Original Research Article

Analysis of GIS based morphometric parameters and hydrological changes in *Indrawati* river sub-basin of Godawari basin, Chhattisgarh, India

Abstract

Basin is main carrying surface of rainwater collected from basin area and moves to main drain as river system. The basin surface characteristic governs the movement, storage and drainage in basin due to rainwater. Morphometric analysis is a quantitative description of a basin with important aspect of the basin character. Godawari basin divided into five sub-basins. *Indrawati* is main tributary river of Godawari originated from Mardiguda, Dandakarnya range of Kalahandi district, Odisha. The basin includes BastarCraton covering a large area (>2105 km^2) in Central India, bounded by two Mesoproterozoic mobile belts, the Eastern Ghats Mobile Belt (EGMB) to the east, Satpura Mobile Belt to the northwest, and two major Palaeozoic tectonic features the Godavari Graben to the southwest and the Mahanadi Graben in the northeast. The basin has been extracted using Advanced Space borne Thermal Emission and Reflection Radiometer (ASTERGDEM)30 m (USGS, 2012) images by giving pour points and it has been projected on WGS 1984 UTM zone 45 for the morphometric analysis was used. Morphometric analysis expresses various aspects of basin characters which are 8 stream order (u), 85636 stream number, 42259.27 Stream length (Lu) (km), 0.493 Mean Stream length (Lsm), 3.144 Bifurcation ratio (Rb), 0.002 Length of overland flow (Lg), 0.110 drainage density (Dd), 3.088 Stream frequency (Fs), 1.220 Form factor (Ff), 2.634 Circulatory ratio (Rc), 0.0040 Elongation ratio (Re), 6.348 Leminscate method (k) and 1.758Reliefratio of *Indrawati* basin.

Keywords: Morphometric analysis, GIS tools, *Indrawati*river, drainage pattern, basin characteristics, land use covers.

