Journal Homepage: -www.journalijar.com
INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)
ISSN NO. 2320-5407
Article DOI:10.21474/IJAR01/8158
DOI URL: http://dx.doi.org/10.21474/IJAR01/8158

RESEARCH ARTICLE

STUDY OF DRAINAGE SYSTEM AND ITS HYDROLOGICAL IMPLICATIONS USING GEO-SPATIAL TECHNIQUES: A MORPHOMETRIC ANALYSIS IN MOHAL KHAD WATERSHED OF KULLU DISTRICT, HIMACHAL PRADESH, INDIA.

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Manuscript Info

Manuscript History
Received: 04 October 2018
Final Accepted: 06 November 2018
Published: December 2018

Keywords:-
Morphometric Analysis, RS & GIS, ASTER, DEM, ArcGIS, IHR.

Abstract

Understanding the behavior of surface drainage network is one of the important prerequisite condition for effective planning and management of water resources within the watershed. Morphometric analysis of a watershed is a crucial step in watershed development and management to understand and interpret the dynamics of drainage system of the watershed and is useful for interpretation of silent features of drainage network. A morphometric analysis was carried out to evaluate the drainage characteristics of Mohal khad watershed which covers an area about 54 km^2 in Kullu district of Himachal Pradesh in Indian Himalayan Region (IHR). Geospatial technique/tool such as Remote Sensing (RS) and GIS was used to evaluate the linear, areal and relief aspects of morphometric parameters. RS and GIS technique is very helpful over the conventional methods that are too laborious and cumbersome. To carry out this study, Survey of India (SOI) toposheet of 1:50,000 scale and ASTER DEM (30 m resolution) data were used and analysis was carried out in ArcGIS 10.5 software. Total 21 morphometric parameters of Mohal khad watershed were evaluated considering the linear, areal and relief aspects. The significance of each morphometric parameter with the hydrological behavior of the watershed is discussed in this study. This exercise provide detailed insight into drainage system of the Mohal khad watershed, which is useful for the development and management of water conservation measures in the area.

Introduction:-

Indian Himalayan Region (IHR) comprise different morphologic region that have special influence on drainage pattern of the watersheds. Understanding the different aspects of the drainage system of the watershed in various

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geologic and climate regimes is of utmost important for the scientific development and management of water resources. Proper planning and management of available water resources is necessary for progress and sustainable economic development of people living in hilly regions. The drainage system/pattern determines the hydrologic behavior of a watershed. Most of the hydrological analyses incorporate morphologic parameter as an important base for the computation of runoff, infiltration and susceptibility to erosion within the catchment (Rawat et al. 2012). Therefore, it is highly imperative for any hydrological investigation to understand the drainage pattern, density geometry of the system that are controlled by topography, climate and geology. Detailed morphometric analysis provide an insight on basin evolution and further its role in development of drainage morphometry of landforms and their characteristics (Sujatha et al. 2013). The different linear, areal and relief aspects of morphometric parameters of a drainage basin are correlated with different hydrological phenomenon. The morphometric analysis of watershed coupled with soil information, land use and slope helps in predicting the hydrological behavior of the watershed, (Pingale et al. 2012). The significance of morphometric analysis have been discussed and used for development and management of water resources by several researcher (Prakash et al., 2016; Thomas et al., 2011; Rawat et al., 2012; Guleria et al., 2014; Pareta and Pareta, 2012; Biswas and Biswas, 2015; Pareta and Pareta, 2011) among others.

The measurement of morphological parameters in the inaccessible mountainous area IHR is a tremendous and tedious task. Further, the conventional methods to carry out the morphometric study is very cumbersome and laborious. Now a days, geo-spatial techniques such as Remote Sensing (RS) and GIS are extensively used in water resources development and management, hydrological investigation, rainfall-runoff simulation modeling etc. (Sujatha et al. 2013; Babu et al. 2016; Thomas et al. 2011; Rawat et al. 2012). RS and GIS works in very flexible environment and are powerful tools for storage, retrieval, manipulation and analyze the spatio-temporal information in monitoring and management of natural resources. In present study, morphometric analysis of Mohal khad watershed was carried out using RS and GIS. The different linear, areal and relief aspects of morphometric parameters for Mohal khad watershed were evaluated in GIS environment using ArcGIS software 10.5. Total 21 morphometric parameters of watershed were evaluated considering the linear, areal and relief aspects. The watershed under study is a small sub-watershed in Beas river basin and become seasonal nowadays. Hence, the study was focused on evaluation of morphometric parameter of Mohal khad watershed to study its drainage pattern and corresponding hydrological implications for planning and management of different water conservation measures for sustainable development.

