Chapter – 5

Study of Ganga River Morphology at Varanasi

5.1 General

As the river precedes downstream the volume increases and erosion gains momentum. The planform of a river depends on both the size of the river and the part of the fluvial system. The type of planform or pattern is key interested for geo-morphologist and geologist. The meandering of river depends on the hydraulics of flow, the sediment transport and the potential for bank erosion that closely related to distribution of sediment within the bend and bed form with the channel. The distinct morphological characteristic of any river shows that relationships for river morphology are not continuous and that there exist several apparent discontinuities between pattern states. The conditions under which different river patterns and types occur have been received interest by many scientists and engineers. A regime river is a system in dynamic equilibrium, or, to be more precise, a system in quasi-equilibrium, for which the sediment transport is balanced by the sediment supply.

The Ganga River is the longest river in India flowing from Himalaya to Bay of Bengal and flow almost North West to South East. The Ganga basin is largest river basin of India, occupies about 26.3% of the total geographical area of the country. During its course through plains of Uttar Pradesh, the river flows in wide belt constantly changing its course. Meandering of Ganga River can observe in this plain area of Uttar Pradesh from satellite images. Meandering river channels are dynamic landforms that migrate over floodplains. The migration of meandering rivers results from interactions among flow, sediment transport and channel form that create complicated sedimentary structures and lead to the evolution of channel plan form over time. River Ganga is an alluvial river and an alluvial channel is always comprised of curved channel segments. Due to the movement of water and sediment transport in the natural channels, there plan and cross sections of the geometry are changed with the passage of time and along the length of the channel. Therefore to get an overall picture of the channel geometry it is necessary to measure channel cross sections at different locations and at different instants. The flow around bends in case of meandering channels is composed of secondary circulations, a water surface slope which is perpendicular to the main flow direction and directed towards the inner channel bend. The secondary circulations at the bend are generated due to the existence of centrifugal forces and pressure gradient which results from transverse water surface slope.

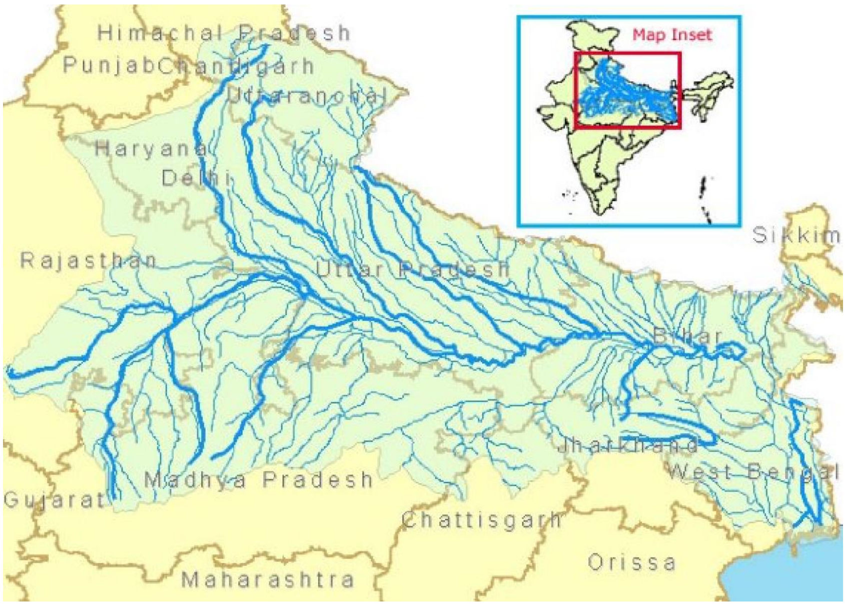
In the present study, the course of River Ganga at Varanasi is studied for last 10 years satellite image available in Google Earth. Attempt has been made to study the effect of bridge piers of Viswasundari Bridge in Ganga river morphology near Varanasi. Planform geometry variables such as wavelength, bank-full width, meander–belt width, sinuosity and radius of curvature were measured on the recent set of aerial photos for each bend.

The satellite image reveals that the morphology of the Ganga River has been changed in last few years in terms of sinuosity and silt deposition.

5.2 Description of study Area

The Ganga River is the longest river in India and flows around 1,569 miles (2,525 km) from the Himalayan Mountains to the Bay of Bengal. The geographical map as shown in the Figure 5.1 is the political and morphological state of the River Ganga basin in India.

Figure 5.1: The River Ganga basin



The study area Varanasi is located in the middle Ganga valley of North India, in the Eastern part of the state of Uttar Pradesh, along the left crescent-shaped bank of the Ganga River. Being located in the Indo-Gangetic Plains of North India, the land is very fertile because low level floods in the Ganges continually replenish the soil.

The stretches and meandering of Ganga River over the Varanasi can be viewed from satellite image as shown in Figure 5.2. The photograph reveals that the river changes courses with time i.e. active meandering of Ganga River takes place. The extent to which changes are propagated both upstream and downstream depends on timescale and mechanism of dynamic river reaches. The two consecutive bends of the Ganga River were selected for the analysis of meandering of river near Varanasi. Figure 5.3 shows the study area with two consecutive bends; bend1 and bend 2 respectively.

