Available Online at http://www.recentscientific.com

ISSN: 0976-3031

International Journal of Recent Scientific Research
Vol. 6, Issue, 2, pp.2821-2826, February, 2015

International Journal of Recent Scientific Research

RESEARCH ARTICLE

DRAINAGE MORPHOMETRY AND ITS INFLUENCE ON LANDFORM CHARACTERISTICS IN VASISHTA NADI, VELLAR RIVER BASIN, TAMIL NADU, INDIA – A REMOTE SENSING AND GIS APPROACH

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ARTICLE INFO

Article History:

Received 14th, January, 2015
Received in revised form 23th, January, 2015
Accepted 13th, February, 2015
Published online 28th, February, 2015

Key words:

Morphometry; Crystalline terrain; Geology; Geographic Information System (GIS); Spatial analysis; Remote sensing; Micro watershed.

ABSTRACT

In this study, LANDSAT TM image of 2012 satellite data along with extensive ground truth information were used. Study about the drainage morphometry and its influence on landform characteristics in Vasishta Nadi of crystalline terrain (Archaean age), Tamil Nadu, South India. Geology and geomorphological landform characteristics of the sub-basin. Morphometric analysis was carried out at micro watershed level using spatial analysis system (ArcGIS ver. 9.3.1) Geographic information system to analyze the influence of drainage morphometry on landforms, drainage and geological characteristics. Four distinct landforms were identified in the basin based on visual interpretation of satellite sensor data. These are Alluvial fan Younger, Dome type Denudational Hills (Large), Dome type Residual Hills , Hilltop Weatered, Inselberg, Intermountain valley/Structural Valley (Large), Linear Ridge/ Dyke, Moderately weathered/moderately buried Pediplain, Pediment/Valley Floor, Ridge type Structural Hills (Large), Shallow Buried Pediment, Shallow Flood Plain, Shallow weathered/shallow buried Pediplain, Upper Piedmont Slope, Valley Fill/ filled-in valley, and water bodies. VasishtaNadi is one of the tributaries of Vellar River, drained in the middle of the sub basin. It is 7th order drainage basin and drainage pattern, mainly in subdendritic to dendritic type. It is observed that the drainage density value is low, which indicates the basin is highly permeable soil and thick vegetative cover. The circularity ratio value reveals that the basin is strongly elongated and highly permeable homogenous geologic formations. The present scenario where water resources are becoming scarce, this exercise of calculating the various attributes of a drainage basin plays a significant role in locating sites for artificial recharge structures.

INTRODUCTION

Recently, in morphotectonic studies traditional geomorphic analysis has been integrated with morphometric analysis of landforms and with geostatistical topographic analysis (Keller *et al.*, 1982; Mayer, 1990; Cox, 1994; Merritts *et al.*, 1994; LupiaPalmieri *et al.*, 1995; LupiaPalmieri *et al.*, 2001; Currado and Fredi, 2000; Pike, 2002; Della Seta, 2004; Della Seta *et al.*, 2004). The Stream Length is one of the quantitative geomorphic parameters included in morpho tectonic investigation (Hack, 1973). Nevertheless, the effectiveness of the parameter in detecting local active structures has not been confirmed for small catchments and origin regions where tectonic activity is less intense (Chen *et al.*, 2003 and references therein; Verrios *et al.*, 2004).

Surface drainage characteristics of many river basins and sub basins in different parts of the globe have been studied using conventional methods (Horton, 1945; Strahler, 1952, 1957, 1964; Morisawa, 1959; Leopold and Miller, 1956; Krishnamurthy *et al.*, 1996). Morphometric studies involve evaluation of streams through the measurement of various stream properties. River basins comprise a distinct morphologic region and have special relevance to drainage pattern and geomorphology (Doornkamp and Cuchlaine, 1971; Strahler, 1957). Horton's law of stream lengths suggests a geometric relationship between the number of stream segments in successive stream orders and landforms (Horton, 1945). Evaluation of morphometric parameters necessitates the analysis of various drainage parameters (viz., ordering of the various streams and measurement of area of basin, perimeter of basin, length of drainage channels, drainage density (Dd), drainage frequency, bifurcation ratio (Rb), texture ratio (T) and circulatory ratio (Rc) (Kumar *et al.*, 2000). Quantitative description of the basin morphometry also requires the characterization of linear and areal features, gradient of channel network and contributing ground slopes of the drainage basin. Detail analysis of drainage parameters is of great help in understanding the influence of drainage morphometry on landforms and their characteristics.

