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MORPHOLOGICAL PARAMETER ESTIMATION DERIVED FROM TOPOSHEETS AND ASTER–DEM – A STUDY ON WATERSHEDS OF DAKSHINA PINAKINI RIVER BASIN IN KARNATAKA, INDIA

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ABSTRACT

With the growing population and rapid industrialization, more thrust is inevitable on natural resources such as water and land. This has necessitated for the planning and management of water and land resources. Therefore, protection of groundwater has become a high priority management goal. In this paper, authors have carried out morphological study on 8 watersheds of Dakshina Pinakini River Basin. Each watershed has a number of distinct characteristics. However, the manual measurement of basin parameters is uneconomical and time consuming. Therefore, ASTER–DEM can be very useful data source for extracting complex morphometric parameters particularly of inaccessible mountainous watersheds. Morphological parameters of the basin have been estimated through DEM derived from ASTER in GIS environment along with establishing the relative importance of the parameters.

The morphometric analysis is carried out by using the three parameters viz., basic, derived and shape parameters. The drainage pattern of the watersheds varies from dendritic to sub-dendritic. Overall results of watersheds NW3, SEW, SW1, SW2, SW3 and EW reveal that they are composed of permeable subsurface material, vegetation cover and low relief when compared with the watersheds NW1 and NW2. This reflects that these watersheds have more infiltration capacity and are the good sites for groundwater recharge.

KEYWORDS: ASTER, DEM, Dakshina Pinakini, Elongation Ratio, GIS, Infiltration Number

INTRODUCTION

Drainage and morphometric characteristics of many river basins have been studied using conventional methods (Krishnamurthy *et al*., 1996; Biswas *et al*., 1999; Kumar *et al*., 2000; Reddy *et al*., 2004; Vittala *et al*., 2004; Satish and Vajrappa, 2012). The morphometric studies involve the evolution of stream parameters through the measurement of various stream properties (Kumar *et al*., 2000). In this paper, an attempt has been made to evolute morphometric parameters derived from Survey of India toposheets of 1:50,000 scale and Advanced Spaceborne Thermal Emmission and Reflection Radiometer Digital Elevation Model (ASTER–DEM) with 30 m resolution. The softwares MapInfo 10 and ArcGIS 9.3 are used to evolute streams and to generate drainage map.

The severity of water stress is felt more especially in the arid and semi-arid regions. Therefore, in this paper, the authors have made an attempt to estimate some of the morphological parameters of watersheds of Dakshina Pinakini River Basin – a tributary of river Cauvery. Modern technologies such as Geographic Information System (GIS), have gained significant importance over the last decade in their applications pertaining to distributed hydrologic modelling. GIS is suitable for the analysis of spatially referenced data (ASTER). GIS can handle both spatial and aspatial data effectively and efficiently. Nowadays, GIS is widely used for resources planning in watershed (Jain *et al*., 2000; Ratnam eat al., 2004). Using the presently available GIS techniques one has to go through tedious steps for generating these characteristics. Since the mid-1980s digital elevation models (DEMs) have been used to delineate drainage networks (Mark, 1983; Anderson, 2004) and watershed boundaries, to calculate slope characteristics, and to produce flow paths of surface runoff (Tarboton *et al*., 1991, 2001). In this study, it has been found that ASTER–DEM can be very useful data to extract the morphometric characteristics of watersheds accurately and in very less time.

Study Area

The present study is conducted on 8 watersheds, viz, Kelaginathota Watershed (NW1), Mailappanahalli Watershed (NW2), Vijayapura Watershed (NW3), Gindur Watershed (SEW), Budigere Amani Kere Watershed (SW1), Yelemalappa Shetty Kere Watershed (SW2), Hulimavu Kere Watershed (SW3) and Hosakote Watershed (EW) of Dakshina Pinakini River – a tributary of river Cauvery, which falls between 77° 32′ and 77° 59′ N longitude and between 12° 49′ and 13° 30′ E latitude, covering an area of 2379 Km^2.

