CHAPTER-7 IMPACT OF DISCHARGE, VELOCITY, DEPTH AND GRAIN-SIZE ANALYSIS ON EROSION, SEDIMENTATION AND RIVER SINUOSITY

7.1 EROSION

Erosion is a process of disintegration and decomposition of the bed and bank of the river and soil material by flow of river, chemical and other physio-chemical processes accompanied by removal of the disintegrated or decomposed product to far off places by the same agent. River erodes rocks and shapes the landscapes by removing and transporting weathered materials from their source to another location where they are deposited and either stored or transported to another location. River erosion is often broken into three distinct categories: rain-splash erosion, sheet erosion, and rill/gully erosion. Rain splash erosion occurs when the impact of a rain drop loosens and mobilizes particles. Sheet erosion is a process where particles loosened buy rain-splash erosion are transported by runoff water down the slope of a surface. Rill erosion occurs when water concentrates during sheet erosion and erodes small rills or gullies into the surface that channel flow down slope. Fluvial erosion can occur during rainfall events, from melt-water runoff, or ground water percolation. Materials being eroded and transported are either suspended in the water, bounced by saltation, or rolled along the ground by traction depending on a variety of conditions. The accumulation of fluvial erosion and associated processes over a large area forms pathways for surface and

groundwater flow and carves v-shaped river valleys that continue to erode, transport, and deposit weathered sediments across the landscape.

7.2 SEDIMENTATION

The entire load of a stream or a river will normally remain in transport unless there is a change in one or other factor responsible for its transport. Thus, as, when and where there is a decrease in the load carrying capacity of a stream due to whatsoever reason, a part or whole of the load may have to dropped down. The process of dropping down of its load by river flow is technically called deposition in rivers or sedimentation in rivers; the resulting accumulation of the load material is termed the deposit or sediment made by the particular agent. Rivers, are important natural agent that make typical deposits on the surface of the earth called fluvial deposits.

Three factors, namely energy, environment and time are sufficient to determine the trend of the process of deposition by Rivers. Thus, if energy (of the river water) available to transport the given volume of the load decreases, a part of the load can no longer be transported; its deposition becomes inevitable. The decrease in energy may take place due to reduction in velocity (as where a stream enters from a steep slope to a gentle one), or due to reduction in volume of water (as due to a dry spell in a given area).

Similarly the factor of environment influences deposition through configuration or shape of the channel. Irregular surface of the channel represent such area that tend to reduce the velocity although there may be no change in the gradient or the volume of the water in river.

The factor of time actually operates indirectly through the first two factors. As to when a stream would drop a part or whole of its load is determined by a general statement wherever and whenever its velocity suffers appreciable check.

7.3 RIVER SINUOSITY

A river's sinuosity is its tendency to move back and forth across its floodplain, in an s-shaped pattern, over time. As the stream meanders across the flood plain, it may leave behind scars of where the river channel once was. A stream that doesn't meander at all has a sinuosity of 1. The more meanders in a stream, the closer the sinuosity value will get to 0.

$$Sinuosity\ Ratio = \frac{Distance\ along\ the\ stream\ between\ two\ points}{Distance\ measured\ in\ a\ straingt\ line\ between\ two\ points}$$

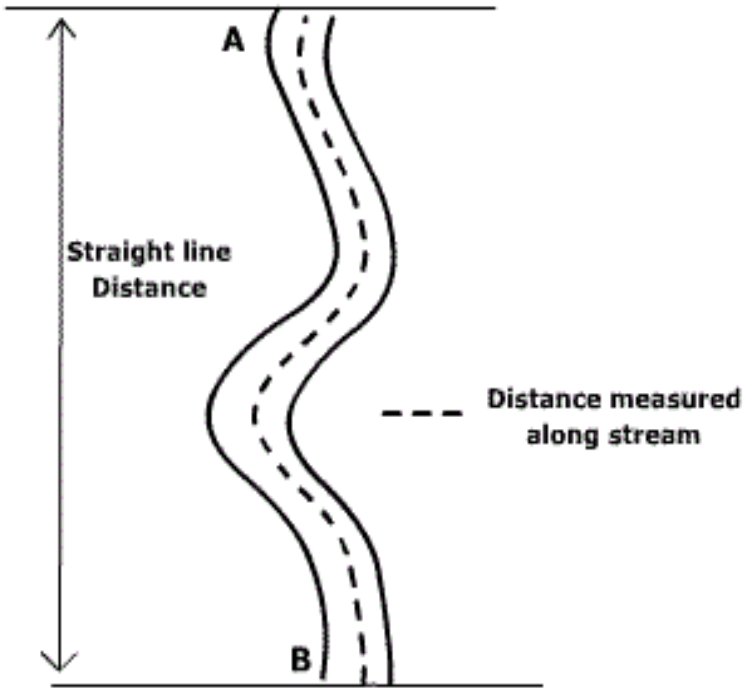

Figure 7.1. Schematic Diagram for Sinuosity Calculation

7.4 APPLICATION OF RIVER MODELLING ON EROSION, SEDIMENTATION AND SINUOSITY

The equation of discharge estimation has been proposed through mathematical modelling of River Ganga at Varanasi bend and their details are given in chapter IV of the present work. It has been observed that there are strong correlation between discharge, velocity and depth of the river. These parameters are related to the energy conditions of river and highly influence the erosion, sedimentation and sinuosity of the river. Through proposed model, the discharge, velocity and depth can be estimated if any two parameters are known. The rating curve of the River Ganga at M-1 cross-section has been also proposed through which the discharge can be estimated at known gauge height. The details are given in Chapter V of the Thesis. The grain size analysis of the sediments has been given in Chapter VI and its impact on erosion and sedimentation on concave and convex side of the river banks are also included in that chapter. To discuss the impact of the above said parameters (discharge, velocity, depth) of the river on erosion, sedimentation and sinuosity, the summary of the average depth, average velocity, area, discharge and maximum depth at each cross-section are given in Table.7.1. The impact of this parameter has been discussed separately at each cross-section under sub heading starting from section M-14 to M-1 with suitable cross-section diagrams of distance of concave side vs. depth along the cross-section (Figure 7.2. to Figure 7.15.).

