Integration of remote sensing (RS) and geographic information system (GIS) for morphometric analysis of watershed-A brief review

Ifra Ashraf[1], Tanzeel Khan[2] , Nyreen Hamid[3]

[1,2,3]*College of Agricultural Engineering and Technology, SKUAST-K, Shalimar*

ABSTRACT

Geographic information system (GIS) and remote sensing (RS) have emerged as proficient tools in the assessment of drainage morphometric parameters and their influence on earth features, eroded land and soil characteristics at watershed level. The mapping competences and measuring capabilities of GIS techniques have enabled them to corroborate as a competent tool in morphometric analysis. Watershed based morphometric analysis is the indicative of the effect of linear, relief and areal aspects of stream (channel) network and contributing ground slopes on the watershed prioritization, land and water resources management, and flood potential assessment of the watershed. This review paper helps in the development of knowledge of different fluvial aspects of morphometric analysis which will provide a strong platform for different researchers to work further upon.

Key Words: GIS, DEM, Morphometry, Linear Aspects, Areal Aspects, Relief Aspects

1. INTRODUCTION

Geographic information system (GIS) techniques provide a flexible and potent tool for manipulation and analysis of spatial information, hence being employed for assessing various terrain and morphometric parameters of the basin [1]. The development of new advanced techniques in Spatial Information including remote sensing and GIS are effectively used for the extraction of information about spatial features [2]. Geographical information systems (GIS) have been used for assessing various basin parameters, providing flexible environment and powerful tool for determination, interpretation and analysis of spatial information related to river basins. Geology, relief and climate are the primary determinants of a running water ecosystem functioning at the basin scale [3].

Morphometry refers to the precise measurement of the geometry or shape of any natural form, whether that being of any animal, plant or relief feature [4]. Morphometry is the measurement and mathematical evaluation of the conformation of the surface of earth, shape and dimension of earth's features [5] [6]. Morphometry takes into account the quantitative study of the area, volume, slope, profile, altitude of the terrain and the drainage and stream characteristics of the concerned area [7]. Morphometric analysis entails measurement of areal aspects, linear features, gradient aspects of stream (channel) network and contributing ground slopes of the concerned watershed [8] [9] [10] [11].

It has two distinct branches viz. relief morphometry and fluvial morphometry. Relief morphometry includes the analysis of terrain characteristics through hypsometric curves, percentage hyphometric curves, clinographic curves, altimertic frequency histograms and curves, area-height curves, projected, composite and superimposed profiles, which abet in dealing with different aspects of landform characteristics of a drainage basin or of any geomorphic unit [7]. Fluvial morphometry includes the consideration of linear, areal and relief aspects of a fluvially originated drainage basin [12]. The linear aspect deals with the hierarchical orders of streams, numbers and length of stream segments and various relationships among them and related morphometric laws of stream numbers and stream lengths. The areal aspect includes the analysis of basin parameters, basin shape – both geometrical and topological, basin area and related morphometric laws viz. law of basin area and law of allometric growth; stream frequency, drainage texture [13] [14]. The relief aspect includes, besides hypsometric, clinograph and altimetric analyses, the study of absolute and relative relief ratios, average slope, dissection index etc. [13]. The linear aspects of the basin are related to the channel patterns of drainage network wherein topological characteristics of the stream segments in terms of open links of the network system (streams) are analyzed [14]. The relief aspects of drainage basins are important to understand the flow direction of water and the extent of denudational process that have undergone within the basin. The relief parameters are useful to study the features involving area, volume and height of landforms to examine different geohydrological characteristics [14].

The consideration of the watershed as the fundamental unit in morphometric analysis is the most plausible choice because it being an areal unit defined by quantitatively measurable characteristics provides an objective basis for classification and analyzing [15] [16]. A watershed is referred to as the surface area drained by a portion or the entirety of single or multiple water channels and considered as a fundamental erosional unit, wherein water and land resources interact in a distinctive manner [17]. The quantitative analysis of morphometric parameters is found to be of immense utility in river basin evaluation, watershed prioritization for soil and water conservation and natural resources management at watershed level [18]. The applications of morphometric analysis are diverse but this paper has considered the fluvial aspects of the morphometry in particular visa viz their importance in some important fields.

