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# Drainage Morphometry of Harangi Watershed, Madikeri District, Karnataka State and Its Influence on the Areas Sensitive to Soil Erosion

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**ABSTRACT**

*Watershed morphometry involves quantitative measurement and mathematical analysis of a drainage basin. Inference on the erosion of the landforms of the watershed area can be made based on the assessment of morphometric parameters. Toposheets in conjunction with the ASTER DEM were used for delineation of Harangi watershed and its subwatersheds in GIS environment as well for extraction of morphometric data. Relevant drainage morphometric parameters for the assessment of the sites for the vulnerability of erosion were evaluated using established mathematical expressions. The observed drainage patterns such as trellis, subparallel and subrectangular and alignment of the streams to the lineaments in the study area suggest an immense control of structure on the drainage pattern in Harangi watershed. The relief values, high values of ruggedness number and moderate values of dissection index suggest that the northern subwatersheds, which are characterised by steep slopes, witness low infiltration at higher reaches, high gravity flow and runoff. Low values of form factor, circularity (0.3) and elongation ratios (0.18) and high values of Gravelius's compactness coefficient indicate that the majority of the subwatersheds are elongated in shape. The evaluated linear, areal and relief parameters in GIS environment indicate that the northern subwatersheds are in their late youth stage geomorphic development and are more prone to soil erosion as they are large in areas and consist of more number of streams and high relief compared to their southern counterparts.*

**KEYWORDS**: *Harangi watershed, Drainage morphometry, GIS, Drainage patterns, Soil erosion.*

## INTRODUCTION

The behaviour of stream and river patterns evaluated by linear, areal and relief parameters is of great importance in the watershed management studies. Drainage basin morphometry through conventional as well as using modern tools such as remote sensing and GIS has successfully been used by several workers including Harlin, (1984), Obi Reddy et al., (2002), Rudraiah et al., (2008), Pareta and Pareta (2011), Golekar et al., (2013), Sreedevi et al., (2013), Farrukh Altaf et al., (2013), Anantha Rama (2014), Singh et al., (2014), Pande and Moharir (2015), Rai et al., (2018), Choudhari et al., (2018) and Patil et al., (2020) to understand the hydrological, morphological and erosional characteristics, groundwater potential and water resource management, to develop hydrologic models and to assess the impact on various socioeconomic aspects and so on.

The geological processes such as erosion and landslides are common in the youth stage of the geomorphic development of an area. In the upstream direction denudation is intense, and is triggered by intense rainfall and flooding, thereby accelerating the processes of erosion and consequent deposition of sediment load in the lowlying areas and reservoirs. The study area, Harangi watershed located in Madikeri district of Karnataka state (Fig. 1), of late, is often in news during monsoon period for landslides and floods. The area with high rising hills, waterfalls and coffee plantation is also suffering from losses due to the effects of land degradation by floods and mass movement of the earth. Added to these miseries is the deposition of the sediment load in almost all the drainage channels and connected water reservoirs of the area. Using pre-landslides and post-landslide open source satellite images and advanced GIS image processing, WRI India (2018) generatedmap (Fig. 2) showing Total Suspended Solid (TSS) concentration within the Harangi reservoir indicate that the TSS has increased by almost 100 times due to flow of increased load of soil and sediment within the reservoir. According to the estimate made by the team of engineers of Karnataka Engineering Research Station, Krishna Raja Sagara, Mandya District, more than one thousand million cubic feet of silt has been accumulated in the reservoir area of Harangi Dam (Fig. 3) and this has reduced the storage capacity of the reservoir considerably. Government is spending significant amount of money for desilting work in Harangi dam (Star of Mysore, 2019 and Deccan Herald 2019).

