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ASSESSMENT OF SUB-WATERSHED FOR SOIL EROSION THREAT IN A SEMI-ARID REGION WATERSHED (BENNIHALLA) OF NORTH KARNATAKA USING MORPHOMETRIC ANALYSIS AND GEO-COMPUTATIONAL APPROACH

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Abstract

Understanding the risks associated with soil erosion and drainage patterns is essential for agricultural output. In the research 9 sub-watersheds of the Bennihalla catchment located in semi-arid regions is studied to priorities for soil erosion-threat through morphometric investigation with the help of Geospatial methods and weighted sum approaches (WSA). ArcGIS was used to build drainage networks; SRTM DEM to delineate sub-watersheds and morphometric parameters (linear, relief and area) following standard formulas. The said parameters used to rank and prioritize sub-watersheds. A weighted sum approach (WSA) and cross-correlation of 18 morphometric parameters were used to approximate the compound factor. The compound factors for various sub-watersheds ranged from 0.0052 to 4.412. Lowest compound factor was given the highest priority. Sub-watersheds were classified as very good, good, moderate, low, and very low according to their compound factor value. The results indicated that, SW1 and SW 9 are influenced by respectively lowest and highest soil erosion threats, the other sub watershed that also need. Soil conservation measures include .SW7, and SW5 (1980.67 km2 area).

Keywords: Drainage Basin Analysis. Bennihalla Watershed. Soil Conservation, Erosion; Prioritization of Sub Watersheds.

INTRODUCTION

Soil is the most important natural resources that sustain human life and the biosphere and soil erosion is a great to ecosystem. Gullying is considered one of the best visible ways of soil erosion [15] Ghosh et al., 2016). Disintegration of rocks result in soil, but its relocation affects the ecosystem and hydrological function in addition to the loss soil fertility [24] Masselink et al., 2017).

Despite the fact that erosion and deposition of soils are both parts of the soil formation process, they are considered hazards when they affect rivers, agricultural loss, deforestation, and land fragmentation. In addition to degrading land quality and productivity, threat to growth of plants, sedimentation in reservoirs, also result in deltas and siltation in navigational channels in the low lands such as estuarine region [43],[7].

Quantitative measurements of soil erosion and the delineation of erosion risk zones at—micro, meso, and macro scale are necessary to understand its consequences on economy and environment in addition to establish management methods [36],[27].

Transport and deposition of the materials eroded by water and wind, manifest in different topographic forms, and offer the basis for morphometric characterization [29], [10]. The drainage basins morphometric evaluation may be considered a quantitative characterization as well as a scientific inquiry into the surface attributes of the basins, as well as the stream characteristics [12], [22].

In recent years studies on morphometric analysis and watershed prioritization have been substantially accelerated by statistical methods and GIS technologies. Remote sensing data—such as digital elevation models (DEMs), Satellite images, and Geospatial technology has proven to be an effective tool. In this endeavor [5], [6], [30], [42]. Most of these investigations focused on the entire basin as the unit of analysis. Further improvement could be achieved by focusing on small-scale sub-watersheds [8]. A number of factors may be considered for prioritization of sub watersheds such as morphometric diversity, groundwater potentiality [19], [13]. Soil erosional risk [2], [32]. Morphometric analysis provides useful way to identifying and prioritizing erosion-prone areas within a watershed. A crucial component of priority is determining and prioritizing the degraded sub-watersheds that currently essential for rehabilitation. Morphometric parameters such as basic, aerial, relief and linear parameters can be used to locate erosion-prone zones that should be prioritized. A number of approaches have been proposed in recent years for prioritizing sub-watersheds, incorporating values for compound factors principal component analysis (PCA), multi-criteria, and weighted sum decision-making; [32],[23],[41]. Simple arithmetic mean calculations based on compound parameter values to also been employed to priorities watersheds. According to these methods, morphometric criteria are considered equally important in recognizing soil erosion-prone watersheds. Present study adopted a statistical correlation matrix-based weighted sum approach which .surpasses the standard techniques in terms of effectiveness and adaptability. And has employed in many scholarly studies [32], [21, [20].

In the current work, morphometric parameters were thoroughly scrutinized, correlation among stream length, stream number and stream order were examined by employing coefficients of determination (R2), and WSA was employed to rank soil erosion-susceptible regions within semi-arid catchment accurately to evolve criteria for prioritization of soil erosion threats. In India 975 million ha of land is under deterioration due to soil erosion in different regions of the country. Bennihall experiences a semi-arid climate, vast area is favorable for agriculture but due to scarcity of rainfall and surface water resources, over exploitation of groundwater became inevitable.

Significant soil erosion is a persistent issue in large portions of the area. To address this problem, it is crucial to recognize the region's geomorphology, and drainage pattern, which will help develop a successful watershed development plan. Therefore, the present study has two objectives. Firstly, it intends to evaluate the hydrological features of Bennihalla catchment by identifying morphometric parameters of sub-watersheds using

SRTM DEM. Secondly, it aims to prioritize sub-watersheds vulnerable to soil erosion using WSA.

Study Area:-

Bennihall basin is the important tributary of Malaprabha River which is principle tributary of Krishna River. The research area bounded between authorizations The uniqueness of the study area (The Bennihalla catchment 75:14:25.3 to 75:36:14.6 N latitude and 15:05:25.3 to 15:06:17.02 E longitudes is that it is lifeline of northern parts of Dharwad and Gadag districts. The taluks of Rona, Gadag, and in the east Shirahatti, in the west Dharwad and Hubli encircle the research area. The talukas of Nargund and Pasargad are in the north, and Shiggaon is in the southwest. Taluk Navalgund is in the middle. The Bennihalla experience flashy floods and large soil erosion problem yet accurate water-scarce.It is the longest drain originating at Tadas Village of Mundagodtaluka and has Tuparihalla, Hanchigonhalla and Gugihalla major tributaries with a catchment of 4300.67 sq km. Area experience flashy floods and erosion is a severe problem. Because of siltation in the water storage provision is getting affecting resulting in further water scarce situation. The research area's physiography is defined by gently varying terrain including ridges that alternate, with slope elevations starting at 600 meters above mean sea level. Geologically, area comprises of granite gneiss and Dharwar schistose rocks. Granitic gneiss makes up the northeastern portion of the study area, which is primarily covered in thick black cotton soil. The remaining portion of the area is covered in altered greywackes of schistose rock, shales and phyllites. The schistose formation strikes in NNW-SSE direction and Dipping varies from 35^0 to nearly vertical.

