Journal Homepage: - www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

ISSN NO. 2320-5407

Article DOI: 10.21474/IJAR01/17024
DOI URL: http://dx.doi.org/10.21474/IJAR01/17024

RESEARCH ARTICLE

STUDY OF DRAINAGE SYSTEM AND ITS HYDROLOGICAL IMPLICATIONS USING GEO-SPATIAL TECHNIQUES: A MORPHOMETRIC ANALYSIS IN MUTHUGAD WATERSHED OF GRAHWAL HIMALYA, UTTARAKHAND

Manju Arya[1], Deepak[2] and J. S. Rawat[2]

1. Kumaun University SSJ Camus Almora, Department of Geography Nanital, Uttarakhand (India).
2. Department of Geography SSJ University Almora, Uttarakhand (India).

……………………………………………………………………………………………………....

Manuscript Info

……………………….

Manuscript History
Received: 25 March 2023
Final Accepted: 30 April 2023
Published: May 2023

Key words:-
Morphometry, Hydrology, DEM, GIS, Mathugad, Grahwal Himalaya, Watershed Management

Abstract

……………………………………………………………………

Measurements of the shape or geometry of any natural form, including those of plants, animals, and relief features, are referred to as morphometry. Morphometry is the accurate measurement of landforms. One of the crucial requirements for effective management and planning of water resources within the watershed is an understanding of the behavior of the surface drainage network. In order to comprehend and interpret the dynamics of the watershed's drainage system and to understand the drainage network features, morphometric study of a watershed is a vital stage in watershed development and management. Watershed characterization includes morphometry as a key component. Aspects that are dimensional, aerial, and relief are typically present for the conservation of surface and ground water, watershed development and management strategies are crucial. Applying mathematical equations and statical measures to data from topographic maps and satellite images, morphometric attributes reflect a measurement of the earth's surface and are processed in accordance with the principles of quantitative analysis. A study of drainage morphometry and its impact on the hydrology of the Mathugad watershed, Grahwal Himalaya, Uttarakhand (India) has been made. Total basin covers 77.12 sq km area. Shuttle Radar Topographic Mission (SRTM) data and on 1:50000 scale and Survey of India Toposheet as reference were utilized to create slope maps, aspect grids, and digital elevation models (DEMs) for the thorough investigation. Geographic information systems (GIS) were employed to assess the linear, areal, and relief aspects of the morphometric parameters. Numerous morphometric features of the Mathugad watershed have been intended by applying GIS techniques and using SRTM data. The research shows that the rainfall has a moderate to large impact on how stream segments develop in the basin area thrusting and faulting's controlling influence is primarily responsible for the basin's elongated structure. Relief ratio indicates that the discharge capability of these watersheds is very high and the groundwater potential is meager. Dendritic drainage pattern in the area shows that the area consists of homogeneous rock material which is structurally undisturbed. Form factor and circulatory ratio statics indicates basin shape is elongated the results clearly indicate relations

Corresponding Author: Manju Arya
Address:- Kumaun University SSJ Camus Almora, Department of Geography Nanital, Uttarakhand (India).

among various morphometric attributes of the basin and help to understand their role in sculpturing the surface of the region. These studies are very useful for planning rainwater harvesting and watershed management.

……………………………………………………………………………………………………....

Introduction:-

Drainage morphometry is the measurement of the linear, areal, and relief properties of any drainage basin. (Clarke, 1966) The arrangement of the topography of the earth, as well as the size and shape of its landforms, are measured and mathematically analyzed. The various drainage morphometric factors can also be used to better understand the geomorphological stages of evolution and their erosional properties (Strahler 1952). Any natural form, whether it be a plant, an animal, or relief features, can have its geometry or shape measured (Strahler, 1969). Horton (1932) was the person who originally introduced drainage morphometry understanding the surrounded structure, geomorphological formations, and hydrological parameters of any basin depends on its drainage morphometric features.

The successful and sustainable economic development of those who reside in hilly areas depends on effective planning and management of the available water resources. The hydrologic behavior of a watershed is governed by the drainage system or pattern. According to Rawat et al. (2012), the majority of hydrological assessments use morphologic parameters as a crucial foundation for determining the levels of runoff, infiltration, and susceptible to erosion within the drainage area. The importance of morphometric analysis has been covered and applied to the development and management of water resources by a number of researchers, including Prakash et al. (2016), Thomas et al. (2011), Rawat et al. (2012), and Guleria et al. (2014). The study of the watershed's morphometric analysis reveals key elements for determining potential groundwater areas, managing water supplies, conveniently locating the location of the drainage system's water-storing systems, runoff, and geographic characteristics. Additionally, this study may be useful in industries including forestry, agriculture, and regional planning. Keeping these factors in mind, efforts are made to accurately characterize the watershed's physical characteristics in order to develop an effective watershed management strategy.

