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Planform Pattern of the Lower Teesta River After the Gazaldoba Barrage

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ABSTRACT

River planform means the overview of river channel pattern type as well as its configuration. The lower Teesta in West Bengal as braided river is characterised by wide, relatively shallow, multiple channels in which the flow divides and re-joins around bars and islands. In the recent time large number of dam constructions on the river Teesta largely impact on the natural channel pattern of the river. The present study focuses on the quantification of the river planform of the river Teesta after Gazaldoba barrage using satellite images of the discrete years (1997, 1990, 1999, 2008) in the GIS environments. The fundamental objective is to establish the relationships between the causes behind the present changes compare to the past with the quantified values of Planform Index. The result found that the PFI values gradually decreasing trend in the recent time. PFI value less than 4 is highly braided where more than 19 low braided. The maximum value is more than 27 in the narrowed down channel near the Teesta Domohani Bridge where the value is less than 1.6 in several reaches of the recent river. But Channel sinuosity has not increased as much after the barrage construction but the bars and islands are developed much more in the river after barrage as PFI study shows that the number of multiple channels increased. On the other hand from the hydrological data it is evident that the Gazaldoba barrage is not solely responsible for the present channel palnform changes but the other upstream factors are. Thus the river Teesta planform pattern has been changed from low braided to highly braided after the human induced changes in the river.

1. Introduction

River planform indicates lthe characteritics of channel pattern type as well as its configuration. Changes in water and sediment input to the downstream reach may induce a change in planform configuration (Brandt, 2000). The lower Teesta as braided river is characterised by wide, relatively shallow, multiple channels in which the flow divides and re-joins around bars and islands. Such braided-channel pattern occurs under conditions of highly variable discharge and due to huge deposition of bed load supplied from the upstream of the river. Perhaps the real key behind the

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cause of braiding is the proportion of bed load to available discharge (Morisawa, 1968). The river Teesta severely restricted to its flood plain areas due to the large number of embankments as well as gradual reduction of water flow discharge to the downstream. The presence of bars leads to complex patterns of flow within the channel, and there can be sudden shifts in the location of sub-channels.

In the recent time large number of dam constructions on the river Teesta largely impact on the natural channel pattern of the river. As the channel response may change from degradation to aggradations over time after dam closer, or even experience several cycles of erosion and sedimentation (Petts, et al., 2005). Constructions of dams are one of the most important reason behind the change in the discharge regime, as a result large number of braided bars emerge on the river where island stabilization is a contemporary phenomenon in the river Teesta.

The type of braiding and the number of sub-channels found within the main channel (braiding intensity) reflect the different environments in which braided channels are found. A number of braiding indexes have been developed, using different criteria, in an attempt to quantify the intensity of braiding (Charlton, 2008). Braiding intensity have been quantified using multiple indexes based on several parameters like number of channels, channel width, bar dimensions, frequencies, channel networks and bifurcations etc. by several authors (Brice, 1960, 1970; Rust,1978; Friend and Sinha, 1993; Egozi and Ashmore, 2008; Akhtar and Sharma, 2011; Sharma et al., 2012; Ghosh, 2013; Gayen et al., 2013). Downward et al., (1994) described the advantages of GIS over planform mapping like digitized boundaries derived easily and directly from historical images and provide geometric accuracy of the channel along with analysis the linear and areal aspects as well as retrieve and manipulation of the historically changing channel pattern in an effective way. The present study focuses on the quantification of the river planform of the river Teesta using satellite images of the discrete years in the GIS environments. The fundamental objective is to establish the relationships between the causes behind the present changes compare to the past with the quantified values of Planform Index.

2. Study Area

The river Teesta is a tributary to the world's largest sandy braided river Brahmaputra which is known as the Jamuna in its lower reaches where it meets with the Padma in Bangladesh. From Pahunuri

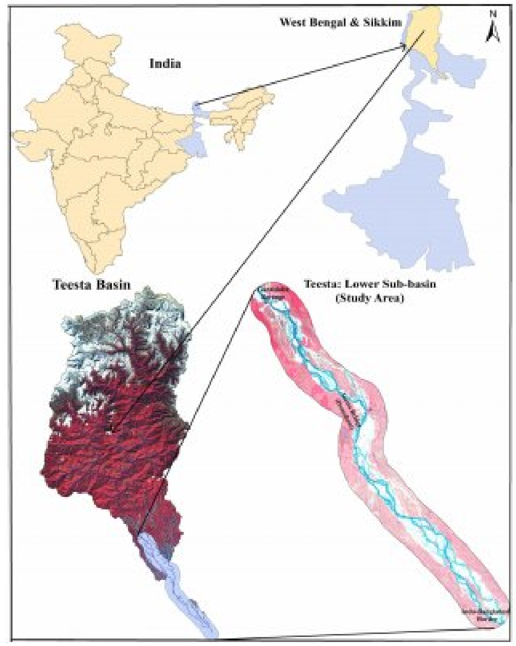

Fig. 1 Study Area

glacier in Sikkim the Teesta finds its way through the Darjeeling ridge in a narrow and deep George, and follows a meandering course thus providing the best cross section of the eastern Himalayas (Mukhopadhaya, 1982). From Melli Bazar (West Bengal and Sikkim border) downstream 30 km., the river leaves the hilly terrain and enters the plains of West Bengal at Sevoke near Siliguri where the river becomes braided with sandy-gravel bars bifurcate multiple channels. Gazaldoba barrage is located 25 km. from the Sevoke and after Gazaldoba the river predominantly a sandy braided river. The river entered into Bangladesh after 75 km. from the Gazaldoba Barrage. The study area focused on 75 Km. downstream flow regime in West Bengal, starting from Gazaldoba barrage in the upstream up to the Indo-Bangladesh border in the downstream.