Table 7.1. Correlation of discharge, velocity and depth at each cross-section from M-14 to M-1

Sr. No.	Name Of Section	Max. Depth (m)	Location of Max width From Concave bank (m)	Max Velocity (m/s)	Location of Max Velocity From Concave bank (m)	Total Width (m)	Avg Depth (m)	Average Velocity (m/s)	Area	Discharge
1	M-14	9.7	50.83	0.95	375.50	694.00	5.41	0.38	3746.07	1271.34
2	M-13	6.9	200.50	1.04	470.88	814.00	3.64	0.53	2893.08	1293.95
3	M-12	5.3	57.41	1.14	51.47	559.00	3.59	0.71	1920.39	1264.49
4	M-11	6.1	169.26	1.01	224.55	422.00	4.28	0.70	1764.33	1189.99
5	M-10	13.1	14.61	1.10	160.28	392.00	5.10	0.64	1939.81	1288.02
6	M-9	9.7	22.98	1.10	22.98	307.00	5.43	0.74	1588.66	1236.52
7	M-8	12.3	43.56	1.21	69.49	312.00	6.72	0.47	2159.18	1358.75
8	M-7	15.5	33.32	1.07	55.80	281.00	9.00	0.51	2533.43	1278.48
9	M-6	17.9	59.22	1.08	116.90	297.00	11.00	0.36	3555.94	1230.66
10	M-5	21.1	91.01	0.92	162.39	386.00	12.09	0.25	5165.94	1388.03
11	M-4	22.7	54.59	1.56	155.45	378.00	12.40	0.28	4789.35	1296.35
12	M-3	20.3	46.28	0.69	95.51	357.00	13.81	0.27	5030.04	1225.82
13	M-2	17.1	65.06	1.28	109.65	434.00	10.86	0.24	5047.36	1253.96
14	M-1	21.9	60.25	1.61	164.06	460.00	13.03	0.22	6544.69	1213.17
15	Bend	14.2571				435.21	8.31	0.45	3477.02	1270.68

7.4.1 M-14 Section (Near Pantoon Bridge)

At the starting section from the upstream i.e. M-14, the maximum depth occurs at the 50.83 meters away from the concave bank and the maximum depth is 9.7 meters, maximum velocity is 0.953 m/s at the distance of 375.5 meters from the concave bank, average depth of flow 5.41 meters, average velocity of flow 0.3831 m/s and the width of flow is 694 meters (Table 7.1.), at this section the erosion as compared to the other section is quite low as the average velocity at this section is

quite low and the width is quite large, here sedimentation is noticed at some large scale as compared to the erosion. The river sinuosity for the Varanasi is stable since ages i.e. 1.598 as it is greater than 1 so that at this Varanasi bend the erosion and the sedimentation phenomenon occur simultaneously.

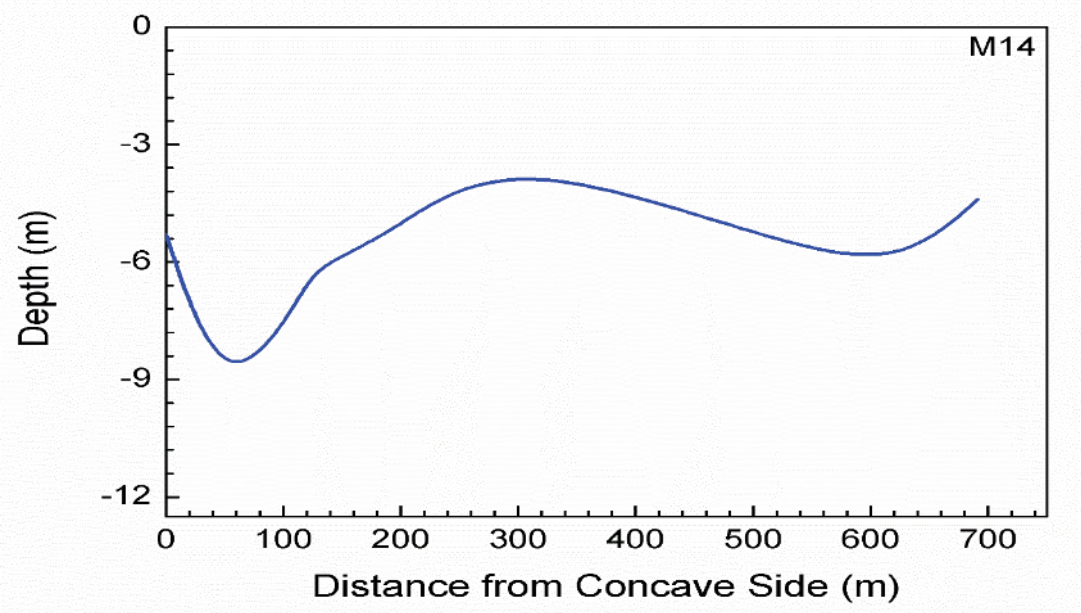

Figure 7.2. Typical Section of River Ganga at M-14

7.4.2 M-13 Section (In between Pantoon Bridge and Ravidas Ghat)

At the second section from the upstream i.e. M-13, the maximum depth occurs at the 200.5 meters from the concave bank and the maximum depth is 6.9 meters, maximum velocity is 1.04 m/s at the distance of 470.88 meters from the concave bank, average depth of flow 3.642 meters, average velocity of flow 0.53 m/s and the width of flow is 814 meters (Table 7.1.), at this section the erosion as compared to the M-14 section is quite low because the total width of flow is more high i.e. 814 meters although the average velocity of flow is little bit higher than the section

M-14, as compared to the other section, the erosion at the section M-13 is quite low as the average velocity at this section is quite low and the width is largest at this section and the average depth of flow is very low, here sedimentation is observed at some large scale as compared to the erosion.