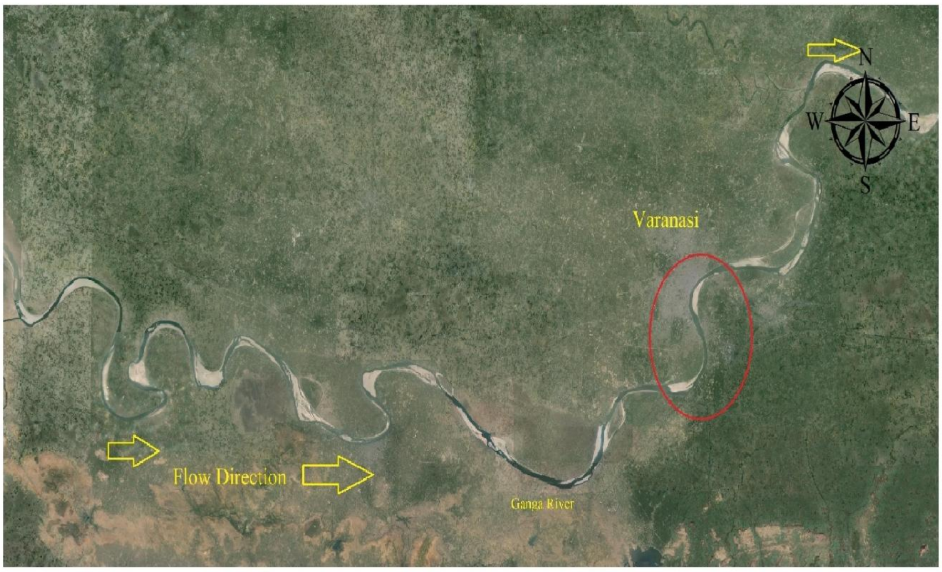


Figure 5.2: Satellite image of River Ganga near Varanasi with meander bend

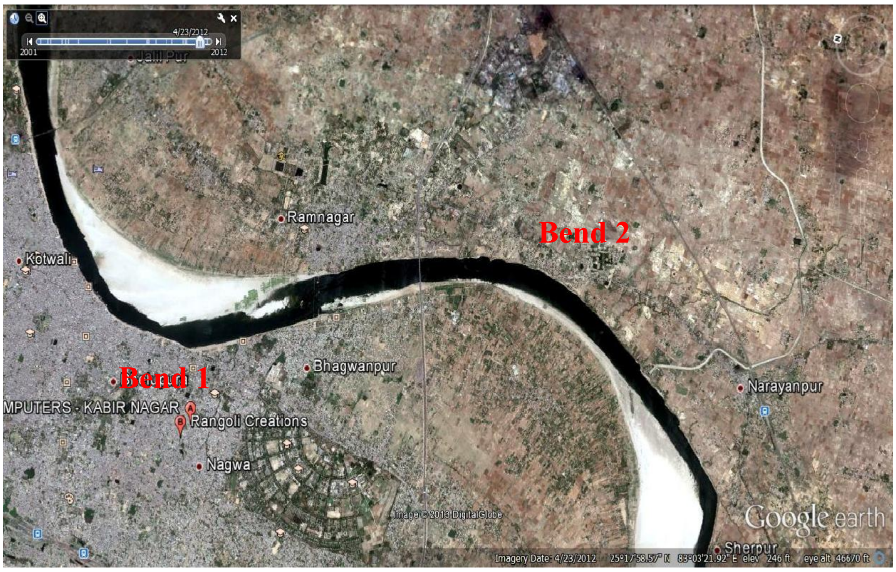


Figure 5.3: Two Reverse bend near Varanasi Bend1 and Bend2

5.3 Methodology adopted

The satellite image of the Ganga River upstream and downstream of Varanasi city is shown in the Figure 5.4 taking from Google earth. The online tool was used to analyze the sand deposition for the both bend of the river. Using this tool, the points were marked on periphery of sand deposition to calculation area. The marked points are analyzed and a text file of result was generated with desired parameters. This pint file can also be overlap on the Google earth image. Air photo prints were geo-rectified using the geo-referencing tools available in ArcGIS 9.1. The ground control points (GCPs) used for rectification were obtained from topographic maps. The recent photography for each study site was geo-referenced using the GCPs. For cross checking, the rectified Google earth image was used for desired output data. The radius of curvature of the bend 1 is determined by Arc-GIS tool and shown in Figure 5.4.

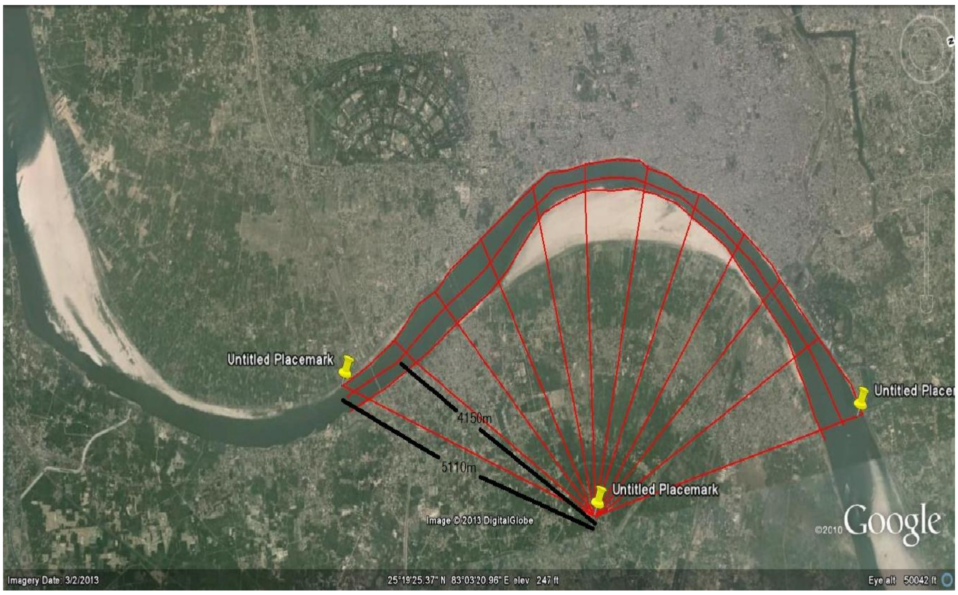


Figure 5.4: Determination of radius of curvature

Outer radius of the Ganga River near Varanasi is 4925 m and the range of this curvature varies from 4399 m to 4927 m. The inner radius of curvature is around 4393 m and its value varies from 3840 m to 4509 m. At Varanasi the river cross-section varies from average depth of 10 m to 60 m. The maximum discharge in Ganga River is 43183 cumec in last 31 years in Varanasi. The top width of the river section is 385.66m. The average flow velocity is 0.66 m/s.