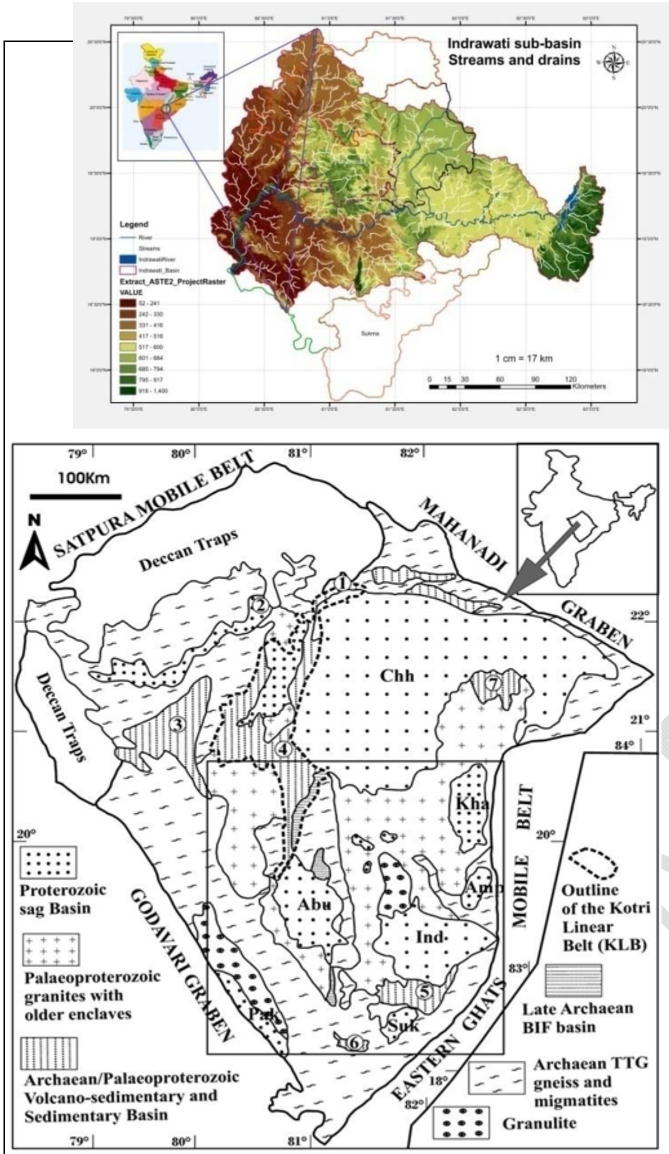
Introduction

The major resources of water on earth is rainfall which directly falls on earth surface and further movement of the water preferably depends on surface morphology either through free movement or obstacles on the way of flow. How much quantity of rainfall received on surface is not so important but the movement of rainwater decides the behaviour of water with land surface. These all aspects make vital the study of morphology. The drainage basin is a basic unit in fluvial geomorphology expresses relationships between landforms and the processes which modify surface. The study of the geometry on the basin through thechanges shows response to processes becoming a major part of geomorphology. Morphometric analysis is a quantitative description of a basin with important aspect of the basin characteras given by Strahler (1964). The term 'morphometry' indicates the meaning 'measurement of form' derived from morpho (form) and metry measurement [24]. The morphometric analysis involves linear, relief, aerial and gradient of channel networks and slopes of the basin [17] [10]; [12]. The remote sensing technique is an authentic way for basin analysis with the satellite images provides the opportunities to get a realistic view on large area. Digital Elevation Model (DEM) in the field of GIS provides the dimensional evaluation of the earth surface. Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) provide the data of DEM and for hydrological analysis and extraction ofstream network of a drainage basin [20]. The DEM is used assuming that the water will flow from higher to lower elevation using steep differences, will also produce a stream extraction model with a thematic layer of aspect, slope, relief, and drainage density, stream frequency [3]. GIS is used for the assessment of various basin parameters, is a reliable and authentic technique for the interpretation and analysis of spatial parameters of the drainage basin [13].

Trend detection of stream flow and rainfall is an active area of interest for both hydrology and climatology in consideration of climate scenario. Stream movement is known to reflect on integrated response of the entire river basin, while rainfall serves as one of the major inputs into the stream processes. Hydro-climatic condition at larger scale may lead to loss of spatial information of the variable levels. Therefore, it seems to be logical to analyse hydro-climate variables at a small scale such as river basin or sub river basin scales [20]. The trend of stream flow and their association with rainfall and other influencing factor at river basin scale. Therefore, this study was carried out to investigate the stream trend in *Indrawati* river sub basin and possible linkages for the observed changes in stream flow with rainfall. Detailed knowledge in hydro-climatic trends is essential in proper planning of water management and thereby the agricultural planning in regions of basin.

Description of the Study Area

Godawari basin divided into five sub-basins namely Godawari lower, Godawari upper, Godawari middle, *Indrawati*, Manjra, Pranhita and others, Wardha and Weinganga which are jointly responsible for total basin flow, the highest and lowest area covers under Weinganga (49695.40 km^2) and Godawari upper (22443.20 km^2) sub-basin, respectively. Among these sub-basins, *Indrawati* sub basin covers utmost 38306.10 km^2, with 21 dam and 15 reservoirs constructed on the way of flow, it includes 60 watersheds havingmaximum, minimum and average area of 992.92 km^2, 648.95 km^2 and 343.14 km^{2}are, respectively.*Indrawati* is main tributary river of Godawari originated from Mardiguda, Dandakarnya range of Kalahandidistrict (Odisha state) and flow through statesOdisha, Chhattisgarh and Maharashtra covering 535 km while travelling from origin to confluence point with Godawari. *Indrawati* forms beautiful water fall at Chitrakotnear Jagdalpur(Chhattisgarh) and hydro-power project in upper *Indrawati* at Mukhiguda, Kalahandi. It flows east to west of southern Chhattisgarh state crossing Koraput district of Odishafrom origin point as perennial river and forms large sub basin area of Godawari basin in the Bastar plateau at traverses in a east-west direction and assumed as life line of Bastar. Indarwati river runs zigzag manner throughout its flow covering six districts of Chhattisgarh except Sukma district, 2 districts of Odishain the sub basin of Godawariinto west,whiletravelling 306.75 km from its origin to joining point of the Godawari River, the whole basin extends between 20^{o}35’59.30” N to 18^{o}26’10.744” N latitude and 83^{o}5’44.349” to 80^{o}4”34.328” E longitude (Figure 1). It is one of the important tributaries of the Godawari Riverin eastern part serving large rain fed area for prosperity and meets with the Godawari at Sukma district. Elevation variation of the basin is from122 to 688 metres above mean sea level from origin to confluence point and drain area covered 38306.10 km^2. The river generally static in nature but during rainyseason, flood flow covers large area of basin due to common drainage of stream into river. Undulating land surface induce erosion and sedimentation in the river. The average bed slope of *Indrawati* River is 26.33 m/km, but itszigzagflow forms small and sharp tracks in medium size hillocks. The relief in the basin is formed due to the morphometric origin, and it is the predominance of shale, sandstone, Arcosic (Abujhmar group) ferruginous formations, which induces erosion with different magnitude of erodability. There is presence of some thrusts in the form of recumbent foldslike Chitrakot waterfall. This whole area ispart of Eastern Ghats and central India.