2.1 Historical Discharge Pattern change

In the period of the last long 18 years (1993-2010) before and after the barrage regulation mean annual discharge at the Gazaldoba barrage as total input water flow, total outflow or to the downstream after canal diversion and the diverted water to the Teesta-Mahananda Link Canal (TMLC) data has been shown in the fig-2. The outflow discharge from the barrage towards the downstream has gradually decreased where the mean annual discharge is drastically reduced from above 700 cumec to below

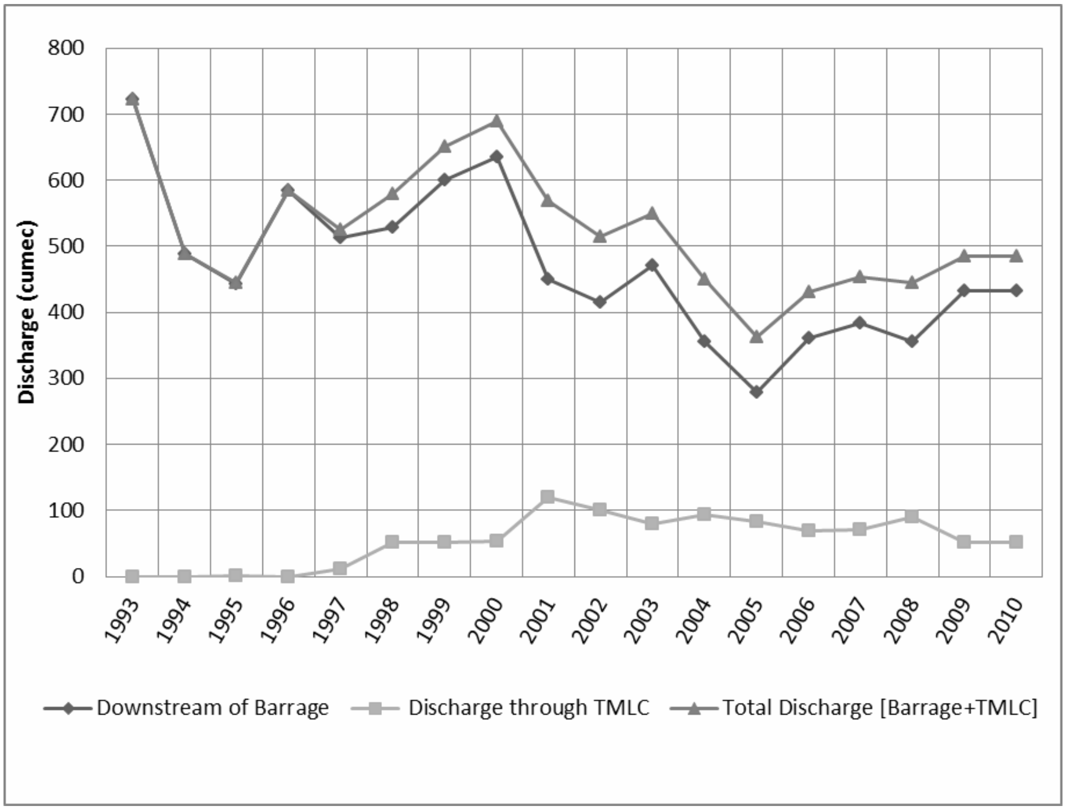

Fig. 2 Mean annual discharge of the Teesta River at Gazaldoba Barrage showing Inflow, Outflow and towards TeestaMahananda Link Canal (TMLC) discharge from 1993-2010.
(Source: Computed from Irrigation and Waterways Department, Govt of west Bengal data)