5.4 Influence of Viswasundari Bridge piers on morphology

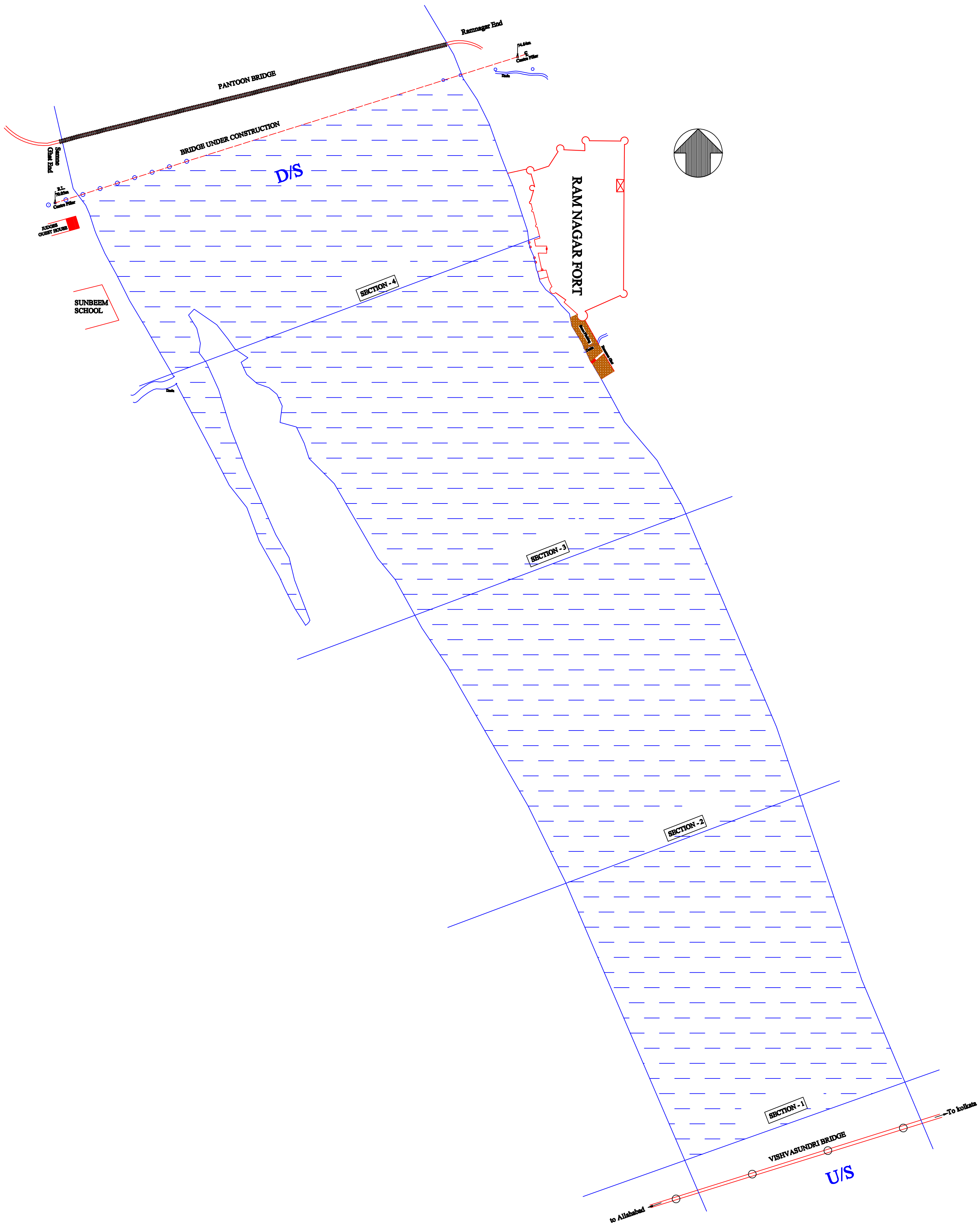
Measurement of planform geometry and migration rate for the Ganga Rivers in this study is completed through GIS analysis of historical aerial photography. The number of time periods examined for each bends of river reach varies according to the availability of suitable air photos.

The historical maps and aerial photographs (Figure 5.4) are used for main sources of data. The evidence on the morphological changes has been used in the analysis of the spatial patterns and interactions of change in the meander bends. These data were digitized and analyzed quantitatively, enabling detailed measurements of rate and locations of change and patterns of evolution of the meanders. Each bend, between points of inflection, has been numbered sequentially towards downstream are used to reference location along the course. The satellite image of Viswasundari Bridge over Ganga River is shown in Figure 5.5. The center to center distance between piers is 125m and the characteristic diameter of pier is 7.25m. Local scour occurs in bridge piers due to obstruction by piers and the consequent changes of flow pattern. It leads to changes of erosion and deposition around the piers and its effect changes the morphology in upstream and downstream of the bridges. The plan form of the Ganga River in downstream of Viswasundari Bridge is shown in Figure 5.7. The width and depth of the Ganga River at four different cross sections downstream of Viswasundari Bridge are shown in Figure 5.8. The bridge pier of Viswasundari Bridges changes the flow pattern around it and changes the morphology of River. The spacing between the piers and in terms of diameter of pier to spacing is 0.058; the interference of piers in flow pattern may not be take place.