Remote sensing and Geographical information system are effective instruments for storing, retrieving, manipulating, and analyzing spatio-temporal information in the monitoring and management of natural resources. They also operate in very flexible environments. Advanced planning and management of land and water resources for the implementation of location-specific technologies benefit from the integration of remote sensing and GIS. A geographic information system (GIS) is a method for tracking and examining instances of geographical properties that is software-based. Maps are included in GIS technology together with standard activities like investigate and statistical analysis. By utilizing Digital Elevation Models (DEMs), GIS enhances calculations for watershed features. The science of remote sensing involves gathering data on areas or objects from a distance, typically using aircraft or satellites. GIS incorporates imagery from remote sensing. Recently, several researchers have examined morphometric parameters using remote sensing data and GIS and have come to the conclusion that remote sensing has become an effective tool for analyzing drainage morphometry (Sridevi et al., 2005; Thomas et al., 2010; Pandey, R.K., 1990). In the present work, RS and GIS were used to perform a morphometric analysis of the Mathugad watershed. Using ArcGIS software 10.4.3, the various linear, areal, and relief components of the morphometric parameters for the Mathugad watershed were assessed. Total of nineteen morphometric watershed characteristics were investigated, taking into account the linear, areal, and relief factors. The analysis of the morphometric watershed simulation yields useful metrics for assessing groundwater potential areas, establishing locations for water harvesting systems, and managing water quality, runoff, and drainage system geo-graphic characteristics. The current study examined the morphological traits of the Mathugad watershed in the Chamoli district of Uttarakhand.

Study Area

Study area Viz., the Mathugad watershed (Grahwal Himalaya) extends in between $30^0 4'02''$ N and $30^0 6'03''$ N latitudes and $79^0 13'15''$ E and $79^0 18'04''$ E longitudes and encompasses an area of about 77.12 Km^2 lies in Gairsain block in district Chamoli. (Figure 1) The watershed situated in the lesser Himalaya Genetic region of the central Himalaya bounded by the others districts Pithoraghrh, Bageshwar in the East, Almora and Pauri garhwal in the south and Rudraprayag and Uttarkashi in the West. The watershed is totally under hilly terrain. Including the elevation from the sea level varying in between 1533m to 3119 m there are 33 villages lies in the watershed having a total population of 5775 male and 6153 female persons. Geographically, the study area is very important it is a summer capital of the Uttarakhand State.

