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Drainage Character Delineation- A Remote Sensing Approach Over Vamanapuram River Basin, Kerala

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Abstract - The drainage pattern of the VRB is dendritic, indicating the homogeneity in texture and lack of structural control. The river network is of sixth order. The lower order streams are mostly dominating in the basin. The sub-division of sixth order basin into sub-basins gives geographical modulations of the basin and each sub-basin of fifth order. The drainage texture of the VRB falls under the category of very fine (>8). The circularity ratio is 0.32 which indicate that the sub-basin is elongated in shape, low discharge of runoff and highly permeable sub-soil condition. SB2 is highly prone to vulnerable hazards. The low form factor and high shape index values categorise them to be elongated in shape and flow for longer duration and support more groundwater recharge. Geographical modifications of wetlands (paddy lands), floodplain degradation in lowland reaches and channelization advance the flood in Attingal Municipality and Vembayam panchayat during heavy rains (MON). The low ruggedness value of the watershed implies that the area has intrinsic structural complexity and is less prone to soil erosion (except SB1, SB2 and SB6). Moderate values of HD offer relatively low channel incision. High value of mRn shows SB1 can make alluvial / colluvial fans.

***Key Words:** VRB, drainage, texture, Dendritic, structural, channelization.*

I. INTRODUCTION

Every basin possesses a quantifiable set of geometric properties that define the linear, aerial and relief characteristics of watershed known as basin morphometry. Morphometric analysis concludes the quantitative evaluation of terrain characteristics and related landform comprising stream units. Morphometry forms an ideal areal unit for the interpretation and analysis of fluvially originated landforms, which could deliver the soul-behaviour of geometrical and mechanical aspects of the river basin which, in turn, helpful in understanding the hydrology, sediment characteristics and landscape evolution of basins [1]. The techniques in geomorphometric analysis are expedient in the quantitative description of the geometry of the drainage basins and its networks, which would help in characterisation of particular network [2].

The selection of variables in morphometric analysis is dependent to the mode of approach and objective of the research. For example, relief ratio is widely accepted as an efficient measure of gradient aspects of the basin, despite uncertainties surrounding definition of its component measures. The drainage density measurements convey numerical measurement of landscape dissection and runoff potential. Shreve's [3&4] magnitude systems have the greatest importance in investigating the relation between rainfalls and run off. This analysis can be carried out by calculating the linear, relief and aerial parameters. Basin morphometry has advantage onto predict flood peaks, assess the sediment yield and estimate erosion rates [5]. After all morphometric analysis provides quantitative description of the basin geometry, the initial slope or inequalities in the parent rock (hardness), structural controls, recent diastrophism, geological and geomorphic history of drainage basin [6].

The Vamanapuram river (L = 82 km; A = 687 km^2, n = 6^{th}), originates from Chemmunji *mottai* (elev.= 1717m. a.m.s.l.), in the high ranges of the Western Ghats in southern Kerala - one of the eight prime "hottest hotspots" of biological diversity in the world, and traverses through the highland and midland of Thiruvananthapuram and Kollam districts before debouching into the Anchuthengu lake in the lowland region at Chiryankeezhu (Fig.1).

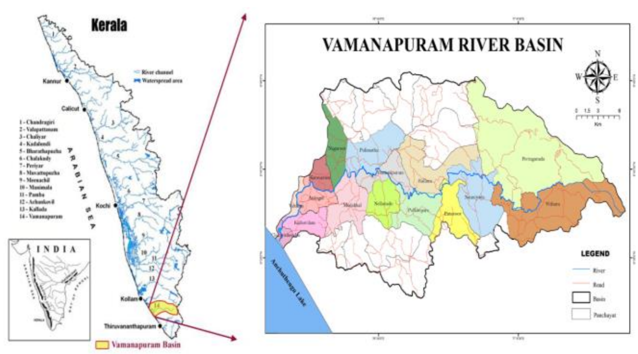

Fig. 1 Location map

The Vamanapuram River Basin (VRB) lies between 8°35' to 8°50' N latitudes and 76°40' to 77°15' E longitudes and is bounded by Nedumangadu taluka of Thiruvananthapuram

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district in the south, Kottarakkara taluka of Kollam district in the north, Tamil Nadu State in the east and the Arabian Sea in the west. It nourishes 29 panchayats and one municipality located within the basin.

