INDIAN JOURNAL OF GEOGRAPHY & ENVIRONMENT 15-16 (2018)
Indian Journal of Geo. and Env. Mang. 15-16 (2018) 49-61
April 2018, Vidyasagar University, West Bengal, India
(http://vidyasagar.ac.in/journal) **ISSN:0972-7388**

VIDYASAGAR UNIVERSITY
Dept. of Geo. and Env. Mang.

Meanders Geometry of Alaknanda River in Srinagar Valley (Garhwal Himalaya)

Sapna Semwal* and D. D. Chauniyal**

*Research Scholar, D. B. S. (PG) College, Dehara Dun
**Department of Geography, HNB Garhwal University, Srinagar (Garhwal) Uttarakhand, India

Article History:
Received 17 October 2017
Received in revised form 09 January 2018
Accepted 15 February 2018

ABSTRACT

The Alaknanda River is a most significant parental river of Ganga and forms an 11.5km long and 2.5 km wide valley locally known as the Srinagar Valley. The main purpose of the present study is to examine the planimetric geometry and hydraulic properties such as depth, width gradient, shape, size, sinuosity index etc in meanders as constructed with straight reach and to examine correlation between different parameters. The entire study has been carried out by remote sensing and GIS techniques on Arc GIS 9.3 software. For the analysis of meander geometry, the Alaknanda River in Srinagar valley is divided into 8 segments of three reaches from Supana to Kirtinagar. Each segment consists of a channel meander. Plan metric geometry and hydraulic properties of each meander bend have been examined and analyzed. Sinuosity index of the Alaknanda River is 1.34 in the study area which indicates that the river is sinuous to meander. The average entrenchment ratio of the channel is 3.27 which shows slightly entrenchment channel. The average wave length of the River is 1.4km. The tectonic control clearly reflects on the pattern, shape and size of the meanders. All the meanders are controlled by transverse fault pattern along the NAT. A strong correlation ship exists between amplitude and sinuosity index (R- 0.94) and width and length ratio (R- 0.96). Finally, it may be concluded that meander amplitude has played a major role in increasing the sinuosity ratio in selected segments in Alaknanda river course.

Keywords:
Sinuosity, meander geometry, entrenchment, tectonic

Introduction:

Assessment of any river condition relative to some ideal state is a concept of fluvial geomorphology. There are two approaches in which river conditions can be assessed and consequently, numerous river assessment methods are correctly in use around the world (Thornton and et al, 2007 p1). The most attention has been paid by geomorphologist and ecologist in the hydrological geometry. Geomorphologists and ecologists have primarily paid attention to Hydrological Geometry. Ecological approach is important for assessing river conditions related to river habitat and ecological conditions. Beside this, geomorphological approach involves some subjective interpretation of river conditions. Hydrological geometry describes the slope width, depth, velocity etc., of a river. Primary contributions in hydrological geometry were made by Leopold and Maddock (1953). Recently Julien and Wagadaldm (1993) have explained a comprehensive approach on theory and application of alluvial geometry. Hydraulic geometry in river network as a method for the assessment of river condition has been used to determine the baseline geometric character in a river (Thornton and et al, 2007). Comprehensive reviewers of the abundant literature on the regime approaches and other methods defining the downstream hydraulic geometry relationships are available in Chilate (1973), Callander (1978) and Yalin (1992). Recently Pal (2017) has been analyzed some geometric characteristics regarding meandering and braiding of the middle-lower part of the Ganga River at different axes.

Correspondence to Sapna Semwal
Research Scholar, D. B. S. (PG) College, Dehara Dun
E-mail address : sapnasemwal@yahoo.com

Any river is more or less straight for a certain distance, but no river can ever maintain a straight path. Meandering is formed where banks resist erosion, leading to the formation of deep & narrow channels. Few ideas have been thought of as the reason for the formation of meanders for example (1) the distribution & dissipation of energy within a river (2) helical flow & (3) the interplay of bank erosion. Meander geometry is a prominent part of channel morphology. Channel morphology includes channel geometry, channel fluid dynamics, hydraulic geometry, channel bed form and channel pattern. From source to mouth the channel course is called a longitudinal profile. Nature and shape of the longitudinal profile depends upon channel gradient, stages of channel, length and base level. Through its course, channel flow in different shape and forms. Shape of the channel refers to sinuosity. Stream sinuosity means deviation channel course from straight channel. Thus, the shape of longitudinal profile can be of three types i. e. straight, sinuous and meandering. Meandering channel is described by the sinuosity index which is the ratio of channel length to valley length (Leopold and et al, 1964).

Problem

Geological evidences of past floods in Alaknanda valley have been reconstructed by large number of workers (Wassan 2008, Wassan and et al, 2013 and Rana and et al, 2013). Most of the floods were an outcome of landslides, natural dam bursts and glacial lake bursts in the upper Alaknanda catchment (Wassan, 2013). Among them the 1970 and 17 June, 2013 events were the highest in magnitude. The 17 June, 2013 flood deposits invariably overlie the 1970 flood sediment and occured at an elevation of 536 m at ITI (Rana and et al, 2013). On the contrary, the 2013, Alaknanda flood which caused large scale damage to life and property was undoubtedly conditioned by the enormous amount of dam excavated materials dumped at the banks of river (anthropogenic ally induced). These floods changed the entire channel morphology of the Alaknanda River in the Srinagar valley. The river changed her channel course at Srikot, Kilkleswar and SSB. The meander length also has changed at Chauras which cuts the meander scarp at Garhwal University Guest House. The Seema Suraksha Bal (SSB) campus was washed away by the river where it exposed the bed rock. Near ITI 6 to 9m sand and silt was deposited by the flood during the event (Plate 1). Out of these natural changes by the natural events in the area, construction of Supana Dam has also changed the morphology of the valley. Its direct and indirect impact can also be seen on channel shape and size and flow pattern of the river. Keeping in view the above consequences, present problem has been taken into consideration in the study area.