2. Applications of morphometery in different fields

2.1 Linear, areal and relief aspects

Detailed morphometric analysis of a basin is of great help in understanding the influence of drainage morphometric network on landforms and their characteristics [19]. Linear aspects of the basins are closely linked with the channel patterns of the drainage network wherein the topological characteristics of the stream segments in terms of open links of the network system are analysed [20]. The analysis of aerial parameters help in measurement of drainage density which provides a numerical measurement of the landscape dissection and runoff potential [21]. Area of a basin (A) and perimeter (P) are the important parameters in quantitative geo-morphology. Basin area directly affects the size of the storm hydrograph, the magnitudes of peak and mean runoff. The maximum flood discharge per unit area is inversely related to size [20]. The relief aspects of the drainage basins are significantly linked with the study of three dimensional features involving area, volume and altitude of vertical dimension of landforms to analyze different geohydrological characteristics [20]. The linear, areal and relief aspects of watersheds have been ascertained by many researchers;

GIS and image processing techniques were adopted for the recognition of morphological features and analyzing their properties of the Lower Gostani River Basin (LGRB) area in Andhra Pradesh state, India [22]. The basin morphometric parameters such as linear and aerial aspects of the river basin were determined and computed. It was observed that the drainage density value was low which indicated the basin was highly porous subsoil and thick vegetative cover. The circularity ratio value exposed that the basin being strongly stretched out and highly permeable homogenous geologic materials. This study would help the local people to utilize the resources for sustainable growth of the basin area.

Morphometric analysis of the Manas river basin using earth observation data and Geographical Information System was carried out to determine the linear, areal and relief aspects of the basin [23]. The mean bifurcation ratio was found out equal to 3.81 indicating the basin was principally controlled by structure. The basin has been found to have medium drainage density of 0.78 per km^2 and the length of overland flow value of the basin was found equal to 0.64, indicating high relief. The study has strengthened in understanding the hydrological, geological and geomorphological characteristics of the Manas drainage basin.

The drainage characteristics of Korattalaiyar river basin were assessed via determination of linear and areal aspects of morphometric parameters using GIS [24]. The quantitative analysis of a various aspects of river basin drainage network distinctiveness revealed complex morphometric attributes. The streams of lower order mostly control the basin. The development of stream segments in the basin area is more or less affected by rainfall. The erosional processes of fluvial origin have been predominately predisposed by the subsurface lithology of the basin.

A study attempted to evaluate the drainage morphometrics of Upper South Koel Basin using Remote Sensing and GIS approach [25]. The low values of bifurcation ratio and drainage density were obtained which suggested that the area has not been much affected by structural disturbances. The study reveals that the different geomorphic units in the study area i.e. Structural hills, Pediments, Valley fills, Pediplains formed under the influence of permeable geology, are moderate to nearly level plains, with medium to low drainage density (<2.0) & low cumulative length of higher order streams. Such studies can be of immense help in planning and management of river basins.

The analysis of the inter-relationships among the basin parameters helps in understanding the terrain characteristics, slope, landforms, soils, soil erosion and ground water potential for watershed development and management as established by a study conducted on GIS based morphometric analysis of the Kochara sub-watershed of India [26]. Using remote sensing data – Geocoded False Colour Composite (FCC) of IRS 1D (LISS III), the drainage networks were characterised coupled with the Survey of India toposheets (1:50,000) and the morphometric analysis was done using ArcGIS software. The study revealed the prodigious relationship between theoretical data sets with field observations, especially the role of geology, geomorphology and tectonism in influencing the basin morphometric and identity.

A study was conducted on morphometric analysis of drainage basin through GIS on Sukhna lake watershed in lower Shiwalik, India [27]. The evaluation of linear aspects of drainage basin showed that the basin had a dendritic pattern with fifth order stream. Bifurcation ratio of basin (4.113 to 4) has fallen under the range (3.0 and 5.0). Drainage density, drainage texture, elongation ratio and relief ratio value of Sukhna watershed was 3.435Km/Km^2 and 9.30 which inveterated that the study area was underlain by impermeable subsurface material of Siwaliks having sparse vegetation and hilly relief and steep slopes with very fine texture caused prone area of soil erosion risk in the Sukhna Lake watershed.

