CHAPTER 5

IDENTIFICATION OF SEDIMENT TRANSPORT OF RIVER GANGA

5.1 INTRODUCTION

Sediment transport dynamics are very complex phenomena, and the estimation of sediment transport of any river is essential to define river behaviour. Therefore, quantification of the physical process of sediment transport is the most significant interest area of researchers. Moreover, sediment transport estimation along different depths for the alluvial river is necessary for any hydraulic structure and river habitat. Hence the understanding of this complex behaviour is essential. This chapter details and results of the study done on the sediment transport of river Ganga near Varanasi. First, the details of the study area and methodologies used are presented, then results and discussions are presented.

5.2 STUDY AREA & FIELD SURVEY

In this study, a stretch of about 10 km in length near Varanasi was selected for the sediment transport behaviour. The detailed description of the section identified along with their names and coordinates, are provided in section 3.2.2 of chapter 3.

5.3 METHODOLOGY USED

The water sampling and Acoustic profiling were done simultaneously to estimate the SSC dynamics and bed profile pattern. For Acoustic profiling, the stretch of about 10000 meters in length was divided into fifteen cross-sections. The ADCP was used for the estimation of SSC and the river bed profile. Figure 5.1 shows a photographic and schematic view of

ADCP attached to the boat. During measurement by ADCP, the boat was moved to and fro from concave bank to convex bank. Then the average of these two data was taken. The distance covered by the boat between two cross-sections is shown in Table 3.5. The average distance between two cross-sections is about 600 m. Sediment load through ADCP was measured in two steps. In the first strep, the backscattering data of ADCP was collected in decibels. In the second step, obtained decibel values were converted in SSC (milligram per litre). The details of these two steps are discussed in subsection 5.3.1 and 5.3.2.

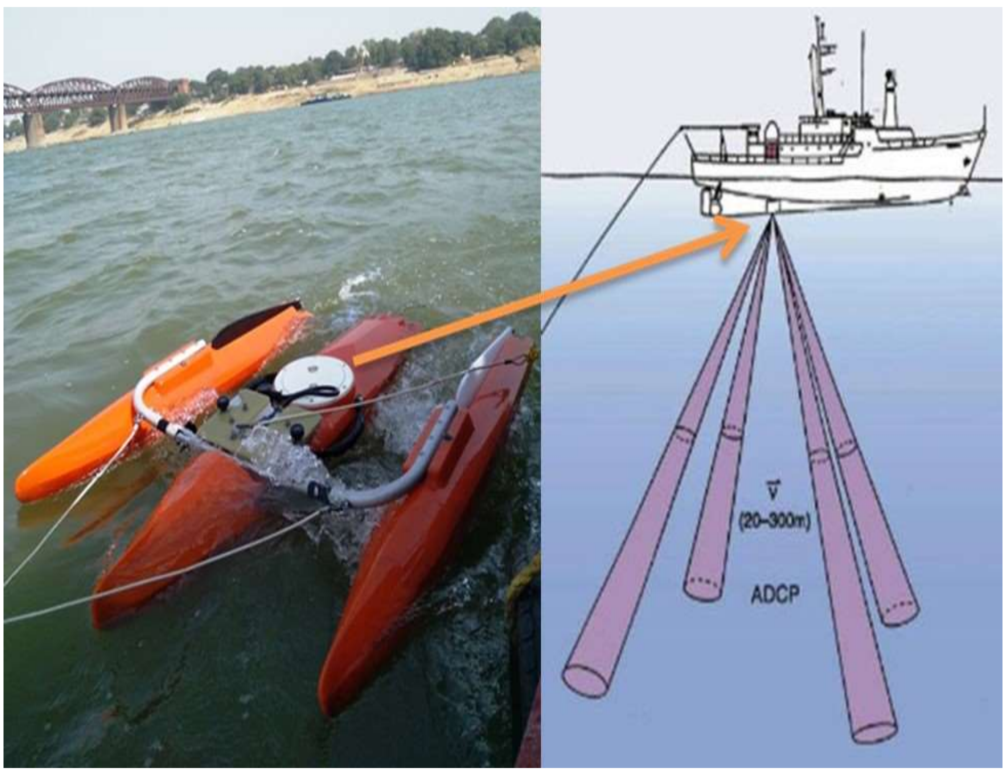

Figure 5.1 ADCP instrument with moving boat

5.3.1 THE ACOUSTIC TECHNIQUE OF FIELD SURVEY

For measurement of the flow, velocity and discharge for a broad river like the Ganga, ADCP is a powerful acoustic instrument. Acoustic technique is also useful for large sand bed river (Gaeuman and Jacobson 2006). Different researchers like; Thorne and Hurther 2014; Urick 1948, Medwin and Clay 1998 have studied the impact of suspended sediment on the scattering of acoustic sound. The response of sound intensity (I) depends on various factor like reference pressure, amplifier gain, pulse length, transmit power of sound, the density of suspended particle, attenuation capacity and geometrical spreading of the sound wave. The transducer of ADCP has four acoustic beams, namely beam A, beam B, beam C and beam D; all beams are generally placed at 20 to 30 degrees from vertical, as shown in Figure 5.2. It worked on the Doppler shift principle. Beams transmit high-frequency wave and receive it on the estimation based upon the frequency difference. All beam produce sound wave to measure the speed and direction of flow along the water column. The equation of sound intensity (Thorne and Hurther 2002) can be written as:

$$I = P_0^2 \, . r_0^2 . \frac{K_t^2 . \, K_s^2 . M_s}{r^2 . \psi^2} . \, e^{-4(\alpha_w + \alpha_s) . r} \tag{5.1}$$

where P_0 is the reference pressure, r_0 is distance, and K_t is acoustic system transmit power, K_s is backscattering coefficient, M_s is the backscattering strength, α_w is attenuation coefficients of viscosity of water, α_s is attenuation coefficients of suspended sediment, and ψ is field correction coefficient.