Location of Study Area

The Alaknanda River rises from the snout of Satopant Glacier at the height of 3760m and after travelling a distance of 191 kms, joins in the Bhagirathi River at Devprayag (442m). The average gradient of the river is about 17.3m/km from source to mouth. Along its course, the River traverses through the Tethyan sedimentary, Higher Himalayan crystalline and Lesser Himalayan meta-sedimentary rocks. After the

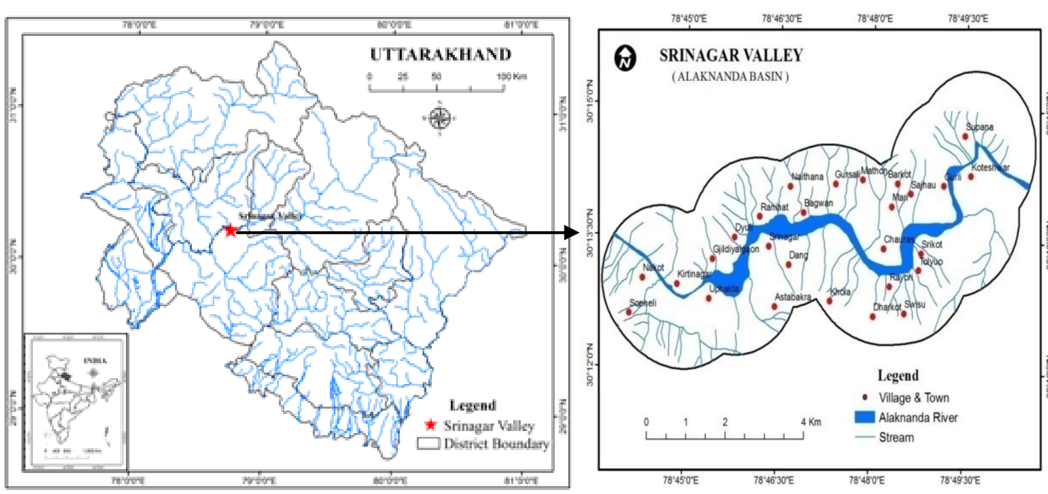


Fig. 1 : Location of the Study Area

distance of 161km downstream, it enters from a narrow valley to the 11.5km long and 2.5 km wide sinuous meandering river valley of Srinagar (Fig. 1). Geographically, it is bounded by 78°43'35" E -78°11' 53" E Long and 30°11' 59" N- 30°15' 24.3" N Lat covering about 38.18 Km^2 area.

Objectives of the Study

1. The main objective of the present study is to examine the planimetric geometry and hydraulic properties such as depth, width, gradient, shape, size, sinuosity index etc., in meander as constructed with meandering and straight reach.
2. To compare sinuosity ratio for each reach and segment.
3. To examine correlation between different hydraulic parameters.

Research Methodology

- The entire study has been carried out by the remote sensing and GIS techniques on Arc GIS 9.3 software.
- The base map of the valley has been prepared on a 1/50000 topographical sheet.
- The Cartoset data with 2.5m resolution has been used for the detail analysis.
- All topographical details such as drainage, contours (20m interval), land use and boundaries have been digitized from topographical sheet.
- Longitudinal profile has been drawn from Supana to Kiratinagar by 1/50000 and Cartoset image. Cross sections are drawn in different places by Dumpy level survey for knowing the configuration of the channel course.
- Meander geometry, types and pattern are measured according to Leopold & et al and Savinder Singh (1998).

4. The scatter plot has been used for showing correlation between different parameters.
5. On the basis of field observations, the vertical and lateral extent of flood has been prepared.

Channel Pattern

Any river is more or less straight for a certain distance, but no river can ever maintain a straight path. Meandering is formed where banks resist erosion, leading to the formation of deep & narrow channels. Few ideas have been thought of as the reason for the formation of meanders for example (1) the distribution &dissipation of energy within a river (2) helical flow & (3) the interplay of bank erosion. Meander geometry is a prominent part of channel morphology. Channel morphology includes the channel geometry, channel fluid dynamics, hydraulic geometry, channel bed form and channel pattern. From source to mouth the channel course is called a longitudinal profile. Nature and shape of the longitudinal profile is dependent upon channel gradient, stages of channel, length and base level. Through her course, channel flow in different shape and forms. Shape of the channel refers to sinuosity.

Stream sinuosity means deviation of channel course from straight channel. Thus, the shape of longitudinal profile can be of three types i.e. straight, sinuous and meandering. Meandering channel is described by the sinuosity index which is the ratio of channel length to valley length. The value of sinuosity varies from 1 to 4 or even more. A river having a sinuosity value of 1.5 or more is called meandering and that below 1.5 is straight to sinuous (Leopold and et al, 1964).

Geometric Properties of the Meander

Meandering rivers (sinuosity 1.5) consist of a series of turns with alternate curvatures connected at the points of inflection or by short straight crossings. They have a relatively low gradient. Meandering rivers migrate gradually and hence sinuosity tends to increase. Meandering is therefore, the result of stream bed instability; in particular, when instability acts on the banks.

The geometry of a meander is described by the meander wavelength, meander amplitude, meander height, channel width, radius of curvature channel length, valley length, bank full discharge, nature of bank, meander neck, sinuosity ratio etc., and their interrelationships (Leopold.and Wolman, 1957). Similarly, channel morphology is also the result of interrelation among fluid dynamics, channel configuration, sediment load and composition of material. This process is also called a hydraulic geometry of the river.

Factors Affecting Meander Geometry

The meander geometry depends on the channel pattern, degree of curvature, meander curvature, radius of curvature, meander ratio, entrenchment and discharge flow.

1. The bed topography is an important determinant of the flow pattern. The bar and pool topography and asymmetrical shape of the channel course the shift of the meander bend outward side.
2. The ratios of curvature/width ratio are an important parameter of the flow pattern of meander. If this ratio is <2, water filaments begin to separate from the inner bank (Maiti, 2016).
3. If the degree of curvature is more than the super elevation and strength of secondary circulation is high. If radius /width ratio becomes less than 2, water attacks the outer bank at a very abrupt angle and thus the flow separation occurs (Maiti, 2016).
4. Higher cross section form ratio is on the wider section, the point bar development is more extensive and shoaling effect directs the inner bank flow rapidly outward (Kinghton, 1998).
5. As far as the discharge is concerned, main normal flow discharge follows a straight path, secondary circulation is dominant in intermediate discharge whereas, at large discharge primary current becomes dominant (Bhathrust, & et al, 1979).
6. Entrenched ratio is the ratio of the width of flood prone area to the bank full surface width of the channel. If the ratio is greater than 2.2, it represents the slightly entrenched stream which developed well flood plain.

Results and Discussion

Meander Geometry of the Alaknanda River

For the analysis of meander geometry the Alaknanda River in Srinagar valley is divided into 8 segments of three reaches from Supana to Kiratinagar (Fig.2). The first reach is from Supana village to Srikot (A), second from Chauras Bridge to SSB-Ranihat (B) and third one is from SSB to Kirtinagar (C). The sinuosity ratio varies for each reach i.e. 1.5, 1.18 and 1.33 for A, B and C respectively. It shows that segment A is a meandering channel, B is almost straight and C is sinuous to meandering channel.