II. MATERIALS AND METHODS

The study area falls in the toposheets 58D/13, 58D/14, 58H/1 and 58H/2 (1:50,000). The toposheets were interpreted and thematic maps generated for the purpose of study of morphometry, mainly in the Kerala State Remote sensing and Environment Centre (KSREC) lab. The morphometric parameters for the Vamanapuram River Basin (VRB) have been computed following the formulae (Table 1) of Horton [2] and Strahler [6] with the aid of Arc Map 9.3 GIS software. For the present study, the total drainage basin of the Vamanapuram river is divided into 6 sub-basins (Fig. 2). The six sub-basins (SB1 to SB6) of stream order 5 and the total drainage area of the VRB were analyzed in detail. The results of morphometric analysis that describe the basin are shown in Tables 2 - 3.

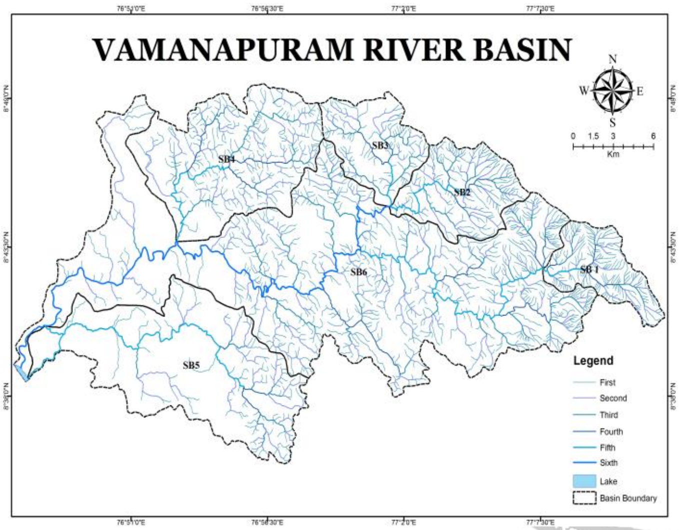

Fig.2 Fifth order sub-basins and drainage networks of VRB

Table 1 Computation of morphometric parameters

Morphometric Parameters	Formulae
Stream number (Nu)	$(N1+N2+N3+.........Nn)$ [2]
Stream length (Lu) (Km)	$(L1+L2+L3+.......Ln)$ [6]
First order streams (Sfi)	$\sum N1$ [7]
Mean stream length (mLu)	$\frac{Lu}{Nu}$ [6]
Stream length ratio (Rl)	$\frac{mLu}{mLu-1}$ [6]
Bifurcation Ratio (Rb)	$\frac{Nu}{Nu+1}$ [6]
Rho coefficient (ρ)	$\frac{Rl}{Rb}$ [2]
Lemniscate ratio (K)	$\frac{\pi(Lb)^2}{4A}$ [8]
Form factor (Ff)	$\frac{A}{(Lb)^2}$ [9]
Elongation ratio (Re)	$2/_{Lb}\sqrt{A/\pi}$ [10]
Circularity Ratio (Rc)	$\frac{4\pi A}{P^2}$ [11]
Texture ratio (Rt)	$\frac{Sfi}{P}$ [12]
Drainage texture (T)	$\frac{\sum Nu}{P}$ [2]
Shape index (Sw)	$\frac{1.27(A)}{(Lb)^2}$ [13]
Stream frequency (Fs)	$\frac{Nu}{A}$ [9]
Drainage density (Dd)	$\frac{Lu}{A}$ [9]
Constant of channel maintenance (C)	$1/_{Dd}$ [10]
Length of overland flow (Lg)	$1/_{2(Dd)}$ [2]
Basin relief (R)	$H-h$ [7]
Melton's ruggedness number (mRn)	$\frac{R}{\sqrt{A}}$ [14]
Ruggedness number (HD)	$R\times Dd$ [15]