In this era, ADCP is widely used for the discharge and velocity measurement of the large stream for precise estimation. On the other hand, acoustic gives reoccurrence of backscattered sound is post-process to decide 3- dimensional velocity information, here we direct the quality of resounded sound. The connection between SSC & the supposed relative acoustic backscatter (RB) can be communicated as (Wall et al. 2006):

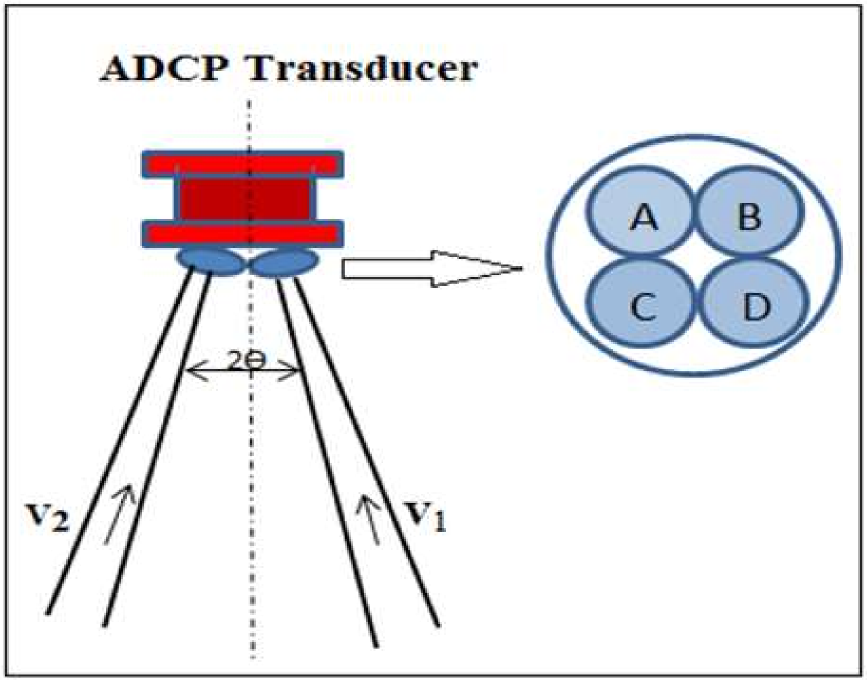

Figure 5.2. ADCP transducer with showing beams A to D

$$\text{Suspended sediment concentration (SSC)} = 10^{(A+B*RB)} \qquad (5.2)$$

where A is intercept and B is the slope. The relative backscatter is the deliberate acoustic backscatter that depends on the reverberation level and loss in the transmission. RB derived from the equation (Sassi et al. 2012):

$$RB = RL + 2.TL \qquad (5.3)$$

where RL = Reverberation level in dB, TL = Transmission losses in dB.

In reverberation of resonance condition (Parker 1976) the reverberation level expressed as:

$$RL = SL - 2.TL + TS \qquad (5.4)$$

where SL= Source level (dB), TS= objective Quality of suspended sediment load. This is a component of molecule shape, measure rigidity, and acoustic wavelength. When measuring with an ADCP, the reverberation level comes from

$$RL = Kc\ (EI - Er) \tag{5.5}$$

where, Kc= Scale factor, EI= Echo strength (in counts) by ADCP and Er = Reference echo strength

Return echo received by the receiver and calculated based on the echo intensity (dB). Temperature impact on echo intensity is considerably based on the formula:

$$\text{Echo intensity scale (dB per RSI count)} = 127.3/(T_e+273) \tag{5.6}$$

where T_e is the temperature in ^{o}C of ADCP electronics. Echo intensity is simply defined in decibels, and the sound absorption coefficient measures this. If the echo intensity more than two times of near zone distance, then the normalization of echo intensity done by the formula:

$$I_{dB} = C.I_{counts} + 20.\log10\ (R) + 2\alpha R - 10.\ \log_{10}\ (LXmit/\cos\Theta) \tag{5.7}$$

where $R = \frac{r+0.5\ L\ Xmit}{\cos\theta}$

R is the range from the transducer to the middle of the bin, θ is the beam angle. LXm the transmit length, A is the sound absorption coefficient, and C is the echo intensity scale. The transmission loss can be given by:

$$TL = 10\times \psi \times \log(R) + \alpha \times R \tag{5.8}$$

where R= slant range in meter from transducer head to bin, α= Coefficient (dB/m). The correction can be calculated based on the so-called critical range $R_{critical}$, where $C_{ritical}$ equal to $\pi a_t^2/\lambda$.

a_t = transducer radius in cm and λ= acoustic wavelength

$$\text{The correction factor } (\psi) = \frac{[1+1.35Z+(2.5Z)^{3.2}]}{[1.35Z+(2.5Z)^{3.2}]} \qquad (5.9)$$

where z = R/ $R_{critical}$. The above equation present correction factor was utilized for near-field calculation of Spreading losses. For the calculation of energy losses by absorption in the water, where used the formula as follows:

$$\alpha_w = 8.687\, \frac{3.38*10^{-6}.f^2}{f_T} \qquad (5.10)$$

where f equal to instrument frequency (Hz), f_T = Relaxation Frequency.

The latter depends on the water temperature, T:

$$f_T = 21.9 * 10^{(6-\frac{1520}{273+T})} \qquad (5.11)$$

Some induce attenuation from suspended sediment (αs) is scattering and occupying the energy. It is shown that energy dissipation depends mainly on particle size, sound frequency under a certain condition, or both of them can be neglected. We did not consider attenuation due to absorption by the sediment here as discussed afterwards a replacing the above-detailed terms into Equation (2), the following relation can be written as:

$$SSC=10^{\,A+B.(Kc\,(EI-Er)+2(10.\log(R)+\alpha.R))} \qquad (5.12)$$

where Kc, EI, Er, R and α were calculated with the help of ADCP and previous equations. A is the intercept, and B is the slope calculated based on the calibration of ADCP backscatter data.

5.3.2 CALIBRATION AND VALIDATION

Calibration is fundamental to achieving consistency of measurement. Often calibration involves establishing the relationship between instrument response and one or more reference values. Linear regression is one of the most frequently used statistical methods in calibration. The backscatter in dB and direct estimated SSC was utilized as a part of the calibration and validation process. For the development of the regression line, the vertical sampling method was used. In this method, a water sample of water was collected from the depth where backscatter data was available. Twenty-five direct samples were collected at different depth for further laboratory process for SSC estimation. Direct samples were collected from the site location for calibration. From this investigation, the regression line developed a linear relation between SSC estimation from sampler and backscatter intensity in dB. This regression analysis used for finding two unknowns A and B, where A is the regression slope and B is intercepted. The range of direct estimation SSC was between 40 - 50 mg/l, and backscatter in dB was between 62 - 80 dB.

5.4 RESULTS AND DISCUSSION

5.4.1 CALIBRATION

The calibration demonstrates that a straight connection between the backscatter of ADCP and SSC from coordinate estimation is substantial, yet the inclination of the best-fit straight lines might be unique. The steady of this proportionality should be evaluated precisely for each site determination.