Study area:-

The study area, Mohal khad watershed, is located in Kullu district of Himalchal Pradesh. The watershed lying between latitudes 31° 50′ 7″ and 31° 55′ 31″ N and longitudes 77° 01′ 30″ and 77° 07′ 37″ E in the Indian Himalayan Region (IHR) and covers an area of 53.79 km^2 (Fig. 1). The elevation varies from 1118 to 3248 m amsl (Fig. 2). The soil of watershed is deep and medium deep loamy soil. The watershed is mostly forested watershed, with forest area covering 65% of total watershed area. The watershed drains into Beas river at village Mohal.

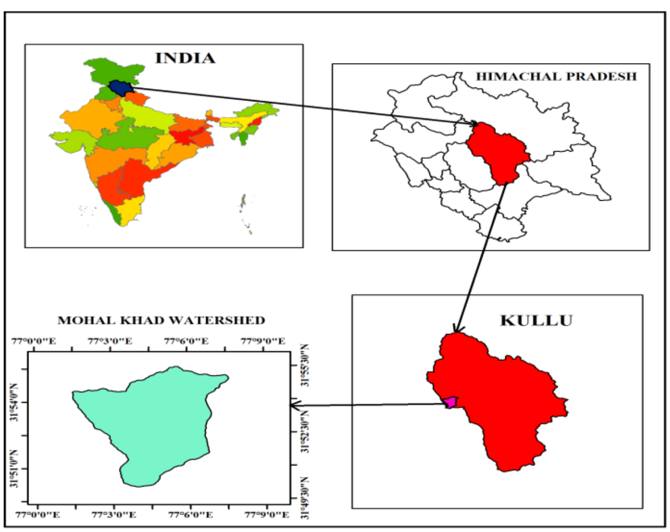

Fig. 1:-Location of Mohal Khad Watershed

Materials and Methods:-

Morphometric analysis of Mohal Khad watershed was carried out using Survey of India (SOI) (53 E/1) toposheet of scale 1:50,000 and digital elevation data of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) DEM with 30 m spatial resolution. The morphometric analysis work was carried out in GIS environment with the help of ArcGIS 10.5 software. The morphometric variables were categorized into Linear, Areal and Relief aspects and were evaluated using standard formulation as given in Table 1.

Table 1:-Linear, Areal and Relief aspects for morphometric analysis of Mohal khad watershed

Sr. No.	Parameters & Labels	Definition & Formulation	Units	Reference
Linear aspects				
1	Perimeters (P)	Length of the drainage basin boundary	Km	Schumm (1956)
2	Basin Length (Lb)	Maximum length of the basin measured parallel to the main drainage line	Km	Schumm (1956)
3	Stream order (Nu)	Hierarchical ordering	Dimensionless	Strahler (1957)
4	Stream Length (Lu)	Length of the major stream	Km	Horton (1945)
5	Bifurcation ratio (Rb)	$Rb = Nu/N(u+1)$ where Nu is number of stream of any given order and Nu+1 is number in the next higher order.	Dimensionless	Horton (1945)
6	Stream length ratio (Rl)	$Rl = Lu/L(u-1)$ where Lu is stream length order "u" and Lu-1 is stream segments length of the next lower order.	Dimensionless	Horton (1945)
Areal aspects				
7	Area (A)	Geographic area of the river basin	Km^2	
8	Drainage Density (Dd)	$Dd = \Sigma Lt/A$ where Σ Lt is the total length of all ordered streams.	$Km\ Km^{-2}$	Horton (1945)
9	Stream Frequency (Fs)	$Fs = \Sigma Nt/A$ where Σ Nt is total number of stream segments of all orders.	Km^{-2}	Horton (1945)
10	Circularity Ratio (Rc)	$Rc = 4\pi A/p^2$	Dimensionless	Miller (1953)
11	Elongation Ratio (Re)	$Re = (1.128\sqrt{A})/Lb$	Dimensionless	Schumm (1956)
12	Length of over land flow (Lg)	$Lg = 1/2Dd$	Km	Horton (1945)
13	Constant of channel maintenance (C)	$C = 1/Dd$	Km	Schumm (1956)
14	Drainage Texture (Rt)	$Rt = Nu/P$ Where, Nu is the total number of stream of all orders and P is perimeters (Km)	Km	Horton (1945)
15	Drainage Intensity (Di)	$Di = Fs/Dd$	Km	Faniran (1968)
Relief aspects				
16	Basin Relief (R)	$R = H-h$ Where, H is maximum elevation and h is minimum elevation within the basin.	M	Schumm (1956)
17	Ruggedness number (Rn)	$Rn = R*Dd$	Dimensionless	Strahler (1958)
18	Gradient Ratio (Rg)	$Rg = (Es-Em)/Lb$ Where, Es is the elevation at the source, Em is the elevation at the mouth.	Dimensionless	Horton (1932)

