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# Morphometric Analysis using Geospatial Techniques to Infer Hydrologic Behaviour of Waghadi Watershed, Maharashtra, India

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***Abstract***: An attempt was made for morphometric analysis using geospatial techniques to study hydrologic behaviour of Waghadi watershed, Maharashtra, India, which helps in decision making regarding implementation of water conservation and management plan. In the study area, SRTM-DEM data was used to generate drainage network and slope map in Arc GIS environment. Results revealed that the drainage pattern of the study area showed dentritic to subdendritic, coarse drainage texture in nature along with $6^{th}$ order streams. The values of form factor (0.28), circulatory ratio (0.37) and elongation ratio (0.6) showed elongated shape with mean bifurcation ratio (5.92) represented strong structural control over the drainage pattern. Majority of its area is agricultural land (55%), followed by forest (39%), and comprises primarily of hydrologic soil groups C and D, which have moderate to high runoff potential zones and are the ideal from harvesting surface runoff point of view. However, most of area has a gentle to moderate slope (3-5%) while the upper and boundary regions are mostly hilly, with moderate steep to very steep slopes >35%, helps in allocation of various water harvesting structures. Such type of study exemplifies how remote sensing and GIS may be used to water harvesting planning.

***Keywords***: Geospatial Techniques, Hydrologic responses, Morphometric analysis, Maharashtra, Waghadi watershed

Globally, the current imbalance between water availability and demand is a primary apprehension, and India is not an exception. In our county, total average water resource potential is to be 1869 BCM, with just 690 BCM being usable. Similarly, the available replenishable ground water is 432 BCM, of which 342 BCM is usable (CWC 2016-17). Rising water shortage issues create a severe challenge to societal sustainability, environmental management, and economic growth. Apart from that, climate change manifestations in the form of severe weather conditions have exacerbated these problems. Due to significant climate fluctuation, drought has long been endemic in semi-arid region states of the country such as Rajasthan, Andhra Pradesh, Karnataka, Maharashtra and Gujarat etc. Maharashtra's agriculture is its lifeblood but the agricultural sector's growth has been inconsistent, and it has been significantly reliant on highly variable rainfall throughout the year. This circumstance highlights the necessity for the government to focus not only on increasing gross state domestic product (GSDP) development in the agriculture sector, but also on reducing variability in growth through better water resource management. The ideal unit for management of these natural resources is watershed. However, water resource development/management requires an assessment of the watershed's hydrologic response based on morphometric analysis. Watershed morphometry refers to shape, size, and configuration of the earth's surface and landforms (Clarke 1996, Agarwal 1998, Reddy et al 2002). Linear, aerial, and relief aspects have been studied in the morphometric analysis in GIS environment (Agarwal 1998). The morphological analysis is a valuable tool for studying a catchment's topography and hydrological condition (Pirasteh et al 2010). It also gives useful criteria for determining groundwater potential zones, identification of suitable sites for water harvesting structures, geographic characteristics and so on (Aher et al 2014, Malik et al 2019a, Rathore et al 2022). Recently, the use of remote sensing and GIS techniques to compute morphological characteristics has proven to be less time-consuming, rapid, and precise, resulting in the best spatial representation of topographic circumstances (Singh et al 2013, Gautam et al 2021). However, it is also helpful for implementing soil and water conservation treatments at the watershed scale. Several scholars who conducted morphometric analysis by geospatial methodologies indicated that detailed and up-to-date drainage basin information may be created in a systematic way (Aparna et al 2015, Ayele et al 2017, Farhan et al 2017, Gizachew and Berhan, 2018, Gutema et al 2017, Javed et al 2009, Kulkarni, 2013, Magesh et al 2012, Pande and Moharir, 2017, Prakash et al 2016, Rai et al 2017, Singh et al 2014, Singh et al 2008, Soni, 2017, Asfaw and Workineh 2019). Their findings provide essential hydrogeologic, erosion-prone, and watershed features in terms of ground and surface water potential. Morphometric analysis also helps to deal with major environmental challenges such as slope instability, flooding, landslides, and extreme surface runoff at various scales like river basin, watersheds etc. (Biswas et al 1999, Kumar et al 2000, Nag and Chakraborty 2003, Vittala et al 2004, Chopra et al 2005, Conforti et al 2011, Dinagara Pandi et al 2017, Magan et al 2019). Even though, this is an established well-known fact, still there is paucity of detailed studies regarding hydrologic response of Waghadi watershed, Maharashtra. However, the study area situated in yavatmal district where water security is jeopardised by improper location of water harvesting and recharging structures as well as their poor operation and maintenance issues (Kumar and Sen, 2021). Along with it, there is rapid declination of ground water up to 4 m in study area (CGWB, 2017-18). Kumar and Sen 2021 observed that most of the water harvesting structures like check dams (>35%), percolation tanks (32%) , farm ponds etc were damaged/encroached and calls for immediate actions for rejuvenation in study area and without knowing hydrologic response there is no worthy of water harvesting planning and management studies. Keeping in view, an attempt has taken to study morphometric parameters of the Waghadi watershed using remote sensing and GIS techniques to infer hydrologic behavior which helps the policy makers/decision makers in planning and implementation of water harvesting structures.

