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Analysis of the Changing Morphometry of River Ganga, shift monitoring and Vulnerability Analysis using Space-Borne Techniques: A Statistical Approach

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Abstract- An attempt has been made to study one of the most severe hazards in West Bengal, India. Study has been carried out to analyze and report the river bank erosion due to morphometric change of the Ganga River, upstream of Farakka Barrage up to Rajmahal. Here, Sinuosity, Braidedness Index, percentage of the island area to the total river reach area have been measured for the year of 1955, 1977, 1990, 2001, 2003, 2005 and 2010. The analysis shows a drastic increase in all of those parameters over the period of time. For increasing sinuosity, the river has been engulfing the large areas of left bank every year. The victims are mostly from Malda district. Another task of this study is to get the temporal shift monitoring for the river reach. 22 cross-sections have been made to get that shift statistics along each cross-section. This task has been followed by vulnerability analysis to assess the risk for the gram-panchayets for next 10 years. These risk zones have been identified by applying linear regression method for each cross-section after proper validation. So, by risk zoning with the aid of remote sensing and GIS technologies, we can plan for better hazard prevention and preparedness programs.

Index Terms- Morphometric change, shift, Vulnerability analysis, remote sensing and GIS.

I. Introduction

Sufficient energy for bank erosion and intensified secondary circulation appear to be necessary for active meandering (Richard, 1973). Bank erosion for channel migration demands available stream energy that reaches its peak level during bank full stage. Higher velocity and direct flow against one bank enforce the changing in direction of the alternate sides in the downward stretch. More dramatic changes may result from the formation of cut-offs. In this process, the pattern of broad channel may change, new bars may be formed and the old bars may be destroyed and the whole channel may shift across the flood plain.

The time sequential Earth Observation Satellite data play a facilitator role in conceptualization of the morphogenesis of the landform units in a meaningful way through visual communication to enrich the individual thinking on the matter. The spatial database generated through comparative study of the SOI toposheets, Police Station maps with the up-to-date satellite imageries reveal that the oscillation of the Ganga River is very much restricted within the limit of the former flood plain of the river, at least in the last century. This base line data may be considered as a synergetic tool by the decision makers for better understanding to put effort in setting up related technical aspects and social adaptations in monitoring of the recurrence of the natural disasters like flood, bank failures etc. in this stretch of river reach.

Remote sensing will give the accurate bird's-eye picture of the total area at a particular time which is spatially corrected and true to scale. GIS will correlate temporal, spatial as well as non-spatial information, to make a comparative analysis among them. So, satellite data interpretation in GIS environment gives us the primary data base to analyze in statistical control followed by the outcome of a tentative tendency of the river oscillation for future.

II. BRIEF DESCRIPTION OF THE STUDY AREA

The study area comprises Ganga River channel flowing through five blocks of Malda district and two blocks of Murshidabad district of West Bengal. These are Manikchak, Kaliachak-I,II,III and English Bazar of Malda District and Farakka and Shamsherganj of Murshidabad District. The area extends from $87^{0}76'$ E to 88^{0} E and from $24^{0}64'$ N to $25^{0}29'$ N. This stretch of the river has been taken to study the morphometric changes in this project. Another micro-level study, carried out for the mouza Jot Kasturi of Kaliachak-II block, has a geographical extent from $24^{0}39'$ N to $25^{0}14'$ N and $87^{0}44'$ E to $88^{0}12'$ E. This mouza has an area of 288.49 km^2. Number of household is 926. Total population of the mouza is 4491 among which 2353 are male and 2138 are female (2001).

III. METHODOLOGY

Firstly, river layers for the total study area have been generated from Police Station Map, Toposheets and satellite images of 1977, 1990, 2001, 2003, 2005, 2009 and 2010. Those river reaches are then used for a comparative analysis of sinuosity, braidedness and island area. These are also used for shift measurement of left bank along 22 cross sections, which are made across the study area river reach. It helps to identify the vulnerable zones along the left bank of the river and analyze the economic viability of the bank protection measures to be taken along those vulnerable banks.