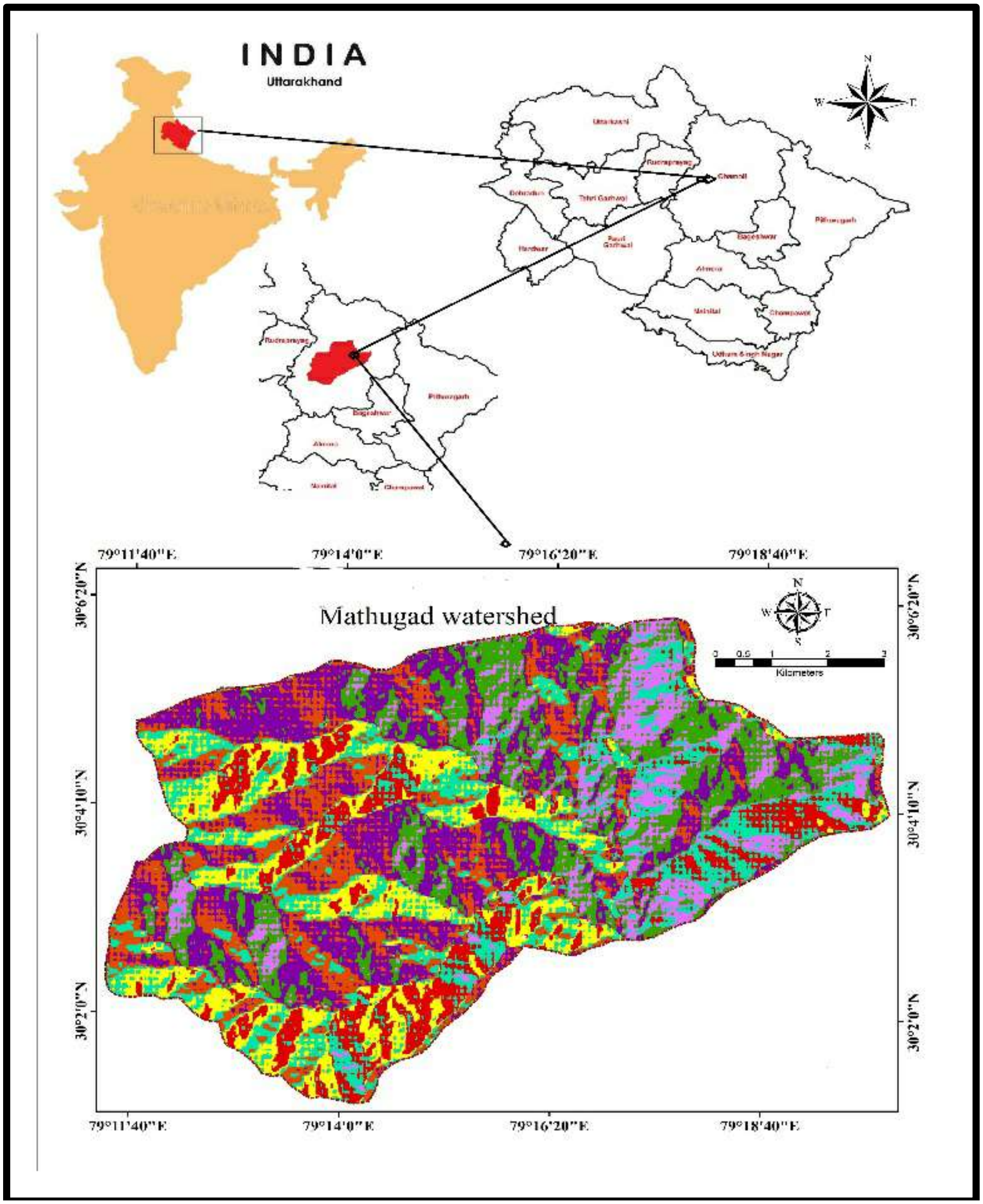

Figure1:- Location map of the Mathugad Watershed, Grahwal Himalaya

Methodology:-

Morphometric analysis of Mathugad watershed was carried out using Survey of India (SOI) (53 0/14) toposheet of scale 1:50,000 and digital elevation data of shuttle radar topographic mission (SRTM) DEM with 90m spatial resolution. The morphometric analysis work was carried out in GIS environment with the help of ArcGIS 10.4.1 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 Muthugad watershed.

S. N	Morphometric parameters	Symbol	Formulae	Unit	References
	Linear aspect				
1	Stream order	(U)	Hierarchical ordering	Dimensionless	Strahler (1964)
2	Streams no	. (Nu)	Nu=number of streams of a particular order 'u'		Strahler (1964)
3	stream length	(Lu)	Length of the major stream	(km)	Horton (1945)
4	Mean Stream length	(Lsm)	Lsm = Lu/Nu; where, Lu=total length of streams (km) of a particular order 'u', Nu=Total number of streams of a particular order 'u'	(km)	Horton (1945)
5	Stream length ratio	(Rl)	Rl = Lu/L(u-1) where Lu is streams length order "u" and Lu-1 is streams segments length of the next lower order	Dimensionless	Horton (1945)
6	Bifurcation ratio	(Rb)	Rb = Nu/N(u+1) where Nu is number of streams of any given order and Nu+1 is number in the next higher order	Dimensionless	Horton (1945)
	Areal aspect				
7	Area	(A)	Geographic area of the river basin	(Km^2)	
8	Basin length	(Km)	Maximum length of the basin measured parallel to the main drainage line	(km)	Schumm (1956)
9	Basin perimeter	(Km)	Length of the drainage basin boundary	(Km^2)	Schumm (1956)
10	Stream frequency	(Fs)	Fs= N/A; where, N =total number of streams of a given basin, A =total area of basin (km2)	(Km^2)	Horton (1945)
11	Drainage density	(Dd)	Dd = ΣLt/A where Σ Lt is the total length of all ordered streams, A =Basin area (km2)	(Km^2)	Horton (1945)
12	Drainage texture	(Rt)	Rt= ∑Nu / P, Where, Rt is the texture Ratio ∑Nu is the total number of streams of the catchment and P is the perimeter of the catchment.	Dimensionless	Horton (1945)
13	Basin circulatory ratio	(Rc)	Rc = 4πA/p2	Dimensionless	Miller,1953
14	Form factor	(Rf)	Rf =A/(Lb)² Where, A=Area of basin, Lb=Basin length	(km)	Horton (1932)
15	Infiltration number	(If)	If= Rt * Fs, Where Rt = Drainage Texture, Fs = Stream Frequency	(Km^2)	Zavoiance (1985)
	Relief aspect				
16	Basin Relief	(R)	H = Z - z where, Z =highest relief, z =lowest relief	(m)	Schumm (1956)
17	Ruggedness number	(Rn)	Rn = R*Dd	Dimensionless	Strahler (1958)
18	Relief Ratio	(Rh)	Rh = H / Lb Where, Bh=Basin relief, Lb=Basin length	(m)	Schumm (1956)
19	Dissection index	(Di)	Di= H/R; H =relative relief (m), R =absolute relief (m)	Dimensionless	DovNir(1957)

Result And Discussion:-

Linear Aspect

In the point of linear aspects, we measure some parameters as drainage order and drainage length, mean drainage length, drainage length ratio and bifurcation ratio. The Mathugad watershed has linear characteristics including its perimeter, basin length, stream order, stream length, bifurcation ratio, and stream length ratio. The size, form, and scale of a watershed are typically indicated by these features (Fig-2).

