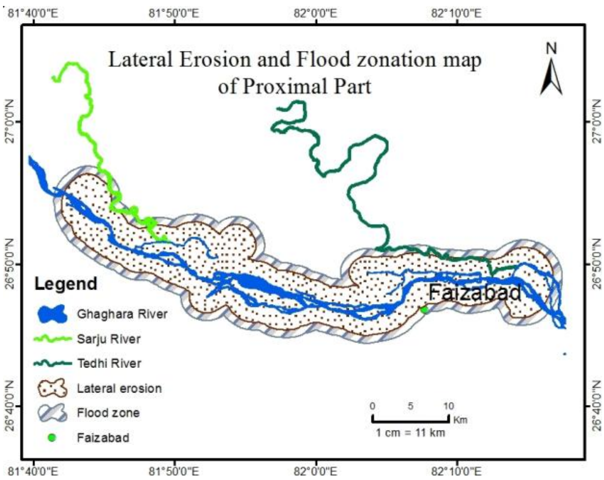

Figure 15: Lateral Erosion and Flood zonation map of proximal part of the River

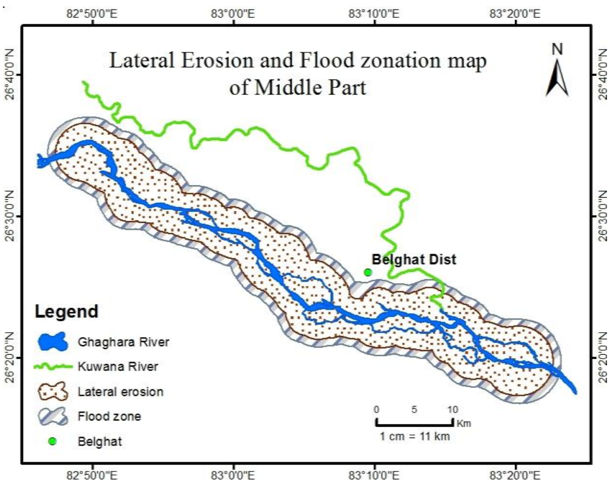

Figure 16: Lateral Erosion and Flood zonation map of Middle part of the River near Ballia, Uttar Pradesh

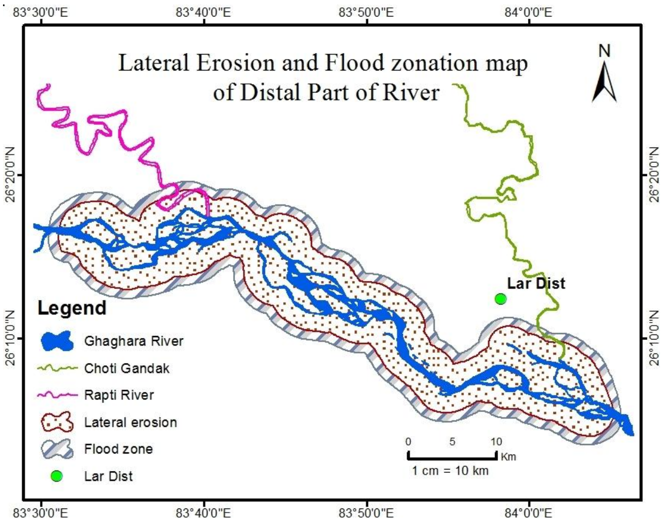

Figure 17: Lateral Erosion and Flood zonation map of distal part of the River near Ballia, Uttar Pradesh

4.8. Mitigation

The occurrence of lateral erosion and flood is a natural phenomenon, and the human disturbance also, Even the lateral erosion and flood hazard could not prevent however it minimize the effect. The impact of flooding and lateral erosion can be reduced to the construction of embankments, building reservoirs detention basins artificial levee, lateral dams, dumping of the boulders, sand and cement bags, desiltation, and afforestation. Beside it the other precaution can be followed such as Predictions, warning system, emergency protection, flood and lateral erosion area delimitation and land use planning.

5. Conclusions

The Ghaghara sinuosity index is indicating high sinuous in nature, the Spatio-temporal changes in the river occur due to Heavy discharge during the monsoon season which generates the high magnitudes of flood. The irregular meandering and lateral shifting of the river occurs due to increase their discharge variability by straightening, widening and deepening and sediment load which may cause the area is subjected to erosion and high flood risk. The Spatio-temporal shifting analysis with respect of abbreviation is very susceptible to identify the food prone site and future migration of the river for both of its bank. Therefore, the trend of the river channel shifting within the valley should be analyzed to save the human population and settlement form river born hazards. Damage impacts can be minimized by better flood management, flood control measures, improved disaster preparedness and flood fighting, including the setting up of forecasting and warning systems. The delineation of the meander belt is helping in planning of flood protection works, Building embankments, improving drainage, reservoir containment and forestation etc.

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