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Morphometric Analysis of Indrayani River Basin using Remote Sensing and GIS Techniques and Priortization of Watershed

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Abstract: Geographical information system (GIS) and Remote sensing has become an efficient tool in delineation of drainage pattern and water resource management. GIS and image processing techniques can be employed for the identification of morphological features and analyzing properties of basin. The morphometric parameters of basin can address linear, areal and relief aspects. The present study deals mainly with the geometry, more emphasis being placed on the evaluation of morphometric parameters such as stream order(Nu), stream length(Lu), bifurcation ratio(Rb), drainage density(Dd), stream frequency (Fs), texture ratio (T), elongation ratio (Re), circularity ratio (Rc) and form factor ratio (Rf) etc.. study area is Indrayani River, geographically located between 18°57' to 18°35' N latitudes and 73°25' to 74°0' E longitudes located in Pune district of Maharashtra state of India. The GIS based morphometric analysis revealed the 7th order drainage basin and drainage pattern mainly. The total numbers of streams of whole river basin area is 14842 in which 9611 are first order, 4539 are second order, 541 are third order, 122 are fourth order, 25 are fifth order, 3 are sixth order and 1 are seventh order streams. The length of stream segment is maximum for first order stream and decreases as the stream order increases. This study would help the local people for the management of the soil and water conservation practices and created structures of CCT, SCT, Terreces and Bunds for the reduces the soil erosion and recharge the ground water potential.

Keywords: Remote sensing, GIS, Morphometric analysis, Watershed Prioritization,

INTRODUCTION

Remote sensing and GIS techniques are the proven efficient tools in the delineation, updating and morphometric analysis of drainage basin. The drainage basin analysis is important in available water resources. Geomorphometry is the measurement and mathematical analysis of the earth's surface and its dimensions of the landforms (Clarke, 1996). The properties gives important information related with the formation and development of hydrologic and geographic properties of watershed. This analysis gives the quantitative description of drainage, which is an important aspect of the basins (Stahler, 1964). The areal parameters shows the shape, geometrical and topological parameters like stream frequency, Drainage density. Morphometry is depends upon the topology of basin or watershed. The information related with the geomorphology, hydrology, geology, and land use pattern is highly important for doing trusted study of drainage pattern of the watershed. In recent decades the morphometric analysis of the various River Basins have been done by many researchers and scientist (Esper,2008; Gaikwad and Bhagat,20017; Akash pandule,2019;) have studied morphometric parameters for watershed and prioritization. In this study to understand various characteristics of Indrayani river basin which helps to understand the topographic relation, agriculture and regional planning. Also understanding of a river basin depends on careful study both the physical and human characteristics of that basin.

Land and water resources are limited and their wide utilization is imperative, especially for countries like India, where the population pressure is increasingly continuous. These resource development programmes are applied generally on watershed basis and thus prioritization is essential for proper planning and management of natural resources for sustainable development. Watershed deterioration is a common phenomenon in most parts of the world due to mismanagement of natural resources and faulty agricultural practices as well as social development activities. Morphometric analysis could be used for prioritization of micro-watersheds by studying different linear, aerial and relief parameters of the watershed. The watershed management concept recognizes the inter-relationships among the linkages between uplands and low lands, land use, geomorphology, slope and soil (Tideman,, 1996). For soil and water conservation watershed is considered as hydraulic entity that can be managed as per the erosion intensity in the basin. Thus the whole basin is divided into several smaller units, as watersheds or sub-watersheds, by considering its drainage system.

STUDY AREA

Indrayani river is the major tributary of Bhima river. The Indrayani river originates in kurvande village near lonavla, a hill station in the Sahyadri mountains of Maharashtra, India. Fed by rain, it flows east from there to meet the Bhima river, through the Hindu pilgrimage centers of Dehu and Alandi. It follows a course mostly north of the city of Pune. It is reversed as a holy river and is associated with religious figures such as Sant Tukaram and Dnyaneshwar. The outlet point is considered in Bhima river near Tulapur, Pune, Maharashtra, India. On the Indrayani River there is a hydroelectric dam called Valvan Dam at Kamshet. The Indrayani river conservation project is one among several projects, started by the state fisheries department and Tata power in 1971, included setting up a Mahseer hatchery at Walwan, Lonavla. The study area of Indrayani river basin is taken about 979.07 Sq. km. The study area lies in areas as the annual average rainfall is about 1296mm. generally major part of the study area is covered by Black cotton soil called Regur formed by whethering of trap rocks. Sandy soil and older alluvial deposits of the Indrayani river also found in pockets along the banks of these river. The catchment area of Indrayani river is 979.07 Sq. km. The elevation at the outlet is 540m from mean sea level and maximum in hilly area of in Indrayani river basin is 1139m from mean sea level. The crops yield 20% decreases due to polluted water in Indrayani river

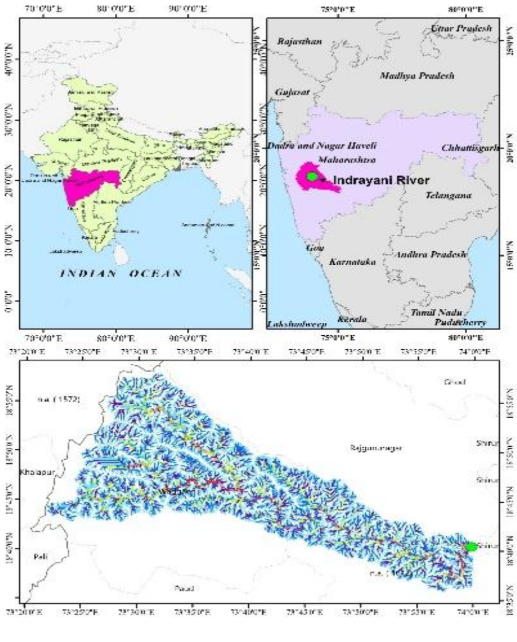

Figure 1: Location map of study area

Data Used and Methodology

In present study, morphometric analysis and prioritization of basin is based on the integrated use of remote sensing and GIS technique. The remotely sensed data is geometrically rectified with respect to Survey of India (SOI) topographical maps at 1:50000. The analysis of drainage pattern is carried out in Arc GIS 10.8.1 Software by using SRTM (Shuttle Radar Topography Mission) DEM (Digital Elevation Model) and Toposheet. For stream ordering

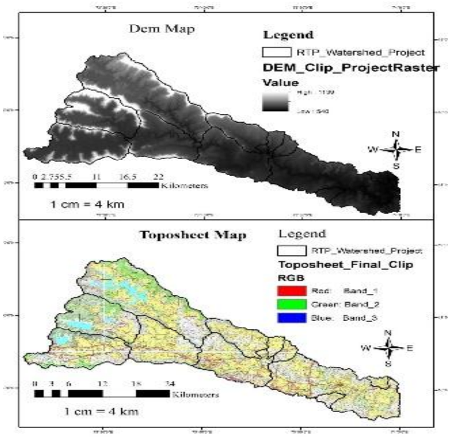

Figure 2: DEM map and Toposheet map

Strahler's law is followed by designating an unbranch stream as first order stream, when first order streams join it is designated as second order. Two second order streams joined together to form third order and so on. The number of streams of each order are counted and recorded. Topographical map: SOI (Scale 1:50000) Number E43H5, E43H6, E43H9, E43H10, E43H13 and E43H14; SRTM (DEM) with 30m×30m spatial resolution. SOI topographic map is georeferenced using WGS1984 datum, Universal Transverse Mercator (UTM) zone 43N projection in Arc GIS 10.8.1. The drainage map along with basin boundaries are digitized as line coverage giving unique id for each order stream. The digitized map is edited, and saved as line coverage in Arcview GIS software. Morphometric parameters under linear and shape are computed using standard methods and formulae (Horton,1932, 1945; Smith 1945; Strahler1964). The fundamental parameter namely; stream length, area, perimeter, number of streams and basin length are derived from drainage layer. The values of morphometric parameters namely; stream length, bifurcation ratio, drainage density, stream frequency, form factor, texture ratio, elongation ratio, circularity ratio and compactness constant are calculated based on the formulae suggested by Horton (1945), Miller (1953), Schumn (1956), Strahler (1964), Nookaratm (2005).

RESULT AND DISCUSSION

The following paragraphs describe the physical meaning of various morphometric parameters. Further values of these parameters are obtained as per methods proposed by various researchers for the study area and indicated in respective descriptions.

Linear aspect

The linear aspects of morphometric analysis of basin include stream order, stream length, mean stream length, stream length ratio, bifurcation ratio, length of main channel, channel index & valley index and RHO coefficient.

