

JIMMA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
CHAIR OF HYDROLOGY AND HYDRAULIC ENGINEERING
MASTER OF SCIENCE PROGRAM IN HYDRAULIC ENGINEERING

Morphometric Analysis, for Surface Irrigation Assessment by Using GIS and Remote Sensing. A Case Study of Gilgel Gibe Watershed, Oromia, Ethiopia.

By

Dawit Debala

A Thesis submitted to the School of Graduate Studies, Jimma Institute of Technology in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering.

April, 2024

Jimma, Ethiopia

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This Thesis is submitted to the Graduate School of Jimma University, Institute of Technology in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering.

Main-Advisor: Dr.-Ing Megersa Kebede (PhD)

Co-Advisor: Mr. Abdata Wakjira (M.Sc.)

April, 2024

Jimma, Ethiopia

DECLARATION

This is to confirm, on behalf of myself, Dawit Debala, that the thesis, "Morphometric Analysis for Surface Irrigation Assessment by using GIS and Remote Sensing in Gilgel Gibe Watershed," is the original work that I finished under the supervision of the main advisor Dr.-Ing Megersa Kebede (PhD) and Co-advisor Mr. Abdata Wakjira (MSc).

Dr.-Ing Megersa Kebede (PhD).

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To the best of my knowledge, this research has not been presented anywhere to satisfy the requirements for a degree program; a list of references is provided at the end.

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APPROVAL SHEET

This is to certify that the thesis prepared by Dawit Debala Tesema, entitled **Morphometric Analysis for Surface Irrigation Assessment by Using GIS and Remote Sensing: Case Study of Gilgel Gibe watershed**, complies with university regulations and upholds accepted standards for originality and quality.

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ABSTRACT

Morphometric analysis of watersheds has a vigorous protagonist in predicting sites for surface irrigation assessment. Morphometric analysis is the measurement and mathematical examination of the arrangement of the earth's surface, shape, and dimension of its landform. The present study analyzed the morphometric parameters (liner, areal, and relief parameters) of the Gilgel Gibe watershed for surface irrigation assessment using GIS and remote sensing. DEM with a 30-meter spatial resolution of the study area was used for the morphometric parameters analysis. The results revealed that the stream orders of the watershed vary from first order to fifth order with a total of 1961 stream numbers measuring a total length of 1741.95kms. The analyzed areal aspects such as circularity ratio, elongation ratio, and form factor show the shape of the watershed is elongated, contains moderate value of bifurcation ratio, low value of drainage density, low stream frequency, generated slopes map shows larger areas of this watershed near flat. Overall, the morphometric analysis reflects that the watershed is favorable for surface irrigation development and it can benefit the local community to meet the food demand. Based on evaluated compound values of all morphometric parameters those sub-watersheds are ranked from 1st to 7th. By considering those ranks of all sub-watersheds, priority for suitability was given. SW-1 and SW-5 are classified under high-priority classes. Whereas SW-2, SW-3, SW-4, SW-6 and SW-7 are under medium priority classes. For a more proper evaluation of the watershed for surface irrigation development, further investigation on the physical land suitability analysis of the watershed is needed.

Keywords: Arc GIS, DEM, irrigation Assessment, and Morphometric analysis.

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ACRONYMS

B _h	Basin relief
D _d	Drainage Density
DEM	Digital Elevation Model
D _t	Drainage texture ratio
FAO	Food and Agricultural Organization
F _s	Stream frequency
GIS	Geographical Information System
GPS	Global Positioning System
L _{sm}	Mean Stream Length
Lu	Total length of stream order
NASA	National Aeronautics and Space Administration
NMSA	National Metrological Service Agency
N _u	Total number of stream segments of order u
MWIE	Ministry of water, irrigation, and energy
R _b	Bifurcation ratio
R _{bm}	Mean Bifurcation ratio
R _c	Circulatory Ratio
R _e	Elongation Ratio
R _h	Relief ratio
R _n	Ruggedness number
RS	Remote Sensing
UTM	Universal Transverse Mercator Coordinate System

CHAPTER ONE

1. INTRODUCTION

1.1 Background

The majority of the Ethiopian nation's agriculture is rain-fed, which makes it extremely susceptible to fluctuations in rainfall and unpredictability (Teklewold, *et al.*, 2019). As a result, there have been numerous crop failures and droughts, which have had a detrimental impact on the nation's agricultural production and food supply for the rapidly expanding population. Due to Ethiopia's arid regions' heavy reliance on rain-fed agriculture and its unpredictable rainfall patterns, alternate strategies are needed to raise agricultural productivity and output. These can be accomplished by developing surface irrigation to its full potential (Gidey, 2020). In Ethiopia, growing crops more than once a year through irrigation is a fundamental tactic to reduce poverty and, ultimately, provide food security by mitigating the impact of unpredictable and variable rainfall. Because of this, to achieve the goal of increasing irrigation efficiency and effectiveness while utilizing additional water and land resources for irrigation, a decision support system must be in place. In this sense, integrating spatially complicated attributes for land suitability analysis is made easy and powerful by GIS and remote sensing.

