Application of Remote Sensing, GIS, and Drainage Morphometric Analysis in Groundwater potential Assessment for sustainable development in Iyenda River Catchment, Konso Zone, Rift Valley, Southern Ethiopia

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Abstract. The present study employed remote sensing data, GIS technologies, and drainage morphometric analysis to assess groundwater potential for sustainable development in the Iyenda River Catchment, Rift Valley, Southern Ethiopia. A 30 m spatial resolution Shuttle Radar Topographic Mapper (SRTM) digital elevation model and toposheets were used to demarcate the present study area’s watershed boundary and extract drainage network in ArcGIS software environment. The current study area was divided into eight watersheds, namely WS-1, WS-2, WS-3, WS-4, WS-5, WS-6, WS-7, and WS-8, and the total areal extend is 497.70 Sqkm. The standard formula was used to determine the necessary linear, relief, and spatial morphometric parameters. According to the present investigation results, the current study region includes undulating topography with slopes ranging from 0° to 52°. The groundwater occurrence is inversely proportional to the following morphometric parameter values: stream frequency, drainage texture, drainage density, bifurcation ratio, and form factor; the lower the values, the more significant groundwater occurrence. The groundwater occurrence is directly proportional to the morphometric parameters: compactness coefficient, elongation ratio, circularity ratio, and length of overland flow. The present study areas’ watersheds were prioritized using compound parameter analysis, which combined the mentioned-above morphometric parameters for each watershed. Compound factor values ranging between 3.78 to 5.11 and same was classified into three categories, and priorities were assigned 3.780 - 4.11 (high), 4.12 - 4.78 (medium), and 4.79 - 5.11 (low). The watersheds (WS-2 and WS-4) need immediate attention to minimize the surface runoff and enhance groundwater recharge. The results show that WS-7 having high and WS-1, WS-3, WS-5, WS-6, and WS-8 have medium groundwater potential. Watersheds with poor groundwater potential demand additional thorough research and remedial procedures, including implementing appropriate recharge systems. The current study demonstrates the effective use of remote sensing, GIS, and drainage morphometry in assessing groundwater potential.

Keywords: Drainage morphometry, Ethiopia, GIS, groundwater potential, Iyenda river, Konso

1. Introduction
Groundwater is a significant and reliable natural resource that is crucial in fulfilling global water supply needs caused by a scarcity of surface water resources [1]. And it is becoming scarce due to over-exploitation, inadequate groundwater recharge, and excessive use, among other factors. Groundwater in Sub-Saharan Africa has traditionally been accessible by springs and dug wells, and generally, it occurs far from settlement and near river valleys and riparian zones [2]. Between 1998 and 2016, there was significant economic growth in Ethiopia, with an average annual growth of 10%. And it has resulted in a fast urbanization rate of 6 to 20%. It has caused rural people to be moved to towns and
towns for employment, resulting in enormous pressures on existing infrastructure, particularly water supplies [3].

Water supply authorities seek to avoid future water shortages by preventing the use of conventional surface-water reservoirs/dams, which take a long time to build and cost a lot of money upfront. The present scenario has pushed the administrators and decision-makers of Ethiopia to concentrate on tapping groundwater resources near settlements. Since the 1970s, pumping and drilling technology development in Ethiopia has allowed groundwater extraction [4]. According to Ethiopia’s federal and state water authority’s data, over 80% of groundwater consumption is met by shallow wells, and their yielding is less than 10 L/s [4]. However, quantitative and qualitative data on groundwater is limited in Ethiopia [5].

The hydrological behavior of a watershed is governed by the form, size, LULC, soil, gradient, and amount of rainfall within it. Furthermore, these factors impact new drainages or alter an existing watershed’s drainages [6]. The climatic, geological, and geomorphological features of the regions determine the long-term viability of water supplies. Evaluating smaller watersheds is a significant component of substantial land and water development. A watershed is a geographic area where rainwater first gathers and flows through the primary and tributaries to the final place where it joins a more extensive water body [7].

Drainage morphometric analysis mainly focuses on providing details on topography, underlying geological structures, and its help full in many applications such as runoff estimation, flood studies, groundwater potential [8, 9]. With the help of temporal datasets such as satellite images, aerial photography, and elevation data, it is possible to identify and evaluate these streams [6]. [10] is the first one to introduce morphometric research. The following researchers contributed to the development and improvement of the concept [11, 12, 13, 14, 15]. Geographic information system (GIS) and Remote sensing are the vital geospatial technologies used to manage watersheds because remote sensing provides different spatial and temporal data sets. GIS has rich toolsets to combine spatial and non-spatial data from various sources.