III. RESULTS AND DISCUSSION

Stream order (S)

The primary step in the drainage basin analysis; behalf of the hierarchical stream ranking [16] & [6], stream order is directly proportional to the size of the contributing watershed, to the channel dimensions and to stream discharge at that place in the system. The classification of streams is based on the number and type of tributary functions, has proven to be a useful indicator of stream size, discharge and drainage area [16]. The advantage of Strahler's ordering system is that it can be derived mathematically from concepts of elementary combinatorial analysis [17]. The VRB is of 6th order according to the satellite imagery, while all the sub-basins except SB6 are 5th order streams.

Stream length ratio (Rl)

In nature, Rl is on the order of 2.1 - 2.9 [18]. All the sub-basins here are disagreeing with this hypothesis with wide variations from 0.9 to 11.9 (SB5). SB4 shows a range with small variations (1.7 to 2.7) supposed to maintaining a natural basin. Stream length ratio between successive stream orders varies due to differences in slope and topographic conditions and has an important relationship with the surface flow discharge and erosional stage of the basin [19]. Rl of six sub-basins (order wise) are shown in Table 3 and those of VRB ranges between 1.6 and 5.3 indicating the dominance of local geology on stream length [20].

Bifurcation ratio (Rb)

The 'Rb' values of six sub-basins of VRB are shown in Table 3. Rb value is ranging between 1 and 6, tends to follow the drainage pattern in all around the sub-basin. Each sub-basin has four or five sub categories according to the stream number. Giusti and Schneider [21] announced the inverse relationship between stream order and Rb; within a basin / sub-basin Rb values should decrease inversely to the stream order. SB1 & SB6 show partially higher values (>5) *i.e.*, structural units have dominant role over them [6]. Three sub-basins show values between <3 and >5, may follow different drainage pattern (SB4 & 5) [22]. The 'Rb' values of VRB ranges between 3.55 and 5 indicating that it is falling under normal basin category [16].

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Table 3 Variables of stream length and stream number

	Bifurcation ratio (Rb)				
	I/II	II/III	III/IV	IV/V	V/VI
SB1	5.32	5.17	2	3	0
SB2	4.27	3.36	2.75	4	0
SB3	4.03	4.43	3.5	2	0
SB4	4.84	4.75	3	4	0
SB5	3.71	3.11	3	3	0
SB6	4.29	4.53	5.67	6	1
VRB	4.42	4.32	3.55	4.4	5
	Stream length ratio				
	II/I	III/II	IV/III	V/IV	VI/V
SB1	1.3	1.7	1.6	1.8	0
SB2	1.6	1.4	1.2	6.6	0
SB3	1.2	3.8	1.2	1.3	0
SB4	1.7	2.1	2.4	2.7	0
SB5	2	0.9	1.7	11.9	0
SB6	1.5	2	2.2	5.6	2.2
VRB	1.6	1.9	1.7	5.3	3.4

RHO Coefficient (RHO)

Higher values indicate high and low values indicate low capacity for the storage of water. RHO coefficient for sub-basins vary from 0.41 (SB1) to 1.30 (SB5). Higher RHO values of SB5 indicate higher storage during hydrologic storms and higher dilution of erosional paradigm during elevated discharge [23].

Lemniscate ratio (K)

Chorley [24] proposed Lemniscate ratio (K) based upon the expression at the basin with Lemniscates' curve (ratio of basin area to basin length) to determine the shape of the drainage basin. Higher values of K would recommend a rather elongate basin; lower values inferring nearly circular / oval basins. All the sub-basins, including total watershed (7.65) are elongated in shape, excluding SB1 (3.02) and SB3 (2.69), where a circular or oval plan view is seen and more details are available from Table 2.