A research was carried out on hydrological and morphometric analysis of upper Yedzaram Catchment, Nigeria using ARC GIS 10.0 software and topographic map of the study area (UBA topographic map sheet 156 edition 1, 1969) Marti [28]. The bifurcation Ratio value of the catchment was 2.74 while the total stream length was 161.97 km with total area coverage of 191.17 sq. km. The Drainage Density (D) of the study area was 0.85. The value indicated that in every square kilometer of the basin, there was 0.85 Kilometer of drainage channel. The analysis carried out for the Yedzaram catchment basin depicted that the basin was tending towards elongated shape.

The study on Wanpura micro-watershed of Kashmir Valley was conducted to evaluate morphometric parameters to understand the nature, landscape development and hydrologic responses of watershed [29]. Drainage network of the basin was of dendritic type indicating the homogeneity in texture. The low value of drainage density (5.48) indicated that the region was composed of permeable sub-surface materials, dense vegetation and low mountainous relief causing lower surface runoff, and a lower level of degree of dissection. Low value of bifurcation ratio (1.79) showed that there was little control of structure on the drainage pattern. Low infiltration number value (0.0111 km/km^4) indicated the high infiltration capacity of the soil which was confirmed by huge vegetative cover of the watershed. This study would help to utilize the resources for sustainable development of the basin area.

The integration of Remote Sensing (RS) and Geographic Information Systems (GIS) constitutes a powerful tool for the evaluation of watershed morphometric parameters [30]. The detailed morphometric analysis of the Wadi Baish catchment area has been performed using the Shuttle Radar Topography Mission (SRTM). The results of the morphometric analysis revealed that the catchment can be described as of eighth stream order and consists of an area of 4741.07 km^2. The most dominant order was the lowest order. The high number of low order streams indicated that the adequacy of the catchment to provide superficial draining was sufficient. The analysis of the linear aspects recommended that there was the presence of impermeable rocks with high slope. The analysis of the areal aspects indicated that the catchment shape was approximately circular, and the basin was characterized by a high runoff, low infiltration capacity, high impermeability of the underlying lithology, mountainous relief, and lack of vegetation. Due to these characteristics, the catchment tended to have higher flood peaks with shorter lag times. The relief aspects indicated the presence of less resistant rocks in the drainage basin. Moreover, the basin is characterized by a relatively high mean value of bifurcation (4.012), which indicated the scarcity of permeable rocks with high slope in the area. This value of bifurcation ratio was consistent with the high drainage density value of 2.064 km/km^2 which confirms the impermeability of the subsurface material and mountainous relief. The hypsometric integral of the catchment was 47.4%, and the erosion integral of the catchment was 52.6%, both being the indications of a mature catchment area.

GIS has proved a viable method of characterizing the hydrological response behaviour of the watershed as confirmed by another morphometric analysis conducted on Kanhar basin [11]. The drainage area of the basin was 5,654 km^2 and showed sub-dendritic to dendritic drainage pattern. The stream order of the basin was mainly controlled by physiographic and lithological conditions of the area. The study area was designated as seventh order basin with the drainage density value being as 1.72 km/km^2. The increase in stream length ratio from lower to higher order showed that the study area has reached a mature geomorphic stage.

The geomorphological characteristics of Karpri-Kalu watershed using GIS techniques were abstracted using geospatial techniques [31]. From bifurcation ratio it was observed that there were less structural disturbances in the watershed. The drainage density value for the basin area was 2.024Km/Km^2 which indicated that the basin was poorly drained. The Form factor and circulatory ratio for the watershed was 0.424 and 0.35 respectively. The circularity ratio was influenced by stream length, stream frequency, geological structures, land cover, climate, relief and slope of the basin. It was found to be an important parameter, which indicated the stage of the basin. The watershed had less elongated shape with the elongation ratio of 0.734 and having a strong relief and steep ground slope. The value of stream frequency for the basin exhibited positive correlation with the drainage density value of the area indicating the increase in stream population with respect to increase in drainage density. The study was found to be useful for the planning of watershed harvesting and groundwater recharge projects on watershed basis.