Morphometric and principal component analysis has been used to identify vulnerable locations that require soil/water conservation at the watershed level in the Deonar river sub-basin, India [16,17]. Prioritizing sub-watersheds is essential for watershed management plans, soil and natural resource conservation, regulating plant growth, and managing surface and groundwater [18, 19].

Remote sensing, GIS, and statistical methods were used to quantify Agula watershed’s drainage morphometry. [20]. In Ethiopia’s Kulfo River basin, sub-watersheds were prioritized using drainage morphometrics and statistical correlation [21]. Toposheets, optical remote sensing data, and a digital elevation model coupled with GIS tools have been used to demonstrate the capabilities of sub-watershed-based drainage morphometric research in the flood vulnerability study, Megech river catchment, Ethiopia [22]. The Dhidhessa River Basin hydrology, geology, and terrain were characterized using morphometric parameters estimated from SRTM -DEM data [23].

In Chelekot micro watershed, water resources were assessed using drainage morphometric analysis [24]. An attempt has been undertaken to research the morphometric aspects of the Didessa watershed, which is part of the Blue Nile River basin in Ethiopia's southwestern region [25]. On the Tikur Wuha river watershed, the hydrological aspects of morphometric parameters were evaluated [26,27]. Quantitative morphometry analysis on Ribb and Gumara watersheds has been undertaken to prioritize the watershed for soil and water conservation [28].

The following authors used drainage morphometry to assess the potential groundwater zones in the different parts of the world. Infiltration, discharge, erosional processes, and quantitative morphometric parameters were studied in Bellary and Davanagere Districts, Karnataka, India [29]. [30] was studied, several morphometric characteristics and identified groundwater potentials in the Savitri and Vashishtih basins were investigated. Determined the artificial recharge potential sites were through drainage morphometric analysis in India's Gagas River Basin [31]. The morphometric features of the Lake Tana Sub-basin’s catchments were assessed using remote sensing data and GIS [32].

Potential groundwater sites have been identified in the Araniar river basin, India, through drainage morphometric analysis [33]. [34] employed morphometric analysis extensively in a combined land and water resource administration and determining suitable groundwater zones for management. A
morphometric study and sub-watershed prioritization for likely groundwater have been carried in the Mula River basin in the Pune district of Maharashtra, India [35]. In a structurally regulatedPageru River basin, morphometric research revealed probable groundwater zones [36]. There has been limited drainage morphometric research only undertaken in Ethiopia. As a result, the purpose of this study was to examine watershed morphometric characteristics to prioritize sub-watersheds for groundwater potential in the Iyenda river catchment, Konso zone, Rift Valley, Ethiopia.

2. Methodology

2.1. Study Area
The present study area, the Iyenda river catchment, is situated in Southern Nations, Nationalities, and People (SNNPR) regional state, Rift Valley, Ethiopia. It is located geographically between 37°16′30″ and 37°33′41″ E longitude and 5°19′00″ to 5°39′42″ N latitude. The present study area's total areal extend is 498 Sqkm. Gidole, Gato, and Konso are the major settlements in the current study area. Figure 1 shows the present study area's location map. The study area has rugged topography and elevation ranging between 1127 m to 2576 m, and the slope of the terrain is between 0° to 49°. The present study area's northwest rift margin has a higher elevation, rugged topography, steep slope, and vice versa in the rift floor, which divided rift margins (Figure 2).

2.2. Materials and methods
2.2.1 LULC of the study area.: The false-color composite of the Landsat-8 (OLI) image, field knowledge was used to prepare the LULC map through visual interpretation in the present study. Agricultural land, bushland, forest, shrubland, and barren land are the major LULC types in the study area. The central portion of the rift floor is covered by agricultural land and bushland. The forest is covered seen in the rift margins where the elevation and rainfall are high, and shrubland is also covered significantly in the rift margins. The present study area's LULC map is shown in figure 3b.