## MATERIAL AND MEHTODS

**Description of study area:** Waghadi watershed located in Yavatmal district, Maharashtra prone to drought with total area of 19541.45 ha lies between 20º 19' and 20º 10' N latitude and 78º 4' and 78 º 14' E longitudes (Fig. 1).

The climate is hot and dry with mild cold winters. The area consists primarily of shallow, well-drained, clayey lakhi soils associated with rock outcrops, as well as very shallow, overly drained Moho soils on steeply sloping side slopes. Major crops are cotton, soyabean, pigeon pea, sorghum, wheat, gram etc. The rainfall variation from 2011 to 21018 (Fig. 2) showed there was declining trend of rainfall during the last ten years and gives emphasis on water conservation and surface water harvesting planning in the study area.

**Methodology**: Manually extracting the drainage network and assign the stream order over a wider area using a published Survey of India (SOI) topographic map and georeferenced satellite data is laborious and time consuming. To overcome this problem, automatic extraction approaches for examining morphometric parameters of a basin were used. The Waghadi watershed was automatically produced from SRTM DEM data (https://earthexplorer.usgs.gov/) with a spatial resolution of 30 m using georeferenced SOI toposheets, and their drainage network was retrieved using a variety of geoprocessing methods. Flowchart of detailed methodology shown in Figure 3.

For hydrological studies, slope, land use/land cover (LULC) pattern, hydrologic soil group as well as morphometric characteristics of study area play significant role. Therefore, slope map was created using spatial analyst tool where as LULC by on screen digitization. However, hydrologic soil group was obtained from NBSS&LUP,