This regression line investigation utilized 25 set of backscatter data in dB and 25 set of direct sample data in mg/l. The results obtained from the analysis show that the slope and intercept of the regression line were 0.0052 and 1.2897, respectively. The coefficient of determination (R^2) was observed to be 0.9065 (90%). The equation which we get from regression is y = 1.2897 + 0.0052x. Figure 5.3 shows the results of the calibration. The graph's vertical axis is the log of SSC, and the horizontal axis represents the value of acoustic backscattering in dB. As shown in Figure 5.3 the data made three clusters C1, C2 and C3. C1 cluster has very fewer points whose values are between 62 dB to 66 dB. C2 cluster belongs to 68 dB to 74.3 dB, and the last cluster lies above 74.3 dB. Table 5.1 show that the C1 cluster is confined till the depth of 0.65m, C2 cluster is confined between 1.1 m to 16.3m and C3 cluster is beyond 16.3 m of depth.

Table 5.1 Observed value of ADCP and Direct sample of SSC at different depth

Sl. No.	Depth (*m*)	Backscatter (*dB*)	Log_{10} SSC (*mg/l*)	Location	Sl. No.	Depth (*m*)	Backscatter (*dB*)	Log_{10} SSC (*mg/l*)	Location
1.	0.25	64.875	1.623249	C1	14.	9.1	71.7	1.672098	C2
2.	0.55	63.8	1.612784		15.	9.9	69.5	1.633468	
3.	0.65	63.25	1.623249		16.	10.7	70.475	1.658011	
4.	1.1	69.9	1.633468	C2	17.	11.5	68.225	1.633468	
5.	1.9	69.675	1.643453		18.	12.3	70.6	1.658965	
6.	2.7	70.2	1.653213		19.	13.1	70.7	1.662758	
7.	3.5	69.15	1.633468		20.	13.9	71.325	1.681241	
8.	4.3	70.175	1.658011		21.	14.7	68.9	1.643453	
9.	5.1	70.25	1.653213		22.	15.5	69.2	1.633468	
10.	5.9	70.525	1.662758		23.	16.3	74.3	1.690196	
11.	6.7	71.125	1.667453		24.	17.1	87.2	1.748188	C3
12	7.5	72.1	1.690196		25.	17.9	96.8	1.778151	
13	8.3	70.2	1.657056						

The samples near the water surface have a low sediment concentration, as the heavy particles settle down. It gives the values between 62dB to 66dB, these clusters are C1, and

C2 are the values where the sediment concentration is higher than C1 and lower than C3 as it belongs to the middle layer of the river section. As we go down the concentration of sediment will increase, so the C3 has the highest values. That is the main reason the Figure 5.4 shows the zone of clustering.

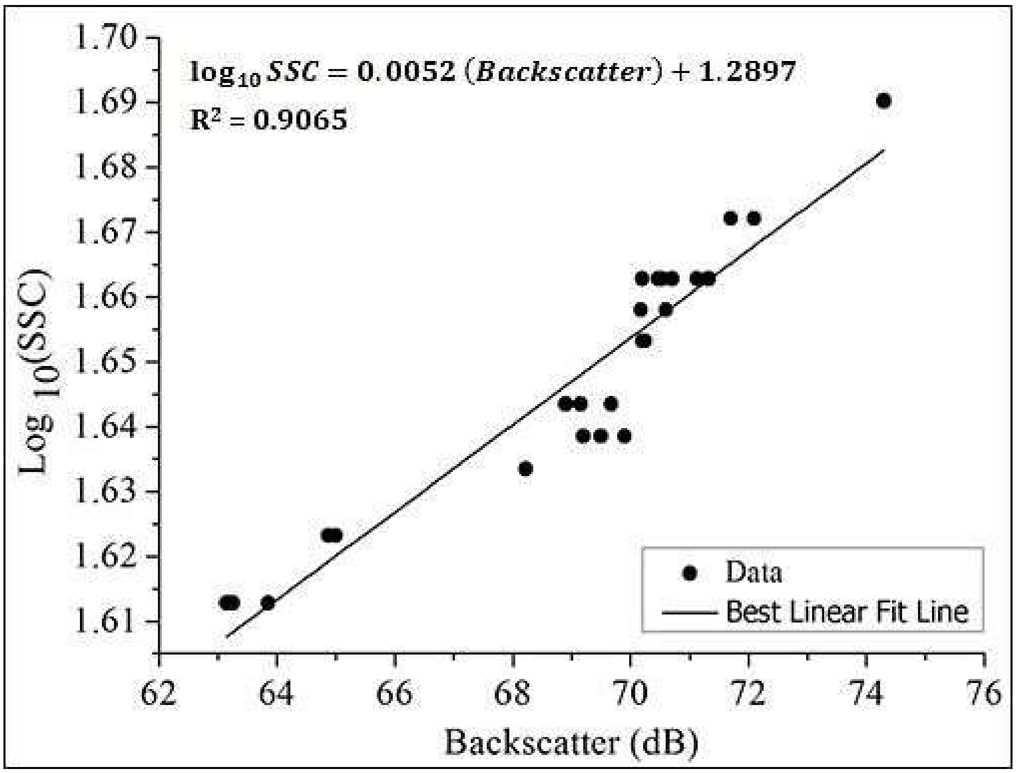

Figure 5.3 Calibration of backscatter intensity (dB) with estimated SSC by direct sampling (mg/l)

5.4.2 VALIDATION

Linear regression analysis result was based on a 95% confidence interval. The standard error in slope is 0.08683. After the critical analysis, it showed that the acoustic technique with the help of ADCP and was perfect for estimation of SSC. Here the validation Figure 5.4 shows a similar pattern as shown in calibration. In the three zones of clustering, the first zone of the cluster receives 40 to 42 mg/l of SSC. The data of the first zone shows that the acoustic and sampling technique both are a very similar pattern. In the cluster of zone 2, SSC from ADCP varies from 42.5 to 46.5 mg/l, and the SSC from the sampler varies from 42.5 to 46 mg/l. Both were not the same but very much similar form both technique. The zone 3 concentration of SSC from ADCP varies from 47 to 48 mg/l and the SSC from the sampler belongs to 46 to 48. The range of sediment concentration found from the sampling technique is higher as compared to the sediment concentration received from the ADCP. From this pattern, it can be observed that cluster zone 2 receive a higher range of concentration, cluster zone 1 and zone 2, while the lowest and the maximum convention is in cluster zone 1 and cluster zone 2, respectively.