The aim of the study was to demonstrate the potential use of remotely sensed data and geographical information systems (GIS) in evaluation of linear, relief and arial morphometric parameters and to analyze their influence on the genesis and processes of landforms. Visual interpretation of satellite sensor data in analysis of landforms in conjunction with the drainage

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patterns facilitates effective delineation of distinct features to evaluate the influence of drainage morphometry on landform characteristics and their processes. Remote sensing and GIS techniques are being used in determining the quantitative description of the basin geometry (Biswas *et al*., 1999). The high spatial resolution remotely sensed data coupled with topographical data analysis procedures have made satellite sensor data-based morphometric analysis a highly effective tool to understand and manage the natural resources (Srinivasan, 1988). It provides the real time and accurate information related to distinct geological formations, landforms and helps in identification of drainage channels, which are altered by natural forces or human-induced activities. Multispectral satellite sensor data provides a convenient means to analyze drainage and distinct landform characteristics at various scales.

The basin morphometric characteristics of the various basins have been studied by many scientists using conventional methods (Horton, 1945; Smith, 1950; Strahler, 1957) and remote sensing and GIS methods (Krishnamurthy and Srinivas, 1995; Srivastava and Mitra, 1995; Agarwal, 1998; Biswas *et al*., 1999; Keller *et al*., 1982; Mayer, 1990; Cox, 1994; Merritts, *et al*., 1994; LupiaPalmieri *et al*., 1995 and 2001; Currado and Fredi, 2000; Pike, 2002; Della Seta, 2004; Della Seta *et al*., 2004. The fast emerging spatial information technology (SIT) viz. remote sensing and GIS. GIS is an effective tool to analyze spatial and non-spatial data on drainage, geology and landforms to understand their inter-relationships. Integration of remotely sensed data and GIS thereby provides an efficient way in analysis of morphometric parameters and landform characteristics for resource evaluation, analysis and management. An attempt has been made to utilize the interpretative techniques of GIS to find out the relationships between the morphometric parameters at micro watershed level and identifying zones for artificial recharge.

Study Area

The study area, lies between the latitudes 11°24’0.347” N to 11°53’26.496” N and longitudes 78°13’55.211” E to 78°58’9.969” E covering an area of 1803.99 Km2. Out of which plain land covers an area of 1354.92 km2 (Fig.1). The study area falls in four districts namely, Salem, Dharmapuri, Namakkal, Perambalur of Tamil Nadu. The climate of the study area is mainly sub-tropical climate with moderate humidity and temperature. The study area is under laid by the Archaean crystalline rocks surrounded by denudational hills and structural hills.

METHODOLOGY

LANDSAT TM image of 2012 was used to delineate the morphometry of the Vasishta Nadi. The drainage network of the basin was traced on transparency and digitized as available on toposheet nos. 58 I/5, 58 I/6, 58 I/7, 58 I/9, 58 I/10, 58 I/11, 58 I/14 and 15 of (1:50,000) and some of the first-order steams were updated with the help of satellite sensor data. A few of the drainage lines were extended through water bodies with the help of collateral data to facilitate the measurement of different drainage parameters. The digital elevation model (DEM) was generated based on the contour values of 20 m interval to generate height and slope maps. The Sub basin was divided into 21 micro watershed and morphometric analysis was carried out at a micro watershed level in the spatial analysis system (ArcGIS ver. 9.3.1). The drainage channels were classified into different orders using Strahler’s (1964) classification. In GIS, drainage channel segments were ordered numerically as order number 1 from a stream’s headwaters to a point downstream. The stream segment that results from the joining of two first order streams was assigned order 2. Two-second order streams formed a third-order stream and so on. The primary basin parameters such as basin area, basin perimeter, basin length and stream length were obtained, which were further used to obtain the derived parameters such as drainage density, Drainage Texture, Bifurcation Ratio, Stream length Ratio, Stream Frequency, Form Factor, Elongation Ratio and Circulatory Ratio. The evaluated morphometric parameters were grouped as linear, relief and areal parameters.

