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Character of Cross-Profiles with Respect to the Optimum Channel Cross-Sections in the Middle Reach of the Ichamati River of West Bengal, India

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Abstract

Channel cross section may be defined as the change of depth of channel with respect to the horizontal distance. The changing form of channel cross-section is a well-known parameter of a river's health. In this paper, we have tried to find out the geomorphic condition of the Ichamati river with regard to the character of channel cross-section, such as, symmetry assessment, contouring pattern in channel bed, bank profile and width-depth ratio. Finally we have constructed the optimum channel cross- sections based on channel width and depth, and have attempted to compare the cross-sections with the help of proposed 'Optimum Cross Section Index'. These characters basically reveal that the present river is decaying from upstream downward.

Keywords: *Cross-section, symmetry assessment, contouring pattern in channel bed, bank profile, width-depth ratio, Optimum Cross Section Index*

Introduction

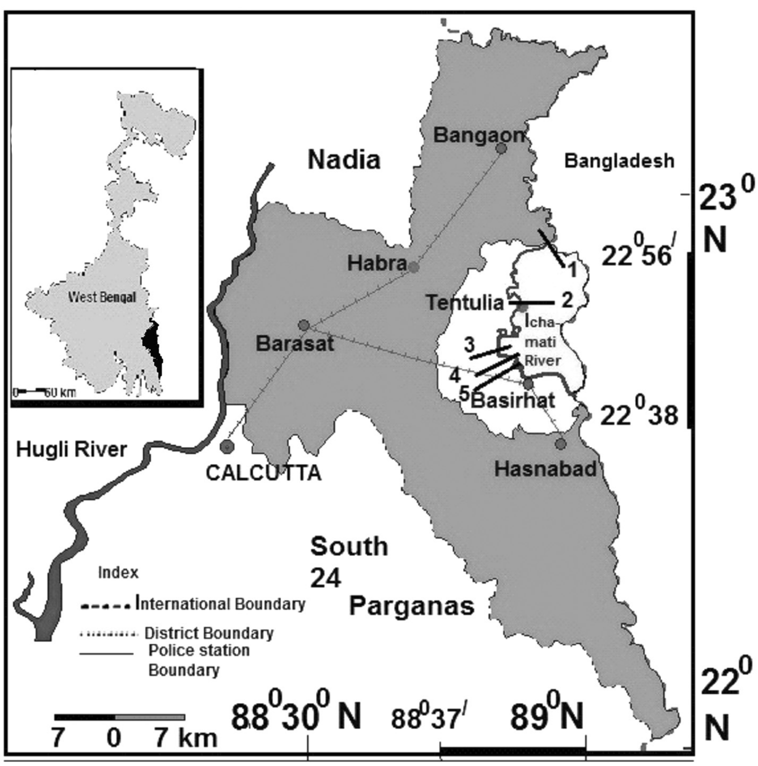
The changing form of cross-section is an important parameter of a river's health. The geomorphic term, 'cross-section' or 'cross-profile' is the change of depth of the channel in respect with the horizontal distance, from one bank to another. The cross-sections consist of two sets of 'series of points' and at every point, direction of angle changes, i.e. (a) transverse series of points: the angle at every points are perpendicular to the flow, (b) longitudinal series of points: at each point, the directions of angles are parallel to the flow. A point, among the second set represents the deepest portion at that particular line, and is subject to the long profile of a river. The first set of points represents the bank properties and second set represents the bed properties. According to set theory, if the set of transverse series of points is X, then X= {x1, x2, x3, x4,, …..x n } and X= {x : p (θ) }, where θ is direction of angle which is perpendicular to the flow direction, but the value of the angle is not same (θ1 ≠ θ2 ... ≠ θn). The set of longitudinal series of points is Y, as Y = {y1, y2, y3, y4,…..yn} and Y = {y : p (φ)} where φ is direction of angle which is parallel to the flow direction, but y1 ≠ y2 …. ≠ yn. The equation of the form of cross section (A) = f (X.Y). From the above equation, we can say that the form of river cross-section can be regarded as a 'union of three vectors', i.e., the longitudinal vector, the transverse vectors on the left and right sides; and it is very difficult to demarcate the line where bank terminates and channel bank begins.

River cross-sectional morphometry and characters are core subject of fluvial research and river management (Lord et. al., 2009), but the transverse river valley remain neglected in fluvial geomorphology (Sinha Roy, 2001). River acts as an element of dynamic equilibrium that is mainly concern with the transport of water and sediments through the slope and produce 3-D channel form. Channel cross-profile is formed as an adjustment to the dynamic equilibrium. This adjustment is the subject matter of gradation. The present paper is a discussion about the characters of the cross-profiles of the river Ichamati.