According to 8 meander bends, the reaches are further sub-divided into 8 segments i.e. (i) Supana, (ii) Koteswar, (iii) Gugali, (iv) Srikot, (v) Chauras, (vi) Srinagar, (vii) SSB and (viii) Sriyantra Tapu (Fig.2). The names have been assigned to them on the basis of localities. Based on Selby (1985) the study area is classified into following meanders properties (Table 1).

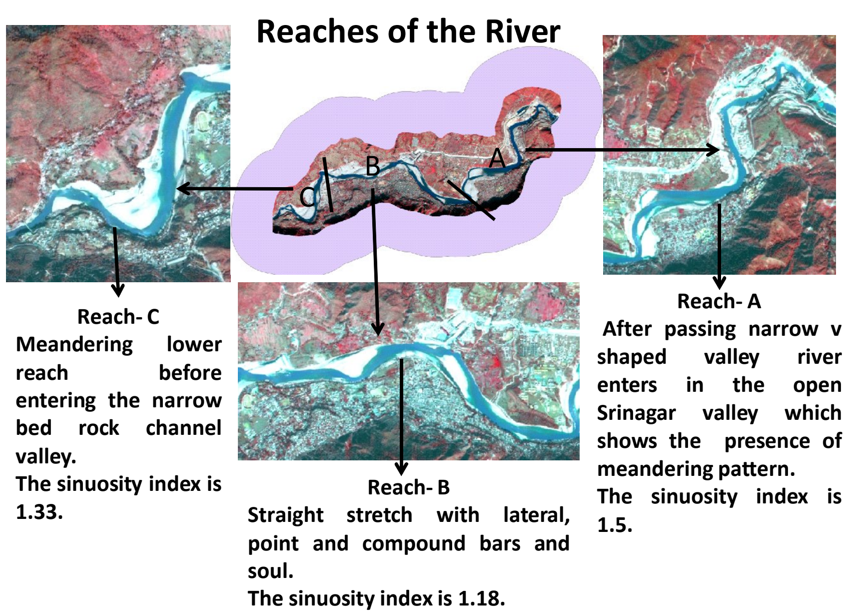


Fig. 2 : Three reaches of the Alaknanda River in Srinagar valley

Meander Wavelength (M L)- Meander wave length is the distance between two successive meander crest.

Channel Width (CW)- Width of the channel is described as the effective water width in a meandering channel.

Channel Length (C L)- It is the representative curvilinear distance measurement along the centre of the channel.

Valley Length (V L)- It represents representative horizontal distance measurement in the thalwag of two cross sections in a linear depression between adjacent uplands .

Bank Full Discharge (Q)- It is the relationship of width(W) of channel, depth(D) of channel and velocity(V) - $Q = W \times D \times V$.

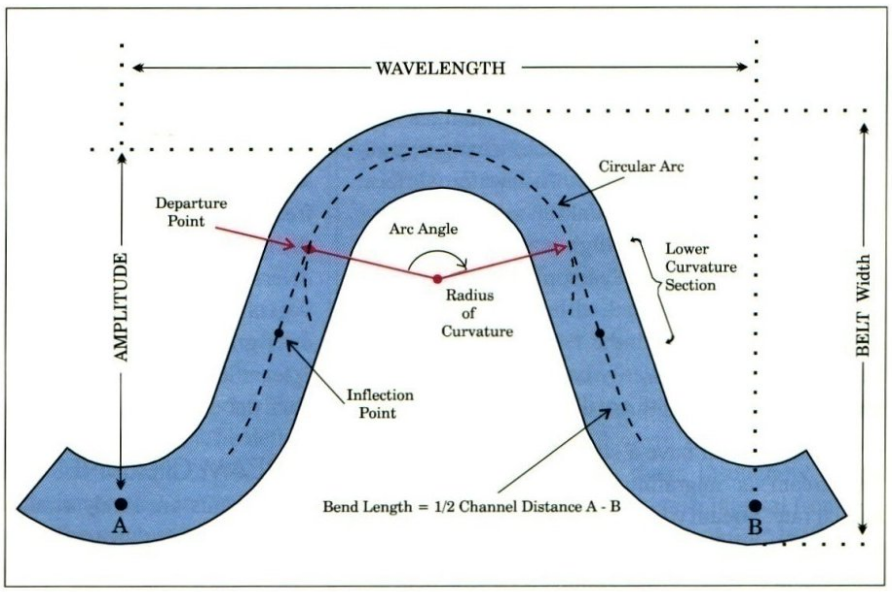


Fig. 3 : Parts of meander

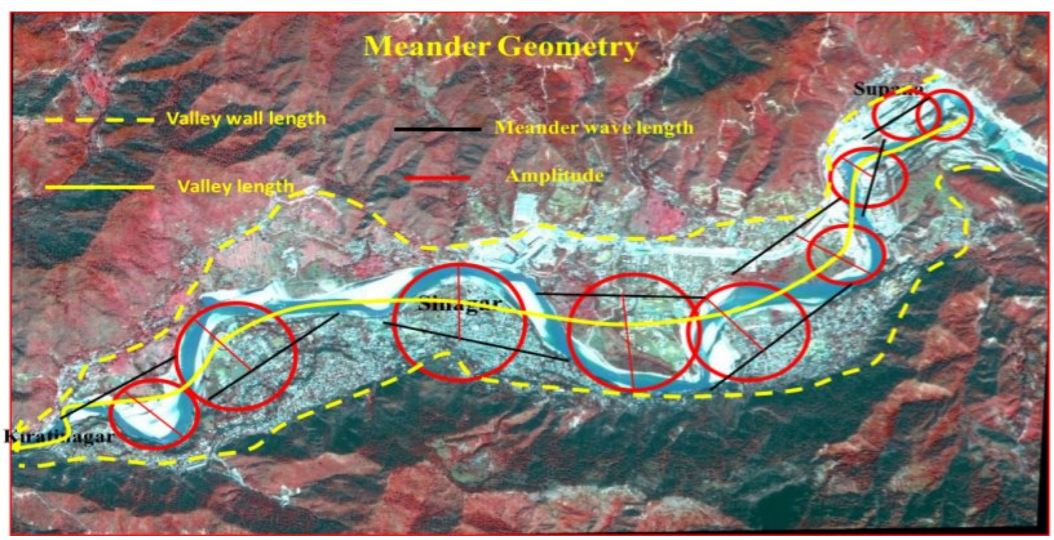


Fig. 4 : Parts of meander

Sinuosity index (S I) is the ratio of channel length (CL) of to the length of meander belt axis or valley length (VL), (Schumm, 1963). It is the only plan-form parameter used in the initial delineation of stream types. Sinuosity describes how the stream has adjusted its slope in relation to the slope of its valley. The range of sinuosity varies from 1-4 or even more. A river having a sinuosity index of less than 1.05 is called straight channel, and that between 1.05 to 1.5 is called sinuous to meandering pattern and that above 1.5 is called meandering channel (Leopold and Wolman, 1957).