Visual interpretation techniques have been followed in delineation of geology, landforms, and slope based on the tone, texture, shape, drainage pattern, color characteristics of the satellite imagery in conjunction with drainage morphometry and collateral data. Subsequently, detailed landform analysis has been carried out based on their genesis, relief and their morphometric characteristics. Finally, to identify the suitable locations for artificial recharge structure's construction.

RESULTS AND DISCUSSION

Slope

The majority of areas fall and parts of area in the micro watersheds were under nearly surface level to very gentle slope (0–3%) and occupy about 51.89% of the total geographical area (TGA) (Fig. 2 and Table 1). Much less drainage density and low stream frequency are observed on these slopes covering the central and eastern parts of the study area. The moderately steep to very steep (more than 10%) of the upland areas and isolated places occupy 33.15% of the TGA. Moderate to gentle slopes (3–10%) are observed in undulating terrain and intermittent valley zones covering 14.96% of the total area.

Table 1 Slope class with area of the Vasishta Nadi

Sl. No.	Class	Area in Km^2	Area in %
1	Nearly surface level (0-1%)	286.10	15.87
2	Very gentle (1-3%)	649.54	36.02
3	Gentle (3-5%)	135.72	7.52
4	Moderate (5-10%)	134.22	7.44
5	Moderately steep (10-15%)	97.93	5.43
6	Steep (15-30%)	220.85	12.24
7	Very steep (>30%)	279.16	15.48

Table 2 Geology with area of the Vasishta Nadi

Sl. No.	Class	Area in Km^2	Area in %
1	Carbonatites	22.54	1.25
2	Charnockite	1.14	0.06
3	Granite	534.08	29.61
4	Granitoid gneiss	50.39	2.79
5	Quartz vein	1189.83	65.96
6	Shales with bands of limestone	6.02	0.33

Geology

The geology map was collected from Geological Survey of India (GSI). The map was traced, scanned, digitized and then taken to GIS. In the field, the rock samples were collected and identified to assess the quantity characteristics of groundwater.

The study area lies mainly over the Archaean crystallines rocks and Semi-consolidated sediments (Fig. 2 and Table 2), and the groundwater occur under pharetic conditions in the weathered and fractured zones of the hard-rock aquifers. The area is made up of high-grade supracrustals of Archaean age and Pliocene sediments, comprising Peninsular Gneiss (Bhavani Group), Acid intrusive, Charnockite group, Alkali rocks and Anaipadi Formation. Acid intrusive occurred as quartz vein deposited. The rocks of Peninsular Gneiss (Bhavani Group) comprising Granite and Granitoid gneiss occur in highly elevated region.

The Quartz vein (1189.82 km^2) occupies in more or less the entire portion of the study area followed by Granite (534.08 km^2) this type of rock occurs largely in hilly area, Granitoid gneiss (50.39 km^2) and Carbonatites (22.53 km^2) occupied in many patches in and around Rangappanaickenpalayam. The development of drainage networks mainly depends on the underlying geology, precipitation, exogenic and endogenic processes of the area. The drainage pattern of the basin ranges from dendritic to sub dendritic at higher elevations and parallel to sub parallel in the lower elevations. A radial drainage pattern was also observed in the areas with isolated hillocks. Based on the drainage orders, the Vasishta Nadi has been classified as seventh order river basin.

8 and 18 are attributed to the characteristics of fewer structural disturbances which, in turn, has not distorted the drainage pattern (Strahler, 1964). Whereas, the higher (Rb) values in the micro watersheds 6, 14 and 20 indicate high structural complexity and low permeability of the sub surface strata.

Areal and Relief Parameters

Drainage density indicates that the low Dd exists in micro watersheds 1, 6, 9, 14 and 20 having high permeable sub surface material and are under dense vegetation cover and low relief (Fig. 4 and Table 4). In contrast, high Dd values are observed in micro watersheds 10, 11, 13, 15 and 16 may be due to the presence of impermeable sub surface material, sparse vegetation and elevated relief. Basin relief (Bh) aspects of the sub basins play an important role in drainage development. Surface and sub-surface water flow, permeability and landforms development properties of the terrain. The analysis reveals that all the sub basins except 6, 12, 14, 17, 19 and 20 are having the relief more than 250 m (Table 3). The high Bh value indicates the gravity of water flow, low infiltration and high runoff conditions.