IV. DATA USED

Police station map of Malda District on 1" to 4 miles scale of 1929-31

SOI Toposheets (Scale- 1:50,000)
- 1:50,000 Scale toposheets number- 72O/16, 72P/13, 72P/14, 78C/4
- Other toposheets of the area are not available

Satellite Imagery

Satellite	Sensor	Path	Row	Date of Pass
LANDSAT	MSS	139	043	10.02.1977
LANDSAT	TM	139	043	21.11.1990
LANDSAT	ETM	139	043	20.10.2001
IRS-1D	LISS-III	107	054	18.02.2003
IRS-P6	LISS-III	107	054	15.11.2005
IRS-P6	CARTOSAT-I	-	-	05.11.2007
LANDSAT	TM	139	043	25.11.2009
LANDSAT	TM	139	043	02.04.2010

V. RESULTS AND ANALYSIS

DETECTION OF CHANGE IN GANGA RIVER MORPHOMETRY WITH TIME:

1920-21 Ganga River reach:

The river course has been taken from the 1920-21 Police Station Map. It shows the river course before the establishment of Farakka barrage. The river course was almost straight. The sinuosity index for the entire river reach from Rajmahal to Farakka Barrage was 1.09. There was a very small island developed in the river reach and the island area is 2.1 km^2. which is 1.72 % of the total river area. The braiding of the river was also very low. The measured Braiding Index is 0.12. The one cause must be that till then there was no obstruction before the river. River width was also quite small.

1977 Ganga River reach:

The river has been digitized from the Landsat MSS data of10th Feb, 1977. Here river started bending just after the Farakka barrage establishment. The river course got a bend about 14 km upstream of the barrage. The sinuosity index of the total river reach was 1.12. From 1920s, the sinuosity has changed 0.03104. The island area in this year has been also increased. It has increased to 24.94 km^2; which is 12.89 % of the total river area. So it's the year when there was a drastic change in the island area, an increase of 11.17% island area, may be partly because of the long gap from the date of survey of the previous data. The river width has also increased. It shows that the lateral erosion has been increased because of high sedimentation. The Braiding Index was also increased with the increasing islands. It has been measured as 0.82. But, the river and island area may have some error because of the low resolution of the Landsat MSS data.

1990 Ganga River reach:

The river course has been traced out from the Landsat TM imagery of 21st November, 1990. In this year, the bend became broader and it was at a higher distance from the barrage than 1977. The sinuosity became slightly lower at 1.1. The total area of the islands increased to 71.13 km^2, which is 29.4% of the total river reach area. So, the island area now has increased by 18.23%.The Braiding Index has been also increased. All the measurements give the hints of higher sedimentation over time.

2001 Ganga River reach:

Here the river reach has been identified from the Landsat ETM+ imagery of 20th October, 2001. The sinuosity has been increased this time to 1.14. That means the river became more sinuous. The linear distance between the barrage and the cross section where the highest bend occurred, is about 21.7 km. Island area has also increased more because of high sedimentation. It had increased to 90.21 km^2, which is 33.78% of the total river reach area. So, the island area was increased by 4.38% from 1990. The braiding index has also increased to 1.32. In this year, a typical character of river morphometry has been found. Two prominent channels were diverted from the main river. They had diverted mainly from the Manikchak area, on the right bank of which there is a rigid geological obstruction in the form of Rajmahal hills. The right cannel diverted from the opposite of Manikchak Ghat area near Rajmahal hills and joined again with the main channel near a place about 15 km upstream of the Farakka Barrage. Another channel called the Central Channel diverts itself about 7.8 km downstream of the right channel diversion and merges with the main channel about 200 mts upstream of the right channel meeting place. Among these channels also, there were many interconnected narrow channels.

2003 Ganga River reach:

The river reach was identified and analyzed from the IRS LISS-III data of February, 2003. Sinuosity measure was higher than the previous years, It was 1.21. The areal distance between the barrage and the cross section where the highest bend occurred, is about 21.8 km. So, the major bend of the river seems to have its trend towards north-east, because, it is moving towards upstream and eroding its left bank. The Braiding index also increased to 2.08. The island area is measured as 119.11 km^2. That is 45.55% of the total river reach area

2005 Ganga River reach:

The river has been identified from the IRS LISS-III satellite imagery. The image is of 15th November, 2005. The sinuosity has been measured as 1.25. The Braiding index has also been increased to 2.17. Here the island area has been measured as 242.57 km^2. It is less than the island area of 2003, but we can see from the previous analysis that the island area has a trend to be increased over time. So, it may be assumed that, because of the higher water level in November than February, the visual island area measurement has given lesser value. In this year the island covers about 39.6% of the total river reach.