MATERIALS AND METHODS

Topographical maps of 1:50,000 scale (57G/11, 12, 14, 15, 16, H/9, 13 and 14) are collected from Survey of India, Bangalore and the same are registered to UTM projection (WGS 84 North, Zone 43). The drainage network has been created manually by digitizing drainage lines in ArcGIS 9.3. ASTER images obtained from the website http://www.gdem.aster.ersdac.or.jp are used. The drainage network from ASTER–DEM has been extracted, using the ArcToolbox→Spatial Analyst→Hydrology Tools in ArcGIS 9.3 (Figure 1) adopting the standard procedures (Band, 1986; Morris and Heerdegen, 1988; Tarboton et al., 1991; Gurnell and Montgomery, 1999; Maidment, 2002; Ahmed et al., 2010).

To obtain watersheds and streams derived from ASTER–DEM, the steps are as follows:

- Fill the sinks in the ASTER–DEM
- Apply the flow direction function to the filled ASTER–DEM
- Apply the flow accumulation function on the flow direction grid
- Apply a threshold condition to the flow direction grid
- Obtain a streams grid from the threshold condition grid
- Obtain the stream links grid
- Obtain watersheds grid from the streams grid
- Vectorize the streams grid
- Vectorize the watersheds grid.

Fill Sinks

The process of filling the sinks uses a function that identifies them and raises the terrain in order to have a smoother surface and let the water flow freely without forming ponds.

Flow Direction

The main concept of this algorithm is again set that the water is going to flow always to lower points. If we translate this into a finite cell system (the grid concept), the water that is stored in a determined cell is going to flow to the neighbor cells with lower elevation. Although water in a cell-based system have to choose just one path to get to the next cell, so the concept is complete when we say that water is going to flow to neighbor cell that has the steepest slope. Water in the scenario is going to reach the lowest point in the minimum amount of time.

Flow Accumulation

Flow accumulation is the next step in hydrologic modeling. Watersheds are defined spatially by the geomorphologic property of drainage. In order to generate a drainage network, it is necessary to determine the ultimate flow path of every cell on the landscape grid. Flow accumulation has been used to generate a drainage network, based on the direction of flow of each cell. The drainage network has been extracted by considering the pixels greater than a threshold of 100 by a trial-and-error approach (Mark, 1983). A feature class specified to define areas that should not be filled. A threshold may also be specified – in that case only sinks, whose depth is lower than the threshold, will be filled. Similarly, watersheds has been delineated by giving an outlet or pour points where water flows out of an area, this is the lowest point along the boundary of the watershed. The cells in the source raster are used as pour points above which the contributing area is determined.

RESULTS AND DISCUSSIONS

The morphometric analyses of Dakshina Pinakini River is carried out by using the three parameters viz., basic, derived and shape parameters.

Basic Parameters

The perimeter (P) is the total length of the drainage basin boundary. The perimeter of the Watersheds of Dakshina Pinakini are as follows: NW1, NW2, NW3, SEW, SW1, SW2, SW3 and EW are 32.38, 27.67, 50.94, 76.3, 49.26, 80.7, 77.51, 59.19 for toposheet and ASTER data. It is clearly noticed that the accurate delineation is possible when a higher resolution image is used. The total drainage area has remained the same for both toposheets and ASTER data approximately 50.95, 36.62, 100.2, 169.4, 143.9, 292.1, 274.8 and 161.3 km^2 for NW1, NW2, NW3, SEW, SW1, SW2, SW3 and EW, respectively. The length of the basin (L) measured parallel to the main drainage line. The values of basin length for both toposheets and ASTER are shown in Tables 1 and 2.

Stream Order

In the present study, the Strahler's method of numbering has been adopted. The designation of stream orders (Nu) is the first step in drainage basin analysis and is based on a hierarchic ranking of streams. Stream order or classification of streams is a useful indicator of stream size, discharge and drainage area (Strahler, 1957). The number of streams (N) of each order (u) for both the data are presented in Tables 1 and 2. The watersheds are fifth order basin; it is observed that decrease in stream frequency as the stream order increases in both the sources of the data. The NW1 and NW2 watersheds are hilly terrain with moderate to steep slope which is clearly depicted by ASTER. Therefore, the satellite data show a very high variation in I, II and III order streams.

