



Morphometric analysis and sub-watershed prioritization of Welmal watershed, Ganale-Dawa River Basin, Ethiopia: implications for sediment erosion

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Received: 4 September 2020 / Revised: 22 November 2020 / Accepted: 2 December 2020 / Published online: 3 January 2021
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Abstract

Watershed analysis based on morphometric parameters plays an important role for proper planning and implementation of management program for soil protection and to prevent erosion of sediments. Morphometric analysis of watershed is the best method to identify the relationship of various aspects in the area. The main objective of the study is to critically evaluate morphometric parameters and prioritization of sub-watersheds based on erosion prone area of Welmal watershed located in Bale zone, Ethiopia using Arc GIS10.4.1. For prioritization, nine sub-watersheds are delineated and parameters, such as stream length, stream order, drainage density, stream frequency, bifurcation ratio, length of overland flow, basin perimeter, form factor, compactness coefficient, and elongation ratio, have been considered. The Geographic Information System based on morphometric analysis of River Basin revealed that it is a fourth-order basin, with drainage pattern of the mainly dendritic type, showing homogeneity in texture and little structural control. Welmal River Basin has a total number of 602 streams, where 526 are first order, 64 are second order, 11 are third order and 1 is fourth order. The length of stream segment is maximum for the first-order stream and decreases as the stream order increases. The drainage density (D_d) of the study area of Welmal River Basin is 1.13 km/km², which suggests that the River Basins are not much affected by structural disturbance. The entire basin elongation ratio (0.22) indicates that the basin is elongated shape and little prone to overflowing. Based on the value of compound value (C_p), the sub-watershed with the lowest C_p value was given by the highest priority and then categorized the sub-watersheds into three classes as high, medium and low in terms of priority. Accordingly, high-priority zone comprises 2 sub-watersheds, medium 2 sub-watersheds and low 5 sub-watersheds. High-priority sub-watersheds are those that are much more prone to soil erosion and should receive greater attention because they need major land conservation measures.

Keywords Morphometric parameter · Prioritization · Welmal sub watershed

1 Introduction

Morphometric analysis consists in the quantitative evaluation of the characteristics of the shape of the earth surface and of any landform unit. This is the most common technique in basin analysis, since the morphometric shape is an ideal area unit for the interpretation and analysis of fluviially originated landforms where they show an example of open systems of operation.

The composition of the stream system of a drainage basin is quantitatively expressed with stream order, drainage density, bifurcation ratio and stream length ratio (Horton 1945). A major emphasis in geomorphology has been given aiming the development of quantitative physiographic methods and to describe the evolution and behaviour of surface drainage

Communicated by M. V. Alves Martins

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networks (Horton 1945; Leopold and Maddock 1953; Abrahams 1984).

Morphometric analysis is very useful in drainage basin evaluation, silt erosion control, flood frequency analysis, watershed prioritization, natural resources management and conservation. Analysis of morphometric parameters of a drainage basin and its associated stream network show its hydrological behaviour (Pophare and Balpande 2014). An integrated set of dependent and independent variable shapes controls the watershed characteristics over time (Aisuebeogun and Ezekwe 2013). Quantitative parameters of drainage network of the basin have a very helpful function in the definition of the hydrological model, watershed prioritization, natural resource management and rehabilitation (Choudhari et al. 2018). In many regions, most of the basins are either ungauged or difficult to access, so study on geomorphology of basins becomes much more important (Khare et al. 2014).

Morphometric analysis and prioritization of river drainage basin using Remote Sensing (RS) and Geographic Information System (GIS) techniques have been attempted by a number of researchers (Agarwal 1998; Akram et al. 2009; Prafull et al. 2012; Gajbhiye et al. 2014). These studies allowed to conclude that the remote sensing and the geographic information system are the most effective tools for analysing land use, morphometric analysis and controlling soil erosion and to take measures to preserve the soil from further erosion. In this context, the current study, intends to analyse the morphometric parameters of Welmal Watershed, from Ganale-Dawa River Basin (Ethiopia), aiming at the conservation of soil erosion, avoiding its erosion and defining the prioritization of sub-watersheds. This information

will be of great importance in the definition of a hydrographic basin sustainable development plan for this region and to prevent soil erosion.