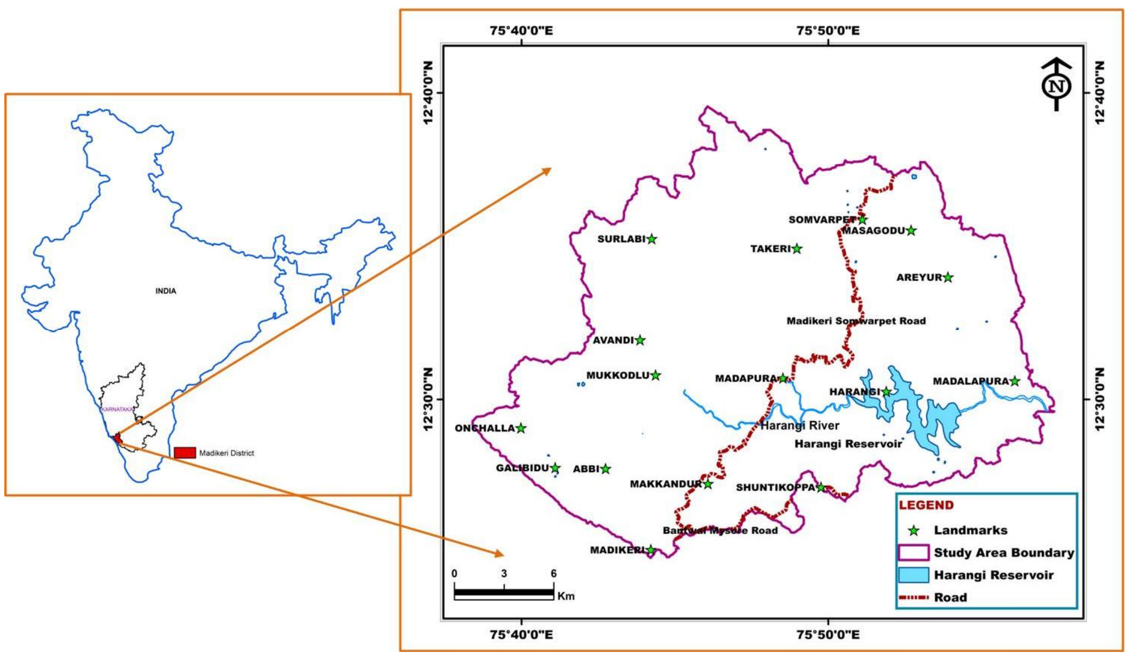


**Figure 1: Location map of the study area**

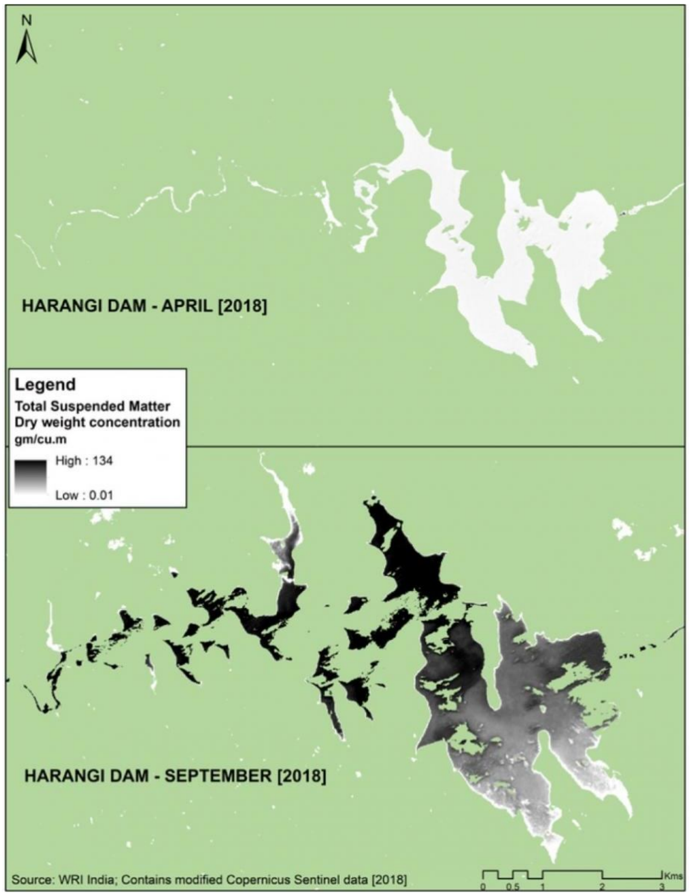


**Figure 2: Satellite imagery showing the contrast in TSS between pre-monsoon and post-monsoon season in Harangi reservoir area (Courtesy: WRI, India)**

**Figure 3: Field photo showing silt deposited in Harangi reservoir (Courtesy: Deccan Herald)**

The present authors have taken up the drainage morphometric analysis of Harangi watershed area which is the main catchment area of river Kaveri in Madikeri district of Karnataka State to analyse the overland flow, soil erosion and other dynamic processes of thebasin. The study can throw light on the areas vulnerable for soil erosion, identify the areas contributing significant sediment load to subwatersheds and draw attention of the decision makers for suitable action to mitigate soil erosion and consequent siltation problem in the Harangi reservoir area.

**Study Area:** The study area, Harangi watershed is a part of Madikeri District of Karnataka State and lies between $75^0$ 38′ E and $75^0$ 55′ E longitude and $12^0$ 24′ N and $12^0$ 40′ N latitudes (Fig. 1).The ~50 Km long Harangi river, which takes birth in the Pushpagiri hills of Western Ghats in Madikeri district, Karnataka State is a tributary of the river Cauvery river. The region forms a part of Survey of India toposheets 48P/10, P/11, P/14 and P/15. Topography of Harangi basin ranges from 818 to 1635 m above mean sea level. The area has a very complex landforms and topography consisting of chains of hill ranges with intervening steep to moderate sloped valleys running in almost NNW-SSE direction, and covered with plantations, ever green forests and cultivated valleys. The landscape of the watershed under consideration is viewed as the product of a series of interactions between fluvial and denudational processes operating on underlying geology that has been subjected to past vertical tectonics (Vinutha et al., 2014A).

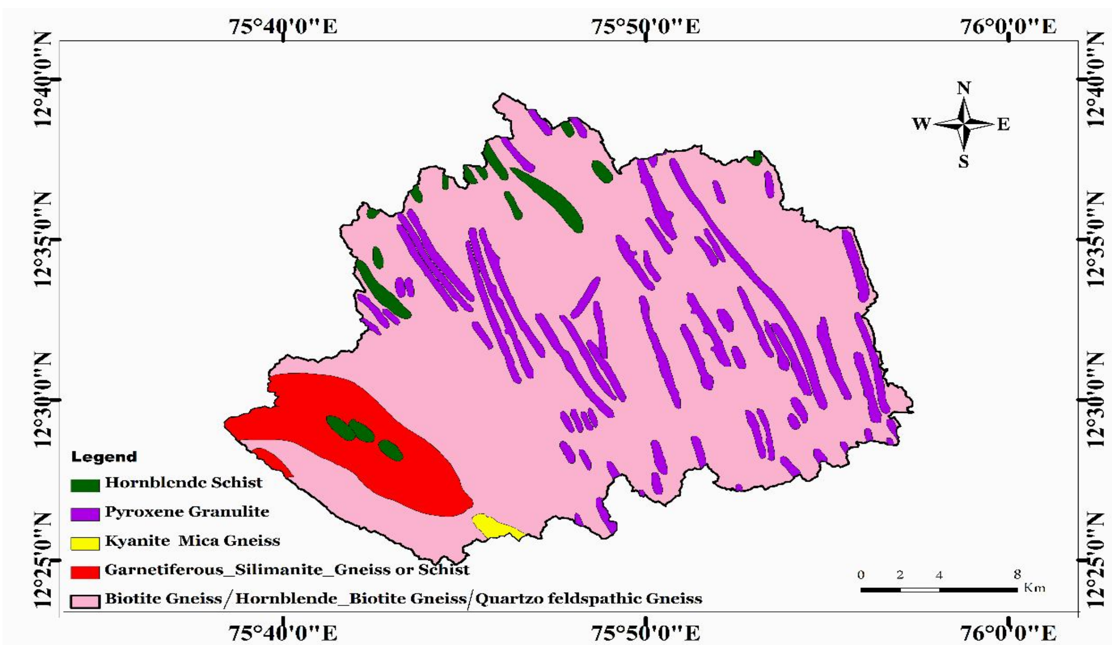


**Figure 4: Lithounits of the Harangi watershed area**

The development of drainage pattern depends on the bedrock lithology and geological structures of the area (Obi Reddy et al., 2002).The geological formations of the study area belong to the Archaean metamorphic complex, comprising igneous and metamorphic rocks. The main rock types include hornblende-schists, garnet-sillimanite-schists, pyroxene granulite, kyanite-mica-gneiss, and Peninsular gneiss. Major part of the study area is covered by granitic gneisses (Fig.4) and form low lands and valley regions of the study area. Schistose and granulites form the ridges in the form of structural hills. On the surface, the soil cover of the Madikeri district consists of lateritic debris found in different stages of weathering developed over granitic gneisses of the region (Janardhana et al., 2016). Soil depth varies from deep to very deep in the slopes and valley regions. At, places it extends to a depth of more than 12m (Vinutha et al., 2014B). The dominant soil texture is characterized by loamy soil. Lateritic clayey and gravelly clay soils cover the valleys and slopes. Other types of soil found at lower slope regions include red clayey and alluvial clayey soils.