2010 Ganga River reach:

The river reach has been taken from LANDSAT TM data received on 25th Nov, 2009. Sinuosity has been slightly increased to 1.22. This year the island area has come to 296.69 km^2. It is 66% of the total river reach. The sinuosity has been decreased here mainly due to the diversion of main flow from left to mid channel. Channel area has been considerably changed for the sudden huge sedimentation in left channel. So, with that braidedness has also increased to about 2.50.

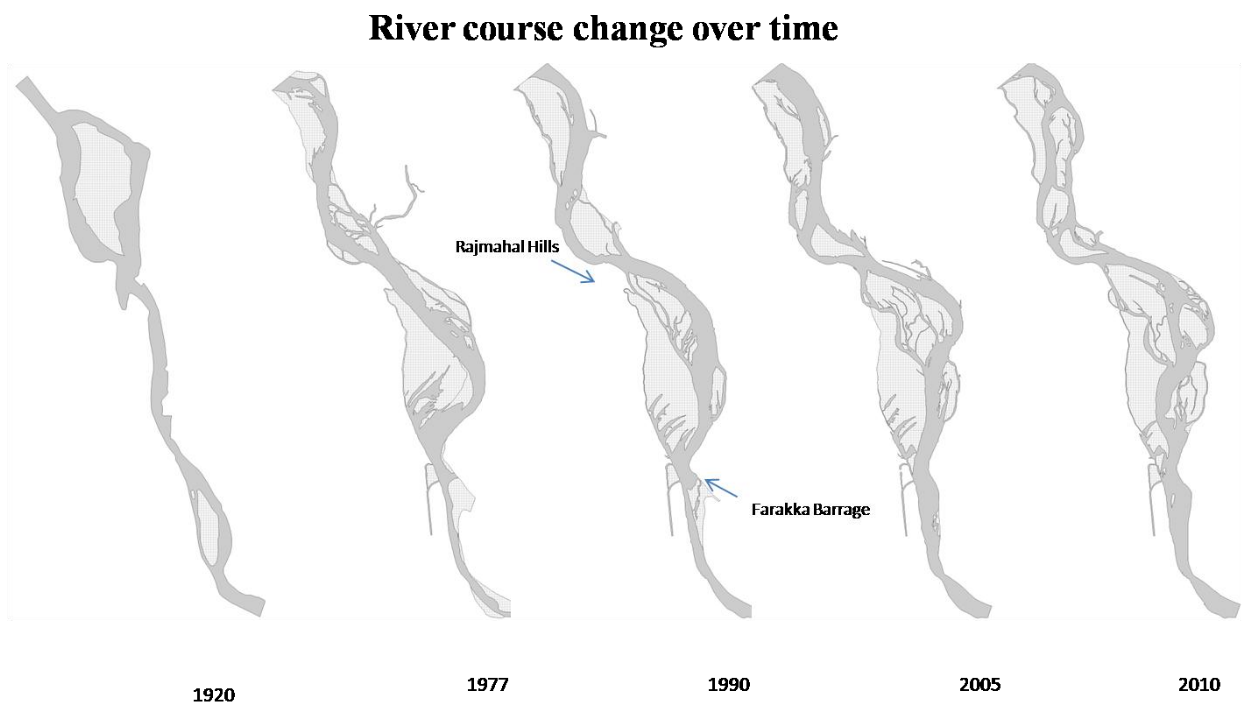