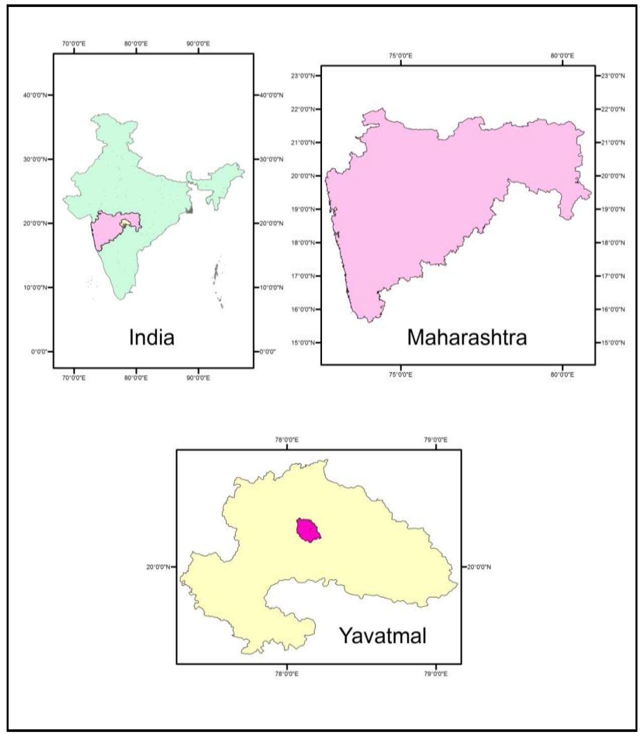


**Fig. 1.** Location of study area

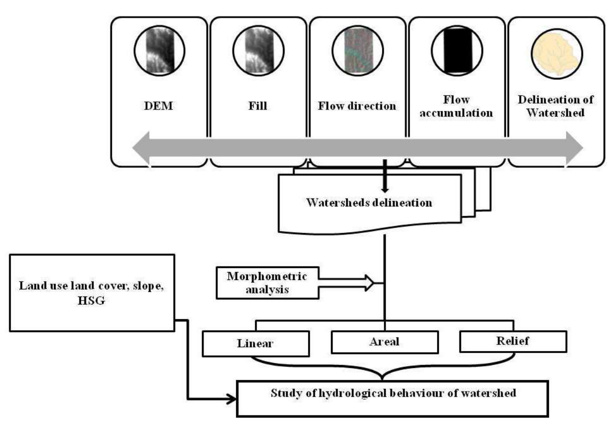


**Fig. 3.** Detailed flowchart of watershed's hydrological behavior study

Nagpur. The drainage map was prepared using spatial analyst tools (Hydrology) as an Add-on to ArcGIS software. After that, morphometric characteristics like area, perimeter, basin length, total stream length, stream order were calculated using GIS software which were later used to calculate other areal and relief parameters with the help of established mathematical equations (Table 1).

**Calculation of Some other Morphometric Parameters of Watershed**

**Bifurcation ratio (Rb):** Bifurcation ratio (Rb) is defined as the ratio of number of streams of any order to the number of streams of the next lower order. This parameter is useful to study the effect of structural control on drainage pattern.

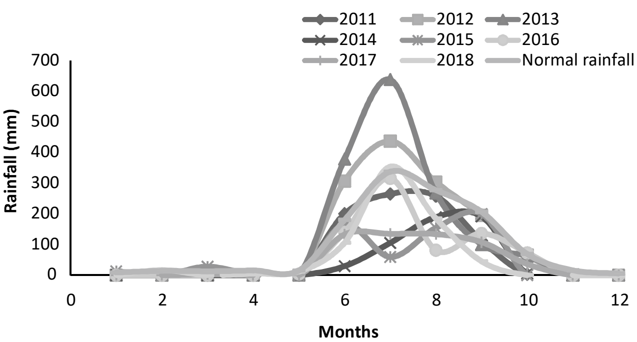


**Fig. 2.** Rainfall variation trend during last 10 years

**Drainage density:** Drainage density (DD) is defined as the sum of the channel lengths per unit area. It is generally expressed in terms of miles of channel per square mile or meter per square meter or kilometer per square kilometer.

**Form factor:** Form factor is defined as ratio of basin area (A) to square of basin length ($L_b$).

**Circulatory ratio:** Circulatory ratio is defined as the ratio of basin area (Au) to the area of circle (Ac) having equal perimeter as the perimeter of drainage basin. Generally, its values lie in the range of 0.6 to 0.7.

**Elongation ratio:** Elongation ratio is defined as the ratio of diameter of a circle having same area as the basin to the maximum basin length ($L_b$).

**Ruggedness number:** Ruggedness number (*R*N) is defined as the product of relief (H) and drainage density (DD). Mathematically, they expressed as shown in Table 1).