Madikeri's climate is classified as tropical and is dominated by SW monsoon. The area witnesses significant rainfall starting in June and ending in October. The SW monsoon provides bulk of annual precipitation and is the main source of water in the catchment area. The drainage pattern is largely parallel, although rectangular, trellis and dendritic patterns of drainage are observed locally. In Madikeri, the average annual temperature is 20.5°C. Annual average precipitation is about2783 mm.

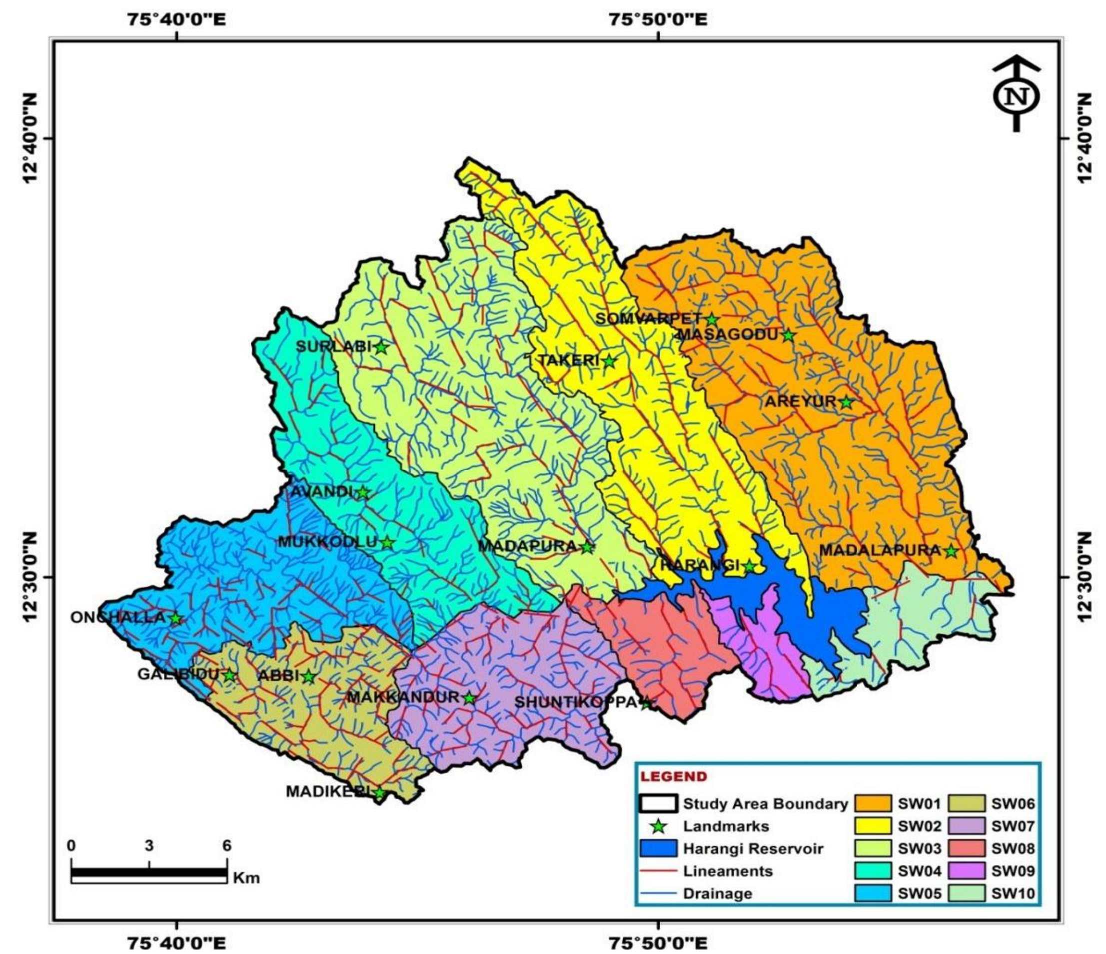


**Figure 5: Drainage map of the study area showing subwatersheds and lineaments**

## MATERIALS AND METHODS

Analysis of the hydrological basin provides valuable information pertaining to stream characteristics, underlying material, velocity of the streams, vulnerability of the basin to erosion and contribution to the sediment load. Basic information on the nature of the streams as well as the delineation of the boundary of the watershed and subwatersheds were made out from the Survey of India (SOI) toposheets (48P / 10, P / 11, P / 14 and P / 15) on 1:50000 scale. SOI Toposheets, georeferenced in ArcGIS desktop 10.2.2.Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM) of 30 m resolution was downloaded.SOI and ASTER information were used to update the basin geometry and linear aspects of the streams. Ridgelines dividing the boundary between the subwatersheds in the drainage network were identified and subwatersheds were delineated. Basin area, basin perimeter and stream length are measured parameters in GIS environment using spatial analyst tool and its extensions. Other drainage morphometric parameters are the derived ones obtained from the computation using various established mathematical expressions. The data obtained on various morphometric parameters pertaining to linear, areal and relief aspects are presented in Tables 1 to 8. Linear and areal aspects are the two-dimensional features on a plane whereas the third dimension of the basin is introduced by the relief aspect.