2 Description of the study watershed

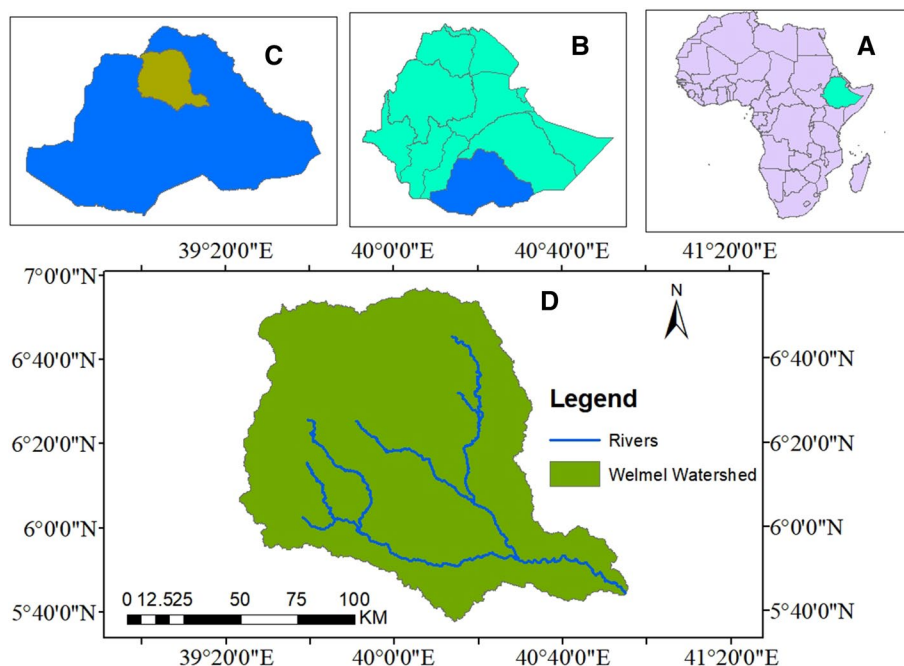
2.1 Location

Welmal watershed found in Southeastern part of Ethiopia, in Oromia regional state, Bale Zone at about 423 km of Addis Ababa. The catchment situated in Genale-Dawa basin at the uppermost portions of the Web Sub-watershed, which is one of the Sub-watersheds of Genale-Dawa Basin. It is located between $5^{\circ} 30' 00''$ N– $7^{\circ} 70' 00''$ N latitudes and $39^{\circ} 00' 00''$ E– $41^{\circ} 00' 00''$ E longitude as shown in Fig. 1. It covers a total drainage area of 506.32 km². Almost all of the rivers are flowing from NW to SE. Most parts of it have an arid or semi-arid climate that is prone to drought and erratic rainfall (Hurni et al. 2016).

2.2 Climate

The northern part of the watershed has a bimodal rainfall distribution, as in most parts of southeastern Ethiopia: from February to May (the “short rains”), with a peak in April, and; from June to September (the “long rains”), with a peak in August (Degefu et al. 2017). The mean annual 80% dependable rainfall is 918.7 mm and annual Potential evapotranspiration (PET) is 8540 mm. Mean maximum, minimum

Fig. 1 Location map of the study area



and average annual temperature is 29.10 °C, 15.6 °C and 22.3 °C respectively.

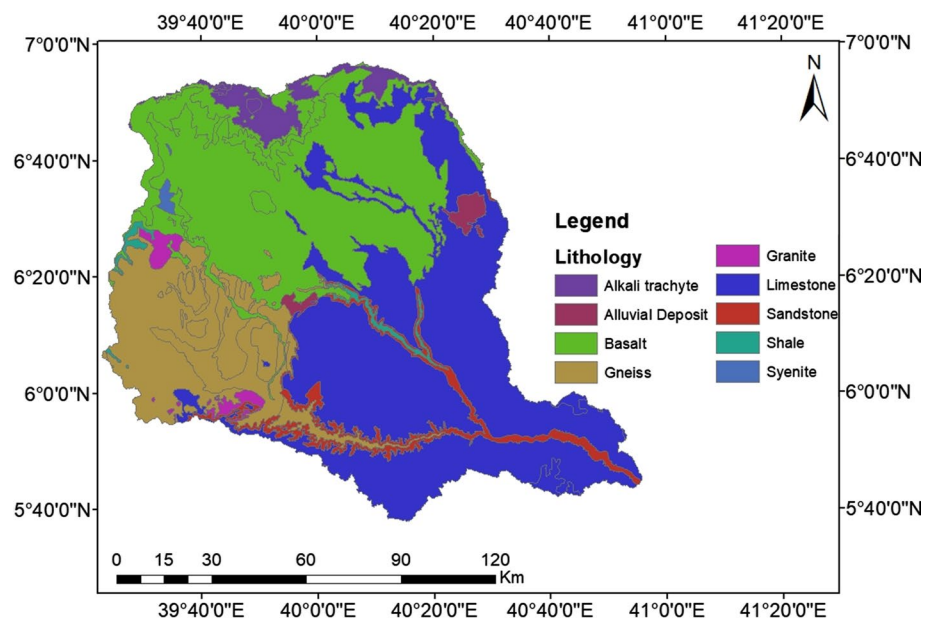
2.3 Geology and geomorphology

Geomorphology of the area is represented by denuding hills, which are structurally controlled with or without complex folding and faulting, residual hills, plateaus, valley fill, pediments, and buried pediments, pedi-plains, and alluvial plains. Pediments are gently sloping smooth surface of erosional bedrock with thin detritus. Alluvial plains land surface produced by extensive deposition of alluvium, usually adjacent to a river that periodically overflows its banks. The major part of the area is characterized by an undulating topography with innumerable local depressions (Welmal Irrigation project 2006). The Welmal watershed (Fig. 2) represented by older group of rocks, granitoid gneisses and basement complex rocks. The older rocks consist of hornblende schist, biotite schist, sandstone and syenite, while granitoid gneisses are represented by hornblende gneiss, hornblende-biotite gneiss, and migmatitic gneiss. Basement complex rock includes hornblende and biotite granites (Welmal Irrigation project 2006).