Table 3 Linear and Relief parameters of micro watersheds

Micro Watershed no.	Basin Length Lb (km)	Perimeter P (km)	Drainage Order (in Number)							Total Number N	Cumulative Length L (km)	Bifurcation Ratio Rb	Basin height Bhm
			N_1	N_2	N_3	N_4	N_5	N_6	N_7				
1	27.91	62.20	109	29	8	3	1			150	182.19	3.26	466.00
2	12.88	34.53	82	20	7	1				110	111.62	4.65	519.00
3	12.14	28.22	41	6	2					49	62.71	4.92	995.00
4	16.14	52.22	227	48	16	3	1	2	1	298	258.99	3.09	766.00
5	9.10	21.29	33	9	3	1				46	52.12	3.22	949.00
6	9.10	27.78	15	2						17	38.77	7.50	245.00
7	17.50	32.53	73	19	5	1				98	93.53	4.21	819.00
8	31.21	54.35	237	48	14	5	2	2	1	309	262.68	2.78	1009.00
9	29.38	68.00	152	40	9	2	1			204	233.53	3.69	351.00
10	24.13	76.13	684	132	25	7	2	1		851	558.44	3.91	836.00
11	15.62	37.40	88	18	5	1				112	87.42	4.50	1028.00
12	21.11	45.67	74	13	3	2				92	101.88	3.84	65.00
13	14.04	34.36	145	33	4	2	1			185	126.10	4.16	990.00
14	29.02	68.71	66	15	2					83	114.88	5.95	82.00
15	13.06	38.80	106	22	6	2	1			137	118.00	3.37	893.00
16	14.03	60.87	527	128	32	8	2	1		698	498.48	3.62	657.00
17	11.71	23.70	26	6	2	1				35	37.90	3.11	136.00
18	25.95	70.13	268	63	20	4	2	1	1	359	332.83	2.90	528.00
19	14.79	38.90	56	16	3	2				77	78.69	3.44	42.00
20	28.99	58.92	120	26	6	1				153	153.30	4.98	97.00
21	26.00	90.25	541	143	35	9	3	1	1	733	606.79	3.13	653.00

Linear parameters

Stream order analysis shows that the main sub basin is fall under seventh order category. Based on the network pattern it has been further sub divided into twenty one micro watersheds. The micro watershed no. 6 was identified second order stream, two watersheds (3,14) under third order stream, eight watersheds (2,5,7,11,12,17,19 and 20) under fourth order stream, four watersheds (1,9,13,15) under fifth order stream, two watersheds (10.16) under sixth order stream and four watersheds (4,8,18,21) under seventh order stream(Fig. 4 and Table 3). The seventh order stream is found in the unclassified area. Analysis of cumulative length of streams (L) shows that micro watershed 10, 16 and 21have the highest L value, whereas, micro watersheds 5, 6 and 17 have the lowest L value. The existence of high (L) value is due to structural complexity, high relief and impermeable bedrock. Analyses of bifurcation ratio (Rb) shows lower (Rb) values in the micro watersheds 4,

The measurement of drainage density provides a numerical measurement of landscape dissection and runoff potential. Analysis of stream frequency (Fu) shows low values of Fu existing in micro watersheds 10, 11, 13, and 16 which are having high permeable geology and low relief. Where elevated value of Fu is noticed in 6 and 14 micro watersheds, where impermeable sub-surface material, sparse vegetation and high relief conditions prevail. Texture ratio (T) indicates that highest T values are found in micro watersheds 10, 16 and 21 whereas the lowest T values are noticed in micro watersheds 6 and 14. Thus, it can infer that T values depend on the underlying geology, infiltration capacity of bedrock and relief aspects of the individual micro watersheds. Analysis of the form factor (Rf) reveals that micro watersheds having low Rf have less side flow for smaller duration and high main flow for longer duration and vice versa.