Sinuosity index of the Alaknanda River is 1.34 in the study area which indicates that the river is sinuous to meander. On the basis of sinuosity index the shape of longitudinal profile is divided into three reaches i.e. nearer to straight (1.18), sinuous to meandering (1.33) and nearer to meandering (1.5). The sinuosity index of each segment has been calculated in Table 1. It shows that sinuosity ratio varies for each segment which indicates different channel pattern in different locations. The range of sinuosity index is from 1.16 to 1.43 (Table 1) which indicates straight to sinuous (1.o5-1.25), sinuous (1.25-1.35) and sinuous to meander (1.35-1.45) pattern. Sinuous to meandering channel pattern has been detected at Koteswar, Gugali and Chauras segments while straight to sinuous pattern at Supana, Sringar and SSB segment. However, Srikot and Sriyantra Tapu segments are following the sinuous channel pattern in the study area.

Width/Depth Ratio: The width/depth (W/D) ratio is defined as the ratio of the bank full surface width to the mean surface width depth of the bank full channel. Leeder (1973) derived an empirical equation between bank full width and channel maximum depth, where D is the elevation difference between the lower bank top and the thalweg. The distribution of energy within channels having high W/D ratios (i.e., shallow and wide channels) is such that stress is placed within the near bank region. W/D ratio is the most sensitive and positive indicator of trends in channel instability. Determination of the width/depth ratio provides a rapid, visual assessment of channel stability. The width/depth ratio is key to understanding the distribution of available energy within a channel. The overall channel width/depth ratio of the Alaknanda River is calculated at 4.83. The high W/D ratio value shows that that the channel grows wider and shallower and the hydraulic stress against the banks also increases. As a result bank erosion is accelerated. Each reach W/D ratio is calculated in Table 2. Sriyantra Tapu, SSB and Srikot reaches have the highest W/D ratio which shows that the river channel is wide and accelerated the bank erosion. Srikot meander reach is a prominent example of these features.

Departure angle is also known as deflation angle. Deflation angle is that which create the meandering path at crossing of sinuous axis and centerline of the meandering platform downstream the river. It shows that if the curvilinear path is more sinuous the angle will be higher. Beside this if the straight or curvilinear the value of angle will be low.

Table 2 reveals that segments Chauras and Koteswar departure angles are 58^0 and 55^0 respectively which are more than average angle i.e. 38^0. These segments are more semi-circular in shape. Beside this Supana, Sriyantra Tapu calculated less than average 20^0 and 25^0 departure angles respectively. It shows that these two segments are less sinuous in nature. Srinagar meander is very less sinuous or initial stage of sinuous because its departure angle is below an average (35^0). It can be concluded that sinuous to meandering path having high departure angle and opposite of lower departure angle.

Meander Belt width is the lateral distance (perpendicular to valley) between the outside edges of two meanders that occupy opposite sides of the valley (Fig.3). Belt width is used as an index of the lateral containment or confinement of a stream when compared with the width of the channel. Meander Width Ratio is the belt width divided by the bank full width. Various meander width ratios by segment type are shown in Table 2.

Table 2 reveals that the average meander width ratio of the Alaknanda River in Srinagar valley is calculated at 4.12 which indicates that the river is passing through sinuous to meandering stage of geomorphic development. Four bed rock channel segments have an above average meander width ratio while four wide alluvial bed channel segments have below average width ratios. It shows that narrow channel width valley has a high meander width ratio and vice-versa. The highest values were calculated in Supana segment (7) followed by Guguali segment (6.67) in which the river is flowing through a bed rock. Beside this lowest value has been calculated at Sriyantra Tapu (1.9) followed by SSB (2.12) in which the river has formed a wide flood plain. It is concluded that as the valley widening process increases, the meander width ratio decreases.

Stream Meander Length (Lm) is the channel distance between the apexes of two sequential

Table 1. Meander Properties

Reach	Segment	Valley Length (km)	Channel length	Sinuosity	Load type	Bed Load	Morphology	Erosion behavior	Deposition behavior	Terrace set
A	Supana	0.43	0.5	1.18	Rocky bank	Under water	Rocky scarp	Pot holes and pools	Bed rock	2 set in right b
	Koteswar	1.25	1.75	1.4	Rocky bank	Under water	Rocky scarp	Pot holes and pools	Bed rock	3 sets in left b
	Surasu	1.75	2.5	1.43	course boulder	Point bar	Pool	Under cut scarp	Point bar	4 sets in right b
	Srikot	1.75	2.25	1.29	Course	Bolder/pebbles	Point bar	Lateral	Stratified	2 sets in left b
B	Chauras	2.12	3.0	1.41	medium	Pebbles	channel point bar	Lateral/under cut	Stratified	6 sets in right b
	Srinagar	2.12	2.25	1.18	Medium fine	Mixed	Point bar	River bank E.	Stratified	4 sets in left b
C	SSB	2.0	2.25	1.25	Medium fine	Medium fine	channel point bar	River bank E.	Flood plain	3 sets in left b
	Sriyantra Tapu	0.95	2.54	1.34	Mixed	Medium fine	Braided	Lateral	Siltation	2 sets in right b
Total	**Alaknanda**	**8.62**	**11.54**	**1.34**	Fine to course	Mixed	meandering	Lateral	Siltation	Left/right

Source : Self computer generated

Table 2. Measurement of Meander Parameters

Reach	Segment	Entrenchment ratio	Meander width ratio	Meander length ratio	W/D ratio	Wave length (km)	Amplitude (km)	Radius (km)	Departure angle	Width (m)	Depth (km)
A	Supana	1.05	7.0	20.0	1.43	1.0	0.35	0.38	20	10	7
	Koteswar	1.66	4.67	11.67	3.33	1.25	0.8	0.43	55	30	9
	Surasu	1.44	6.67	16.67	2,86	1.5	1.0	0.4	39	20	7
	Srikot	3.79	2.29	7.14	6.25	1.5	0.8	0.43	40	50	8
B	Chauras	1.87	5.5	15.0	2.73	1.25	1.15	0.5	58	30	11
	Srinagar	2.56	2.8	10.0	4.37	1.75	0.8	0.4	35	35	8
C	SSB	6.20	2.12	6.25	8.33	1.5	0.9	0.4	34	50	6
	Sriyantra Tapu	2.43	1.9	5.0	9.17	1.5	1.0	0.5	25	55	6
Average	**Alaknanda**	2.63	4.12	11.47	4.83	1.4	0.86	0.43	38	35	7.25

Source : Self computer generated

meanders (Fig. **3**). Meander length ratio is the stream meander length divided by the bank full width (Lm/ Wbkf). Various meander length ratios by segment type are shown in Table 2. The average length ratio of Alaknanda River in Srinagar valley is 11.47. Similar plan pattern in all the meander segments is also found in meander length ratio in the study area as found in width ratio.