2.2.2. Drainage extraction and demarcation of watershed's boundary: Initially, the Iyenda river catchment was identified using toposheets prepared by the Ethiopian mapping agency at a scale of 1:50,000, and the toposheet numbers are 0537 A4, 0537 A4, and 0537 B3. SRTM-DEM with 30 m spatial resolution data was downloaded from (https://earthexplorer.usgs.gov/), and the tile number is N05E037V3. Archydro toolset of ArcGIS software was used to extract the present study area's drainage and watershed boundary through the following steps: fill dem, flow direction flow accumulation, stream definition, stream segmentation, catchment grid delineation, and catchment polygon processing as suggested by [37]. The present study area was divided into eight watersheds, namely WS-1, WS-2, WS-3, WS-4, WS-5, WS-6, WS-7, and WS-8. Figure 3a shows the Iyenda River's drainage system and watershed boundaries.
The morphometric parameters of the present study area (basic, linear, areal, and relief) such as area, length, and perimeter of the catchment, order, number, and length of drainage were calculated and extracted through Statistics and calculate geometry tools of the ArcGIS software. Further, the following morphometric parameters like density and frequency of drainage, drainage length ratio, mean drainage length, form factor ($F_f$), circulatory ratio ($R_c$), elongation ratio ($R_e$), length of overland flow ($L_o$), etc., were calculated from the mentioned-above morphometric parameters using the standard formula. Figure 4 shows the methodology flow chart of the present study.
3. Results and discussions

3.1. Calculate and analysis of linear morphometric aspects

3.1.1. Drainage order, number, and length. The first stage in morphometric analysis is drainage ordering. [42] was proposed a method, and the same was adopted to order the drainage in the present study. Watershed-wise drainage orders are shown in Table 1. First-order streams have the highest drainage order frequency, followed by second, third, fourth, fifth, and sixth-order drainages. In further from Table 1, it is noticed that drainage orders having a negative relationship with the number of drainages. 498, 243, 130, 92, and 21 are the 1st, 2nd, 3rd, 4th, and 5th order drainages are found in the present study area. Many of the first-order drainage in the present reflects the terrain's complexity and the compactness of the bedrock [38]. The present study area has 397.93kms, 226.88kms, 93.85kms, 71.55kms, 10.3kms, and 800.56kms length of 1st, 2nd, 3rd, 4th, 5th, and total order of drainages (Table 1). The length of the first-order drainages provides around 50% of the overall drainage length, with the remaining 50% shared by all subsequent drainage orders. Overall stream length closely relates to mean annual runoff [39]. In the present study area, WS-1 has a maximum drainage length of 161.25kms, whereas WS-6 has a minimum drainage length of 59.41kms.

3.1.2. Bifurcation ratio ($R_b$). The ratio between the amount of drainage segment of the given order ($N_u$) to the amount of drainage segment of the next higher-order ($N_{u+1}$) is defined as bifurcation ratio ($R_b$) [40]. The bifurcation ratio can be used to determine the degree of structural and lithological influence over a given area [41]. The bifurcation ratio shows a drainage basin's intricacy and segmentation. According to [41], bifurcation ratio values range to 2 for the flat area, 3 for rolling drainage catchment, and 4 for severely dissected or mountainous basins. [42] stated that geological features do not dominate the drainage pattern where the bifurcation value is between 3 and 5. Except in locations where geological structures influence predominates, the bifurcation ratio in most areas ranges between 3 and 5 [34]. Compared to regions with a dendritic or trellised drainage pattern, regions with a parallel or rectangular drainage pattern exhibit a greater bifurcation ratio. The present study area exhibits a dendritic drainage pattern. The current study area's mean bifurcation ratio values ranging in between 1.66 to 3.60 (Table 1). WS-2 and WS-7 exhibit maximum and minimum bifurcation values in the present study area.

Figure 3. Watersheds, drainage, and LULC map
Figure 4. Methodology flow chart
Table 1. Results of morphometric drainage calculation