Stream order (Su)

Stream order designation is the first step in morphometric analysis of drainage basin. There are four different system of ordering streams that are available [Gravelius(1914), Horton(1945), Strahler(1952) and Schideggar(1970)]. Strahler's system, which is a slightly modified of hortons system, has been followed because of its simplicity, where the smallest un-branched fingertip streams are designated as 1^{st} order, the confluence of two 1^{st} order channels give a channels of segment 2^{nd} order, 2^{nd} order streams join form a segment of 3^{rd} order and so on. When two channel of different order join then the higher order maintained. The trunk stream is the stream segment of highest order. In this present study basin is divided in sub-watershed(SW). It is found that SW1, SW3, SW5, SW9, SW10 and SW11 6^{th} order is trunk order. In SW2, SW4, SW6 and SW7 found trunk order is 4^{th} order and in SW8 founded highest order 5^{th} order.

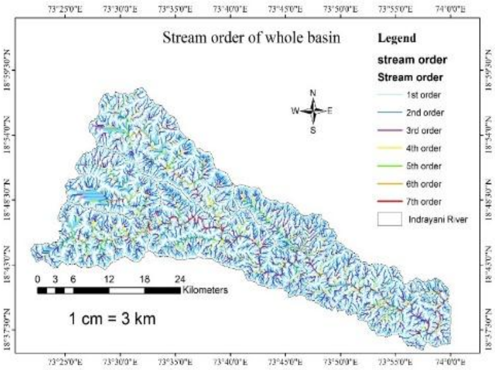

Figure 3: Stream order Map

Stream Number (Nu)

The summation of order wise stream segments is known as stream number. Stream number is an inverse of stream order. As the basin has 1st order stream has more number of stream number so it is responsible for sudden removal of water after heavy rainfall. In whole basin stream numbers of 1st, 2nd, 3rd, 4th, 5th, 6th and 7th streams are 9611, 4539, 541, 122, 25, 3 and 1 respectively. The stream number of basin is sub-watershed wise given in (Table No1).

Stream Order	Stream Numbers											Whole Besin
	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	SW11	
1	4227	79	2272	102	2176	133	105	530	2042	1173	1293	9611
2	445	12	241	23	242	27	24	126	516	135	304	4539
3	105	4	63	5	59	6	4	28	102	56	78	541
4	29	1	16	1	16	1	1	5	22	13	21	122
5	3		5		4			1	5	4	5	25
6	1		1		1				1	1	1	3
7												1
Total stream number	4810	96	2598	131	2498	167	134	690	2688	1382	1702	14842

Table 1: Stream number for sub-watersheds of Indrayani river

Stream Length (Lu)

The stream length (Lu) has been computed based on the law proposed by Horton. Stream length is one of the most significant hydrological features of the basin as it revels surface runoff characteristics. The stream of relatively smaller length is characteristics of areas with larger slopes and finer textures. Longer lengths of stream are generally indicative of flatter gradient. The total length of stream segments is maximum in first order stream and decreases as stream order increases. The numbers of streams are of streams are various orders in a watershed are counted and their lengths from mouth to drainage divide are measured with the help of GIS software. The stream length of sub-watershed is given in table. The changes may indicate following of streams from high altitude, lithological variation and moderately steep slopes(Singh,1997). The observation of stream order verifies the Horton's law of stream number i.e. the number of stream segment of each other forms an inverse geometric sequence with order number.

Table 2: Stream length for Sub-watersheds of Indrayani river

STREAM LENGTH (Lu)											
Stream order	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	SW11	Whole basin
1	453.72	21.56	243.46	24.11	244.67	35.19	26.71	136.56	584.95	436.25	344.39	2613.40
2	237.86	15.13	131.93	10.05	145.62	14.77	14.71	63.36	232.93	135.14	145.14	1099.79
3	144.16	2.85	51.31	8.15	67.54	8.05	8.42	32.33	103.13	65.76	63.68	503.34
4	66.93	2.66	22.69	4.22	24.46	4.55	3.71	10.58	49.09	22.17	37.75	234.14
5	13.18		22.44		8.33			12.49	17.38	13.16	9.96	75.12
6	38.22		18.69		21.82				30.40	10.33	15.03	56.34
7												83.34
Total stream length	954.07	42.2	490.52	46.53	512.44	62.56	53.55	255.32	1017.88	682.81	615.95	4665.47

Mean stream Length (Lum)

The mean stream length is characteristics property related to the drainage network and its associated watershed surfaces (Strahler,1964). The mean stream length (Lum) has been calculated by dividing the total length of order by the number of stream. The mean stream length of stream increases with the increase of the order. The values of mean stream length of watershed given in Table No 3.

Stream Length Ratio (Lurm)

The stream length ratio can be defined as the ratio of the mean stream length of a given order to the mean stream length of next lower order has an important relationship with surface flow and discharge(Horton,1945). When stream length ratio increase from lower order to higher order indicates mature geographic stage of basin. The Lurm values between streams of different order in the basin revels that there are variations in slope and topography. Stream length ratio shows in (Table No3).

Table 3: Mean stream length ratio and stream length ratio for Sub-watersheds of Indrayani river

Stream length ratio (Lur)											
Stream order	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	SW11	Whole basin
2/1	4.98	4.62	5.11	1.85	5.35	2.07	2.41	1.95	1.58	2.69	1.79	0.89
3/2	2.57	0.57	1.49	3.73	1.90	2.45	3.43	2.30	2.24	1.17	1.71	3.84
4/3	1.68	3.73	1.74	2.59	1.34	3.39	1.76	1.83	2.21	1.45	2.20	2.06
5/4	1.90	0	3.16	0			0	5.90	1.56	1.93		1.57
6/5	0		0					0	0	0		6.25
7/6												4.44
Mean Stream Length Ratio	2.78	2.23	2.88	2.04	2.86	2.64	1.90	3.00	1.90	1.81	1.90	3.17

Bifurcation ratio (Rb)

Bifurcation ratio (Rb) may be defined as the ratio of the number of stream segments of given order to the number of segments of the next higher order(Schumn,1956). Horton (1945) considered the bifurcation ratio as an index of relief and disscetions. Strahler (1957) demonstrated that the bifurcation ratio shows a small range of variation for different regions or different environmental conditions, except where the geology dominates. Bifurcation ratio is dimensionless property. Lower value (<5) of bifurcation ratio indicate that watershed has less structural disterbances (Strahler, 1964) and drainage pattern has been not distorting (Nag, 1998). A higher value (>5) of bifurcation ratio indicates that strong structural control on the drainage pattern and lower values indicates that watershed is not affected by structural disturbance. The values of bifurcation ratio shows in (Table No 4).

Table 4: Bifurgation ratio of sub-watersheds for Indrayani river

Bifuegation Ratio (Rb)												
Stream order	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	SW11	Whole basin
1/2	9.50	6.58	9.43	4.43	8.99	4.93	4.38	4.21	3.96	8.69	4.25	2.12
2/3	4.24	3	3.83	4.6	4.10	4.5	6	4.50	5.06	2.41	3.90	8.39
3/4	3.62	4	3.94	5	3.69	6	4	5.6	4.64	4.31	3.71	4.43
4/5	9.67		3.2					5	4.4	3.25		4.88
5/6												8.33
6/7												3
mean bifurgation ratio	6.76	4.53	5.10	4.68	5.59	5.14	4.79	4.83	4.51	4.66	3.96	5.19

Weighted mean Bifurcation ratio (Rbwm)

Strahler (1953) used a weighted mean bifurcation ratio in order to arrive at a more representative bifurcation ratio by multiplying the bifurcation ratio of each successive pair of orders by total number of streams in this ratio and then calculated the mean of sum of these values. The obtained values of Rbwm is shown in below table.

Length of main channel (CI)

Length of main channel (CI) is the length along the longest watercourse from outflow point of watershed to the uppermost watershed boundary. The length of main channel (CI) is computed by using Arc GIS 10.8.1 software, obtained values of sub-watershed is given in table.

Channel Index (Ci) & Valley Index (Vi)

For the measurement of valley length, channel length and shortest distance between the mouth and source of river (Adm). Adm is used for the computation of channel index and valley index. The calculated Channel Index (Ci) &Valley Index (Vi) is gives in below table.

RHO Coefficient

RHO coefficient is calculated by dividing the stream length ratio to the bifurcation ratio. The relation between the drainage density and physiographic development of basin is determined by RHO coefficient (Horton, 1945). RHO coefficient is influenced by factors like climatic, biologic, anthropogenic and geomorphologic factors. The calculated value of RHO coefficient for this study area is shows in below table.