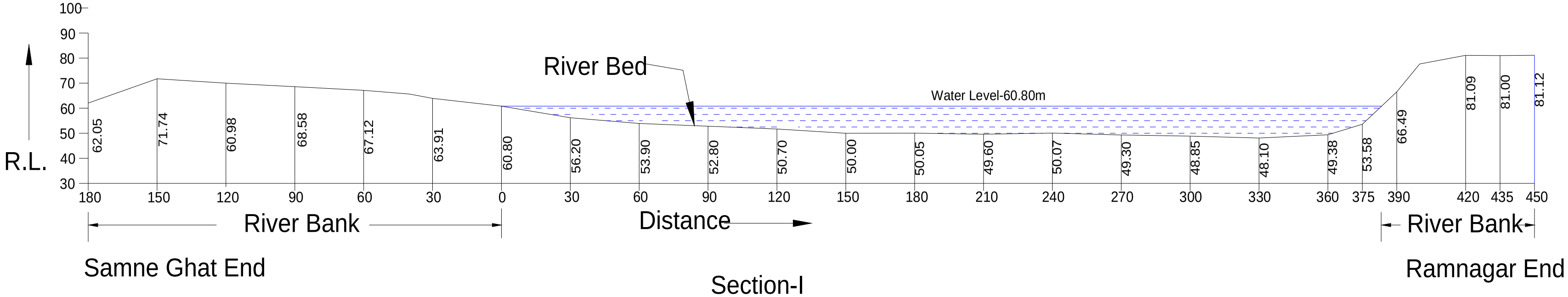
Figure 5.5: Satellite image of Viswasundari Bridge on Ganga River at Varanasi

The photograph of Viswasundari Bridge with three bridge piers in the river valley is shown in photograph 5.6.

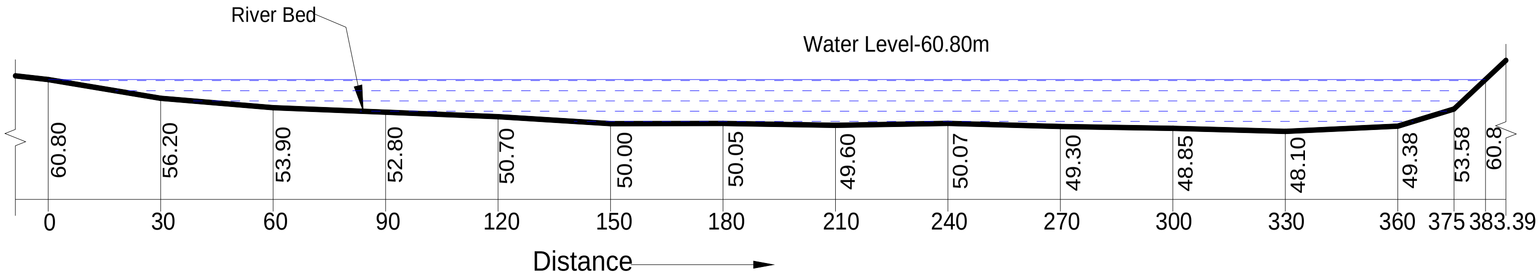
Figure 5.6: Photograph of Viswasundari Bridge with bridge piers



Ramnagar End
PANTOON BRIDGE
BRIDGE UNDER CONSTRUCTION
Samne Ghat End
Centre Pillar
D/S
JUDGES GUEST HOUSE
SUNBEEM SCHOOL
RAM NAGAR FORT
SECTION - 4
SECTION - 3
SECTION - 2
SECTION - 1
VISHVASUNDRI BRIDGE
U/S
to Allahabad
To kolkata

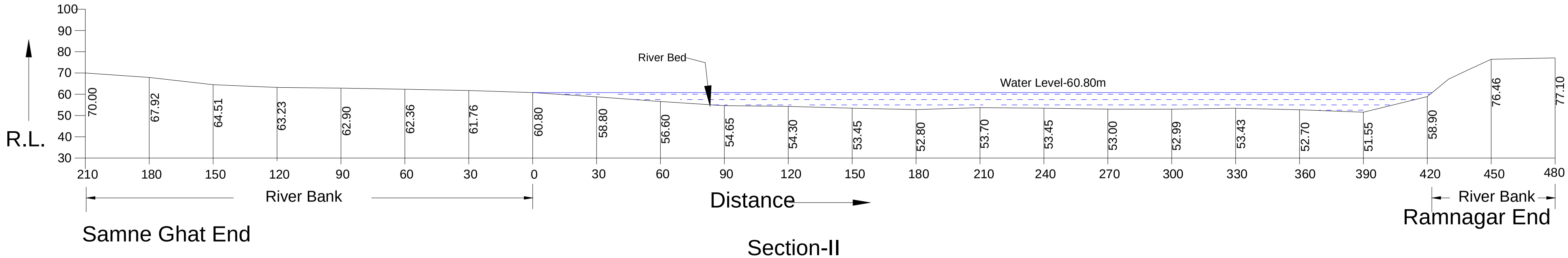


Section-I
(50 Meter Down Stream from Vishwasundari Bridge)