| Morphometric parameters | WS-1  | WS-2  | WS-3  | WS-4  | WS-5  | WS-6  | WS-7  | WS-8  | Iyenda River catchment |
|-------------------------|-------|-------|-------|-------|-------|-------|-------|-------|------------------------|
| Stream order Vs numbers |       |       |       |       |       |       |       |       |                        |
| I\(^{st}\) order        | 109   | 74    | 43    | 68    | 47    | 38    | 57    | 62    | 498                   |
| II\(^{nd}\) order       | 58    | 43    | 21    | 33    | 27    | 11    | 24    | 26    | 243                   |
| III\(^{rd}\) order      | 33    | 6     | 9     | 21    | 14    | 13    | 18    | 16    | 130                   |
| IV\(^{th}\) order       | 15    | 21    | 9     | 3     | 9     | 14    | 12    | 92    |                        |
| V\(^{th}\) order        | 0     | 4     | 0     | 3     | 4     | 4     | 0     | 6     | 21                    |
| Total                   | 215   | 148   | 82    | 134   | 95    | 75    | 113   | 122   | 984                   |
| Bifurcation ratio       |       |       |       |       |       |       |       |       |                        |
| I\(^{st}\) / I\(^{nd}\) | 1.88  | 1.72  | 2.05  | 2.06  | 1.74  | 3.45  | 2.38  | 2.38  | 2.21                  |
| II\(^{nd}\) / III\(^{rd}\)| 1.76  | 7.17  | 2.33  | 1.57  | 1.93  | 0.85  | 1.33  | 1.63  | 2.32                  |
| III\(^{rd}\) / IV\(^{th}\)| 2.20  | 0.29  | 1.00  | 2.33  | 4.67  | 1.44  | 1.29  | 1.33  | 1.82                  |
| IV\(^{th}\) / V\(^{th}\)| 0     | 5.25  | 0     | 0.75  | 2.25  | 0     | 2     | 1.66  |                        |
| Bifurcation ratio ratio in mean | 1.94  | 3.60  | 1.79  | 2.24  | 2.27  | 1.99  | 1.66  | 1.83  | 2.16                  |
| Drainage length (kms)   |       |       |       |       |       |       |       |       |                        |
| I\(^{st}\) order        | 91.26 | 67.60 | 35.92 | 41.99 | 42.21 | 31.63 | 42.24 | 45.08 | 397.93                |
| II\(^{nd}\) order       | 45.30 | 50.76 | 22.58 | 32.08 | 22.88 | 8.87  | 20.42 | 23.99 | 226.88                |
| III\(^{rd}\) order      | 15.78 | 4.44  | 9.45  | 12.60 | 19.28 | 11.11 | 12.20 | 8.99  | 93.85                 |
| IV\(^{th}\) order       | 8.91  | 14.73 | 5.47  | 13.38 | 2.97  | 7.32  | 6.03  | 12.74 | 71.55                 |
| V\(^{th}\) order        | 0     | 2.35  | 0     | 1.41  | 1.17  | 0.48  | 0     | 4.89  | 10.3                  |
| Total                   | 161.25| 139.88| 73.42 | 101.46| 88.51 | 59.41 | 80.89 | 95.74 | 800.56                |
| Mean drainage length    |       |       |       |       |       |       |       |       |                        |
| I\(^{st}\) order        | 0.84  | 0.91  | 0.84  | 0.62  | 0.90  | 0.83  | 0.74  | 0.73  | 0.80                  |
| II\(^{nd}\) order       | 0.78  | 1.18  | 1.08  | 0.97  | 0.85  | 0.81  | 0.85  | 0.92  | 0.93                  |
| III\(^{rd}\) order      | 0.48  | 0.74  | 1.05  | 0.60  | 1.38  | 0.85  | 0.68  | 0.56  | 0.79                  |
| IV\(^{th}\) order       | 0.59  | 0.70  | 0.61  | 1.49  | 0.99  | 0.81  | 0.43  | 1.06  | 0.84                  |
| V\(^{th}\) order        | 0.00  | 0.59  | 0.00  | 0.47  | 0.29  | 0.12  | 0.00  | 0.82  | 0.29                  |
| Average                 | 0.54  | 0.82  | 0.72  | 0.83  | 0.88  | 0.68  | 0.54  | 0.82  | 0.73                  |
| Drainage length ratio   |       |       |       |       |       |       |       |       |                        |
| II\(^{nd}\) / I\(^{st}\) | 0.50  | 0.75  | 0.63  | 0.76  | 0.54  | 0.28  | 0.48  | 0.53  | 0.56                  |
| III\(^{rd}\) / II\(^{nd}\)| 0.35  | 0.09  | 0.42  | 0.39  | 0.84  | 1.25  | 0.60  | 0.37  | 0.54                  |
| IV\(^{th}\) / III\(^{rd}\)| 0.56  | 3.32  | 0.58  | 1.06  | 0.15  | 0.66  | 0.49  | 1.42  | 1.03                  |
| V\(^{th}\) / IV\(^{th}\)| 0.00  | 0.16  | 0.00  | 0.11  | 0.39  | 0.07  | 0.00  | 0.38  | 0.14                  |
| Average                 | 0.35  | 1.08  | 0.41  | 0.58  | 0.48  | 0.57  | 0.39  | 0.68  | 0.57                  |