Geological map of the Bastar Craton. Inset in the upper part shows the location of the Bastar and other cratons in India, modified after Ramachandra et al. (2001); (1) Chilpi Belt, (2) Sausar Belt, (3) Amgaon Belt, (4) Kotri Linear Belt, (5) Bengpal Belt, (6) Sukma Belt, (7) Sonakhan Belt, Chh = Chhattisgarh Basin, Kha = Khariar Basin, Amp = Amphani Basin, Ind = Indravati Basin, Abu= Abujhmar Basin, Suk = Sukma Basin, Pak = Pakhal Basin. Figure 3. SRTM-DEM image of southern Bastar Craton (studied area).

Courtesy: Yellappa*et al.*, (2011)

Figure 2. Geological map of theregion

Geology of Bastar

The BastarCraton covers a large area (>2105 km^2) in Central India, bounded by two Mesoproterozoic mobile belts, the Eastern Ghats Mobile Belt (EGMB) to the east, Satpura Mobile Belt to the northwest, and two major Palaeozoic tectonic features the Godavari Graben to the southwest and the Mahanadi Graben in the northeast. The craton comprises a number of linear supra crustal belts such as the Bengpal-Sukma Belt in the south, Kotri-Dongargarh Belt in the centre and north, the Amgaon Belt in the west and the Sasur-Chilipi Belt in the north and the Sonakhan Belt in the east, near Bhopalpatnam, located on the northern shoulders of the Godavari Rift. The other important granulite belts in the region include: the Kondagaon Belt (70.11 km) at the northern margin of the Indravati Basin and the Konta granulite Belt in the south of the Sukma Basin, sub-parallel to the Eastern Ghats Mobile Belt (EGMB)[15][14][18][21][22][29]. A distinct North-South trending linear belt of banded iron formation (Bailadila) is well developed in the centre of the region overlying rocks of the Bengpal Group [4]. It was also reported similar formations by Mishra *et al.* (1988) in lithological association and tectono-metamorphic history with those of the iron formations of other belts in the region. In the southern part of BastarCraton, several episodes of mafic magmatism include mafic dykes and mafic volcanic rocks trending in a NW-SE direction, that occur mostly in the west of the Indravati, Sukma basins and around the Bailadila Iron Formation. Some of the shear zones cut across the sedimentary basins of Indravati, Sukma, Abujhmar, Khariar and Amphani. Karimnagar-Godavari Shear Zone (KGSZ) This zone, trending NW-SE extends for more than 200 km in length and a few kilometres wide passing through the Pakhal Basin sediments and older metamorphic rocks shows a dextral sense.These formations north of the Abujhmar Basin are strongly deformed and show a clear-cut north-south sinistral displacement suggesting major continental extensional tectonics during the Palaeoproterozoic, which was probably responsible for the evolution of the sedimentary basins. Several mafic dykes are also observed to the west and south of the *Indravati* Basin (Figure 2).

Methods and Materials for the Study

The basin has been extracted using ASTERGDEM (USGS, 2012 [28]) images and by giving pour points and it has been projected on WGS 1984 UTM zone 45for the morphometric analysis was used. The freely available Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) 30 m GDEM (version 2) of one arcsecond (arcsec) grid was downloaded for the study area in GeoTIFF format with geographic coordinates (USGS, 2012). The slope and relief of the basin were studied using digital elevation model data (DEM) available at USGS Earth Explorer for river basin and construct the stream analysis. The law of Strahler’s method of stream ordering has been adopted for ordering the streams [25]. The result of the stream order has been converted from raster to feature. A manual correction has been done by merging the stream of the same order and assigning these as same order streams[5]. The stream order, number of stream, stream length, mean stream length, bifurcation ratios, relief ratio, drainage density, stream frequency, form factor, circulatory ratio and elongation ratio were estimated using the mathematical formula given in Table1 with the ASTERGDEM satellite images. ArcGIS software has been used for the entire image processing and calculation of all parameters of morphometry study [30][1][19][2]. To show the changes in the hydrology of the Indrawti river basin, the trend of water flow discharge has been analysed. The fluctuations in the trend exert the peak flow of the river. The data has been collected from several research paper and available reports.