Table 5: Linear Aspects for sub-watersheds of Indrayani riaver basin

Sr. no	LINEAR ASPECT													
1		STREAM NUMBER (Nu)	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	SW11	Whole Besin
		1	4227	79	2272	102	2176	133	105	530	2042	1173	1293	9611
		2	445	12	241	23	242	27	24	126	516	135	304	4539
		3	105	4	63	5	59	6	4	28	102	56	78	541
		4	29	1	16	1	16	1	1	5	22	13	21	122
		5	3		5		4			1	5	4	5	25
		6	1		1		1				1	1	1	3
		7												1
	TOTAL		4810	96	2598	131	2498	167	134	690	2688	1382	1702	14842
2	STREAM LENGTH (Lu)	1	453.72	21.56	243.46	24.11	244.67	35.19	26.71	136.56	584.95	436.25	344.39	2613.40
		2	237.86	15.13	131.93	10.05	145.62	14.77	14.71	63.36	232.93	135.14	145.14	1099.79
		3	144.16	2.85	51.31	8.15	67.54	8.05	8.42	32.33	103.13	65.76	63.68	503.34
		4	66.93	2.66	22.69	4.22	24.46	4.55	3.71	10.58	49.09	22.17	37.75	234.14
		5	13.18		22.44		8.33			12.49	17.38	13.16	9.96	75.12
		6	38.22		18.69		21.82				30.40	10.33	15.03	56.34
		7												83.34
	Total		954.07	42.2	490.52	46.53	512.44	62.56	53.55	255.32	1017.88	682.81	615.95	4665.47
3	Mean Stream Length	1	0.11	0.27	0.11	0.24	0.11	0.26	0.25	0.26	0.29	0.37	0.27	0.27
		2	0.53	1.26	0.55	0.44	0.60	0.55	0.61	0.50	0.45	1.00	0.48	0.24
		3	1.37	0.71	0.81	1.63	1.14	1.34	2.11	1.15	1.01	1.17	0.82	0.93
		4	2.31	2.66	1.42	4.22	1.53	4.55	3.71	2.12	2.23	1.71	1.80	1.92
		5	4.39		4.49					12.49	3.48	3.29		3.00
		6												18.78
		7												83.34
4	stream length ratio (Lur)	2/1	4.98	4.62	5.11	1.85	5.35	2.07	2.41	1.95	1.58	2.69	1.79	0.89
		3/2	2.57	0.57	1.49	3.73	1.90	2.45	3.43	2.30	2.24	1.17	1.71	3.84
		4/3	1.68	3.73	1.74	2.59	1.34	3.39	1.76	1.83	2.21	1.45	2.20	2.06
		5/4	1.90	0	3.16	0			0	5.90	1.56	1.93		1.57
		6/5	0		0					0	0	0		6.25
		7/6												4.44
5	Mean Stream Length Ratio		2.78	2.23	2.88	2.04	2.86	2.64	1.90	3.00	1.90	1.81	1.90	3.17
6	Bifuegation Ratio (Rb)	1/2	9.50	6.58	9.43	4.43	8.99	4.93	4.38	4.21	3.96	8.69	4.25	2.12
		2/3	4.24	3	3.83	4.6	4.10	4.5	6	4.50	5.06	2.41	3.90	8.39
		3/4	3.62	4	3.94	5	3.69	6	4	5.6	4.64	4.31	3.71	4.43
		4/5	9.67		3.2					5	4.4	3.25		4.88
		5/6												8.33
		6/7												3
7	mean bifurgation ratio		6.76	4.53	5.10	4.68	5.59	5.14	4.79	4.83	4.51	4.66	3.96	5.19
8	Lur-r	2+1	691.58	36.69	375.39	34.16	390.29	49.96	41.42	199.92	817.88	571.39	489.53	3713.19
		3+2	382.02	17.98	183.24	18.2	213.16	22.82	23.13	95.69	336.06	200.9	208.82	1603.13
		4+3	211.09	5.51	74	12.37	92	12.6	12.13	42.91	152.22	87.93	101.43	737.48
		5+4	80.11	2.66	45.13	4.22	32.79	4.55	3.71	23.07	66.47	35.33	47.71	309.26
		6+5	51.4	0	41.13	0	30.15	0	0	12.49	47.78	23.49	24.99	131.46
		7+6												139.68

	total		1416.2	62.84	718.89	68.95	758.39	89.93	80.39	374.08	1420.41	919.04	872.48	6634.2
9	Lur*Lur-r	1												
		2	3443.88	169.51	1917.74	63.15	2088.68	103.29	99.80	390.17	1288.85	1537.96	877.49	3308.72
		3	981.25	10.16	272.62	67.89	405.52	55.97	79.44	219.72	752.71	235.67	357.08	6155.78
		4	354.84	20.57	128.85	32.03	122.86	42.73	21.38	78.64	335.94	127.70	223.33	1521.25
		5	152.50	0	142.82	0	0	0	0	136.17	103.55	68.16	0	484.20
	total		4932.47	200.24	2462.03	163.07	2617.06	201.99	200.62	824.70	2481.04	1969.49	1457.90	11469.95
10	Luwm		3.48	3.19	3.42	2.36	3.45	2.25	2.50	2.20	1.75	2.14	1.67	1.73
11	Nu-r	1												
		2	4672	91	2513	125	2418	160	129	656	2558	1308	1597	14150
		3	550	16	304	28	301	33	28	154	618	191	382	5080
		4	134	5	79	6	75	7	5	33	124	69	99	663
		5	32	1	21	1	20	1	1	6	27	17	26	147
	TOTAL		5388	113	2917	160	2814	201	163	849	3327	1585	2104	20040
12	Rb*Nu-r	1												
		2	44378.75	599.08	23691.02	554.35	21742.02	788.15	564.38	2759.37	10122.94	11365.07	6792.50	29961.59
		3	2330.95	48	1162.92	128.80	1234.61	148.50	168	693	3126.35	460.45	1488.82	42621.29
		4	485.17	20	311.06	30	276.56	42	20	184.8	574.91	297.23	367.71	2940.02
		5	309.33		67.2		0	0	0	30	118.8	55.25	0	717.36
	TOTAL		47504.2087		25232.2039		23253.1892	978.648148	752.375	3667.16508	13943	12177.9939	8649.03809	76240.26695
13	Rbwm		8.82		8.65		8.26	4.87	4.62	4.32	4.19	7.68	4.11	3.80
14	Rho Coefficient (Lur/Rb)		0.52	0.70	0.54	0.42	0.60	0.42	0.55	0.46	0.40	0.31	0.42	0.42
			0.61	0.19	0.39	0.81	0.46	0.55	0.57	0.51	0.44	0.49	0.44	0.46
			0.46	0.93	0.44	0.52	0.36	0.57	0.44	0.33	0.48	0.34	0.59	0.47
			0.20		0.99					1.18	0.35	0.59		
15	mean rho		0.45	0.61	0.59	0.58	0.47	0.51	0.52	0.62	0.42	0.43	0.48	0.45
16	Main Channel Length (Cl) km		40.82	5.68	21.28	6.21	22.34	7.63	6.74	15.13	38.73	18.8	24.03	106.84
17	Vally Length (Vl) Km		40.04	4.01	20.75	5.01	21.76	6.64	6.1	14.17	38.12	18.34	22.09	104.91
18	Maximum Areial Distance(Adm)		27.06	4.71	16.33	5.38	16.41	6.068	6.39	13.9	29.23	15.67	19.3	68.68
19	Channel index(Ci)		1.51	1.21	1.30	1.15	1.36	1.26	1.05	1.09	1.33	1.20	1.25	1.56
20	Valley index (Vi)		1.48	0.85	1.27	0.93	1.33	1.09	0.95	1.02	1.30	1.17	1.14	1.53

Areal Aspects

It deals with the total area projected upon a horizontal plane contributing overland flow to the channel segment of the given order and includes all tributaries of lower order. It comprises of drainage density, drainage texture, stream frequency, form factor, circularity ratio, elongation ratio and length of overland flow.

Length of basin (Lb)

Length in a straight line from the mouth of a stream to the farthest point on the drainage divide of its basin. Basin length is the longest dimesion of basin parallel to principal drainage line (Schumm,1956). Gregory and Walling (1973) defined as the basin length as the longest in the basin in which are end being the mouth. It is calculated according Schumm (1956) and its values shows in below table.

Basin area (A)

Area has the same importance like other parameter that is the total stream length. Schumm (1956) recognized a remarkable connection between the total watershed areas and the total stream lengths, which are supported by the contributing areas. Total area of the Indrayani river basin is 979.07 Sq. Km. and sub-watershed basin area given in below table.

Basin perimeter (P)

Basin perimeter is the outer boundary of the watershed that enclosed its area. It is measured along the divides between watershed and may be used as an indicator of watershed size and shape. The length of map line that encloses the catchment area of the drainage basin. The basin perimeter is computed by using ArcGIS 10.8.1 software, which is found to be whole basin is 515.74 Sq. Km. and Sub-watershed values shown in below table.

Length area relation (Lar)

Hack(1957) and Gray have both found that data on mainstream lengths and basin areas can be represented by the equation Lar= CA^n,where C is about 1.4 (measurements in miles), and n is about (0.6). this equation gives the relation between the stream length and basin area.

Lemniscate's (K)

For the determination of the slope of the basin Chorely(1967) gives a Lemnicate's value it is determined by using the formula K= Lb^2/4*A where Lb is basin length in km and A is the area of the basin im Sq. Km.