Stream Length

The number of streams of various orders in watersheds are counted and their lengths are measured. The stream length (L_u) characteristics of the watersheds confirm Horton's second law (1945) "law of stream length" which states that the average length of streams of each of the different orders in a drainage basin tends closely to approximate a direct geometric ratio. In general, the total length of stream segments is high in first order streams and decreases as the stream order increases. In this case, the stream segments of various orders show variation from general observation. When stream length has been calculated for all watersheds from toposheets, the IV order stream of the watersheds show considerable variation for toposheets. It has been found that it follows a general pattern for ASTER, that is, stream length is maximum in the first order and decreases with the least at fifth order except the fourth order of SEW watershed, which is elongated (Figure 2). This change may indicate again the morphology of the terrain and the slope accuracy obtained from the satellite data. The values of length (L_u) and total stream length (L_t) are shown in Tables 1 and 2.

The maximum and minimum height (H,h) corresponds to the highest and lowest points of the basin. The maximum and the minimum heights of the watersheds are 1459 m and 864, respectively.

DERIVED PARAMETERS

Bifurcation Ratio

It is observed from Tables 1 and 2, that the bifurcation ratio (Rb) is not the same from one order to its next higher order. These irregularities are dependent on the geology and lithology of the basin (Strahler, 1964). The Rb ranges between 3.0 and 5.0 when the influence of geological structures is negligible (Ozdemir and Bird, 2009). The Rb for both data is given in Tables 1 and 2. The Rb values for I and II order streams are higher than the Rb of higher order stream indicate the hilly terrain and active gullies and ravines (NW1 and NW2). The mean Rb may be defined as the average of bifurcation ratios of all orders. In the present case, mean Rb varies from 2.9 to 4.36 for toposheets and 3.7 to 4.6 for ASTER data, which indicates that all the watersheds are in Mature stage (Tables 3 and 4).

$$R_{\mathrm{b}} = \frac{N_{\mathrm{u}}}{N_{\mathrm{u+1}}}$$

Where, N_u=total no. of stream segments of order u and N_{u+1}=no. of stream segments of next higher order.

Stream Frequency

Horton (1932) introduced stream frequency or channel frequency. The total number of stream segments of all orders per unit area. Stream frequency is related to permeability, infiltration capacity and relief of watershed. The watersheds NW1 and NW2 show high stream frequency followed by the watersheds SEW, SW1, SW2, NW3, EW and SW3 as shown in Tables 3 and 4. The stream frequency is high for NW1 and NW2 watersheds, which correspond to the rocky, hilly terrain of the watersheds with sparse vegetation and impermeable subsurface strata. For all the watersheds stream frequency ranges from 1 to 2.43 for toposheet and 1.6 to 4.7 for satellite data.

$$F_{\mathrm{s}} = \frac{N_{\mathrm{u}}}{A}$$

Where, *N*u=total no. of streams of all orders and *A*=area of the watershed (Km^2).

Drainage Density

The values of D_d vary from 1.14 to 2.26 Km/Km^2 and 1.57 to 2.93 for toposheets and satellite data, respectively. The D_d of NW1 and NW2 (2.05 and 2.26 Km/Km^2 and 2.23 and 2.93, for toposheets and ASTER, respectively) indicates that regions under these watersheds are composed of impermeable subsurface material, sparse vegetation and mountainous relief, whereas D_d of NW3, SEW, SW1, SW2, SW3 and EW reveals that these watersheds are composed of permeable subsurface material, vegetation cover and low relief. This reflects that these watersheds have more infiltration capacity and are the good sites for groundwater recharge (Tables 3 and 4). Overall D_d indicates watersheds NW1 and NW2 contribute much runoff to the catchment than other watersheds (Bhat and Romshoo, 2008).

$$D_\mathrm{d} = \frac{L_\mathrm{u}}{A}$$

Where, L_u=total stream length of all orders.