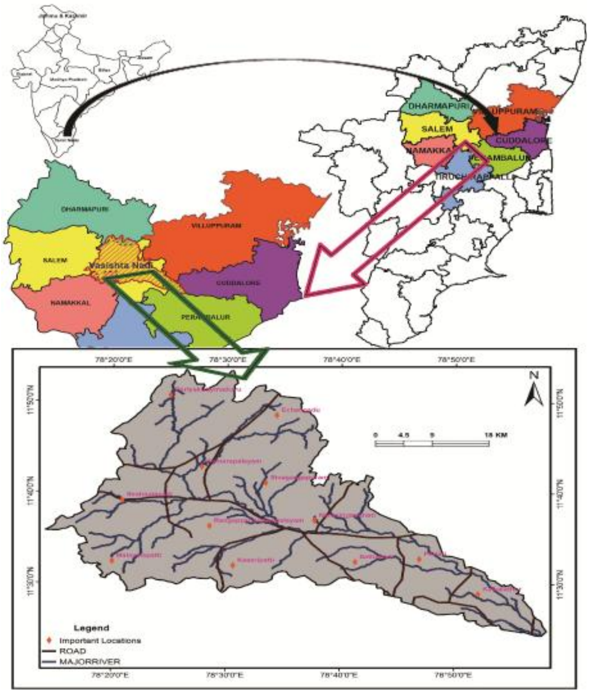

Fig.1 Study Area Map of Vasishta Nadi with stream networks and water bodies

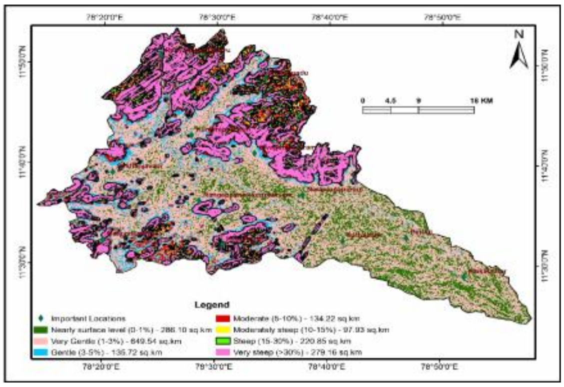

Fig. 2 Slope map of Vasishta Nadi

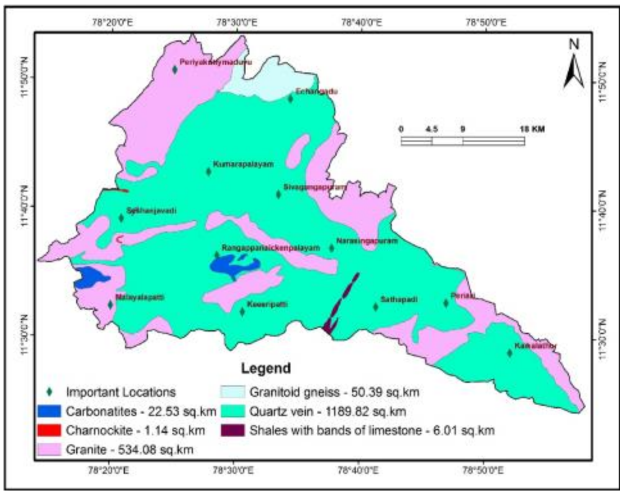

Fig. 3 Geology map of Vasishta Nadi

This condition prevails in micro watersheds 7, 11, 12 and 17. High Rf exists in micro watersheds 16 and 21 with high side flow for longer duration and low main flow for shorter duration causing high peak flows in a shorter duration. Circulatory ratio (Rc) values approaching 1 indicates that the basin shapes are like circular and as a result, it gets scope for uniform infiltration and takes long time to reach excess water at the micro watershed outlet, which further depend on the existing geology, slope and land cover. The micro watersheds 4 and 16 are having highest Rc value of 5.23 and 11.45 respectively, which support the above concept. Analysis of an elongation ratio (Re) indicates that the areas with higher Re values have high infiltration capacity and low runoff. The micro watersheds 16 and 21 are characterized by high Re and 7, 11, 12 and 17 micro watersheds have low Re respectively. The micro watersheds having low Re values are susceptible to high erosion and sedimentation load. Constant of channel maintenance (C) depends on the rock type, permeability, climatic regime, vegetation cover and relief as well as duration of erosion (Schumm, 1956). The micro watersheds 10 and 13 have low C values of 0.32 and 0.29 respectively.