Form factor (Ff)

The form factor of entire VRB is 0.10 and those of six sub-basins are varying from 0.06 (SB 6) to 0.29 (SB3). When recategorizing based on form factor, all basins along with VRB have elongated appearance.

Elongation ratio (Re)

According to this, VRB and all independent sub-basins are elongated in shape. SB3 belongs to high relief and steep slope terrain.

Circularity ratio (Rc)

Circularity ratio is uniform between 0.6 and 0.7 for homogenous rock types (SB2 & SB3) and 0.40 to 0.5 for quartzitic terrain (SB1), and it is mainly concerned with length and frequency of streams, geological structures, land-use / land cover, climate, relief and slope of the basin [25]. The entire study area has generated an 'Rc' value of 0.32, while those of all six sub-basins are shown in Table 2. The sub-basins exhibit inconsistency in 'Rc' values that range between 0.16 (SB6) and 0.62 (SB3). Circularity index less than 0.5 is considered as elongated. It is well noticed that VRB as a whole is elongated by attaining the 'Rc' value less than 0.5, whereas some of the sub-basins have greater than 0.5 values, suggesting that they are more or less circular in shape and are characterised by high to moderate relief (SB2, SB3 & SB4) and are prompted to prolonged flood hazard.

Texture ratio (Rt)

The 'Rt' values of VRB is 9.01 and has a fine texture class. All the sub-basins, except SB5 and SB6, are belonging to intermediate class, while the excluded one will go to course. Groundwater recharge potential is more in SB5 and SB6 than all other sub-basins.

Drainage texture (T)

About 65% of the basin following fine texture, remaining are satisfied with coarse to moderate texture.

Shape index (Sw)

Basins having lower values of Sw are of groundwater potential zones and indicate that the basin length is long which resulted in a good chance for groundwater recharge [13]. While the higher values indicate that the basin length is short which resulted in more ostentatious flood. The calculated value of Sw for VRB is 0.13, while it ranged from 0.07 for SB6 to 0.37 for SB3.

Drainage pattern (Dp)

SB2 shows a deviation from general trend in addition to SB4. SB2 follows a parallel pattern especially at NE portions. Parallel drainage patterns form where there is a pronounced slope to the surface where parallel, elongate landforms like outcropping resistant rock bands exist. A parallel pattern somehow indicates the presence of a major fault that cuts across an area of steeply folded bedrock [26]. SB4 has a trellis pattern. Trellis drainage is characteristic of folded mountains [27].

Stream frequency (Fs)

The Fs of whole basin is 2.81, while those of six sub-basins are shown in Table 2, ranging between 6.68 (SB1) and least value 1.13 (SB5). All sub-basins and VRB alone are considered as areas of poor stream frequency.

Drainage density (Dd)

For a higher drainage density basin (> 4.0) permeability will be very low, slope of terrain will be steep and infiltration capacity become poor [28]. The drainage density of an area varies between 1.24 and 3.37 km km-^{2} indicating low drainage density and trend a positive correlation with lower relief [29].

Nag [30] suggested that low drainage density indicates the watersheds of highly permeable sub-soil and thick vegetation cover. Low Dd will lead to course drainage texture, while high drainage density leads to fine drainage texture. The drainage density of all six sub-basins is shown

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in Table 2. High drainage density of the study area suggests (SB1= 4.25 km km^{-2}) very low permeability, slope of the terrain with steep and minimum infiltration capability. Dd of VRB is 2.22 km km^{-2} favourable to a natural watershed.

Constant of channel maintenance (C)

The reciprocal of Dd is C and signifies how much drainage area is required to maintain a unit length of channel. Low values of C indicate that among all sub- basins, these are the weakest or very low resistant soils, sparse vegetation and mountainous terrain.

Length of overland flow (Lg)

The 'Lg' value of the whole basin is 0.22; while those of six sub-basins are ranging between 0.12 (SB1) and 0.40 (SB5). Moderate to high values of Lg of sub-basins and the VRB as a whole indicate the geomorphic maturity. Fourth order basins of the VRB are in the state mature to older [31].