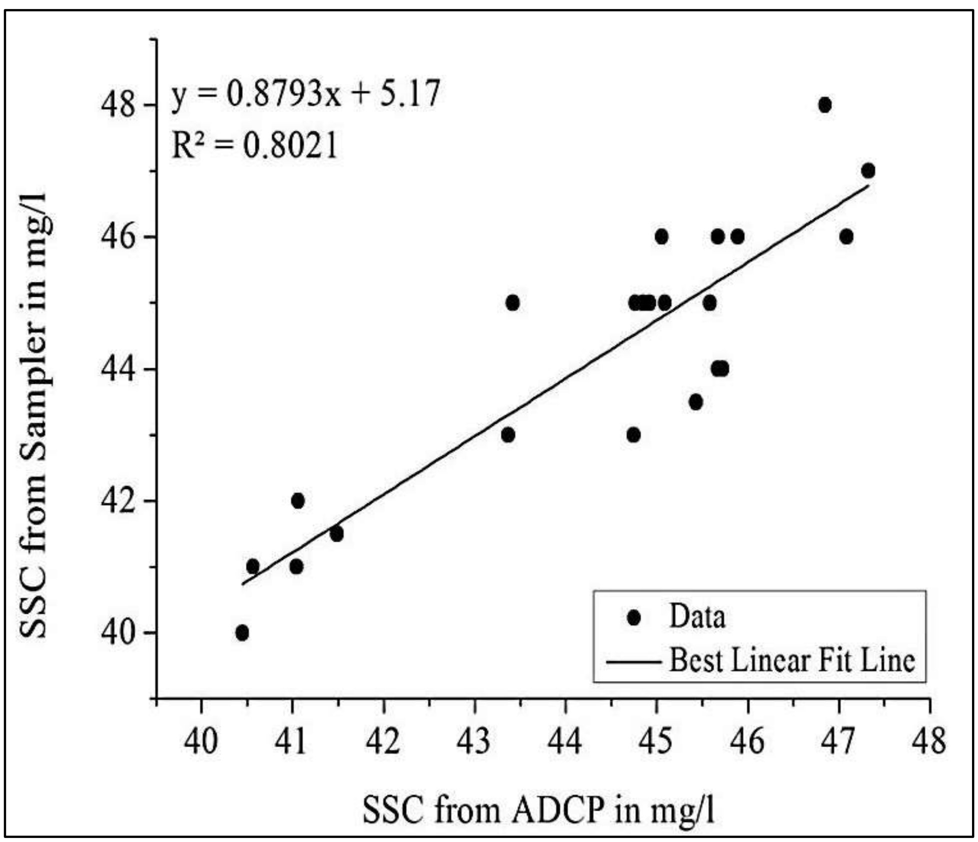

Figure 5.4 Validation of evaluated SSC from ADCP and direct sampling

5.4.3 SEDIMENT TRANSPORT BEHAVIOR

Suspended sediments generally travel at the same velocity as the fluid. High velocity carries a higher concentration of sediments, and small velocity carries a lower concentration of sediments in suspension. As mentioned earlier, fifteen sections (CS 15 to CS 1) were selected in the stretch under consideration. Due to deposition and erosion depth of the river bed get affected. The depth of the river also has a significant impact on sediment transport behaviour. In this study, variation of the river's depth considered for six years from 2012 to 2017. All data (CS 1 to CS15) were collected at the time of pre-monsoon. Table 5.2 shows the variation of the maximum depth at different cross-section from 2012-2017. It can be observed that the depth of the water column increases from the cross-section on the upstream side to the downstream side up to CS2. But after CS2 sudden decrease in the water level takes place up to CS1. Assi river, which is a tributary of river Ganga, is on the upstream side of the CS14. At the confluence point of the two rivers, the deposition of sediments gets increased. This could be the possible reason for the shallower depth of the water at CS15-CS12.

Further in downstream side erosion process rises. A similar trend was observed for CS1, which is near the confluence point of river Varuna and river Ganga. CS2, i.e. near Raj Ghat, is deepest among all the cross-section. From an erosion point of view, CS2 and CS5 are critical. It can be further noted that the maximum depth was observed in 2014. This happened due to the severe flood that occurred in 2013. In 2013 the flood water flowed 1.36 m above the danger line. Because of the high discharge due to the flood, an increase in erosion was taken place.

Table 5.2 Maximum Water column depth (in m) of cross-sections in different years

Cross-Section	Location	2012	2013	2014	2015	2016	2017
CS 15	Near Samne Ghat Bridge	4	4.5	3.5	3.5	3.5	4
CS 14	Near RavidasGhat	3	2	1	1.5	1	1.5
CS 13	Ravidas Ghat	4	4.5	3.5	3.5	3.5	4
CS 12	AssiGhat	4.5	6	6	4.5	3.5	4
CS 11	Shrinishad Raj Ghat	12	13	13	14	15	14.5
CS 10	HarishchandraGhat	11	10.5	12	10	9	10
CS 09	MansarowarGhat	10.5	12	11	14	13	14
CS 08	DashaswamedhGhat	12	13	14	14	14	13
CS 07	ManikarnikaGhat	14	15	16	16.5	16	17
CS 06	Ramghat and Jatar Ghat	16	15	20.5	16	17	18
CS 05	HanumangarhiGhat	17	16	21.5	16.5	17.8	18.9
CS 04	TeliyanaGhat	14	16	19	15	17	17
CS 03	Guru Ravidas Temple	13	14	15	13	13.5	14
CS 02	Near Rajghat	18	16	22	17	18	19
CS 01	Near Varuna	3	4	3.5	3	4	3.5

Backscattering data obtained from the ADCP at CS2 from the year 2012-2017, which is the most critical cross-section from an erosion point of view, are presented in Figure 5.5 -5.10. The river's depth is shown on the vertical axis, and on the horizontal axis, length is presented. The concentration of suspended particle is significantly less as compared to the year 2014 to 2017. The bed profile changes every year due to sediment transport behaviour. The bed profile of 2012 has a very mild slope, but after 2012 the bed profile changes as shown in Figure 5.6 and mark under the red circle. The red circle shows the clear change of bed profile from the year 2013 to 2014. After 2014 the bed slope increases at two points with the high water depth. In 2014 Q (discharge) was 427 m^3/s, and the max depth is 22 m; on the other hand, in 2017, where discharge is 246 m^3/s, but maximum depth is 19m which is high compared to the 2014 discharge condition. In 2012 the bed slope was mild, and the depth of the middle section is 14 m. In 2013, the bed profile did not show a gentle slope, and the middle section of river depth is about 10m. In 2014, the slope changed its pattern and the maximum depth of concave and depth of the middle section is 22 and 18 b m, respectively.