2.2 Watershed prioritization

Watershed prioritization has gained importance in natural resources management, especially in the context of watershed management and morphometric analysis has been commonly applied to prioritize the watersheds [32]. The concepts of prioritization play a very important role in soil and water conservation for watershed development and planning. A watershed is an ideal unit for the management of natural resources like land and water and for mitigation of the impact of natural disasters for achieving sustainable development [33]. The morphometric analysis is a significant tool for prioritization of micro-watersheds even without considering the soil map [34]. Prioritization of watersheds using remote sensing and Geographical Information System (GIS) data has been successfully attempted by several workers;

A study has been carried out to determine the priority categories of sub-watersheds of Kawal Khad watershed based on sediment yield index (SYI) and to propose suitable soil and water conservation measures [35]. Landcover/Landuse physiography cum soils cape maps obtained from visual understanding of IRS-IC LISS-Ill imagery and terrain slope data obtained from topographic map were used to make available inputs to

SYI model. Landuse physiography cum soils cape and slope maps were integrated (two at a time) to generate compound erosion intensity units, (CEIU). The CEIUs were assigned weightage values and release ratios to compute SYI. They prioritized watershed into 12 sub-watersheds and suggested suitable soil conservation measures based on the SYI.

The study conducted to assess the importance of morphometric characteristics obtained using GIS has been used for the prioritization of Hiranyakeshi basin for its planning and development [36]. Using ArcSWAT software, the whole study area was divided into 19 sub-watersheds named as H-1 to H-19. By applying GIS techniques and using SRTM data, various morphometric characteristics of the Hiranyakeshi basin have been evaluated. Strahler's, Horton's and Schumm's methods have been employed to evaluate the fluvial characteristics of the study region. Each morphometric characteristic has been considered as a single parameter and on the basis of its role in soil erosion, knowledge based weightage has been allocated to all morphometric parameters. The compound parameter values were computed and the sub-watershed with lowest compound weight was given highest priority.

Morphological parameters-based prioritization has been found to be in good agreement with the geological field investigation carried out during the field work [37]. Manot River catchment, a tributary of the Narmada River has been prioritized into 14 sub-watersheds employing the morphometric analysis [37]. The geomorphological characteristics of a watershed are more commonly used for developing the regional hydrological models for solving various hydrological problems of the un-gauged watersheds in inadequate data situations. Therefore, in this study to find out the most vulnerable sub-watershed to soil erosion, prioritization was done upon morphometric analysis. The morphometric parameters considered for analysis were stream order, stream length, stream frequency, drainage density, texture ratio, form factor, circulatory ratio, elongation ratio, bifurcation ratio and compactness ratio. After analysis of morphometric parameters, compound parameter values were calculated and prioritization rating of 14 sub-watersheds was carried out.

The morphometric parameters influencing the soil erodibility have been successfully considered to prioritise the sub-watersheds [38]. The study area of 420 sq.km was divided into 22 sub-watersheds which have been taken up for prioritization. They used ArcGIS-10.1 software for the measurement of linear, aerial and relief parameters of sub-watersheds. The ranks were assigned on the basis of relationship with erodibility, to arrive at a compound parameter (Cp) value for the final ranking of each sub-watershed. The sub-watershed with the lowest Cp value has been given the highest priority and then they were categorized into three classes as high, medium and low in terms of priority.

Watershed prioritization of micro-watersheds through morphometric analysis using remote sensing and GIS was conducted to prioritize six inaccessible micro-watersheds of Maniari river catchment of Mungeli district, Chhattisgarh [2]. DEM (Digital Elevation Model) was used in the extraction of drainage network and in determining the quantitative description of catchment geometry i.e. morphometric analysis. The micro-watersheds were classified into three priority categories as high, medium and low for conservation and management.

2.3 Soil and water conservation

Morphometric analysis has gained prominence in conservation and management of soil and water at micro level with the aid of remote sensing and GIS tools [38].The morphometric analysis of a watershed joined with land use/land cover information can play an important role in predicting the hydrological behavior of a watershed [39]. The proper watershed management needs utilization of land, water and soil resources of a watershed for optimum production with minimum hazard to natural resources, and morphometric analysis can be tailored for devising a conservation plan for concerned watersheds by studying different linear, aerial and relief aspects of the watershed [34]. Several researchers have applied morphometric analysis to assess the hydrological behavior of the watershed, thereby devising the soil and water conservation plan;

Morphometric analysis of Karso watershed of Hazaribagh, Jharkhand was carried out by [39]. A range of morphological parameters viz. perimeter, elevation, stream length, area, stream order were determined using Arc Info GIS. Incorporation of land use/land cover information with morphometric parameters has been used to define the areas suitable for adapting soil and water conservation measures. The shortage of available land and water resources has resulted due to growing inhabitant's pressure. This has necessitated its proper planning and management within the accessible resources. Proper scientific planning and management requires immense data to make predictions of water accessibility. Each watershed has a number of its distinct characteristics, which govern the amount of runoff formed by a rainfall event.