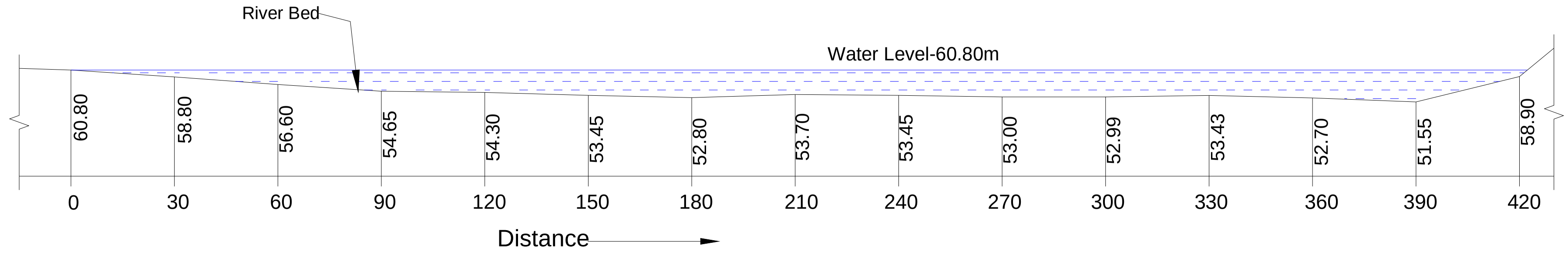


Section-I
(50 Meter Down Stream from Vishwasundari Bridge)

Figure 5.8(a): Cross section of River Ganga 50 m Downstream of Viswasundari Bridge



Section-II
(550 Meter Down Stream from Vishwasundari Bridge)



Section-II
(550 Meter Down Stream from Vishwasundari Bridge)

Figure 5.8(b): Cross section of River Ganga 550 m Downstream of Viswasundari Bridge

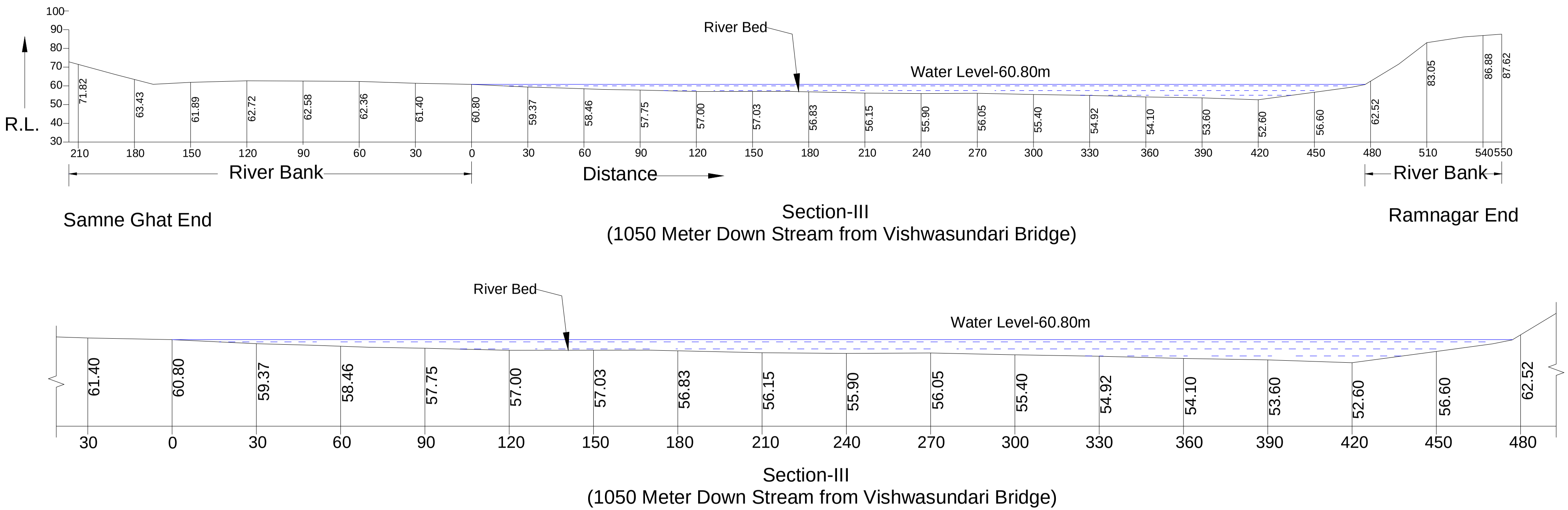


Figure 5.8(c): Cross section of River Ganga 1050 m Downstream of Viswasundari Bridge