Meander Wavelength (L) is the longitudinal distance between two successive meander crests, (**Fig 3**) and is negatively correlated with sinuosity. Meander wavelength is expressed as a ratio to the bank full width (L/Wbkf). The average wave length of the Alaknanda River in Srinagar valley is 1.4km. The minimum wave length was recorded at Supana meander (1km) followed by Koteswar and Chauras, 1.25km each respectively. The maximum meander wave length recorded of Srinagar meander i.e. 1.75km. Rest of the meanders wave length has been recorded at 1.5 each (Table 2).

Radius of Curvature (Rc) is the radius of a circle drawn through the apex of meander bend and two crossover midpoints. It is a measure of the "tightness" of an individual meander bend and is negatively correlated with sinuosity. Radius of curvature is measured from the outside of the bank full channel to the intersection point of two lines that perpendicularly bisects the tangent lines of each curve departure point (Fig.3). Radius of curvature is expressed as a ratio to the bank full channel width (Rc / Wbkf).

Various meanders radios curvature ratios by segment type are shown in Table 2. It shows that maximum ratio is found in the Supana meander (7.6) followed by Koteswar (2.87) which are flowing through a bed rock channel. Beside this minimum curvature ratio has been calculated in the Sriyantra Tapu (1.0), SSB (1.0), Srikot (1.23) and Srinagar (1.6) which show wide flood plain. Results are verified on the field and found to be correct. There is a positive relationship between radius of curvature and bank full width.

Entrenchment Ratio: *Entrenched* is defined as the vertical containment of river and the degree to which is incised in the valley floor. An important element of this is the relationship of the river to its valley or landform features. This interrelationship determines whether the river is deeply incised or entrenched in the valley floor. Entrenchment Ratio is the ratio of width of the flood prone area to the bank full surface width of the channel.

$$\text{E. Ratio} = \frac{\text{FPW}}{\text{BW}}$$

Entrenchment ratio of 1-1.4 represent entrenchment stream, 1.41-2.2 represents moderate entrenchment stream and ratio greater than 2.2 is slightly entrenchment stream or well developed flood plain. The average entrenchment ratio of the Alaknanda River in the study area is 2.63 which shows slightly entrenchment channel. The entrenchment ratio is calculated of all the 3 reaches and all 8 segments. It shows that reach C is well developed flood plain (4.32) while reach A is representing entrenched channel (1.98). Reach B represents moderate entrenchment ratio (2.22). The highest entrenchment ratio is found in the segment of SSB (6.2) and Srikot (3.79) while lowest value is calculated at Supana (1.05), Surasu (1.66) and Koteswar (1.44) segments (Table —). Rest of the segments i.e. Chauras, Sringar and Sriyantra Tapu have entrenchment ratios of 1.87, 2.56 and 2.43 respectively. The ratio at Chauras segment is low because there is a narrow channel passage at Chauras Suspention Bridge.

Amplitude is the maximum distance between crest and trough height (Maiti, 2016). A meandering river consists of a number of consecutive bends. The meander development consists of translation and expansion of their bends due to bank erosion. Flow parameters may be the most important factors in the bank erosion process.

The range of amplitudes is from 0.35 to 1.15 in the study area (Table 2). The average amplitude value of the Alaknanda meanders is 0.85. Four meanders have amplitudes more than average value while four meanders have less than average value. The meanders bends are litho logically and tectonically controlled so that no sharp results came out from the analysis. The shape and size of the bends are strongly influenced by the geological composition of banks and flood plains. For instance, the meanders will have finite amplitude when the flood plains consist of rock, the river banks cannot be eroded, so there is only translation of the river ends. In this case the geological characteristics of the flood plain act as boundary restrictions. Also the meanders reach maximum amplitude because of the existence of high bank (hills, bluffs).

Flow Pattern through Meander

Evolution and development of a meander can be understood by water flow pattern. Peak runoff plays a significant role in shape, size, erosion and deposition of a meander. There are two main features of the flow pattern through a meander as suggested by Kinghtion (1998). To know the flow pattern of through meander, a case study of Srikot meander is taken into consideration.

At the time of bank full discharge the meander reach full of water from concave bank to convex bank. High currents of water were observed on the concave and low on convex bank of the meander. Before understanding the flow pattern through the meander it is necessary to explain the channel flow on the different part of the meander. The meander cross section is divided into inner bank region, mid bank region and outer bank region (Markham and Thorne, 1992). It shows that the concave bend of the meander is outer bank zone and convex side is inner bank zone. When the primary currents; which are also known as transverse currents, converged in the concave bend the level of water elevates. The maximum velocity is directed towards the outer bank (Dietrich, 1987). The secondary circulation is the primary property of flow in meandering system. In fact, the primary circulation of water moves along the bottom towards the point bar and surface water moves the surface towards the undercut bank that is called an outer bank or concave bank. The maximum erosion is experienced at the outer bank (Fig.5).

Effects of Helical Flow

Helical or helicoidally flow concept was derived first by Dietrich (1987) and explained by Maiti (2016) in his book 'Modern Approach to Fluvial Geomorphology'. Basically, helical is a type of shape related to helix broadly spiral. In this process water is winding around a center between outer and inner bank. Water circulates along the bottom towards the point bar and along the surface towards the undercut bank.

It shows that the centrifugal force acts outwardly on the water from the meandering bend. As the water level at outer bank is high, a pressure gradient is generated towards the inner bank (Maiti, 2016). The centripetal force acts inwardly on the water as in eddy motion. Thus, during super level of water, interaction of downstream velocity and centrifugal and centripetal forces are developed in spiral or helicoidally pattern of movement at meander bends. In this process the downstream flow removes the sediment material from outer bank towards the point bar. Due to the helical effect the material deposits in the center in the form of shoaling. Srikot' and Sriyantra Tapu middle bar, point bars and river shoaling are the prominent effects of Helical Flow. The process of helical flow has been shown in Fig.5. The helical flow process is protecting the formation of middle and point bar in the channel.