## RESULTS AND DISCUSSION

### Basin length and area

Total area of the Harangi watershed is about 530 $Km^2$. Harangi watersheds has been divided into ten subwatersheds. Five subwatersheds (SW01, SW02, SW03, SW04 and SW 05) are located in the northern part of the river Harangi and the remaining five subwatersheds (SW06, SW07, SW08, SW09 and SW10) are located in the southern part of the river Harangi (Fig. 5). Individual subwatersheds area and basin lengths calculated in GIS platform are presented in Table 1. Area and basin length of the subwatersheds located in the northern part of the Harangi River are large compared to the southern subwatersheds (Table 1 and Fig. 5).

**Table 1: Physical characteristic of Harangi subwatersheds**

| Subwatershed | Area $(km)^2$ | Perimeter (km) | Basin length (km) |
|---|---|---|---|
| SW01 | 112.401 | 61.151 | 19.178 |
| SW02 | 79.040 | 78.284 | 15.701 |
| SW03 | 100.525 | 61.37 | 17.999 |
| SW04 | 53.495 | 46.792 | 12.578 |
| SW05 | 51.874 | 44.864 | 12.360 |
| SW06 | 39.116 | 34.458 | 10.530 |
| SW07 | 46.258 | 32.98 | 11.582 |
| SW08 | 19.308 | 25.575 | 7.052 |
| SW09 | 9.767 | 22.385 | 4.789 |
| SW10 | 18.863 | 33.838 | 6.959 |

### Drainage pattern

Drainage pattern is defined as “the configuration or arrangement, in plain view, of the stream courses in an area, including gullies or first-order areas of channelized flow, tributaries, and main streams” (Schoeneberger and Wysocki, 2008). The pattern is reflective of local topography, the local relief, underlying geology and the geological structures such as fault, lineation, etc. The study area largely exhibits subparallel, trellis and subrectangular along with dendritic drainage patterns. Trellis and Subparallel drainage patternsare restricted to high slope regions. Fig. 5 shows the drainage pattern along with the lineations in the study area. The subrectangular drainage pattern is compared with the lineaments visually and it can be easily made out that the pattern is largely controlled by the structural features of the geologic formations. Dendritic pattern is noticed in the low lying areas where the relative relief is relatively low.

### Linear Aspects

***Stream Order (U)***

Determination of the Stream Order (U) is important as it provides an insight into the size and scale of the each of the subwatersheds in the study area. According to Haghipour and Burg (2014), ‘U’ depends on basin shape, size and relief characteristics of the basin. The ‘U’ analysis was carried out based on Strahler’s method (1964) using ArcGIS. The results indicated that the Harangi watershed is of sixth order and the ‘U’ varies from $1^{st}$ to $5^{th}$ order streams for subwatersheds. The subwatersheds SW01, SW02, SW03, SW05 and SW06 are classified as fifth order basins, watersheds SW04, SW07 and SW08 as fourth order basins, and the remaining two SW09 and SW10 as third order basins (Table 2).

**Table 2: Stream order and number of streams of Harangi subwatersheds**

| Subwatershed | Stream Order (U) | | | | | |
|---|---|---|---|---|---|---|
| | I | II | III | IV | V | |
| | Number of streams (Nu) | | | | | Total |
| SW01 | 352 | 77 | 22 | 3 | 1 | 455 |
| SW02 | 244 | 44 | 10 | 3 | 1 | 302 |
| SW03 | 309 | 65 | 14 | 3 | 1 | 392 |
| SW04 | 182 | 47 | 10 | 1 | - | 240 |
| SW05 | 151 | 38 | 10 | 2 | 1 | 202 |
| SW06 | 119 | 27 | 8 | 2 | 1 | 157 |
| SW07 | 137 | 30 | 5 | 1 | - | 173 |
| SW08 | 62 | 14 | 4 | 1 | - | 81 |
| SW09 | 29 | 6 | 1 | - | - | 36 |
| SW10 | 72 | 17 | 3 | - | - | 92 |
| Total | 1657 | 365 | 87 | 16 | 05 | |

***Stream Number (Nu)***

Number of stream segments of the northern subwatersheds is more than those of the subwatersheds located in the southern direction. Further, lower order streams are successively higher in 'Nu' owing to its higher altitude course indicating young topography. This can also be inferred in the sudden drop of 'Nu' from the 1st to successive higher orders. The 1st order streams account for 75 – 80%of the total 'Nu' in the basin area. The maximum number of 1st order streams indicates the intensity of permeability and infiltration characteristics of the area as well as the river of fairly smaller length is physiognomies of regions with steep gradients and better textures (Rai et al., 2018). From the study, it is inferred that the subwatersheds located to the North of the river have relatively higher discharges, and velocity. The northern subwatersheds are mostly characterised by higher stream orders (U=5) (Table 3) pointing to more surface runoff in relation to southern subwatersheds and this indicates that the sediment load being contributed from the subwatersheds located in the North is relatively more than that of southern watersheds.

**Table 3: Stream Order and Length of Harangi Subwatersheds**

| Subwatershed | Stream Order (U) | | | | | Total length(km) |
|---|---|---|---|---|---|---|
| | I | II | III | IV | V | |
| | Stream length (km) (Lu) | | | | | |
| | 1 | 2 | 3 | 4 | 5 | |
| SW01 | 135.847 | 66.235 | 30.667 | 26.398 | 8.349 | 267.496 |
| SW02 | 97.434 | 40.316 | 19.448 | 7.332 | 13.940 | 178.47 |
| SW03 | 125.200 | 51.348 | 23.957 | 6.754 | 19.597 | 226.856 |
| SW04 | 70.896 | 32.738 | 13.234 | 13.143 | - | 130.011 |
| SW05 | 64.024 | 28.281 | 17.812 | 5.237 | 6.890 | 122.244 |
| SW06 | 43.135 | 20.530 | 17.475 | 3.030 | 5.858 | 90.028 |
| SW07 | 56.511 | 28.574 | 15.396 | 4.304 | - | 104.785 |
| SW08 | 25.864 | 8.349 | 7.023 | 3.171 | - | 44.407 |
| SW09 | 12.946 | 3.667 | 5.800 | - | - | 22.413 |
| SW10 | 29.176 | 11.200 | 4.638 | - | - | 45.014 |

***Stream Length (Lu)***

Lengths, for which stream run are reflective of runoff characteristics. Generally, shorter lengths of stream indicate steep to moderate slopes and finer textures whereas longer lengths point to gentle to flat gradients and coarser texture. The computed lengths in GIS platform (Table 3), shows that the stream segments gradually decrease from first order to the next higher order. As can be made out from the Table 3, the total stream length of all orders in the northern subwatershed is greater than the South side subwatershed so also the basin lag time although both northern and southern sides' subwatersheds are covered with similar vegetation cover, soil and underlying geology. Generally, the total length of streams in 1st order is maximum for the given water basin and stream length decreases as stream order increases (Avijit Mahala, 2020).The inconsistency in the values of the 'Lu' may be due to structural disturbances in the area or break in elevation suggesting geological as well as morphological control on watershed area. This anomaly is noticed in 5th order streams of SW02, SW03, SW05 and SW06 and 3rdorder streams of SW09.