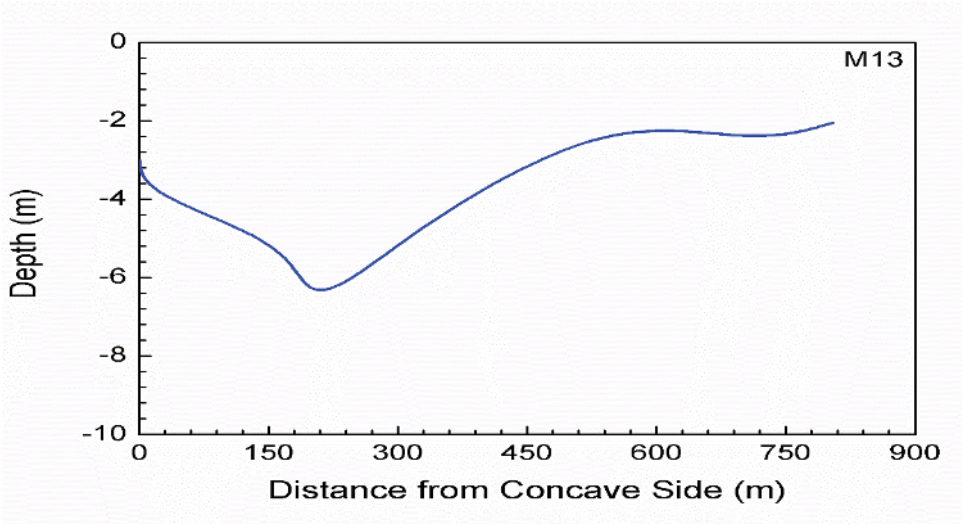

Figure 7.3. Typical Section of River Ganga at M-13

7.4.3 M-12 Section (In front of Ravidas Ghat)

At the section M-12, the maximum depth occurs at the 57.41 meters from the concave bank and the maximum depth is 5.3 meters, maximum velocity is 1.14 m/s at the distance of 51.47 meters from the concave bank, average depth of flow 3.589 meters, average velocity of flow 0.7068 m/s and the width of flow is 559 meters (Table 7.1.), at this section the erosion as compared to M-14 & M-13 is quite high because the average velocity of this section is greater than the both sections and the width of this section is also smaller than both sections so erosion is high and sedimentation also occurs at the quite high strength as the average width of flow is low.

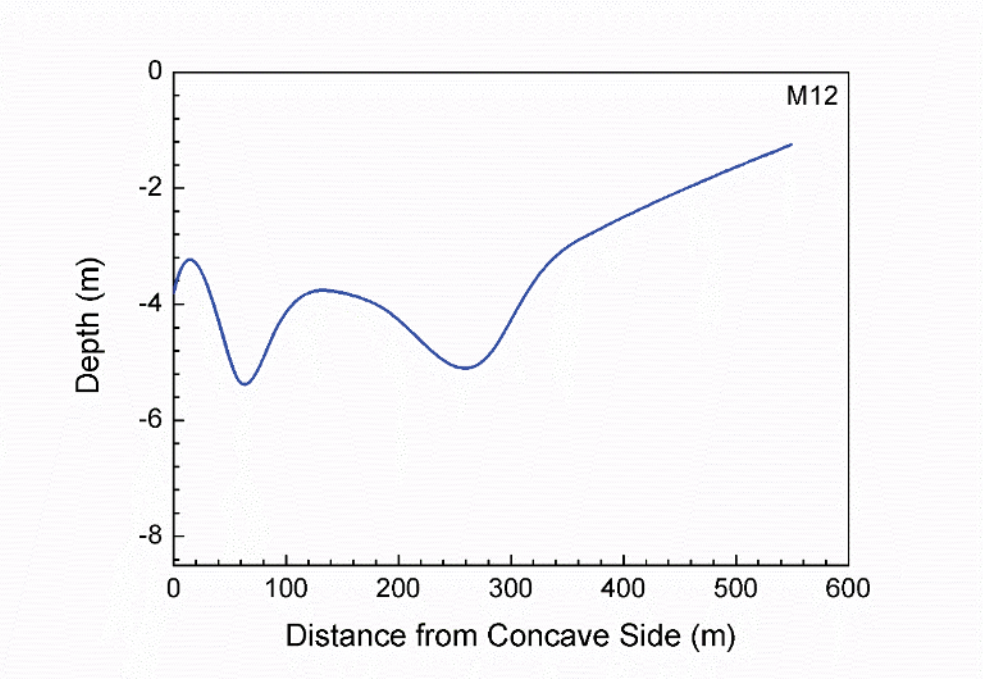

Figure 7.4. Typical Section of River Ganga at M-12

7.4.4 M-11 Section (In front of Assi Ghat)

At the M-11 section, the maximum depth occurs at the 169.26 meters from the concave bank and the maximum depth is 6.1 meters, maximum velocity is 1.01 m/s at the distance of 224.54 meters from the concave bank, average depth of flow 4.279 meters, average velocity of flow 0.70m/s and the width of flow is 422 meters (Table 7.1.), at this section the erosion as compared to M-14, M-13 & M-12 is quite high because the average velocity of this section is greater than the M-14 & M-13 and nearly same as M-12 sections. The width of this section is also smaller than the M-14, M-13 & M-12 sections so erosion is high and sedimentation also occurs at the quite high strength as the average width of flow is lower than the M-14, M-13 & M-12 sections. Average depth of flow at this section is greater than the M-13

& M-12 sections, it also shows the high erosion at this section. This section is confluence of the Assi River and sedimentation also occurs here at high speed.