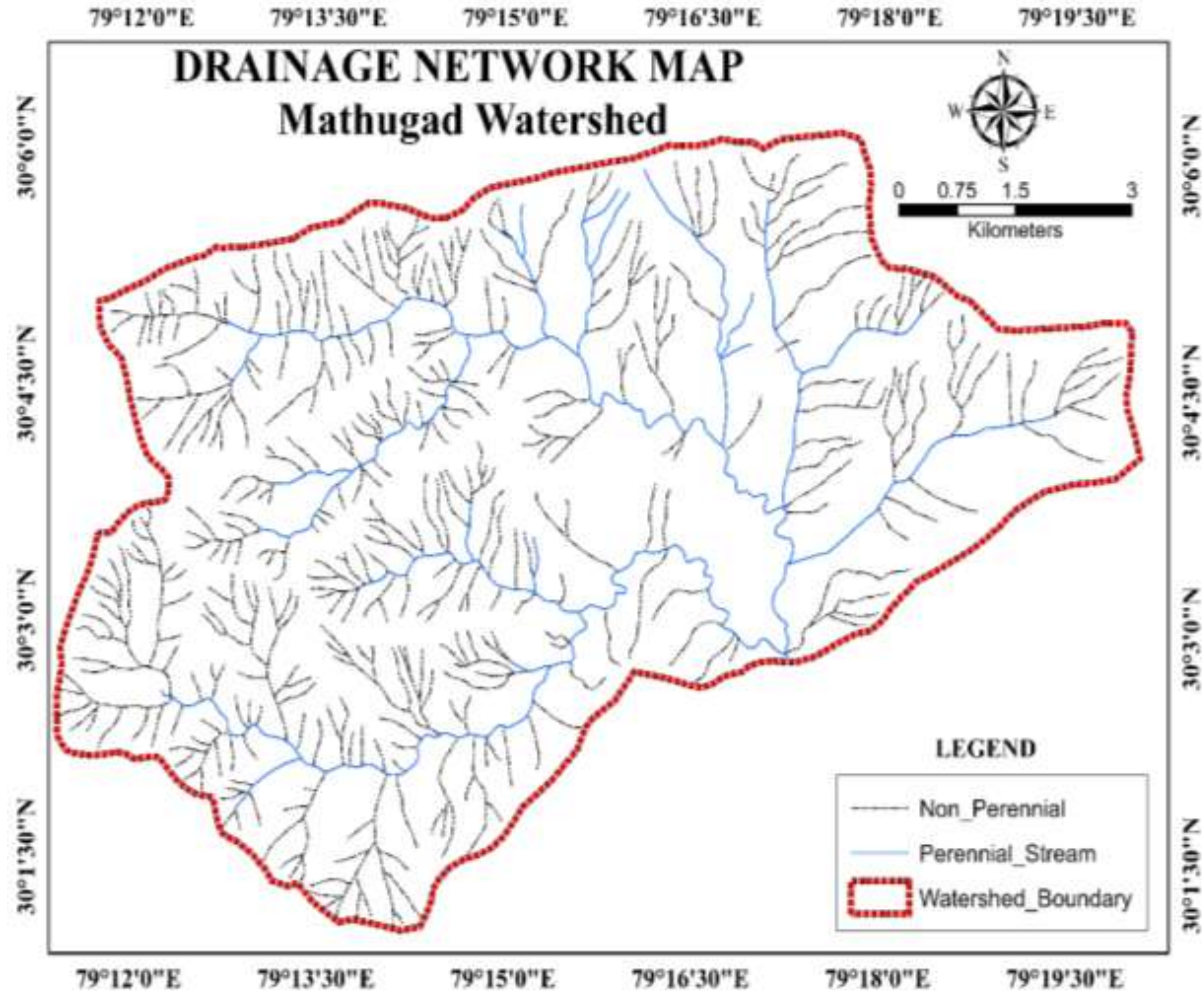

Figure 2:- Drainage network map of Muthugad watershed, Grahwal Himalaya, district-Chamoli, Uttarakhand.

Table 2:- Linear morphometric statics.

Stream order	Total Stream Number	Total stream length (km)	Mean Stream Length (Km)	Bifurcation ratio	Stream length ratio
First order	371	178.94	0.48	4.03	-
Second order	93	37.32	0.41	3.83	0.21
Third order	24	24.77	1.03	4.00	0.66
Fourth order	6	16.65	2.78	3.00	0.67
Fifth order	2	12.84	6.42	2.00	0.77
Sixth order	1	0.12	0.12	-	0.01

