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ROLE OF DRAINAGE MORPHOMETRY AND HYPSOMETRY IN THE PROGNOSIS OF BASIN GEOENVIRONMENT - A REVIEW

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ABSTRACT

Morphometry and Hypsometry involves the mathematical analysis of landforms which help to implement a comprehensive understanding of its influence in the Geo-environmental setting. Morphometry has been used for the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimensions of its landforms, in various studies. It examines the linear, geometric, relief and areal aspects of the drainage networks and also requires measurement of the linear features, gradient of streams and slopes of the drainage basin. Similarly, hypsometric analysis helps to examine the tectonics and elevation of the watershed. This paper attempts to review the role of these two metage by perpending the different methodologies and parameters employed in their analysis, using case studies.

INTRODUCTION

Morphometric analysis is defined as the capacity and mathematical analysis of the shape of the earth's surface and dimension of its landforms [1, 2]. Morphometric research is a quantitative technique for analysing the land surface features. It is also helpful for the detailed study to aid watershed management and to give physiographic information, like watershed slope, channel network, channel length, location of the drainage etc. Insights on the existing climate, geology, geomorphology and structural antecedents of the catchment can be obtained from the morphometric analysis of the drainage basin and its channel network, thereby aiding in understanding the geo-hydrological behaviour of the drainage basin. Further, it helps to identify the geomorphologic and structural control of flow and runoff, predicting floods, their extent and intensity in the watershed.

Hypsometric analysis is mainly used in the field of hydrology and tectonics and hypsometry is a technical term which is related to the measurement of heights. Hypsometric analysis aims at developing a relationship between horizontal cross-sectional area of the watershed and its elevation in a dimensionless form that permits comparison of watersheds irrespective of scale issues [3]. It has been used to attain valuable information of erosion status and runoff potential of the river and also it is more effective in comparing different catchments, irrespective of their size.

Parameters involved in morphometric analysis

Drainage morphometry depicts through its various components, the existing scenario of the topographical and hydrological setting of a river basin [4]. Pioneers in the field have worked out various parameters involved in the calculation of morphometricvariables [5-7] and these involve mainly the linear, aerial and relief aspects.

a. Linear aspect:

The linear aspects parameters involve stream order (U), stream numbers (Nu), stream length (Lu), mean stream length (Lsm), stream length ratio (Rl) and bifurcation ratio (Rb).

b. Areal aspect:

The areal aspect parameters include drainage density, stream frequency, drainage texture, infiltration number, form factor ratio, elongation ratio, circularity ratio and length of overland flow. Area of a basin and perimeter is the main parameters in quantitative morphology.

c. Relief aspect:

The relief aspects of the drainage basin analysis have relationship with the study of three-dimensional features involving area, volume and altitude of vertical dimension of landforms to analyse different geo-hydrological characteristics [8]. The relief aspects parameters encompass basin relief, relief ratio and ruggedness number.

METHODOLOGIES EMPLOYED FOR MORPHOMETRIC ANALYSIS

Following the work of the earlier scientists, the rapidly emerging spatial information technology has evolved as an effective tool to accomplish the objective of morphometric analysis more accurately in a time-saving manner [9-13].Case studies reported from different terrain segments across the world as well as in India clearly illustrate the application of GIS in the management of landform, soil and water resources [14, 15].

The study of the morphometric analysis of the Sarabanga Watershed, Cauvery River, Salem district, Tamil Nadu, India [16] highlights the extraction of river basin and analysis of its drainage networks. The analysis was done using SRTM data with 30 m spatial resolution and was processed for achieving the automated extraction of watershed and drainage network. The watershed tool in hydrology toolbox of the GIS software accurately delineates the boundary of the watershed. The drainage order was calculated based on Strahler and Horton methods of stream orders. The morphometric parameters have been calculated using extracted drainage network. Subsequently, various maps on slope, aspect and topographic anomalies in five different sites were also delineated from SRTM-DEM data. This study helps to understand the terrain characteristics, such as surface runoff, infiltration capacity, topography, lithology and hydrological properties. The vulnerability for unpredicted flood during heavy rainfall was shown by the bifurication ratio and stream number of the watershed. The study shares valuable evidences and results for planning watershed development activities of the area.

The methodology used for the morphometric analysis of Barpani River basin [17], was using GIS and Remote Sensing techniques. The SRTM Digital Elevation Model has been widely used in the analysis of drainage basin. The work has been done using SRTM DEM of 90 m resolution and the three morphometric parameters viz., linear, areal and relief aspects were analysed. Using the hydrology Tool box of ArcGIS, extraction of basin boundary, flow direction, flow accumulation, stream length, stream ordering were done. Different thematic map such as Contour, Slope, Aspect and Stream ordering of the study area were also delineated. An analysis of the morpho and hypsometric parameters in this investigation helped to infer that the river basin has dendritic stream pattern and it facilitates low concentration of runoff with high infiltration capacity because of the low infiltration value. The study implies that the area was less prone to soil Erosion and have intrinsic structural complexity in relation with relief and drainage density.