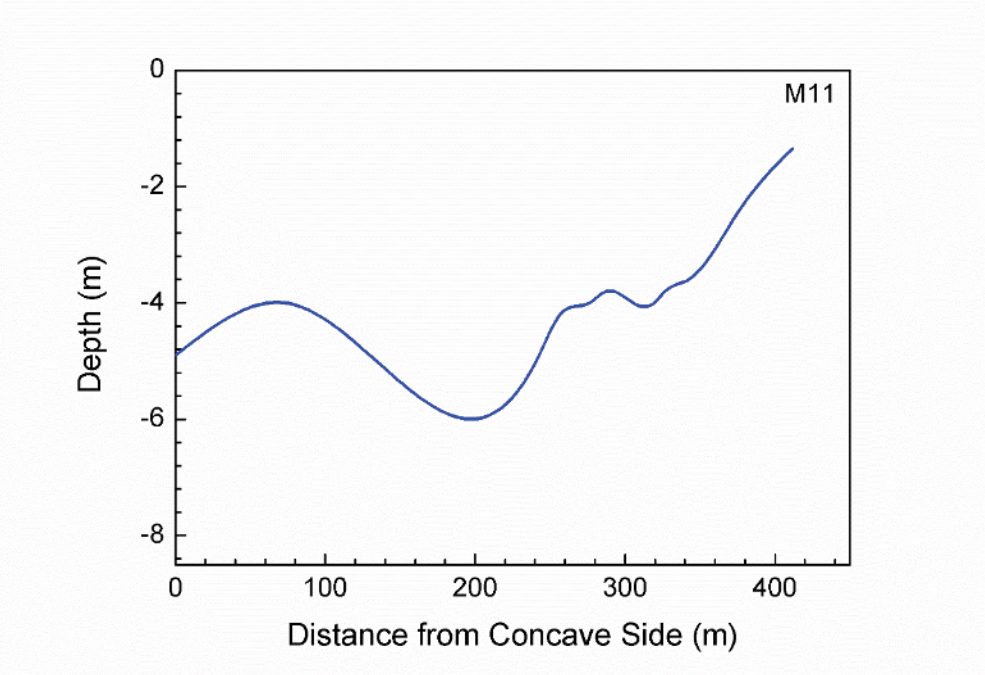

Figure 7.5. Typical Section of River Ganga at M-11

7.4.5 M-10 Section (Near Shrinishad Raj Ghat)

At section M-10, the maximum depth occurs at the 14.61 meters from the concave bank and the maximum depth is 13.1 meters, maximum velocity is 1.1 m/s at the distance of 160.28 meters from the concave bank, average depth of flow 5.1 meters, average velocity of flow 0.6418m/s and the width of flow is 392 meters (Table 7.1.), at this section the erosion as compared to M-14, M-13, M-12 & M-11 is quite high because the average velocity of this section is greater than the M-14 & M-13 and nearly same as M-12 & M-11 sections. The width of this section is also smaller

than the M-14, M-13, M-12 & M-11 sections so erosion is high and sedimentation also occurs at the quite high strength as the average width of flow is lower than the M-14, M-13, M-12 & M-11 sections. Average depth of flow at this section is greater than the M-13, M-12 & M-11 sections and nearly same as M-14 section, it also shows the high erosion.

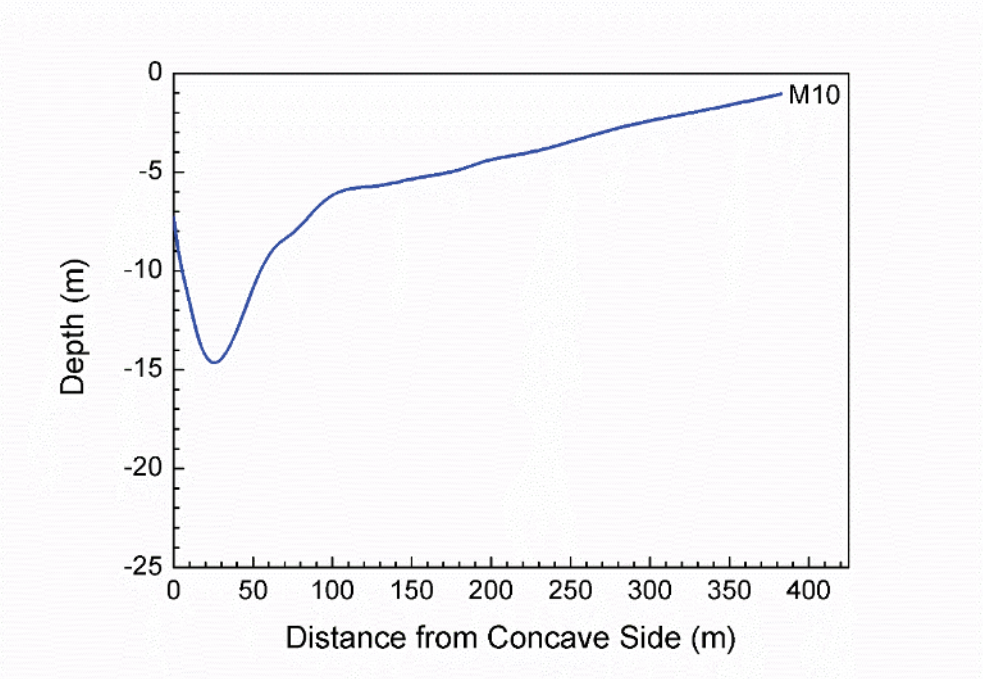

Figure 7.6. Typical Section of River Ganga at M-10

7.4.6 M-9 Section (Harishchandra Ghat)

At the section M-9, the maximum depth occurs at the 22.98 meters from the concave bank and the maximum depth is 9.7 meters, maximum velocity is 1.099 m/s at the distance of 22.98 meters from the concave bank, average depth of flow 5.43 meters, average velocity of flow 0.74m/s and the width of flow is 307 meters

(Table 7.1.), at this section the erosion as compared to M-14, M-13, M-12, M-11 & M-10 is quite high because the average velocity of this section is greater than all the M-14, M-13, M-12, M-11 & M-10 sections. The width of this section is also smaller than the M-14, M-13, M-12, M-11 & M-10 sections so erosion is high and sedimentation also occurs at the quite high strength as the average width of flow is lower than the M-14, M-13, M-12, M-11 & M-10 sections. Average depth of flow at this section is greater than the M-14, M-13, M-12, M-11 & M-10 sections; it also shows the high erosion.

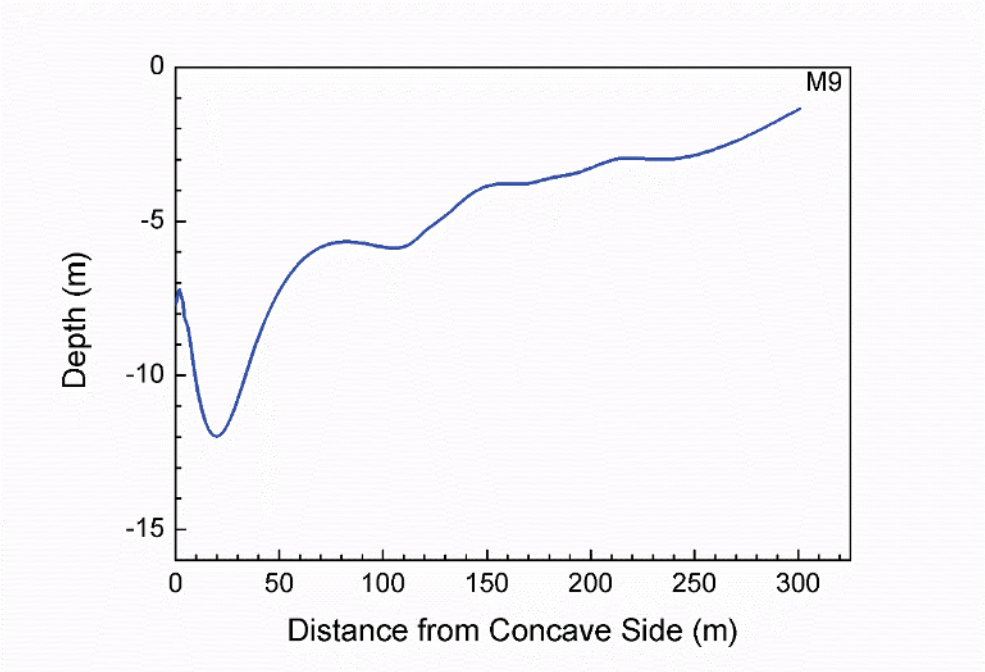

Figure 7.7. Typical Section of River Ganga at M-9

7.4.7 M-8 Section (Near Mansarowar Ghat)

At the section M-8, the maximum depth occurs at the 43.56 meters from the concave bank and the maximum depth is 12.3 meters, maximum velocity is 1.21