## RESULTS AND DISCUSSION

After delineating the watershed and generating the slope, land use land cover map as well as hydrological soil group map, their hydrological behavior had been studied based on morphometric characteristics viz., linear, areal and relief. Description of thematic layers like slope, Hydrologic soil group and LULC and their detailed morphometric metrics were discussed below**:**

**Slope characteristics:** The degree of soil erosion is greatly

**Table 1.** Morphological parameters of watershed

| Morphological parameters | Formula | Reference |
|---|---|---|
| Basin area ($Km^{2)}$ [A] | - | |
| Basin perimeter (Km) | - | |
| Stream length (Km) [L] | - | |
| Stream order | Hierarchical rank | Strahler (1964) |
| Basin length (Km) [$L_b$] | $1.312A^{0.568}$ | Nookaratnam et al (2005) |
| Basin relief (Hb) | $Hb = Z_{max} - Z_{min}$ | Strahler (1957) |
| Drainage Density (DD) | L/A | Horton (1932) |
| Length of overland flow (Km) | 1/(2DD) | Horton (1945) |
| Form factor | $A/L_b^2$ | Horton (1945) |
| Circulatory ratio | $4\pi A/P^2$ | Miller (1953) |
| Elongation ratio | $(2/L_b)(A/\pi)^{0.5}$ | Schumn (1956) |
| Compactness coefficient | $0.2821P/A^{0.5}$ | Horton (1945) |
| Stream frequency | Total stream number/ area | Horton (1932) |
| Bifurcation ratio (Rb) | Rb = Nu/Nu+ 1<br>Where, Nu = Total no. of stream segments of order 'u'<br>Nu+l= Number of segments of the next higher order | Schumm (1956) |
| Ruggedness number (*R*N) | Hb*Dd | Schumm (1956) |
| Relief Ratio (Rh) | Rh = Hb/Lb<br>Where, Rh=Relief Ratio<br>H=Total relief (Relative relief) of the basin in Kilometre<br>Lb= Basin length | Schumm (1956) |

influenced by the land slope. Many researchers discovered that the higher the slopes, the greater the erosion, assuming all other circumstances remains constant. Figure 4 showed the slope of the watershed were classified into six categories such as 0-3%, 3-5%, 5-10%, 10-15%, 15-35%, and >35%, based on the feasibility of water harvesting structures (IMSD, 1995). Results revealed that the majority of the watershed has a gentle to moderate slope (3-5%), with exceptionally steep slopes (>35%) located exclusively in the boundary mountainous terrain region.

**Hydrological soil characteristics:** Hydrological soil classification of Waghadi watershed illustrated that only 2 hydrologic soil group C (58.3%) and D (41.7%), indicates to moderately high to high runoff potential zones, suitable for surface water harvesting (Figure 5).

**Land use/land cover characteristics:** Land use and land cover is vital for water planning and management in watershed. It is an important component of modelling and comprehending the earth feature system. It also allows for a better understanding of land use issues such as agricultural patterns, fallow lands, forests, pasture areas, wastelands, and surface water bodies, all of which are important for development planning and management. The spatial distribution of distinct classes within the watershed was revealed using a land use/land cover map (Figure 6). It clearly indicated that agricultural land (about 55%) is dominant followed by forest (39%) and least was settlement area (0.73%) (Table 2). Later on, Figure 7 showed a schematic representation of the drainage system, as well as the stream order.