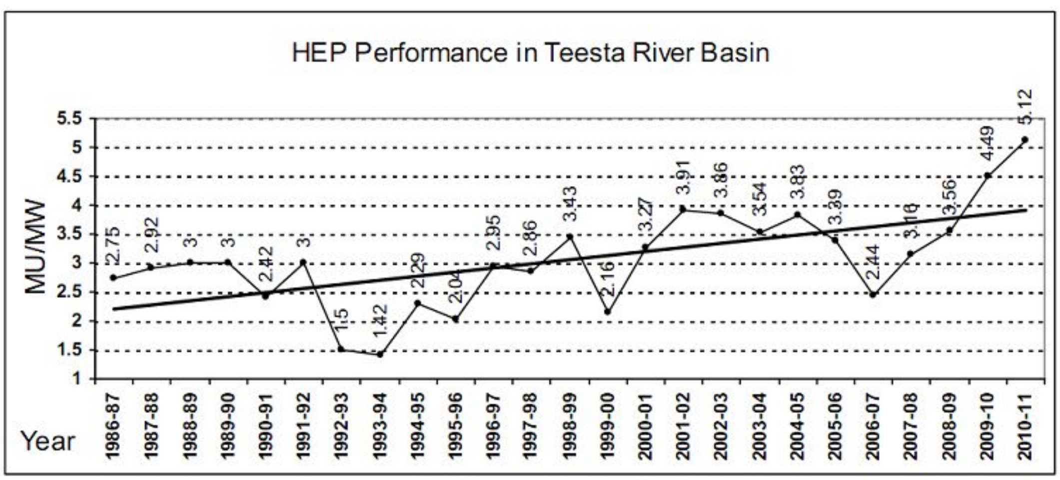

Fig. 3 Hydro Electric Production (HEP) in the Teesta River basin 1986-87 to 2010-2011.
(Source: South Asia Network on Dams, Rivers & People (www.sandrp.in).

300 cumec, more than 50% of the mean annual reduced discharge has been noticed and the canal got maximum water in the low water season also. But from the fig-2 it is clearly evident that the average discharge as inflow to the barrage has decreased more than the barrage diverting a small percentage of the water to the canal specifically during the dry season. Thus it is the upstream (upstream dam, upstream water drafting, change in rainfall pattern, climate change, landuse change in the upstream, tributary etc.) which is more responsible to this change.

3. Method

For better visualization and quantification of the historical changes in river planform of the Teesta River, satellite images have been analysed to study the river planform change. Historical photo and image information promote an appreciation for better visualization of the historical stability of rivers and of the sensitivity of river channels to human induced change (Downward et al., 1994).

3.1 Data acquisition

The era of space based earth observation at a fine spatial resolution is very significant for the mapping, investigating and monitoring of large rivers which is in this study started in the year of 1977 of Multispectral scanning system (MSS) with a spatial resolution of 80 meter. In 1990, Thematic Mapper (TM) sensor used, in 2001 the ETM+ data and Indian Remote Sensing Satellite series LISS-III 2008 images are used, having spatial resolution 30 meter or less than 30 m. Most of the images are in the same season as multiple channels are distinctly visible during the dry months. All the collected images have used under the same projection system i.e.; UTM WGS84 N45 In ArcGIS 9.3 software it is very easy to calculate the geometricproperties of the features to extract the quantitative information using universal datum and projection system as UTM-WGS84.

3.2 River boundary delineation

River boundary delineation is most important aspect of the proper study. The present river boundary is delineated on the basis of embankments visible in the high resolution satellite images and the sharp water and riparian vegetation mark and digitized in the GIS environments. Area polygons have created using ArcGIS 9.3 and using Google tools to cover our area of interest. Information have extracted using

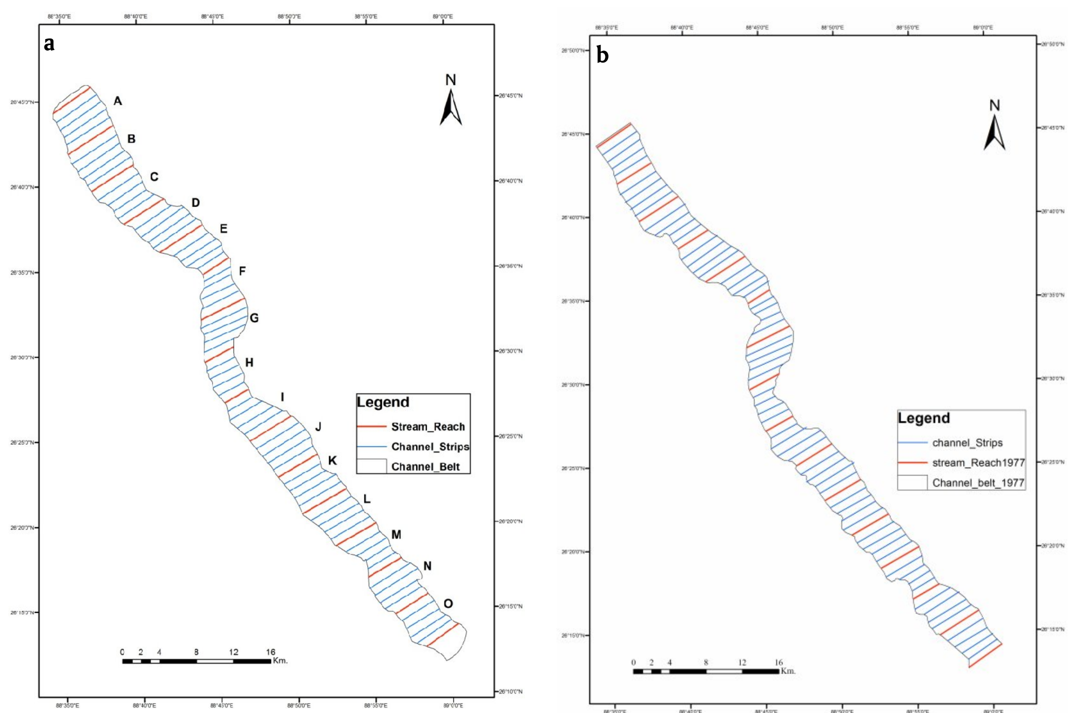

Fig. 4 (a) Delineation of river reaches (A to O) and strips in post-barrage construction period (1990, 1999 & 2008) (b) boundarydelineation of river reaches (A to O) and strips in pre-barrage construction period (1977).