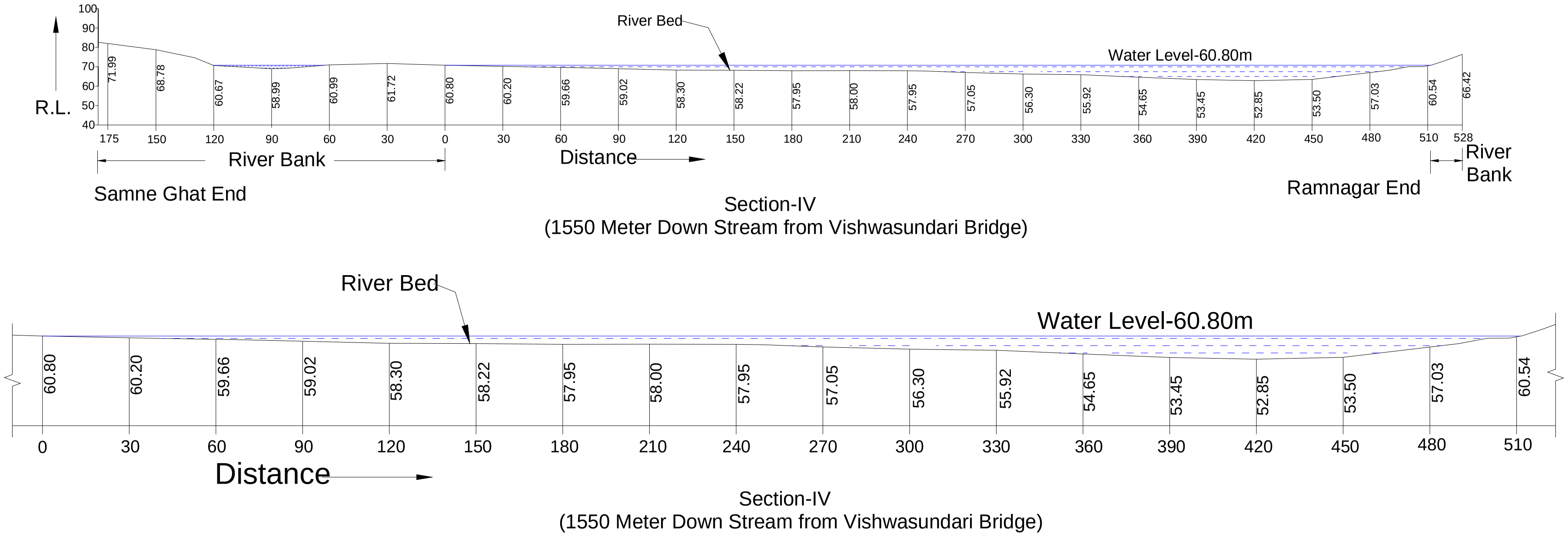


Figure 5.8(d): Cross section of River Ganga 1550 m Downstream of Viswasundari Bridge

5.4.1 Morphological change of Ganga River at Varanasi

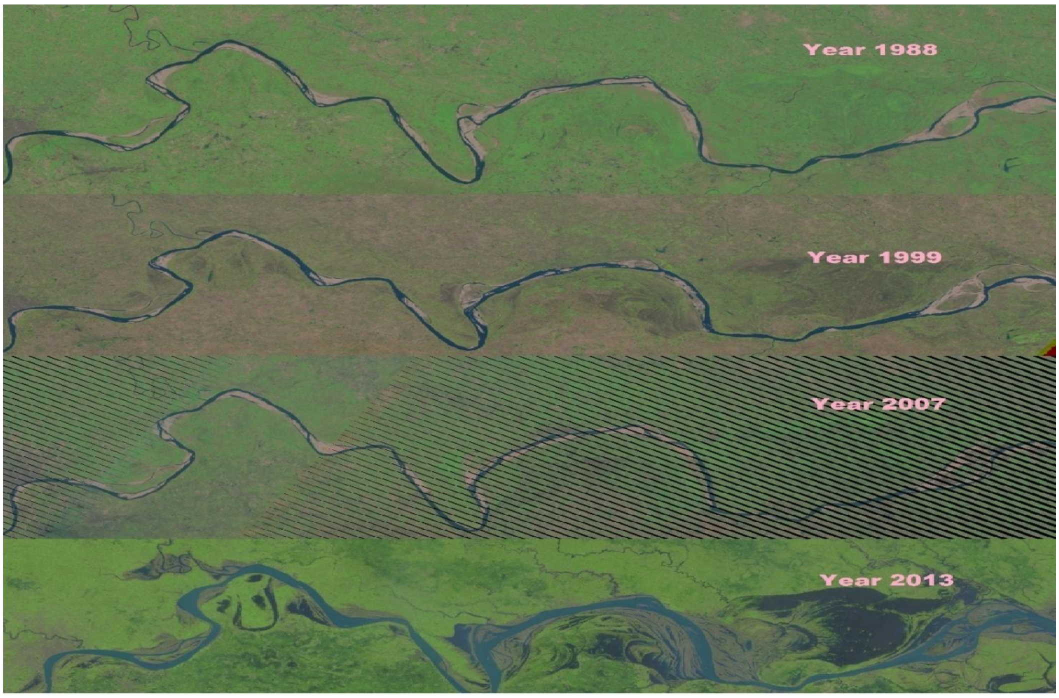


Figure 5.9: Historical and recent courses of the River Ganga, 1988–2013**.**

Measurements of planform geometry were conducted in GIS using ArcGIS 9.1 software. Channel outlines were digitized using the water boundary to demark the edge of the channel because it is clearly defined in the aerial photography. Although, several other studies were used the limit of vegetation or change in vegetation type to denote channel boundaries, initial overview of the sites indicated that this approach is difficult to adopt here.

Planform geometry variables such as wavelength, bank-full width, meander–belt width, sinuosity, and radius of curvature were measured on the recent set of aerial photos for each bend. The historical change of the river course with time is shown in the Figure 5.9 & 5.10.

