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Application of remote sensing and GIS for morphometric analysis of watershed: A Review

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Abstract
Morphometry is the study which includes the mathematical analysis and measurement of land forms, land shape and land surface dimensions. Different linear, areal and relief aspects of watershed represents the morphometric nature of watershed. The morphometric analysis of watershed is useful to investigate the erosion status of watershed, flood proneness and critical area suffering to soil erosion within drainage basin. Prioritization of watershed on the basis of degree of erosion within river basin using different morphometric parameters can be performed using geospatial technology. Different watershed management treatment to prevent soil erosion can be performed on priority basis which prevent further degradation of critically eroded area. In all collected 39 literatures, we found that the researchers used remote sensing and GIS technology for morphometric analysis and prioritization by considering different linear, areal and relief aspect of watershed. In this paper we focused on input data used, methodology adopted and conclusions for better watershed management. This paper is divided into six sections namely introduction, conceptual framework, methodology, results, conclusion and references.

Keywords: remote sensing, geographical information system (GIS), Morphometric analysis

Introduction

Wide use of available natural resource such as soil and water is must for the country like India (Sangale and Yannawar 2014) [27]. Indiscriminate use of these resources seriously deteriorates and degrades their nature for sustainable development (Muhammad *et al.,* 2015) [22]. Due to degraded quality of water most of the available water is not safe even for consumption and use (Aravinda and Balakrishna 2013) [5]. These problems are raised due to over-exploitation of these resources, faulty adoption of agricultural practices and ignorance of watershed treatments. Because of all these faulty agricultural practices, it has reduced groundwater recharge, increased runoff, increased soil erodibility and reduced storage capacity of reservoir (Chougale and Jagdish 2017) [9]. Watershed management represents the sustainable use of available natural resource to get optimum production without any hazard to environment (Nigam *et al.,* 2017) [23]. Morphometric analysis gives an overall idea about the hydrological processes occurs on land surface, hence this study receives importance for development of groundwater and surface water resource in the watershed or river basin. For watershed management and development the study of drainage pattern, lithology, erosoinal status, and topography of the drainage basin is important (Lole *et al.,* 2016, Tarate *et al.,* 2018) [20, 34].

The morphometric analysis can be studied through different relief, areal and linear parameters of watershed (Bharadwaj *et al.,* 2014) [6]. Artificial recharge sites can also be investigated through morphometric analysis using remote sensing and GIS techniques (Yahya *et al.,* 2015) [38]. Morphometric analysis can be useful to differentiate the watershed on the basis of different topographical and geomorphological features (Kibate and Gessesse 2018) [19]. Remote sensing using satellite data provides synoptic view covering large areal extent (Nigam *et al.,* 2017) [23]. The morphometric parameters can also be determined using conventional methods but the use of digital elevation model (DEM) with integrated remote sensing and GIS is more easy and less time consuming (Aher *et al*., 2014) [2]. GIS provides flexibility with high accuracy for manipulation of spatial data of different morphometric parameters which varies spatially within the basin (Chandrashekar *et al.,* 2015, Swatantra 2015, Chougale and Jagdish 2017; Surendra and Mitthan 2017, Yahya 2017, Adhikary and Dash 2018, Zainab 2018) [8, 33, 9, 32, 37, 1, 39]. For better watershed planning and management prioritization is the scientific method for identifying the critical eroded area and its conservation from further degradation(Salvi *et al.,* 2017) [26].

Prioritization in to different small watershed will be indicative to adopt different mitigating measures on priority basis. Hence this technology will be helpful to decision makers to study the drainage network within the watershed or river basin and conserve natural resource on priority basis. This approach will be beneficial for sustainable development and well being of people within watershed or river basin.

Conceptual framework

As per Horton (1945) [14] first order stream is the smallest fingertip tributary which does not have any tributary. When two first order streams meet they forms next higher order that is second order and so on. When lower order stream meets to higher order stream then resulting stream order will be same as lower order. The stream order increases in the direct proportion with drainage area (Strahler 1964) [31]. The number of streams of lowest order will be more as compared to all the other higher order streams and the number of streams of respective order will decreases with increasing stream order (Strahler 1964) [31]. Bifurcation ratio is the ratio of number of streams of lower order to the number of streams of immediate next higher order stream (Strahler 1964). The plot of natural log of number of streams against stream order shows a straight line relationship with small deviation. Any deviation will be indicative of lithological control on drainage network. Different morphometric parameters were categorized in to three groups as linear, shape and relief parameters. Circular watershed will be prone to flood hazard than elongated watershed. The watershed with maximum forest area and high basin shape parameter would have lower soil erosion and vice a versa. The highest value of linear and relief parameters and lowest value of shape parameters would have highest erosion hence watershed with high value of linear, relief parameters and low value of shape parameters should be assigned with first priority (Biswas *et al.*, 1999) [7].