2.4 Soil

The Welmal watershed area has eight soil types, i.e., eutric cambisols, chromic cambisols, leptosols (formerly lithosols), rendzic leptosols, developed from limestone (formerly rendzinas), chromic luvisols, pellic vertisols and chromic vertisols (Yared et al. 2020). The largest area is occupied by chromic vertisols and rendzic leptosols (altogether, 49% of the studied area) (Yared et al. 2020).

Fig. 2 Geological map of the study area



2.5 Land cover

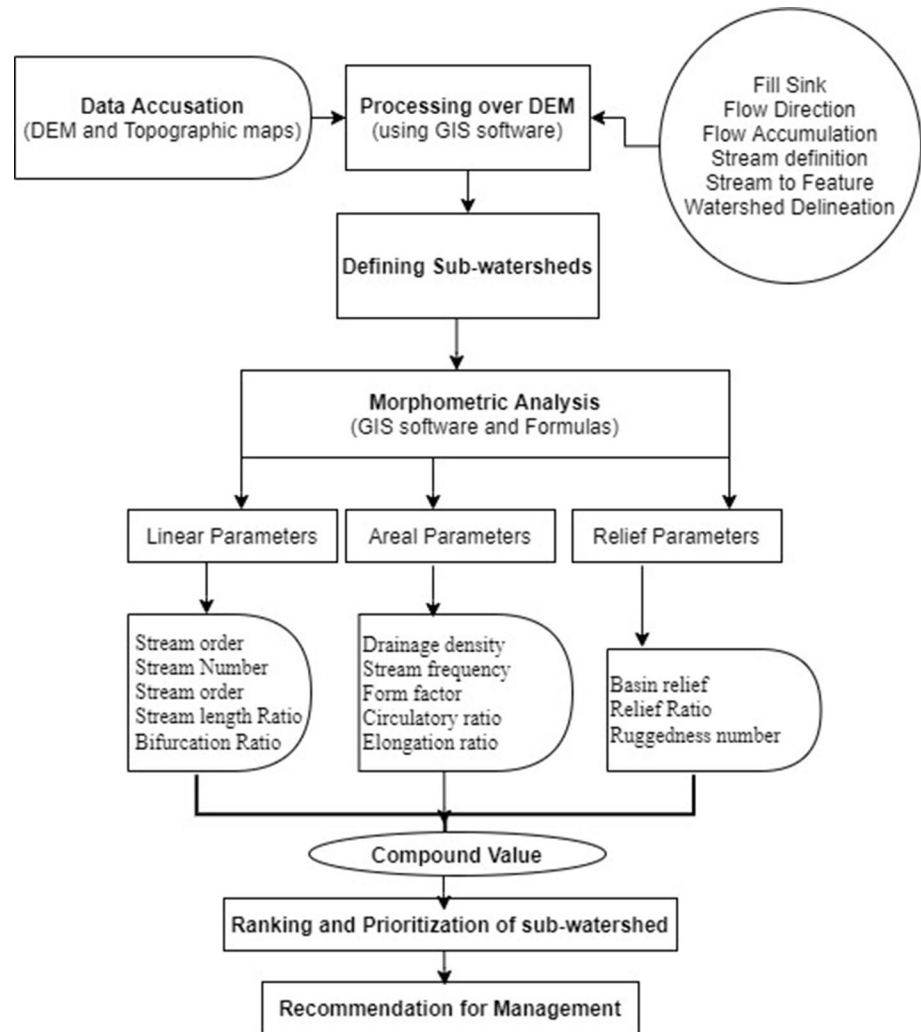
The land cover of the watershed encompasses dense forest in the northern part and open forest in the middle of the watershed; however, the lower altitude southern part of the study area is characterized by shrub lands, grasslands and degraded bare grounds (Hurni et al. 2016).

3 Materials and methods

Remote Sensing (RS) data and Geographic Information System (GIS) applications are integrated for the morphometric analysis of watershed characteristics of the Welmal River watershed. Drainage map of the study area, considered as the base-map, has been prepared in 1:50,000 scale using a topographical map and a Digital Elevation Model (DEM), with 12.5 m of resolution were obtained from the Ministry of Water Irrigation and Energy (MWIE) of Ethiopia. Watershed boundary was delineated and drainage network map was derived as a line coverage giving unique ID for each order of stream from DEM data. ArcGIS (version 10.4.1) software was used for integrating maps and other relevant data where the attributes were allocated to generate the digital data base for drainage layer of the river basin. Prioritization of sub-watershed was done to identify the critical zone with high erosion so that appropriate conservation measures can be taken for minimizing soil erosion in the area. The methodological flow chart used for watershed morphometric analysis is shown in Fig. 3. Morphometric analysis parameter of Welmal river basin addresses the linear, aerial and relief aspects.