Table1. Mathematical formulae for analysis of basin characteristics

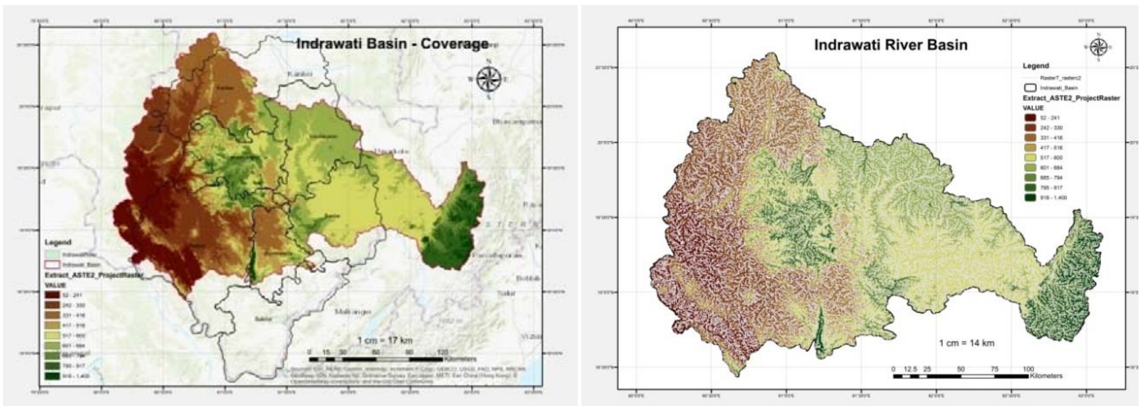
S. No.	Parameters	Formulae	References	Results
1	Stream order (u)	Hierarchical rank	Strahler (1952)	8
2	Stream number	Based on stream order	Strahler (1964)	85636
3	Stream length (Lu) (km)	Length of stream	Horton (1945)	42259.27
4	Mean Stream length (Lsm)	Lu=SL/Nu	Strahler (1964)	0.493
5	Bifurcation ratio (Rb)	Rb=Nu/Nu+1	Schum (1956)	3.144
6	Length of overland flow (Lg)	Lg=1/Dx2	Horton (1945)	0.002
7	Drainage density (Dd)	Dd=∑Lu/Au	Horton (1945)	1.041
8	Stream frequency (Fs)	D=∑Nu/Au	Horton (1945)	3.088
9	Form factor (Ff)	$Ff=A/LP^2$	Horton (1945)	1.220
10	Circulatory ratio (Rc)	$Rc=4\prod A/P^2$	Strahler (1964)	2.634
11	Elongation ratio (Re)	Re=D/Lb	Schum (1956)	0.901
12	Leminscate method (k)	K=L2/4A	Chorteyet *al*. (1957)	6.348
13	Relief ratio	Rh=H/Lb	Schum (1963)	1.758

Results and discussion

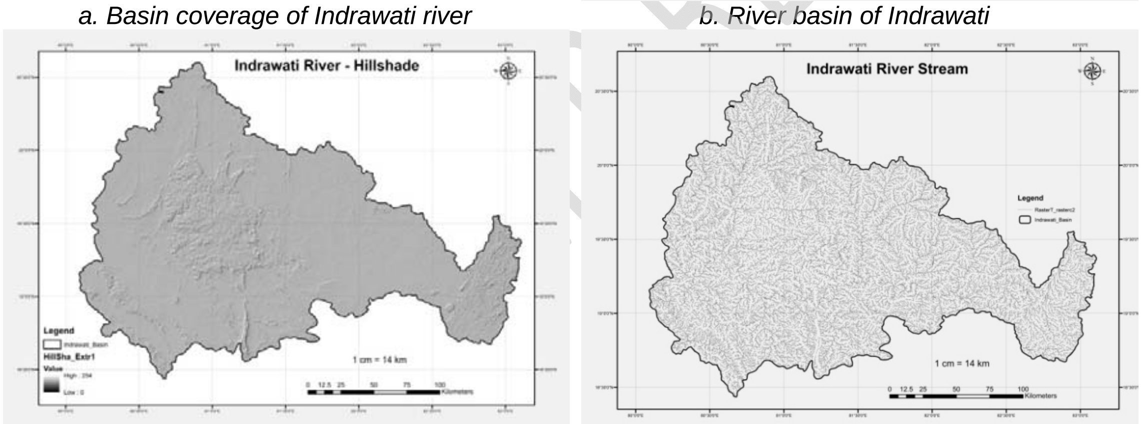
***Indrawati* River Basin: Linear aspects of morphometry**