Fig-1: Changing Course of river through time

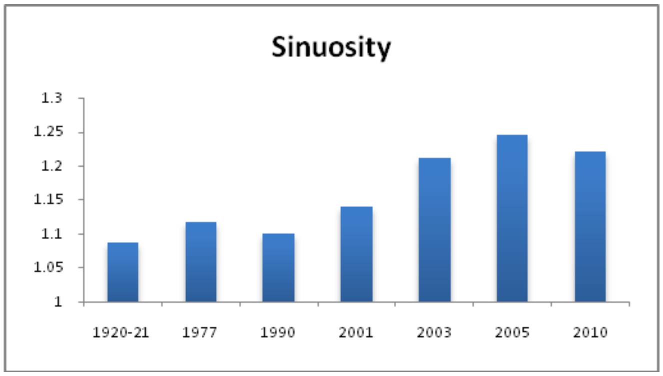


Chart-1

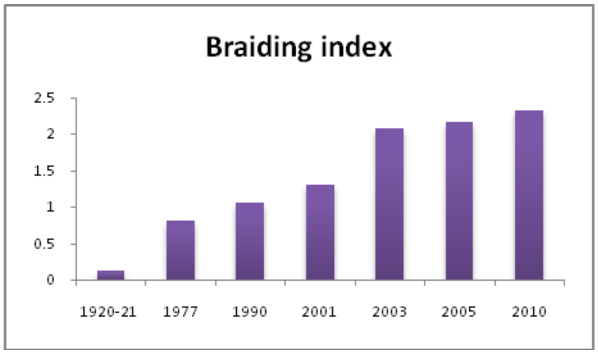


Chart-2

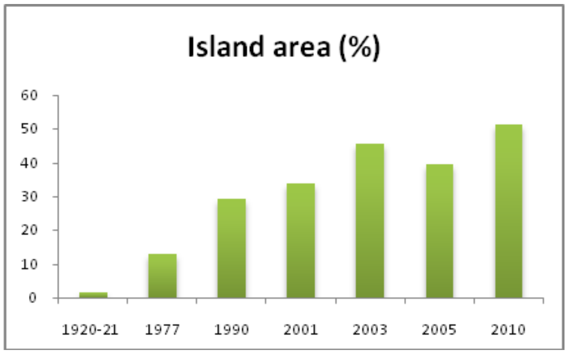


Chart-3

<u>LEFT BANK SHIFT ANALYSIS AND STATISTICAL APROACH TO IDENTIFY VULNERABLE AREAS:</u>

For the temporal study on left bank shift of Ganga River, 22 cross-sections, parallel to each other have been made covering the entire stretch of the river. Superimposing left bank position in different years, average and highest shifts per year for the study area have been measured as follows.