The detailed morphometric characteristics (more than 85 morphometric parameter of all aspects) of Karawan watershed in Dhasan basin, which itself is part of the mega Yamuna basin in Sagar district, Madhya Pradesh was evaluated to assess the erosional and drainage development of the area [1]. Digital elevation model (DEM), was prepared by using ASTER data and the various aspects of watershed such as linear, relief and areal aspects were computed by using geographical information system (GIS) was used in evaluation of linear, areal and relief aspects. ArcHydro Tool in ARC GIS was used for preparation of watershed boundary, flow accumulation, flow direction, flow length, stream ordering were prepared using; and Surface Tool in ArcGIS-10 software, and ASTER (DEM) was used for preparation of contour, slope-aspect, hill shade. Using ArcGIS software, different thematic maps i.e. drainage density, slope, relief, superimposed profile, and longitudinal profiles were prepared. The erosional development of the area by the streams was found to have increased significantly on the basis of analysis of all morphometric parameters and the drainage development was found to be influenced by lithology. These studies are very advantageous for planning rainwater harvesting and watershed management. Similar study has been conducted by substituting the ASTER DEM with CartoSAT-1 based DEM data with 2.5m spatial resolutions and 53 morphometric parameter of all aspects have been ascertained for a watershed of Ravi river basin in Himachal Pradesh, India [40].

The morphometric analysis of major watersheds based on satellite images using hydrological module of ARC GIS software in the drought prone Barind Tract in the north-western part of Bangladesh was carried out for its relevance in the water resource management [41]. The watersheds contains stream orders ranging from 1st to 6th showing dendritic drainage pattern which represents homogeneity of soil texture; possibility of flash flood after heavy rainfall with low discharge of runoff. The moderate drainage density indicated semi-permeable soil lithology with moderate vegetation. Elongated shape watersheds are with low to moderate relief and are bounded in the east by land area of the Barind Tract of moderate to steep slope. It reveals a flatter peak of runoff flow for longer duration and gravity flow of water. Flat to gentle but undulating slope of the watersheds represented good category for water resource management owing to favorable site for infiltration due to maximum time of runoff water percolation. The east facing slopes of the watersheds showed higher moisture contents and higher vegetation. The major part of the watersheds comes under cultivated land which supported the future basin development and management for water resource.

2.4 Flood potential

From the integrated analysis of the morphometric parameters, important hydrologic behaviour of watersheds could be inferred because of the significant impact of the spatial variations of the morphometric parameters on the hydrology of a watershed [42]. Basin morphometric parameters play an important role in hydrological processes, as they largely control a catchment's hydrologic response. Their analysis becomes even more significant when studying runoff reaction to intense rainfall, especially in the case of ungauged, flash flood prone basins [43]. Based on geomorphic parameters, a potential hazard map can be prepared by using GIS to estimate to estimate the risk degree of individual sub-basin by combining normalized values of the parameters [44].

The realistic measures of flood potential in small (<100 m^2) drainage basins in terms of morphometric parameters like stream magnitude, drainage density, and relief ratio has been envisioned by employing certain Stereoscopic interpretation of low altitude aerial photographs [45]. These photographs provided the most precise maps of basins for generating these distinct parameters. Various field surveys of a high-density limestone basin in Central Texas implicated that 1:24,000 scale topographic maps exactly portrayed the competent stream channel system but failed to reveal many small gullies that may form portions of hill slope hydrologic systems. Flood potential in drainage basins can be defined by a regional index computed as the standard deviations of the logarithms of the annual maximized stream flows. High potential basins tend towards greater drainage density, greater relief, and thus greater severity numbers than low-flash flood possible watersheds. For a given number of first-order channels (basin magnitude), flash flood regions had bigger ruggedness numbers, representing higher drainage densities in combination with steep hill slopes and stream channel gradients as well. Transient controls on flood responses, like differences between local rainstorm intensities, appeared to be the main influences on hydrographs in areas of moderate dissection and relief. Morphometric parameters for low-potential flash flood regions (Indiana and the Appalachian Plateau) has been ascertained to be superior estimators of common low-magnitude runoff events (mean annual flood), while the same parameters associated better with the maximum flood of record in high-flood potential regions like southern California, north central Utah and central Texas.