**Fig. 5.** Hydrologic soil group of study area

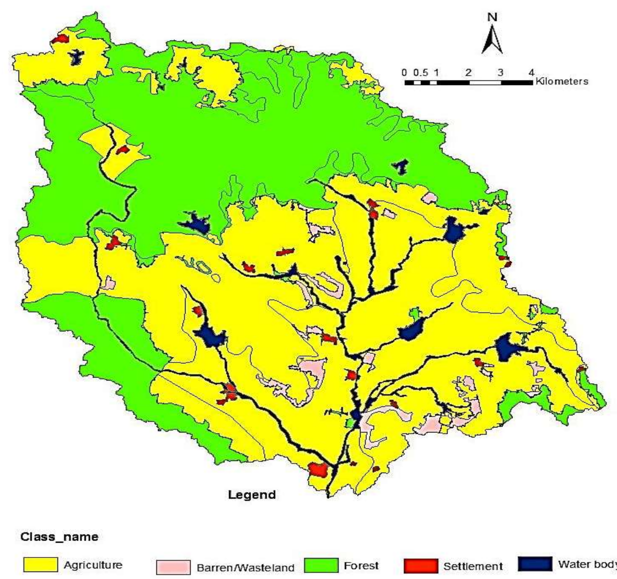


**Fig. 6.** Land use/land cover (LULC) map

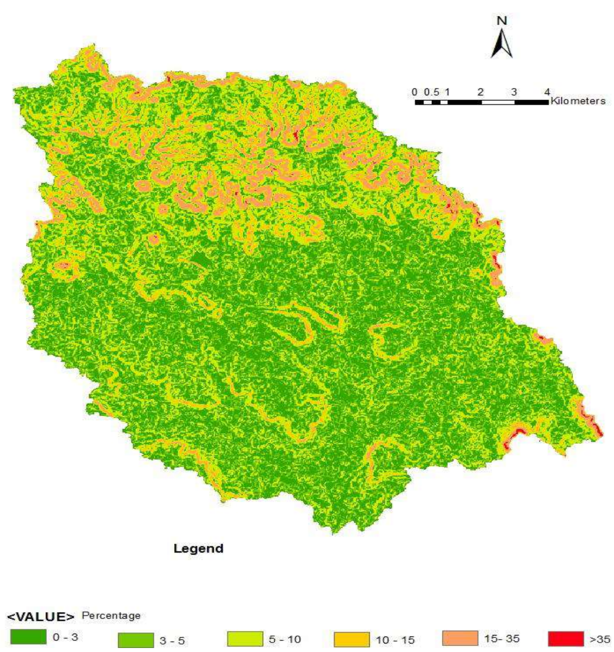


**Fig. 4.** Slope map of study area

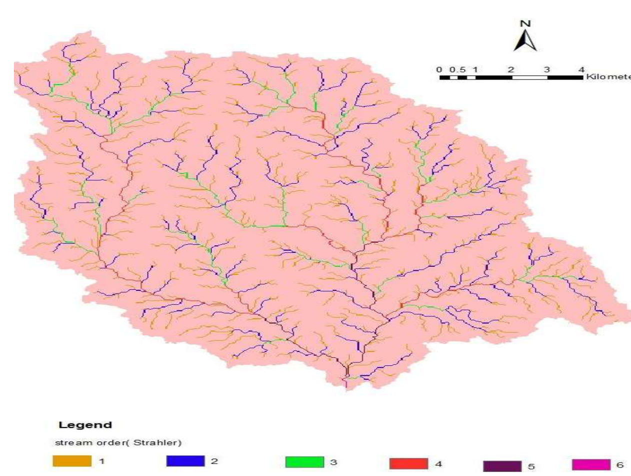


**Fig. 7.** Drainage network of study area

**Analysis of morphometric parameters of watershed:** Waghadi watershed is extended to an area of 195.43 $km^2$ which has a perimeter of 81.27 km. The watershed as a whole is of $6^{th}$ order, with a total stream length is 470.85 km and a mean stream length ratio is 0.41. In order to examine drainage characteristics in the Waghadi watershed, morphometric analysis was performed. Linear, aerial, and relief features of watershed had been calculated and presented in Table 3.

The Waghadi watershed had a mean bifurcation ratio of 5.92, which indicated a hilly location with moderate to high ground slope, moderate to high run-off, and moderate bed rock permeability. These results demonstrated that the structural changes had significant impact on the drainage pattern of the watershed. A high drainage density indicates a watershed that is well-drained and responds quickly to rainfall events, whereas a low drainage density indicates a watershed that is poorly drained and responds slowly to rainfall events (Melton 1958). The drainage density value was 2.36, which indicated adequate vegetative coverage and moderate permeability (Table 3). The form factor value was 0.28 that indicated to an elongated watershed with a flatter peak flow over a longer period of time. Generally, low value of form factor, the watershed will have a more extended shape. The value of circulatory ratio (0.37), indicated an extended shape with tributaries in their youth period. The length of the overland flow was around 0.85, which indicated the location is relatively high in relief. Reduced rock permeability is generally associated with lower watershed constant of channel maintenance values. The Waghadi watershed's average channel maintenance constant was 0.42, which indicated low to moderate permeability, a high to moderate slope, and a high to moderate surface runoff (Table 3).