Stream order (u): Stream order is defined as a measure of the position of a stream in the hierarchy of tributaries [11][6] [25], have developed stream ordering system. The *Indrawati*river, which is a main stream of the study area, is the eightstream orders (Based on Strahler's method of stream order). The variation extends order and size of the tributary basin is due to physiographic and structural conditions prevailing in the basin. The river basin develops over the shale, sandstone, gneiss and slate as major rock and thereby the number and order of streams are more. Total stream number is 85636 showing value 31.023 and 8179.61 as minimum and maximum, respectively from total mean length of 0.493 km and standard deviation of 692.83 while study of the *Indrawati* basin. The highest number of first order streams are 600150 followed by second order stream of 308424 and lowest was 3035expressing initiation and formation of new stream apparently.

Stream number: The total stream segments in each order are known as stream number. R. E. Horton states that the number of stream segments of each order from an inverse geometric sequence with the order number. The number of streams orders has been counted with the help of ArcGIS software. A total numberof streams in the basin are 85636. The underlying tender rocks and undulating plain favour a large number of streams further more initiation. In the *Indrawati* basin, the first order of the streams is associated with the highest number of streams and remainingare gradually decreased.



a. Basin coverage of Indrawati river *b. River basin of Indrawati*



c. Hillshade of Indrawati river *d. Stream networks of Indrawatibasin*

Figure 3: Basin characteristic map of Indrawati river

Stream lengths (Lu): The total streams lengths of various orders have been measured with the help of calculate geometry of GIS tools. It is indicative of the chronological development of streams and derived from source to mouth of the streams [13]. The total length of the *Indrawati* river is about 535kms, and the length of the total streams of the *Indrawati* river basin is 42259.27 km as length of streams increase flow coverage automatically increased.

Mean stream length (Lsm): The total length of stream measured and totalstream length is divided by the total number of segments in that order.There is the relationship between mean stream length and basin order*i.e.* mean stream length increases with successive increasing orders. Itis related to the size of the drainage network [26]. MeanStream Length of the *Indrawati* River basin is 0.493 km and is quitesmall while flowing takes many things away.

Bifurcation ratio (Rb): It is the ratio between the numbers of stream segments of any given orderto the number the next higher order. The bifurcation ratio rangesin between 3 to 5. The irregularities of bifurcationratio depend on the geological and the lithological development ofthe drainage basin. The lower value of the bifurcation ratio revealsthat the basin has suffered less structural disturbances and the highervalues of the bifurcation ratio indicate strong structural control onthe drainage pattern [26]. Bifurcation ratio having >10 indicates the drainagebasin developed over the easily erodible rocks [8]. The average value ofbifurcation is 3.144 and values of the bifurcation ratio of different orderranges from 2 to 5.26 due to large area coverage and topography of plateau as district demarcation lines by hillocks and hills favours less structural disturbances.

Length of overland flow (Lg): Normally, a higher value of Lg represents low relief and whereas a low value of Lg is an indicative of high relief. The lengthof the overland flow of *Indrawati* River is 0.002km/km^2. The value isusually low that indicates the basin is consists of high relief and slope,and thus rainwater enters the stream very quickly, meanwhile entry of rain water in stream way, the flow washes a lot of materials on the way.

Aerial aspects of morphometry

Drainage density (Dd): Drainage density (Dd) is the ratio of thetotal length of the streams in a given drainage basin and the area ofthat drainage basin [6]and envisagedthat the value of the drainage density ranges from 0.93 km/km^2 to 1.24km/km^2 in the steep impervious area of the high precipitation regionand zero for the permeable basin with high infiltration rate. Langbien considered that the drainage 4 density is ranged from 0.55 to 2.09 for thehumid region with the average drainage density of 1.03. Low drainage densityindicates permeable subsurface and coarse drainage [13]. Drainage density of the *Indrawti* River Basin is 1.041km/km^2, and it means weaksubsurface material and belongs to medium texture of the basin with steep impervious.