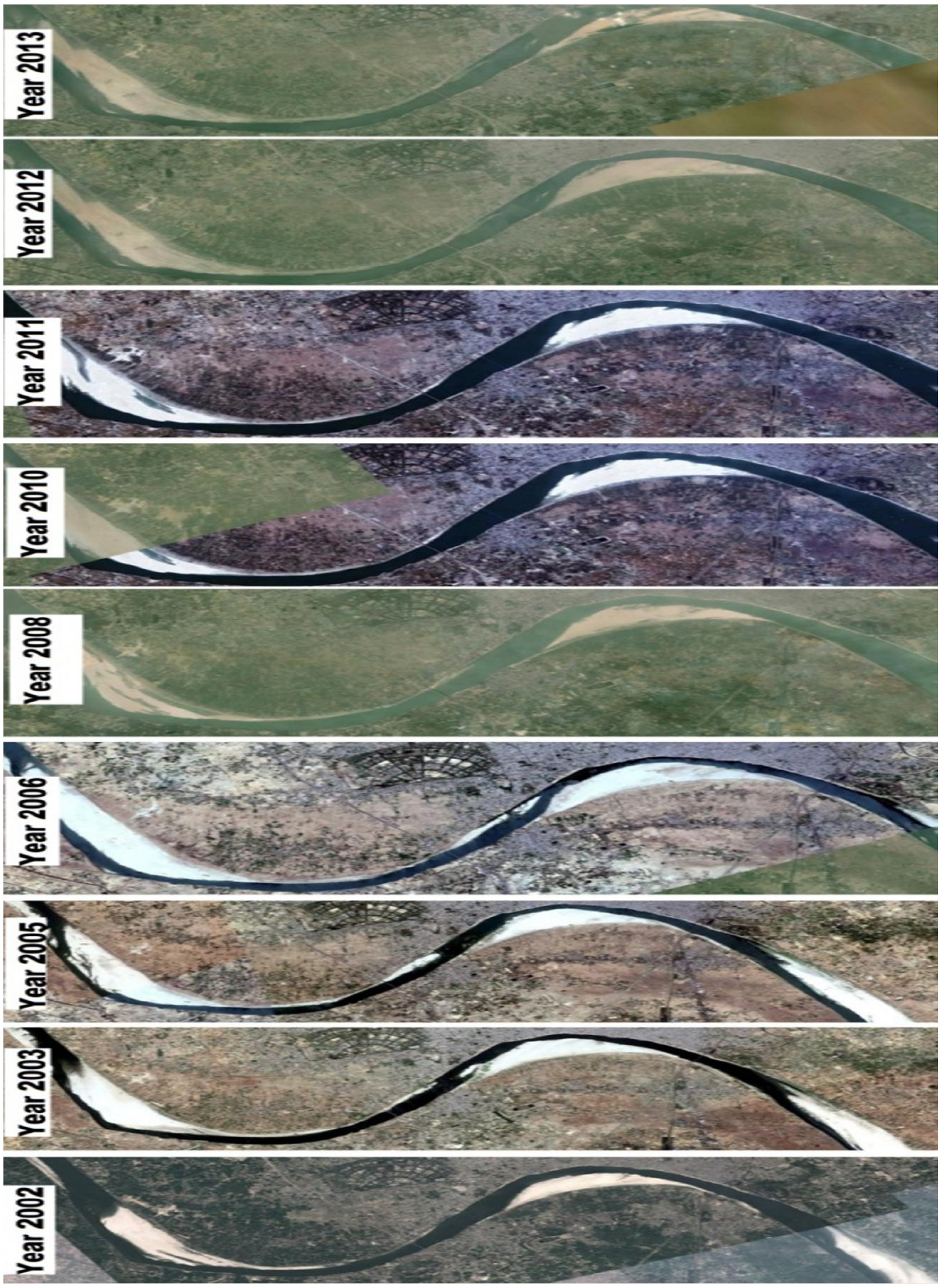


Figure 5.10: Movement of the meander bends of the River Ganga at Varanasi [2002-2013].

A change in sinuosity causes a major impact on different parameters of the meandering channel. Among these are lateral slope of the bed and water surface, magnitude of transverse components of the secondary flow, depth averaged velocity magnitude and deviation of this velocity vector from the direction of channel.
Bank-full width is measured at meander inflection points and it was the distance across the channel between vegetation boundaries. The arithmetic averages of several measurements are used for analysis. To calculate meander wavelength, a line defining the valley axis is split at each crossing of the channel center line. The length for each line segment is multiplied by 2, and the average of these calculations is taken to be the meander wavelength for that study reach. Sinuosity is calculated in the same way with the channel center line split into segments at each crossing of the cross section. The length of each segment of the channel center line is multiplied by 2 to give equivalence of the channel length over one wavelength then divided by the average wavelength of the reach; the arithmetic average of all calculated sinuosity values is used for analysis.

Summary of all planform geometry and migration data for the bends are presented in Table 5.1. The sinuosity values and sand deposition at bend 1 are analyzed from satellite imagery data using Arc GIS. The variation of sand bed deposition in upstream and down steam side is calculated from Figure 5.11 and Figure 5.12 and presented in Table 5.2. An alluvial channel's ability to mobilize and transport sediment directly influences the plan-form and long profile morphology of a fluvial system, which is in turn dependent on the broad relationship between the river channel, landscape denudation and topographic uplift.