The Application of remote sensing provides a reliable source for the preparation of various thematic layers for morphometric analysis. The digital elevation data is used for generating the elevation model of a landscape to any extent. The resolution of the image may vary concerning the satellite sensors. The processed Digital Elevation Model (DEM) is used for generating the stream network and other supporting layers (Magesh *et al.*, 2019). Geographical information systems (GIS) have been used for assessing various basin parameters, providing a flexible environment and a powerful tool for the determination, interpretation, and analysis of spatial information related to river basins. Geology, relief, and climate are the primary determinants of a running water ecosystem functioning at the basin scale. A detailed study of morphometric analysis of a basin is a great help in understanding the influence of drainage morphometrics on landforms and their characteristics (Wilson *et al.*, 2019).

The Gilgel Gibe watershed is part of the Omo-Gibe basin located in southwestern Ethiopia. In this Basin, a 175,000-hectare area of land is being developed for agricultural purposes in the lower

course of the Omo-Gibe River to produce sugarcane(Sisay *et al.*, 2022). The potential irrigable land area in the Gilgel Gibe watershed is 249,165 ha or 75.52% of the total area(Akalu, 2022).

Knowledge of watershed management can be obtained from the morphometry of a basin's response to a specific hydrology, especially in river basins where agriculture is the main activity. Indicators of drainage morphometric factors are crucial for comprehending the morphological and hydrological features of any area. Using GIS and its morphometric analysis methodology to create and view the net result of morphometric parameters turns out to be a useful approach. The morphometric parameters are analyzed using remote sensing and GIS.

An essential component of characterizing river basins is the quantitative description of the drainage system that is provided by morphometric analysis. The physiographic features of a drainage basin, including its size, form, slope, drainage density, contributors' length and size, and others, are connected with a variety of hydrological phenomena. The measurement and mathematical analysis of the landforms' dimensions, shapes, and structure on Earth is called morphometrics.(Kuntamalla *et al.*, 2018). The morphometric analysis of the study consists of three parts. These three types of aspects include relief, areal, and linear. The analysis of the watershed's morphometry is crucial for the assessment of surface irrigation. Consequently, the goal of this study is to use GIS and remote sensing technology to prioritize sub-watersheds based on the analysis of each watershed's morphometrical quantities. Based on the compound values calculated from all of the morphometrical parameters of each sub-watershed that were evaluated, a priority map for sub-watersheds was created. With the aforementioned conversation in mind, the goal of this study is to examine the morphometrical elements of surface irrigation evaluation in the context of the Gilgel Gibe watersheds. Using remote sensing and GIS. This research describes the ways to analyze the various morphometric parameters of the Gilgel Gibe watershed by using GIS and a remote sensing environment for the assessment of surface irrigation.

1.2 The statement of problem

The many agricultural practices in Ethiopia in general and in the study area in particular are rain-fed agriculture and seasonal. Rainfall agriculture is a high degree of rainfall variability and unreliability. Irrigation is necessary to minimize the impact of rainfall variability and to increase the number of annual crops, perennial, and commercial crops with controlled regulated water supply throughout the year(Siffan, 2020). Without a doubt, irrigation can sustainably and greatly enhance food production, especially in the less developed parts of Africa. In Ethiopia, irrigation Assessment has not improved for many years due to a lack of attention from the government and different organizations. However, over the past two decades, the government has made significant progress as a result of its focus on the sector. For instance, the country's irrigated land area increased from 176,105 hectares in 1982 to 1.2 million hectares in 2010, of which 490,000 hectares were fully and partially developed with large and medium-sized irrigation systems, and the remaining portion was not being used to its full potential. This represents less than 8% of the 15 million hectares of irrigated land that have been irrigated so far and only 20% of the 5.8–7.5 million hectares that are predicted to be irrigated. Although this is a relatively encouraging Assessment, irrigation Assessment is still very low in terms of the country's water and land Assessment potential(MOWIE, 2021).

Gilgel Gibe is a perennial river; however, surface irrigation is not employed with it. This leads to extremely low agricultural production in this watershed. Because rain-fed agriculture and traditional irrigation systems were the methods used in this area. The primary obstacle to agricultural Assessment in this area is landform conformance is not studied i.e. morphometry of this watershed for doing surface irrigation is not studied. Therefore, this study going to study the morphometry of this study area for assessment of surface irrigation.