19	Basin Slope (Sb)	Sb = ((M*N)/A) *100 Where, M is the total length of the contours within the watershed in meters, N is the contour interval in meters and A is the basin area in m^2	Percent (%)	Verstappen (1983)
20	Infiltration number (If)	If = Fs*Dd	Dimensionless	Faniran (1968)
21	Form factor (Rf)	$Rf = A/Lb^2$	Dimensionless	Horton (1932)

Result and Discussion:-

The morphometric characteristics (i.e. linear, areal and relief aspects) of Mohal khad watershed has been carried out using the formulation mentioned in Table 1 and the results are presented in Table 2, 3 and 4. Further, the discussion of drainage system and its hydrologic implications on Mohal khad watershed is discussed in subsequent paragraphs according to morphometry of the watershed.

Drainage Pattern:-

The drainage pattern of the watershed reflects the influence of slope, lithology and geographic structure which directly affects the water storage characteristics of the watershed. Drainage pattern presents some characteristics of drainage basins through drainage density and drainage texture. Mohal khad has dendritic and radial pattern of drainage system. Total drainage area of Mohal khad watershed is 53.79 km^2. Mohal khad watershed is of 5^{th} order drainage system and is dominated by first order streams (75% of total stream order) followed by second order streams.

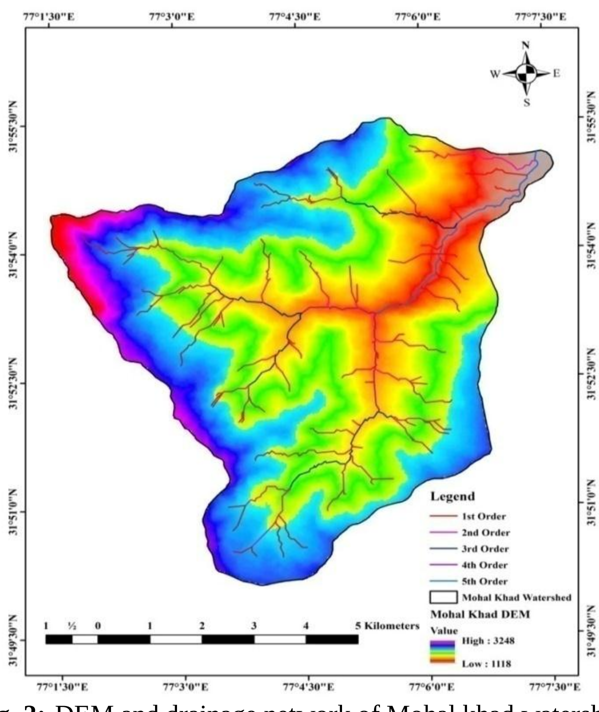

Fig. 2:-DEM and drainage network of Mohal khad watershed

Linear Aspects:_

The linear aspects of the Mohal khad watershed are perimeter, basin length, stream order, stream length, bifurcation ratio and stream length ratio. These characteristics are usually act as indicators of watershed size, shape and scale.