The study dealt mainly with erosion risk assessment parameters and has been used for prioritizing

Fig. 3 Flowchart of research in the study area



sub-watersheds. Parameters, such as bifurcation ratio (R_b), drainage density (D_d), stream frequency (F_s), and drainage texture (R_t), have direct relationship, i.e., higher the value, more is the erodibility and ranked accordingly. Whereas the other parameters, i.e. circulatory ratio (R_c), elongation ratio (R_e), form factor (R_f), basin shape (B_s) and constant channel maintenance (C), have inverse relationship, i.e. it means lower the value, more is the erodibility and ranked accordingly (Biswas et al. 1999).

Prioritization of the sub-watersheds of Welmal watershed was performed by assigning the ranks based on the highest or lowest values for linear, aerial and relief parameters as the case may be. After assigning the ranks to each parameter from nine sub-watersheds, rank values were added and averaged out to get a compound value (i.e. C_p). On the basis of the range of C_p values, the sub-watersheds were then categorized into three classes: high (2.6–3.6), medium (4.0–4.5) and low (> 4.5) priority. The sub-watershed with the highest C_p value was assigned as having the least priority.

4 Results and discussion

The morphometric analysis of Welmal river basin is performed with the obtainment of linear parameters and areal parameters.

4.1 Linear aspects

Computation of the linear aspects, such as stream order, stream number for various orders, bifurcation ratio, stream lengths for various stream orders and length ratio, is described below.

Stream order (U) the first step in morphometric analysis of drainage basin analysis is a measure of the position of a stream in the hierarchy of tributaries (Strahler 1964). According to Strahler (1964), the smallest fingertip tributaries are designated as order 1. Where two first-order channels join, a channel segment of order 2 is formed; where two of order 2 joins, a segment of order 3 is formed, and so forth. The trunk stream through which all discharge of

water and sediment passes is therefore the stream segment of highest order. It was observed that, as the stream order increases, number of streams decreases. This shows that the Horton's law (1945) is applied to the basin. Application of this ordering procedure through GIS shows that the drainage network of the study area is of a fourth-order basin. One sub-watershed (6) was in the second order, seven sub-watersheds (1–5, 7 and 8) were identified in third order, and one sub-watershed (9) was in fourth order (Table 1).

Stream length (L_u) is the distance measured along the stream channel from the source to a given point or to the outlet. This distance was estimated for all stream orders within a watershed and they were added together to find out the total stream length of the watershed. The maximum total length of the watershed is 571 km and that of the nine sub-watersheds are 70, 59, 51, 66, 38, 43, 83, 91 and 70 km, respectively (Table 1).

Stream length ratio (R_L) is defined as the ratio of mean stream length (L_u) of segment of order u , to mean stream segment length (L_{u-1}) of the next lower order $u-1$ (Horton 1945). The values of the RL vary from 0.37 to 5.04 for the sub-watersheds, while it ranges from 1.65 to 2.92 for the whole basin. This parameter reveals that the sub-watershed 1 and 3 have higher surface runoff and also high stream erosion as compared to other sub-watersheds (Table 1).

Bifurcation ratio (R_b) is the ratio between the number of streams in one order and in the next. It is calculated by dividing the number of streams in the lower by the number in the higher of the two orders. Low R_b means that the drainage pattern is not affected by the geologic structures, whereas the high class signifies that the drainage pattern is controlled by the geologic structures (Rai et al. 2017). R_b characteristically ranges between 3.0 and 5.0 for watershed where the influence of geological structure on the drainage network is negligible (Verstappen 1983). R_b of the sub-basin of the Welmal watershed varies from 3.36 to 5.81 (Table 1), which indicates that the geological structure affects the drainage networks and systematic branching pattern of the streams.

4.2 Areal aspect

The areal aspects of a drainage basin reflect the influence of lithology, geological structure, climatic conditions, and denudation history of the basin. The aerial aspects consist of morphometric parameters, such as drainage density (D_d), stream frequency (F_s), elongation ratio (R_e), and circulatory ratio (R_c).

Drainage density (D_d) It indicates the closeness of spacing between channels and is a measure of the total length of the stream segment of all orders per unit area (Dikpal et al. 2017). The high D_d value indicates greater runoff and as a result low infiltration rate. While, low drainage density of an area implies low runoff and high infiltration (Resmi et al. 2019). Drainage density in the study area varies between 0.68 and 2.21 (Table 2) indicating low drainage density. The low drainage density of the study area suggests that is highly permeable subsoil and coarse drainage texture (Horton 1932). The entire drainage density of Welmal River Basin is 1.13 km/km² (Table 2).