Form factor (Ff)

Form factor is the ratio of the basin area to the square of the basin length and used to predict the intensity of a basin of a defined range (Horton,1945; Sreedevi et al. 2013). It is also known as index as it is dimensionless form used to represent the different basin shapes (Horton, 1932). Ff varies between 0.1 to 0.8. Higher value of form factor indicates basin is circular and small value shows enlongated basin. The value of form factor should be always less than 0.78. Basin with high form factors experience larger peak flow of shoter duration, whereas elongated watersheds with low form factors experience lower peak flow of longer duration.

Elongation ratio (Re)

Schumm (1956) defined elongation ratio as the ratio of diameter of a circle of the same area as the drainage basin and the maximum length of basin. It is the dimension-less property. Values of Re generally vary from 0.6 to 1.0 over a wide variety of climatic and geologic types. The slope of watershed is classified with the help of elongation ratio, i.e elongated (0.5-0.7), less elongated (0.7-0.8), oval (0.8-0.9), circular (0.9-0.10). the elongation ratio of sub watershed basin values shows in below table.

Texture ratio (Rt)

Drainage texture ratio is the total number of stream segments of all orders per perimeter of that area (Horto, 1945). It depends upon a number of natural factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development. Obtained values of sub-watershed basin is given in below table.

Circulatory ratio (Rc)

Circulatory ratio is the ratio of the area of a basin to the area of circle having the same circumference as the perimeter of the basin (Miller, 1953). It is influenced by the length and frequency of streams, geological structures, land use/ land cover, climate and slope of the basin. The high value of circulatory ratio shows the late maturity stage of topography. The values varies from 0.4 to 0.6 of circulatory ratio according to Miller (1953). The obtained values given in below table.

Drainage texture (Dt)

Drainage texture is one of the important concept of geomorphology which means that the relative spacing of drainage lines. Drainage texture is on the underlying lithology, infiltration capacity and relief aspect of the terrain. Dt is total number of streams segments of all orders per perimeter of that area Horton (1945). (Smith, 1950) has classified drainage texture ratio into the five different textures i.e., very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8) and very fine (>8). In the present study the drainage texture of the sub-watershed is given in below table.

Compactness coefficient (Cc)

Compactness coefficient is calculated by dividing the perimeter of watershed to circumference of circular area, which is equal to the area of watershed (Gravelius, 1944). Compactness coefficient depends only on the slope but not on the size of watershed. The present study area basin Cc is found is given in below table.

Fitness ratio (Rf)

Fitness ratio is the ratio of the main channel length to the length of watershed perimeter. Which is measure of topographic fitness (Melton, 1957). The fitness ratio obtained is given below table.

Wandering ratio (Rw)

Wandering ratio (Rw) is the ratio of the mainstream length to the valley length (Smart and Surkan,1967). The straight line distance between outlet of basin and remost point on the ridge is called valley length. In this study the values of wandering ratio is shows in table.

Watershed Eccentricity (τ)

The expression for watershed eccentricity, which is: $\tau=[(|Lcm2-Wcm2|)]0.5/Wcm$ where τ= watershed eccentricity, Lcm= Straight length from the mouth to the center of mass of the watershed, and Wcm= width of watershed at the center of mass and perpendicular to Lcm. The watershed eccentricity is dimensionless property. For given watershed the watershed eccentricity is given below table.

Center of Gravity of watershed (Gc)

Center of Gravity of watershed (Gc) is calculated by measuring the length from the outlet of watershed to a point on stream nearest to the center of watershed. The center of Gravity of watershed calculated by using the ArcGIS 10.8.1 software, which is latitude and longitude given table.

Sinuosity Index (Si)

Sinuosity index (Si) is the ratio of channel length to down valley distance. In general, its value ranges from 1 to 4 or more. If sinuosity of any river is 1.5 then it is identified as sinuous, and above 1.5 is known as meandering (Miller,1953). The 'Si' is substantial quantitative index for studying the significance of drainage in the development of land forms and valuable for geomorphologists, hydrologists and geologists. The sinuosity index is given in table.

Stream frequency (Fs)

The stream frequency (Fs) is the number of stream segments per unit area (Horton,1932, 1945). Stream frequency is also known as channel frequency. It exhibits positive correlation with drainage density in the watershed indicating an increase in stream population with respect to increase in drainage density. Obtained values is shown in table.

Drainage density (Dd)

Horton (1932), introduced the drainage density is an important indicator of the linear scale of land form elements in stream eroded topography. It is the ratio of total channel segment length cumulated for all order within a basin to the basin area, which is expressed in terms of km/sq.km. The stream length per unit area in region of watershed is called drainage density. The drainage density, indicates closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole basin. The drainage density is calculated by using Spatial analyst tool in ArcGIS 10.8.1. the range for Dd are vary from very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8) and very fine (>8). The sub-watershed basin has found Dd is shows in below table.

Infiltration Number (If)

Infiltration number is the product of drainage density (Dd) and stream frequency (Fs) i.e., If =Dd*Fs. Higher value infiltration number means lower the infiltration capacity and higher runoff (Horto,1964). The infiltration number found in sub-watershed is given in table.

Drainage pattern (Dp)

Drainage pattern (Dp) helps in identifying the stage of erosion. In drainage pattern influence of slope, lithology and structure reflects. The study area has dendritic and radial pattern. Howard (1967) related drainage patterns to geological information.

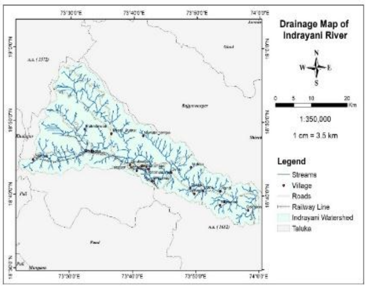

Figure 4: Drainage Map of Indrayani River

Length of overland flow (Lg)

The length of Overland flow(Lg) is the length of water over the ground surface before it gets concentrated into definite stream channel (Horton,1945). Lg is one of the most important independent variables affecting hydrologic and physiographic development of drainage basins. The length of overland flow is approximately equal to the half of the reciprocal of drainage density. This factor is related inversely to the average slope of the channel and is quiet synonymous with the length of sheet flow to a large degree. The Lg is obtained values is given in table.

Constant channel maintenance (C)

Schumm (1956) used the inverse of drainage density as a property termed constant of stream maintenance C. this constant, in units of square feet per foot, has the dimension of length and therefore increases in magnitude as the scale of the land-form unit increases. Specifically the constant C provides information of the number of square feet of watershed surface required to sustain one linear foot of stream. The value Cof is given in below table.

Table 6: Areal Aspects for Sub-watersheds of Indrayani river basin

Sr. No.	AREAL ASPECTS													
			SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	SW11	Whole Besin
21	Length from W's Center to Mouth of W's (Lcm) Kms		11.19	1.91	7.26	2.89	6.85	3.35	3.59	6.68	15.53	8.25	8.47	37.82
22	Width of W's at the Center of Mass (Wcm) Kms		9.83	2.42	9.48	2.97	7.58	2.82	2.77	4.44	9.02	8.86	9	12.09
23	Basin Length (Lb) Kms		26.94	4.39	18.25	5.02	18.80	5.83	5.50	12.73	28.09	19.72	20.37	65.57
24	Lb in Meters		26935.38	4388.71	18249.43	5023.48	18800.59	5833.39	5499.54	12727.69	28086.47	19718.20	20373.12	65571.53
25	Mean Basin Width (Wb)		7.59	1.91	5.64	2.12	5.77	2.37	2.27	4.29	7.84	5.99	6.14	14.93
26	AREA		204.43	8.38	103.01	10.63	108.55	13.83	12.467	54.62	220.06	118.05	125.04	979.067
27	PERIMETER		102.583	15.07	50.26	17.37	61.27	19.02	17.26	38.61	80.92	52.84	60.53	515.733
28	Relative Perimeter (Pr)		1.99	0.56	2.05	0.61	1.77	0.73	0.72	1.41	2.72	2.23	2.07	1.90
29	Length Area Relation (Lar)		34.08	5.01	22.59	5.78	23.31	6.77	6.36	15.44	35.62	24.51	25.37	87.22
30	Lemniscate's (k)		3.55	2.30	3.23	2.37	3.26	2.46	2.43	2.97	3.58	3.29	3.32	4.39
31	Form Factor Ratio (Rf)		0.28	0.44	0.31	0.42	0.31	0.41	0.41	0.34	0.28	0.30	0.30	0.23
32	Shape Factor Ratio (Rs)		3.55	2.30	3.23	2.37	3.26	2.46	2.43	2.97	3.58	3.29	3.32	4.39
33	Elongation Ratio (Re)		0.60	0.74	0.63	0.73	0.63	0.72	0.72	0.66	0.60	0.62	0.62	0.54
34	Elipticity Index (Ie)		6.16	1.51	3.28	1.85	3.42	2.50	2.34	2.89	5.18	2.24	3.06	8.82
35	Texture Ratio (Rt)		41.21	5.24	45.20	5.87	35.51	6.99	6.08	13.73	25.23	22.20	21.36	18.64
36	Circularity Ratio (Rc)		0.24	0.46	0.51	0.44	0.36	0.48	0.53	0.46	0.42	0.53	0.43	0.05
37	Circularity Ration (Rcn)		1.99	0.56	2.05	0.61	1.77	0.73	0.72	1.41	2.72	2.23	2.07	1.90
38	Drainage		46.89	6.37	51.69	7.54	40.77	8.78	7.76	17.87	33.22	26.15	28.12	28.78