3.1.3 Mean drainage length. The mean drainage length reveals the typical size of drainage network components and their contributing catchment surface. The mean drainage length was calculated by multiplying the total number of drainages in the order by the total length of the drainage order [42]. Generally, in the present study area, it was observed that Lower order streams have the most considerable mean drainage length, whereas higher-order streams have the least (Table 1). The differences in slope and terrain of the present study area are mostly to account for this. The highest mean drainage length causes more surface runoff and vice versa. In the current study area, the mean drainage length ranges from 0.29 to 0.93, and the same was noticed in the Vth and IIInd order drainage, respectively. The highest (0.88) and the lowest (0.54) mean drainage length values were seen in WS-5 and WS-7, respectively.
Table 2. Results of morphometric drainage calculation

| Morphometric parameters | WS-1   | WS-2   | WS-3   | WS-4   | WS-5   | WS-6   | WS-7   | WS-8         | Iyenda River catchment |
|-------------------------|--------|--------|--------|--------|--------|--------|--------|--------------|------------------------|
| Areal morphometric parameters |        |        |        |        |        |        |        |              |                        |
| Watershed area (km²) | 113.73 | 73.94  | 39.72  | 63.76  | 48.43  | 35.20  | 59.61  | 63.31        | 497.70                 |
| Watershed perimeter (P) (km) | 49.70  | 47.34  | 29.29  | 46.74  | 37.67  | 32.68  | 37.45  | 38.05        | 39.87                  |
| Watershed length (Lb) (km) | 19.31  | 15.12  | 10.62  | 13.90  | 11.89  | 9.92   | 13.38  | 13.84        | 13.50                  |
| Circularity ratio (Rc) | 0.57   | 0.41   | 0.58   | 0.36   | 0.43   | 0.41   | 0.53   | 0.55         | 0.48                   |
| Elongation ratio (Re) | 0.623  | 0.642  | 0.670  | 0.648  | 0.661  | 0.675  | 0.651  | 0.649        | 0.65                   |
| Form factor (Ff) | 0.305  | 0.323  | 0.352  | 0.330  | 0.343  | 0.358  | 0.333  | 0.331        | 0.33                   |
| Drainage density (Dd) | 1.42   | 1.89   | 1.85   | 1.59   | 1.83   | 1.69   | 1.36   | 1.51         | 1.64                   |
| Drainage frequency (Df) | 1.89   | 2.00   | 2.06   | 2.10   | 1.96   | 2.13   | 1.90   | 1.93         | 2.00                   |
| Compactness coefficient (Cc) | 1.32   | 1.55   | 1.31   | 1.65   | 1.53   | 1.56   | 1.37   | 1.35         | 1.46                   |
| Drainage texture (Dt) | 4.33   | 3.13   | 2.80   | 2.87   | 2.52   | 2.29   | 3.02   | 3.21         | 3.02                   |
| Length of overland flow (Lg) | 0.710  | 0.945  | 0.925  | 0.795  | 0.915  | 0.845  | 0.680  | 0.755        | 0.82                   |
| Relief morphometric parameters |        |        |        |        |        |        |        |              |                        |
| Maximum elevation (Z) (m) | 2576   | 1915   | 1560   | 2281   | 1919   | 1679   | 1804   | 1782         | 1939.5                 |
| Minimum elevation (z) (m) | 1253   | 1148   | 1154   | 1139   | 1129   | 1127   | 1275   | 1129         | 1169.2                 |
| Basin relief (H) (m) | 1323   | 767    | 406    | 1142   | 790    | 552    | 529    | 653          | 770.25                 |
| Relief ratio (Rr) | 0.069  | 0.051  | 0.038  | 0.082  | 0.066  | 0.056  | 0.040  | 0.047        | 0.06                   |
| Ruggedness number (H) (km) | 1.88   | 1.45   | 0.75   | 1.82   | 1.45   | 0.93   | 0.72   | 0.99         | 1.25                   |

3.1.4. Drainage length ratio. [43] defined the drainage length ratio as the ratio of drainage lengths of one order to the next lower order. The drainage length ratio has an intense relationship with flow discharge and catchment erosion stage [43]. Table 1 shows the present study area’s drainage length ratio values. The highest (1.08) and lowest (0.35) drainage length ratio values were seen in WS-1 and WS-2. The variations in drainage length ratio are primarily due to changes in slope and topographic characteristics.