Table 4 Areal Morphometric parameters of micro watersheds

Micro watershed	Area A (km^2)	Stream Frequency Fu	Drainage density	Texture Ratio	Form factor Rf	Circulatory Ratio	Elongation Ratio	Constant of Channel Maintenance C
no.			Dd	T		Rc	Re	
1	113.67	1.32	1.60	1.75	4.07	1.83	2.59	0.62
2	45.88	2.42	2.43	2.37	3.56	3.47	2.27	0.41
3	32.04	1.59	1.96	1.45	2.64	2.73	1.68	0.51
4	108.53	2.75	2.39	4.35	6.72	5.23	4.28	0.42
5	23.96	1.92	2.18	1.55	2.63	3.63	1.68	0.46
6	28.20	0.67	1.37	0.54	3.10	4.28	1.97	0.73
7	38.44	2.55	2.43	2.24	2.2	1.58	1.40	0.41
8	115.14	2.68	2.28	4.36	3.69	1.48	2.35	0.44
9	135.71	1.51	1.72	2.24	4.62	1.97	2.94	0.58
10	178.22	4.77	3.13	8.98	7.39	3.84	4.70	0.32
11	32.81	3.44	2.66	2.35	2.10	1.69	1.34	0.38
12	44.45	2.11	2.29	1.62	2.11	1.25	1.34	0.44
13	36.26	5.13	3.48	4.22	2.58	2.31	1.64	0.29
14	76.39	1.10	1.50	0.96	2.63	1.14	1.68	0.66
15	45.06	3.06	2.62	2.73	3.45	3.32	2.20	0.38
16	179.44	3.89	2.78	8.66	12.79	11.45	8.15	0.36
17	21.08	1.71	1.80	1.10	1.80	1.93	1.15	0.56
18	144.01	2.49	2.31	3.82	5.55	2.69	3.53	0.43
19	36.88	2.11	2.13	1.44	2.49	2.12	1.59	0.47
20	98.55	1.56	1.56	2.04	3.40	1.47	2.17	0.64
21	269.18	2.72	2.25	5.99	10.35	5.00	6.59	0.44

Table 5 Geomorphological features with area of the Vasishta Nadi

SI. No.	Class	Area in Km2	Area in %
1	Alluvial Fan Younger	8.75	0.49
2	Dome Type Denudational Hills (Large)	45.25	2.51
3	Dome Type Residual Hills	15.33	0.85
4	Hilltop Weathered	78.74	4.36
5	Inselberg	3.97	0.22
6	Intermountain Valley/Structural Valley (Large)	5.31	0.29
7	Linear Ridge/ Dyke	5.20	0.29
8	Moderately Weathered/Moderately Buried Pediplain	332.44	18.43
9	Pediment/ Valley Floor	181.79	10.08
10	Ridge Type Structural Hills (Large)	499.02	27.66
11	Shallow Buried Pediment	3.38	0.19
12	Shallow Flood Plain	5.38	0.30
13	Shallow Weathered/Shallow Buried Pediplain	612.47	33.95
14	Upper Piedmont Slope	5.00	0.28
15	Valley Fill/ Filled-in Valley	0.90	0.05
16	Water Body Mask	1.06	0.06

It indicates that these micro watersheds are under the influence of high structural disturbance, low permeability; steep to very steep slopes and high surface runoff. The micro watersheds of 6, 14 and 20 have highest C values of 0.73, 0.66 and 0.64 respectively and are under very fewer structural disturbances and fewer runoff conditions.