Maximum and minimum elevations (H&h)

Maximum and minimum heights are corresponding to the highest and lowest points of the basin and sub-basins. The maximum height of the VRB is 1720 m. (*i.e.*, Chemmunji *mottai*) in the northern sector and minimum height is 20 m. in the southern sector. This is directly related to basin relief.

Melton's Ruggedness Number (mRn)

0.25 - 0.75 will be the range of minimum MRn value for colluvial fans [32]**.** In general, ruggedness number can be high, up to 2.0 or 3.0 for a first or second order basin, and rarely above 1.0 for a third or fourth order basin [33]. The study area got the record of 0.06 and attains maximum (0.29) for SB1 and minimum (0.02) for SB5.

Ruggedness number (HD)

For high basin relief and drainage density, ruggedness number attains high values. The 'HD' value of the VRB is 3.78 and those of six sub-basins varying between 0.34 (SB5) and 6.8 (SB1) and are shown in Table 2. Steepness in the sub-basin can be well explained with higher values of HD. The VRB showing moderate value of HD displays lower degree of channel incision in the natural condition. The low ruggedness value of the watershed implies that the area is less prone to soil erosion and have intrinsic structural complexity in association with relief and drainage density [34].

Table 2 Morphometric evaluation of Vamanapuram river basin

Parameters	Sub-basins						
	SB1	**SB2**	**SB3**	**SB4**	**SB5**	**SB6**	**VRB**
Stream order	V	V	V	V	V	VI	VI
Stream number	206	211	166	350	145	857	1932
First order streams	165	158	125	276	104	661	1489
Basin length	10.89	14.94	11.42	22.84	34.72	77.90	81.87
Basin width	2.83	2.96	3.33	4.30	3.71	4.46	8.4
Basin area	30.82	44.29	38.07	98.22	128.81	347.28	687.51
Lemniscate ratio	3.02	3.96	2.69	4.17	7.35	13.72	7.65
Form factor	0.26	0.20	0.29	0.19	0.11	0.06	0.10
Elongation ratio	0.58	0.50	0.61	0.49	0.37	0.27	0.36
Circularity ratio	0.49	0.60	0.62	0.51	0.33	0.16	0.32
Texture ratio	5.87	5.18	4.50	5.60	1.48	3.96	9.01
Drainage texture	7.33	6.91	5.98	7.10	2.06	5.13	11.70
Shape index	0.33	0.25	0.37	0.24	0.14	0.07	0.13
Stream Frequency	6.68	4.76	4.36	3.56	1.13	2.47	2.81
Drainage density	4.25	3.37	2.82	2.53	1.24	2.11	2.22
Constant of channel maintenance	0.24	0.30	0.35	0.39	0.80	0.47	0.45
Length of overland flow	0.12	0.15	0.18	0.20	0.40	0.24	0.22
Maximum Height	1720	1060	460	320	290	1220	1720
Minimum Height	120.00	60.00	60.00	20.00	20.00	20.00	20.00
Basin relief (km)	1.60	1.00	0.40	0.30	0.27	1.20	1.70
Melton's Ruggedness Number	0.29	0.15	0.06	0.03	0.02	0.06	0.06
Ruggedness number	6.80	3.37	1.13	0.76	0.34	2.54	3.78

IV. CONCLUSION

The morphometric analysis of the drainage networks of the study area shows dendritic pattern (which indicates the homogeneity in texture and lack of structural control). The river network is of the sixth order. The lower order streams mostly dominate in the basin. The low drainage density of the study area suggests that, it has high permeable sub-soil and coarse drainage texture; while some sub-basins (SB1, SB2 & SB3; representing the highland) are beyond the range and exhibit very low permeability, slope of the terrain with steep and minimum infiltration capability and sparse to thick vegetation cover. Rb declares that SB1 - SB7 show some structural control on drainage pattern (Rb > 5). The variation in stream length ratio might be due to change in slope and topography.