A study of the drainage characteristics of Phulambri area in Aurangabad district in Maharashtra [18] was obtained through RS and GIS based morphometric analysis. Morphometric analysis of a drainage pattern needs the demarcation of all the existing streams. The attributes were allocated to generate the digital data base for drainage layer of the river basin. Various morphometric parameters such as linear aspects and areal aspects of the drainage basin were computed. The study reveals that the drainage area of the river basin was passing through premature stage of the fluvial geomorphic cycle. The outcome of the study illustrates the rocks in the region shows advantageous condition and good water bearing characteristics which was found to be useful for groundwater investigation.The Landsat Enhanced Thematic Mapper (ETM+) image of geo-coded false colour composites (FCC) and Google Terrain data was used for the study on the quantitative evaluation of Kallar watershed using geospatial technology, Thiruvananthapuram [19]. The delineation of watershed and stream vectorization was carried out from SOI Toposheets and the morphometric parameters have been divided into three categories: basic parameters, derived parameters and shape parameters. The data in the first category includes stream order, stream number, basin length, drainage pattern, Maximum and minimum heights and area. Those of second category are bifurcation ratio, mean bifurcation ratio, slope, aspect, meandering ratio, stream length ratio, RHO coefficient, stream frequency, drainage density, stream junction density, dominant flow direction, longitudinal profile, Sinuosity, drainage texture, Constant channel maintenance, basin relief and basin ratio. The shape parameters include circulatory ratio, elongation ratio, form factor, asymmetry factor and traverse topographic symmetry. The quantitative computation of Kallar River basin was mainly based on Horton's and Strahler [5, 7] methods. The gradual morphological change was manifested in the light of morphotectonic indices and morphotectonic characteristics of the river basins.

Parameters involved in hypsometric analysis

Hypsometry deals with the vertical dimensions of the topography and erosive processes in the basin can be explained on the basis of the slope of different hypsometric parameters such as hypsometric curve, hypsometric head and hypsometric integral.

a. Hypsometric curve shape:

Based on the shapes of the hypsometric curves of river basins, they are grouped into three. Those with an upward concave shape come under the first group and represent old stage. This curve represents the flood plain region without runoff and thus will process more infiltration. The second group is characterized by a concave-convex shape representing fluvial slope wash process. The third group characterized by an upward convex curve representing young stage. This curve represents greater runoff and less infiltration.

b. Hypsometric head and toe:

The values of hypsometric head and toe have significant importance in hydrological response of the river basin. Higher values of hypsometric head indicate that the contribution of diffusive process is more. As the hypsometric toe value increases, the mass accumulation is greater at the mouth, derived mainly through fluvial processes [20].

c. Hypsometric integral and slope inflection point:

Hypsometric integral value can be an indirect estimator of the erosion from the watershed system [21]. The hypsometric integral (Hsi) can be estimated using the elevation relief-ratio method and is expressed in percentage units. This method is found to be less cumbersome and faster than other methods.

d. Hypsometric integral and basin area:

For small basins, the hypsometric curve is convex and the value of hypsometric curves approaches to unity indicating the greater rate of runoff and in the case of large basin, the hypsometric curve is concave and the value of the hypsometric curves approaches to zero indicating the low rate of runoff [22]. For scale dependency check, statistical analysis can be carried out between area and hypsometric integral.

METHODOLOGIES EMPLOYED FOR HYPSOMETRIC ANALYSIS

Langbein, [23] introduced the concept of Hypsometric analysis to express the overall slope and the forms of drainage basin. Strahler, [7] opined that it is a continuous function of non- dimensional distribution of relative basin elevations with the relative area of the drainage basin. According to Hurtrez ,[24] the hypsometric curve is related to the volume of the soil mass in the basin and the amount of erosion that had occurred in a basin against the remaining mass.

Subsequently, several researchers found that employing Geographical Information System (GIS) techniques in hypsometric analysis of digitized contour maps helps in improving the accuracy of results and save time[25-26].

In a study on hypsometric analysis in 22 rivers of northern Kerala, [27] the main aspects was to analyse the runoff potential and erosion status of the river basins to aid in the planning and management of water resources. The study was carried out using Cartosat-1 stereo images and DEM with a ground resolution of 5m and DEM thus generated through automatic mode was found to be very effective to carry out hypsometric analysis for the river basin. Hypsometric curve was derived for each river basins in the study area from the 30m Catosat -1 (IRS –P5) DEM in Arc GIS environment using Cal Hypso tool. Using hypsometric curves of 22 river basins, various parameters such as maximum concavity (Eh), coordinates of slope infection point and normalized height of hypsometric curve (h) were calculated. By the help of hypsometric integral and hypsometric curves, the landforms were classified into youth, mature and old. Downward concave part of right hand side of hypsometric curve is called toe, upward concave part of left hand side of the curve is called body [22]. In this study, hypsometric curve were obtained for all the 22 river basin of northern Kerala in GIS environment. The normalized height of hypsometric curve (h) which provides the elevation relative to maximum height that covers the spec proportion of catchment area, was calculated for all the river basins. The study was carried out for understanding the type of erosive process and runoff potential using various hypsometric parameters. This study highlights the importance of hypsometric analysis in understanding different landforms and also the utility of GIS as a tool in accomplishing this objective.