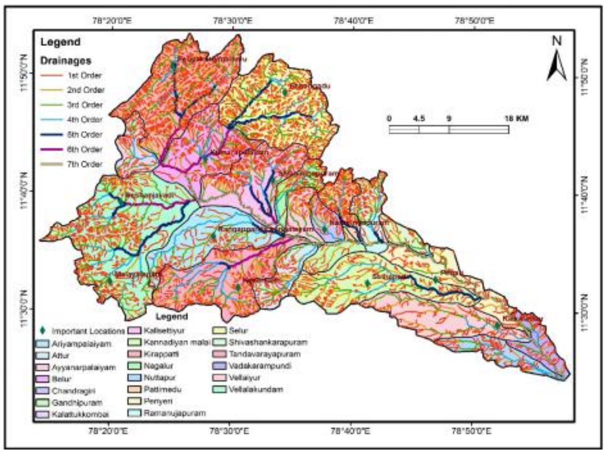

Fig.4 Micro watersheds and stream orders of Vasishta Nadi

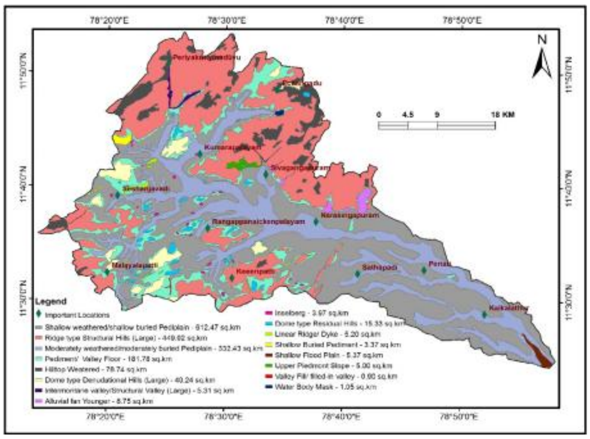

Fig.5 Geomorphology of the Vasishta Nadi

Drainage morphometry and its impact on landform characteristics the underlying geology, exogenic and endogenic activities, drainage morphometry and considerable changes in climate during the Quaternary, influences the genesis and morphology of landforms (Subramanyan, 1981). In this study area, the Ridge type structural hills are located in the almost all micro watersheds except these micro watersheds (12, 14, 17, 19, and 20). Two types of pediplain cover nearly 52 percentages of the sub basin. The Pediment/Valley floor covers 181.78 sq.km of the study area. These are identified and mapped as major landforms on the upper reaches. These landforms are associated with high drainage density, high bifurcation ratio and high cumulative length of first, second and third-order streams. Upper piedmont slope, Inselberg, Flood plain, Pediment and main Residual hills are analyzed and mapped as landforms of the Vasishta Nadi (Fig. 5 and Table 5). Which are formed by the influence of permeable geology, moderate to nearly level plains, medium to low drainage density (<2.0), low cumulative length of streams having fifth and sixth order streams. Land forms of upper reaches. The fluvio-denudational geomorphological processes are actively involved in landscape reduction processes at upper reaches. The physio-chemical weathering and multiple slope dissections under the influence of steep slopes, high drainage density and precipitation conditions lead to the development of Intermountain-valley land systems in the South western and North Western part of the area. The occurrences of alluvium and colluviums deposits at places are dissected by incoming third and fourth order streams. They are noticed in the upper parts of micro watersheds. Foot slopes are low in relief and consist of deposited sediments that are regularly carried out from upland catchments.

CONCLUSIONS

The study reveals that remotely sensed data and GIS based approach in evaluation of drainage morphometric parameters and their influence on landforms and land characteristics at a micro watershed level is more appropriate than the conventional methods. Interpretation of multi-spectral satellite sensor data is of great help in analysis of drainage parameters and delineation of distinct geological and landform units, relief and slope. GIS based approach facilitates analyzing different morphometric parameters and to explore the relationship between the drainage morphometry on one hand and properties of landforms and geology on other hands. Geomorphology spatial variation in the upper parts of micro watersheds. Foot slopes are low in relief and consist of deposited sediments that are regularly carried out from upland catchments. The majority of these landforms are occupied in the micro watershed of the study area. The seventh order stream is found in the unclassified area. Analysis of cumulative length of streams (L) shows that micro watersheds 10, 16 and 21 have the highest L value, whereas, micro watersheds 5, 6 and 17 have the lowest L value. The existence of high (L) value is due to structural complexity, high relief and impermeable bedrock.

The micro watersheds 10 and 13 have low C values of 0.32 and 0.29 respectively. It indicates that these micro watersheds are under the influence of high structural disturbance, low permeability; steep to very steep slopes and high surface runoff. The micro watersheds of 6, 14 and 20 have highest C values of 0.73, 0.66 and 0.64 respectively and are under very fewer structural disturbances and fewer runoff conditions. The present scenario where water resources are becoming scarce, this exercise of calculating the various attributes of a drainage basin plays a significant role in locating sites for artificial recharge structures.

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How to cite this article:

Palanisamy. S.A *et al*. Drainage morphometry and its influence on landform characteristics in vasishta nadi, vellar river basin, tamil nadu, india – a remote sensing and gis approachvannamei. *International Journal of Recent Scientific Research Vol. 6, Issue, 2, pp.2821-2826, February, 2015*

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