The outer boundary that encloses the watershed area and act as divide between the watersheds called as perimeter of the watershed. Whereas, basin length as define by Schumm (1956) is the longest dimension of the basin parallel to the principal drainage line of the watershed. The perimeter and basin length of the Mohal khad watershed was found to be 34.10 km and 9.22 km respectively. The stream length of the watershed were computed using SOI toposheet and ASTER DEM in ArcGIS 10.5 software and uses principle of Horton (1945). The number of streams of various order in the Mohal khad watershed were counted and their respective lengths from drainage divide to outlet were measured in ArcGIS environment. The total stream length of the watershed of various orders was found to be 77.73 km (Table 2).

After detail analysis of drainage network of Mohal khad watershed, it was found that the watershed is of 5th order and drainage pattern is dendrite. The stream order is also an indicator of the amount of discharge (stream flow produced by the watershed through its drainage network), stream size and drainage area. Stream orders were calculated based on the method proposed by Strahler (1957). The stream length of 1st, 2nd, 3rd, 4th and 5th order streams were 40.56, 17.92, 10.00, 3.79 and 5.46 km respectively (Table 2). It also showed that first order streams have maximum length of stream segment and subsequently decreases towards fifth order stream. Further, the drainage analysis also shows that frequency of 1st, 2nd, 3rd, 4th and 5th order streams was found to be 85, 20, 5, 2 and 1 respectively (Table 2). It is also found that there is decrease in stream frequency with increase in stream order. The stream length ratio was 0.44, 0.56, 0.38, and 1.44 for II/I, III/II, IV/III and V/IV orders respectively (Table 2). The increasing trend of stream length ratio from lower to higher stream order (except for IV/III) indicates the matured geomorphic stage (Singh and Singh, 1997). According to Sreedevi et al. (2004) the variability of stream length ratio among the successive stream orders is a reflection of difference between slope and topography which controls the discharge from the watershed and erosion stages of the watershed. The mean stream length ratio of the Mohal khad watershed is 0.71.

Horton (1945) considered the bifurcation ratio as an index of relief and dissertation. It is also denote the effect of structural disturbance on drainage pattern of the watershed. The lower values of bifurcation ratio are characteristics of the watersheds which are suffered less structural disturbance (Strahler, 1964) and drainage pattern has not been distorted because of the structural disturbances (Nag, 1998). Bifurcation ratio is also useful for hydrograph shape of the watersheds (Pingale et al., 2012). Bifurcation ratio for Mohal khad watershed was found to be 4.25, 4.00, 2.50 and 2.00 for I/II, II/III, III/IV and IV/V orders respectively (Table 2). It is also showed that the values of bifurcation ratio is not same from one to next order streams. Normally bifurcation ratio values varies from 2 to 5 and tends to be more for elongated basins (Beaumont, 1975). Bifurcation ratio values for Mohal khad watershed varies from 2 to 4.25 with mean of 3.19 (Table 2). Low value of bifurcation ratio shows that the watershed has less structural disturbance on its drainage pattern; whereas, higher values indicates structural complexity and low permeability (Pankaj and Kumar, 2009).

Table 2:-Statistics of drainage network

Stream Order	Number of Stream Segments	Stream Length (km)	Mean Stream Length (Lsm) (km)	Stream Length Ratio (RL)	Bifurcation Ratio (Rb)
I	85	40.56	0.48	-	4.25
II	20	17.92	0.90	0.44	4.00
III	5	10.00	2	0.55	2.50
IV	2	3.79	1.90	0.38	2.00
V	1	5.46	5.46	1.44	-

Areal aspects:-

In the morphological analysis, the areal aspect represents the geometry of watershed that includes the drainage density, stream frequency, circulatory ratio, elongation ratio, length of overland flow, constant of channel maintenance, drainage texture, drainage intensity etc.