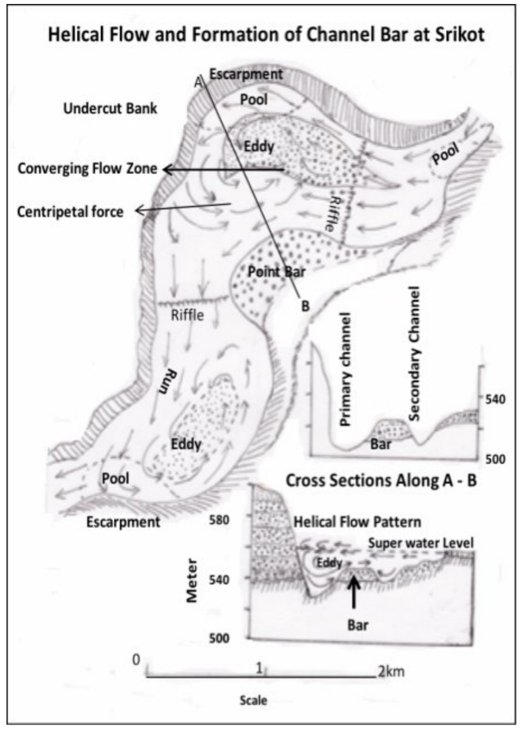


Fig. 5 : Halical flow system and associated features at Srikot segment

Tectonic Control in Formation of Meander

Tectonic control is reflected on the formation of meanders of the Alaknanda River in Srinagar valley. The major tectonic features are thrust, faults, fractures and lineaments of different deformation phases. The North Almora Thrust (NAT) is just across the Alaknanda River at Supana river bend (Fig.6). Here the river forms a hogback feature and turns towards south-east direction. At this location, the river traverses along the N-S trending transverse fault (Ahmad et al, 2000). The important lithology in the area is quartzite (Shekhar , et al, 2006). The river shifts here towards south-east and forms the Supana meander (Fig.6). A paleochannel is also observed at Supana village parallel to the river which is separated by a 40m quartztic rocky cliff (Chaudhary and et al, 2015). Now this cliff and paleo-channel has been modified by the Supana hydroelectric project.

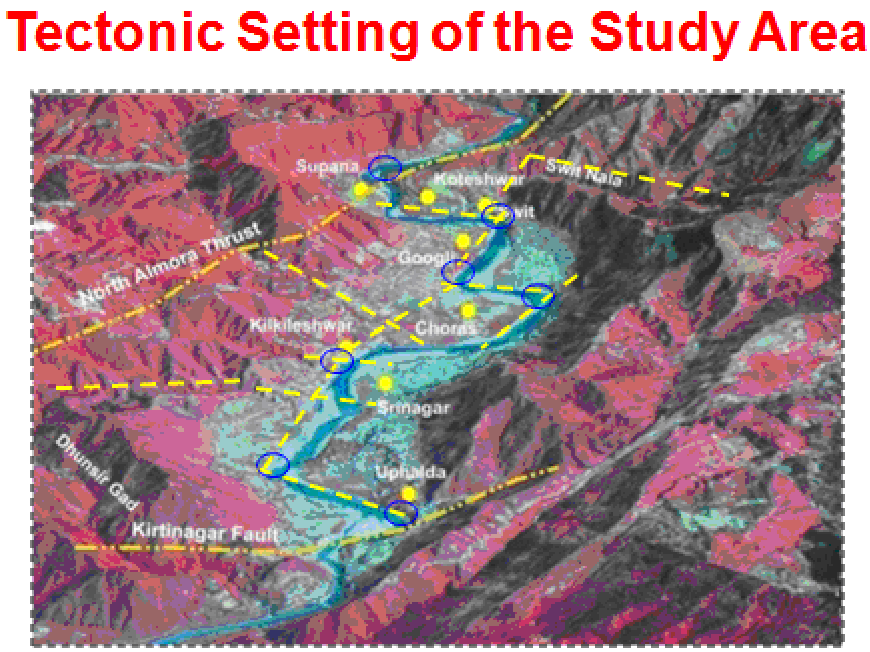


Fig. 6 : Tectonic control on meandering pattern

After flowing a half km distance it further follows the pattern of Koteswar fault which extend from North to South direction up to Sweet Nala. In this segment the meander is known as Koteswar meander (Fig. 6). The important lithology at the river bank is phyllite which is folded in many places (Srivastava and Ahmad, 1979). In this segment the meander is known as Koteswar meander (Fig.6). At the junction point of Koteswar fault and Sweet Nala fault, there is a 10m deep pool and opposite of this there is a point bar feature.

From this point the Sweet Nala fault extends towards the West and forms the 50m high Surasu-Chauras terraces scarp along the river. At the junction of the Sweet Nala fault and Koteswar transverse fault the river turns towards the West and forms a hogback feature. Surasu meander is the result of this tectonic setting. The sinuosity index of the Surasu meander is 1.43. Further down at Chauras scarp a neo-tectonic transverse fault developed in the North-South direction and river Alaknanda turns towards this newly developed fault. This new generation fault displaced the earlier generation Sweet Nala-Chauras-Kilkileswar Fault at Chauras.

From the confluence of Sweet Nala to the hogback bend of Chauras the river flows in a state way east-west direction. This is the site of under cutting in which a 7m pool has been formed. Opposite of undercut site, there is extensive deposition of point bar (Fig.6). At the hogback bend the Alaknanda River forms a prominent Srikot meander (Fig. 5). The sinuosity index of the Srikot meander is 1.29. Here the valley is quite wide with numerous channel morphological features. The detail characteristics of the meander geometry are given in Table 1. Fig — shows that all the meanders bend are tectonically controlled. However, two linear features are joining each other the river formed a hogback feature, pool and scarp on the outer bend of the meanders. Ranihat, Kilkileswar and Sriyantra Tapu are the other examples of this fact (Fig. 6).

Correlation between Different Geometric Parameters

There is correlation ship between geometric parameters. Mostly it is assumed that there is a relation between variables. A variable is a characteristic that takes on two or more values. The variable that changes in relationship to change in other variables is known as dependent variable. However, the variable whose change results in the change in another variable is called an independent variable. The dependent variable is 'dependent' on the independent variable. An independent variable is the one that influences the dependent variable in either a positive or negative way (Chakarborty, 2016). It has been tried to establish the relationship between the different parameters of the study area.