Geomorphometric analysis of the basins provides great opportunity on accepting geomorphic evolution and flood risk of the basins which was shown by a research conducted on eight main river basins of Albania

[46]. The morphological and hydrological characteristics of rivers were analyzed using easily usable and highly precise ASTER GDEM, which covers all the land on earth and is available to all users despite size or location of their target areas and GIS. For this cause, ASTER GDEM of Albania were pre-processed by fill and sink operations in GIS previous to analysis. After that slope hypsometric curve and integral, ruggedness number, form factor, stream power index, drainage networks and other related morphometric characteristics like drainage density, length of overland flow, bifurcation ratio, and time of concentration were analyzed and consequences were evaluated among the basins in points of flood risk.

3. Conclusions

The morphometric analysis based on GIS technique is very useful to understand the prevailing geohydrological characteristics and for watershed planning and management. The GIS and RS technique used for computation and analysis of various morphometric parameters of the basin helps to understand various terrain parameters such as nature of the bedrock, infiltration capacity, surface runoff, erosion dynamics of land and soil etc. The quantitative analysis of linear, relief and aerial parameters is found to be of immense utility in river basin evaluation, basin prioritization for soil and water conservation and natural resource management. The morphometric analysis can also be beneficial for the sound planning of groundwater recharge projects and water harvesting on watershed basis. Also, the detailed morphometric analysis provides a immense importance in hydrological behavior of basin for water quality projects and flood forecasting, erosion control and environmental management, it is also essential for accurate modeling analysis.

REFERENCES

[1] 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*, *2(1*), 2011, 248-269.

[2] L. Kumar, D. Khalkho, P. Katre, G.K. Nigam and S.R. Bhattacharya, Watershed prioritization of micro-watersheds through morphometric analysis: a remote sensing and GIS perspective. *International Journal of Advanced Biological Research, 7(1),* 2017, 36-46.

[3] J.J. Wilson and N. Ch, Morphometric Analysis of Major Sub-Watersheds in Aiyar & Karai Pottanar Basin, Central Tamil Nadu, India Using Remote Sensing & GIS Techniques. *Bonfring International Journal of Industrial Engineering and Management Science*, *2*, 2012, 8-15.

[4] A.N. Strahler, Quantitative analysis of erosional landforms (*Physical geography, 4*, 1969).

[5] C.S. Agarwal, Study of drainage pattern through aerial data in Naugarh area of Varanasi district, U.P., *Journal of Indian Society of Remote Sensing, 26(4),* 1998, 169-175.

[6] G.E. Obi Reddy, A.K. Maji and K.S. Gajbhiye, GIS for morphometric analysis of drainage basins, *GIS lndia, 11(4),* 2002, 9-14.

[7] S. Singh, Altimetric analysis - A morphometric technique of landform study, *National Geographic, 7*, 1972, 59-68.

[8] M.D. Nautiyal, Morphometric analysis of drainage basin using aerial photographs, a case study of Khairkuli basin, District Dehradun, U.P., *Journal of the Indian Society of Remote Sensing, 22(4),* 1994, 251-261.

[9] S.K. Nag and S. Chakraborty, Influence of rock types and structures in the development of drainage network in hard rock area, *Journal of the Indian Society of Remote Sensing, 31(1),* 2003, 25-35.

[10] N.S. Magesh, K.V. Jitheshlal, N. Chandrasekar and K.V. Jini, GIS based morphometric evaluation of Chimmini and Mupily watersheds, parts of Western Ghats, Thrissur District, Kerala, India, *Earth Science Informatics, 5(2),* 2012, 111–121.

[11] P.K. Rai, A GIS-based approach in drainage morphometric analysis of Kanhar River Basin, India, *Applied Water Science, 7,* 2017, 217-232.