m/s at the distance of 69.49 meters from the concave bank, average depth of flow 6.72 meters, average velocity of flow 0.47 m/s and the width of flow is 312 meters (Table 7.1.), this section is nearly the middle section of the complete bend so the exact effect of the velocity, depth and discharge is not applicable as on the other sections. At this section the effect of all the parameters are moderate as compared to the other sections. At this section the erosion as compared to M-14, M-13, M-12, M-11, M-10 & M-9 is quite high because the average velocity of this section is smaller than all the M-14, M-13, M-12, M-11, M-10 & M-9 as well as the average area of flow is 2159.183 m^2 which is responsible for high discharge in low average flow width.

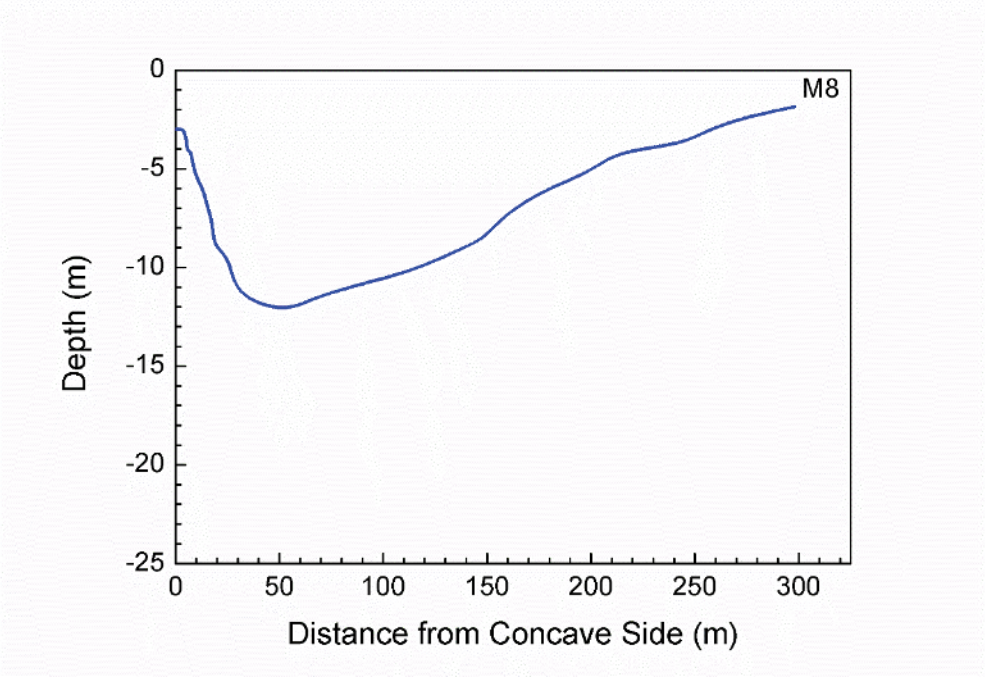

Figure 7.8. Typical Section of River Ganga at M-8

7.4.8 M-7 Section (Near Dashaswamedh Ghat)

At section M-7, the maximum depth occurs at the 33.32 meters from the concave bank and the maximum depth is 15.5 meters, maximum velocity is 1.07 m/s at the distance of 55.8 meters from the concave bank, average depth of flow 9 meters, average velocity of flow 0.51 m/s and the width of flow is 281 meters (Table 7.1.), this section is nearly the middle section (as the section M-8) of the complete bend so the exact effect of the velocity, depth and discharge is not applicable as on the other sections here the effect of all the parameters are moderate as compared to the other sections. At this section the erosion as compared to M-14, M-13, M-12, M-11, M-10, M-9 & M-8 is quite high because the average velocity of this section is smaller than all the M-14, M-13, M-12, M-11, M-10, M-9 & M-8 as well as the average area of flow is 2533.427 m^2 this tends to the high discharge in low average flow width.