The study area

The study area includes the middle part of the Ichamati river (Kalanchi bridge to Basirhat Bridge) under the police stations of Gaighata, Swarupnagar, Baduria and Basirhat, all located in the eastern portion of the district of North 24 Parganas of West Bengal, India; and cover an area of about 1884.96 sq. km. Geographically, the study area is situated between 22010/N to 22056/N of latitudes and 88037/E to 890E of longitudes (Fig.1).

The district of North 24 Parganas of West Bengal is lying in the southern part of the Bengal Basin which is actually a pre-cratonic basin (Basu et. al., 2003). Geological investigations reveal that the



1. Kalanchi, 2.Tentulia, 3. Sarfarajpur, 4. Bibipur, 5. Harispur

Fig.1. Location of the Study area

sub-surface geology, completely blanketed by the quaternary sediments (clay loam is predominating) comprising a succession of silty-clay, sand of various grades and sand mixed with occasional gravels and thin intercalations of silty-clay (Sikdar. et. al., 2009). In West Bengal the average depth of the water level in the target area of North 24 Parganas vary from 1.02 m to 6.36 m below the ground level (bgl) for the month of January. In April, it is from 2.13 m to 7.85 m bgl, and in November from 0.62 m to 4.22 m bgl (Smith et. al., 2003). Early report on the hydrology of the area suggests that there is shallow aquifer (12-15 m bgl) in the upper plain and there is generally a south-easterly gradient of the water surface sub-parallel to the general slope of the area. All the aquifers are interconnected due to spatial variations in grain size (Basu et. al. 2003, Chakraborty et. al., 2009). It embraces the moribund delta in the north, matured delta in the middle, and active delta in the south. However, the study area lies mostly in the middle delta.

Materials and Methods

The primary data sets of two years, e.g., 2004 and 2012, were used here to identify the cross-profile of the middle Ichamati River. We have considered the hydrographic parameters for the month of February 2004 and 2012. The field survey comprises of 35 cross-sections (confined into the middle Ichamati channel), at different places throughout the reach. The data about cross-sections have been collected with the help of conventional string/ pole sounding, which have been calibrated with modern echo-sounding measures taken at selected points. Then we have constructed the cross-profiles with the help of surface heights taken by dumpy level survey, based on local Bench Mark at every cross-section. After these the river has been divided into two windows so that all reaches are comparable in terms of channel length (Harmar and Clifford, 2007). We have compared the geomorphic conditions of cross-profiles of each window based on their own parameters.

The collected data have been used to construct the cross-profiles with the help of Microsoft Excel- 2007. We have selected 0.0 m as datum. We have presented a non-traditional 'river flow map' to visualize the contouring pattern of the riverbed at a glance. We have plotted the mid-point of each cross-section on the Y-axis (which represent the river length), whereas the X-axis represents the horizontal distance between one bank to another. The point O, represents the mid- point of the cross section. OX is the left bank side and OX/ represents the right bank side of the cross section.

In order to obtain the channel symmetry we have used the 'Areal Difference Asymmetry Index (ADAI) technique. This techniques compares cross-sectional area on either side of the channel centreline, $A^* = A_r – A_\ell / A$ where, A_r = area to the right of channel centreline, A_ℓ = area to the left of channel centreline, and A = total area (Frothingham and Brown, 2002). To find out the symmetrical form of the river cross-section we have calculated A^* = (0.01-0.08) m.

The study of slope includes many aspects such as gradient, alignment, aspect, and composite features. A slope is measured by gradient over some distance. Slope is the ratio of vertical interval to the horizontal equivalent (Sen, 1993). We know that gradient changes at every point along the profile (if the angle of slope Δy ➔ 0, is a dependent variable changes in respect of horizontal distance Δ x ➔ 0, that is independent variable, the gradient will be Δy/Δ x, Lt x ➔ 0, here the equation is y = f (x). In this study, we have taken the average value of slope angle with the help of clinometers. Then we have measured the slope length and calculated the bank height applying the 'cos ɵ' formula.

Discussions

a) Contouring of the river bed

We have divided the reach of the Ichamati River in the study area into two windows i.e. the 1st window and the 2nd window, based on channel width (w) and the value of contour line. The width of the Ichamati varies from 30m in the upper reach to 70m in the lower reach in the first window, and from 70- 500m in the 2nd window. A contour line of -1.4 m divides the river reach in the study area into two windows. We have discussed the contouring pattern of the individual window indicating the datum line as 0.0 m, as follows:

The 1st window (length: 31.4 – 59.4 km): Here, the orientation of the leading contour lines (-1m, 0.0m and +1.5m) are symmetrical and parallel with the riverbank. Most of the area of the left side of the river channel (central point to left bank) is occupied by the 0.0m and 1.5m contour lines. But in the right side of the river channel, the river bed is represented by 1.5m and -0.15m contour lines. The 0.0 m contour line runs through the central most position of the river channel. After that, the line swings towards left side and disappears ultimately at the left bank (Fig.2).