***Mean Stream Length (Lum)***

Strahler (1964) advocated that the mean stream length of a given order is less than the next higher order. In the present study area also it is noticed that the mean stream lengths of the higher orders are less than the lower orders (Table 4). The 'Lum' of each consecutive orders of a basin tends to evaluate a direct geometric series with stream length increasing towards higher order of streams. However, a departure from the established rule is noticed in the SW01 and SW06 and similar anomalies are also noticed in other drainage basins (Vittala et al., 2004, Sandeep Soni, 2017) which may be due to the variation in the stream flow, rock types, slope and topography. Most of the studies indicate low 'Lum' value in mountain environment than plateau or plain morphology (Rai et al., 2018). Low 'Lum' values in the upper reaches indicate young morphological development and high erosion potentiality.

**Table 4: Mean stream length of Harangi subwatersheds**

| **Subwatersheds** | **Mean stream length (km) (Lum)** | | | | |
|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** |
| SW01 | 0.386 | 0.861 | 1.394 | 8.800 | 8.349 |
| SW02 | 0.400 | 0.917 | 1.945 | 2.444 | 13.940 |
| SW03 | 0.406 | 0.790 | 1.697 | 2.252 | 19.597 |
| SW04 | 0.390 | 0.697 | 1.324 | 13.143 | |
| SW05 | 0.425 | 0.745 | 1.782 | 2.619 | 6.890 |
| SW06 | 0.363 | 0.761 | 2.185 | 1.515 | 5.858 |
| SW07 | 0.413 | 0.953 | 3.080 | 4.304 | |
| SW08 | 0.418 | 0.597 | 1.756 | 3.171 | |
| SW09 | 0.447 | 0.612 | 5.800 | | |
| SW10 | 0.406 | 0.659 | 1.546 | | |

***Stream Length Ratio (Lur)***

Horton (1945) stated that "the number of streams of different orders in a given drainage basin tend closely to approximate a geometric series". The values of the 'Lur' obtained following Horton's (1945) procedure are disorderly as noticed in majority of the subwatersheds of the study area (Table 5) and do not show any definite pattern at the subwatershed levels. This anomaly is attributed to differences in slope and topographic conditions (Vittala et al., 2004 and Sreedevi et al 2005) and points to their late youth stage of geomorphic development (Singh and Singh, 1997). This conforms well to the field condition in the study area and studies by Magesh and Chandrashekhar (2014) and Avijit Mahala (2020) who suggested that the mountain-plain front river basins have irregular tendency of stream length ratios.

**Table 5: Stream length ratios (Lur) of Harangi subwatersheds**

| **Subwatersheds** | **Stream length ratio (Lur)** | | | |
|---|---|---|---|---|
| | **2/1** | **3/2** | **4/3** | **5/4** |
| SW01 | 0.488 | 0.463 | 0.861 | 0.316 |
| SW02 | 0.414 | 0.482 | 0.377 | 1.901 |
| SW03 | 0.410 | 0.467 | 0.282 | 2.902 |
| SW04 | 0.462 | 0.404 | 0.993 | - |

| | | | | |
|---|---|---|---|---|
| SW05 | 0.442 | 0.630 | 0.294 | 1.316 |
| SW06 | 0.476 | 0.851 | 0.173 | 1.933 |
| SW07 | 0.506 | 0.539 | 0.280 | - |
| SW08 | 0.323 | 0.841 | 0.452 | - |
| SW09 | 0.283 | 1.582 | - | - |
| SW10 | 0.384 | 0.414 | - | - |

***Bifurcation Ratio (Rb)/Mean Bifurcation Ratio (Rbm)***

Bifurcation Ratio (Rb) is expressed as the ratio of number of streams of a given order to its next higher order (Horton, 1945). According to Straher's definition of stream order (1953), the minimum possible value of 'Rb' is 2, but theoretically there is no maximum value of 'Rb' (Milton, 1967). According to Horton (1945), the 'Rb' has a relatively low value in flat or rolling country, and a higher value in mountainous or highly dissected terrain suggesting that the value of 'Rb' is related to geomorphic factors such as relief ratio, drainage density, runoff intensity, soil types, relative relief and geological structures. Analysis of the results presented in Table 6 shows that the values of mean bifurcation ratio (Rbm) of the 10 subwatersheds vary from 3.446 to 6.191. 'Rbm' does not precisely remain constant from one order to the next, because of possibility of variations in watershed geometry and lithology, but it tends to be a constant throughout the series (Farruk Altaf et al., 2013).Elongated basins have low'Rb' values while circular basins have high 'Rb'values (Morisawa1985). Consequently, watersheds showing high 'Rbm' values indicates early hydrograph peak with a potential for flash flooding during the storm events (Rakesh et al., 2000). Strahler (1964) and Verstappen (1983) opine that the geological structures do not influence the drainage network when the 'Rbm' values ranges between 3.0 and 5.0. However, in the present study lineaments have played a major role on the drainage network (Fig. 5) although majority of the subwatersheds have 'Rbm' values in the range of 3.0 to 5.0. Further, the Rbm values imply elongated nature of the subwatersheds. According to Milton (1967), the value of 'Rb' is set by the angular relationships of the streams and the drainage density. Accordingly, the streams showing dendritic pattern will have the value of 'Rb' fairly low and streams of steep sided valley of washout gulley show high bifurcation ratio. Subwatersheds namely SW01, SW04, SW07 and SW09 show anomalies in the values of 'Rb' which could be due to the structural disturbance in the area.