	Texture (Dt)													
39	Compactness Coefficient (Cc)		0.00	0.06	0.00	0.04	0.00	0.03	0.03	0.00	0.00	0.00	0.00	0.00
40	Fitness Ratio (Rf)		0.40	0.38	0.42	0.36	0.36	0.40	0.39	0.39	0.48	0.36	0.40	0.21
41	Wandering Ratio (Rw)		1.52	1.29	1.17	1.24	1.19	1.31	1.23	1.19	1.38	0.95	1.18	1.63
42	Watershed Eccentricity (τ)		0.54					0.64	0.82	1.12			0.36	
43	Centre of Gravity OF the Watershed (Gc)		73.53E & 18.40N	73.57 E & 18.40 N	73.35E & 18.45N	73.52 E & 18.38 N	73.42E & 18.43N	73.48 E & 18.45 N	73.46 E & 18.45 N	73.43E & 18.46N	73.33E & 18.52N	73.29E & 18.49N	73.27E & 18.45N	73.39E &18.46N
44	Hydraulic Sinuosity Index (Hsi) %		1.96	35.68	2.61	23.03	2.72	14.93	11.15	6.79	1.62	2.58	8.42	1.82
45	Topographic Sinuosity Index (Tsi) %		98.04	64.32	97.39	76.97	97.28	85.07	88.85	93.21	98.38	97.42	91.58	98.18
46	Standard Sinuosity Index (Ssi)		1.02	1.42	1.03	1.24	1.03	1.15	1.10	1.07	1.02	1.03	1.09	1.02
47	Longest Dimension Parallel to the Principal Drainage Line (Clp) Kms		40.04	4.01	20.75	5.01	21.76	6.64	6.1	14.17	38.12	18.34	22.09	104.91
48	Stream Frequency (Fs)		23.53	11.46	25.22	12.32	23.01	12.08	10.75	12.63	12.21	11.71	13.61	15.16
49	Drainage Density (Dd) Km / Kms2		4.67	5.04	4.76	4.38	4.72	4.52	4.30	4.67	4.63	5.78	4.93	4.77
50	Constant of Channel Maintenance (Kms2 / Km)		0.21	0.20	0.21	0.23	0.21	0.22	0.23	0.21	0.22	0.17	0.20	0.21
51	Drainage Intensity (Di)		5.04	2.27	5.30	2.82	4.87	2.67	2.50	2.70	2.64	2.02	2.76	3.18
52	Infiltration Number (If)		109.81	57.69	120.10	53.94	108.64	54.62	46.17	59.05	56.50	67.71	67.05	72.24
53	Drainage Pattern (Dp)													
54	Length of Overland Flow (Lg) Kms		0.11	0.10	0.11	0.11	0.11	0.11	0.12	0.11	0.11	0.09	0.10	0.10

Relief Aspect

The relief refers to the relative height of points on surface and lines with respect to the horizontal base of reference. Relief expresses the magnitude of the vertical dimension of the landforms. The relief aspect includes relief ratio, relative relief, ruggedness number, average slope of overall basin and channel gradient. The above mentioned Linear and Areal features is considered as the one and two dimensional aspects a river basin mainly deals with the length and width related parameters. Beside these two parameters there are one more important aspects which is related to the height/elevation of the basin. This third dimension is the concept of relief. It plays an important role in determining basin drainage systems - the effectiveness of erosion, transportation, and deposition, total energy of a river etc. Relief aspect is represented by following parameters

Maximum basin relief (H)

Maximum basin relief (H) is the elevation difference between the highest point in the catchment and the catchment outlet. Maximum basin relief is calculated by the formula H=Z-z where Z= maximum elevation of catchment area, z=elevation of the catchment outlet. The basin relief is found in whole basin is 599m. and sub-watershed basin values of maximum basin relief is shown in below table.

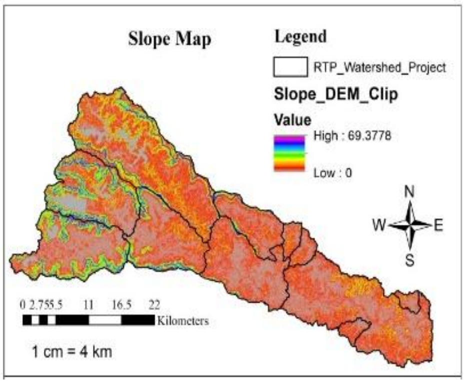

Figure No 5: Slope Map of Indrayani River

Relief ratio (Rhl)

The relief ratio (Rhl) is ratio of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line (Schumm,1956). The Rhl normally increases with decreasing drainage area and size of watersheds of given drainage basin (Gottschalk, 1964). Relief ratio measures the overall steepness of drainage basin and is an indicator of the intensity of erosion process operating on slope of the basin (Schumm,1956). The elevation difference between the highest point and lowest point of watershed on the valley floor is the total relief of river basin. In this present study obtained values of relief ratio is given in below table. Relief ratio is directly proportional to the surface run-off and intensity of erosion. The high values of Rr indicate steep slope and high relief and vice-versa. Relief controls the rate of conversion of potential to kinetic energy of water draining through the basin. Run-off is generally faster in steeper basins, producing more peak discharges and greater erosive power.

Relative relief (Rhp)

The maximum basin relief is calculated from the highest point on the basin perimeter to the mouth of stream. Using the basin relief, a 'Rhp' was computed as proposed by Schumm (1956). Relative relief is calculated by using the formula given by the Melton (1957) is Rhp =H*100/P, where P is perimeter in meter & His total basin relief. In present study area it is obtained by visual analysis of the digital elevation model prepared from SRTM data.

Absolute relief (Ra)

Absolute relief is the difference between the given location and the sea level.the absolute relief is calculated by using ArcGIS 10.8.1 and obtained values of sub-watershed is shows in below table.

Channel gradient (Cg)

Channel gradient (Cg) m/kms is calculated by using the formula given by the Broscoe (1959) is Cg=H/ {(π/2) * Clp} where H is total basin relief and Clp is the longest dimension parallel to the principal drainage line (Clp) kms. Channel Gradient is the total drop in elevation from the source to the mouth of the trunk channels in each drainage basin. It is a dimensionless measurement. In general, river channel exhibits high gradient in their upper course or in their youth stage while low channel gradient is found in their lower course. The higher Rg values represent higher channel slope associated with steep V-shaped valleys. Channel gradient is actually the outcome of interaction between stream power and lithological characteristics of the basin. It is expressed as –

□□ = □□ − □□ □□

Where, Rg is Gradient ratio, Es is elevation at the source, and Em is elevation at the mouth.

Raggedness Number (Rn)

It is the product of maximum basin relief (H) and drainage density (Dd), where both parameters are in the same unit. An extreme high value of ruggedness number occurs when both variable are large and slope is steep (Strahler, 1956). The surface unevenness or roughness is measured by the ruggedness number(Rn). The obtained values of ruggedness number for various sub-watershed is given in table.

Melton Ruggedness number (MRn)

The MRn is a slope index that delivers specialized depiction of relief ruggedness within the basin (Melton,1957). The 'MRn' of the basin is given in below table. The slope index that gives special representation of the relief ruggedness within the watershed is called Melton Ruggedness number(MRn).

Gradient ratio (Rg)

It is the indicator of the channel slope, which enables assessment of the runoff volume (Sreedevi 2004). The gradient values found in present study is given in table.

Gradient & Channel slope (Sgc)

The steepness of slope is the gradient expressed as a variation between its vertical intervals (Vei) reduced to unity and its horizontal equivalent (Hoe). Gradient is calculated by using the formula Sgc= Vei/Hoe.

Slope analysis (Sa)

Slope is demarcated by a plane tangent to the topographic surface. Slope of the basin is acquired from SRTM DEM which is important feature of the earth's surface system. Maximum slope line is noticeable in the direction of the channel reaching downwards on the ground surface. Slope analysis (Sa) is calculated by ArcGIS 10.8.1. It is the average slope in the degree. The values shown in table.

Average slope of overall basin (S)

Erodibility of a river basin can be calculated and equated from its average slope. More the percentage of slopes more are its erosion, if all other things are kept constant. Erodibility of watershed studied by using the average slope (Wenthworth, 1930). The slope of watershed computed by using the formula S= [z* (Ctl/H)] / (10*A). The values shown in table.