Stream frequency (Fs): It is expressed as the ratio of a total number of channelscumulated for all orders within a given drainage basin and the area of the drainage basin [6]. It indicates the index of various stages of landscape development and depends on thenature and amount of rainfall, the nature of rock and soil permeability of the region. Stream frequency of the *Indrawati* River basin is 3.088/km^2, which indicates high relief and high infiltration of the basin because of compartmentation. Hence, both the drainage density and the stream frequency are the parametersfor measuring the spacing of stream channel in the basin.

Form factor (Ff): The value of the form factor varies from 0 (highlyelongated shape) to 1 (perfect circular shape). The valueof form factor of the *Indrawati* River basin is 1.22 which depicts that thebasin form belongs to perfectly circular shape and cause flood situation in the district in rainy season, and it is the indicationof high peak flow of the basin.

Circulatory ratio (Rc): The Circulatory ratio is to provide a quantitative index of the shape of the basin. Circulatory ratio is the ratio of basin area tothe area of the circle having the same parameter as the basin. A circular basin has a maximum efficiency of the movement of runoff, whereasan elongated basin has the least frequency. This information is very significant for forecast of drainage discharge, particularly in a timeof the flood [7]. The value of the circulatory ratio is 2.364 whichexplainhigh circular shape and high run off flow of discharge of the*Indrawati* River basin while heavy down pour.

Elongation ratio (Re): This ratio usually runs from 0.6 to 1.0 over a broad range of climaticand geological type. Values near 1.0 are a typical region of low reliefwhile values from 0.51 to 0.94 are associated with strong relief and steepground slope. The ratio is a meaningful index for classifying drainagebasins into varying shapes as circular (above 0.9), oval (0.8-0.9),less elongated (0.7-0.8) and elongated (below 0.7). The valueof elongation ratio of the *Indrawati*river basin is 0.901. So, the basin hasa circular in shape and associating strong relief of surface and low peakflow.

Leminscate method (K): It is the comparison of the basin with theleminscate curve. The high value of K indicates elongated shape andon the contrary, a little value indicates the circular shape of the basin.The K value of *Indrawati* river basin is 6.348 that depicts that the riveris a perfectlycircular and it indicates high peak flow ofdischarge of the basin.*Indrawati* basin has higher K means high order stream is present and further it will increase with progress.

Relief aspects of morphometry

Relief Ratio: The Relief ratio is the ratio between the total reliefof a basin and the longest dimension of the basin parallel to the maindrainage line [23] and a dimensionless height-length ratio equal to the tangent of the angle formed by two planesintersecting at the mouth of the basin, one representing the horizontal,the other passing through the highest point of the basin. It denotes theoverall steepness of a drainage basin and is an indicator of the intensityof degradational processes operating on slopes of that basin. The reliefratio of the river basin is 1.758 that indicates this basin is composed ofmore resistant in flow by hindrance of hills and hillocks of basin, and the basin is under intense relief and steep slope.

Drainage patterns of the *Indrawati* river basin

In the *Indrawati* river basin, Tree-like dendritic type of drainagepattern mainly develops over the existing rocks apart from the dendritic pattern also exhibits the Herringbone, parallel and centrifugal type of drainage pattern. Theparalleldrainage pattern, where the control of the regional slope, parallelfaults and lineaments predominate is discernible too. In this drainagepattern, parents and tributaries flow in right angle to meet. In some peak ofthe ridges, Centrifugal drainage pattern, where streams radiate in alldirections from a common centre, is significant feature of the hillocks.