Land Use Land Cover Classification on ERDAS Imagine software in the selected reach subset with the constructed polygons and features are identified with the help of Google earth high resolution data.

3.3 Teesta River Braiding and Planform Index (PFI)

In this study Plan Form Index (PFI) following Akhtar et al., (2011) has been prepared for the historical changes of the river Teestaplanformwith the help of remote sensing data and GIS software to establish the braiding pattern. Akhtar et al., (2011) calculates the degree of braiding of the River Brahmaputra by using discrete years of satellite images to generate the PFI values and measured the degree of braiding generally into two categories: (1) the mean number of active channels or braid bars per transect across the channel belt; and (2) the ratio of sum of channel lengths in a reach to a measure of reach- length (total sinuosity). Plan Form Index (PFI) is used mainly to measure the braiding pattern of the river, it is named as braiding index developed by Sharma (2004) here with the help of satellite imagery the following formula can be derived.

$$PFI = \frac{\frac{T}{B} \times 100}{N}$$

Where, T = flow top width (m); B= overall width of the channel (m); N = number of braided channel.

Sharma (2004) from Akhtar et al, (2011), Sharma (2012) used threshold values for PFI as follows, in order to provide a broad range of classification of the braiding phenomenon, these are:

Highly Braided : PFI < 4

Moderately Braided : 19 > PFI > 4

Low Braided : PFI > 19

Here, the fluvial landform deposition with respect to a given water level and its lower value indicates high degree of braiding. The above mentioned braiding indicator has been used by Akhtar et al, (2011) in their study of the River Brahmaputra braiding behaviour, a temporal and spatial variation of braiding intensities based on the remote sensing image analysis.

In this study remote sensing image based PFI values has been generated where the downstream of the River Teesta more than 75 Km. studyreach has been divided into total 15 (A to O) reaches with 75 strips and PFI values has been calculated from this 75 strips cross section of the river. After the barrage to the India-Bangladesh border where actually the river Teesta enter into Bangladesh the reaches have been divided into equal 5 Km. interval where reach no. A is starting cross section number after the barrage and reach number O is the end of reach at India-Bangladesh border in (Fig. 4). Here Barrage is starting reference point for each reach in discrete years but before the barrage image (1977) the same location is to be considered for the starting reference of the reach. Intermediate channel widths (T), and total widths (B) of the channel at each predefined cross sections were measured using GIS software tools for computing Plan Form Indices for each cross section for further analysis (Akhtar et al., 2011).

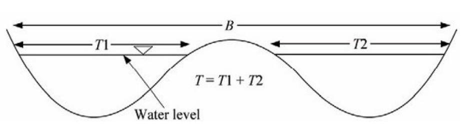

Fig. 5 Definition sketch of PFI. Source: Adapted from Akhtar et al. (2011).

4. Results and Discussion

4.1 Analysis of Braided Channel Pattern using PFI

Planform index has been calculated for each references 75 km. cross sections across the study reaches and values are plotted against each reach number for the four discrete years 1977, 1990, 1999 (Landsat Images) and 2008 (Liss-III Image). From the Fig. 6 it is to be clearly said that the period 1999 and 2008 the PFI values are very less in comparison to PFI values are very less in comparison to PFI values of 1977 and 1999. Therefore, it can be calculated from the plot that the braiding intensity has drastically increased during this period after barrage constructions year (1999, 2008) in majority of the cross sections of the river reaches on the contrary the pre-dam (pre-water drafting) situation the PFI values of the year 1977 and 1990 has the highest number of maximum peak in most of the reach cross-sections.

4.2 PFI and narrowed channel

One interesting thing can be noticed from the PFI plots Fig. 6 that in the reach number F the PFI values has drastically increased in the following years 1990, 1999, 2008 except in the year of 1977. As in the reach F the river becomes narrowed down in a 'bottleneck' situation due to human made concrete bridge (Domohani, Teesta Bridge). Therefore, inference can be drawn from the above plot that how the human made construction, in this particular reach 'F' control the river braiding pattern by increasing braiding reducing the widths of the river in comparison to the natural uncontrolled river in the year of 1977. Again the PFI, values of 1977 are very much fluctuating in nature through the reaches and showing the less braiding situation in contrast to 1990, 1999 and 2008.

4.3 Mean, Maximum and Minimum PFI

Each year Mean, Maximum and Minimum PFI value has been calculated and plotted cumulatively on a single graph in Fig. 9 where the maximum PFI value indicates highest braiding within a reach and mean or average values shows the immediate situation of PFI values of a reach. Thus, the Fig. 9 is important as because of the fluctuating value of the maximum and minimum can easily be identified and inference can be drawn smoothly regarding braiding phenomena variability in a specific reach number. According to Akhtar et al., (2011) the mean PFI enveloping with maximum and minimum cross sectional PFI suggest the ranges of variation in braiding. Suppose, in the year 1999 the braiding is least in the reach F as because previously mentioned that 'bottleneck' situation prevails here due to road bridge construction but PFI value fluctuate the highest (Max.) value and low due to the variability within 5 Km. reach and mean or average value of the reach reduced such variability and provide an overall information regarding the braiding in that particular reach.