Mean slope of overall basin (ϴs)

Mean slope of overall basin was computed after (Chorley,1979) but slightly modified as ϴs=ΣCtl*Cin/A. where ϴs= mean slope of overall basin, Ctl= total length of contour in the watershed, Cin= contour interval, and A= area of the watershed. The obtained value of mean slope of overall basin given in below table.

Table 7: Relief Aspects for sub-watersheds of Indrayani river basin

Sr. No.	Relief Aspect												
		SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	SW11	Whole Besin
55	Height of Basin Mouth (z) m	540	546	580	558	564	569	571	571	581	603	603	540
56	Maximum Height of the Basin (Z) m	757	644	1139	747	888	782	786	1110	1134	1039	1081	1139
57	Total Basin Relief (H) m	217	98	559	189	324	213	215	539	553	436	478	599
58	H in kilometer	0.22	0.10	0.56	0.19	0.32	0.21	0.22	0.54	0.55	0.44	0.48	0.60
59	Relief Ratio (Rhl)	0.01	0.02	0.03	0.04	0.02	0.04	0.04	0.04	0.02	0.02	0.02	0.01
60	Absolute Relief (Ra) m	757	644	1139	747	888	782	786	1110	1134	1039	1081	1139
61	Relative Relief Ratio (Rhp)	0.21	0.65	1.11	1.09	0.53	1.12	1.25	1.40	0.68	0.83	0.79	0.12
62	Dissection Index (Dis)	0.29	0.15	0.49	0.25	0.36	0.27	0.27	0.49	0.49	0.42	0.44	0.53
63	Channel Gradient (Cg) m / Kms	3.45	15.57	17.16	24.03	9.48	20.43	22.45	24.23	9.24	15.14	13.78	3.64
64	Gradient Ratio (Rg)	0.01	0.02	0.03	0.04	0.02	0.04	0.04	0.04	0.02	0.02	0.02	0.01
65	Watershed Slope (Sw)	0.01	0.02	0.03	0.04	0.02	0.04	0.04	0.04	0.02	0.02	0.02	0.01
66	Ruggedness Number (Rn)	1.01	0.49	2.66	0.83	1.53	0.96	0.92	2.52	2.56	2.52	2.35	2.85
67	Melton Ruggedness Number (MRn)	15.18	33.85	55.08	57.97	31.10	57.28	60.89	72.93	37.28	40.13	42.75	19.14
68	Total Contour Length (Ctl) Kms	692.96	34.45	591.46	30.31	362.73	44.77	42.33	307.24	1726.04	1110.87	1013.12	5960.9
69	Contour Interval (Cin) m	20M	20M	20M	20M	20M	20M	20M	20M	20M	20M	20M	20M
70	Slope Analysis (Sa)	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.01
71	Average Slope (S) %	1.18	2.70	1.17	1.13	0.92	1.19	1.24	1.16	1.61	2.24	1.83	1.16
72	Mean Slope of Overall Basin (ϴs)	0.34	0.41	0.57	0.29	0.33	0.32	0.34	0.56	0.78	0.94	0.81	0.61
73	Relative Height (h/H)	IN Hypso metric table	IN Hypso metric table	IN Hypso metric table	IN Hypso metric table	IN Hypso metric table	IN Hypso metric table	IN Hypso metric table	IN Hypso metric table	IN Hypso metric table	IN Hypso metric table	IN Hypso metric table	IN Hypso metric table
74	Relative Area (a/A)	IN Hypso metric table	IN Hypso metric table	IN Hypso metric table	IN Hypso metric table	IN Hypso metric table	IN Hypso metric table	IN Hypso metric table	IN Hypso metric table	IN Hypso metric table	IN Hypso metric table	IN Hypso metric table	IN Hypso metric table
75	Surface Area of Relief (Rsa) Sq Kms	204.43	8.38	103.01	10.63	108.55	13.83	12.47	54.62	220.06	118.05	125.04	979.07
76	Composite Profile area (Acp) sq.km.	204.43	8.38	103.01	10.63	108.55	13.83	12.47	54.62	220.06	118.05	125.04	979.07

Hypsometric Analysis (Hs)

The value of integral and the form of hypsometric curve both are important elements in the topographic form. It shows the variation in regions differ in geologic structure and the stage of development. The starting of hypsometric curve is large and it decreases at the stage of maturity and old age (Strahler,1952). The values of hypsometric analysis is given in Table 8.

Table 8: Hypsometric calculations for sub-watersheds of Indrayani River

SW1	Value	area km2	AREA	MIN	MAX	RANGE	a	a/A	h	h/H
	1	2.19	2189874.734	540	550	10	204.42	1.00	10	0.05
	2	146.84	146839313	551	600	49	202.23	0.99	59	0.28
	3	51.38	51379023.51	601	650	49	55.39	0.27	108	0.51
	4	3.89	3891589.893	651	700	49	4.01	0.02	157	0.74
	5	0.10	102194.1543	701	750	49	0.12	0.00	206	0.97
	6	0.01	13686.71709	751	757	6	0.01	0.00	212	1.00
SW2	Value	area km2	AREA	MIN	MAX	RANGE	a	a/A	h	h/H
	1	1.10	1097022.735	546	560	14	8.37	1.00	14	0.15
	2	5.94	5939776.75	561	600	39	7.28	0.87	53	0.56
	3	1.33	1328454.441	601	640	39	1.34	0.16	92	0.97
	4	0.01	7289.187605	641	644	3	0.01	0.00	95	1.00
SW3	Value	area km2	AREA	MIN	MAX	RANGE	a	a/A	h	h/H
	1	5.55	5554325.167	580	600	20	102.99	1.00	20	0.04
	2	70.46	70458727.1	601	650	49	97.43	0.95	69	0.13
	3	13.01	13014348.99	651	700	49	26.98	0.26	118	0.22
	4	4.17	4168944.425	701	750	49	13.96	0.14	167	0.30
	5	2.43	2432417.673	751	800	49	9.79	0.10	216	0.39
	6	2.42	2419615.474	801	850	49	7.36	0.07	265	0.48
	7	2.09	2089501.647	851	900	49	4.94	0.05	314	0.57
	8	1.73	1728296.767	901	950	49	2.85	0.03	363	0.66
	9	0.54	535863.4422	951	1000	49	1.12	0.01	412	0.75
	10	0.31	307252.7586	1001	1050	49	0.59	0.01	461	0.84
	11	0.21	213065.157	1051	1100	49	0.28	0.00	510	0.93
	12	0.07	65839.87685	1101	1139	38	0.07	0.00	548	1.00
SW4	Value	area km2	AREA	MIN	MAX	RANGE	a	a/A	h	h/H
	1	5.00	5004535.658	558	590	32	10.62	1.00	32	0.18
	2	5.54	5540931.386	591	640	49	5.61	0.53	81	0.45
	3	0.05	45611.88168	641	689	48	0.07	0.01	129	0.71
	4	0.02	19156.99031	691	738	47	0.03	0.00	176	0.97
	5	0.01	7297.901068	741	747	6	0.01	0.00	182	1.00
SW5	Value	area km2	AREA	MIN	MAX	RANGE	a	a/A	h	h/H
	1	54.36	54363872.55	564	600	36	108.55	1.00	36	0.11
	2	45.80	45795966.22	601	650	49	54.18	0.50	85	0.27
	3	6.52	6524797.23	651	700	49	8.39	0.08	134	0.42
	4	1.09	1090510.623	701	750	49	1.86	0.02	183	0.58
	5	0.54	537035.3823	751	800	49	0.77	0.01	232	0.73
	6	0.21	212804.8369	801	850	49	0.23	0.00	281	0.89
	7	0.02	20093.16056	852	888	36	0.02	0.00	317	1.00
SW6	Value	area km2	AREA	MIN	MAX	RANGE	a	a/A	h	h/H
	1	0.98	981004.544	569	600	31	13.83	1.00	31	0.15
	2	9.09	9085470.921	601	650	49	12.85	0.93	80	0.39
	3	3.67	3673063.525	651	700	49	3.76	0.27	129	0.63
	4	0.06	63879.36566	701	750	49	0.09	0.01	178	0.86
	5	0.02	23726.62153	754	782	28	0.02	0.00	206	1.00
SW7	Value	area km2	AREA	MIN	MAX	RANGE	a	a/A	h	h/H
	1	0.11	110639.1019	571	580	9	12.44	1.00	9	0.04
	2	3.56	3563310.578	581	630	49	12.33	0.99	58	0.28
	3	7.63	7627697.42	631	680	49	8.77	0.70	107	0.51
	4	1.04	1035069.945	681	730	49	1.14	0.09	156	0.75
	5	0.11	105152.8654	731	780	49	0.11	0.01	205	0.98
	6	0.00	2743.118228	782	786	4	0.00	0.00	209	1.00
SW8	Value	area km2	AREA	MIN	MAX	RANGE	a	a/A	h	h/H
	1	3.64	3636752.554	571	600	29	54.64	1.00	29	0.05
	2	17.84	17838622.81	601	650	49	51.00	0.93	78	0.15
	3	23.31	23306078.07	651	700	49	33.17	0.61	127	0.24
	4	4.54	4541603.616	701	750	49	9.86	0.18	176	0.33
	5	1.54	1544912.207	751	800	49	5.32	0.10	225	0.43
	6	0.83	830892.4992	801	850	49	3.77	0.07	274	0.52
	7	0.56	561537.2385	851	900	49	2.94	0.05	323	0.61
	8	0.63	630930.4582	901	950	49	2.38	0.04	372	0.70
	9	0.96	955982.9084	951	1000	49	1.75	0.03	421	0.80
	10	0.48	483013.3319	1001	1050	49	0.79	0.01	470	0.89
	11	0.30	296747.3211	1051	1100	49	0.31	0.01	519	0.98