SHAPE PARAMETERS

Elongation Ratio

Schumm (1956) defined elongation ratio (R_e) as the ratio between the diameter of the circle of the same area as the drainage basin (D) and the maximum length of the basin (L). Results of Re exhibit that watersheds NW1 and NW2 are circular in shape with higher value of 0.8 and 0.82, respectively, whereas the remaining watersheds are more or less elongated. A circular basin is more efficient in the discharge of runoff than an elongated basin (Singh and Singh, 1997). The value of Re varies from 0 (in highly elongated shape) to the unity, that is, 1 (in circular shape). The Re of watersheds varies from 0.5 to 0.8 for both toposheets and ASTER data (Tables 3 and 4).

$$R_\mathrm{e} = \frac{2\sqrt{A/\pi}}{L_\mathrm{b}}$$

Where, L_b is length of the watershed.

Circularity Ratio

It is the ratio of the area of watershed to the area of a circle having the same circumference as the perimeter of the watershed (Miller, 1953). Rc is influenced by the length and frequency of streams, geological structures, land use/land cover, climate and relief of the basin. The Rc of the watersheds NW1, NW2, NW3, SEW, SW1, SW2, SW3 and EW are 0.61, 0.6, 0.48, 0.36, 0.74, 0.56, 0.57 and 0.57, respectively.

Results show that the watersheds NW1, NW2 and SW1 are more or less circular and are characterized by high-to-moderate relief. The remaining watersheds are more or less elongated and characterized by moderate-to-low relief.

$$R_\mathrm{c} = \frac{4\pi A}{P^2}$$

Form Factor

The ratio of the watershed area to the square of watershed length is called the form factor (R_f). It is used as a quantitative expression of the shape of watershed form. The results show that R_f varies between 0.14 and 0.53. Thus, NW1 and NW2 watersheds are circular in shape with higher value of 0.5 and 0.53, respectively, whereas the remaining watersheds are elongated (Tables 3 and 4).

$$R_\mathrm{f} = \frac{A_\mathrm{u}}{{L_\mathrm{b}}^2}$$

Infiltration Number

Infiltration number (If) is the product of the Dd and Fs. It plays significant role in observing the character of watershed. It is inversely proportional to the infiltration capacity of the watershed. The If of watersheds NW1, NW2, NW3, SEW, SW1, SW2, SW3 and EW are 4.55, 5.49, 1.88, 1.15, 1.4, 1.38, 1.64 and 1.72 for toposheet and 7.22, 14, 5.99, 7.06, 5.17, 3.33, 2.74 and 2.59 for ASTER data, respectively. The higher value of If reveals that watersheds NW1 and NW2 have low infiltration capacity with steep slope and impermeable rocks.

$$I_\mathrm{f} = D_\mathrm{d} \times F_\mathrm{s}$$

CONCLUSIONS

The drainage pattern varies from dendritic to sub-dendritic. The D_d of watersheds NW3, SEW, SW1, SW2, SW3 and EW reveals that these watersheds are composed of permeable subsurface material, vegetation cover and low relief when compared with the watersheds NW1 and NW2. This reflects that these watersheds have more infiltration capacity and are the good sites for groundwater recharge. Overall results of stream frequency reveals that these watersheds are covered by vegetation and having very good infiltration capacity. Infiltration number reveals that watersheds NW1 and NW2 having low infiltration capacity with steep slope and impermeable rocks. The remaining watersheds have high infiltration capacity with undulating to low relief with weathered and fractured rocks. Hence, a systematic analysis of morphometric parameters within the drainage network using ASTER data can provide significant value in understanding the basin characteristics. Considerable positive variations of the stream order, total number of streams, and stream length in I, II, III, IV and V order, are seen in satellite images when compared with toposheet. The variations in the morphometric parameters from various sources can be attributed to the depth of data/information obtained from the terrain. The satellite data give more detailed information of the terrain and morphometric features, therefore, the variations in I, II, III, IV and V order streams can be seen between SOI toposheets and ASTER data. The results show that the morphometric parameters derived from the ASTER data provide good and satisfying results. The results will be more efficient when the DEM cell size is smaller or the resolution of the image is higher.