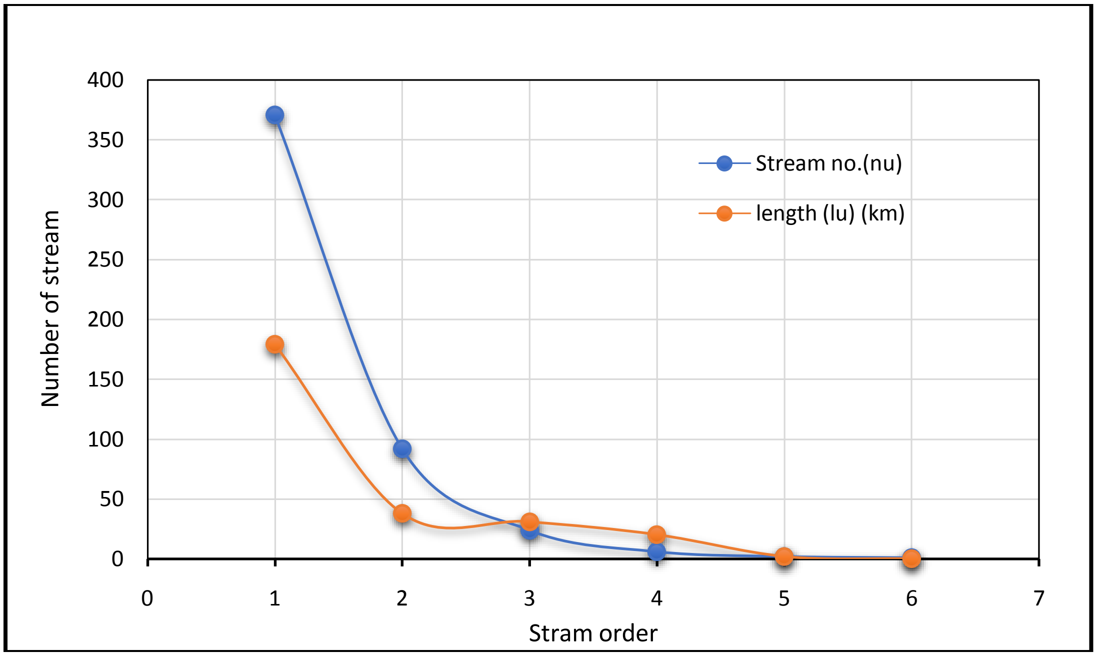

Figure 3:- Geometric relationship between Stream Orders and stream number (A) Stream order and stream Length (B) in the river basin.

Stream Order (U)
Any drainage basin analysis's first step is to designate the drainage orders, which are based on the drainages' rank in importance. The stream order also serves as a gauge for drainage area, stream size, and the quantity of discharge (stream flow) that the watershed produces through its drainage system. The Strahler (1964) approach was used to calculate stream ordering. The drainage network was examined, and it was discovered that the dendritic Mathugad watershed is of the sixth order.

Stream Number (Nu)
After defining stream orders, every segment of each order is added up to determine how many segments there are in the given order (u). The total number of streams in the watershed can be determined by counting each stream individually. There are 490 streams in the Mathugad watershed. Table 1 and a diagrammatic representation of the number of streams in various orders are provided. Table-3.1, which is shown in graph 2, reveals that there are 371 first order streams, 92 second order streams, 24 third order streams, 6 fourth order streams, 2 fifth order streams, and 1 sixth order stream in the research region. According to Fig.3 which is entirely based on Horton (1945), stream numbers, the number of streams reduces as the order rises.

Stream Length (Lu)
The study area's total stream length is 270.84 km, according to Table 3.1. Arc GIS 10.4 software and topography data were used to measure the length of a watercourse. Out of the overall stream length, the first order stream makes up 178 km, while the second, third, fourth, fifth, and sixth order streams make up the remaining 24.77 km, 16.55 km, 12.84 km, and 0.12 km, respectively (table.2). It also showed that first order streams have maximum length of stream segment and subsequently decreases towards fifth order stream (Fig.3).

Mean stream Length (Lsm)
A parameter related to drainage network elements and the accompanying basin surface is mean stream length (L) (Strahler, 1964). This was computed by dividing the order's total stream length by the number of streams that jointly make up each segment the mean stream length of the first order stream in the study area is the 0.483 km. The mean stream length of the second, third, fourth and fifth, sixth order stand at 0.412, 4.066, 2.116 and 0.116km, respectively.

Stream Length Ratio (RL)

The mean stream length ratio for the study area is shown in Table 3.1, which is shown in Table 3.2 and shows that the second, third, fourth, fifth, and sixth order streams had mean stream length ratios of 0.21, 0.82, 0.65, 0.10, and 0.05, respectively. Because of the differing degrees of resistance of the rocks present in the watershed, the stream length ratio has a significant impact on the surface flow discharge and erosional stage.

Bifurcation Ratio (Rb)

Bifurcation ratio is also useful for hydrograph shape of the watersheds (Pingale et al., 2012). Bifurcation ratio for Mathugad watershed was found to be 0.21, 0.82, 0.65, 0.10 and 0.05 for first, second, third, fourth, fifth and sixth order streams orders respectively, according to Pankaj and Kumar (2009), and a low bifurcation ratio suggests that the watershed's drainage pattern is not as structurally disturbed as one with a greater value. It also implies that the watershed has poor permeability.

Areal Aspect:

In a morphological study, the areal aspect is a representation of the geometry of the watershed and contains factors like drainage density, stream frequency, circulatory ratio, elongation ratio, length of overland flow, constant of channel maintenance, drainage texture, drainage intensity, etc. (table-3).

Table 3:- Areal morphometric statics.

Area (km2)	77.12
Perimeter (kilometer)	40.16
Basin length (kilometer)	13.05
Drainage Density (Dd)	3.50
Stream frequency (fs)	6.44
Circulatory Ratio (Rc)	0.56
Drainage Texture (Dt)	12.37
Infiltration number (If)	22.54
Form Factor (Rf)	0.45
Elongation Ratio (Re)	0.75

Basin Area (A)

For hydrologic research and design on hydraulic structures inside the watershed, a watershed's area is also a crucial component. The region contained within the watershed boundary is known as the watershed area. 77.12 km^2 make up the Mathugad watershed area.