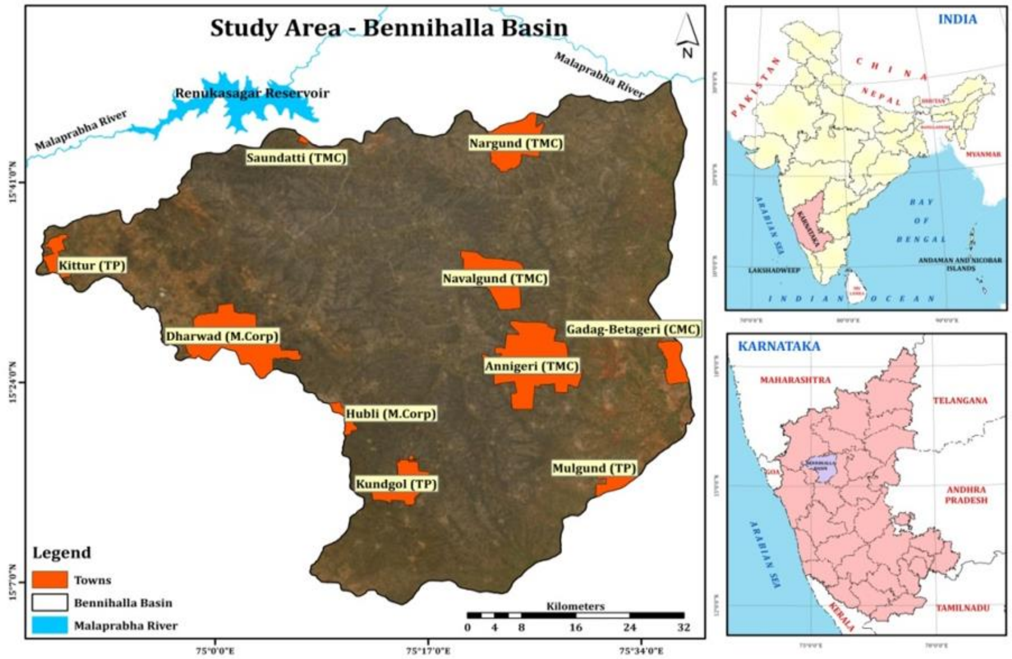

Fig 1: Location map of research area

METHODOLOGY

To derive a drainage network, delineate Sub-watersheds and to determine morphometric parameters, we utilized a pre-processed SRTM DEM with Arc GIS spatial analyst extension tool and Arc hydro tools. Eight-direction flow models ranging from 1 to 128were used for drainage extraction **[3].** The direction of in which the water flows in the raster and a combination of pixels with a threshold value larger than 150 were used to determine the accumulation of flow. The workflow for determining the boundaries of watersheds and sub-watersheds is shown in Figure 2A. Pour points were used to delineate the boundaries of watersheds and sub-watersheds. Cross-verification was conducted using topographic maps from the SOI open series featuring the sheet numbers (D43D1, D43D2, D43D3, D43D4, D43D5, D43D6, D43D7, D43D8, D43D9, D43D10, D43D12 and D43C14, C15) on a scale of 1:50,000.Extracted stream order were converted to vector format to calculate the morphometric parameters. Morphometric parameters such as linear, relief, and arealaspects were computed with ArcGIS software. Methodology employed for morphometric analysis of the watershed were presented in figure 2A and Table 1.

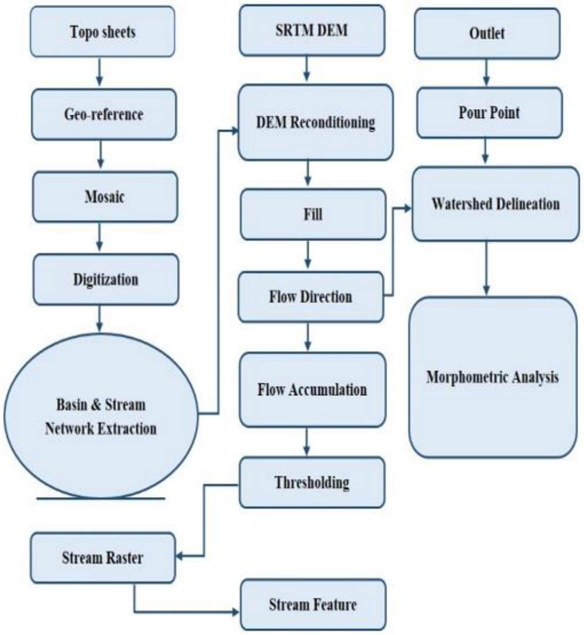

Fig 2 A: Workflow of drainage network extraction from ASTER DEM for the Research area.

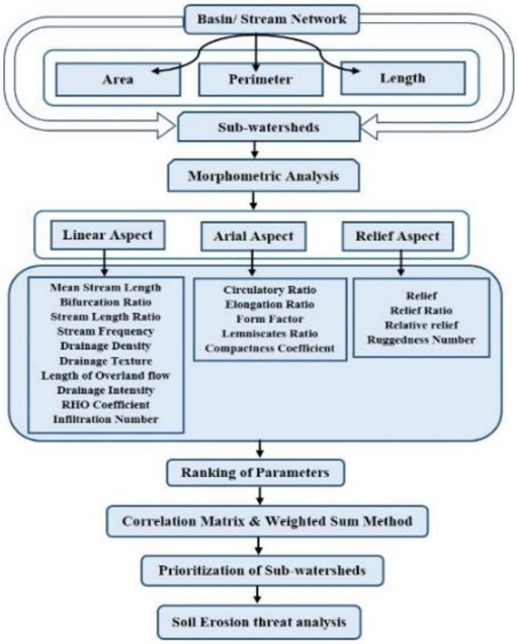

Fig 2 B: Methodological flowchart for morphometric analysis of watershed

Preliminary priority ranking of sub-watersheds

Morphological characteristics of sub watersheds were used to prioritize the sub basin. This analysis included linear factors such as bifurcation ratio, stream frequency, stream length, drainage density and intensity, overland flow length, RHO (Spearman's rank correlation) coefficient, and infiltration rate. Additionally, we considered areal aspects such as Lemniscate, circulation and elongation ratios, form factor & compactness coefficient, including ruggedness number, relative relief and relief ratio. As explained by various studies, a basin's erosion potential and runoff intensity vary proportionally to the linear and relief factors while soil erodibility is anti-correlated with the areal and form parameters [31],[16]. Therefore, relief parameter and linear are given priority based on their significance, with the most critical value being considered first and the least important value being considered last whereas the areas with the least values for these parameters are the most vulnerable to soil erosion. The rankings for these areas are determined by the order of their parameter values, lowest being first and the highest being prioritized last, as all morphometric criteria have same weight in the ranking.

Weighted sum approach (WSA)

Sub watershed rankings were based on the compound factor (CF), expressed as

$$CF= PPR_{MP} \times W_{MP} \text{ ---- } (1)$$

Is computed by multiplying the weights found from the cross-correlation analysis by preliminary rankings obtained from morphometric investigation [44] **c.f.**

The cross-correlation analysis is used to calculate the weighted morphometric parameter **(WMP).**

PPRMP is the preliminary priority rank obtained from morphometric parameters.

Table 1: The formulae and methods used to calculate watershed morphometric parameters

Parameters and aspects	**Formulae/ methods**	**Units**	**Reference**
Basic Parameters			
Area(A)	GIS software analysis	km^2	
Perimeter(P)	“	Km	
Maximum elevation (H)	“	M	
Minimum elevation (h)	“	“	
Length	“	“	
Stream order(U)	Hierarchical rank	Dimensionless	Nookaratnam et al. (2005)
Stream number(N_u)	$N_u=N_{u1}+N_{u2}+\ldots+N_{un}$	“	Strahler (1964)
Stream length(L_u)	$L_u=L_{u1}+L_{u2}+\ldots+L_{un}$	Km	Horton (1945)
Derived parameters			
Linear aspects			
Mean stream length (L_{sm})	$L_{sm}=L_u/N_u$	Km	Horton(1945)
Bifurcation ratio(R_b)	$R_b=N_u/(N_u+1)$	Dimensionless	Schumm(1956)
Stream length ratio(R_L)	$R_L= L_u/(L_u-1)$	“	Horton(1945)
Mean bifurcation ratio (R_{bm})	R_{bm} = Average of bifurcation ratios of all orders	“	Schumm(1956)
Mean stream length ration (R_{lm})	R_{lm}= Average of stream length ratios of all orders	“	Schumm (1956)
Stream frequency(F_s)	$F_s=N_u/A$	km^{-2}	Schumm(1956)
Drainage density(D_d)	$D_d=L_u/A$	“	Schumm(1956)
Drainage texture(D_t)	$Dt=Nu/ \rho$	km^{-1}	Schumm(1956)
Length of overland flow(L_o)	$L_o=1/2D_d$	Km	Schumm(1956)
Drainage intensity(D_i)	$D_i=F_s/D_d$	km^{-1}	Faniran(1968)
RHO Coefficient(ρ)	$\rho =R_{lm}/R_h$		Horton(1945)
Infiltration number(I_f)	$I_f = F_s/D_d$	km^{-3}	Faniran(1968)
Relief aspects			

Relief(B_h)	B_h = H-h	Km	Strahler(1952)
Relief ratio(R_h)	Rh = H/L_b	Dimensionless	Schumm(1956)
Relative relief(R_{hp})	R_{hp} = H× 100/P	“	Melton (1957)
Ruggedness number(R_n)	R_n=R×D_d	“	Strahler (1954)
Areal/ shape aspects			
Circulatory ratio(R_c)	R_c=4ΠA/P^2	Dimensionless	Miller (1953)
Elongation ratio(R_e)	R_e = 2/L_b ×$A^{0.5}$/Π	“	Schumm (1956)
Form factor(F_f)	F_f = A/L_b^2	“	Horton (1945)
Lemniscates ratio(K)	K= L_b^2/4A	“	Chorley et al. (1957)
Compactness coefficient(C_c)	C_c=P/2$(ΠA)^{0.5}$	“	Horton (1945)

RESULTS AND DISCUSSION

Present research area is divided into nine sub-watersheds labeled SW-1 to SW-9, with a typical dendritic to sub-dendritic drainage pattern. DEM and drainage networks for each sub-watershed of the study area are shown in Figures 3 and 4. Soil erosion is directly or inversely connected to a number of morphometric factors that are described below. These parameters are obtained from the properties of rocks and soil types.