[12] V. Singh and A. Dubey, Linear aspects of Naina-Gorma river basin Morphometry, Rewa district, Madhya Pradesh, India, *International journal of geomatics and geosciences, 3(2),* 2012, 364-372.

[13] M. Khakhlari and A. Nandy, Morphometric Analysis of Barapani River Basin In Karbi Anglong District, Assam, *International Journal of Scientific and Research Publications, 6(10),* 2016, 2250-3153.

[14] G. Shailaja, G. Gupta, S.T. Padmane and S.N. Patil, Morphometric Analysis of Trap Covered Suki River Basin, Maharashtra for Water Resource Management Using Geo-Spatial Tools, *Asian Journal of Applied Science and Technology, 1(9),* 2017, 347-360.

[15] P. McCullagh, *Modern concepts in geomorphology,* 6 (Oxford University Press, 1978)

[16] M.M. Malik, M.S. Bhat and N.A Kuchay, Watershed based drainage morphometric analysis of Lidder catchment in Kashmir valley using geographical information system, *Recent Research in Science and Technology, 3(4),* 2011, 118-126.

[17] A. Senthilvelan, A. Ganesh and K. Banukumar, Linear and areal morphometric aspects of Porandalar Watershed, Amaravathi Sub Basin, Tamil Nadu. *International Journal of Advances in Remote Sensing and GIS, 1*, 2012.

[18] A.N. Strahler, Quantitative geomorphology of drainage basin and channel networks. *Handbook of applied hydrology*, 1964.

[19] R.A. Hajam, A. Hamid, D.N. Ahmad, and S.U. Bhat, Morphometric analysis of Vishav drainage basin using geospatial technology (GST), *International Research Journal of Geology and Mining, 3(3),* 2013, 136-146.

[20] R.A. Hajam, A. Hamid, and S. Bhat, Application of morphometric analysis for geo-hydrological studies using geo-spatial technology-A case study of Vishav Drainage Basin. *Hydrology Current Research*, 4(157), 2013.

[21] B.V. Rekha, A.V. George, and M. Rita, Morphometric analysis and micro-watershed prioritization of Peruvanthanam sub-watershed, the Manimala River Basin, Kerala, South India. *Environmental Research, Engineering and Management, 57(3),* 2011, 6-14.

[22] K.N. Rao, P.S. Latha, P.A. Kumar and M.H. Krishna, Morphometric analysis of Gostani river basin in Andhra Pradesh state, India using spatial information technology. *International journal of geomatics and geosciences 1(2)*, 2010, 179-187.

[23] J. Nongkynrih and Z. Husain, Morphometric analysis of the Manas river basin using earth observation data and Geographical Information System. *International Journal of Geomatics and Geosciences, 2(2),* 2011, 647-654.

[24] G.B. Geena and P.N. Ballukraya, Morphometric analysis of Korattalaiyar river basin, Tamil Nadu, India: a GIS approach. *International journal of geomatics and geosciences 2(2)*, 2011, 383-391.

[25] P. Parveen, U. Kumar and V.K. Singh, Geomorphometric Characterization of Upper South Koel Basin, Jharkhand: A Remote Sensing & GIS Approach. *Journal of Water Resource and Protection 4,* 2012, 1042-1050.

[26] C.K. Baiju, B.A Kumar, G.Gopinath, M.S.Chandran, and T. Ramkumar, GIS Based Morphometric Analysis of the Kochara Sub-Watershed of Greater Periyar Plateau (GPP) of South Western Ghats, India, *International Journal of Advanced Remote Sensing and GIS, 4(1),* 2015.

[27] J.A. Yangchan, A.K. Tiwari, and A. Sood, Morphometric Analysis of Drainage Basin through GIS: A Case study of Sukhna Lake Watershed in Lower Shiwalik. India, *International Journal of Scientific and Engineering Research, 6(2),* 2015.

[28] A.K. Martins and B.L. Gadiga, 2015. Hydrological and morphometric analysis of upper Yedzaram catchment of Mubi in Adamawa state, Nigeria using Geographic Information System (GIS), *World Environment,* 5(2), pp.63-69.