The calculation and analysis of PFI has been elaborated to see the trend with time for the discrete year by comparing the mean, maximum and minimum values of PFI in the studied reachs. The mean value of PFI actually considered as the actual values for braiding measurement and it can be figure out from the Fig 8 that the mean value is decreasing in the year of 1999 from satellite images has shown a highest braiding pattern due to the huge amount of sand deposition and now quantitatively it is also proved. The year 1977 the mean PFI values has been gradually increased over the other year and it also has similarity with its image while visualises less braided comparatively. From, the mean value of the discrete year it is very clear that the braiding gradually increase from the natural condition of the river in the year 1977 to semi-natural condition 1990 to regulated 1999 but braiding reduced in the year 2008 in comparison to its previous year 1999.

4.4 Maximum PFI

Maximum PFI values are also plotted where 1977 and 1990 shown the highest value means less braiding. But, 2008 PFI values in the reach numbers have shown very fluctuating value with several peaks. Therefore, partially it can be say that the river is going to be in an equilibrium planform condition (2008) from a quasi-equilibrium stage (1990, 1999) to natural stage (1977). Again the minimum PFI values of different

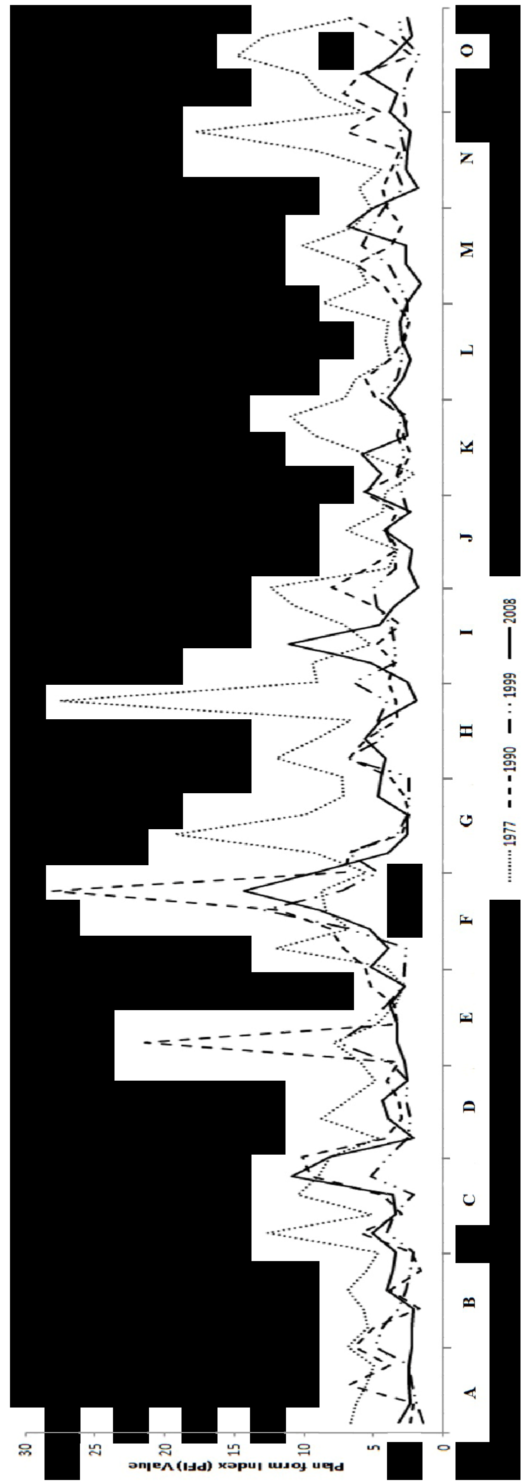

Fig. 6. Total PFI value of several reaches in discrete years.

year shows highest braiding phenomena where in most of the reach number 1999 and 2008 shows the highest number of braiding.

4.5 Bar development and stabilization in the river Teesta

Bars are in-channel accumulations of sediment which may be formed from boulders, gravel, sand or silt. Braided river like Teesta is characterised by numerous bars and islands formedby sediment deposits in the channel. The deposited sediments act as nuclei for further deposition of sediments resulting in the formation of both upstream and downstream mid-channel bars.

The phenomenon of complex of islands stabilization has increased in the river by growing of vegetation as well as agricultural practices on such islands in the regulated flow situation and experiences further high stage sedimentation.The formation of the bar deflects the mainstream towards the banks and may cause bank erosion (Akhtar *et al.* 2011). Thus very recently after 1977 the number of embankments along the river have increased to protect the sudden change of the course of the river.