Stream frequency/drainage frequency (F_s) is the total number of stream segments of all orders per unit area (Horton 1932). The stream frequency is related to the permeability, infiltration capability and relief of watershed. F_s values of the sub-watersheds vary from 0.32 (SW6) to 2.81 (SW1), indicating that the sub-watersheds have lower F_s values bearing low relief and permeable sub-surface material whereas, sub-watersheds with higher F_s values show resistant or low conducting subsurface material, sparse vegetation and high relief (Said et al. 2018).

Form factor (R_f) R_f is the ratio of basin area A , to the square of maximum length of the basin boundary (L_b). It is a dimensionless property and is used as a quantitative expression of the shape of basin form (Meshram and Sharma 2017). The sub-watershed-9 has maximum R_f value of 0.45 while sub-watershed-1 has minimum value of 0.20 (Table 2). The lower the value of the form factor is, the more elongated the basin will be. The basin with a high form factor has

Table 1 Linear morphometric parameters of the Welmal sub-watersheds

S. no	Morphometric parameter	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	Welmal Basin
1	Basin area (km ²)	31.57	42.32	49.21	53.48	34.17	47.68	64.23	81.35	102.31	506.32
2	Stream order	3	3	3	3	3	2	3	3	4	4
3	Number of stream	72	81	76	63	36	15	70	61	128	602
4	Stream length (km)	70	59	51	66	38	43	83	91	70	571
5	Basin perimeter (km)	18.02	15.73	21.24	22.98	17.76	20.58	24.46	24.58	25.25	190.60
6	Basin Length (km)	12.55	11.79	13.22	13.12	12.49	12.78	13.35	13.62	14.36	117.32
7	Mean stream length (km)	1.92	0.75	1.55	0.85	1.02	1.45	3.15	5.43	1.19	2.059
8	Stream length ratio	2.22	0.98	2.37	0.75	0.88	0.37	5.04	0.80	3.18	1.63
9	Bifurcation ratio	5.61	5.81	5.57	5.11	3.92	4.67	5.5	5.33	3.36	4.986

SW sub-watershed

Table 2 Areal morphometric parameters of the Welmal sub-watershed

S. no	Morphometric parameter	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	Welmal Basin
1	Drainage density (km/km ²)	2.21	1.39	1.04	1.24	1.12	0.91	1.30	1.12	0.68	1.13
2	Stream frequency (km ⁻²)	2.81	1.91	1.54	1.18	1.06	0.32	1.01	0.75	1.25	1.19
3	Drainage texture	5.06	2.67	1.60	1.54	1.72	0.29	1.41	0.84	0.86	1.34
4	Form factor	0.20	0.30	0.28	0.31	0.22	0.23	0.36	0.44	0.45	0.037
5	Circulatory ratio	1.22	2.15	1.37	1.27	1.36	1.41	1.35	1.70	2.02	0.18
6	Elongation ratio	0.50	0.62	0.60	0.63	0.53	0.61	0.68	0.75	0.78	0.22
7	Overland flow (Km)	1.11	0.67	0.52	0.62	0.56	0.45	0.64	0.56	0.34	0.56

SW sub-watershed

high peak flows of shorter duration, whereas the basin with a low form factor has lower peak flows of longer duration. Therefore, sub-watershed-1 will have lower peak flows of longer duration. However, sub-watershed-9 will have high peak flows of shorter duration. For the whole watershed, R_f value is 0.037 (Table 2).

Circulatory ratio (R_c) R_c is the ratio of the watershed area and the area of circle of watershed perimeter (P). Circulatory ratio (R_c) is influenced by the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin (Miller 1953). Values of circulatory ratio of all sub-watersheds are presented in Table 2. The sub-watershed-1 has minimum R_c value ($R_c = 1.22$), while sub-watershed-2 has maximum R_c value ($R_c = 2.15$). According to the Miller range, sub-watersheds are elongated in shape, with low discharge of runoff and high permeability of subsoil condition. The R_c of the study area is 0.18 (Table 2).

Elongation ratio (R_e) R_e is defined as the ratio of the diameter of a circle having the same area as the basin and the maximum basin length (Schumm 1956). Elongation ratio also determines the shape of the watershed and can be classified based on these values as circular (0.9–1), oval (0.8–0.9), less elongated (0.7–0.8), elongated (0.5–0.7), and more elongated (<0.5) (Mudashiru et al. 2017). Regions with low elongated ratio values are susceptible to more erosion whereas regions with high values correspond to high infiltration capacity and low runoff. The elongation ratio of Welmal Watershed value is 0.22 as shown in Table 2. This value (<0.5) indicates that Welmal watershed is more elongated and more susceptible to erosion.

4.3 Relief aspects

The relief aspect of a drainage basin refers to the vertical component of a drainage basin (Fig. 5). The relief aspects considered for the present study include basin relief, relief ratio and ruggedness number. The aspect-slope map generally denotes the direction to which slope faces. The value of the output raster data set represents the compass direction of

the aspect (Magesh et al. 2011). The aspect map of Welmal watershed is shown in Fig. 4. On the basis of the majority of the raster cells, it is very clear that the South-facing slope mainly occur in the Welmal watershed.