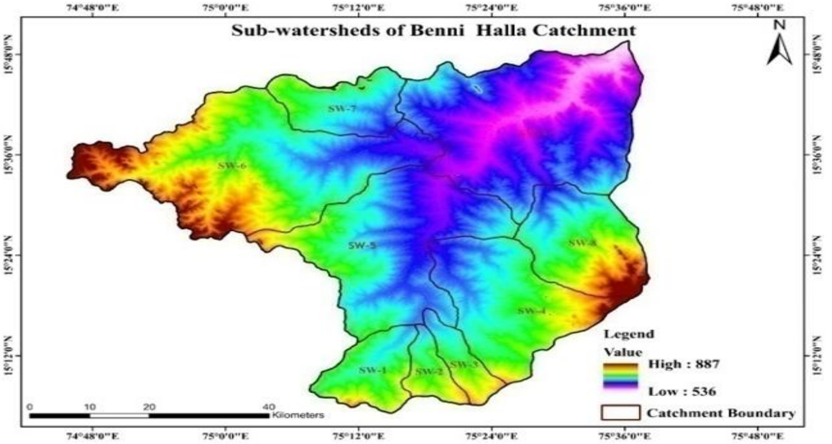

Fig 3: Study area showing 9 sub watershed and DEM

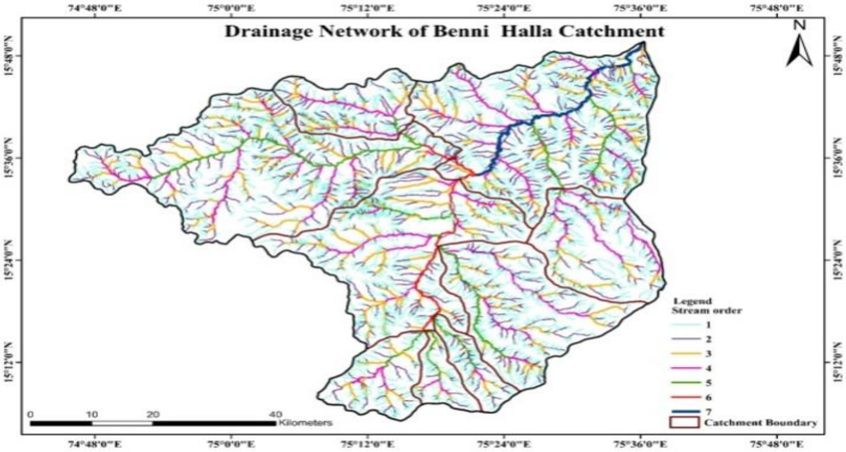

Fig 4: Drainage network of the study area

Basic Parameters:

Catchment Area (A) is one of the most essential features of watersheds, which directly measures the volume of water contained within them. Bennihalla's catchment area is 4300.7 km^2, with sub-watersheds ranging from 93.94 km2 (SW2) to 1015.93 km^2 (SW6). In Table 2, Specific regions of all sub-watersheds are displayed.

Drainage boundary length defined as its **perimeter (P),** indicates its size. The measured sub-watershed perimeters range from 49.43 km for SW2 (the shortest) to 180.91 km for SW6 (the longest) (Table 2).

A **watershed length (L_b)** refers to the longest dimension of a catchment area that is in close proximity to a drainage network [34].Watershed's middle channel is principal pathway for most of the water to flow. A sub-watershed with a length of 62.06 km (SW6) is the longest, while sub-watershed SW 2(19.69 km) is the shortest in the present research (Table 2).The height between a watershed's outlet point and the highest elevation point (B_h)of the research area referred to as Watershed relief (B_h) ranges from 92 to 304 meters above MSL

Stream order (U): The position of a stream within a network called Stream order (U) of its tributaries is generated [40] categorize streams based on the number and type of tributary junctions they have indicated the highest stream orders found in SW9, SW6, and SW5 were the 7th and 6th, respectively, while the 5th order was found in other sub-watersheds. Stream order increases from upstream to downstream .Water, sediments, and runoff all flow through the highest-order streams. The "stream number" (Nu) [17] reveals that the maximum number of streams is 2186 (SW9), and the minimum at 126 (SW2).

Stream length (Lu) [30] is most significant factor and increases with stream order Areas with nearly level-gentle slopes and coarser textures have the longest Lu, whereas those with steeper slopes and fine textures have shorter Lu [40]**.** This measurement also evaluates the bedrock formation and hydrological parameters of the area. For instance, a well-drained watershed and relatively permeable bedrock can shorten stream length [35], [6]. In this study, SW9 had the most extended Lu at 1921.12 km, while SW2 had the shortest at 120.62 km respectively as presented in Table 2.

The mean stream length (L_{sm}) determined by the size of drainage network and watershed surface [40]. L_{sm} is typically more significant for higher-order streams than lower-order ones(Table 2) provides evidence supporting Horton's law of 'Nu' and 'Lu' and the connection between the geometry hypotheses and increasing stream order [31].

Stream length ratio (R_L) [17] **Horton's law (**is the ratio among average length of one stream order and the next lower stream order. Significantly change in this ratio from one order to another represent a shift from a young to a mature stage of geomorphic evolution. It often occurs in high elevated areas due to heavy soil erosion rates, [5]. A direct correlation exists between the RL and the discharge of surface flows and erosional stages in a basin. When R_L is low, there is a higher discharge in conjunction with a more erosion rate, and vice versa [38]. Stream number and length of different orders within a drainage basin are determined by two fundamental laws [17].

1. Inverse geometric progression of stream numbers is calculated using the bifurcation ratio, a relationship among the stream numbers in a given sequence and the stream order. According to this rule, all sub-watersheds complies with law of stream number [17]**.** Relationship among stream order and stream number for the Bennihalla sub watersheds exhibit a strong inverse relationship, with coefficients of determination (R_L) 0.97 (SW9) to 0.99 (SW4, SW6, SW7) respectively (Figure 6).
2. This rule gives a straightforward geometric series representation of the average length of streams of a given order, to its order number. Observed relation for the sub watershed differed from Horton's law (Figure 5) especially for higher order streams in sub basins 2, 3, 5 8 and 9. The coefficients of calculation (R2) range between 0.52 (SW3) to 0.99 (SW7), indicating a weak association between Lu and U. Variations and deviations between sub-watersheds could mean that there are different bedrock types, different geological controls, and different erosion processes exist.

The bifurcation ratio (Rb): [39] Strahler's demonstrated that there is a moderate range of variation in the bifurcation ratio between the different orders with in a basin except for those with a powerful geological impact. The Rb values of 9 sub-watersheds do not remain constant with the order (Table 2). These abnormalities results from the watershed's lithologic /geological control on the drainage network [40].

It has been shown that sub-watersheds with a lower Rb value have less interventions of physiographic [40]. High Rb numbers indicate that the drainage pattern is subject to substantial structural control. The average Rb of every orders is known as mean Rb (Rbm). This research indicates that the range of Rbm values is 3.26 (SW2) to 4.85 (SW4).

Derived Parameters

Drainage density (D_d) measures length of total streams in a specific region, indicating growth of channels in a watershed and their spacing. D_d is an essential component to consider in soil erosion calculations, as it reflects the impact of topographic features on the outflow. Various factors that affect D_d include watershed dimensions, vegetation, climate &relief **[26].**

Basin with little vegetation and significant relief, soft and impermeable underlying rocks, facilitate development of more drainage and hence higher Dd. Coarse D_t is directly linked with low D_d, while fine D_t is associated with high D_d, excessive runoff, and erosion potential [40].