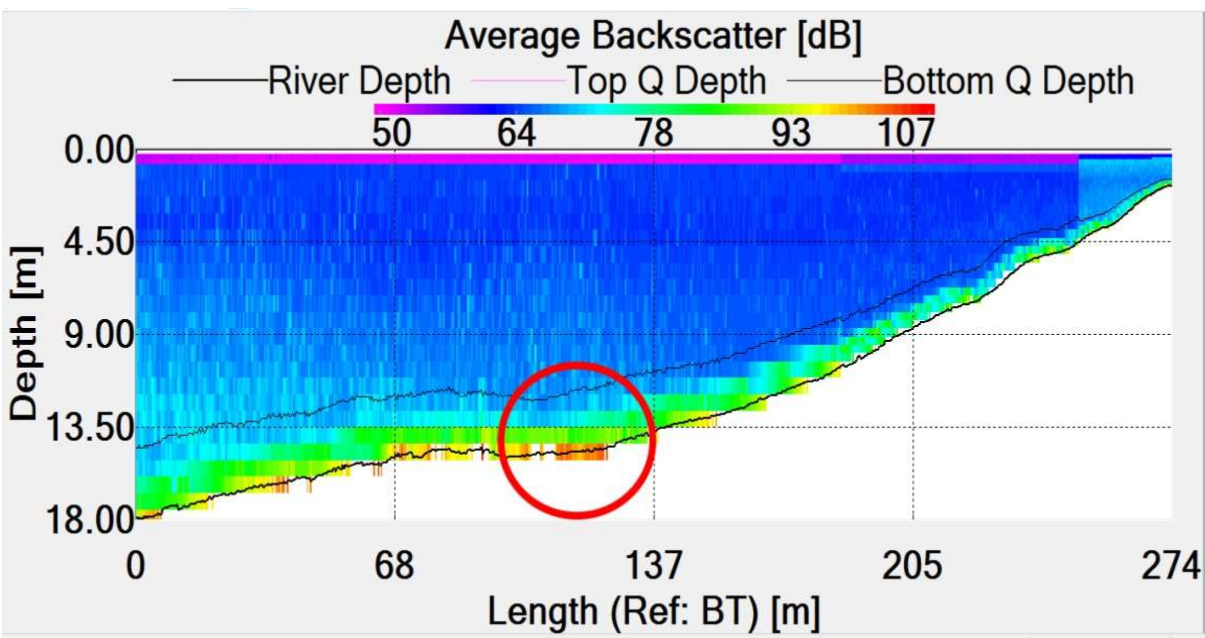

Figure 5.5 Backscattering profile for the year 2012 at CS2 cross-section

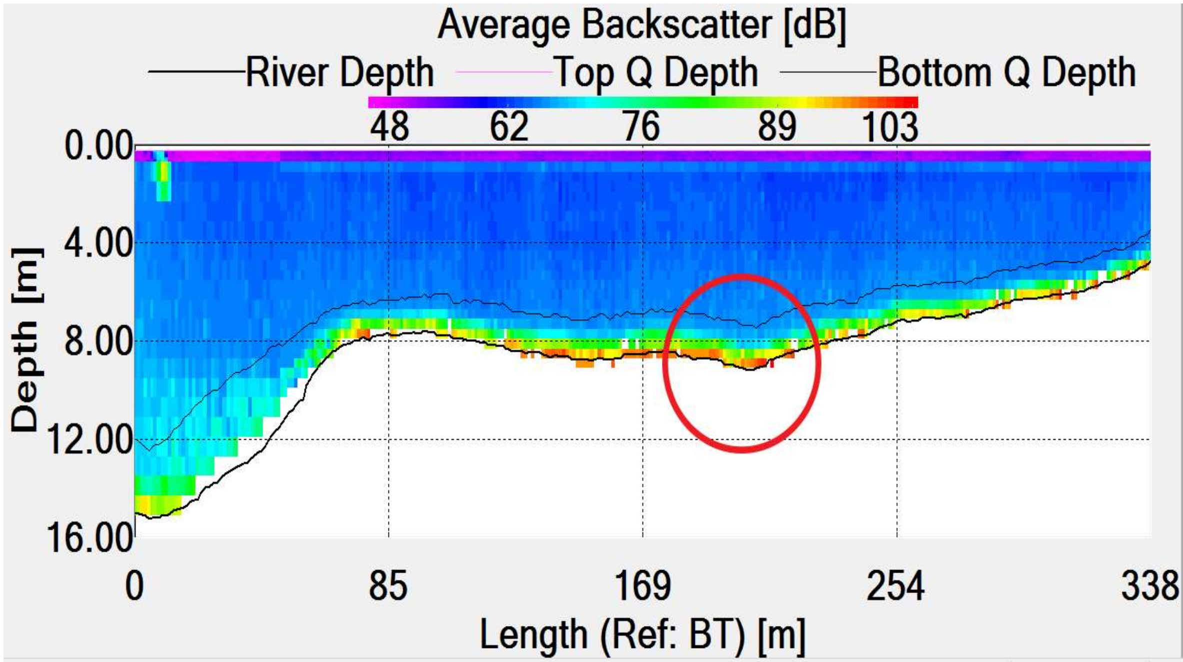

Figure 5.6 Backscattering profile for the year 2013 at CS2 cross-section

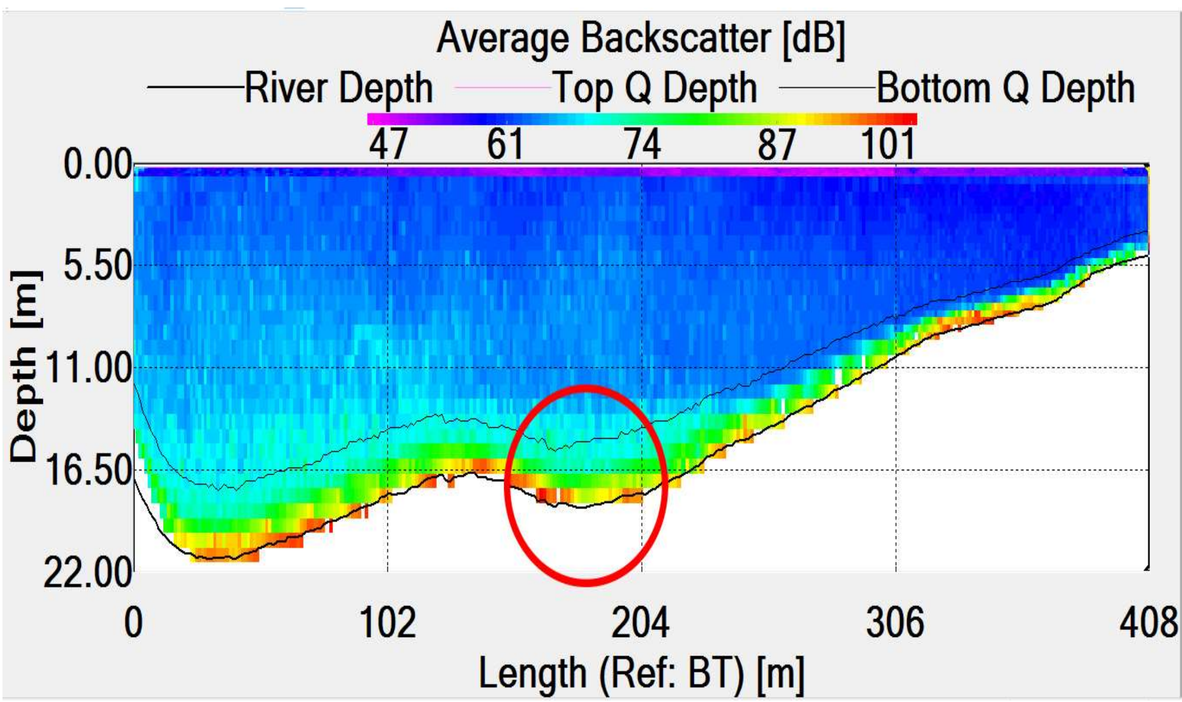

Figure 5.7 Backscattering profile for the year 2014 at CS2 cross-section

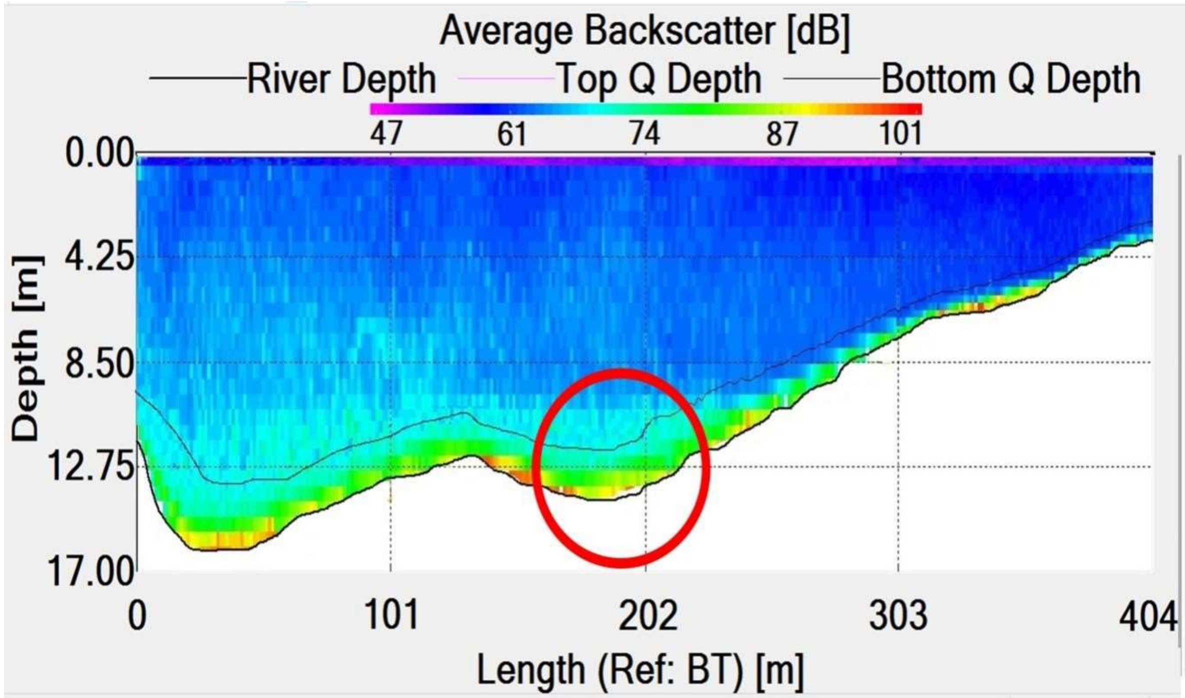

Figure 5.8 Backscattering profile for the year 2015 at CS2 cross-section

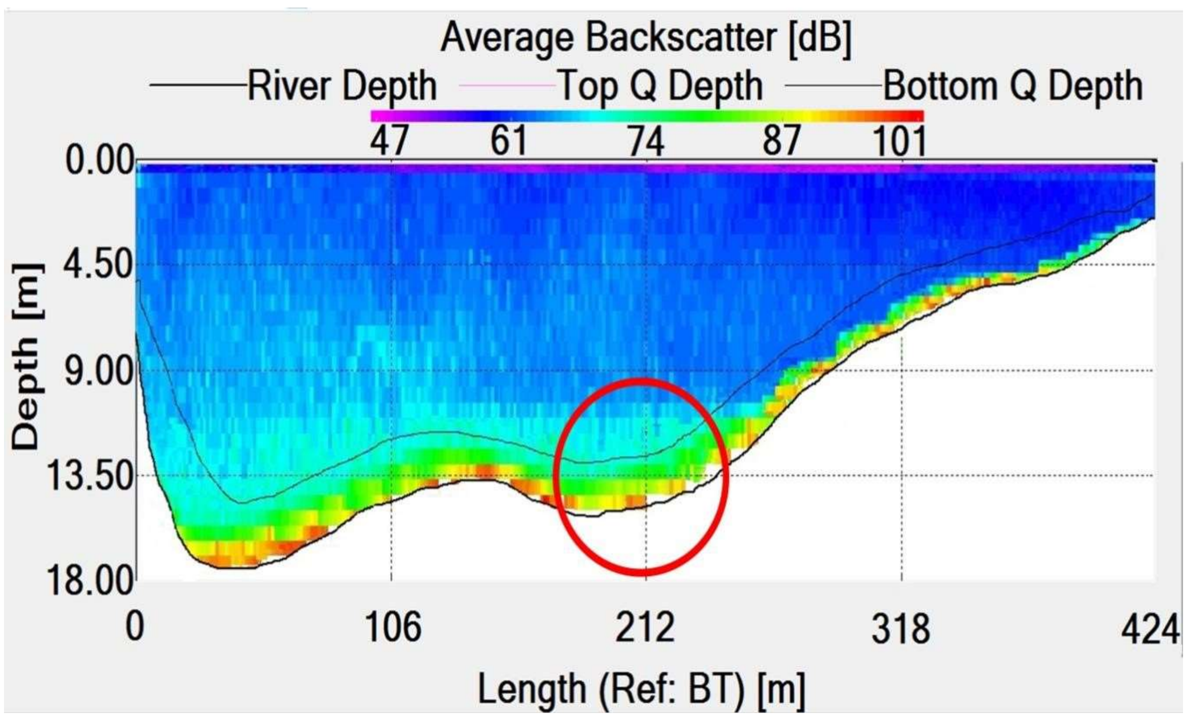

Figure 5.9 Backscattering profile for the year 2016 at CS2 cross-section

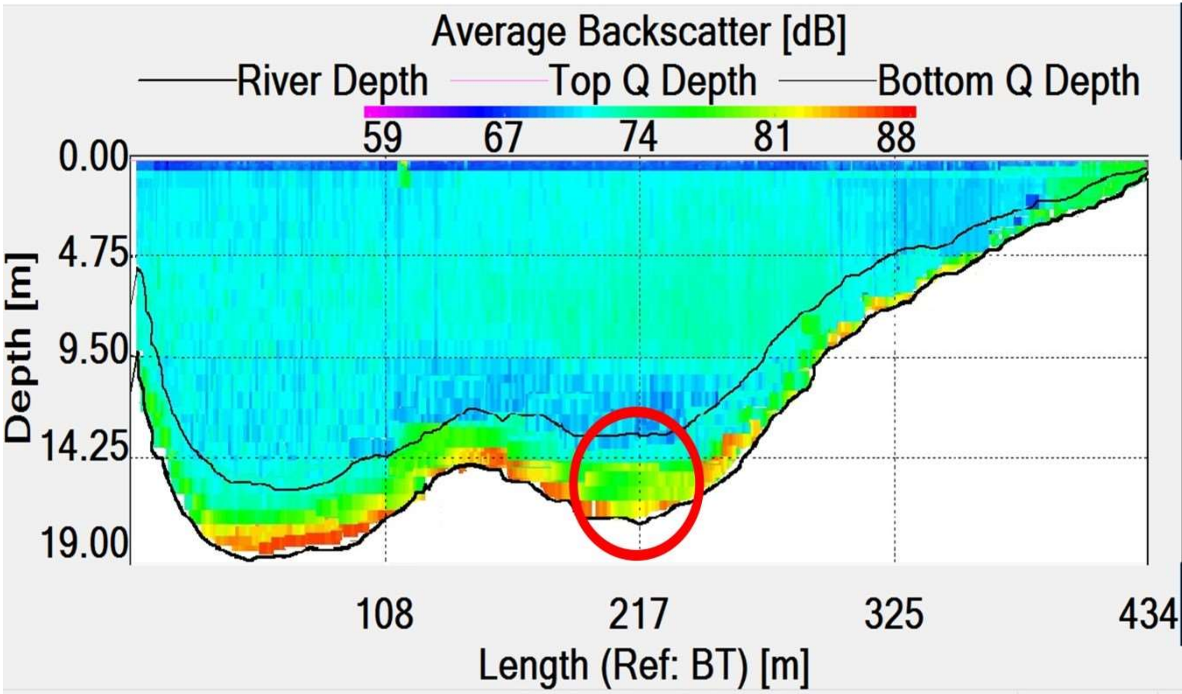

Figure 5.10 Backscattering profile for the year 2017 at CS2 cross-section

The maximum depth at the concave bank and the middle section is continuously increasing in pattern. In 2017 the concave bank maximum depth and the middle section depth increased where the maximum depth is 19 m, and the middle section depth is 18 m. The depth of the middle section of the river starts rising from 2014 to 2017 is shows the erosion pattern and increases the depth.

In Figure 5.11 bed profile of the river is shown. The green line shows the flood line, which indicates the boundary of the flood plain. The red line shown indicates the river's main channel, where water flows all over the year. The bed cross-section thalweg path is presented in Figure 5.12 for three years from 2015 to 2017. The thalweg path is drawn by joining the minimum elevation point of all the cross-sections selected under the study. The thalweg path was also indicating that CS15-CS12 is shallower. The CS11 shows the more erosion bed as compared to the CS 10. The CS 3 shows some deposition as compared to CS 2, and it may be because one bridge is situated between CS3 and CS2, the flow of river gets reduced, and it starts deposition near the CS3. But on the downstream side of these cross-sections depth of water increases. Also, from the thalweg path, it can be noted that CS2 and CS 5 are critical sections from an erosion point of view