Methodology

Morphometric parameters of drainage basin can be derived using GIS as an effective tool for analysis of spatial information. After collecting analyzing the different literatures we come to the conclusion that for better watershed management different linear, relief and areal aspect should be studied.

Data used

Survey of India (SOI) Toposheets (1: 50000 scale), Shutter Radar Topography Mission (SRTM) with 90 m resolution, Advanced Space Borne Thermal Emission & Reflection (ASTER) DEM with 30 m spatial resolution, CARTOSAT DEM data, Remote sensing Data like IRS-P6, LISS IV (5.8 m spatial resolution), RESOURCESAT-2 LISS-III data and Landsat Thematic Mapper OLI data were used as a raw input data in all research papers [1-38].

Process

Morphometric analysis of drainage basin consists of delineation of watershed boundaries, drainage network and digitization of drainage basin using Arc GIS (hydrology tool), ERDAS IMAGINE or QGIS. There are number of tools and software's available for completing different steps of morphometric analysis. Fig 1. Shows the flowchart of different steps required for performing morphometric analysis.

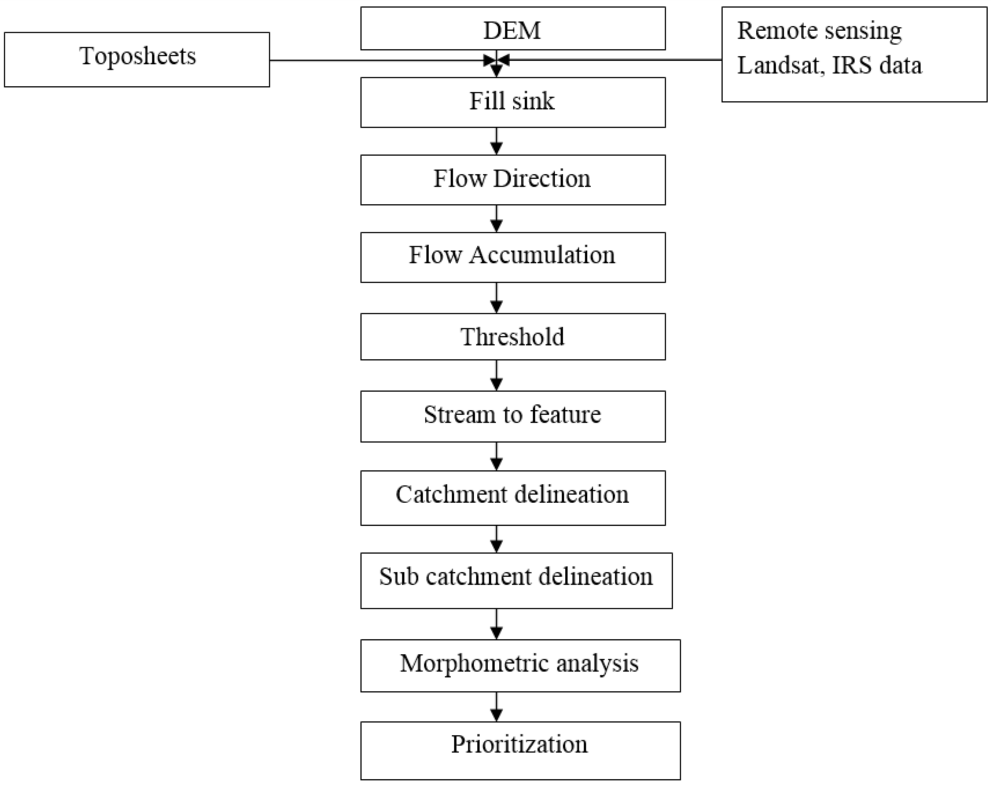

Fig 1: Flowchart of process of morphometric analysis

Results

In all papers the researchers studied different morphometric parameters as shown in Table 1. The study of morphometric analysis reveals the drainage nature of basin, stage of basin development and flood hazard proneness of basin. This analysis will helps for better watershed managements to increase agricultural outputs.