It is observed that SW9 has 1.94 D_d, while SW1 has a D_d of 1.21 implying that SW9 has soft and impervious underlying material, scarce vegetation, and steep terrain, making it risk for more soil erosion than the other sub-watersheds. Therefore, SW9 is ranked the most vulnerable to erosion with a rank of 1, while SW1, with the lowest D_d of 1.21, is ranked 9th as the least susceptible.

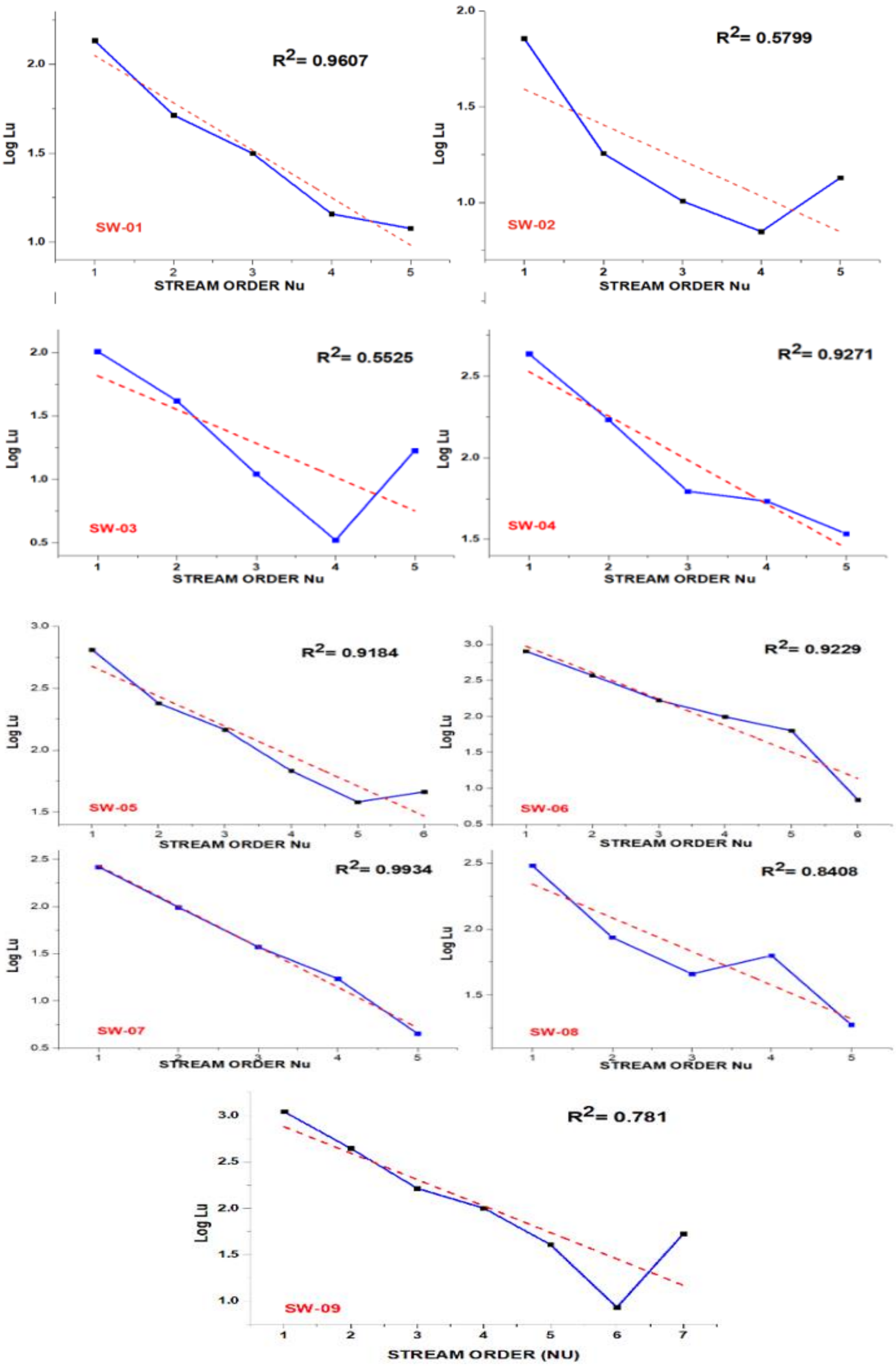

Fig 5: Stream order and stream length Relationship

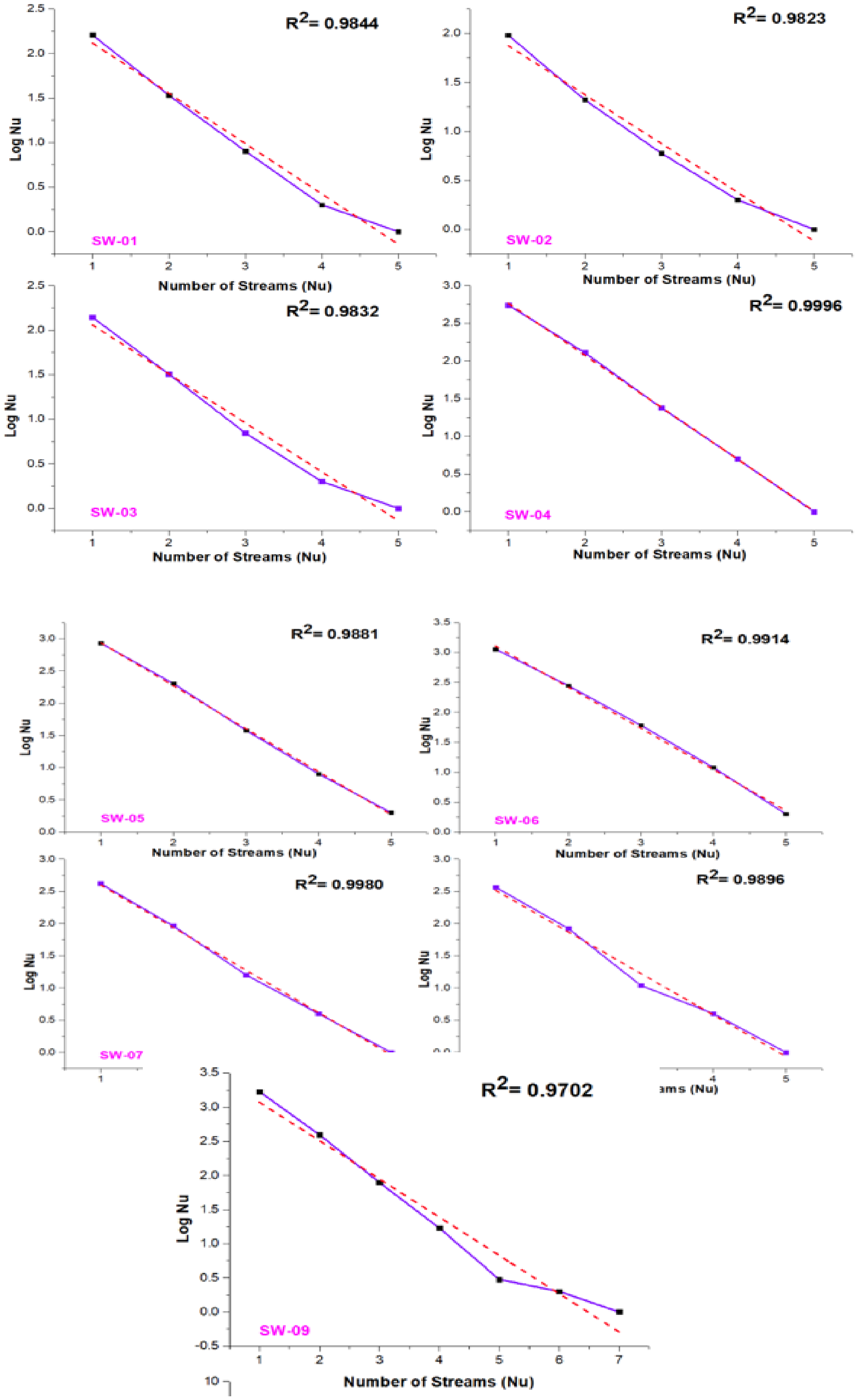

Fig 6: Stream order and stream number Relationship

Linear parameters: of streams per unit area designated as stream frequency [17] (Fs) show positive correlation with Dd, meaning that Fs and Dd increase at the same time [16]. Low Fs values are attributed to permeable material and severe relief [33]. A significant rate of erosion is indicated by the increase in Fs values.