Fig-2: Cross-Sections across the river reach

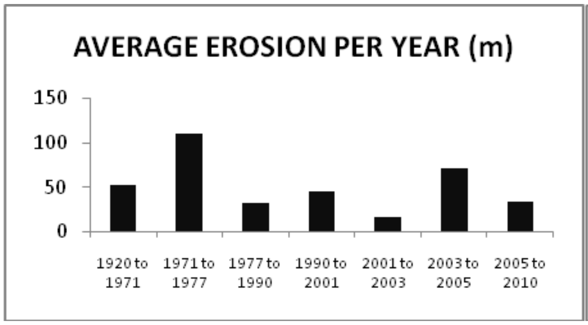


Chart-4

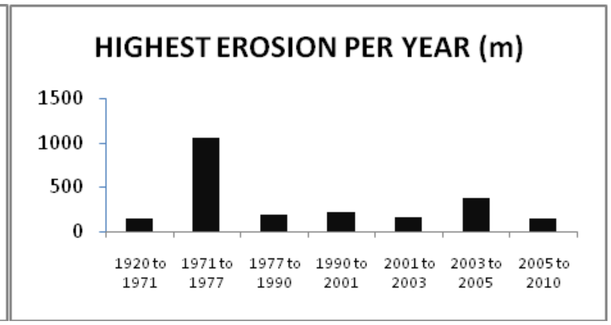


Chart-5

Table-1: Showing Shifts along Cross-Sections

	1920-1971	1971-1977	1977-1990	1990-2001	2001-2003	2003-2005	2005-2010
A	3075	208	1277	381	1	-49	236
B	0	1395	1089	-465	-8	94	521
C	-1064	1021	2100	1222	16	50	736
D	1513	-101	875	876	167	264	27
E	2436	232	194	65	-54	473	334
F	2458	421	-72	-1347	44	56	-226
G	2742	709	-402	520	-91	-21	-78
H	-355	279	-408	687	159	402	472