**Table 6: Bifurcation ratios of Harangi Subwatersheds**

| Subwatersheds | Bifurcation ratio (Rb) | | | | Mean Bifurcation ratio (Rbm) |
|---|---|---|---|---|---|
| | 1/2 | 3/2 | 3/4 | 4/5 | |
| SW01 | 4.571 | 3.500 | 7.333 | 3.000 | 4.601 |
| SW02 | 5.545 | 4.400 | 3.333 | 3.000 | 4.070 |
| SW03 | 4.754 | 4.643 | 4.667 | 3.000 | 4.266 |
| SW04 | 3.872 | 4.700 | 10.000 | - | 6.191 |
| SW05 | 3.974 | 3.800 | 5.000 | 2.000 | 3.693 |
| SW06 | 4.407 | 3.375 | 4.000 | 3.000 | 3.446 |
| SW07 | 4.567 | 6.000 | 5.000 | - | 5.189 |
| SW08 | 4.429 | 3.500 | 4.000 | - | 3.976 |
| SW09 | 4.833 | 6.000 | - | - | 5.417 |
| SW10 | 4.235 | 5.667 | - | - | 4.957 |

**Areal Aspects**

***Drainage Density (Dd)***

Drainage density (Dd) is defined as the stream length per unit area in basin area (Strahler, 1964) and this parameter facilitates numerical measurement of runoff potentiality of the basin and landscape dissection. Thus, 'Dd' has a bearing on the length of the watershed and the controlling factors are many including geology of the area, forest cover and climate. All these factors decide the lag time of water in the basin. The 'Dd' values of the study area range from 2.257 to 2.430 km/km$^2$ (Table 7) and do not show much variation. The 'Dd' values of Harangi subwatersheds fall under medium category and according to Sandeep Soni (2017) the values indicate gentle to steep slope terrain, medium dense vegetation, and less permeable with medium precipitation. However, the present authors have observed high 'Dd' values at upper reaches of the basin indicating relatively less permeable formations, high relief and high runoff. Thus higher 'Dd' values indicate higher runoff with greater flow velocity.

**Table 7: Areal Aspects of the Harangi subwatersheds**

| Subwatersheds | Drainage Density (Dd) Km/Km$^2$ | Stream Frequency (Fs) Km$^{-2}$ | Drainage texture (Dt) | Length of overland flow (Lg) | Constant of channel maintenance (C) Km$^2$/Km | Form factor (Ff) | Circulatory ratio (Rc) | Elongation Ratio (Re) | Gravelius'sCompactness coefficient (GC) |
|---|---|---|---|---|---|---|---|---|---|
| SW01 | 2.380 | 4.048 | 7.441 | 0.21 | 0.42 | 0.306 | 0.378 | 0.176 | 1.63 |
| SW02 | 2.258 | 3.821 | 3.858 | 0.22 | 0.44 | 0.321 | 0.162 | 0.180 | 2.48 |
| SW03 | 2.257 | 3.900 | 6.388 | 0.22 | 0.44 | 0.310 | 0.335 | 0.177 | 1.73 |
| SW04 | 2.430 | 4.486 | 5.129 | 0.22 | 0.41 | 0.338 | 0.307 | 0.185 | 1.81 |
| SW05 | 2.357 | 3.894 | 4.502 | 0.21 | 0.42 | 0.340 | 0.324 | 0.186 | 1.76 |
| SW06 | 2.302 | 4.014 | 4.556 | 0.22 | 0.43 | 0.353 | 0.414 | 0.189 | 1.55 |
| SW07 | 2.265 | 3.740 | 5.246 | 0.22 | 0.44 | 0.345 | 0.534 | 0.187 | 1.37 |
| SW08 | 2.300 | 4.195 | 3.167 | 0.22 | 0.43 | 0.388 | 0.371 | 0.198 | 0.61 |
| SW09 | 2.295 | 3.686 | 1.608 | 0.22 | 0.43 | 0.426 | 0.245 | 0.208 | 2.02 |
| SW10 | 2.386 | 4.877 | 2.719 | 0.21 | 0.42 | 0.390 | 0.207 | 0.199 | 2.20 |

***Stream Frequency (Fs)***

Stream frequency (Fs) is the total number of streams of all orders per unit area. 'Fs' provides drainage basin response to runoff processes and thus depends on the rainfall, relief and 'Dd' of the basin. The higher value of 'Fs' indicates good drainage network, high slope, greater rainfall and lower permeability. The analysis of the results (Table 7) shows that 'Fs' values vary from 3.686/km$^2$ to 4.877/km$^2$.The values observed in Harangi watershed do not vary much between the subwatersheds. Most of the study area is covered by residual hills with a thick soil cover and moderate to dense vegetation. Therefore, it can be inferred that the present 'Fs' values indicate moderate permeability so also infiltration capacity and relief with good amount of vegetation. 'Fs' is thus related to permeability and relief of the basin.

***Drainage Texture (Dt)***

The drainage texture (Dt) is the product of drainage density and stream frequency (Smith, 1950) and is governed by soil infiltration and volume of water available in a given period of time to enter the surface (Ritter, 2012). Fewer drainage channels will develop in areas where the surface is flat and the soil infiltration is high. Fewer numbers of channels indicate coarser drainage texture 'Dt'. This further indicates that the watersheds exhibiting coarser texture will have high basin lag time periods. Smith (1950) categorized the values of 'Dt' into five classes and ranked them as very coarse (<2), coarse (2–4), moderate (4–6), fine (6–8), and very fine (>8). According to this classification, SW09 has very coarse 'Dt' value (1.608) and indicates that the basin consists of highly resistant permeable material with low to moderate relief, SW02 (3.858), SW08 (3.167) and SW10 (2.719) have coarse 'Dt', SW04 (5.129), SW05 (4.502), SW06 (4.556), and SW07 (5.246) have moderate 'Dt', and SW01 (7.441), and SW03 (6.388) have fine 'Dt' values (Table 7).

***Length of Overland Flow (Lg)***

Length of overland flow (Lg) of subwatershed is almost half of the reciprocal of the value of its drainage density and depends on permeability of the formation, intensity of rainfall, rate of infiltration and relief of the region as the overland flow is possible only when rate of infiltration is less than that of the intensity of the rainfall. Table 7provides the computed values of 'Lg' of the subwatersheds which is around 0.22 for all the 10 subwatersheds. Low values of 'Lg' indicate low surface runoff. From the obtained results it may be inferred that the region is covered with permeable soil and vegetation. However, the study area along with permeable soil and moderate to high vegetation is also characterized by moderate to steep slopes. The values also indicate more of channel erosion (Horton, 1945).