The analysis shows that interrelationship of different channel geometric parameters have yielded perfect positive degree to no degree of correlation (Fig.7-10).

sinuosity index (Fig. 8b), the correlation between them is moderately positive (R= 0.563) which shows that the sinuosity is dependent upon the independent variable valley width. As the valley width will increase the dependent variable sinuosity will also increase proportionally.

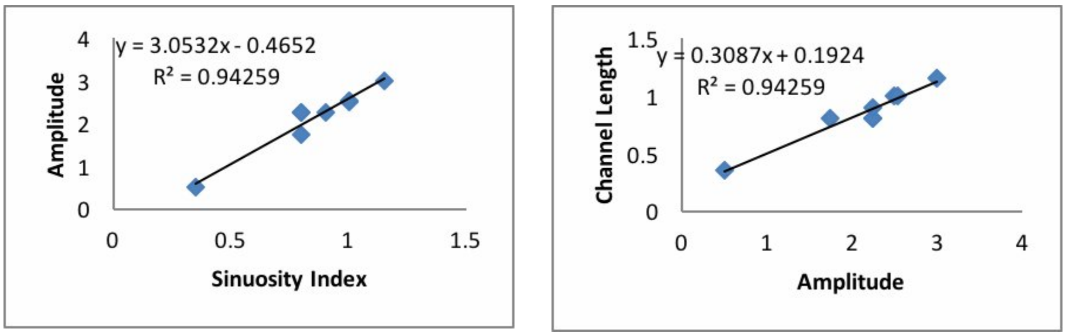


Fig.7 a and b showing correlation between amplitude and sinuosity index and channel length and amplitude

Fig, 7a shows that there is a perfect positive correlation (R^2= 0.977) between amplitude and sinuosity index. It shows that as the amplitude increases the value of sinuosity index also increases. The amplitude increases in a meander depicts maturity and formation of meander. Wide channel usually tends to show a positive correlation ship to amplitude. Similarly, there is a perfect positive correlation ship (R^2= 0.942) between channel length and amplitude (Fig.7b). It shows that as the channel length increases of a meander the amplitude is also increases which indicates that the development of meander is increasing.

Fig. 8a shows that perfect correlation ship (R= 0.956) is found in between width ratio and length ratio. It shows that the length ratio is depending upon the width ratio. As the width of the channel increases the length of the channel also increases in the formation of meander formation. In the case of valley width and

Channel length and sinuosity index (Fig.9a) shows a correlation ship (R= 0.530) as found in channel width and sinuosity (R= 0.563). Both the parameters are moderately correlated to each other. But trend line shows the negative trend in between these two parameters. Fig.9b shows the relationship between wave length and amplitude which indicates the negligible positive correlation nearer to zero (R= 0.211).

The correlation values also found in between sinuosity index and radius of curvature which shows low level positive correlation (R= 0.398). Both the variables are equally dependent to each other (Fig. 10a).

Channel length shows a moderately positive correlation with valley length (Fig.10b). The valley length increases in a meander depicts maturity stage of development and formation of the meander. Valley length usually tends to show a positive correlation ship to channel length.

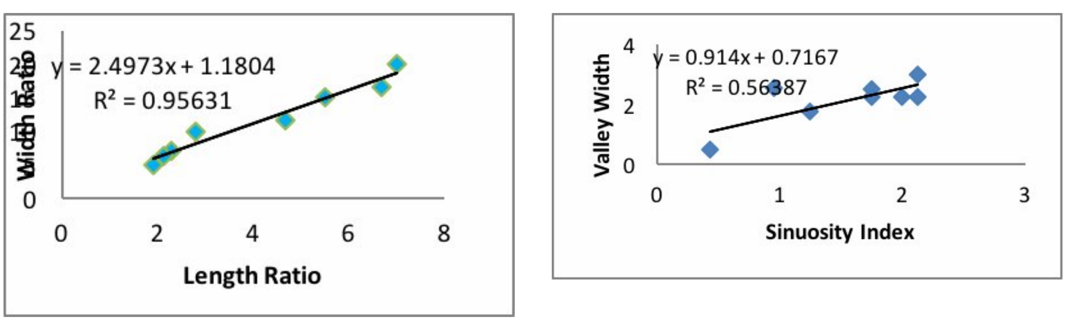
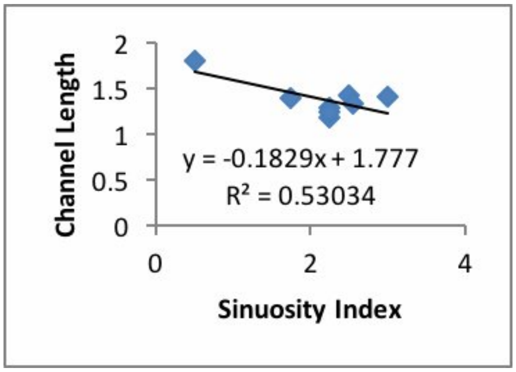


Fig. 8a and b showing the correlation between width ratio and length ratio and valley width and sinuosity index



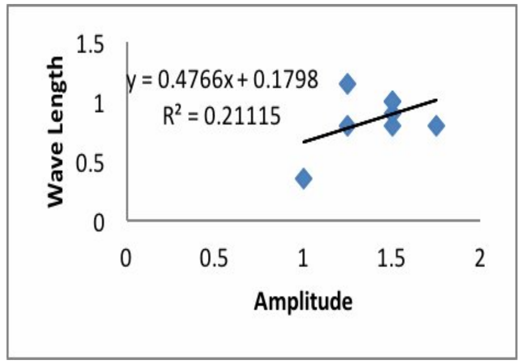
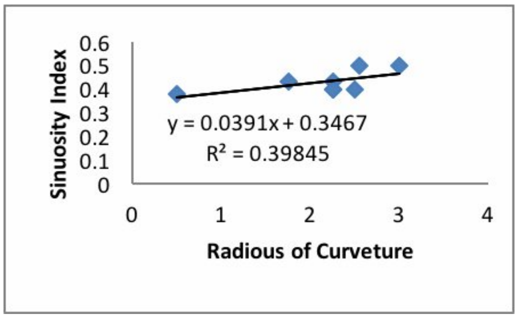


Fig. 9a and b showing correlation between channel length and Sinuosity index and wave length and amplitude