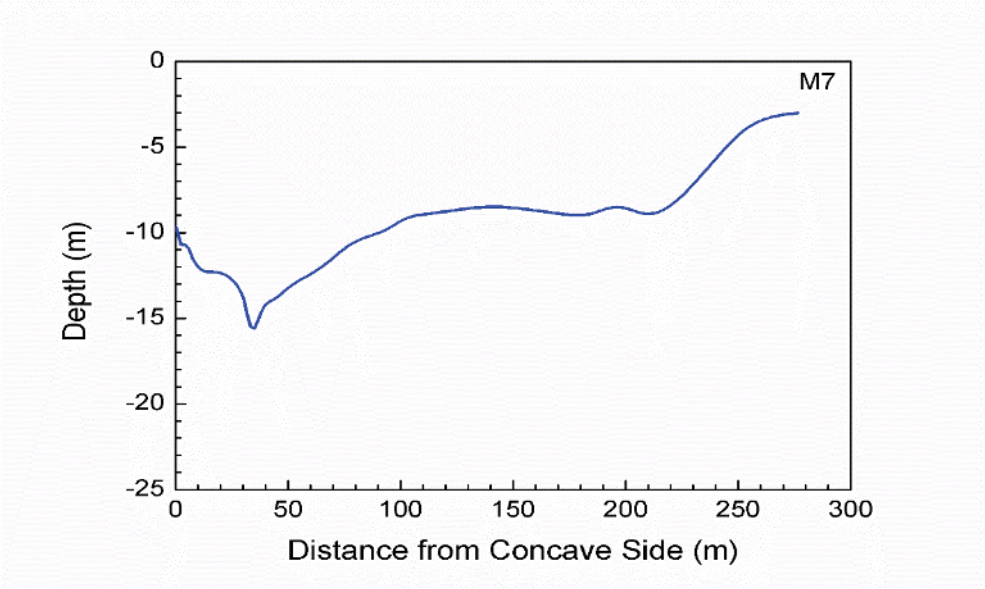

Figure 7.9. Typical Section of River Ganga at M-7

7.4.9 M-6 Section (Near Manikarnika Ghat)

At the section M-6, the maximum depth occurs at the 59.22 meters from the concave bank and the maximum depth is 17.9 meters, maximum velocity is 1.08 m/s at the distance of 116.89 meters from the concave bank, average depth of flow 10.99 meters, average velocity of flow 0.36 m/s and the width of flow is 297 meters (Table 7.1.), this section is just in downstream from the middle section of the complete bend so the exact effect of the velocity, depth and discharge is applicable on this section. At this section as the average velocity is quite low but the average area of flow is 3555.938 m^2 which shows a high discharge of flow so the erosion at this section is very high on the other hand the sedimentation at the other side is also very high. Average width of flow is 297 meters. It also shows the erosion at high level, because the same discharge is flowing in same area of flow so it resulted in high rate of erosion.

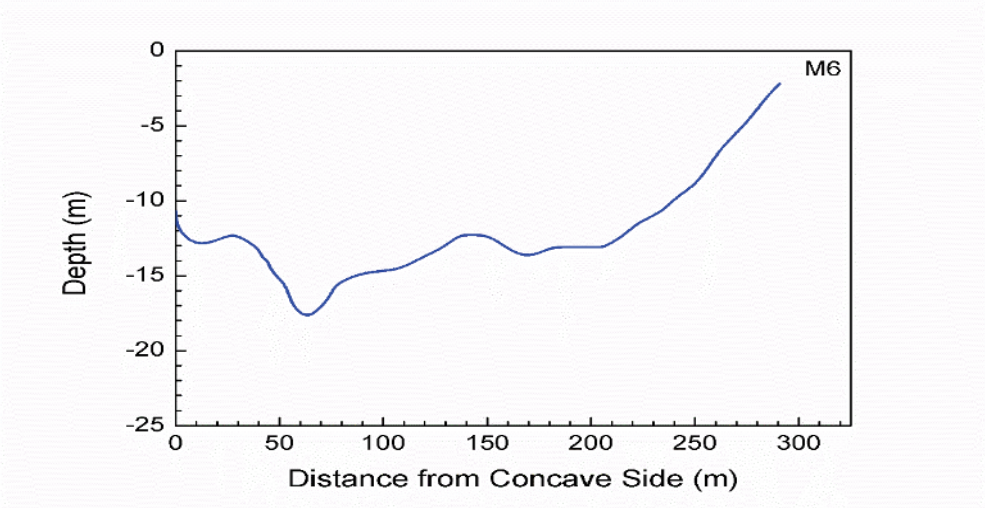

Figure 7.10. Typical Section of River Ganga at M-6

7.4.10 M-5 Section (In centre of Ramghat and Jatar Ghat)

At the section M-5, the maximum depth occurs at the 91.01 meters from the concave bank and the maximum depth is 21.1 meters, maximum velocity is 0.92 m/s at the distance of 162.385 meters from the concave bank, average depth of flow 12.09 meters, average velocity of flow 0.253 m/s and the width of flow is 386 meters (Table 7.1.), this section is in downstream from the middle section of the complete bend so the exact effect of the velocity, depth and discharge is applicable on this section. At this section as the average velocity is quite low but the average area of flow is 5165.938m^2 with high discharge of flow. The erosion at this section is very high and on the other hand the sedimentation at the other side is also very high. Average width of flow is 386 meters. It also shows the erosion at high level, because the same discharge is flowing in same area of flow so it resulted in high rate of erosion.

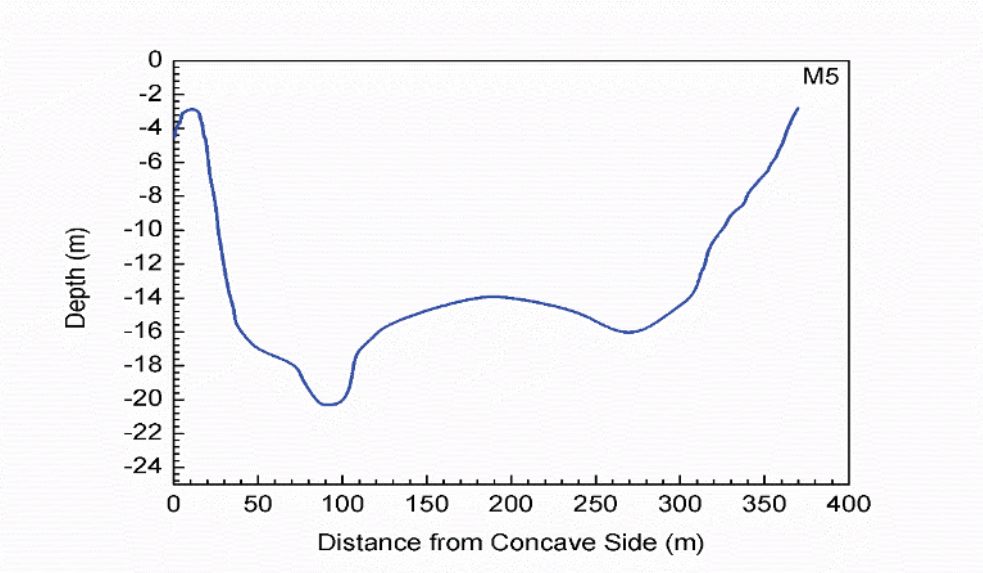

Figure 7.11. Typical Section of River Ganga at M-5

7.4.11 M-4 Section (Near Hanumangarhi Ghat)

At M-4, the maximum depth occurs at the 54.59 meters from the concave bank and the maximum depth is 22.7 meters, maximum velocity is 1.56 m/s at the distance of 155.45 meters from the concave bank, average depth of flow 12.4 meters, average velocity of flow 0.28 m/s and the width of flow are 378 meters (Table 7.1.). This section is in downstream from the middle section of the complete bend so the exact effect of the velocity, depth and discharge is applicable on this section. At this section as the average velocity is quite low but the average area of flow is $4789.346m^2$ with high discharge of flow so the erosion at this section is very high on the other hand the sedimentation at the other side is also very high. Average width of flow is 378 meters. It also shows the erosion at high level, because the same discharge is flowing in same area of flow so it resulted in high rate of erosion. At this section the erosion is very high as compared to the M-6 & M-5 because the average depth of flow is high and the average area of flow is quite low as compared to the M-5 section so the impact of the discharge on this section is very high it resulted in high rate of erosion.