Basin relief (B_h) describes the maximum vertical distance between the highest and the lowest elevation within the basin. The basin relief plays a significant rate in landforms development, drainage development, surface and subsurface water flow, permeability and erosional properties of the terrain (Mudashiru et al. 2017). The maximum relief of Welmal River Basin is 3.67 km and minimum relief is 1.09 km (Table 3). These values indicate that the elevation of the Welmal Basin represent that the land has gentle to moderate slope.

Relief ratio (R_h) is the dimensionless height-length ratio equal to the tangent of the angle formed by two planes intersecting at the mouth of the basin, one representing the horizontal, the other passing through the highest point of the basin (Schumm 1963). The relief ratio of the Welmal Basin is 0.035; while those of the 9 Sub-watersheds are shown in Table 3. While high values are characteristic of hill regions, low values are characteristic of pedi-plains and valley. Low relief ratios also indicate that the discharge capabilities of the Welmal River Basin in terms of groundwater potential are good (Mudashiru et al. 2017).

Ruggedness number (R_n) is the product of relief and drainage density is an index which reflects slope steepness and length (Hart 1986). Extremely high values of the ruggedness number occur when both variables are large, i.e., when slopes are not only steep but long as well (Chow 1964). The estimated ruggedness number value for the watersheds of the study area ranges from 0.93 to 7.54 (Table 3). For the whole watershed, R_n value is 4.60 (Table 3).

4.4 Prioritization of sub-watersheds

The compound values (C_p) of all nine sub-watersheds and whole morphometric parameters of Welmal watershed are calculated in Tables 4 and 5, respectively. Compound factor is computed by summing all the values of all parameters and

Fig. 4 Aspect grid map of Welmal Watershed

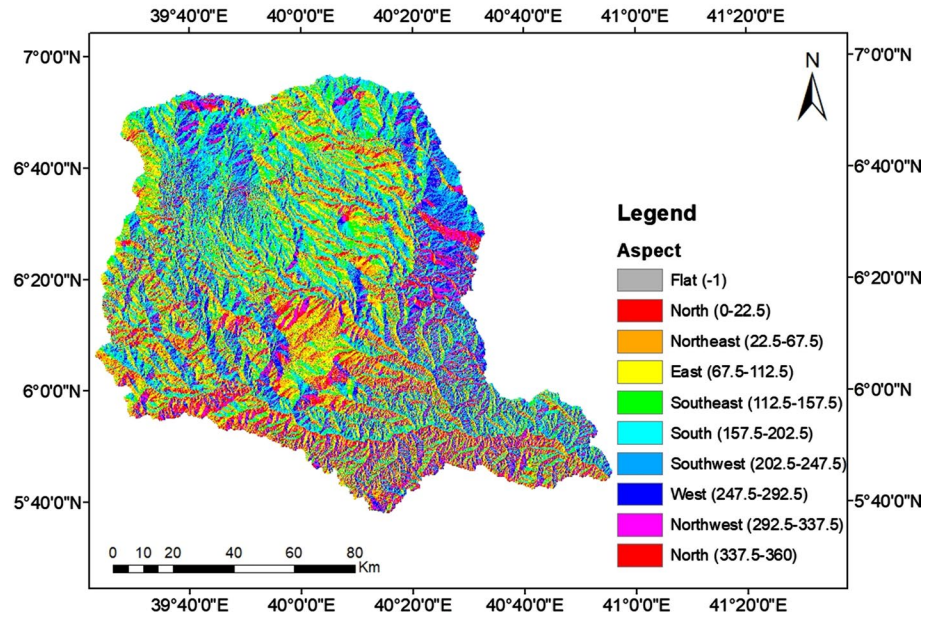


Table 3 Relief morphometric parameters of the Welmal sub-watershed

S. no.	Morphometric parameter	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	Welmal Basin
1	Basin relief (km)	3.41	3.67	3.43	1.09	1.84	3.50	1.65	2.40	1.38	4.07
2	Relief ratio	0.27	0.31	0.26	0.08	0.15	0.28	0.12	0.17	0.10	0.035
3	Ruggedness number	7.54	5.10	3.56	1.34	2.06	3.18	2.14	2.72	0.93	4.60