The bank erosion on both the bank of the River Teesta after barrage reveals that the bank erosion within the channel makes the channel wider and shallower and

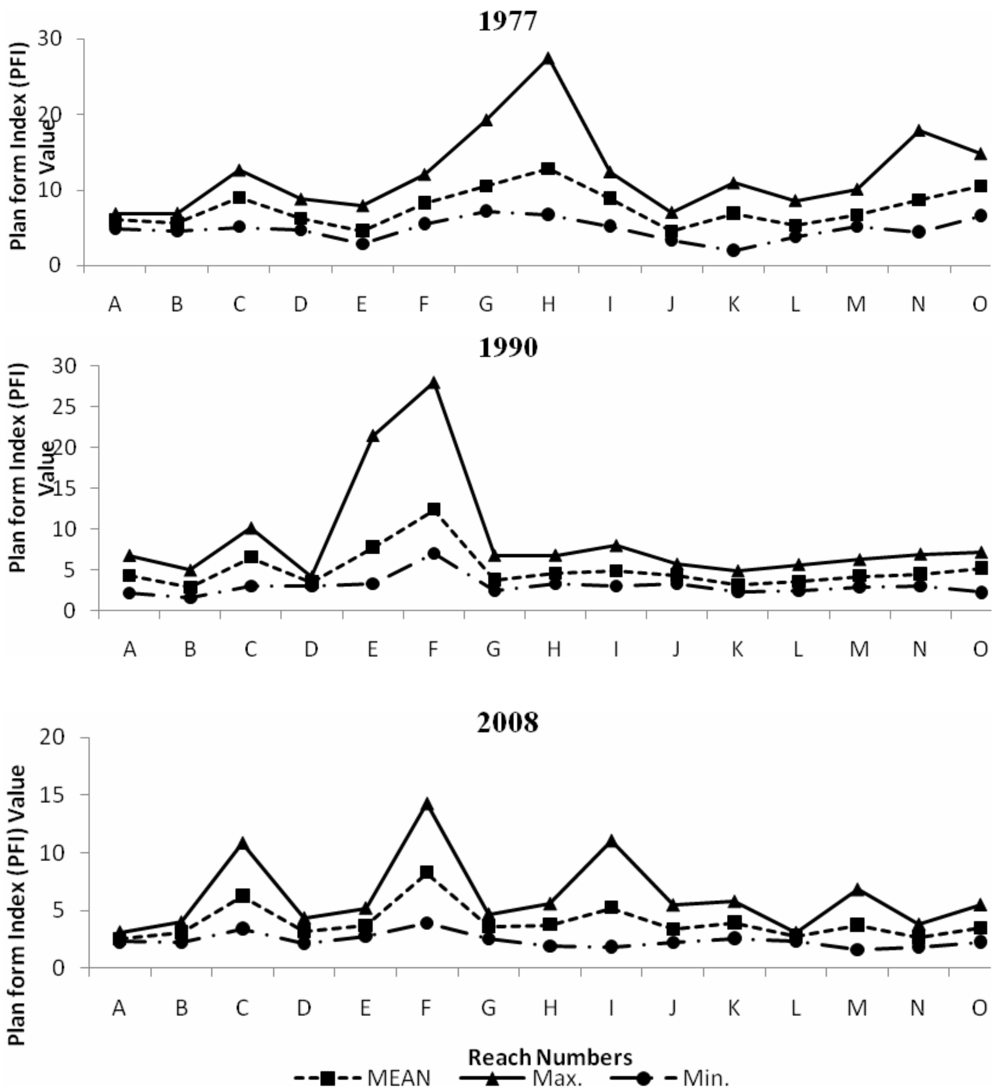

Fig. 7 Mean, Maximum and Minimum PFI values in different reach in different years.

supplies large quantities of sediment into the channel, thus mid channel bars appeared, lateral bars are constructed and vegetated islands are intensified leading rivers to highly braided pattern.

4.6 Change in Channel Sinuosity

Different regulated rivers responds differently by changing its channel planform from sinuous to meander, wandering to braided depending upon the mode of operation of dam, natural to human processes, bank materials, etc. The sinuosity ratio gives an indication of how 'bendy' a channel is and can be worked out by measuring the length of a channel reach and dividing this by the straight line distance along the valley. Channels with a sinuosity ratio of less than 1.1 are described as straight, those between 1.1 and 1.5 are sinuous, and meandering channels have a ratio of more than 1.5. Although widely used, these descriptions are somewhat arbitrary, since they are not based on any physical differences (Charlton, 2008).

In this study Sinuosity Ratio calculated using the method given by Schumm (1963) Sinuosity Ratio (SR) as Stream Length / Valley Length. In the case of the river Teesta more than one channel branch can be observed, therefore to find out the actual stream length the two main branches of the river has been identified and their average value has been divided by the actual valley length to find out the Sinuosity Ratio (SR).