It is found that F_s were high at 2.27 (SW7) and low at 1.07 (SW1). SW 7 is highly vulnerable to soil erosion because of subsurface materials are impermeable in nature, bare vegetation, high relief and infiltration rate is also low. As a result, it has been given rank 1, which indicates highest vulnerability to soil erosion. The lowest sub-watershed having F_S (5.86), SW1, has been given rank 9.

Drainage texture (D_t) refers to the ratio of total number of streams of all orders to the catchment perimeter [17]**.** Drainage line of 0–2 indicate very coarse, 2–4 medium, 4–6 moderate, 6–8 fine, and > 8 very fine [37]. D_t is affected by the presence of vegetation cover. Softer rock areas without vegetation protection tend to have a fine texture, while resistant rocks result in coarse drainage. Among the sub watersheds of the Bennihalla, SW9 has the highest D_t value of 14.17, followed by SW6 with 8.24. Conversely SW2 has the lowest value of 2.54, followed by SW1 with 3.25. A higher texture typically means a higher rate of erosion. As a result, SW9 had the highest erosion ranking of 1, while SW2 had the lowest (least erosion) among the 9subwatersheds,

Length of Overland flow (L_o): It is defined as the amount of time that water flows over land before condensing into defined stream courses also known as the length of overland flow. It is equal to half of D_d reciprocal (30). In the case of sub watersheds of the BennihallaL_o is high (0.971 for SW9 followed by SW 7 (0.945) and lesser in SW1 (0.609), SW2(0.642). Generally, the surface area for surface runoff increases with increasing L_o value and therefore, the more likely it is that water will be able to infiltrate and less erosion will occur. Accordingly, SW9 is assigned the highest ranking, while SW1 is assigned the lowest ranking.

Drainage Intensity (D_i). It is ratio between F_s and D_d [14]. Watersheds with low D_d, implies it is susceptible to flooding, erosion. Among nine sub-watershedsSW7 (1.20) and SW (1.13) have a higher drainage intensity, while SW1(0.83) and (SW5(0.935) have a lower drainage intensity. According to this criteria, sub-watersheds SW7 and SW9 have higher soil erosion; accordingly SW7 is ranked highest, whereas SW1 is ranked lowest.

The Rho coefficient (ρ): It is the ratio of L_u to $R_{b(}$30). The ρ is an essential physiographic evolution indicator of drainage networks' storage capacity [17]. The Rho coefficients of SW3 and SW9 are 0.420 and 0.357, respectively, which are more significant than the coefficients of SW7 and SW6, which have this ratio of 0.081 and 0.103, respectively. Therefore, during the floods SW3 has the highest storage capacity and the most intense erosion.

The infiltration number (I_f): The outcome of D_d and F_s calculates the $I_{f.}$ This value has an inverse relationship with a basin's infiltration capacity. Ff the values are low infiltration is intense [14] and vice a versa. The infiltration values are higher for SW7 (4.297) and SW9 (4.296), while for SW1 and SW3, they are lower (1.244 1.722 respectively). This indicates that SW7 and SW9 sub-watersheds experience higher levels of soil erosion. Accordingly the highest ranking and lowest rankings are assigned to SW7 and SW1 respectively.

Areal parameters

Circularity ratios (R_c) are calculated by comparing the size of a watershed to a circle which has the same circumference as that of the watershed **[45]**. Several elements can affect R_c, comprising stream features, geology, land use, climate, terrain, and slope. R_c value reflect the shape of the basin. As the R_c value increases, the basin become rounder and rounder, with a shorter stream flow duration, increasing the danger of flooding at the outflow point [9].

The lesser the R_c value, the more elongated the shape. For the study area out of nine sub-watersheds, SW5 and SW6 have a lower circulatory ratio of 0.369 and 0.390, while SW8 and SW1 have a higher circulatory ratio of 0.769 and 0.632, respectively and hence higher floods and erosion potential.

The elongation ratio (R_e): Measures a watershed's shape, calculated by dividing a diameter of a circle of the same area as the basin to the maximum basin length. $R_e$values depends upon the climate and geology and it is a measure f the shape of the basin. These values are categorized into three groups: circular (>0.9), oval (0.9 to 0.8), less elongated (0.7). Among the 9 subwatershdsSW3 and SW2 have lower R_e values (0.5 and 0.56), whereas SW9 and SW7 have higher R_e values (0.83 and 0.8) respectively. The results imply that the sub-watersheds in the study area have an oval or less elongated shape, which influences the amount of runoff and soil erosion. Oval-shaped SW9, SW7 experience higher intensity, whereas less elongated SW3 and SW2 experience lower intensity.

Form factor (F_f): It is the ratio of the watershed area (A) to the square of the watershed length (L_b)[40]. Most researchers agree that a perfectly circular basin would have a F_f> 0.78[16],[1]. A watershed with elongated, low Fc causes low but longer duration of runoff. On the other hand watershed with a rounded shape and high Fc values, experiences high runoff with a low concentration time, making it more prone to flooding. For a watershed with a rounded shape, the maximum form factor does not exceed 0.7854.

Among the sub watersheds of the Bennihalla, SW3 and SW2 have lower form factor values (0.195 and 0.242, respectively), while SW9 and SW7 have higher values (0.539 and 0.504, respectively). The higher values (SW 9) suggests a lower erosion risk, while lowest values (SW3), indicating a higher erosion risk.

The Lemniscate's ratio (K): It is used to calculate watershed gradient [11]. SW9 (1.855) and SW7 (1.984) have lower K values, while SW3 (5.140) and SW2 (4.127) higher in K value.

Compactness coefficient (C_c): It is referred to as Gravelius indexes (GI), obtained by dividing the watershed perimeter by the circumference of equivalent circular area [17]. Only watershed's slope influences this computation, the watershed's size has no bearing.

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Lower C_c values imply higher elongation and less erosion while higher values indicate less elongation and more erosion. For the sub watersheds the C_c of SW8 and SW1 (1.140 and 1.257, respectively) is lower, while SW5 and SW6 (1.645 and 1.602, respectively) have significantly higher values. Thus, SW5 is less vulnerable to soil erosion (Cc 1.645, while SW8 has a high vulnerability to soil erosion (Cc 1.140).

Relief parameter

Relief ratio (Rh): Refers to the basin relief divided by the length of the longest flow path. Essentially, it represents the overall steepness of the watershed, in addition to the severity and mechanisms of erosion [34]. Water flowing through a basin is converted from potential energy to kinetic energy at a rate determined by its relief ratio. High Rh values typically indicate elevations, whereas low levels indicate valleys [4]. There is a potential for more erosive forces to be generated in steep basins with high R_h values [1]. According to this study, R_h values are higher for 0.0387(SW7) and 0.0351(SW2), while they are lower for 0.0127(SW6) and 0.0184(SW9).

Relative relief (Rhp): The morphometric quantity known as relative relief (R_{hp}) is used to analyze the physical features of different terrains. Watershed relief and perimeter calculations are used to determine it [25]. Among the Bennihalla sub watersheds, SW2, show higher relative relief (1.4019), while SW5 and SW6 have lower values (0.4647 and 0.4361, respectively).

The Ruggedness number (R_n): It is a measures a basin's structural complexity. It is computed by multiplying basin's maximum relief (H) and Dd. Low Rn number denotes an area less prone to soil erosion while high Rn value indicates a terrain particularly vulnerable to soil erosion. R_n values were found to be higher in SW9 (0.4876) and SW7 (0.4666) and lower in SW2 (0.1181) and SW1 (0.1423).

Prioritization of sub-basins using the weighted sum approach (WSA)

Assigning priority rankings for different watersheds within a catchment known as prioritization of watershed is very crucial for managing watershed [28]. A comprehensive program for watershed development might not be able to be completed consistently due to financial and resource constraints.