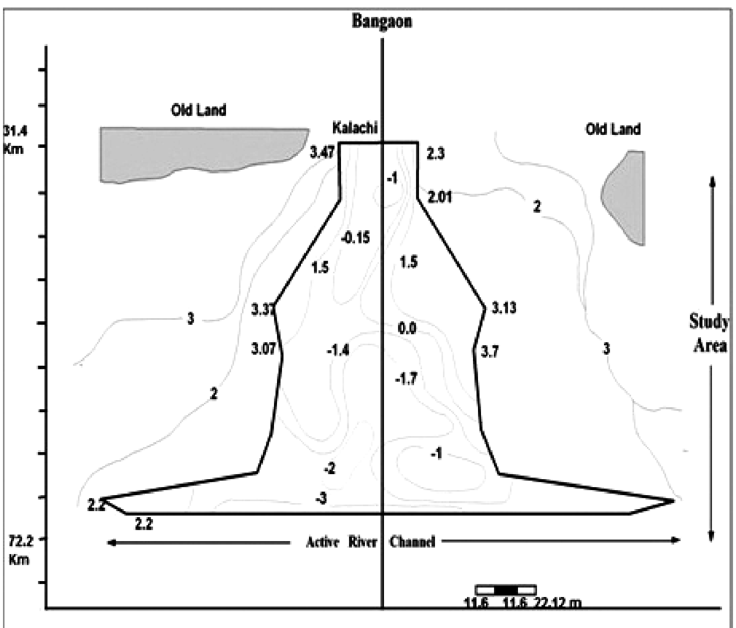


Fig.2: Contour pattern at the channel bed

The 2nd window (Length: 59.4 – 85km): The leading contours i.e. -1m, -1.4m, -1.7m and - 3m are symmetrically orientated and run transversely to the channel cross-section. The contour lines such as -1.4m and -1.7m run across from one bank to another. Summarily, the contour pattern shows that the bed level in the second window is much lower than the datum level of the first window (Fig.2).

b) Symmetrical assessment of cross-section

We have divided the middle Ichamati reach into three different zones i.e. Kalanchi to Tentulia, Tentulia to Baduria and Baduria to Basirhat for symmetrical assessment. We have surveyed approximately ten irregularly spaced cross-sections in each reach. Summary of the results are given in Table-1.

Table 1 : Summary results of the Areal Difference Asymmetry Index

Reach	A*	Symmetry	Asymmetry
1st zone (KalanchiTentulia)	0.02-0.05	90%	10%
2nd zone (Tentulia-Baduria)	0.05-0.15	8%	92%
3rd zone (Baduria-Basirhat)	0.15-0.48	0%	100%

Source : Calculated by the researchers based on field data

The values of A* indicate a paradox situation of symmetry- asymmetry properties among the reaches. 90% of the cross-sections in the 1st zone represent the symmetrical cross-sections, but the lower reach exhibits 100% asymmetrical. In the 1st zone the value of A* varies between 0.01 and 0.5. In the 2nd zone the value of A* varies between 0.05 and 0.15 while in the 3rd zone the values range between 0.15 and 0.48. The values of Symmetry Index of selected individual cross-sections are given in Table 2 and represented in Fig.3.

Table 2 : Asymmetry Index at different Stations

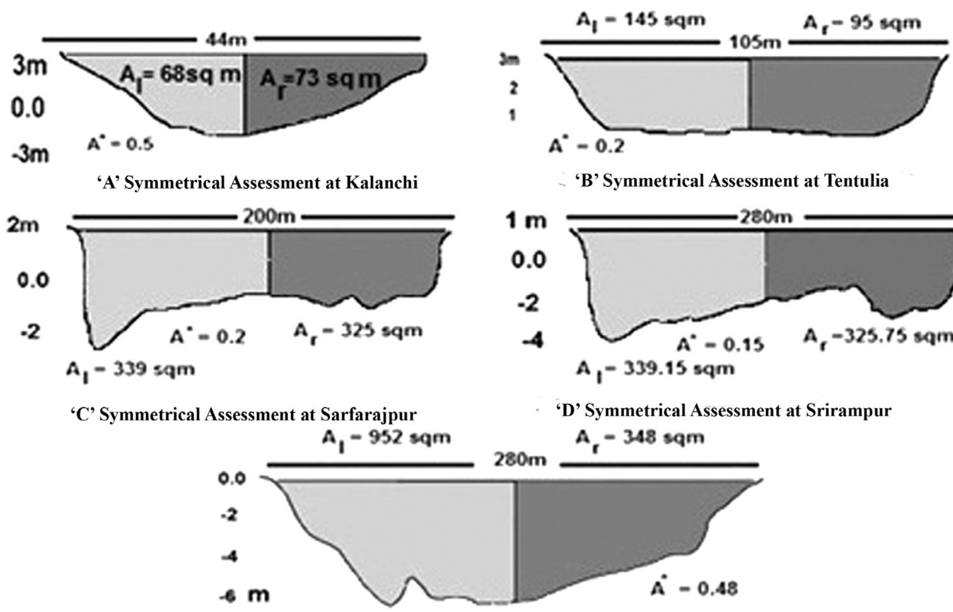
Station	Total area Sq m	Area of left side(sq m)	Area of right side (sq m)	A*	HR
Kalanchi	140	66.3	73.9	.05	0.56
Tentulia	240	95	145	0.2	0.9
Sarfarajpur	665	339.15	325.75	.02	2.31
Srirampur	487	281	206	0.15	2.01
Harispur	1300	348	952	0.48	4.3