From the table-1, it can be seen that in case of the river Teesta the sinuosity does not exceed too much after the impoundment but according to SR values of

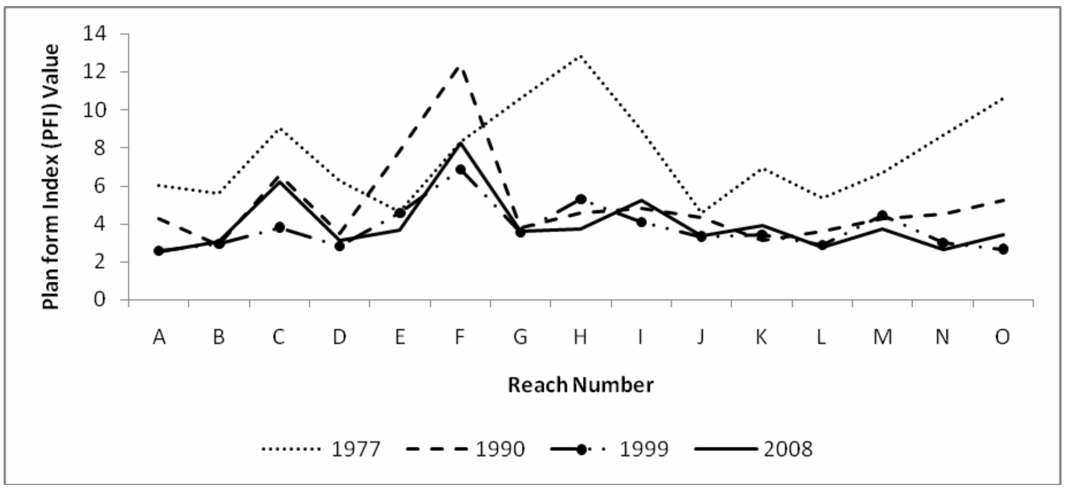

Fig. 8 Mean PFI values in different reaches in different years.

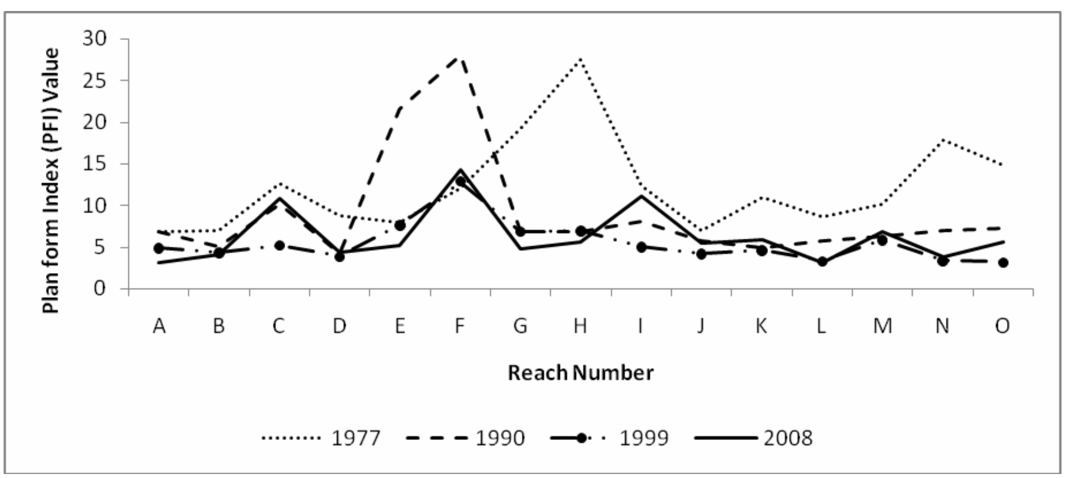

Fig. 9. Maximum PFI values in different reaches in different years.

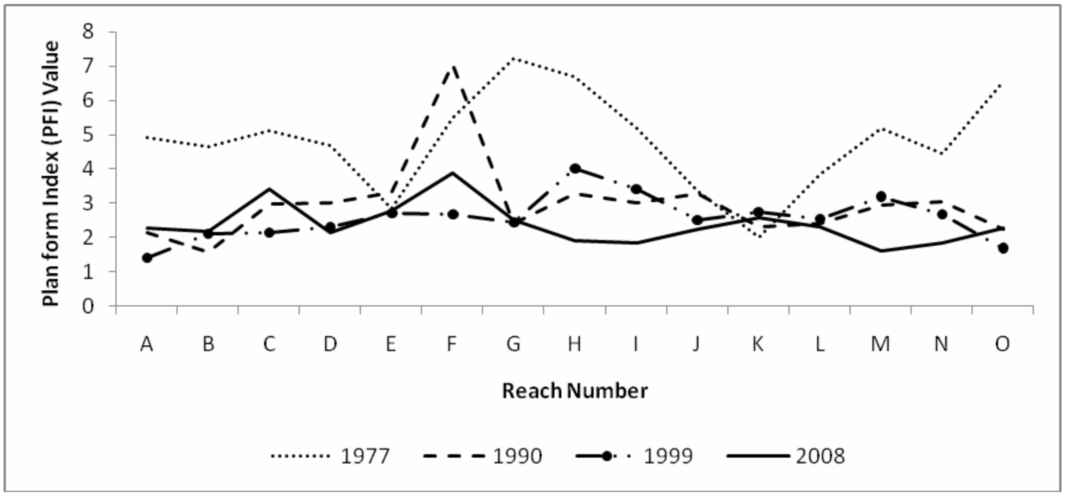

Fig. 10 Minimum PFI values in different reaches in different years.