Perimeter (P)

The perimeter of Muthugad watershed stands at 40.16 km.

Basin length (L)

Maximum length between drainage basin mouth and reach has been considered as basin length which is found 13.05 km.

Stream frequency (Fs)

The total number of stream segments for all orders inside a given area is referred to as stream frequency. The lithology of the basin affects stream frequency, which is a measure of the drainage network's texture (Horton, 1945). The research area's stream frequency was calculated using the formula below:

$$Fs = \sum Nu/Ab$$

Where: Sf = Stream frequency, Nu = Total number of stream segments of all orders, Ab = Area of the unit. As a result of the preceding formula, the region's average drainage frequency, which indicates high stream frequency, is 6.44 N/km2. Increased runoff from the basin is indicated by the watershed's high drainage stream frequency.

Drainage Density (Dd)

Drainage density is one of the most important parameters that indicate the landforms in a stream eroded topography. The concept of drainage density was introduced by Horton (1932). It is expressed as:

$$\text{Drainage density} = \Sigma\, Lu / Ab$$

Where Lu = length of all order streams Ab = the area of the watershed

Using the previously mentioned formula, the area's drainage density comes out to 3.50 km/km2, which is low. The drainage densities of Mathugad watershed and the stream orders of the watersheds reveal that the nature of subsurface strata is permeable in character since the values are less than 5.0.

Form factor (Rf)

A watershed's form factor is calculated by dividing its average width by its axial length, where axial length is the distance along the longest watershed dimension that is parallel to the main drainage line. Form factor is written as:

$$F = A/L^2$$

Where, F = form factor, A = basin Area, L = basin length

The form factor's value ranges from 0 (zero) to 1(one). Zero indicates a very extended shape, whereas one indicates a perfectly circular shape. The entire Mathugad watershed has a form factor value of 0.45, which indicates less elongated. the index of form factor shows the inverse relationship with peak discharge.

Texture Ratio (Rt)

Drainage texture denotes the relative spacing of the drainage lines or closeness or proximity of one channel to another. Drainage texture was first introduced by Smith (1950) using the contour with· most crenulations divided by the length of the perimeter of the basin. (R. Shyamalan, M. Sc, 2014).

$$Dt = \Sigma Nu / Bp$$

Where Dt is the texture ratio, Nu is the total number of catchment streams, and Bp is the basin perimeter. According to Smith (1950), drainage density can be divided into five different textures: extremely coarse (<2), coarse (2-4), moderate (4-6), fine (6-8) and very fine (>8). In the current study, the Mathugad watershed texture ratio is 12.37, indicating very fine texture and an area with high relief and steep slopes.

Infiltration Ratio (If)

The infiltration number (If) is calculated as the sum of the drainage density and stream frequency for each basin area. Calculated was the Mathugad catchment's infiltration rate by applying the formula:

$$If = Dd * Fs,$$

Where, Dd is the drainage density, and Fs is the drainage frequency. It provides information about infiltration into the basin. its characteristics. A higher Infiltration number denotes less infiltration, whereas a lower Infiltration value denotes significant outflow. According to the formula above, the infiltration ratio for the Mathugad watershed is 22.54.

Circularity ratio (Rc)

According to Strahler (1964) and Miller (1953), the circularity ratio is a numerical representation of the watershed that is calculated by dividing the area of the watershed (Au) by the area of a circle (Ac) with the same perimeter. With the aid of the following formula, the presented circularity ratio was obtained;

$$(Rc) = 4Ab/Bp2$$

Where Rc is basin circularity ratio, Ab is the area of the basin, Bp is perimeter of the basin. A perfect circular basin is indicated when the basin circularity ratio equals unity. This ratio may be one or less, but it may never be greater than one. Using the aforementioned formula, the Mathugad watershed has a circularity ratio of 0.56 which indicate the Muthugad watershed in semi- circular.

Elongation ratio (Re):

The elongation ratio (Re), which is defined as the "ratio between the diameter of a circle with the same area as the basin and the maximum length of the basin as measured for the relief ratio," can also be used to describe the shape of a drainage basin (Schumm,1956). According to Strahler, the elongation ratio (Re) is represented statistically as follows:

$$Re = \sqrt{(Au/\pi)} / Lb$$

Where, A=Area of basin, π=3.14, Lb=Basin length. Re ranges in value from 0 to 1. The number 0 has a greatly elongated appearance, and the number 1 displays a circular shape. The Mathugad Re (0.75) geometry of the basin is less elongated.

Relief Aspect

The study of three-dimensional properties involving area, volume, and height of vertical landform dimensions is related to the relief elements of watersheds. The description of altitudinal zones, absolute and relative relief, hypsometric analysis, slope, aspect, dissection index, and roughness number are all included in the relief morphometry of the watershed (table-4).

Table 4:- Areal morphometric statics.

Basin Relief (R)	1586
Relief ratio (Rh)	230.09
Ruggedness number (Rn)	5,551
Dissection index (Di)	0.21

Basin relief (R)

The difference between a watershed's highest and lowest point is known as the basin relief. Basin relief (R) is represented mathematically as follows Schumm (1956):

$$R = H-h$$

Where, H is maximum elevation and h is minimum elevation within the basin. The hilly topography of the area, which led to the watershed's high flow, is indicated by the basin relief for the Mathugad watershed, which is calculated to be 1586 meters (Table 4).