Source: Calculated by the researchers based on field data

The form of the cross-sections in the upper reach of the Ichamati are symmetrical often having a unit slope profile, but are asymmetrical at the lower portions. But at the lower reach of the river the both sides of the river bank consist of a number of segments, which reveal the complex character of the bank profile.

c) Bank Profile

The bank characters such as bank height, slope, length etc show the paradox scenario in two windows. We have devided the bank slope into three classes based on the trend of slope angle, e.g.: (a) low angle slope : 00- 300, (b) medium angle slope : 300- 600 and (c) high angle slope : 600-900.



'A' Symmetrical Assessment at Kalanchi

'B' Symmetrical Assessment at Tentulia

'C' Symmetrical Assessment at Sarfarajpur

'D' Symmetrical Assessment at Srirampur

'E' Symmetrical Assessment at Harispur

Fig 3: **Form of cross sections at different Stations with Areal Difference Asymmetry Index**

The 1st window (Length: 31.4 – 59.4 km): Here, the bank profile of both sides represent a unit profile. The bank height does not exceed more than 1 to 1.5m at any place. The slope is medium and high angle type. In this region, the slope can maintain its steepness due to smaller height and adhesiveness of the bank materials.

The 2nd window (Length: 59.4 – 85km): In this window the both banks consist of a number of segments. In this window there are point bars allmost at every convex side of the bank which consist of a number of segments. Every segment of the point bar indicates the older position of the past point bar deposition.The upper segment of the profile often shows a wash slope, formed by fine sediment and are usually muddy. On the other hand, the concave slope is erosive bank which represent a single unit of profile. The convex bank profile mostly consist of three segments (1st, 2nd and 3rd segment). The first segments are of almost low angle type, which are inundated during high tidal period and are covered by grasses. The 2nd and 3rd segments are medium and low angle type. The variations of the angle of point bar indicate the different sedimentation regime in the different seasons. The angle of the concave profile is high and consist of single profile. This is due to slope failure by helical flow. At some places there are two segments on the concave bank. The 1st segment of the profile is formed during the high tidal period, and the 2nd segment is formed durinng the low tidal period (Table- 3 and Fig.-4 a & b).

Table 3 : Character of the river bank profiles

	Station	Bank Propertise					
		Concave Bank			Convex Bank		
		H(m)	Segment	Angle	H(m)	Segment	Angle
1st window	Kalanchi	0.5	1st	60°	0.9	1st	90°
	Nischandapur	2.1	1st	60°	0.9	1st	90°
	Gobra	2	1st	55°	1.5	1st	40°
	Saguna	1.2	1st	30°	0.6	1st	30°
	Bhakutia	2	1st	40°	1	1st	55°
	Durgaour	2	1st	35°	1.5	1st	45°
	Tentulia	0,3	1st	-	0.4	1st	55°
2nd window	Kabilpur	5	1st	90°	2	1st	10°
	Media	4	1st	80°	3	2nd	50° 90° 45°
	Polta	1.5	1st	80°	5.5	1st, 2nd, 3rd	80° 2° 75°
	Sarfarajpur	4	Broken	—	—	—	—
	South Media-P1	6	1st, 2nd	20°, 30°	2	1st 2nd 3rd 4th	0° 6° 26° 10°
	South Media-P2	5.7	B.O.S, 1st	90°, 11°	1.2	1st 2nd 3rd	0° 8° 12°
	South Media-P3	5	1st, 2nd	5°, 12°	2	1st 2nd	15° 25°
	Srirampur-P1	4.3	1st	80°	3.9	1st. BOS,2nd	0°, 90°, 20°
	Srirampur-P2	5	1st	75°	4	1st,BOS,2nd 3rd	0°, 90°, 8°, 15°
	Srirampur-P3	5	1st	85°	4.1	1st,BOS,2nd 3rd	15°, 90°, 10°, 5°
	Srirampur-P4	4.8	1st	85°	4	1st,2nd,BOS 3rd	0°, 18°, 90°, 10°
	Srirampur-P5	4.5	1st	80°	4	1st, BOS,2nd BOS,3rd	5°, 90°, 10°, 90°, 60°
	Harispur-P1	3.5	1st	60°	6	1st,2nd	90°, 30°
	Harispur-P2	3.4	1st	65°	5.5	1st, 2nd	90°, 25°
	Harispur-P3	3.3	1st	60°	6	1st	35°
	Harispur-P4	3	1st	55°	5	1st,2nd,3rd	1°, 60°, 8°
	Harispur-P5	3.2	1st	85°	5	1st, 2nd,3rd	1°, 30°, 60°