Therefore, morphometric analysis identifies and defines high-risk erosion areas [41]. For the sub watersheds of the Bennihalla prioritization is made based on the shape, areal, and linear aspects (Table 4).A strong positive correlations were observed between D_d, R_{lm}, R_{bm}, F_s, D_t, D_i, ρ, B_h, R_{hp}, R_n, R_c, K, I_f and C_c. while F_f and R_e, L_o and R_h have a significant negative correlation.

Using Equation 2 compound factor was calculated (see appendix 1) and Sub-watersheds, were prioritized. Weights for each morphometric parameter as derived by dividing the total correlations by the sum of the correlation coefficients for each parameter, (Table 4). At the end a model that assigns weights to different parameters to determine final priority ranking and CF for watershed prioritization was computed.

Appendix 1:

Compound factor (CF) = (0.023×PPR of Rb_m) + (0.042×PPR of Rl_m) + (0.115×PPR of F_s) + (0.112× PPR of D_d) + (0.0846×PPR of D_t) – (0.1156× PPR L_o) + (0.105×PPR of D_i) + (0.030× PPR of ρ) + (0.117× PPR of I_f) + (0.074× PPR of B_h) –(0.016×PPR of R_h) + (-0.029× PPR of R_{hp}) + (0.1035×PPR of R_n) + (0.0302× PPR of R_c) – (0.0563×PPR of R_e) – (0.060×PPR of F_f) + (-0.043×PPR of K) + (-0.037×PPR of C_c)---------------------Equation.2

Where PPR= Preliminary priority ranking, Rb_m= Mean bifurcation ratio, Rl_m=Mean stream length ratio, F_s= Stream frequency, D_d= Drainage density, D_t= Drainage texture, L_o= Length of overland flow, D_i= Drainage intensity, ρ= RHO coefficient, I_f= Infiltration number, B_h= Relief, R_h= Relief ratio, R_{hp}=Relative relief, R_n= Ruggedness number, R_c=Circulatory ratio, R_e=Elongation ratio, F_f= Form factor, K= Lemniscates ratio, C_c=Compactness coefficient

The morphometric parameters of each sub-watershed have different values, but the equation uses a similar weighted factor for all of these. In the same way, WSA values for each of the nine sub-watersheds have been obtained.

The relationship between physical characteristics can differ between sub-watersheds in different terrain and weather conditions. As a result, number 1 indicates sub-watershed that has the lowest CF and has been assigned the highest priority. Based on the CF value sub-watersheds was ranked, and the highest value have high priority.

This indicates that runoff and soil erosion are more likely to affect the sub-watershed with the highest priority. The ranking was done in descending order. This procedure was performed for all the nine sub-watersheds.

Based on the CF all sub-watersheds were ranked and SW-9 received the highest priority rank (1), followed by SW-7, SW-5, SW-6, SW-3, SW-4, SW-8, SW-2, and SW-1.(Table 5). The sub-watersheds SW9, SW7, and SW5 have distinct geomorphometric characteristics, they are more vulnerable to soil erosion and land degradation.it is essential that these areas receive top priority for soil and water conservation strategies. According to the severity of soil erosion, the sub-watersheds are categorized into five class: Very High, High, Medium, Low, and Very Low.

The areas covered by each category are as follows: Very High covers 988.77 Sq.km, High covers 991.9 Sq.km, Medium covers 1119.3 Sq.km, Low covers 909.87 Sq.km, and Very Low covers 295.52 Sq.km.

The erosion risk priority map is generated (Fig. 8). The research discovered that sub-watersheds aerial aspect values are lower and linear relief is more prominent in high and extremely high soil erosion-prone levels, contributing to increased soil erosion.

Table 2: Results of 9 sub-watersheds Morphometric analysis

SL No	Stream order	Catchment Area (Sq. km)	Stream order (U)							Stream Length (Lu)						
			I	II	III	IV	V	VI	VII	I	II	III	IV	V	VI	VII
1	V	201.58	161	34	8	2	1	-	-	136.05	51.38	31.60	14.43	11.94	-	-
2	V	93.94	96	21	6	2	1			71.85	18.04	10.18	7.06	13.47		
3	V	103.37	139	32	7	2	1	-	-	102.31	41.60	11.06	3.33	16.91	-	-
4	V	528.06	550	129	24	5	1	-	-	432.90	171.16	62.28	54.15	34.26	-	-
5	VI	759.79	857	202	38	8	2	1	-	647.76	238.95	146.31	67.97	38.14	46.09	-
6	VI	1015.93	1136	280	61	12	2	1	-	806.88	370.89	167.22	98.55	63.45	6.95	-
7	V	232.11	415	92	16	4	1	-	-	263.30	98.04	37.27	17.13	4.48	-	-
8	V	381.81	366	84	11	4	1	-	-	302.77	86.59	45.89	63.12	18.84	-	-
9	V	988.77	1690	394	79	17	3	2	1	1107.86	445.46	164.41	100.69	40.72	8.55	53.41

SL No	Mean Stream Length in km (Lsm)							Stream Length Ratio (RL)						Bifurcation Ratio (Rb)					
	I	II	III	IV	V	VI	VII	II/I	III/II	IV/III	V/IV	VI/V	VII/VI	I/II	II/III	III/IV	IV/V	V/VI	VI/VII
1	0.84	1.51	3.95	7.21	11.94	-	-	0.377	0.615	0.456	0.827	-	-	4.73	4.25	4	2	-	-
2	0.74	0.85	1.69	3.53	13.47			0.251	0.564	0.693	1.907			4.57	3.5	3	2	-	-
3	0.73	1.30	1.58	1.66	16.91	-	-	0.406	0.265	0.301	5.078	-	-	4.34	4.57	3.5	2	-	-
4	0.78	1.32	2.59	10.83	34.26	-	-	0.395	0.363	0.869	0.632	-	-	4.26	5.37	4.8	5	-	-
5	0.75	1.18	3.85	8.49	19.07	46.09	-	0.368	0.612	0.464	0.561	1.208	-	4.24	5.31	4.75	4	2	-
6	0.71	1.32	2.74	8.21	31.72	6.95	-	0.459	0.450	0.589	0.643	0.109	-	4.05	4.59	5.08	6	2	-
7	0.63	1.06	2.32	8.85	4.48	-	-	0.372	0.380	0.459	0.261	-	-	4.51	5.75	4	4	-	-
8	0.82	1.03	4.17	15.78	18.84	-	-	0.285	0.529	1.375	0.298	-	-	4.35	7.63	2.75	4	-	-
9	0.65	1.13	2.08	5.92	13.57	4.27	53.41	0.402	0.369	0.612	0.404	0.209	6.246	4.28	4.98	4.64	5.66	1.5	2

Parameters	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9
Area (*A*)	201.58	93.94	103.37	528.06	759.79	1015.93	232.11	381.81	988.77
Perimeter(P)	63.27	49.43	54.13	109.22	160.73	180.91	71.21	78.96	154.18
Max elevation(H)	719	693	695	773	747	789	831	887	787
Min.elevation(h)	602	601	598	582	568	571	584	583	536
Length (L_b)	20.81	19.69	23.05	34.08	40.16	62.06	21.46	28.45	42.83
Highest Stream order (U)	V	V	V	V	VI	VI	V	V	VII
Stream Number (N_u)	206	126	181	709	1108	1492	528	466	2186
Stream length (L_u)	245.42	120.62	175.24	754.77	1185.26	1513.96	438.48	517.22	1921.12
Linear aspects									
Mean Stream length (L_{sm})	1.191	0.957	0.968	1.064	1.069	1.014	0.830	1.109	0.878
Bifurcation ratio (R_b)	14.98	13.07	14.41	19.43	20.3	21.75	18.26	18.73	23.06
Stream length ratio (R_l)	2.275	3.415	6.05	2.259	3.213	2.25	1.472	2.487	8.242