Relief Ratio (Rh)

According to Schumm (1954), the relief ratio is the proportion of a basin's total relief, or the elevation difference between its lowest and highest points, to its longest dimension that is parallel to the main drainage line. This ratio has no dimensions the basin's Rh value is 230.09 which denotes High Rh values and a steep slope point to relief and vice-versa, more peaked basin discharges and erosive power are typically a result of steeper basins' faster run-off.

Ruggedness index

The drainage density and basin relief are the components which collectively make up the ruggedness number (Strahler, 1952), it is expressed as:

$$Rn = R*Dd$$

Were, R is basin relief and Dd is drainage density. Mathugad watershed has a ruggedness score of 5,551 (Table 4). This indicates the watershed's extremely high relief, which is a typical feature of the mountainous area. The watershed is more vulnerable to soil erosion due to the steep relief, high slope, and heavy runoff from the watershed.

Hypsometric curve

Strahler identified three types of landforms, namely, young, mature and monadnock on the basis of hypsometric curve shape. The value of relative area (a/A) always varies from 1.0 at the lowest point in the basin (h/H=0.0) to 0.0 at the highest point in the basin (h/H=1.0) (Strahler, 1952). The curve is created by plotting the proportion of total height against the proportion of total basin area (Figure 4) shows the upper part is characterized by concavity, while the lower section is convex. The broad convexity in the lower part of the curve shows the presence of steep sided valleys (pandey, 1980). Hypsometric curve is showing that younger landform is existing into high relief with lower drainage order. Mature landform is at foot hill with moderate to low relief and older at flat basin. Table- 5 (fig. 4) shows that the hypsometric curve of Mathugad watershed signify that it is in the early mature stage of development.

Table 5:- Hypsometric data of Muthugad watershed.

Relative Relief(h) meters	Relative Height (h/H)	Area (A) Sq km	Relative Area(a/A)
0	0.00	11.36	1
310	0.20	16.73	0.85

512	0.33	16.91	0.63
705	0.46	14.35	0.41
910	0.59	10.62	0.22
1152	0.75	7.69	0.08
1541	1.00	-	0.00

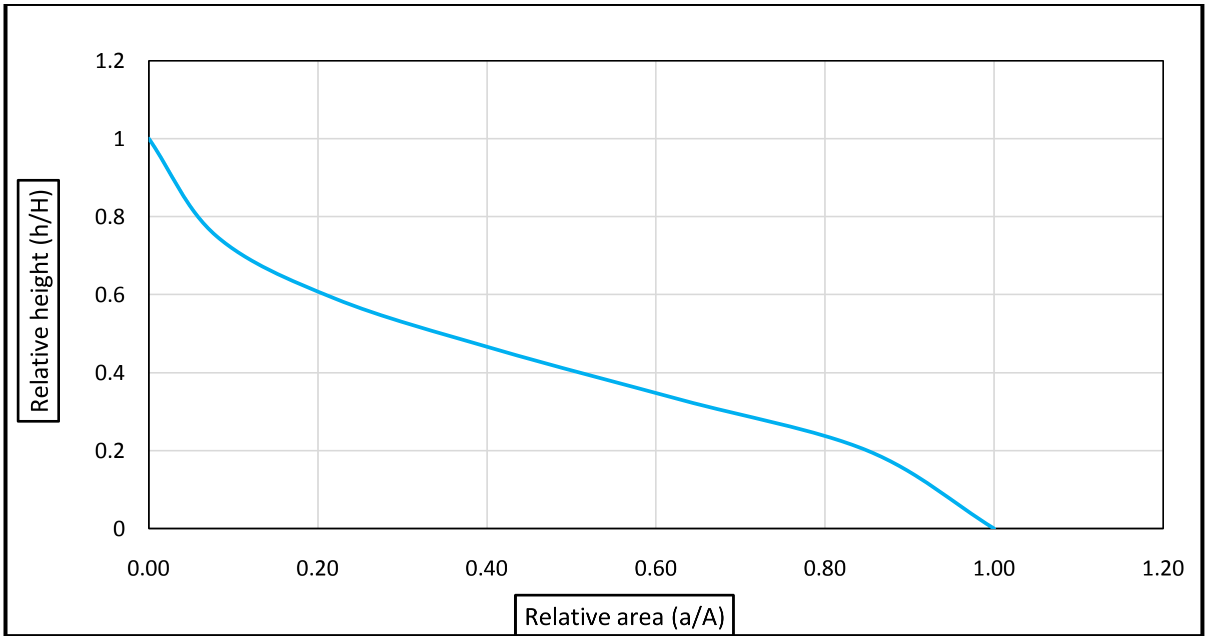

Figure 4:- Hypsometric Curve map of the Mathugad Watershed.