***Constant of Channel Maintenance (C)***

The reciprocal of the drainage density (Dd) is constant of channel maintenance (C) (Schumm, 1956) and signifies the number of square kilometre area required to develop and sustain a channel 1 km long. In the present study, the 'C' value range from 0.41 to 0.44 $Km^2$ / Km (Table 7). Low values of 'C' in the present case indicate mountain environment that all the subwatersheds are low erodible (Schumm, 1956) implying high relief, low permeability and high to moderate surface runoff.

***Form Factor (Ff)***

It indicates the flow intensity of a basin and the values vary from 0 for highly elongated basin to 1 for perfectly circular basin (Horton, 1945). In the present study, the 'Ff' values (Table 7) indicate that the form of the basin vary from elongated (0.321) to near circular (0.426) in shape. Lower value of 'Ff' implies more elongated basin with flatter peak of low flow for longer duration, lower erosion and sediment transport capacities. (Sandeep Soni, 2017). The smaller the value of the 'Ff', the more elongated will be the basin and basins with high 'Ff' experience larger peak flows of shorter duration whereas, elongated basin with low 'Ff' experience lower peak flows of longer duration (Rai et. al. 2018).

***Circulatory Ratio (Rc)***

Miller (1953) defined Circulatory Ratio (Rc) as the ratio of the area of the basin (A) to the area of the circle having the same circumference as the perimeter (P) of the basin. Erosive power as well as the dissection potential of the streams owing to the geology and steep slopes can be inferred from the values of the 'Rc'. Lithological characteristics of the basin have a strong bearing on the 'Rc' values. The values of 'Rc' of the subwatersheds of the study area range from 0.162 to 0.534 and majority of the subwatersheds have a 'Rc' value of around 0.3 thus indicating strongly elongated basins, lower runoff and permeable soil conditions. Low values of the 'Rc' of the basin indicate youth stage of a river. The study region is largely characterized by very low to low values of 'Rc' (Table 7) thus indicating steep slope, high erosive power of the streams and greater sediment load.SW07 shows the moderate value of 'Rc' (0.534), thus suggesting the subwatershed of moderate slope and moderate erosive power of the streams.

***Elongation Ratio (Re)***

Elongation Ratio (Re) is the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin (Schumm, 1956).The maximum and minimum values of Elongation Ratio (Re) of the subwatersheds of the Harangi region are 0.176 and 0.208 respectively (Table 7).According to Strahler's (1952) classification, the 'Re' values of the Harangi subwatersheds indicate that they are more elongated. Further, the region is characterized by moderate to high relief, high structural effects and steep ground slope of subwatersheds. The elongated watersheds imply the delayed time to peak flow and longer durations for the discharge thus facilitating high infiltration of water.

***Gravelius's Compactness Coefficient (GC)***

Different indices such as the shape factor, the elongation ratio, the circularity ratio and the aspect ratio are used to assess the shape of subwatersheds. Gravelius Compactness Coefficients (GC)(Gravelius, 1914 cited in Timothee et al., 2018) is often used to describe the shape of the catchment area (Fig 6a and 6b) of the subwatershed. According to Timothee et al., (2018), the values of 'GC'is 1 for ideally circular watershed and the values of 'GC' increases with both basin elongation and irregularity of the basin boundaries. Rate of water and sediment yield along the length and relief of the drainage basin is largely affected by the shape. 'GC' values obtained for the present study area (Table 7) reveals that the subwatersheds are more elongated in nature.

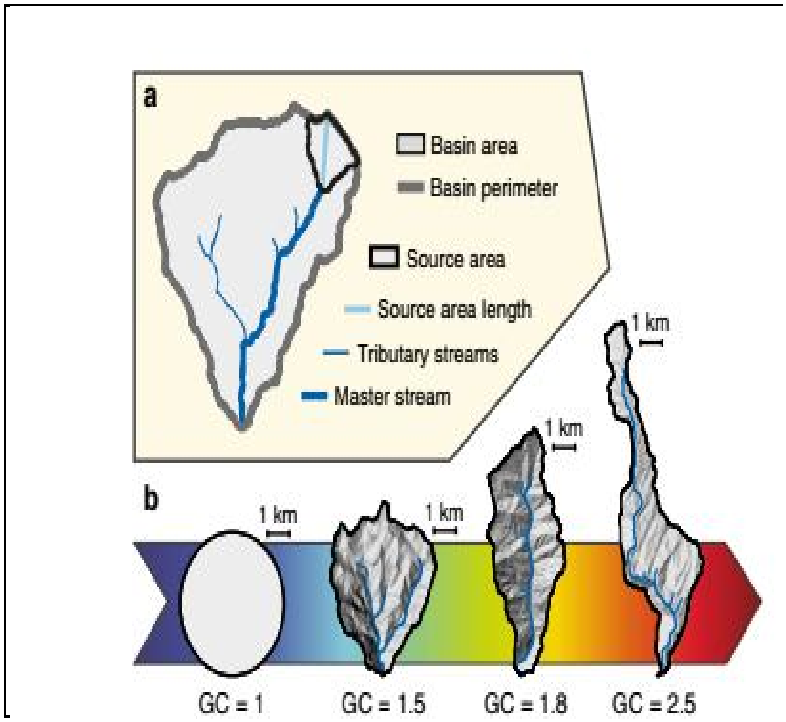


**Figure 6: (a) Main drainage basin features, (b) selected basin shapes and associated Gravelius coefficients (after Timothee et al., 2018)**

## Relief Aspects

### *Basin Relief (Z)*

Basin relief is expressed by maximum height (Z) above the mean sea level (MSL) and relative relief (H) of the basin. 'H' is altitudinal difference in the maximum and minimum values of the altitude of the given basin. The maximum height (Z) and basin relief (H) of the subwatersheds of the Harangi watershed is shown in Table8. The highest altitudinal point of the Harangi watershed is 1600 m above MSL and highest 'H' value is 700 m. Relief characteristics of the basin suggest that the area is vulnerable for erosion and the area is in youth stage of geomorphic development.