H : height, P: profile B.O.S.: Break of slope

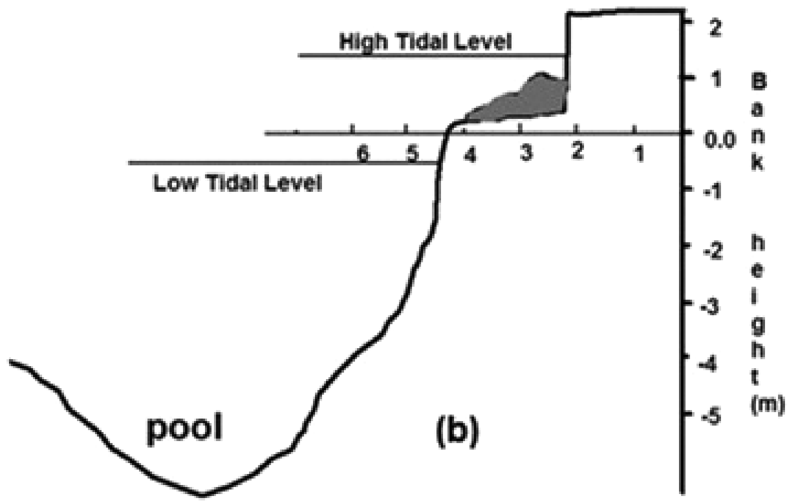


Fig. 4(a) segment of slope and (b) height of different stations

Width –depth Ratio (w: d)

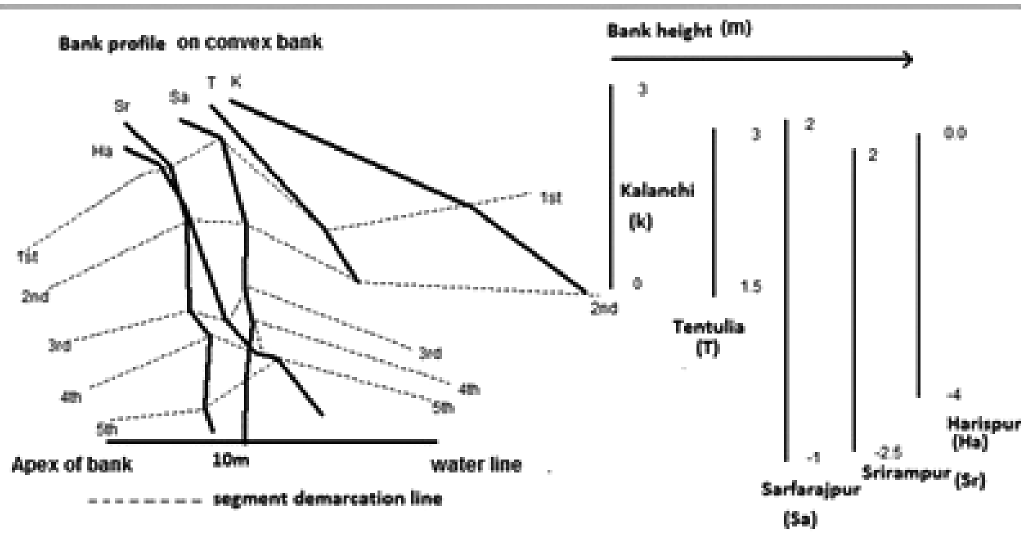


Fig.4 (b) Segments of bank profile

The width–depth ratio (w:d) is a good indicator of river bank stability (Rosgen, 2001,b). Increasing 'w:d' reduces the transport capacity of a river. The ratio is not uniform throughout the reaches of the river Ichamati. A holistic aproach to analyse the 'w:d' represents a negative corelation (r2= -0.45) that indicates the overall deteorating condition of the river (Fig.5b). Here we have used the linear regression, "best fitting" straight lines obtained by the Least Squares Method. We have devided the total reach into two windows (Fig.5a): (a) the first window (Length: 0-26 km) and (b) the second window (Length: 26-55km) based on homogenious value of 'w: d'. In the first window, the ratio represents a high negative value (r2 = - 0.58). This value reveals that the river is unable to maintain its depth according to width in the first window. In the second window, the ratio represents a merginal positive value (r2 = 0.169). This indicates that the river is in a relativlybetter dynamic condition in the second window (Fig.5a).