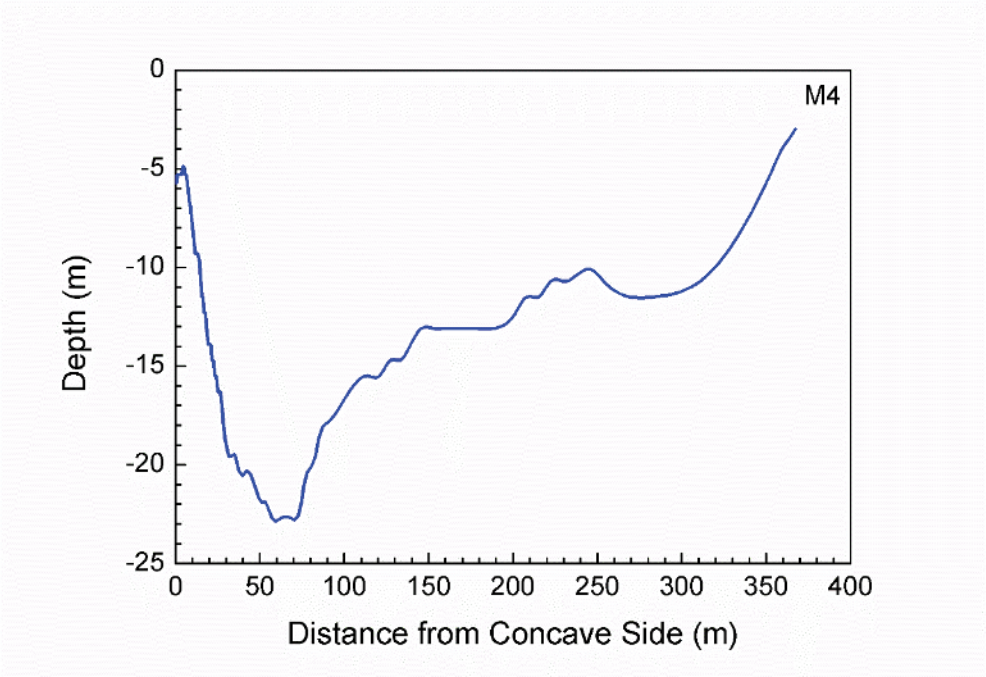

Figure 7.12. Typical Section of River Ganga at M-4

7.4.12 M-3 Section (Near Teliyana Ghat)

At the section M-3, the maximum depth occurs at the 46.28 meters from the concave bank and the maximum depth is 20.3 meters, maximum velocity is 0.6895 m/s at the distance of 95.505 meters from the concave bank, average depth of flow 13.814 meters, average velocity of flow 0.272 m/s and the width of flow is 357 meters (Table 7.1.). This section is in downstream from the middle section of the complete bend so the exact effect of the velocity, depth and discharge is applicable on this section. At this section as the average velocity is quite low but the average area of flow is 5030.038m^2 which shows a high discharge of flow so the erosion at this section is very high on the other hand the sedimentation at the other side is also

very high. Average width of flow is 357 meters it also shows the erosion at high level, because the same discharge is flowing in same area of flow so it resulted in high rate of erosion. At this section the erosion is very high because the average depth of flow is high and the average area of flow is quite high as compared to the M-4 section. The impact of the discharge on this section is very high it resulted in high rate of erosion but this erosion is quite low as compared to the M-4 section.

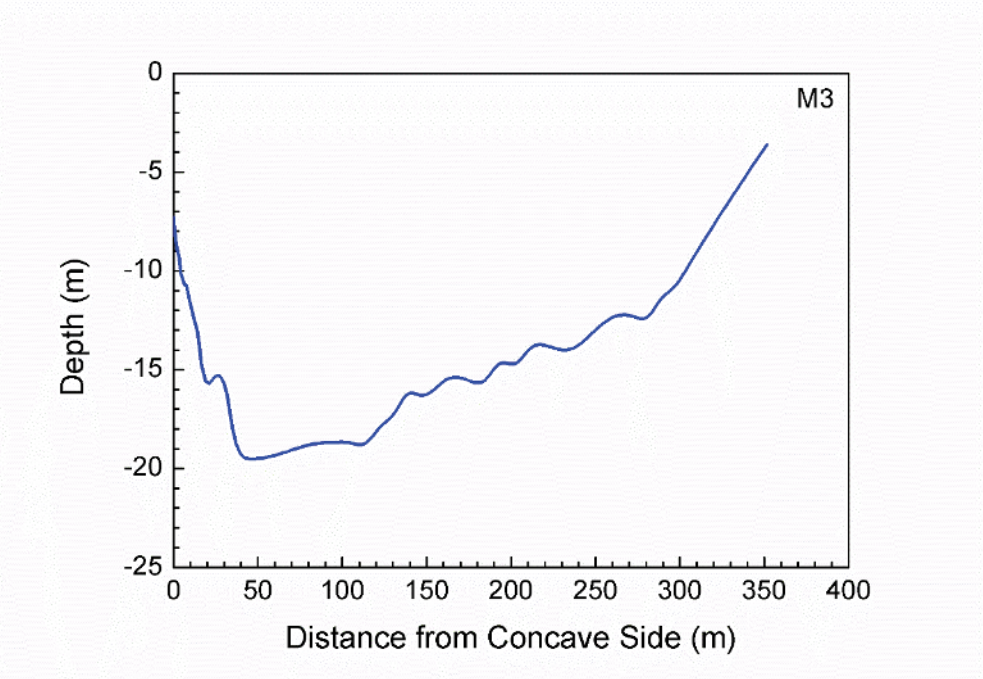

Figure 7.13. Typical Section of River Ganga at M-3

7.4.13 M-2 Section (Near Guru Ravidas Temple)

At the section M-2, the maximum depth occurs at the 65.06 meters from the concave bank and the maximum depth is 17.1 meters, maximum velocity is 1.28 m/s at the distance of 109.646 meters from the concave bank, average depth of

flow 10.86 meters, average velocity of flow 0.236 m/s and the width of flow are 434 meters (Table 7.1.). This section is in just upstream of the Rajghat bridge so on this section the average depth of flow is abruptly decrease due to the sedimentation occurs as the flow is restricted by the piers of the bridge, at this section the effect of erosion is quite low as compared to the upstream sections to M-2 section. As the area of flow is 5047.356m^2 and the average flow velocity is 0.236 m/s. It also shows an erosion upto an extent quite high but little bit low from the upstream sections but in the downstream from the middle sections.