[29] R. Kumar, I. Ashraf, T. Khan, N. Hamid, J. N. Khan, O. A. Bhat and D. Ram. Geomorphometric Characterization of Upper South Koel Basin, Jharkhand: A Remote Sensing & GIS Approach, *Journal of Soil and Water Conservation, 15(3),* 2016, 265-272.

[30] F. Radwan, A.A Alazba, and A. Mossad, 2017. Watershed morphometric analysis of Wadi Baish Dam catchment area using integrated GIS-based approach, *Arabian Journal of Geosciences*, *10*(12), p.256.

[31] R.D. Bansod and G.S. Ajabe, Determination of geomorphological characteristics of Karpri-Kalu watershed using GIS techniques, *Journal of Pharmacognosy and Phytochemistry, 7(1),* 2018, 1940-1944.

[32] M.Y. Javed, Khanday and Ahmed R., Prioritization of Sub-watersheds based on Morphometric and Land use Analysis using Remote Sensing and GIS techniques, *Journal of the Indian Society of Remote Sensing, 37*, 2009, 261-274.

[33] K. Nookaratanam, Y.K. Srivastava, V.V Rao, E. Amminedu and K.S.R. Murthy, Check Dam Positioning by prioritization of microwatersheds using SYI Model and Morphometric Analysis – Remote Sensing and GIS perspective, *Journal of the Indian Society of Remote Sensing, 33 (1),* 2005, 25-28.

[34] S. Biswas, S. Sudhakar, and V.R. Desai, 1999. Prioritisation of Sub-watersheds based on Morphometric Analysis of Drainage Basin: A Remote Sensing and GIS Approach. Journal of the Indian Society of Remote Sensing, 27 (3), 155-166.

[35] J.C. Sharma, J. Prasad, A.R. Bhandari, K. Singh, and K.R. Sharma, Prioritisation and management needs of KawaI Khad watershed based on sediment yield index in southern Himachal Pradesh using remotely sensed data and GIS techniques, *Journal of Agropedology, 12,* 2001, 38-49.

[36] S.S. Panhalkar, S.P. Mali and C.T. Pawar, Morphometric analysis and watershed development prioritization of Hiranyakeshi basin in Maharashtra, India, *International journal of environmental sciences 3(1),* 2012, 525-534.

[37] S. Gajbhiye, S.K. Mishra, and A. Pandey, Prioritizing erosion-prone area through morphometric analysis: an RS and GIS perspective, *Journal of Applied Water Science 4*, 2014, *51–61*.

[38] F. Ahmed and K.S. Rao, 2015. Prioritization of Sub-watersheds based on Morphometric Analysis using Remote Sensing and Geographic Information System Techniques, *International Journal of Remote Sensing & GIS*, *4(2)*, 51-65.

[39] A. Pandey, V.M. Chowdary, and B.C. Mal, Morphological analysis and watershed management using GIS, *Hydrology Journal, 27(3-4),* 2004, 34-40.

[40] K. Pareta and U. Pareta, Quantitative Geomorphological Analysis of a Watershed of Ravi River Basin, H.P. India, *International Journal of Remote Sensing and GIS, 1*, 2012, *41-56.*

[41] M.F. Rahaman, C.S. Jahan, R. Arefin, Q.H. and Mazumder, morphometric analysis of major watersheds in Barind tract, Bangladesh: A remote sensing and GIS-based approach for water resource management, *Hydrology*, *5*(6), 2018.

[42] F. Altaf, G. Meraj, and S.A. Romshoo, Morphometric analysis to infer hydrological behaviour of Lidder watershed, Western Himalaya, India, *Geography Journal,* 2013.

[43] M. Diakakis, A method for flood hazard mapping based on basin morphometry: application in two catchments in Greece, *Natural hazards, 56(3),* 2011, 803-814.

[44] M. Abdelkareem, Targeting flash flood potential areas using remotely sensed data and GIS techniques. *Natural Hazards, 85(1),* 2017, 19-37.

[45] P.C. Patton and V.R. Baker, Morphometry and floods in small drainage basins subject to diverse hydrogeomorphic controls, *Journal of water resources research, 12(5),* 1976, 941-95.

[46] H. Ozdemir, Geomorphometric analysis of Albania river basins, *International Balkan Annual Conference, 2*, 2012, 149-164.