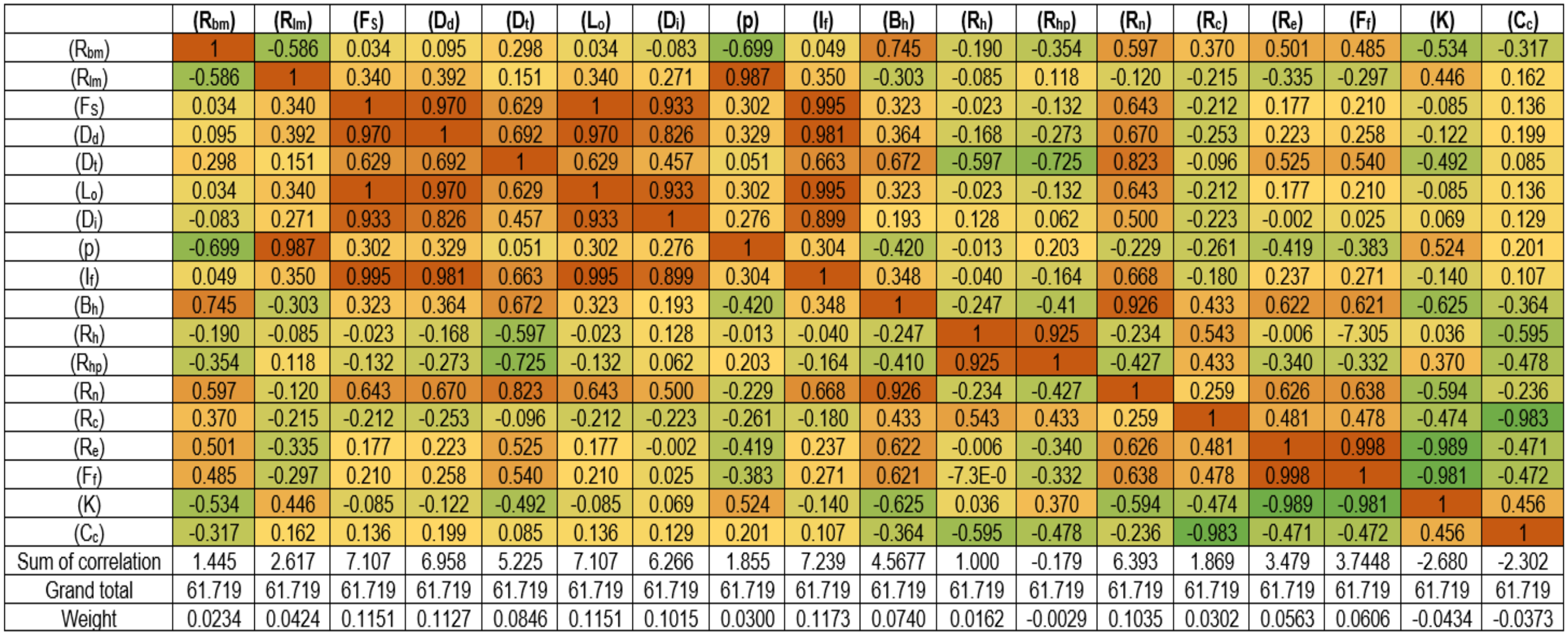
Mean Bifurcation ratio (R_{bm})	3.74	3.26	3.60	4.85	4.06	4.34	4.56	4.68	3.84
Mean Stream length ratio (R_{lm})	0.568	0.853	1.512	0.564	0.642	0.45	0.368	0.621	1.373
Stream Frequency (F_S)	1.022	1.341	1.751	1.343	1.458	1.469	2.275	1.221	2.211
Drainage density (D_d)	1.217	1.284	1.695	1.429	1.560	1.490	1.889	1.355	1.943
Drainage texture (D_t)	3.256	2.549	3.344	6.491	6.894	8.247	7.415	5.902	14.178
Length of overland flow (L_o)	0.609	0.642	0.848	0.715	0.780	0.745	0.945	0.677	0.971
Drainage intensity (D_i)	0.839	1.045	1.033	0.939	0.935	0.985	1.204	0.901	1.138
RHO coefficient (p)	0.152	0.261	0.420	0.116	0.158	0.103	0.081	0.133	0.357
Infiltration number (I_f)	1.244	1.722	2.968	1.919	2.275	2.189	4.297	1.653	4.296
Relief aspects									
Relief (B_h)	117	92	97	191	179	218	247	304	251
Relief ratio (R_h)	0.0345	0.0351	0.0301	0.0226	0.0186	0.0127	0.0387	0.0311	0.0184
Relative relief (R_{hp})	1.1363	1.4019	1.2839	0.7077	0.4647	0.4361	1.1669	1.1233	0.5104
Ruggedness number (R_n)	0.1423	0.1181	0.1644	0.2729	0.2792	0.3248	0.4666	0.4119	0.4876
Areal aspects									
Circulatory ratio (R_c)	0.632	0.483	0.443	0.556	0.369	0.390	0.575	0.769	0.522
Elongation ratio (R_e)	0.770	0.556	0.498	0.761	0.775	0.580	0.801	0.775	0.829
Form factor (F_t)	0.465	0.242	0.195	0.455	0.471	0.264	0.504	0.472	0.539
Lemniscate ratio (K)	2.148	4.127	5.140	2.199	2.123	3.791	1.984	2.120	1.855
Compactness coefficient (C_c)	1.257	1.439	1.502	1.341	1.645	1.602	1.319	1.140	1.384

Table 3: 9 sub-watersheds are ranked on the basis of preliminary priority using shape, area, and linear parameters

	Parameters	**SW 1**	**SW2**	**SW3**	**SW4**	**SW5**	**SW6**	**SW7**	**SW8**	**SW9**
	Linear aspects									
1	Mean Stream length (L_{sm})	1	7	6	4	3	5	9	2	8
2	Bifurcation ratio (R_b)	7	9	8	4	3	2	6	5	1
3	Stream length ratio (R_l)	6	3	2	7	4	8	9	5	1
4	Mean Bifurcation ratio (R_{bm})	7	9	8	1	5	4	3	2	6
5	Mean Stream length ratio (R_{lm})	6	3	1	7	4	8	9	5	2
6	Stream Freuency (F_S)	9	7	3	6	5	4	1	8	2
7	Drainage density (D_d)	9	8	3	6	4	5	2	7	1
8	Drainage texture (D_t)	8	9	7	5	4	2	3	6	1
9	Length of overland flow (L_o)	9	8	3	6	4	5	2	7	1
10	Drainage intensity (D_i)	9	3	4	6	7	5	1	8	2
11	RHO coefficient (p)	5	3	1	7	4	8	9	6	2
12	Infiltration number (I_f)	5	8	3	7	4	6	1	9	2

Relief aspects										
13	Relief (B_h)	7	9	8	5	6	4	3	1	2
14	Relief ratio (R_h)	3	2	5	6	7	9	1	4	8
15	Relative relief (R_{hp})	4	1	2	6	8	9	3	5	7
16	Ruggedness number (R_n)	8	9	7	6	5	4	2	3	1
Areal aspects										
17	Circulatory ratio (R_c)	8	4	3	6	1	2	7	9	5
18	Elongation ratio (R_e)	5	2	1	4	6	3	8	7	9
19	Form factor (F_t)	5	2	1	4	6	3	8	7	9
20	Lemniscate ratio (K)	5	8	9	6	4	7	2	3	1
21	Compactness coefficient (C_c)	2	6	7	4	9	8	3	1	5

Table 4: Matrix of cross-correlation among relief, aerial, and linear parameters. All morphometric parameter has a different correlation depending on the positive and negative values of color