discrete years it can be concluded that the river channel pattern has changed from near straight to sinuous. The sinuosity or the SR value of 1977 is 1.16, in 1990 SR is 1.25, in 1999 it decreased to 1.23 and in 2008 it increased to its highest SR value 1.32. Thus the sinuosity is increased in recent time in comparison to pre- and post-dam but according to the SR value at 1977 to 2008 the river pattern does not change that is sinuous range from SR value 1.1 to 1.5. But in general after dam construction the river becomes sinuous as because it releases its load in the upstream barrage and the river termed as 'Hungry water' with clean water and less load and with high capacity of scouring downstream barrage. As a result, the valley deepening started in the downstream which decrease the width–depth ratio, then, river become sinuous and meander may form. But it is not the case of the Teesta River thus the resulting braided pattern is due to the complete response of the processes and materials (load, bank etc.) which is explained in Jiangxin (1996) work "Channel Pattern Change Downstream from a Reservoir" and first introduced by Schumm (1973) the concept of "Complex Response in Geomorphological System".

5. Conclusion

Dam operations change the natural flow system of the river which gives a new equilibrium condition to the river and it is evident from the river planform pattern changes. But one of the most significant findings to emerge from the study is that the Teesta barrage is solely not responsible for altered river flow but the other factors are, like several dam

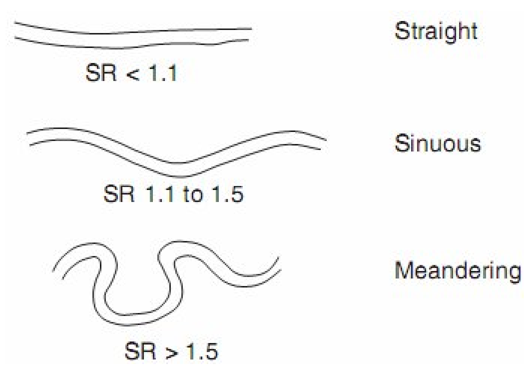

Fig. 11. Sinuosity Ratio (SR) values showing the Channel Pattern

construction on the upstream rivers, increasing landslide in the hills, river engineering, bridge, embankment constructions etc.The evaluation of the planform index (PFI) shows that the river braiding has drastically increased in the year 1999 just after the dam/barrage operation (1993) and recently in 2008 but in comparison of pre – barrage operations year 1977 and 1990 where PFI values have shownan increasing trend in most of the reaches indicating less braiding of the river planfofm. Channel sinuosity has not increased as much after the barrage construction but the bars and islands are developed much more in the river after barrage asPFI study shows that the number of multiple channels increased. Thus, it can be conclude that the river Teesta planform pattern has been changed from low braided to highly braided after the human induced changes in the river.

6. Acknowledgement

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Table 1: Calculation of Sinuosity ratio.

Year	Left branch stream (Km.)	Right branch stream (Km.)	Average Length (Km.)	Valley length (Km.)	Sinuosity Ratio (SR)
1977	86.55	84.52	85.53	73.58	1.16
1990	94.38	89.84	92.11	73.58	1.25
1999	89.41	91.30	90.35	73.58	1.23
2008	92.81	94.50	93.65	73.58	1.32

Table 2: Variation of planform index (PFI) values in different reaches for the year 1977, 1990, 1999 and 2008 of the Teesta River.

Reach No.	1977			1990		
	Mean	Max.	Min.	Mean	Max.	Min.
A	6.02	6.83	4.94	4.29	6.77	2.16
B	5.62	6.90	4.66	2.90	4.96	1.60
C	9.02	12.62	5.12	6.56	10.14	2.99
D	6.24	8.77	4.70	3.52	4.17	3.02
E	4.59	7.89	2.87	7.79	21.47	3.31
F	8.30	12.04	5.49	12.39	27.98	7.04
G	10.59	19.30	7.21	3.77	6.78	2.44
H	12.85	27.51	6.69	4.58	6.80	3.29
I	8.93	12.38	5.18	4.84	7.98	3.04
J	4.56	7.02	3.34	4.36	5.70	3.29
K	6.94	10.92	2.03	3.15	4.88	2.33
L	5.35	8.59	3.86	3.61	5.65	2.44
M	6.66	10.09	5.18	4.26	6.26	2.96
N	8.67	17.89	4.46	4.50	6.94	3.07
O	10.59	14.81	6.55	5.24	7.15	2.25
Reach No.	1999			2008		
A	2.57	4.86	1.43	2.54	3.15	2.29
B	2.94	4.34	2.12	3.09	4.01	2.19
C	3.79	5.21	2.16	6.23	10.88	3.41
D	2.80	3.83	2.33	3.15	4.37	2.15
E	4.56	7.61	2.74	3.70	5.23	2.79
F	6.84	12.80	2.69	8.27	14.30	3.88
G	3.52	6.82	2.45	3.64	4.71	2.52
H	5.28	6.92	4.02	3.75	5.61	1.90
I	4.09	5.01	3.42	5.24	11.08	1.85
J	3.32	4.17	2.51	3.37	5.49	2.24
K	3.39	4.62	2.76	3.93	5.81	2.58
L	2.87	3.32	2.56	2.77	3.10	2.31
M	4.43	5.80	3.21	3.74	6.85	1.61
N	2.97	3.38	2.68	2.65	3.82	1.85
O	2.66	3.20	1.70	3.47	5.54	2.28

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