As like stream length, an area of the watershed is also an important parameter for hydrologic analysis and design on hydraulic structures within the watershed. Area of the watershed represents the area enclosed within the boundary of watershed divide. The area of Mohal khad watershed is 53.79 km^2. The drainage density of Mohal khad watershed was found to be 1.45 km/km2. It is an expression to indicate the closeness of spacing of channels (Horton, 1932). The drainage density depends on many factors like topography, lithology, climate, pedology and vegetation (Sujatha et al. 2013). Higher the drainage density, higher is the relief and rainfall; whereas, lower the drainage density, lower is the relief and rainfall (Thomos et al. 2011). The drainage density of the Mohal khad watershed indicates coarse drainage pattern, relatively better or thick vegetative cover over the drainage area. The relative spacing of these drainage line is represented by drainage texture. Drainage texture is the total number of stream segments of all orders per perimeter of that area (Horton, 1945). Drainage texture ratio for Mohal khad watershed is 3.31 (Table 3). Drainage texture is classified into five different textures based on drainage density values, i.e., very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8) (Smith, 1950). Thus Mohal khad watershed comes under coarse texture. Underlying lithology, infiltration capacity and relief aspects influence the drainage texture. Stream frequency, which is an indication of texture of drainage network, also depends on lithology of the basin (Horton, 1945). It defined as the total number of stream segments of all order per unit area and is found to be 2.10 per km^2 for Mohal khad watershed (Table 3). Drainage intensity along with drainage density and stream frequency gives the behavior of the watershed towards the flooding situation (Pareta and Pareta, 2011). Drainage intensity is defined as the ratio of the stream frequency to the drainage density. Drainage intensity of the Mohal khad watershed is 1.45 (Table 3).

A property of landforms which indicates the magnitude of surface area of watershed required to develop and/or sustain unit length of stream segment is represented by constant of channel maintenance. It's a reciprocal value of drainage density. For Mohal khad watershed constant of channel maintenance was found to be 0.69 km. Further, the length and frequency of streams, geological structures, land use/land cover and slope of the basin influences the circulatory ratio of the watershed. The circulatory ratio for Mohal khad watershed was estimated to be 0.58 (Table 3). In hydrological analysis, this circulatory ratio indicates the basin shape, implying the rate of infiltration and time taken for the excess water to reach the basin outlet (Sujatha et al., 2013). The basin shape can be further decided based on elongation ratio, which was estimated using formulation of Schumm,(1956) and classified by Strahler (1964) indexing; i.e. circular (0.9-0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7) and more elongated (<0.5). The Mohal khad watershed is of oval shape having elongation ratio of 0.90 (Table 3).

Length of overland flow is the length measured from a point on drainage divide to a point on the adjacent stream channel (Horton, 1945). In general it's a length of run of rain water directly falls on the ground surface till it reaches into specific channels. It is one of the most crucial factors which determine the hydrological and physiographical development of the watershed (Pingale et al. 2012). The length of overland flow of Mohal Khad Watershed is 0.34 km (Table 3). Low or shorter length of overland flow values of Mohal khad watershed indicate the quicker surface runoff which is analogous considering the hilly terrain of Mohal khad watershed.

Table 3:-Results of Areal aspects of morphometric analysis

Area (A)	53.79
Drainage Density (Dd)	1.45
Stream frequency (fs)	2.10
Circulatory Ratio (Rc)	0.58
Elongation Ratio (Re)	0.90
Drainage Texture (Dt)	3.31
Drainage Intensity (Di)	1.45
Length of over land flow (Lg)	0.34
Constant of channel maintenance (C)	0.69

Relief aspects:-

For Mohal khad watershed different relief aspect has been calculated that essentially includes basin relief, ruggedness number, gradient ratio, basin slope, infiltration number and form factor.

Basin relief is the different between the highest and lowest point of a the watershed. The basin relief for Mohal khad watershed is determined as 2130 meter (Table 4) indicating the mountainous topography of the region which resulted in high runoff nature of the watershed. Values of basin relief helps in the determination of stream gradient or slope which ultimately influences the flood pattern of the watershed and the sediments it carries (Babu et al. 2016). Ruggedness Number is the product of the basin relief and the drainage density (Strahler 1952). The Ruggedness Number of Mohal khad watershed is 3088.5 (Table 4). This denotes the high relief of the watershed which is a typical characteristic of the mountainous region. Because of the high relief the watershed is more prone to soil erosion associated with high slope and high runoff from the watershed. Gradient ratio which is indicator of channel slope helps in the assessment of runoff volume from a particular stream (Sreedevi et al. 2004). The gradient ratio of Mohal khad watershed is 0.22 (Table 4). This higher value represent higher channel slope associated with steep V-shaped channel of the Mohal khad watershed. Further, basin slope of the watershed controls the runoff from the watershed as well as indicates the time of concentration of the runoff which is of great significance in hydrological study of any drainage basin (Mesa, 2006). Basin slope of the Mohal khad watershed is 62.84% (Table 4) representing the typical moderate to highly sloping mountainous river basin having faster runoff producing capacity with less time of concentration. Infiltration number which represents the infiltration characteristics of the watershed is defined as the product of drainage density and stream frequency (Faniran, 1968). The higher infiltration number, lower will be the infiltration and the higher runoff (Pareta and Pareta, 2011). Infiltration number of Mohal khad watershed is found to be higher i.e. 3.05 (Table 4), making it high runoff producing watershed which in turn may cause soil erosion.