3.2 Calculate and analysis of areal morphometric aspects

3.2.1. Watershed length, area, and perimeter. The present study calculated watershed length using the following equation (1) defined by [44].

\[
\text{Watershed length} = 1.312 \times A^{0.568} \quad (1)
\]

Where A = watershed area. The watershed lengths vary between 9.92km to 19.31km in the present study area, and Table 2 shows the watershed-wise length. The Iyenda River watershed covers a total area of 497.70 square kilometers. Sub-watershed wise areal extent is shown in Table 2. WS-3 and WS-1 are the smallest and largest watershed in the present study area and having areal coverage of 39.72 sqkm and 113.73 sqkm, respectively. The perimeters of the Iyenda catchment were calculated using calculate perimeter tool of ArcGIS software. The Iyenda river catchment perimeter is 318.92 km, and the watershed-wise perimeter is shown in Table 2.
3.2.2. **Circularity ratio (Rc).** The circularity ratio was calculated using the following equation as suggested by [45]. It varies with drainage frequency and length, lithological units, land use/land cover, climatic conditions, elevation, and watershed slope. Rc ranges from 0 to 1. Elongated basins are near to 0, while circular basins are close to 1. Less Rc values indicate low infiltration rates and high-velocity runoff [46]. The lowest Rc value (0.36) was observed in WS-4, whereas the highest (0.58) was observed in WS-3. The watershed-wise Rc values are shown in Table 2.

3.2.3. **Elongation ratio (Re).** The present study area's elongation ratio was calculated using the following equation (2) proposed by [47].

\[
Re = 2\sqrt{\frac{A}{\pi}}/Lb
\]

where \( A \) is the area of the watershed, \( \pi = 3.14 \), \( Lb \) is the basin length.

The elongation ratio ranges from 0.6 to 1.0 across a wide range of climatic and geologic conditions. The watershed's highest elongation value indicates groundwater occurrence, whereas low values indicate the watershed's vulnerability to soil erosion and surface runoff [48, 49]. WS-1 has the lowest elongation ratio value (0.623), and WS-6 has the highest value (0.675). Table 2 shows the watershed-wise elongation ratio values.

3.2.4. **Form factor (Ff).** The form factor (Ff) of the present study area was calculated using the Horton (1945) equation (3).

\[
Ff = \frac{A}{Lb^2}
\]

where \( A \) is the area of the basin and \( Lb \) is (maximum) basin length.

The form factor directly connects to the peak discharge capacity. Therefore, it might be beneficial to forecast the watershed flow intensity. High form factor values imply high peak flow in a shorter time frame and vice versa [41]. Table 2 shows the computed form factor values. WS-6 has the highest form factor value (0.358), and WS-1 has the lowest value (0.305).

3.2.5. **Drainage density (Dd).** Drainage density (Dd) is vital in groundwater investigation. It is the length of drainage per square kilometre. Drainage density is low when there is an underlying permeable material, dense vegetation, and low relief. At the same time, it is high where there is impermeable subsurface material, less vegetation, and mountainous relief. [50]. In this investigation, WS-2 had the greatest Dd (1.89/km), indicating the most negligible permeability and hence the most susceptible to erosion and least chances for groundwater occurrences. WS-7 had the lowest Dd (1.36/km), indicating higher permeability and more prospects to groundwater occurrence than other watersheds in the present study area. Table 1 shows the watershed-wise drainage density values. Table 2 shows the watershed-wise Dd values.

3.2.6. **Drainage frequency (Df).** Drainage frequency is the ratio of total stream count to the watershed area. Drainage frequency was calculated using the following equation (4) defined by [41].

\[
Ff = \frac{\Sigma Nu}{A}
\]

where \( Nu \) is total number of stream segments of the order 'u' and \( A \) is area of the basin (km²)

Drainage frequency is directly proportional to a watershed's relief and inversely proportional to permeability. High drainage frequency denotes high relief and limited groundwater infiltration capacity, and vice versa. WS-1(1.89) had the lowest drainage frequency of the eight watersheds studied, indicating the significant permeability and ability to resist soil erosion. WS-6 has the highest drainage frequency value of 2.13 in the present study area. Table 2 shows the watershed-wise drainage frequency values.