	(R_{bm})	(R_{lm})	(F_S)	(D_d)	(D_t)	(L_o)	(D_i)	(p)	(I_f)	(B_h)	(R_h)	(R_{hp})	(R_n)	(R_c)	(R_e)	(F_f)	(K)	(C_c)
(R_{bm})	1	-0.586	0.034	0.095	0.298	0.034	-0.083	-0.699	0.049	0.745	-0.190	-0.354	0.597	0.370	0.501	0.485	-0.534	-0.317
(R_{lm})	-0.586	1	0.340	0.392	0.151	0.340	0.271	0.987	0.350	-0.303	-0.085	0.118	-0.120	-0.215	-0.335	-0.297	0.446	0.162
(F_S)	0.034	0.340	1	0.970	0.629	1	0.933	0.302	0.995	0.323	-0.023	-0.132	0.643	-0.212	0.177	0.210	-0.085	0.136
(D_d)	0.095	0.392	0.970	1	0.692	0.970	0.826	0.329	0.981	0.364	-0.168	-0.273	0.670	-0.253	0.223	0.258	-0.122	0.199
(D_t)	0.298	0.151	0.629	0.692	1	0.629	0.457	0.051	0.663	0.672	-0.597	-0.725	0.823	-0.096	0.525	0.540	-0.492	0.085
(L_o)	0.034	0.340	1	0.970	0.629	1	0.933	0.302	0.995	0.323	-0.023	-0.132	0.643	-0.212	0.177	0.210	-0.085	0.136
(D_i)	-0.083	0.271	0.933	0.826	0.457	0.933	1	0.276	0.899	0.193	0.128	0.062	0.500	-0.223	-0.002	0.025	0.069	0.129
(p)	-0.699	0.987	0.302	0.329	0.051	0.302	0.276	1	0.304	-0.420	-0.013	0.203	-0.229	-0.261	-0.419	-0.383	0.524	0.201
(I_f)	0.049	0.350	0.995	0.981	0.663	0.995	0.899	0.304	1	0.348	-0.040	-0.164	0.668	-0.180	0.237	0.271	-0.140	0.107
(B_h)	0.745	-0.303	0.323	0.364	0.672	0.323	0.193	-0.420	0.348	1	-0.247	-0.41	0.926	0.433	0.622	0.621	-0.625	-0.364
(R_h)	-0.190	-0.085	-0.023	-0.168	-0.597	-0.023	0.128	-0.013	-0.040	-0.247	1	0.925	-0.234	0.543	-0.006	-7.305	0.036	-0.595
(R_{hp})	-0.354	0.118	-0.132	-0.273	-0.725	-0.132	0.062	0.203	-0.164	-0.410	0.925	1	-0.427	0.433	-0.340	-0.332	0.370	-0.478
(R_n)	0.597	-0.120	0.643	0.670	0.823	0.643	0.500	-0.229	0.668	0.926	-0.234	-0.427	1	0.259	0.626	0.638	-0.594	-0.236
(R_c)	0.370	-0.215	-0.212	-0.253	-0.096	-0.212	-0.223	-0.261	-0.180	0.433	0.543	0.433	0.259	1	0.481	0.478	-0.474	-0.983
(R_e)	0.501	-0.335	0.177	0.223	0.525	0.177	-0.002	-0.419	0.237	0.622	-0.006	-0.340	0.626	0.481	1	0.998	-0.989	-0.471
(F_f)	0.485	-0.297	0.210	0.258	0.540	0.210	0.025	-0.383	0.271	0.621	-7.3E-0	-0.332	0.638	0.478	0.998	1	-0.981	-0.472
(K)	-0.534	0.446	-0.085	-0.122	-0.492	-0.085	0.069	0.524	-0.140	-0.625	0.036	0.370	-0.594	-0.474	-0.989	-0.981	1	0.456
(C_c)	-0.317	0.162	0.136	0.199	0.085	0.136	0.129	0.201	0.107	-0.364	-0.595	-0.478	-0.236	-0.983	-0.471	-0.472	0.456	1
Sum of correlation	1.445	2.617	7.107	6.958	5.225	7.107	6.266	1.855	7.239	4.5677	1.000	-0.179	6.393	1.869	3.479	3.7448	-2.680	-2.302
Grand total	61.719	61.719	61.719	61.719	61.719	61.719	61.719	61.719	61.719	61.719	61.719	61.719	61.719	61.719	61.719	61.719	61.719	61.719
Weight	0.0234	0.0424	0.1151	0.1127	0.0846	0.1151	0.1015	0.0300	0.1173	0.0740	0.0162	-0.0029	0.1035	0.0302	0.0563	0.0606	-0.0434	-0.0373

Table 5: Each sub-watershed final priority ranking founded on the value of compound factor

Prioritized Rank	Compound factor	Sub-Watershed	Soil Erosion risk
1	0.0052	SW-9	Very High
2	0.7856	SW-7	High
3	2.1355	SW-5	High
4	2.1483	SW-6	Medium
5	2.5008	SW-3	Medium
6	3.2414	SW-4	Low
7	3.3106	SW-8	Low
8	4.0987	SW-2	Very Low
9	4.4127	SW-1	Very Low

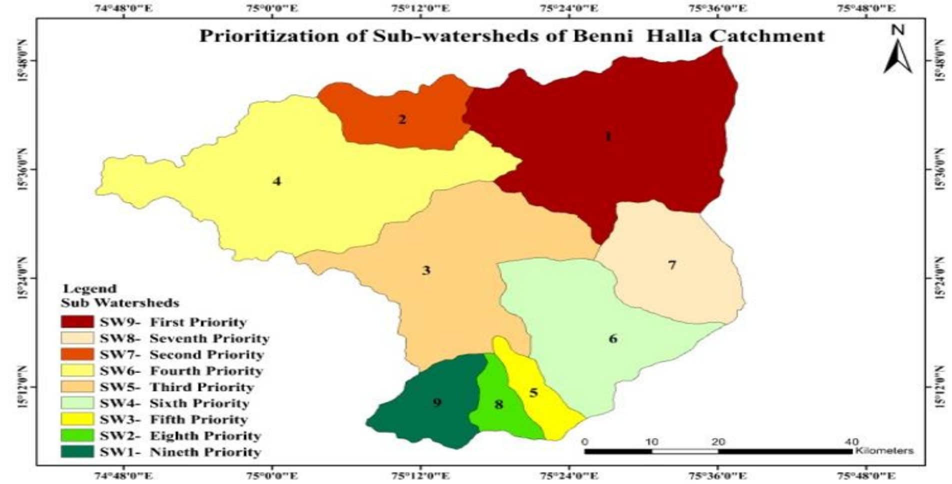


Fig 7: Prioritization map of 9 sub watershed

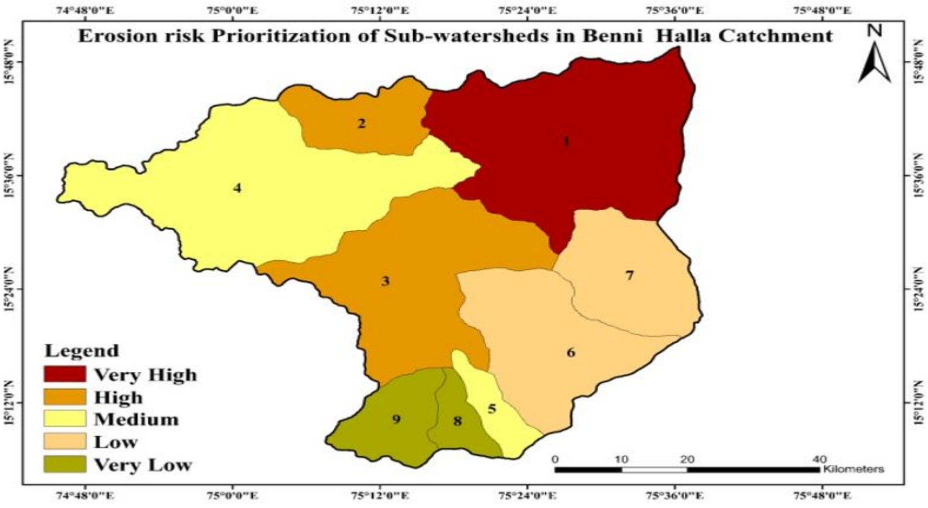


Fig 8: Prioritization map of erosion risk for the Bennihalla catchment

CONCLUSION

Quantitative morphometric analysis for each of the sub-watersheds of the Bennihalla, were performed following a weighted sum approach and geospatial technology was used.

- Findings showed that drainage density of all sub-watersheds have a low value, implying porous in nature of the underlying rocks. The distinct topographies and geometric features contribute to the differences in bifurcation ratios among sub-watersheds and positive correlation between stream frequencies and drainage density.
- The approach adopted in the present study to prioritize soil erosion threats for all sub-watersheds is most suitable and dynamic, and effective than conventional watershed ranking methods.
- The sub-watersheds SWS-9, SWS-7, and SWS-5 are at an elevated risk of experiencing soil erosion. Hence it is crucial to implement effective soil erosion management techniques while being mindful of resource allocation.

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