	12	0.01	13696.03021	1101	1110	9	0.01	0.00	528	1.00
SW9	Value	area km2	AREA	MIN	MAX	RANGE	a	a/A	h	h/H
	1	3.54	3543271.257	581	600	19	220.03	1.00	19	0.04
	2	35.57	35566213.88	601	650	49	216.49	0.98	68	0.13
	3	103.42	103418715.5	651	700	49	180.92	0.82	117	0.22
	4	32.63	32627356.12	701	750	49	77.50	0.35	166	0.31
	5	10.61	10607868.35	751	800	49	44.88	0.20	215	0.40
	6	5.73	5725011.958	801	850	49	34.27	0.16	264	0.49
	7	5.04	5044703.877	851	900	49	28.54	0.13	313	0.58
	8	5.72	5719525.603	901	950	49	23.50	0.11	362	0.67
	9	10.79	10786174.9	951	1000	49	17.78	0.08	411	0.76
	10	5.35	5346453.429	1001	1050	49	6.99	0.03	460	0.85
	11	1.54	1544409.072	1051	1100	49	1.65	0.01	509	0.94
	12	0.10	101497.5766	1101	1134	33	0.10	0.00	542	1.00
SW10	Value	area km2	AREA	MIN	MAX	RANGE	a	a/A	h	h/H
	1	44.17	44173123.44	603	650	47	118.01	1.00	47	0.11
	2	24.64	24643885.61	651	700	49	73.84	0.63	96	0.22
	3	8.16	8159080.984	701	750	49	49.20	0.42	145	0.34
	4	6.95	6948632.655	751	800	49	41.04	0.35	194	0.45
	5	7.25	7245293.214	801	850	49	34.09	0.29	243	0.57
	6	7.66	7660068.624	851	900	49	26.84	0.23	292	0.68
	7	9.01	9009691.043	901	950	49	19.18	0.16	341	0.80
	8	9.89	9889600.91	951	1000	49	10.17	0.09	390	0.91
	9	0.28	282926.2736	1001	1039	38	0.28	0.00	428	1.00
SW11	Value	area km2	AREA	MIN	MAX	RANGE	a	a/A	h	h/H
	1	80.29	80287410.29	603	650	47	125.02	1.00	47	0.10
	2	13.43	13431300.42	651	700	49	44.73	0.36	96	0.20
	3	8.90	8896938.965	701	750	49	31.30	0.25	145	0.31
	4	7.80	7798256.57	751	800	49	22.40	0.18	194	0.41
	5	6.71	6712435.005	801	850	49	14.60	0.12	243	0.52
	6	4.32	4316645.968	851	900	49	7.89	0.06	292	0.62
	7	2.66	2657598.805	901	950	49	3.57	0.03	341	0.73
	8	0.40	403278.9061	951	1000	49	0.91	0.01	390	0.83
	9	0.46	456559.4905	1001	1050	49	0.51	0.00	439	0.94
	10	0.06	55117.84594	1051	1081	30	0.06	0.00	469	1.00
Basin	Value	area km2	AREA	MIN	MAX	RANGE	a	a/A	h	h/H
	1	2.20	2204557.161	540	550	10	981.70	1.00	10	0.02
	2	230.74	230743649.5	551	600	49	979.50	1.00	59	0.10
	3	366.12	366116637.2	601	650	49	748.75	0.76	108	0.18
	4	197.70	197704576.4	651	700	49	382.64	0.39	157	0.27
	5	60.34	60343918.31	701	750	49	184.93	0.19	206	0.35
	6	30.08	30075870.11	751	800	49	124.59	0.13	255	0.43
	7	23.19	23189488.78	801	850	49	94.51	0.10	304	0.52
	8	19.54	19539935.45	851	900	49	71.32	0.07	353	0.60
	9	19.85	19845590.12	901	950	49	51.78	0.05	402	0.68
	10	22.70	22696231.7	951	1000	49	31.94	0.03	451	0.77
	11	6.95	6954101.232	1001	1050	49	9.24	0.01	500	0.85
	12	2.10	2102977.317	1051	1100	49	2.29	0.00	549	0.94
	13	0.18	184857.0139	1101	1139	38	0.18	0.00	587	1.00

Hypsometric Curve:

The value of integral and the form of hypsometric curve both area important elements in the topographic form. It shows the variation in regions differ in geologic structure and stage of development. The starting of hypsometric curve is large and it decreases at the stage maturity and old stage (Srahler,1952)