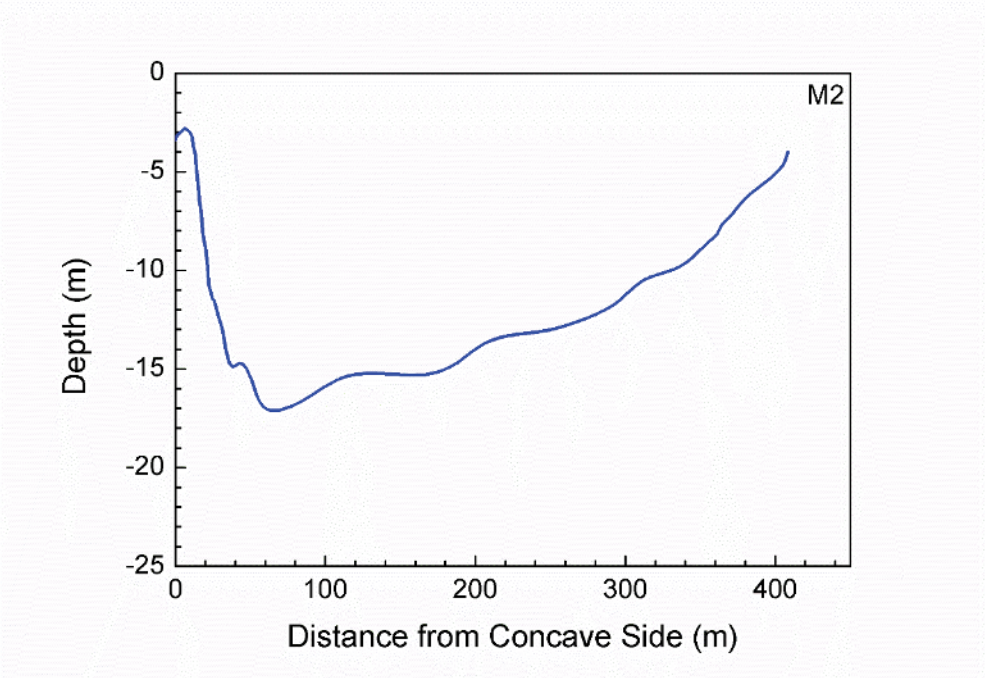

Figure 7.14. Typical Section of River Ganga at M-2

7.4.14 M-1 Section (Near Rajghat)

At the section M-1, the maximum depth is obtained at the 60.25 meters from the concave bank and the maximum depth is 21.9 meters, maximum velocity is 1.61

m/s at the distance of 164.06 meters from the concave bank, average depth of flow 13.03 meters, average velocity of flow 0.2219 m/s and the width of flow is 460 meters (Table 7.1.). This section is in just downstream of the Rajghat Bridge so the effect of erosion here takes place at high level as it is clearly shown with the average depth of flow increases instantly from 10.86 meters to 13.03 meters. At this section the area of flow is 6544.694 m^2 which is just increases from 5047.356 m^2 and represents a high rate of erosion. It also shows a high rate of sedimentation but rate of sedimentation is quite low as compared to the M-2 section.

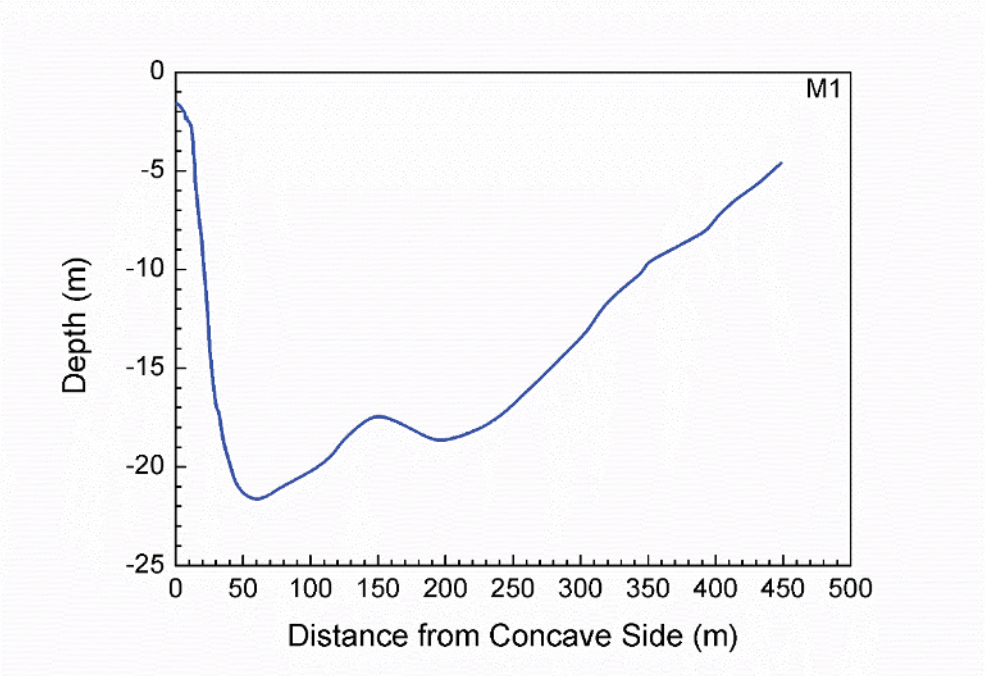

Figure 7.15. Typical Section of River Ganga at M-1

7.5 COMPLETE VARANASI BEND AS A WHOLE

The complete Varanasi bend having the arc length of 7476 meters, average radius of curvature is 4672 meters and the arc angle is 91.71°. Total average area of the flow at complete bend is 3477.01, average width of flow at the bend is 435.21

meters, average velocity of flow is 0.4510 m/s, average depth of flow is 8.31 meters, average discharge of flow is 1270.68 m^3/s and sinuosity of bend is 1.598, it shows the bend is highly sinuous and the erosion and sedimentation takes at very high rate due to its sinuous nature and high discharge, depth and velocity. As we move forward from the middle section the erosion increase at high rate because the average width of flow is very high and the average area of flow is also very large so the discharge is very high.