Figure 5.11: Sand deposition on Bend1 in year 2001

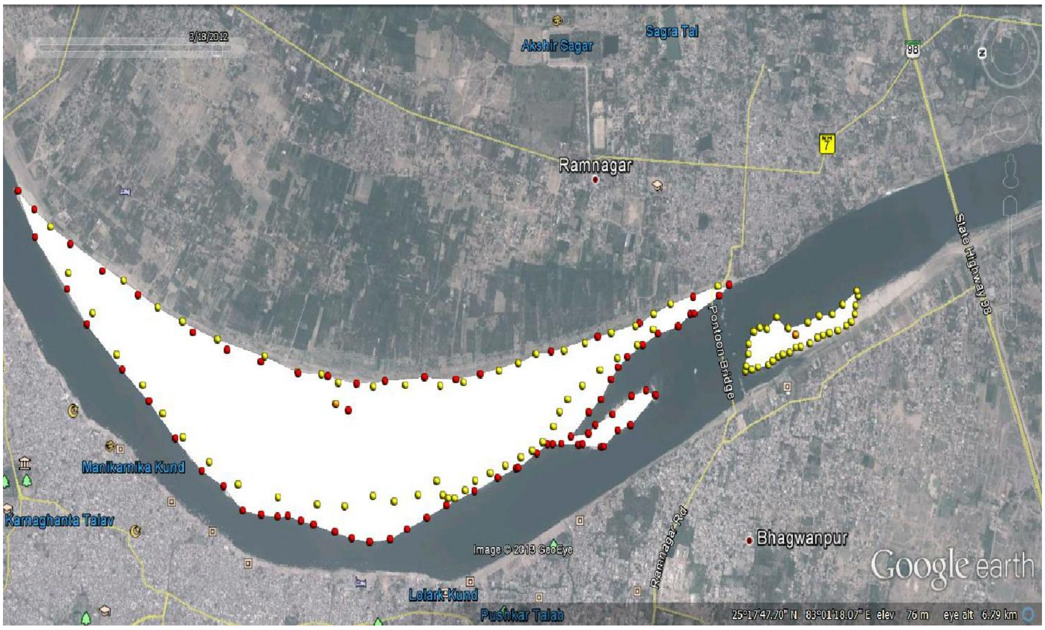


Figure 5.12: Sand deposition on Bend1 in year 2012

Table 5.1: Siltation on downstream and upstream side

Location	Year	Area (km^2)	Perimeter (Meters)	Bounding Box Maximum (Degrees)	Bounding Box Minimum (Degrees)
Down Stream	2001	2.4983	11,546.2636	25.3169849°, 083.0289700°	25.2720961°, 083.0112691°
	2012	2.9438	12,257.8261	25.3356849°, 083.0289741°	25.2720911°, 083.0112613°
Upstream	2001	0.1316	2,209.0171	25.2705493°, 083.0223940°	25.2626771°, 083.0179533°
	2012	0.301	2,421.0112	25.2705433°, 083.0223951°	25.2626778°, 083.0179539°

The inner and outer mean radius of curvature of the bends are 4925m and 4393m respectively in the River Ganga at Varanasi. The sinuosity in the River Ganga decreased from 1.66 to 1.26 in last 10 years and sand deposition also changes over time. This implies that the channel morphology of River is changing continuously. The erosion and deposition also depends on the manmade obstruction in the river course which influence the river dynamic. It is observed from sinuosity data that sand deposition varies year to year that may depends on the discharge and flow velocity change due to climate change. Such changes distort the natural quasi-equilibrium of a river; in the process of restoring the equilibrium, the river will adjust to the new conditions by changing its slope, roughness, bed material size, cross-sectional shape, or meandering pattern.

Table 5.2: Variation of sinuosity and sand deposition from 2002 to 2013**.**

Year	Sinuosity	Sand Deposition (Km^2)	
		Bend 1	Bend 2
2002	1.66	4.2	2.42
2003	1.62	4.12	3.20
2005	1.51	3.14	2.65
2006	1.49	3.24	2.75
2008	1.40	2.45	2.89
2010	1.34	4.52	3.14
2011	1.30	3.145	2.95
2012	1.28	3.425	2.94
2013	1.26	3.215	2.84

The comparison of sand deposition in two consecutive bends is shown in the Figure 5.13.

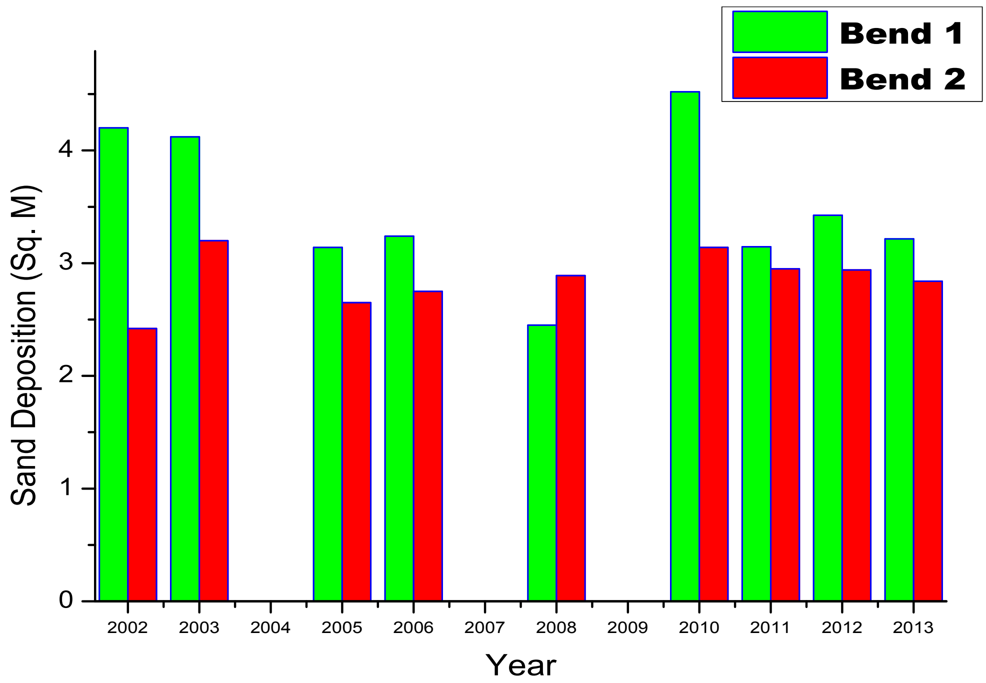


Figure 5.13: Comparison of sand deposition at both bends in bank of Ganga River at Varanasi**.**

Examination of the pattern of meander migration over the period reveals that the river meanders generally tend to translate downstream as a package and cutoffs are relatively uncommon compared to the case of freely meandering rivers. Bend over tightening commonly proceeds the generation of a cutoff in meandering rivers, leading to a decrease in the channel curvature. As the bends migrate downstream, the inflection points move with the bend and the bend curvature remains relatively constant. Furthermore, although these confined meanders have very sharp bends at the point of impingement on the valley wall, most of each meander is comparatively open.