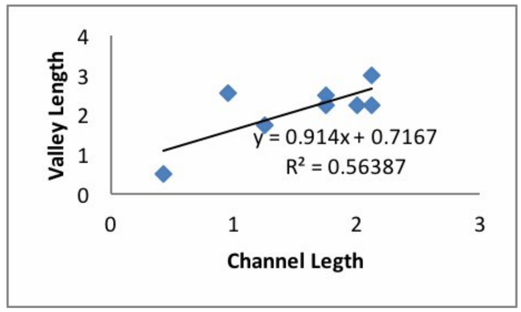


Fig. 10a and b showing correlation between Sinuosity index and radius of curvature and valley length and channel length

Conclusion

Channel morphology includes the channel geometry, channel fluid dynamics, hydraulic geometry, channel bed form and channel pattern. The average sinuosity index of the Alaknanda River is estimated at 1.34 which shows that the river is flowing through sinuous to meandering pattern. The average entrenchment ratio is calculated at 0.87 while the average amplitude of the valley is 0.85. Overall average gradient of the channel course from Supana to Kirtinagar is 3.5m/km. Tectonic control is reflected on the formation of meander bends in the Alaknanda River. All the meanders are control by transverse fault pattern along the NAT.

The correlation between different geometric parameters concluded that amplitude v s. sinuosity, channel length v s. amplitude and width ratio v s. length ratio have a perfect correlation ship (R= >0.942). Increase of channel length and meander amplitude is the result of topographic factors and frequent flooding due to heavy rainfall in the hill regions. On the other hand, valley width v s. sinuosity and channel length v s sinuosity index have moderate correlation ship (R= 0.53). Beside these, wave length vs. radius of curvature and wave length vs. amplitude have very low correlation values (R= <0.4). Finally, it may be concluded that meander amplitude has played major role in increasing sinuosity ratio in selected segments in Alaknanda river course.

References

Bhathrust J.C. and et al, 1979. Secondery Flow and Shear Stresses at River Bends, Journal of Hydraulic Division, ASCE, Vol. 105, Pp 1277-95.

Callander, R. A., 1978. River meandering. Annual Review of Fluid Mechanics, Vol. 10, pp. 129-158.

Chaudhary, S. and et al, 2015. Formation of paleovalleys in the Central Himalaya during valley. Quaternary International No. 371 Pp 255.

Chitale, S., 1973. Theories and relationship of river channel patterns. Journal of Hydrology, v.19, pp: 285-308.

Dietrich, W. E., 1987. Mechnics of Flow and Sediment Transport in a River Bend. In Rechards, K S. (ed), River Channel : Environment and Process. Oxford: Blackwell, PP 179-227.

George. H Allen,G.H. and et al, 2013. Lithologic and tectonic controls on bedrock channel form at the northwest Himalayan front. Journal of Geophysical Research: Earth Surface (JSR), Vol. 118, Pp1-20.

Hey, R.D., Geometry of River Meanders. UK Geol. Soc. Misc. Pap. 3. Pp 42-56.

Julion, P.Y. and Wargadalam, J., 1995. Alluvial Channel Geometry: Theory and Applications. Journal of Hydraulic Engineering, Vol. 121, No. 4.

Kinglhton,D., 1998. Fluvial Forms and Processes. London: Hodder Education.

Kinglhton,D., 1998. Fluvial Processes in Geomorphology. Oxford Unioversity Prtess, New York.

Leeder, M.R., 1973. Fluviatile fining-upwards cycles and the magnitude of paleo-channels. Geol. Mag., 110: 265-276.

Leopold, L. B.,and et al, 1964. *Fluvial Processes in Geomorphology.* Freeman, London.

Leopold, L.B & Wolman, M. G. & Miller, J. P. 1964. Fluvial processes in geomorphology. Dover Pub Inc. NY.

Leopold, L.B., M.G. Wolman, and J.P. Miller. 1964. Fluvial Processes in Geomorphology. Freeman, San Francisco, 522pp. 1 3 2 C B A 2.

Leopold, L.B.and Wolman, M.G., 1957. River Channel Pattern- Braided, Meandering and Straight. United State Waterways Engineering Experimental Station. Vol. 282A.

Maiti, R., 2015. Modern Approaches to Fluvial Geomorphology. Primus Books, Delhi, P71.

Rana, N. and et al, 2013. Recent and past floods in the Alaknanda valley: causes and consequences. Current Science Vol. 105, No. 9, 10 November, 2013.

Schumm, S. A., 1971. Fluvial Geomorpholgy , Channel Adjustment and River Metamorphosis. In Shen, H.W.(ed), River Machnics. Fort Collins, Colo, Pp5-1-5-22.

Singh, S 1998. Geomorphology. Prayag Pustak Bhawan. Allahabad. India.

Srivastava, R.N., Ahmed, A., 1979. Geology and structure of Alaknanda Valley. Himalayan Geology 9, pp225-254.

Thornton, E. and et al, 2007. Hydraulic Geometry in River Channel Network as a Method for the Assessment of River Condition. Procedding of the 5th Australian Stream Management Conference. Charles State University, N. South Wales.

Wasson, R. J. et al., 2008. Environ. Manage., 88, 53–61.

Wasson, R. J., 2013. *Quaternary Sci. Rev*., No **77**, Pp156–166.

Wolman M.G., 1959. Factors Influencing Erosion of a Cohesive River Bank. American Journal of Science, Vol. 257. Pp2014-16.

Chakraborty, S., 2014. The relationship between some of channel geomorphic parameters and consequent sinuosity ratio- A case study of lower Duduya River course. Geo-Analyst, Pp27-35.

Yalin, M. S. and Ferreira da Silva, A. M., 2001. Fluvial Processes, International Association of Hydraulic Engineering and Research Monograph, Delft, p. 197.

Shekhar, S. and et al, 2006. Geological structure of Srinagar Garhwal Himalaya. In Saklani, P. S. (Ed), Geology and Structure of Srinagar, Garhwal Himal: In Himalaya (Geological Aspect), Vol 4, Satish Seriel Publishing House New Delhi. Pp 153-169.

Pal, R., 2017. Meandering-braiding aspects of the middle-lower part of the Ganga River, India. J. Ind. Geophys. Union, V. 21, no.3, pp: 191-197.

Julien, P.Y, 1985. Plan form Geometry of Meandering Alluvial Changes. Civil Engineering Department Engineering Research Center Colorado State University Fort Collins, Colorado.

Selby, M.J., 1985. Earth Changing Surface: An Introduction to Geomorphology. Oxford University Press, Oxford.