I	3665	66	903	591	-12	39	264
J	5178	-101	147	2436	12	35	3
K	7120	126	-400	2415	38	37	106
L	7078	350	201	2200	330	756	16
M	7335	619	-501	-500	0	439	355
N	7037	2436	0	7	0	31	45
O	385	6301	1305	-79	30	-6	12
P	145	827	2464	334	58	32	40
Q	-520	196	0	17	15	33	26
R	78	225	-40	0	8	176	689
S	1680	202	590	616	-10	28	40
T	TOPO U.A	202	60	384	13	17	191
U	TOPO U.A	36	412	-407	-22	237	-196
V	TOPO U.A	-1159	-718	780	-2	18	-11

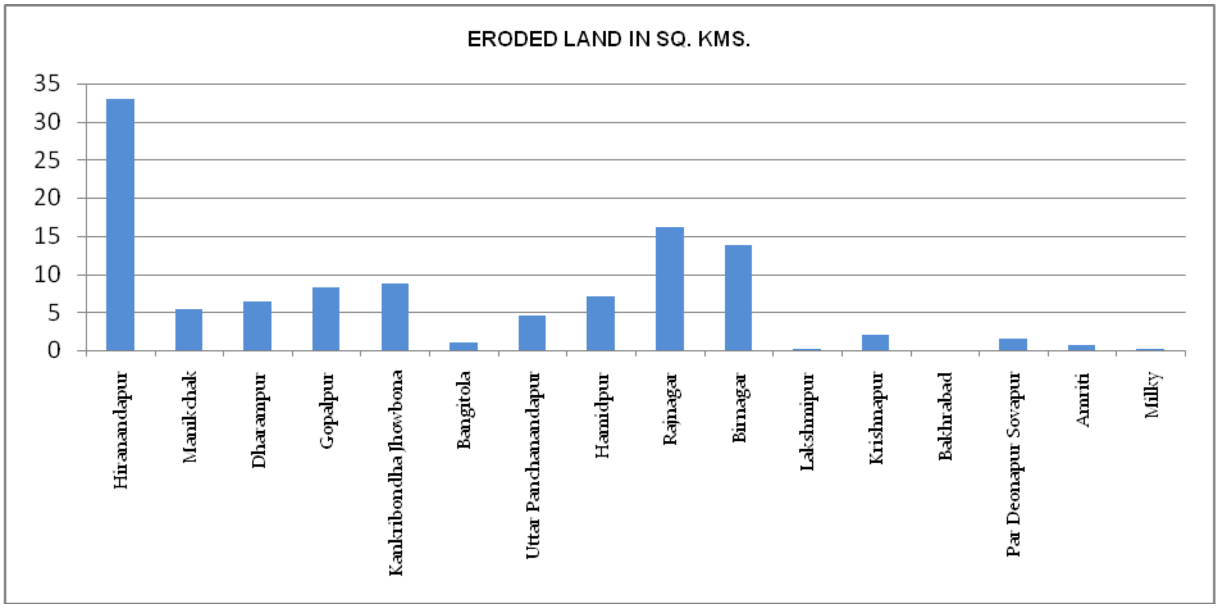
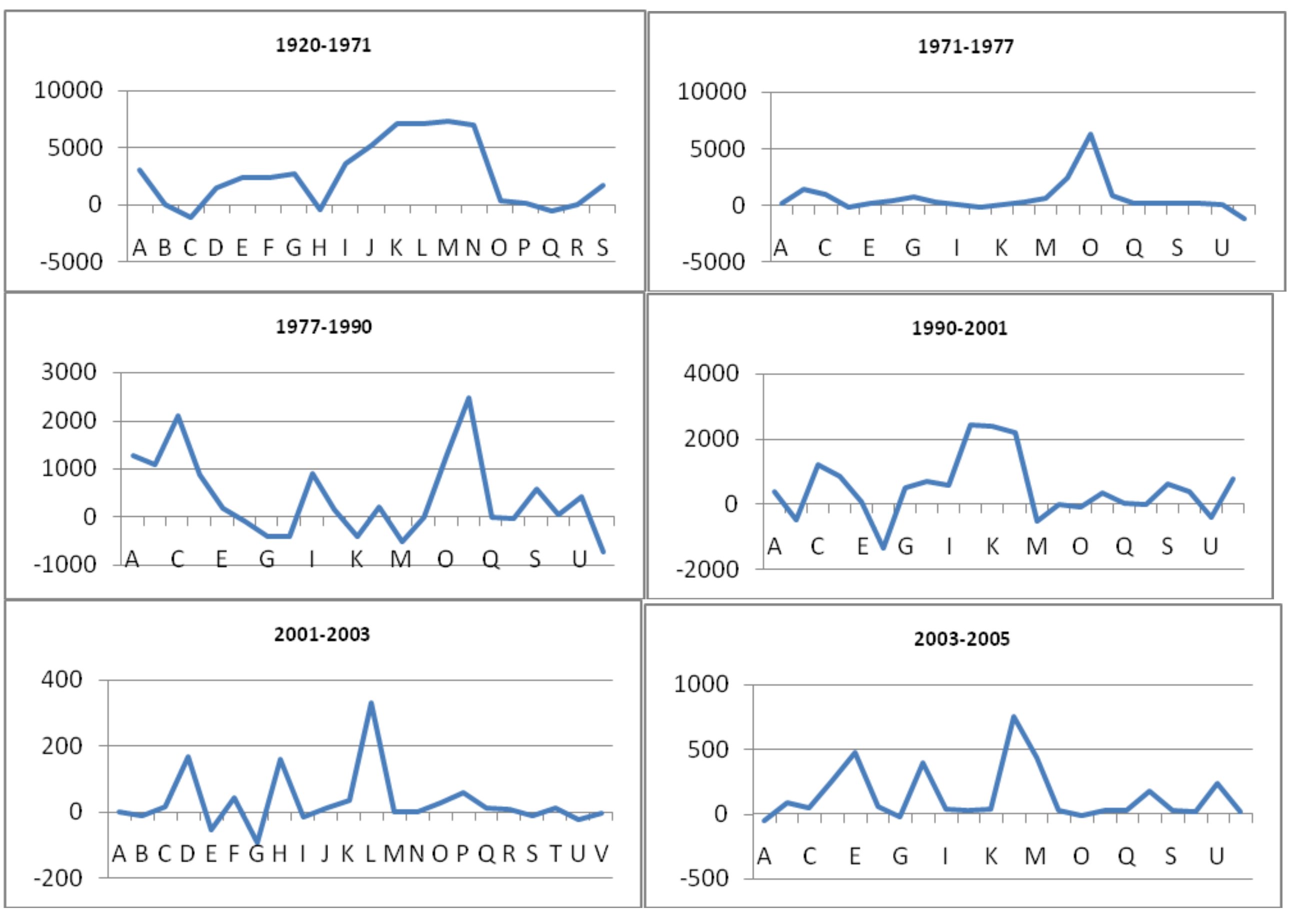