SW sub-watershed

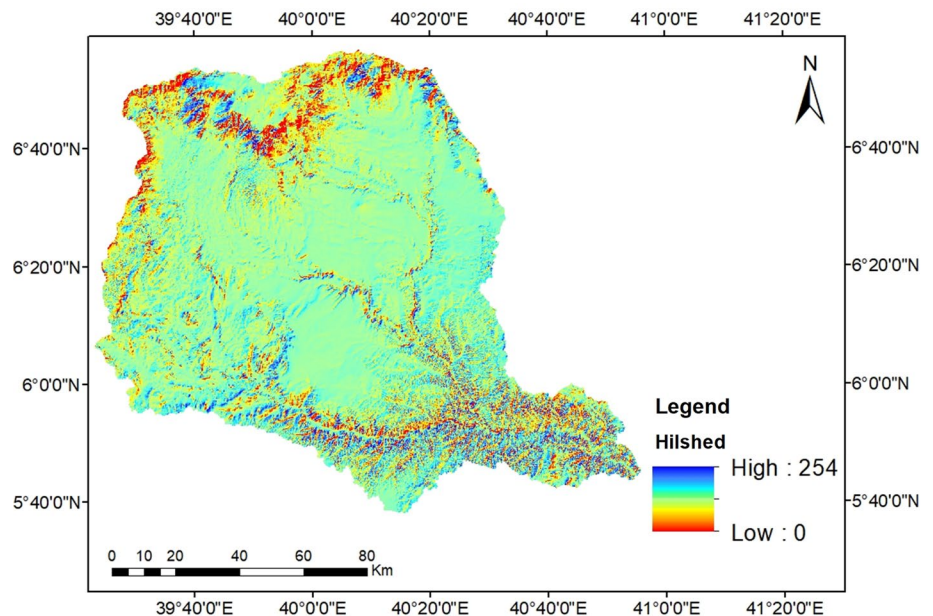
Table 4 Priorities of sub-watersheds and their ranks

SW	Area (km ²)	Morphometric Parameter										C _p	Priority	
		Rank	D _d	F _s	R _b	R _c	R _e	F _f	L _o	B _h	R _n			R _n
1	13.57		2.21	2.81	5.61	1.22	0.5	0.3	1.11	3.41	0.27	7.54	3.6	High
	Rank	1	1	2	9	9	5	1	4	3	1			
2	42.32		1.39	1.91	5.81	2.15	0.62	0.2	0.63	3.67	0.31	5.1	2.6	High
	Rank	2	2	1	1	5	9	2	1	1	2			
3	49.21		1.04	1.54	5.57	1.37	0.6	0.28	0.52	3.43	0.26	3.56	4.8	Low
	Rank	7	3	3	5	7	6	7	3	4	3			
4	53.48		1.24	1.18	5.11	1.27	0.63	0.31	0.62	1.09	0.08	1.34	6.1	Low
	Rank	4	5	6	8	4	4	4	9	9	8			
5	34.57		1.12	1.06	3.92	1.36	0.53	0.22	0.56	1.84	0.15	2.06	6.6	Low
	Rank	6	6	8	6	8	8	5	6	6	7			
6	47.68		0.9	0.32	4.67	1.41	0.61	0.23	0.45	1.65	0.28	3.18	6.5	Low
	Rank	8	9	7	7	6	7	8	7	2	4			
7	64.23		1.3	1.01	5.5	1.35	0.68	0.36	0.67	3.51	0.12	2.14	4.3	Medium
	Rank	3	8	4	4	3	3	3	2	7	6			
8	81.35		1.14	0.75	5.33	1.7	0.75	0.44	0.56	2.4	0.17	2.72	4.5	Medium
	Rank	5	7	5	3	2	2	6	5	5	5			
9	102.31		0.68	1.25	3.36	2.02	0.78	0.45	0.34	1.38	0.1	0.93	6	Low
	Rank	9	4	9	2	1	1	9	8	8	9			

SW sub-watershed, D_d drainage density, F_s stream frequency, R_f form factor, R_c circulatory ratio, R_e elongation ratio, L_o overland flow, R_h relief ratio, R_n Ruggedness number, B_H Basin relief, R_b drainage texture

Table 5 Morphometric parameters of the Welmal watershed

S.no	Morphometric parameter	Formula/definition	Value	References
1	Basin area (km ²)	Total basin area (A)	506.32	Horton (1945)
2	Stream order	Hierarchical rank	4	Strahler (1964)
3	Number of stream	Hierarchical order	602	Strahler (1964)
4	Stream length (L_u)	Total length of the stream (km)	571	Horton (1945)
5	Basin perimeter (km)	Length of watershed divide which surround the basin (P)	190.65	Horton (1945)
6	Basin length (km)	Distance between outlet and farthest point on basin boundary (L_b)	117.32	Horton (1945)
7	Mean stream length	$L_{sm} = L_u/N_u$; where, L_u =total stream length of a given order (km), N_u =number of stream segment	2.059	Horton (1945)
8	Stream length ratio	$RL = L_u/L_{u-1} - 1$ where, L_u =total stream length of order (u), L_{u-1} = the total stream length of its next lower order	1.63	Horton (1945)
9	Bifurcation Ratio (R_b)	$R_b = N_u/N_{u+1} + 1$ where, N_u =number of stream segments present in the given order N_{u+1} = number of segments of the next higher order	8.34	Horton (1945)
10	Drainage density (D_d)	$D_d = L/A$ where, L =total length of stream, A =area of basin	1.13	Horton (1945)
11	Stream frequency (F_s)	$F_s = \Sigma N_u/A$, where, N_u =total number of stream segments of all order	1.19	Horton (1945)
12	Form factor (R_f)	$R_f = A/(L_b)^2$ where, A =area of basin, L_b =basin length	0.037	Horton (1932)
13	Length of overland flow (L_o)	$L_o = 1/2 D_d$ where, D_d =s drainage density	0.56	Horton (1945)
14	Circulatory ratio (R_c)	$R_c = 2\pi (A/P^2)$ where A =area of basin, $\pi=3.14$, P =perimeter of basin	0.18	Miller (1953)
15	Elongation ratio (R_e)	$R_e = (2/L_b) \times \sqrt{(A/\pi)}$ where, A =area of basin, $\pi=3.14$, L_b =basin length	0.22	Schumn (1956)
16	Basin relief	Vertical distance between the lowest and highest points of basin	4.07	Schumn (1956)
17	Relief ratio (R_h)	$R_h = B_h/L_b$ where, B_h =basin relief, L_b =basin Length	0.035	Schumn (1956)
18	Ruggedness number (R_n)	$R_n = B_h \times D$ where, B_h =basin relief, D_d =drainage density	4.60	Schumn (1956)