3.2.7. **Compactness coefficient (Cc).** Cc is one of the essential morphometric parameters in groundwater potential assessment, and the same was calculated using the following equation (5) described by [41].

\[
Cc = \frac{P}{2\sqrt{\pi A}}
\]

where \( P \) is perimeter of the watershed (km) and \( A \) is watershed area (km²).
Floods are more likely when Cc is near to one. In contrast, Cc values larger than one reduce flood peaks and promote groundwater recharge [51]. All watersheds in the present study area had Cc values >1, indicating less prone to flooding and soil erosion. Table 2 shows the watershed-wise Cc values.

3.2.8. Drainage texture (Dt). Low infiltration areas will have greater Dt and hence more erosion. Dt is the total number of drainages per unit perimeter. The drainage texture measured in the present study ranges from 2.29 to 4.33. A drainage texture is coarse if it is less than 4, moderate if it is between 4 and 10, and fine if it is between 10 and 15. Climatic conditions, the thickness of vegetation, soil type and lithology, infiltration rate, elevation, and stage of development influence drainage texture [51]. The fine drainage texture is characterized by soft or weak rocks, whereas large and resistant rocks represent coarse drainage [51]. The computed drainage texture values are shown in Table 2.

3.2.9. Length of overland flow (Lg). The length of overland flow is half the reciprocal of drainage density [41]. Lg in the research region varies from 0.680 (WS-7) to 0.945 (WS-2). In watersheds with shorter overland flow values, rainwater enters the stream rapidly, and even minor rainfall contributes significantly to stream discharge. Smaller values might induce floods on heavy rain days owing to decreased soil water infiltration [52]. Hence groundwater recharge is high where Lg values are more. Watershed-wise Lg values are shown in Table 2.

3.3 Calculate and analysis of relief morphometric aspects

The current study considered the following relief factors: watershed relief, relief ratio, and roughness number. Watershed relief is the height difference on the watershed perimeter between the mouth and the top point and is represented in meter. In watersheds with more relief, it results in a more significant denudation rate, a more incredible amount of sediment carried by the river, and a higher discharge rate [53], 552m and 1323m are the minimum and maximum relief in the present study area, respectively. Watershed-wise relief values are shown in table 2. The relief ratio is the basin's overall relief proportion to its longest dimension parallel to the main drainage line. The relief ratio quantifies the potential energy available for water and sediment movement downslope and is inextricably linked to these processes [54]. In the present study area, a high relief ratio (0.082) is found in WS-4 and a low relief ratio (0.040) in WS-7.

The ruggedness number, drainage density, and relief product indicate slope steepness and length of the watershed [55]. The measured ruggedness number is shown in table 2. The roughness number is exceptionally high when both factors are high, i.e., steep and lengthy slopes [56]. Ruggedness number has a direct relationship with relative peak discharge. In the Iyenda river catchment, the high (1.88) and low (0.72) ruggedness numbers are seen in the WS-1 and WS-7. Table 2 shows the watershed-wise ruggedness number.

3.4 Prioritization of sub-watersheds for groundwater potential

Ranking of sub-watersheds in a hierarchical order depending on their groundwater potential is the process of Prioritization. The watershed with the highest groundwater potential receive the elevated priority ranking conversely [57]. Given the considerable investment in traditional approaches in potential groundwater assessments in terms of resources and time, statistical ranking of morphometric characteristics is a relatively easy and valuable tool for obtaining initial watershed-level priority. In the present study, prioritization was done for the Iyenda river basin in Ethiopia. Because the entire river catchment cannot be assessed at once, it has been split into eight sub-watersheds (WS-1 to WS-8). Different morphometric parameters were calculated using the standard formula. Watersheds were prioritized using compound parameter analysis, which combined the linear and shape parameters for each watershed.