Form factor is the ratio of basin area to square of the basin length (Horton, 1932). It ranges from 0 to 1; where 0 represents highly elongated shape of the watershed and 1 represents perfectly circular shape of the watershed. Mohal khad watershed has form factor of 0.63 (Table 4) that represents the oval shape of the watershed with the characteristics of high peak flow for shorter duration.

Table 4:-Results of Relief aspects of morphometric analysis

Basin Relief (R)	2130
Ruggedness number (Rn)	3088.5
Gradient ratio (Rg)	0.22
Basin Slope (Sb)	62.84
Infiltration number (If)	3.05
Form Factor (Rf)	0.63

Morphometric analysis showed that Mohal khad watershed has characterized with high runoff producing watershed which more likely causes soil erosion. Nature of drainage system of the watershed showed the chances of high peak flow with less time of concentration which controls the flooding pattern of the watershed. This necessitate the need of soil and water conservation measures in the watershed to prevent the soil erosion and harvesting of rain water using appropriate bio-engineering measures to reduce the surface runoff and minimize the flood hazards. The results of this morphometric analysis can be utilized to prepare a comprehensive watershed development and management plan in order to conserve both soil and water.

Conclusion:-

An attempt has been made to study in detail the different morphometric characteristics of Mohal khad watershed in order to study the drainage system and its hydrological implications on the watershed. Different linear, areal and relief aspects of watershed morphometry has been studied and quantified. This study demonstrate the use of geospatial technology i.e. Remote Sensing and GIS, for morphological analysis of the watershed using ASTER DEM dataset. The Mohal khad watershed is classified as a 5th order watershed, where the first order streams followed by second order streams dominates the watershed drainage network/pattern which enables sufficient draining from the watershed. The watershed is characterized with high relief and high gradient that results in high runoff from watershed with less time of concentration which may results in soil erosion and flood like situation when there is peak flow. The quantified linear, areal and relief aspects of the watershed indicates the mountainous configuration of the basin that influences the soil erosion and runoff from the watershed. This analysis forms a basis for watershed development and management plan where the drainage characteristics helps in constructing the location specific rainwater harvesting structures.

Acknowledgement:-

The research work has been carried out as a part of In-house project of the G. B. Pant National Institute of Himalayan Environment and Sustainable Development at Himachal Regional Centre of the Institute for which authors gratefully acknowledges the respected Director of the Institute for providing funding and necessary facilities to carry out the work.

References:-

1. Babu, k. J., Sreekumar, S and Aslam, A. (2016) Implication of drainge basin parameters of a tropical river basin of South India. Appl Water Sci 6:67-75.
2. Beaumont, P. (1975) Hydrology in Whitton B A (ed.) River ecology, Blackwell scientific, Oxford, pp 1-38.