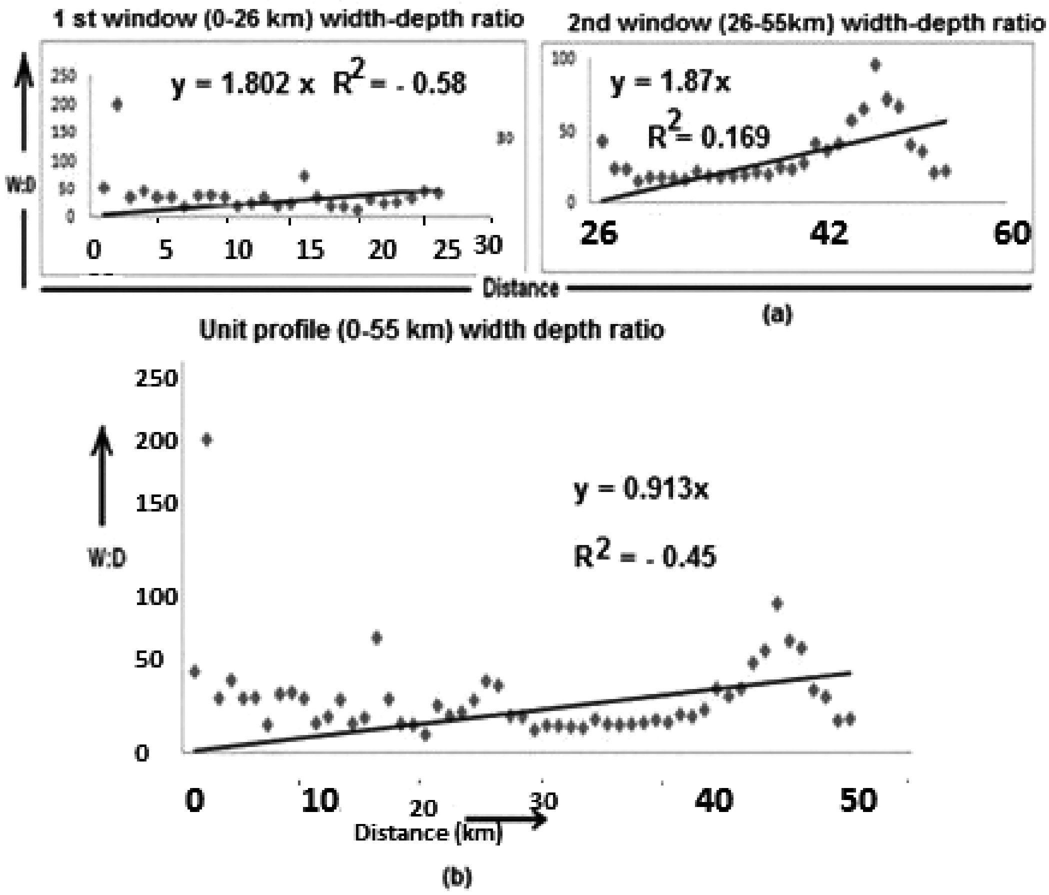


Fig. 5(a) width -depth ratio of two different windows (b) width-depth ratio of single profile

d) **Computation of the optimum Cross section or projected cross section**

Traditional channel design methods for fixed boundary or threshold channels focus on efficient flow conveyance where water surface elevation and velocity are of primary importance. There are two types of hydraulic design variables: i.e. independent variables such as design, discharge and channel roughness; and the others are the dependant variables such as width (w), depth (d) and slope (s) (NEH, 2007).

The common cross-section shapes are rectangular, trapezoidal, circular, and compound cross-sections (Swamee, et. al. 2000). The ideal form of the channel for the efficient discharge of water is semi-circular in cross-section (Spark, 1960). This is because semi circular channel has the maximum hydraulic radius (l) and exerts the minimum frictional force (Leopold et. al., 1964). From the point of hydraulic aspects such a section is hydraulically efficient channel which has the least perimeter among all sections with the same area; hence, it is the most hydraulically efficient of all sections (Merkeley, 2004). We have selected two types of cross sections: i.e., (a) trapezoidal cross-section, and (b) semi-circular cross-section. Here, we have drawn the channel form based on the following equations based on surface width (w) and depth of water (h).