Chart-6

For the shift monitoring of Ganga River, there are sufficient temporal satellite data from 1977 onwards, whereas, topographical sheet (1:50,000) of 1971 and police station map of 1920 are also available. Because of the variation of intensity of bank erosion in different locations along the left bank of river reach in different time span, 22 cross-sections have been drawn across the river bank randomly. Temporal shifts have been calculated on those individual cross-sections, as shown in the following table.

Here all positive values represent erosion, whereas, all negative values represent deposition.



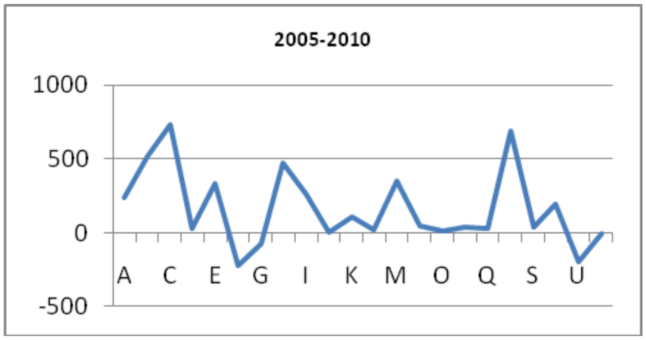


Chart-7

For the risk zoning, along each segment the temporal shifts have been measured. Then regression trend line has been drawn for each cross-section. On the basis of this temporal shift of left bank since remote past, this study went through a validation procedure which suggests a statistical technique that results a prediction closest to the fact. In that procedure, regression analysis has been carried out for the shifts up to 2003, based on which, the trend of erosion has been predicted for 2003-2010. We have the actual shift measurements for that predicted time span. So, we can compare the linear as well as polynomial regression methods. We can get the most preferable method to be used which has less discrepancy between the predicted and actual shift during 2003-2010. As a result, Linear Regression Method was preferred most because it has the highest similarity with the actual scenario.

	POLYNOMIAL				**LINEAR (Y-ax+b)**	**ACTUAL 2003-2010**
A	$-344.5x^2 + 1592.x - 912$	-3762		A	28.1	88
B	$543.1x^3 - 3883x^2 + 7540.x - 2806$	19955.6		B	-1514.8	510
C	$-571.2x^2 + 2466.x - 793.2$	-6560.4		C	-272.8	391.4
D	$-421.2x^2 + 2186.x - 1853$	-3900.2		D	736	147.6
E	$-20.25x^2 + 2.55x + 254.7$	-459		E	-236.2	581.4
F	$471x^2 - 2595.x + 2718$	4104		F	-1080.6	-182.4
G	$-594.3x^3 + 4582.x^2 - 10698x + 7419$	-20185.8		G	-333.3	-418
H	$-567.5x^3 + 4296x^2 - 9602.x + 6153$	-19383		H	436.5	539
I	$-360x^2 + 1745.x - 1276$	-3766		I	195.9	190
J	$-668x^2 + 3602.x - 3373$	-5809		J	1543.3	30
K	$-1422.x^3 + 10204x^2 - 21181x + 12526$	-54368		K	1437.6	119
L	$-1002.x^3 + 7091x^2 - 14402x + 8664$	-38904		L	1448.9	347
M	$405x^2 - 2210.x + 2393$	3713		M	-745.1	-171
N	$-409.5x^3 + 3678.x^2 - 10605x + 9772$	-9902		N	-1944.6	-20
O	$-353.1x^3 + 3925x^2 - 14299x + 17028$	-3735.6		O	-5176	9
P	$-478.2x^2 + 1947.x - 361.2$	-5894.4		P	-632.2	82
Q	$-38.66x^3 + 338.5x^2 - 940.8x + 837$	-972.36		Q	-127.1	71
R	$68.25x^2 - 402.3x + 542.2$	585.4		R	-165.6	665
S	$-253.5x^2 + 1206.x - 765.5$	-2655.5		S	136	75
T	$-193.5x^3 + 1394x^2 - 2969.x + 1971$	-11397		T	79.7	203
U	$399.8x^3 - 2996.x^2 + 6566.x - 3934$	13962.8		U	-342.8	45
V	$-305.7x^2 + 2025.x - 3045$	-1900.2		V	1464.4	11

With this method, trend identification has been made on the cross-sections for the next 10 years on the basis of measured shifts in past time spans.

CROSS-SECTIONS	**TRENDLINE EQUATION BY LINEAR REGRESSION**	**LEFT BANK SHIFT WHEN x IS 10 YEARS (positive shows erosion, negative shows deposition)**	
A	-365.5x+2205	-1450	Deposition
B	-76.28x+680.2	-82.6	Deposition
C	49.07x+386.7	877.4	Erosion
D	-158.4x+1151	-433	Deposition
E	-216.8x+1393	-775	Deposition
F	-309.5x+1428	-1667	Deposition
G	-343.1x+1855	-1576	Deposition
H	117.6x-294	880	Erosion
I	-399x+2384	-6374	Deposition
J	-549.5x+3299	-2196	Deposition
K	-742.2x+4317	-3105	Deposition
L	-723x+4453	-2777	Deposition
M	-742.8x+4078	-3350	Deposition
N	-920.9x+5048	-4161	Deposition
O	-536x+3279	-2081	Deposition
P	-153.9x+1173	-366	Deposition
Q	47.39x-222.8	251.1	Erosion
R	63.67x-92.42	544.28	Erosion
S	-209.5x+1287	-808	Deposition
T	5.571x+1001.5	157.21	Erosion
U	-22.14x+97.14	-124.26	Deposition
V	108.4x-589.8	494.2	Erosion