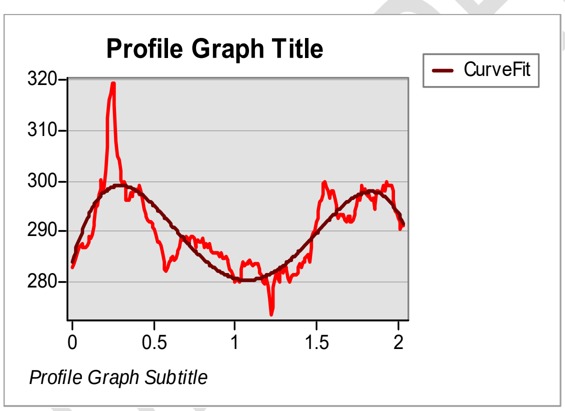


Figure 4. Long profile of Indrawati basin

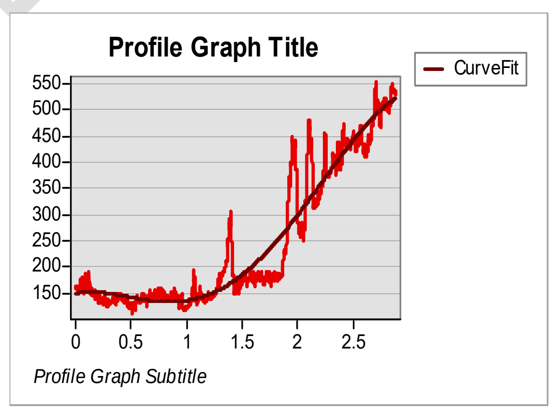


Figure 5. Cross profile of Indrawati basin

Long profile of the river: It is generallyconcave to the sky, but the slope is decreasing rapidly at first and then gradually [9][11]. The River originates at 688 m above mean sea level and runs 535 km. The long profile of a river is dependent uponthe lithology of the underlying structure, stream flow, discharge, theamount and texture of the channel load, flow resistance, flow velocity,width and depth of the channel, and regional slope [8]. The *Indrawati* River has a different channel slope and concavity. The regular concaveprofile is interrupted by the convex profile at about 20-30kms from theorigin. The convex slope is between 1500-3000 metres due to plateau shortly change in movement on structural differences and concave inbetween 1000-2000 metres above meaning sea level having sharp turn due to landforms. The irregularities aredue to the presence of the more resistance hillocks and change in slope (Figure 3).

Cross profiles of the river: The cross profile varies from thenarrow, steep-sided trenches to gentle open form, ultimately dependson the resistance offered by the undulating plateau slopes and the erosive capacity ofthe water during rain. Cross profile of the *Indrawati* River in different regimes exertsthe processes and dominant controlling factor. Most of the cross profiles are 'U' shaped in natureand it represents lateral cutting rather than down erosion. Near the source, the dominance of hills and riverhasmore stream power for lateral cutting, thus flat 'U' shaped profile issignificant(Figure 4).

Recent Hydrological Changes in *Indrawati* River Basin

The significant changes have been observed in the *Indrawati* RiverBasin mainly due to climatic and anthropogenic causes.The climatic variability leads to heavy and erratic rainfall of theregion induces soil loss and thereby retreat of sedimentation of the river basin isdiscernible and consequences of the events are shallow depth, diversion, flood with small quantum of rainfall washing out top agriculturally important soil. The source region of the *Indrawati*river, is eastern ghats experienced with abrupt changes. Deforestation in the basinarea also increases the erosion capacity of the rivers alongwith tributaries. As a result,basin might be more prone to soil and water loss in coming years (Figure 3).

Temporal changes in discharge of *Indrawati* River

A tendency of decrease in average annual and seasonal discharge of the *Indrawati* River has been experienced. It issignificant from the several studies that the decline of discharge is also experienced. The flow characteristic is controlled by variability of rainfall. The gradual decrease of discharge in winter onwardsis noticed due to less flow and uneven distribution between states like Odisha and Chhattisgarh during lean periods. Simultaneously, the irregularity of the Monsoondisrupts the average discharge of the river in a lesser extent. The present study on drainage basin has been done on the basis ofgeo-morphological perspective. Study of the morphometry is concernedwith the genesis, development and distribution of landforms[27]. Animportant property of the drainage basin is its hierarchical in nature,each tributary in a drainage system has its basin area. In any drainagebasin, there are several variables which always interacting with othervariables and give birth to particular types of landforms.

Conclusion

The study reveals that the drainage basin is associated withthe early stage of drainage development, and high order of streamdominates the river basin. The circular shape of the basin revealshigh runoff and low infiltration capacity and uncontrolled flow of river water with disturbing dependent factors of basin. Recently, severalanthropogenic activities like house construction on banks, fast deforestation, siltation and climatic variability (erratic rainfall and rising temperature) caused the severalhydrological changes in the *Indrawati* River basin. Recent changes indischarge can affect the aggradational and degradational processes that also affect the overall welfare of society.

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