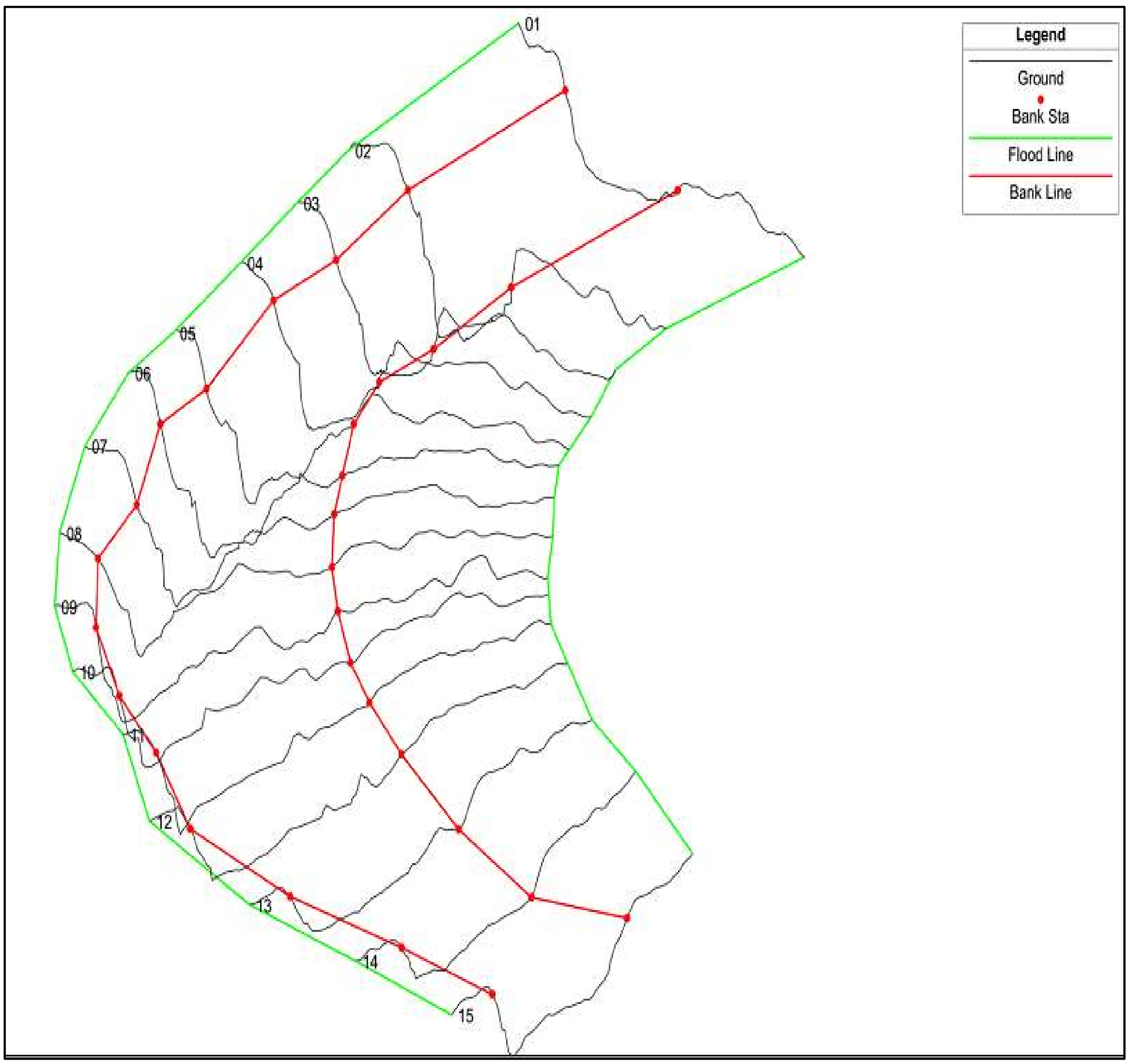

Figure 5.11 Bed profile of all cross-section of the river

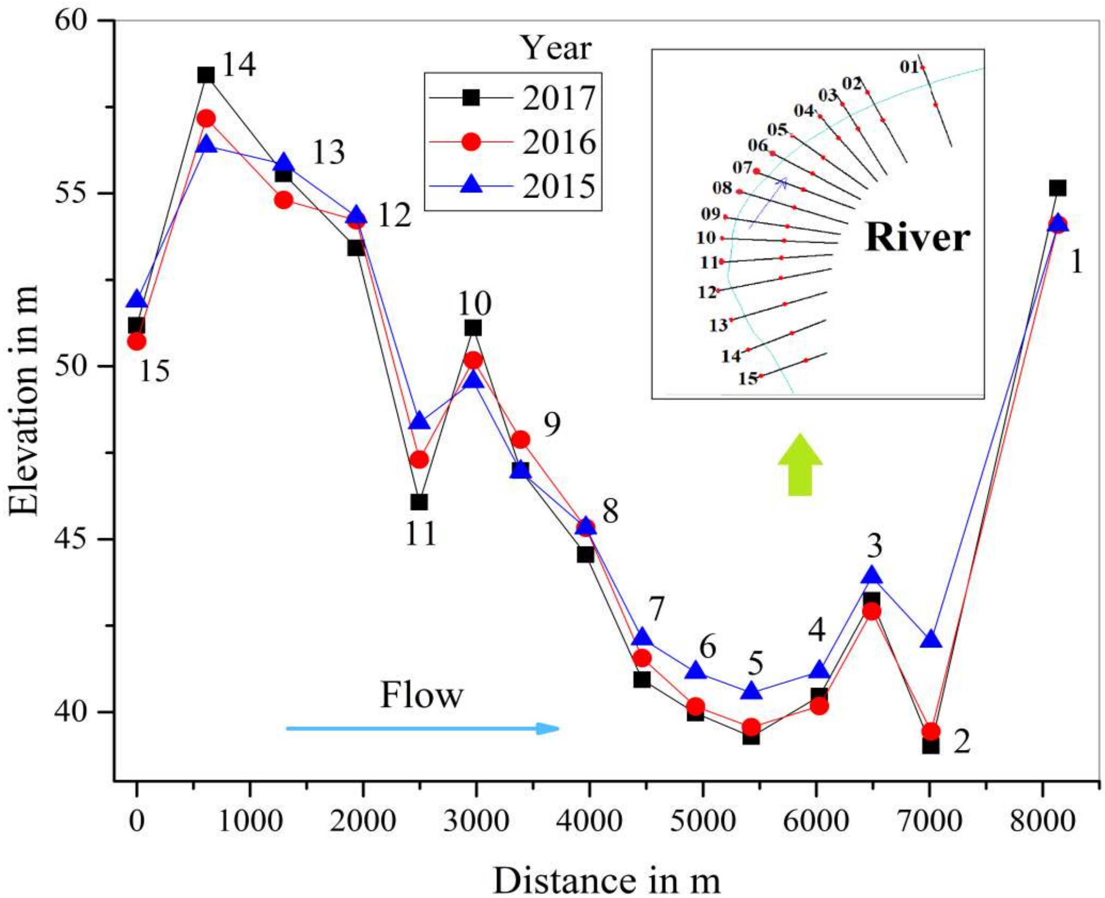

Figure 5.12 Shifting of thalweg path from the year 2015 to 2017

5.5 CONCLUSION

The sediment transport process for any alluvial river is one of the most complex phenomena. Where SSC is one of the essential parameters for sediment transport calculation and their estimation, on the other hand, the conventional method's use comes with lots of limitations compared to ADCP. It is used frequently to estimate hydrological parameter and sediment load (in dB) with the help of acoustic backscatter intensity. ADCP of 600 kHz is used along with the water sampler. A study area of river Ganga (length 10 km) along Varanasi is divided into fifteen cross-sections for analysis. Suspended samples have been collected for SSC calculation in terms of mg/l. These samples were categorized into two parts; the first part was utilized for calibrating the backscatter and attributing the intensity to suspended particle concentration using a linear regression method. The second part was used for the validation of acoustic intensity. Six years of observed data were used from the year 2012 to 2017. As a result of backscatter intensity, it was visible that there is an increase in suspended sediment concentration load year by year along the river cross-section. The change in the average sediment concentration was found about 10-15%. When the bed profile was created, it was found that the depth of bed has increased near the Raj Ghat cross-section (CS 2). The study of sediment transport is highly essential for the identification of critical section i.e the section where bed profile is relatively changing faster than other cross-section, for the reduction in losses due to floods and droughts.