Table: 1

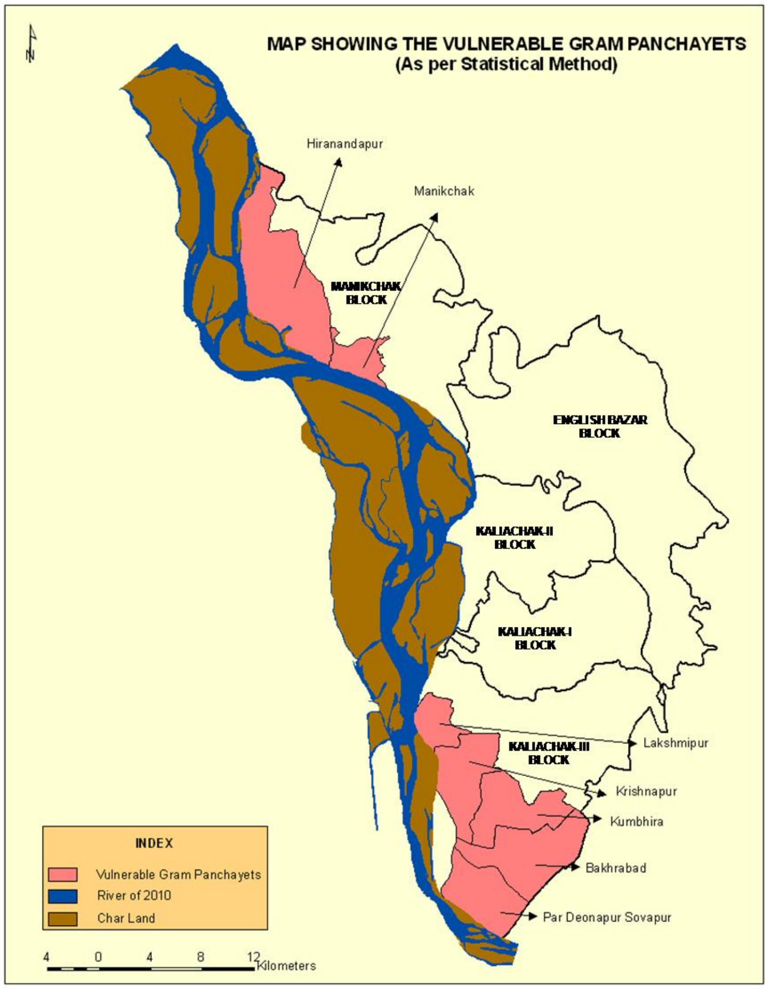


Fig: 6

VI. Conclusion

To conclude on the study, it can be said that remote sensing and GIS technology with the aid of GPS can prove itself very important in utilization of land resources and mitigation purposes. Since the middle of 20th century, thousands of people had been changed from land owners to refugees. Changes in their lifestyles are evidenced by the linear bamboo huts along the roads. Sometimes clashes occur between refugees and local people. Trend of the river course is now to shift westward again. Mid channel is going to be the main channel and a huge land is expected to be added to the mainland with the sedimentation in the left channel. This is the land which was once eroded relatively. The main discharge is expected to flow through the mid-channel, which will naturally hit the left bank south of Panchanandapur. After 1977, the river was shifting westward in this area leaving numerous spill channels. But, those areas again are becoming vulnerable to erosion. These areas should be kept in government authorities' attention to take preventive bank erosion measures like making spurs. The expected additional land including left channel should be bounded by permanent bank protection schemes, so that, further eastward devastating shift can be avoided in future. In this area, it is natural for the river to swing eastward and westward. But with the help of study of river oscillation from multi-dated satellite images, we can make a conceptual prediction on the river's future trend and thus vulnerable areas can be identified, so that, it can help the administration to make mitigation programs for natural hazards like river bank erosion.

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