Trapezoidal Cross-section: Rectangular cross-sections are just special case of trapezoidal sections. Trapezoidal cross-section can be symmetrical and non-symmetrical. The parameters of the

Table 4: Characters of the cross-profiles of the Ichamati river

Station	Character of cross profile													
	Symmetrical							Compound						
	T	B	A	W_p	HR	W_1	W_2	T	b	A	W_p	HR	W_1	W_2
Kalanchi	44	41.78	174.6 (tan30°, Tan60°)	50.8, 52.93 (tan30°, Tan60°)	0.56 0.5 tan30°, Tan60°)	W30° 4.52, W60° 7.9		-	-	-	-	-	-	-
	Non-symmetrical Form													
Sarfarajpur	200	185	1043.6	202.5	2.31	11	7.7	200	182.84	14443.6	206.31	3.1	8.5	14.9
Srirampur	280	265.8	1745.1	285.3	2.01	7.29	12.73	280	260	2305.1	287	2.3	9.5	16.7
Harispur	280	265.8	1745.1	285.3	4.3	7.29	12.73	280	260	2305.1	287	4.46	9.5	16.7

	Semi-Circular Form			
	D	T	h	β
Kalanchi	50.1	44	9	112°
Sarfarajpur	278.03	200	42.4	92°
Srirampur	300	280	95	137°
Harispur	300	280	95	137°

Source: Calculated by the researchers based on field data trapezoidal cross section are: width of bank full flow (T), bottom width (b), regular side slope (m1), inverse side slope (m2) [the inverse side slope is usually between zero to 2.0 and high inverse side slope are more stable and may require less maintenance], normal bank length (ω1) and inverse bank length (ω2), and bank height or water depth (h). For symmetrical cross-section, we have applied the equation, area (A) = h (b + mh), T = b+ 2mh, wetted perimeter (□p) = b +2h√m2 + 1, w = h √m2 +1; and for non-symmetrical cross-section, the equation is: area (A) = h [b + 0.5 (m1 +m2) h], T = b+ (m1 +m2) h, wetted perimeter (□p) = b +h [√m12 +1 +[√m22 +1, w1 = h √m12 +1 , w2 = h √m22 +1. For the most efficient trapezoidal section, m = 1/tan 600 (m1) = 0.557, tan 600 (m2) =1.73, or tan 450 = 1 (Merkeley, 2004).

Semi-circular cross-section: We have applied the equation T= D sin (β/2) and area (A) = D2/8 (β – sin β), where, β = angle in radian, r = D/2, wetted perimeter (□p)= βD/2, h = depth of water, to construct the semi- circular cross section.

Here, we have constructed some cross-sections along with their optimum form (shown in broken line). The semi-circular form of each profile is usually non-existent in reality. On the other hand, trapezoidal cross-sections are more close to the reality. We have selected four cross-sections to compare with their optimums. At Kalanchi, the form of the river cross-section is only symmetrical. Here, the symmetrical trapezoidal form is a better fit than the optimum semi-circular form. In this form, the present river bed attains the optimum channel bed (Fig. 6 a & b). Moreover, this form is efficient to discharge.