Dissection index (Di)

The dissection index is a ratio of relative relief to absolute relief for the dissection index's derivation following formula as given below: (Nir, 1957).

$$DI = A_R, / R_R$$

The Mathugad watershed relative and absolute relief is used to construct the dissection index, where R_R stands for relative relief and A_R for absolute relief. Using above formula, the dissection index for the studied area is 0.21, indicating a mature stage in the erosion cycle.

Conclusion:-

In an effort to better understand the Mathugad drainage system and its hydrological effects on the watershed, a detailed study of the various morphometric aspects of the watershed has been attempted.It has been examined and quantified how various linear, areal and relief components of watershed morphometry. This study shows how to use employing SRTM DEM dataset and geospatial technology, such as remote sensing and GIS to analyses the morphology of the watershed. The Mathugad watershed is a sixth order watershed meaning that first order streams followed by second order streams, predominate the watershed drainage network or pattern and allow for adequate draining from the watershed. As a result of the watershed's high gradient and high relief there is high runoff from the watershed with little time for concentration which could lead to soil erosion and flood-like conditions during times of peak flow. The watershed's quantifiable linear, area, and relief characteristics show that the basin is mountainous, which affects the runoff and soil erosion from the watershed. Based on this study, a watershed development and management plan can be created, and the drainage characteristics can be used to build site-specific rainwater collection structures. According to the morphometric analysis of the Mathugad River, the watershed is of fifth order and is transitioning from an early mature to an old stage of the fluvial geomorphic cycle. The average length of a given order's channel segments is larger than the average for the next lower order but shorter than the average for the next higher order. Given the uniform nature of the lithology and the well-developed stage of the drainage network in the studied area, the mean bifurcation ratio of the catchment indicates that there does not seem to be much of a strong geological influence on the development of the drainage. With steep slopes, high drainage density, many streams and less susceptible subsurface lithology, the northern upper part of the basin has high relief. The Mathugad watershed is substantially elongated, making flood flows easier to control than those in circulatory basins, according to the elongation ratio, circulatory ratio, and form factor. The analysis also demonstrates that the watershed has a very thin texture and a significantly extended basin. The drainage channel size analysis shows that the flooding is minimal.

References:

1. Clarke, J. I. (1966): Morphometry from maps, Essay in Geomorphology (ed. G. H. Dury), London: Pp-235-274.
2. 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 vol (2): Pp-78-86.
3. Horton R. E. (1932) Drainage basin characteristics. Transactions of American Geophysics Union, 13: Pp.350 - 361.
4. Horton, R E (1945): Erosional development of streams and their drainage basin: Hydrophy approach to quantitative morphology, Geo. Soc. Am. Bull, 56, Pp 275-370.
5. Kumar.S, (2017): Remote sensing and GIS based watershed studies in Kasalya- Jhajhara watershed, north India. Pp 45-1.
6. 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.
7. Morisawa, M. E. (1968): 'Streams: their dynamics and morphology, New York, P. 215.
8. Morisawa, M.E (1959): Relation of quantitative geomorphology to stream flow in representative watershed of the Appalachian Plateau, Pp.389-042.
9. Nir, D. (1957): The ratio of relative and absolute altitude of Mount Carmel, Bulletin of the Geological Society America, Vol. 56, Pp. 564-569.
10. Pandey, A., Chowdary, V.M. and Mal, B. C. (2004): Morphological analysis and watershed management using GIS, Hydrology Journal, Vol.27 (3-4), Pp 71-84.
11. Prakash, K., Singh, S. and Shukla, U. K. (2016) Morphometric changes of the Varuna River basin, Varanasi district, Uttar Pradesh. Journal of Geomatics, 10 vol. (1), Pp.48-54.
12. Rawat, J.S (1981): The lower Ramganga catchment: A qualitative geomorphic study, unpublished Ph.D. thesis, Department of Geography Kumaun University Nanital.
13. Rawat, K. S., Mishra, A. K. and Tripathi, V. K. (2012) Hydro-morphometrical analyses of sub-Himalayan region in relation to small hydro-electric power. Arab J Geosci., DOI 10.1007/s12517-012-0586 P-6.
14. Schumm, S. A. (1954): The relation of drainage basin relief to sediment loss, Pub. International Association of Hydrology, IUGG, Tenth Gen. Assembly, Rome, 1, 1954, Pp. 216-219.
15. Schumm, S. A. (1956): The evaluation of drainage systems and slopes in bad land, at Perth Amboy, New Jersey, Bull. Geol. Soc. Am., 67, Pp- 597- 646.
16. 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, Pp. 412-420.
17. Strahler, A. N. (1956): Quantitative slope analysis. Bull. Geol. Soc. Am., 67. Pp.1-629.
18. Strahler, A. N (1952) Hypsometric Analysis of Erosional Topography. Bulletin of the Geological Society of America, 63, Pp 1117-42.
19. Strahler, A. N. (1964): Quantitative geomorphology of drainage basins and channel networks, in a Handbook of Applied Hydrology (ed.) by Chow, V. T., McGraw Hill, U.S.A., Pp.40- 73.
20. 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), Pp.1077-1088.
21. Zävoiance, I., (1985): Developments in water science, Elsevier, Chapter XI Hypsometric Curves and Longitudinal Stream Profiles, Vol.20, Pp.185-200.