3. Biswas, A. and Biswas, M. (2015) Morphometric and landuse and landcover change analysis of Lokjuriya river basin, Jharkhand, India using Remote sensing snd GIS technique. IOSR Journal of Humanities and Social Science, 20(7): 77-85.
4. Faniran, A. (1968) The Index of Drainage Intensity - A Provisional New Drainage Factor. Australian Journal of Science, 31, pp 328-330.
5. Guleria, S. S., kishore, N. and Rishi, M. S. (2014) Morphometry and geomorphological investigation of the Neugal watershed, Beas river basin, Kangra district, Himachal Pradesh using GIS tools. Journal of Environment and Earth Science, 4(2):78-86.
6. Horton R. E. (1932) Drainage basin characteristics. Transactions of American Geophysics Union, 13: 350 361.
7. Horton R. E. (1945) Erosional development of streams and their drainage basins: Hydro-physical approach to quantitative morphology. Geological Society of America Bulletin, 56(3): 275–370.
8. Mesa, L. M. (2006) Morphometric analysis of a subtropical Andean basin (Tucumam, Argentina). Environ Geol, 50(8): 1235-1242.
9. Miller, V.C. (1953) A quantitative geomorphic study of drainage basin characteristics in the Clinch mountain area, Virginia and Tennessee. Technical Report 3, Office of Naval Research, Department of Geology, Columbia University, New York.
10. Naag, S. K. (1998). Morphometric analysisusing remote sensing technique in the Chaka sub basin Purulia district, West Bengal. J. Indian Soc Remote Sensing, 26: 69-76.
11. Pankaj, A. and Kumar, P. (2009) GIS-based Morphometric analysis of five major sub-watersheds of Song river, Dehradun district, Uttarakhand with special reference to landslide incidences. Journal of Indian Society of Remote Sensing, 37(1): 157-166.
12. Pareta, K. and Pareta U. (2011) Quantitative Morphometric analysis of a watershed of Yamuna basin, India using ASTER (DEM) data and GIS. International Journal of Geomatics and Geoscience, 2(1):248-268.
13. Pareta, K. and Pareta U. (2012) Quantitative Geomorphometric analysis of Ravi river basin, H.P. India. International Journal of Remote Sensing and GIS, 1(1): 41-56.
14. Pingale, S. M., Chandra, H., Sharma, H. C. and Mishra, S. S. (2012) Morphometric analysis of Maun watershed in Tehri-Garhwal district of Uttarakhand using GIS. International Journal of Geomatics and Geosciences, 3(2):373-386.
15. Prakash, K., Singh, S. and Shukla, U. K. (2016) Morphometric changes of the Varuna river basin, Varanasi district, Uttar Pradesh. Journal of Geomatics, 10(1):48-54.
16. Rawat, K. S., Mishra, A. K. and Tripathi, V. K. (2012) Hydro-mophometrical analyses of sub-himlayan region in relation to small hydro-eletric power. Arab J Geosci., DOI 10.1007/s12517-012-0586-6.
17. Schumm, S. A. (1956) Evolution of Drainage Systems & Slopes in Badlands at Perth Anboy, New Jersey. Bulletin of the Geological Society of America, 67, pp 597-646.
18. Singh, S., and Singh, M. C. (1997) Morphometric analysis of Kanhar river basin. National Geographical Journal of India, 43(1): 31-43.
19. Smith, K. G. (1950) Standards for grading texture of erosional topography. American journal of Science, 248, pp. 655-668.
20. Sreedevi, P. D., Subrahmanyam, K. and Ahmed, S. (2004) The significance of Morphometric analysis for obtaining groundwater potential zones in a structurally controlled terrain. Environmental Geology, 47: 412-420.
21. Strahler A. N. (1957) Quantitative analysis of watershed geomorphology. Transactions of American Geophysical Union, 38: 913–920.
22. Strahler A. N. (1958) Dimensional analysis applied to fluvially eroded landforms. Geological Society of America Bulletin, 69: 279–300.
23. Strahler A. N. (1964) Quantitative geomorphology of drainage basin and channel networks. In: Chow V T. Handbook of Applied Hydrology. New York: McGraw Hill, 4–76.
24. Strahler, A. N (1952) Hypsometric Analysis of Erosional Topography. Bulletin of the Geological Society of America, 63, pp 1117-42.
25. Sujatha, E. R., Selvakumar, R., Rajasimman, U. A. B. and Victor, R. G. (2013) Morphometric analysis of sub-watershed in parts of Western Ghats, South India using ASTER DEM. Geomatics, Natural Hazards and Risk, 6(4):326-341.
26. Thomas, J., Joseph, S., thrivikramji, K. P. and Abe, G. (2011) Morphometric analysis of the drainage system and its hydrological implications in the rain shadow regions, Kerala, India. J. Geogr. Sci., 21(6):1077-1088.
27. Verstappen, H. T. H. (1983) Applied Geomorphology: Geomorphological Surveys for Environmental Development. New York: Elsevier.