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APPENDICES

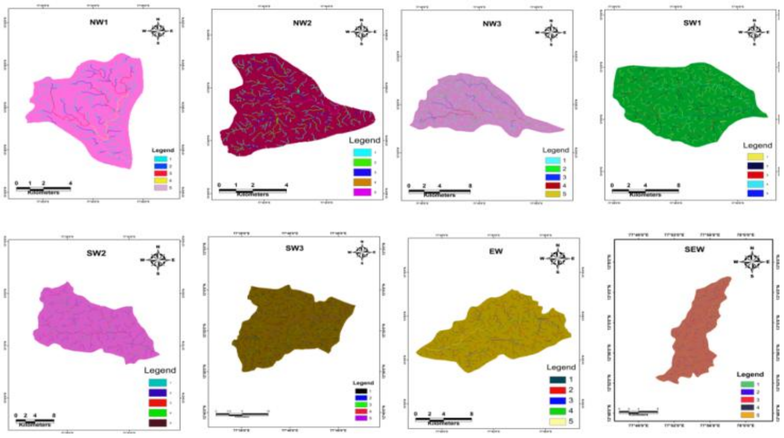

Figure 1: Drainage Maps of Dakshina Pinakini Watersheds Evoluted by ASTER–DEM

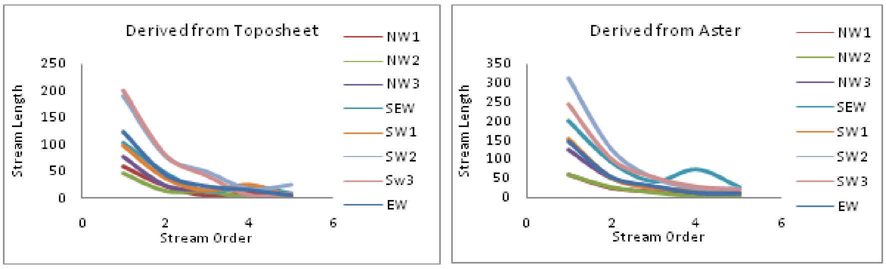

Figure 2: Relation of Stream Order to Stream Length Derived from Toposheet (a) and ASTER–DEM (b)

Table 1: Morphometric Analyses of the Watersheds Derived from Toposheets

Watershed	Area (Km^2)	*P* (Km)	L_b (Km)	Stream Order	Stream Count	Total No. of Streams	Stream Length	Total Length	Mean Length	R_b
NW1	50.95	32.38	10	1	87		59.99		0.69	4.83
				2	18		23.72		1.32	3.60
				3	5	113	6	104.68	1.20	2.50
				4	2		11		5.50	2.00
				5	1		3.97		3.97	
NW2	36.62	27.67	8.26	1	65		47		0.72	4.06
				2	16		14.86		0.93	3.20
				3	5	89	13.7	82.9	2.74	2.50
				4	2		3.32		1.66	2.00
				5	1		3.98		3.98	
NW3	100.2	50.94	19	1	100		76.29		0.76	4.35
				2	23		25		1.09	4.60
				3	5	131	16.18	144	3.24	2.50
				4	2		19.7		9.85	2.00
				5	1		7		7.00	
SEW	169.4	76.3	28.5	1	130		103.55		0.80	4.06
				2	32		47.71		1.49	5.33
				3	6	171	11.48	193	1.91	3.00
				4	2		22.15		11.08	2.00
				5	1		8.3		8.30	
SW1	143.9	49.26	18.9	1	122		98.47		0.81	3.70
				2	33		37.7		1.14	6.60
				3	5	163	13.98	178	2.80	2.50
				4	2		25.26		12.63	2.00
				5	1		2.6		2.60	
SW2	292.1	80.7	27.5	1	246		189.87		0.77	3.67
				2	67		78.36		1.17	4.79

Table 1: Contd.,

				3	14	330	48.92	359	3.49	7.00
				4	2		16.87		8.44	2.00
				5	1		24.87		24.87	
SW3	274.8	77.51	24.9	1	268		200.8		0.75	3.72
				2	72		81.76		1.14	4.24
				3	17	363	42.72	342	2.51	3.40
				4	5		6.96		1.39	5.00
				5	1		9.7		9.70	
EW	161.3	59.19	21.42	1	164		122.52		0.75	4.82
				2	34		44.87		1.32	3.40
				3	10	211	23	213	2.30	5.00
				4	2		16.37		8.19	2.00
				5	1		6.44		6.44	