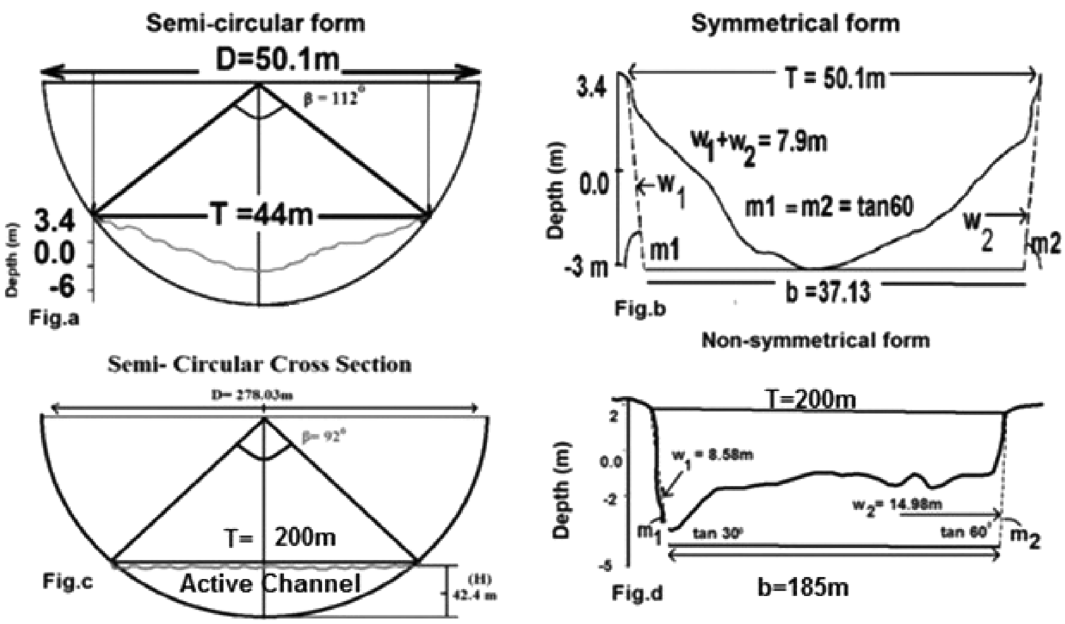


Fig. 6 (a) Semi-circular form and (b) Symmetrical form at Kalanchi
(c) Semi-circular form and (d) Non-Symmetrical form at Sarfarajpur

The rest three cross-sections are non-symmetrical. In every case, the projected semi- circular forms are invalid in the sense of reality (Fig.-6 c, Fig.-7, a, c). On the other hand, the projected non-symmetrical trapezoidal forms are the best fit. The deepest point of every cross-section usuallyt attain the level of the bottom width (b) and comparatively little mass have to be excavated from the both side of the channel bank (Fig. 6, d, Fig. 7, b, d). The amount of projected mass, which will be excavated, would be decreased with increasing distance from upstream downward. Thus, the proposed 'Optimum Cross-Section Index (OCI)' = Optimum Channel Area/ Present Channel Area. When the OCI = 1, the cross section will be optimum. In this study the values of OCI decrease with increasing distance from upstream downward, such as in Kalanchi (2.1), Sarfarajpur (1.7), Bibipur (1.5) and Harispur (1.3). The values of the index indicate the cross-sectional areas in the upstream zone are not able to maintain their optimum area in respect of their widths.

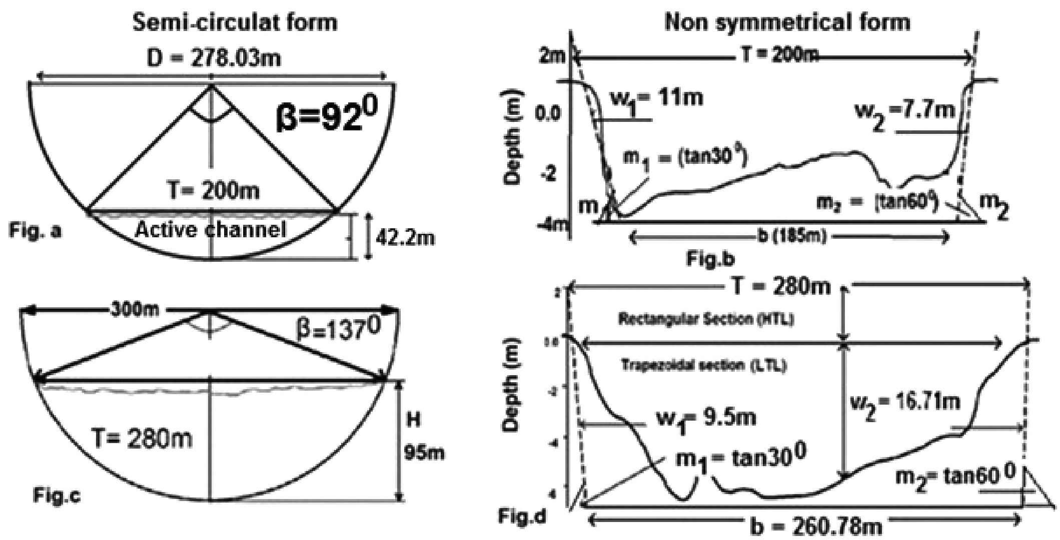


Fig. 7 (a) semi circular form and (b) Non symmetrical form at Bibipur (c) semi circular form and (d) Non symmetrical form at Harispur

Conclusions

Contour pattern of the Ichamati river shows that the river is more wider and deeper in the second window than the first window. Not only this, but the value of the hydraulic radius (l.0) is greater than the first window, e.g. Kalanchi it is 3.43 while 6.11 in Srirampur. Symmetrical assessment of cross-section of the river indicates that the channel form in the upstream is more symmetrical than the lower one, such as in Kalanchi (A* =0.05), Srirampur (A* = 0.15) and Harispur (A* = 0.48). These reveal that the lower portion of the river Ichamati is characterised by pool and riffle. These are the indicators of its dynamic character. Therefore, the first window or the upper portion of the river Ichamati has lost its dynamic character while its lower reach is gradually decaying.

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