The methodology used for the hypsometric analysis of Varattaru river basin of Harur talk, Dharmapuri district, Tamil Nadu [28] describes the utility of this analysis in rainwater harvest practices and management for the river basin at suitable locations for controlling further erosion, reducing the runoff, increasing the groundwater potential and various stages of landform processes in the Varattaru river basin. ASTER DEMs and Landsat ETM 30m data were used in the study to know the land use land cover pattern of this basin. Hypsometric cure was derived for Varattaru river basin from the 30m ASTER DEM. Calculation of the hypsometric integral was automated in System for Automated Geoscientific Analyses (SAGA) open source software, using the hypsometric function in morphometric analysis. Integration of the hypsometric curve gives the hypsometric integral (I). Pike and Wilson [29] proved mathematically that the elevation-relief ratio (E) which is defined as Integration of the hypsometric curve gives the hypsometric integral (I). It is identical to the hypsometric integral (I) but has the advantage that it is much more easy to obtain numerically [24]. Information regarding the relative elevation, relative area, absolute elevation and absolute area were contained in the output table. The output data were normalised and generated hypsometric curve. Elevation contour was derived from DEM and overlaid on Landsat ETM. Slope map was derived from ASTER DEM for understanding the topography-relief variation. This study highlights the importance of hypsometric analysis for the management of river basin at suitable locations for controlling erosion and runoff and help rainwater harvesting. It also determines the increasing groundwater potential and various stages of landform processes in the river basin.

A study undertaken in the Tuirini drainage basin in Mizoram [30] employed the methodology of hypsometric analysis to describe the erosional stages and relative age of landforms. Contour interval of 40 m was accurately digitized within GIS environment from the scanned SoI topographic maps and also spot heights were digitized. From the DEM, relief and aspect maps have been prepared. The hypsometric curves for the Tuirini basin and its sub-basins were prepared based on Strahler [7] method. Hypsometric integrals of all the sub-basins have been calculated using empirical formula proposed by Pike and Wilson[29] . The study was used for the identification of erosional stages and relative age of landforms and also helps to take appropriate measures to conserve soil and water resources for sustainable development of the basin area.

A hypsometric analysis of Drainage Basins in Karnataka, was done [31] for the detection of the drainage basins using contour line's elevation value to create a Triangulated Irregular Network (TIN) model. The drainage basin's boundaries have been identified through a toolset (fill, flow direction, flow accumulation and snap pour point) in GIS using DEM model as input. The elevation value of DEM has been used to find out the Hypsometric Integral for each drainage basin in the study area. Ultimately, the relationship between the drainage basins in the study area was found out by calculating Moran's I spatial autocorrelation. The study implies that among the seven drainage basins in the area, six drainage basins were maturely dissected landform while the South Ponnar drainage basin was in the old state of dissection. The study area detects no drainage basin in youthful state. The hypsometric curve graph in the study has shown that 'S' shaped, concave and convex hypsometric curve means that the erosional process differs from one basin to another. Negative spatial autocorrelation between the drainage basins are indicated by Moran's I showing that HI values were random in the study area.

A hypsometric analysis of Bunbuni River, Chotanagpur Plateau [32] in which it was identified that the hydrologic response of the basin in old stage, will have moderate rate of erosion during peak runoff and require suitable soil and water conservation procedures. The hypsometric curve expresses medium to complex denudational processes and the linear river morphological changes of the river basin. This study suggests that many artificial recharge structures can be employed at many places identified by the analysis to increase the groundwater potential and to control the soil erosion. Suitable locations for recharge structures can be sited on areas with Low hypsometric integral and moderate values are suitable sites for preventing soil erosion and also runoff.

CONCLUSION

The various case studies discussed above, undoubtedly establish the pivotal role of mathematical analysis of landforms in the understanding of its geo-environment. Several investigations also prove that remote sensing And Geographical Information System techniques are more efficient for computation and analysis of the morphometric and hypsometric parameters. It will help to understand the terrain characteristics, such as surface runoff, infiltration capacity, topography, lithology, and hydrological properties of the study area. GIS is helpful for extracting watershed and its drainage network by automatic methods and also highlights the resolution on terrain, landscape and soil analysis. It helps in ascertaining the dominance of either tectonic or erosional processes in shaping the watersheds as well.

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