Table 2: Morphometric Analyses of the Watersheds Derived from ASTER

Watershed	Area (Km^2)	P (Km)	L_b (Km)	Stream Order	Stream Count	Total No. of Streams	Stream Length	Total Length	Mean Length	R_b
NW1	50.95	32.38	10	1	125		60		0.48	3.9
				2	32		26		0.8125	6.4
				3	5	165	16.7	113.71	3.34	2.5
				4	2		7.41		3.705	2
				5	1		3.6		3.6	
NW2	36.62	27.67	8.26	1	135		59.42		0.44	4.21
				2	32		27.29		0.85	6.4
				3	5	175	13.32	107.52	2.66	2.5
				4	2		4.04		2.02	2
				5	1		3.45		3.45	
NW3	100.2	50.94	19	1	184		124.81		0.67	2.92
				2	63		51.12		0.81	5.25
				3	12	263	28.92	228.89	2.41	4
				4	3		12.79		4.26	3
				5	1		11.25		11.25	
SEW	169.4	76.3	28.5	1	355		200.22		0.564	4.17
				2	85		92.37		1.08	3.69
				3	23	468	41.27	432.99	1.79	5.75
				4	4		73		18.25	4
				5	1		26.13		26.13	
SW1	143.9	49.26	18.9	1	285		155.56		0.54	3.16
				2	90		53.58		0.59	3.75
				3	24	404	25.12	265.08	1.04	6
				4	4		21.01		5.25	4
				5	1		9.81		9.81	
SW2	292.1	80.7	27.5	1	385		310.76		0.8	3.63
				2	106		127.67		1.2	4.07
				3	26	525	52.78	542.22	2.03	3.71
				4	7		26.5		3.78	7
				5	1		24.51		24.51	
SW3	274.8	77.51	24.9	1	350		245.57		0.7	4.11
				2	85		101.4		1.19	3.69
				3	23	466	51.78	444.94	2.25	3.28
				4	7		27.34		3.9	7
				5	1		18.85		18.85	
EW	161.3	59.19	21.42	1	201		147.52		0.73	4.18
				2	48		54.211		1.12	3.69
				3	13	266	29.7	253.941	2.28	4.33
				4	3		12.31		4.1	3
				5	1		10.2		10.2	

Table 3: Morphometric Parameters Derived from Toposheets

Watershed	R_b	D_d	F_s	R_e	R_f	R_c	I_f
NW1	3.23	2.05	2.21	0.8	0.5	0.61	4.55
NW2	2.94	2.26	2.43	0.82	0.53	0.6	5.49
NW3	3.36	1.43	1.30	0.61	0.30	0.48	1.88
SEW	3.59	1.14	1	0.51	0.2	0.36	1.15
SW1	3.69	1.23	1.13	0.71	0.4	0.74	1.4
SW2	4.36	1.22	1.29	0.7	0.38	0.56	1.38
SW3	4.08	1.24	1.32	0.75	0.44	0.57	1.64
EW	3.8	1.32	1.3	0.66	0.35	0.57	1.72

Table 4: Morphometric Parameters Derived from ASTER

Watershed	R_b	D_d	F_s	R_e	R_f	R_c	I_f
NW1	3.7	2.23	3.23	0.8	0.5	0.61	7.22
NW2	3.77	2.93	4.77	0.82	0.53	0.6	14
NW3	3.79	2.28	2.62	0.59	0.27	0.48	5.99
SEW	4.4	2.55	2.76	0.51	0.2	0.36	7.06
SW1	4.22	1.84	2.8	0.71	0.4	0.74	5.17
SW2	4.6	1.85	1.79	0.7	0.38	0.56	3.33
SW3	4.5	1.61	1.69	0.7	0.44	0.57	2.74
EW	3.8	1.57	1.64	0.66	0.35	0.57	2.59