The groundwater occurrence and surface runoff are inversely and directly proportional to the following morphometric parameter values: drainage density, bifurcation ratio, stream frequency,
drainage texture, and form factor; the lower the values, the more significant groundwater occurrence. The sub-watershed with the highest value was assigned rank one for the above parameters, and the second-highest was given the second rank. The groundwater occurrence and surface runoff are directly and inversely proportional to the morphometric parameter’s values, respectively: elongation ratio, compactness coefficient, circularity ratio, and length of overland flow. Rank one was assigned to the sub-watershed with the lowest value for the above parameters, and the second-lowest was given the second rank. By averaging the parameter values of Table 3, the compound values were calculated for each sub watershed. Compound factor values ranging between 3.78 to 5.11 and same was classified into three categories, and priorities were assigned 3.780 - 4.11 (high), 4.12 - 4.78 (medium), and 4.79 - 5.11 (low). The watersheds (WS-2 and WS-4) need immediate attention to minimize the runoff and enhance the groundwater recharge. The results show that WS-7 having high and WS-1, WS-3, WS-5, WS-6, and WS-8 have medium groundwater potential. The groundwater potential map is shown in figure 5.

![Groundwater Potential Zones Map](image_url)

**Figure 5.** Groundwater potential zones map

| Compound factor calculation |
|-----------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| D_d | R_h | D_f | D_t | L_g | R_e | C_c | R_c | F_f | Average | Priority |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|----------|
| WS-1 | 7   | 5   | 8   | 1   | 2   | 1   | 2   | 7   | 8       | 4.56     | 1      |
| WS-2 | 1   | 1   | 4   | 3   | 8   | 2   | 6   | 2   | 7       | 3.78     | 1      |
| WS-3 | 2   | 7   | 3   | 6   | 7   | 1   | 8   | 2   | 4.78    | 2        |
| WS-4 | 5   | 3   | 2   | 5   | 4   | 3   | 8   | 1   | 6       | 4.11     | 1      |
| WS-5 | 3   | 2   | 5   | 7   | 6   | 5   | 4   | 3   | 4.56    | 2        |
| WS-6 | 4   | 4   | 1   | 8   | 5   | 8   | 7   | 2   | 1       | 4.44     | 2      |
| WS-7 | 8   | 8   | 7   | 4   | 1   | 5   | 4   | 5   | 4.51    | 3        |
| WS-8 | 6   | 6   | 6   | 2   | 3   | 4   | 3   | 6   | 4.56    | 2        |

**Table 3.** Compound factor calculation
4. Conclusions
This study examines the Iyenda river catchment morphometric features utilizing DEM and GIS technologies by morphometric parameter ranking. The use of GIS to analyze morphometric parameters aids in the understanding of the basin’s different hydrogeological features. The dendritic pattern of streams indicates the homogeneous nature of the underlying subsurface. First-order streams have the highest drainage order frequency, followed by second, third, fourth, fifth, and sixth-order drainages. The current study area’s mean bifurcation ratio values ranging in between 1.66 to 3.60. the mean drainage length ranges from 0.29 to 0.93, which was noticed in the Vth and IIth order drainage, respectively. The highest (0.88) and the lowest (0.54) mean drainage length values were seen in WS-5 and WS-7, respectively. The lowest Rc value (0.36) was observed in WS-4, whereas the highest (0.58) was observed in WS-3. WS-1 has the lowest elongation ratio value (0.623), and WS-6 has the highest value (0.675). In this investigation, WS-2 had the greatest Dd (1.89/km), indicating the most negligible permeability and hence the most susceptible to erosion and least chances for groundwater occurrences. WS-7 had the lowest Dd (1.36/km), indicating higher permeability and more prospects to groundwater occurrence than other watersheds in the present study area. High drainage frequency denotes high relief and limited groundwater infiltration capacity, and vice versa. WS-1 (1.89) had the lowest drainage frequency of the eight watersheds studied, indicating the significant permeability and ability to resist soil erosion. Compound values were calculated for each sub watershed by averaging the parameter rankings. Compound factor values ranging between 3.78 to 5.11 and same was classified into three categories, and priorities were assigned 3.780 - 4.11 (high), 4.12 - 4.78 (medium), and 4.79 - 5.11 (low). The watersheds (WS-2, and WS-4) need immediate attention to minimize the runoff and enhance the groundwater recharge. The results show that WS-7 having high and WS-1, WS-3, WS-5, WS-6, and WS-8 have medium groundwater potential. Adopting appropriate groundwater recharge techniques in high-priority watersheds may help enhance the watershed’s groundwater potential. The present study results will help the planners and administrators for sustainable groundwater development in the current study area.

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