### *Relief Ratio (Rh)*

Relief ratio (Rh) measures the overall steepness of a drainage basin and is an indicator of the intensity of erosion process operating on slope of the basin (Schumm, 1956). Higher values of relief ratio indicate hilly terrains that are characterized by moderate to steep slopes. In the present study as presented in Table 8, 'Rh'values of subwatersheds of the study area ranges from 0.02 to 0.05. Northern and southern subwatersheds do not show much contrast in their Rh values. However, all the subwatersheds are characterized by moderate relief ratio thus implying moderate vulnerability of the area for erosion.

### *Ruggedness Number (Rn)*

The ruggedness number (Rn) is the product of drainage density and basin relief (Strahler1958). 'Rn'in association with the relief and drainage density indicates the structural complexity of the terrain. The low value of 'Rn' (<0.5) indicates the area is least susceptible to soil erosion. In the present study, values of 'Rn'vary from moderate (Rn = 0.35) to high (Rn = 1.70) as seen in Table 8. This data indicate that most of the subwatersheds of the study area barring SW08 and SW09 witness intensive denudation activities. The 'Rn' values of subwatersheds suggest youthful stage of geomorphic development of subwatershed areas and significant susceptibility for soil erosion.

**Table 8: Relief Aspects of Harangi subwatersheds**

| Subwatersheds | Maximum height (Z)above MSL (m) | Relative relief (H) (m) | Relief ratio (Rh) | Ruggedness number (Rn) | Basin slope | Dissection Index (Di) |
|---|---|---|---|---|---|---|
| SW01 | 1300 | 450 | 0.023 | 1.07 | 23.464 | 0.346 |
| SW02 | 1350 | 450 | 0.029 | 1.02 | 28.661 | 0.333 |
| SW03 | 1600 | 700 | 0.039 | 1.58 | 38.891 | 0.438 |
| SW04 | 1600 | 700 | 0.056 | 1.70 | 55.653 | 0.438 |
| SW05 | 1300 | 350 | 0.028 | 0.83 | 28.317 | 0.269 |
| SW06 | 1300 | 350 | 0.033 | 0.81 | 33.238 | 0.269 |
| SW07 | 1250 | 350 | 0.030 | 0.79 | 30.219 | 0.280 |
| SW08 | 1050 | 150 | 0.021 | 0.35 | 21.271 | 0.143 |
| SW09 | 1100 | 200 | 0.042 | 0.46 | 41.762 | 0.182 |
| SW10 | 1150 | 300 | 0.043 | 0.72 | 43.110 | 0.261 |

***Dissection Index (Di)***

The degree of dissection of a land feature can be made out by computing Dissection Index (Di) which is defined as the ratio of the maximum relative relief to maximum absolute relief (Singh and Dubey, 1994). The values of 'Di' vary from 0 for flat surface and negligible vertical erosion to 1 for cliffs. 'Di' values calculated for the Harangi subwatersheds range from about 0.2 to 0.4 (Table 8) indicating moderately dissected landscape and derivation of moderate amount of sediment load.

## CONCLUSION

The present study throws light on the nature of the landform of the study area with regard to its hydrological characteristics, infiltration capacity of the soil, surface runoff, erosion and consequent sedimentation in the lower reaches of the basin based on drainage morphometry carried out by using conventional and modern techniques. Harangi watershed has been divided into ten subwatersheds in GIS environment following the topographic divide. Five watersheds located in the northern side are larger based on area and stream numbers. Stream order analysis following Straher's method reveals that Harangi watershed is of sixth order. However, subwatersheds are classified as third order to fifth order basins. Cumulative lengthwise, all subwatersheds located in the northern part have highest number of streams. Subwatersheds SW01 and SW03 have about 267 and 227 km cumulative stream lengths and subwatersheds of the southern part have low cumulative stream lengths and the minimum cumulative stream length being about 22 km in SW09. The anomaly in cumulative stream lengths between subwatersheds of northern and southern parts can be attributed to relief and area of the individual subwatersheds. Moderate to high values of bifurcation ratio of all subwatersheds suggest that the study area has been disturbed structurally and the observed drainage patterns such as trellis, subparallel and subrectangular patterns and their alignment to the lineaments of the study area further validates the structural control on the drainage basins. However, dendritic drainage pattern is noticed in low relief areas. Subwatersheds located on the northern side have high relief compared to its counterparts. The relief of the northern watersheds varies from 350 m to 700 m and the maximum relative relief of 700 m is witnessed by SW03.High drainage density is found in all the subwatersheds at higher altitudes suggesting low infiltration, high runoff and moderate forest cover. The finding of drainage density studies is validated by high values of stream frequency of all subwatersheds. The intermediate and low values of drainage texture respectively of the northern and southern subwatersheds indicates that the basins are characterized by coarse to intermediate textures, thus implying high runoff, low permeability and consequently more of soil erosion. Low average values of length of overland flow in subwatersheds (0.22) imply low permeability, high runoff, steep slope and structural disturbance in the area. All the subwatersheds are characterized by low values of constant of channel maintenance (0.42 to 0.44) and this feature also points to the structural disturbance in the area in addition to low permeability, high surface runoff, and steep slopes. Low form factor (Ft) values of subwatersheds (0.306 to 0.390) indicate less side flow for shorter duration and high main flow along longer duration. This is further supported by the low values of the circularity (0.3) and elongation ratios (0.18) as well as relatively high values of Gravelius's compactness coefficient. All these parameters indicate that the majority of the subwatersheds are elongated in shape. The relief values suggest that the northern subwatersheds characterised by steep slopes witness low infiltration at higher reaches, high gravity flow and runoff. Hence, erosion and consequent sediment load from the northern subwatersheds are relatively more than those located on the southern side. This observation is further validated by the high values of ruggedness number of northern watersheds in comparison with those of the southern watersheds. Moderate dissection index values of the northern watersheds also support this view. From the analysis of linear, areal and relief aspects of the Harangi watershed, it may be concluded that the subwatersheds located in the North direction warrants more attention from the authorities with regard to their potentiality of the soil erosion as they are large in areas, number of streams, high relief compared to their southern counterparts. The present study throws light on the soil erosion in the basin and gives better ideas for drainage management.

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