Basin morphological characteristics and the basin relief ratio (Schumn 1956, Chopra et al 2005, Rudraiah et al 2008) showed the overall steepness of a drainage basin and the intensity of erosion processes operating on the slope of the basin (Schumn 1956, Chopra et al 2005, Rudraiah et al 2008, Hadley and Schumm 1961). The basin relief ratio (0.01) showed a high to moderate slope in the region, which is characterized by plateau with undulating landforms. The Ruggedness number (Rn) was also taken into consideration during the examination. It described the smoothness and roughness of the basin, as well as its vulnerability to soil erosion at the watershed level (Selvan et al 2011, Gutema et al 2017). Ruggedness values range from 0 to 1. The value close to 0 indicates a comparatively smoother environment, while value nearer to 1 indicates more difficult terrain features. The ruggedness number of watershed (0.44), showed moderated rugged topography.

**Table 2.** Distribution of different LULC classes

| LULC classes | Area (ha) | % Area distribution |
|---|---|---|
| Agriculture land | 10683.97 | 54.67 |
| Forest | 7626.21 | 39.03 |
| Barren/Wasteland | 411.70 | 2.11 |
| Settlement | 143.45 | 0.73 |
| Water body | 676.11 | 3.46 |

**Table 3.** Morphometric parameters of watersheds

| Parameters | | Values |
|---|---|---|
| Area ($km^2$) | Linear | 195.43 |
| Perimeter (km) | | 81.27 |
| Total no. of stream order | | 6 |
| Basin length (km) | | 26.25 |
| Total stream length (km) | | 470.85 |
| Mean stream length ratio | | 0.41 |
| Mean bifurcation ratio | | 5.92 |
| Drainage density (km/$km^2$) | Areal | 2.36 |
| Form factor | | 0.28 |
| Circulatory ratio | | 0.37 |
| Elongation ratio | | 0.6 |
| Length of overland flow (km) | | 0.85 |
| Constant of channel maintenance | | 0.42 |
| Basin relief (m) | Relief | 0.186 |
| Relief ratio | | 0.01 |
| Ruggedness number | | 0.44 |

## CONCLUSION

Drought-like conditions persist every year in the Waghadi watershed of Maharashtra due to low average rainfall and call for integrated watershed management for which thorough understanding of a watershed's hydrological behavior play an important role. However, Government of India gives more emphasis on in-situ water harvesting under jal sakti abhiyaan and decision about site suitability for water harvesting structures without knowing morphological parameters is no worthy. Keeping these facts, remote sensing and GIS based approach to study hydrological response of Waghadi watershed through morphometric analysis has been carried out and overall concluded that watershed is of $6^{th}$ order, elongated in shape with dendritic to sub dendritic pattern. Agricultural land (55%) is dominated followed by forest (39%) and it mainly consists of Hydrologic soil group C (58.3%) and D (38.8%) showed moderately high to high runoff potential zones, most favorable for water harvesting structures. However, majority area comes under gentle to moderate slope (3-5%) and it provide suitable environment for construction of water harvesting structures whereas upper and boundary regions mainly hilly areas consists of moderate steep to very steep (>35%),unfavorable for water harvesting structures but may be favorable for ground water recharge structures. Overall, it has been recommended that there is huge scope of harvesting the surface runoff and construction of water harvesting structures, has been suggested as a way to improve agriculture through irrigation in these places from hydrological point of view, rather than relying on rain fed agriculture.

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