The drainage texture falls under the very fine category (>8). The circularity ratio (0.32) indicates the basin is elongate in shape, have low discharge runoff and highly permeable sub-soil condition. SB2 is highly prone to vulnerable hazards. The low form factor and high shape factor categorise them to be elongate in shape and flow for longer duration and attract more groundwater recharge. The elongated basins

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(SB5 & SB6) are facing floods during heavy rain. Basins with higher circularity and elongation ratios (Rc and Re) tend to have higher flash flood potentiality [35]. The low ruggedness value of watersheds implies that study area has intrinsic structural complexity and is less prone to soil erosion (except SB1, SB2 and SB6). Moderate values of HD offer relatively low channel incision. Higher value of mRn showed that SB1 can make alluvial / colluvial fans. In VRB, flood and landslides appear in association with the monsoons. Low value of drainage intensity implies that the VRB favours agents of denudation, making it highly susceptible to flooding, gully erosion and landslides. The VRB as a whole shows fine texture, but because of moderate drainage density the highland and lowland regimes have moderately permeable sub-soil.

REFERENCES

[1] D. R. Montgomery, and J. M. Buffington, Channel-reach morphology in mountain drainage basins. *Geological Society of America Bulletin*, vol. 109(5), pp. 596-611, 1997.

[2] R. E. Horton, Erosional Development of Streams and their Drainage Basins; Hydrophysical Approach to Quantitative Morphology. *Bulletin of the Geological Society of America*, vol. 56, pp. 275-370, 1945.

[3] R. L. Shreve, Statistical law of stream numbers. *The Journal of Geology*, vol. 74, pp. 17-37, 1966.

[4] R. L. Shreve, Infinite topologically random channel networks. *The Journal of Geology*, vol. 75, pp. 178-186, 1967.

[5] L. R. Gardner, The role of rock weathering in the phosphorus budget of terrestrial watersheds. *Biogeochemistry*, vol. 11(2), pp. 97-110, 1990.

[6] N. Strahler, Quantitative geomorphology of drainage basins and channel networks. *In*: Chow, V. T. (Ed.), Handbook of applied Hydrology, vol. 4, pp. 394-376, 1964.

[7] N. Strahler, Hypsometric (area-altitude) analysis of erosional topography. *Bulletin of the Geological Society of America*, vol. 63, pp. 1117-1142, 1952.

[8] R. J. Chorley, Illustrating the laws of Morphometry, *Geological Magazine*, vol. 94, pp. 140-150,1957.

[9] R. E. Horton, Drainage Basin Characteristics. *Transactions- American Geophysical Union,* vol. 13, pp. 350-361, 1932.

[10] S. A. Schumm, The evolution of drainage system and slopes in Bad Lands at Perth Amboy, New Jersey. *Bulletin of the Geological Society of America*, vol. 67, pp. 597-646, 1956.

[11] C. Miller, A Quantitative Geomorphic Study of Drainage Basin Characteristics in the Clinch Mountain area, Virginia and Tennessee, Tech Rep 3, Proj. NR 389-402, Department of Geology, Columbia University, New York, 1953.

[12] S. A. Schumm, *Quaternary paleohydrology*. NA, 1965.

[13] P. Haggett, Locational analysis in modern geography. Arnold, Londres, 1965.

[14] M. A. Melton, The geomorphic and paleoclimatic significance of alluvial deposits in southern Arizona. *The Journal of Geology*, vol. 73(1), pp. 1-38, 1965.

[15] P. C. Patton, and V. R. Baker, Morphometry and floods in small drainage basins subject to diverse hydrogeomorphic controls. *Water Resources Research*, vol. 12(5), pp. 941-952, 1976.

[16] N. Strahler, Quantitative analysis of Watershed Geomorphology. *Transactions - American Geophysical Union*, vol. 38, pp. 913–920, (1957).

[17] M. A. Melton, A derivation of Strahler's channel-ordering system. *Journal of Geology*, vol. 67, pp. 345-346, 1959.