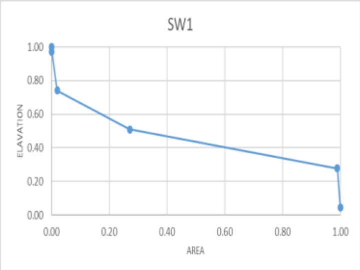

Fig. No. 6 Hypsometric curve of SW1

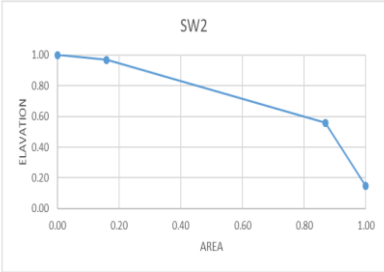

Fig. No. 7 Hypsometric curve of SW2

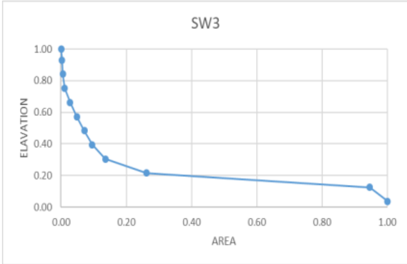

Fig. No. 8 Hypsometric curve of SW3

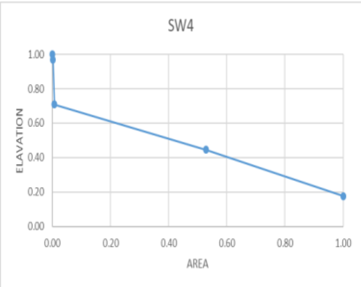

Fig. No. 9 Hypsometric curve of SW4

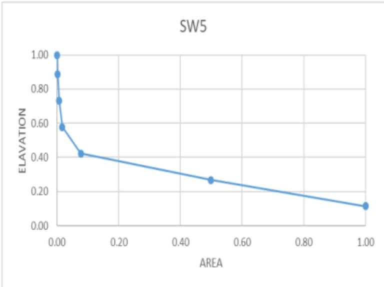

Fig. No. 10Hypsometric curve of SW5

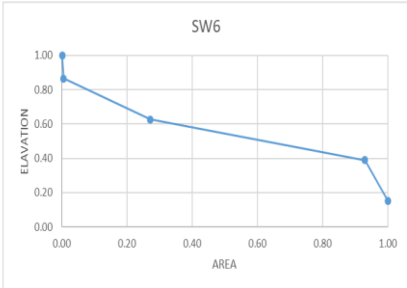

Fig. No. 11 Hypsometric curve of SW6

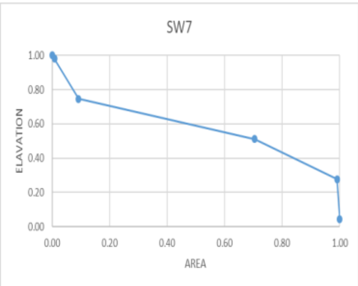

Fig. No. 12 Hypsometric curve of SW7

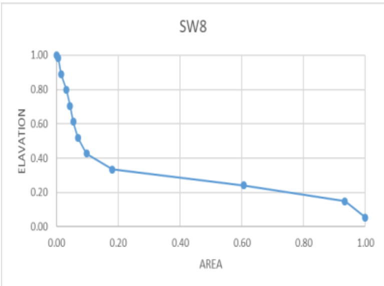

Fig. No. 13 Hypsometric curve of SW8

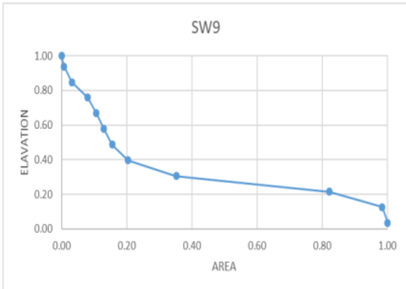

Fig. No. 14 Hypsometric curve of SW9

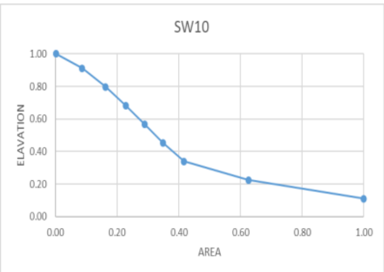

Fig. No. 15 Hypsometric curve of SW10

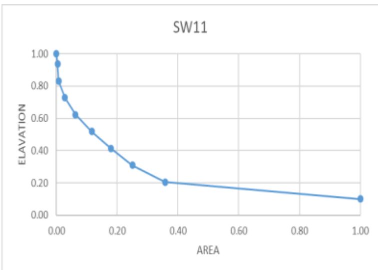

Fig. No. 16 Hypsometric curve of SW11

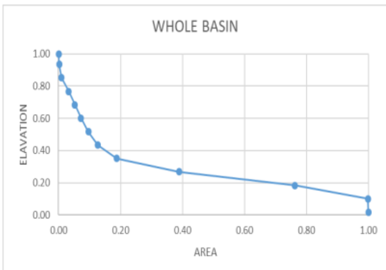

Fig. No. 17 Hypsometric curve of Whole basin

Prioritization

The evaluated morphometric parameters were grouped as linear, relief and areal parameters. Visual interpretation techniques were followed for delineation of geology, landforms, and soil boundaries and degraded lands based on the tone, texture, shape, drainage pattern, color and differential erosion characteristics of the satellite imagery in conjunction with drainage morphometry. The stream ordering is carried out using Strahler's law. The fundamental parameters namely; stream length, area, perimeter and number of streams are derived from the sub watershed layer and basin length was calculated from the stream length. Bifurcation ratio was calculated from the number of streams. The other parameters were calculated from area, perimeter, basin length and stream length. The linear parameters such as drainage density, stream frequency, bifurcation ratio, drainage texture, length of overland flow. Hence for prioritization of sub-watersheds, the Lowest value of parameters was rated as rank 1, second lower value was rated as rank 2 and so on, and the least value was rated as last in rank.

The highest value was rated last in rank. Hence, the ranking of the sub-watersheds has been determined by assigning the highest priority/rank based on highest value in case of all parameters. The prioritization was carried out by assigning ranks to the individual indicators and a compound value (Cp) was calculated. Sub-watersheds with highest Cp were of low priority while those with lowest Cp were of high priority Table 9. Thus an index of high, medium and low priority was produced. Sub-watersheds have been broadly classified into three priority zones according to their compound value (Cp). High (8-12), Medium (4-8) and Low (1-4)

Table 9: Compound value of morphometric parameters and final priority of sub-watersheds

Sr No	Parameters	SW 1		SW 2		SW 3		SW 4		SW 5		SW 6		SW 7		SW 8		SW 9		SW 10		SW 11	
1	Bifurgation Ratio (Rb)	6.76	1	4.53	8	5.10	4	4.68	6	5.59	2	5.14	3	4.19	10	4.83	5	4.51	9	4.66	7	3.96	11
2	stream fequency (Fs)	23.53	2	11.46	10	25.22	1	12.32	6	23.01	3	12.08	8	10.75	11	12.63	5	12.21	7	11.71	9	13.61	4
3	Drainage Texture (Dt)	46.89	2	6.37	11	51.69	1	7.54	10	40.77	3	8.78	8	7.76	9	17.87	7	33.22	4	26.15	6	28.12	5
4	Form Factor (Rf)	0.28	2	0.44	11	0.31	6	0.42	10	0.31	5	0.41	8	0.41	9	0.34	7	0.28	1	0.30	4	0.30	3
5	Circularotory Ratio (Rc)	0.24	1	0.46	7	0.51	9	0.44	5	0.36	2	0.48	8	0.53	10	0.46	6	0.42	3	0.53	11	0.43	4
6	Elongation Ratio (Re)	0.60	2	0.74	11	0.63	6	0.73	10	0.63	5	0.72	8	0.72	9	0.66	7	0.60	1	0.62	4	0.62	3
7	Compactness Coefficient (Cc)	0.00	2	0.06	11	0.00	5	0.04	10	0.00	6	0.03	8	0.03	9	0.00	7	0.00	1	0.00	3	0.00	4
8	Shape Factor (Rs)	3.55		2.30		3.23		2.38		3.26		2.46		2.43		2.97		3.58		3.29		3.32	
9	Length Of Overland Flow (Lg)	0.11	5	0.10	10	0.11	8	0.11	2	0.11	7	0.11	3	0.12	1	0.11	6	0.11	4	0.09	11	0.10	9
10	Drainage Density (Dd)	4.67	8	5.04	3	4.76	5	4.38	10	4.72	6	5.52	2	4.30	11	4.67	7	4.63	9	5.78	1	4.93	4
11	Stream Length Ratio (Lur)	2.78	4	2.23	6	2.88	2	2.04	7	2.86	3	2.64	5	1.90	8	3.00	1	1.90	9	1.81	10	0.90	11
12	Drainage Intensity (Di)	5.04	2	2.27	9	5.30	1	2.82	4	4.87	3	2.67	6	2.50	8	2.70	5	2.64	7	2.02	10	0.76	11
13	Infiltration No (If)	109.81	2	57.69	7	120.10	1	53.94	10	108.64	3	54.62	9	46.20	11	59.05	6	56.50	8	67.71	4	67.05	5
14	Rugdness No (Rl)	1.01	7	0.49	11	2.66	2	0.83	10	1.53	6	0.96	8	0.92	9	3.52	1	2.56	3	2.52	4	2.35	5
15	Relief Ratio (Rhl)	0.01	11	0.02	7	0.03	5	0.04	2	0.02	10	0.04	4	0.04	3	0.04	1	0.02	9	0.02	8	0.02	6
16	Relative Relief Ratio (Rhp)	0.21	11	0.65	9	1.11	4	1.09	5	0.53	10	1.12	3	1.25	2	1.40	1	0.68	8	0.83	6	0.79	7

17	RHO Coefficient	0.45	9	0.61	2	0.59	3	0.58	4	0.47	8	0.51	6	0.52	5	0.62	1	0.42	11	0.43	10	0.48	7
18	Lamniscate (K)	3.55	10	2.30	1	3.23	6	2.37	2	3.26	7	2.46	4	2.43	3	2.97	5	3.58	11	3.29	8	3.32	9
	Compaund parameter (CP)	4.765		7.88		4.059		6.647		5.235		5.941		7.529		4.59		6.176		6.824		6.353	
	Ranking	3		11		1		8		4		5		10		2		6		9		7	
	Final priority	Low		High		Low		Medium		Low		Medium		High		Low		Medium		High		Medium	

In the present study, knowledge-based weightage system has been adopted for sub-watershed prioritization based on its factors and after carefully observing the field situation. The basis for assigning weightage to different themes was according to the relative importance to each parameter in the study area. The eleven sub watersheds were delineated from study area for prioritization of sub-watersheds on the basis of water holding capacity and the morphometric parameters, such as bifurcation ratio, drainage density, stream frequency, texture ratio, length overland flow and constant channel maintenance of delineated sub watersheds, were separately calculated. Then, the calculated values were added as compound value. Further, specific weight and specific ranks were assigned based on the water holding capacity in relation to morphometric parameters Table 9.

CONCLUSION

The Morphometric characteristics of different sub-watersheds indicate their relative characteristics with respect to hydrologic response of the watershed. It has been observed that drainage morphometry derived from various methods fallows standard rules. Remote Sensing and GIS technique in prioritizing watershed based on morphometric analysis proved to be valuable for watershed management practices. The different prioritization ranks are assigned after evaluation of the compound parameters. On the basis of relation between these composite values of the selected morphometric parameters, the watersheds are grouped into three categories: high, medium and low priority. The result of prioritization analysis revealed that the sub watersheds, such as SW1, SW3, SW5 and SW8 are the zones having lowest compound score and were considered under high priority which clearly indicates that it is subjected to maximum soil erosion and hence these may be taken for conservation practices. Medium prioritized zone is represented for SW4, SW6 SW9 and SW11. And SW2, SW7 and SW10 is low priority assigned in compound score. Those sub-watersheds susceptible to soil erosion as per morphometric analysis, therefore, immediate attention towards soil conservation measures is required in these sub-watersheds to preserve the land from future erosion and natural hazards.

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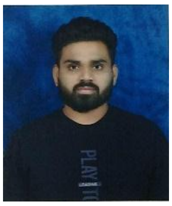

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