Table 1: Formulas used for computation of results of morphometric parameters

Morphometric Parameters	Formula/Method	References
Linear		
Stream order	Hierarchical Order	Strahler, 1964
Stream Length	Length of the Stream in km	Horton, 1945
Mean Stream Length (L_{sm})	$L_{sm} = \frac{L_m}{N_m}$, Where, L_m = Total stream length of order 'm' and N_m = Total no. of streams of order 'm'	Horton, 1945
Stream Length Ratio (R_L)	$R_L = \frac{L_{sm}}{L_{sm-1}}$, Where, L_{sm}=Mean stream length of a given order 'm', L_{sm-1}= Mean stream length of next lower order 'm-1'	Horton, 1945
Bifurcation Ratio (R_b)	$R_b = \frac{N_m}{N_{m+1}}$, Where, N_m = No. of streams of a given order 'm', N_{m+1}= No. of stream segments of next higher order	Schumn, 1956
Areal		
Drainage density (D_d)	$D_d = \frac{L}{A}$, Where, D_d = Drainage Density (1/Km), L = Total stream length of all orders (Km); A = Area of the basin (Km^2)	Horton, 1945
Stream Frequency (F_s)	$F_s = \frac{N}{A}$, Where, F_s = Stream Frequency (number/ Km^2); N = Total no. of streams of all orders and ; A = Area of the basin (Km^2)	Horton, 1945
Texture Ratio (T)	$T = \frac{N_1}{P}$, Where, N_1 = No. of streams of 1^{st} order ; P = Basin perimeter (Km)	Horton, 1945
Form Factor (R_f)	$R_f = \frac{A}{L_b^2}$, Where, A = Area of the basin (Km^2); L_b = Basin length (Km)	Horton, 1945
Compactness coefficient (C_c)	$C_c = \frac{0.2821\ P}{A^{0.5}}$, Where, P = Basin perimeter (Km); A = Area of the basin (Km^2)	Partha *et al.*, 2018
Drainage texture (D_t)	$D_t = \frac{N}{P}$, Where, N = No. of streams of all order ; P = Basin perimeter (Km)	Horton, 1945
Circulatory Ratio (R_c)	$R_c = \frac{4\pi A}{P^2}$, Where, A = Basin area (km^2) ; P= Basin perimeter (Km)	Miller, 1953
Elongation Ratio (R_e)	$R_e = \frac{2\sqrt{(A/\pi)}}{L_b}$, Where, A= Area of the basin (Km^2); L_b= Basin length (Km)	Schumn, 1956
Channel Main tainance conatant (C)	$C = \frac{1}{D_d}$, Where, D_d = Drainage Density (Km/ Km^2)	Horton, 1945
Infilteration Number (I_n)	$I_n = D_d \times F_s$ Where, D_d = Drainage Density (Km/ Km^2); F_s = Stream frequency (Number/ Km^2)	Faniran, 1968
Length of Overland Flow (L_{of})	$L_{of} = \frac{1}{2D_d}$ Where, D_d = Drainage Density (Km/ Km^2)	Horton, 1945
Relief		
Basin relief (H)	Vertical distance between the lowest and highest points of watershed	Schumn, 1956
Relief Ratio (R_h)	$R_h = \frac{H}{L_b}$, Where, H = Basin Relief (Km) ; L_b = Basin length (Km)	Schumn, 1956
Relative Relief (R_r)	$R_r = \frac{H}{P}$, Where, H = Basin relief (Km); P = Basin Perimeter (Km)	Melton (1957)
Ruggedness Number (R_n)	$R_n = H \times D_d$ Where, H = Basin Relief (Km) ; D_d = Drainage Density (Km/ Km^2)	Schumn, 1956

Conclusions

All the researchers proposed that morphometric analysis is very important for overall watershed analysis and management. Different watersheds have different problems like hazard due to soil erosion, flood proneness and drought affected area etc. These problems can be identified and solved after studying the drainage network, lithology of soil, shape factors and relief factors of the watershed. In most of the papers researchers used survey of India (SOI) toposheets (1:50000 scale), ASTER and SRTM DEM data for preparing drainage network and watershed delineation. One researcher proposed that higher resolution satellite data like ASTER (30 m) is more useful to study fine nature of watershed at meso and micro watershed level. Researchers also proposed that GIS based morphometric analysis is more appropriate than conventional methods. The researchers stated that morphometric analysis using satellite data is in good agreement with the geological field investigation carried out on the field. GIS based morphometric analysis will represent presence or absence of structural control on drainage network, lithological and topographical nature which would be beneficial to locate artificial recharge sites like percolation tanks, check dams and recharge shafts. Hence this analysis will improve living standard of people in the watershed or river basin by making appropriate plan for watershed management.

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