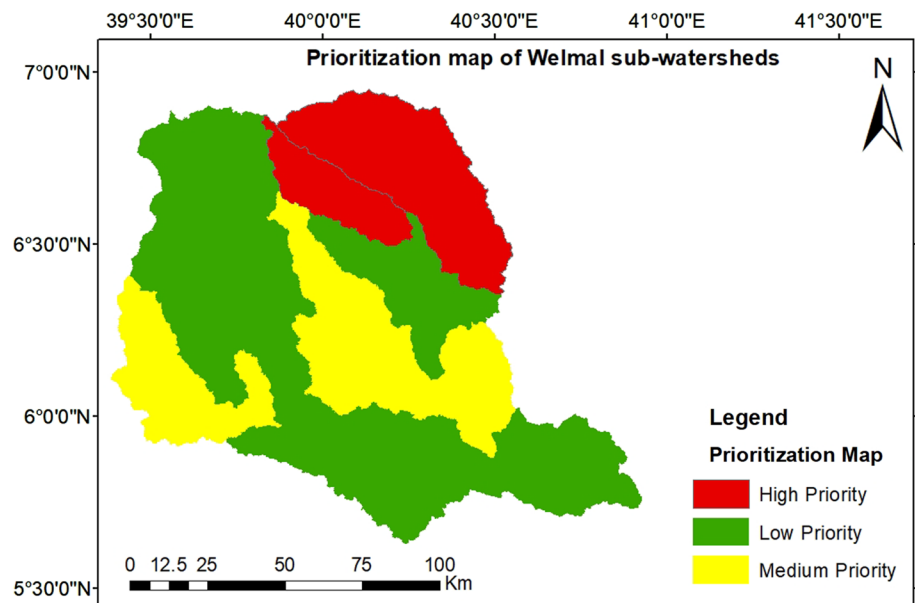
Fig. 5 Hilshed grid map of Welmal Watershed

then dividing by number of parameters. Compound parameters values are calculated and the sub-watershed with the lowest rank was given higher priority according to Vandana (2013). The prioritization was carried out by assigning ranks to the individual indicators and a compound value (C_p) was calculated. Sub-basin with highest C_p values has been low priority while those with lowest C_p values have been high

priority. The sub-watersheds have been broadly classified into three priority zones according to their compound value (C_p), i.e. High (<4.0), Medium (4.0–4.5) and Low (>4.5) (Fig. 6).

High priority Highest priority indicates the greater degree of soil erosion in the particular sub-watershed and it becomes potential area for applying soil conservation

Fig. 6 Prioritization Map of Welmal River Basin



measures. The two sub-watersheds, i.e. sub-watershed SW1 and SW2 with a C_p value of 3.6 and 2.6, respectively, are grouped under high-priority class should be provided with immediate soil and water conservation measures as they are likely to be subjected to maximum soil erosion.

Medium priority There are two sub-watersheds, i.e. sub-watershed SW7 and SW8 with a C_p value of 4.3 and 4.5, respectively, falling in medium priority. These sub-basins are characterized by moderate slopes, high to moderate values of drainage density, drainage texture, form factor and circulatory ratio.

Low priority The five sub-watersheds, i.e. sub-watershed SW3, SW4, SW5, SW6 and SW9 have come under the low priority with slight erosion susceptibility zone and may need agronomical measures to protect the sheet and rill erosion.

5 Conclusion

Prioritization of the watershed is one of the important aspects of planning for implementation of its development and management programs. The present study has helped to decipher information relating to the form, geomorphic and hydrologic processes of the 9 sub-watersheds of the Welmal Watershed in Bale Zone, Ethiopia. Prioritization of sub-watershed using the GIS and RS gives a clear understanding of the Soil erosion prone areas of the watershed. Results of morphometric analysis show that sub-watershed 1 and 2 are possibly having high erosion. Hence, suitable soil erosion control measures are required in these watersheds to preserve the land from further erosion. These outcomes in current research will be helpful for researchers, students,

and policy makers and planners for conservation measures in the watershed management.

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