[18] E. Scheidegger, Theoretical Geomorphology. George Allen and Unwin Ltd. London, pp. 243-248, 1970.

[19] P. D. Sreedevi, K. Subrahmanyam, and S. Ahmed, The significance of morphometric analysis for obtaining groundwater potential zones in a structurally controlled terrain. *Environmental Geology*, vol. 47, pp. 412–420, 2005.

[20] J. P. Majumdar, Morphometric analysis of the 4th order drainage watersheds of the Khowai river basin, Tripura, India: Some preliminary results and observations. *Journal of the Indian Society of Photo-Interpretation and Remote Sensing*, vol. 10(3), pp. 49-53, 1982.

[21] E. V. Giusti, and W. J. Schneider, The distribution of brances in river networks. USGS Professional Paper-422G, 1965.

[22] H. T. Verstappen, "Applied Geomorphology: Geomorphological Surveys for Environmental Development". Amsterdam: Elsevier Science Pubishers, pp. 1-437, 1983.

[23] L. M. Mesa, Morphometric analysis of a subtropical Andean basin (Tucuma´n, Argentina). *Environmental Geology*, vol. 50, pp. 1235–1242, 2006.

[24] R. J. Chorley, D. E. C. Malm, and H. A. Pogorzelski, A new standard for measuring drainage basin shape. *American Journal of Science*, vol. 255, pp. 138-141, 1957.

[25] S. Joji, and A. S. K. Nair, The sustainability of water resources in Vamanapuram river basin, southern Kerala, India. *Indian journal of geomorphology*, Vol. 7(1&2), pp. 99-110, 2002.

[26] T. Subramani, and K. Babu, A Study on Agricultural Drainage Systems. International Journal of Application or Innovation in Engineering & Management, vol. 4(5), pp. 304-312, 2015.

[27] M. E. Ritter, (Fluvial systems in The Physical Environment: an Introduction to Physical Geography,

 DOI : 10.18231/2454-9150.2018.0034

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2006. http://www.earthonlinemedia.com/ebooks/tpe_3e/fluvial_systems/channel_geometry_and_flow.html

[28] S. A. Schumm, Variability of river patterns. *Nature (Physical Science)*, vol. 237, pp. 75-76, 1972.

[29] D. M. Thomas, and M. A. Benson, Generalization of streamflow characteristics from drainage-basin characteristics. Washington, DC, USA: US Government Printing Office, 1970.

[30] S. K. Nag, Morphometric analysis using remote sensing techniques in the Chaka sub-basin, Purulia district, West Bengal. *Journal of the Indian Society of Remote Sensing*, vol. 26(l &2), pp. 69-76, 1998.

[31] S. Sajikumar, Micro level and water resource studies for sustainable land use development: A case of Vamanapuram river basin, Kerala, Centre for Earth Science Studies, Thiruvananthapuram, 2001.

[32] F. A. de Scally, I. F. Owens, and J. Louis, Controls on fan depositional processes in the schist ranges of the Southern Alps, New Zealand, and implications for debris-flow hazard assessment. *Geomorphology*, vol. 122(1), pp. 99-116, 2010.

[33] S. Goudie, Encyclopedia of Geomorphology, vol. 1. Routledge, New York. ISBN 0-415-32737-7, 2004.

[34] K. Pareta, and U. Pareta, Quantitative Morphometric Analysis of a Watershed of Yamuna Basin, India using ASTER (DEM) Data and GIS. *International Journal of Geomatics and Geosciences*, vol. 2 (1), pp. 248-269, 2011.

[35] Omran, D. Schröder, A. El Rayes, and M. Geriesh, Flood Hazard Assessment in Wadi Dahab, Egypt Based on Basin Morphometry Using GIS Techniques. GI_Forum Program Committee, Herbert Wichmann Verlag, VDE Verlag GMBH, Berlin, pp.1-11, 2011.

 DOI : 10.18231/2454-9150.2018.0034