1.3 Objectives of the study

1.3.1 General objective

The main objective of this study is to analyze the morphometry of the Gilgel Gibe watershed for surface irrigation Assessment by using GIS and remote sensing.

1.3.2 Specific objective

Based on the general objective, the following specific objectives were proposed which were evaluated and achieved by the research outputs.

- 1) To identify morphometric aspects of Gilgel Gibe for the Assessment of surface irrigation.
- 2) To analyze the morphometry of the Gilgel Gibe watershed for surface irrigation Assessment.
- 3) To prioritize and rank sub-watersheds for surface irrigation Assessment based on analyzed morphometrical parameters.

1.4 Research questions

- 1) What are the morphometric aspects of the Gilgel Gibe watershed that are relevant for the Assessment of surface irrigation?
- 2) How is the morphometry of the Gilgel Gibe watershed for surface irrigation Assessment?
- 3) How can morphometrical parameters be used to prioritize and rank sub-watersheds for surface irrigation Assessment?

1.5 Significance of the study

Ethiopia has abundant potential for irrigation due to its water and land resources. Ethiopia is currently experiencing droughts more regularly as a result of population growth, degrading land, unequal rainfall distribution in space and time, and depletion of water resources. Thus, unless the agricultural production system changes to include both irrigated and rain-fed agriculture, Ethiopia will not be able to continue producing enough food.

Gilgel Gibe is a perennial river, but surface irrigation is not employed with it by using this available water. This shows that agricultural production in this watershed is smaller. The direction of Assessment in the future is largely dependent on how we manage sectors and all other resources. Surface irrigation for agricultural purposes can be developed by planners and decision-makers

using the knowledge of the morphometric analysis within this watershed. The Ethiopian economy is growing as a result of the population's ability to profit or benefit from harvests produced twice or three times a year by using surface irrigation.

1.6 Scope of the study

The study's primary focus was on morphometric analysis of the study area's watershed, which identifies suitable land for surface irrigation Assessment. Therefore, the only morphometric analysis considered in this study were the linear aspects, areal aspect, and relief aspect for surface irrigation Assessment, those three aspects include; stream length ratio, bifurcation ratio, drainage density, stream frequency, elongation ratio, circularity ratio, basin relief, ruggedness number, aspect map, slope map and length of overland flow are studied. Additionally, the watershed boundary was delineated by using ArcGIS. Finally, the suitability rank for all seven watersheds is given.

1.7 Organization of the Thesis

The thesis is divided into five chapters. Chapter 1 is an introduction, discussing the study's area history, the problem of the statement, objectives, research question, scope, and significance of the study. Chapter 2 reviews the literature on the idea of morphometric analysis for surface irrigation Assessment, including earlier research on various regions and the use of GIS. The research methodology was meticulously organized in Chapter 3, which covered the subject regions, data sources, and morphometric parameter computation techniques. The findings and discussion of morphometric analysis, which can be linear, areal, or relief, are presented in Chapter 4. Finally, the conclusions and recommendations are presented in Chapter 5. At the end, the references are listed.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Irrigation

Irrigated agriculture plays a fundamental role as a supplier of food and raw materials. However, it is also the world's largest water user. In recent years, there has been an increase in the number of studies analyzing agricultural irrigation from the perspective of sustainability with a focus on its environmental, economic, and social impacts (Sustainable Irrigation in Agriculture: An Analysis of Global Research). To achieve the goals of the 2030 Agenda which include decreasing poverty, enhancing food and nutrition security, increasing agricultural productivity, bolstering rural livelihoods, and managing land and water resources sustainably significant and responsible public and private investments in irrigation are essential. Investments in agriculture and rural areas have prioritized irrigation and will do so in the future. Several obstacles must be overcome for the irrigation industry to grow, including the effects of climate change, competition for scarce resources, and water scarcity and degradation (Gebul, 2021).

A drainage basin's morphometric study shows the dynamic equilibrium that resulted from the interplay of matter and energy (Thakare, 2021). Despite the efforts made to provide sustainable irrigation Assessment and access to irrigation water, several obstacles continue to impede the schemes' effectiveness and ease of execution.

2.2 Irrigation Potential in Ethiopia

Ethiopia is known for having an abundance of groundwater and surface water resources, which has led to the nickname "the water tower of East Africa." Across Ethiopia's many areas, one can also find a significant number of lakes, dams, and reservoirs. Experts differ in their assessments of Ethiopia's potential for irrigation. Conversely, Ethiopia's enormous potential for water resources is little being utilized for irrigated farming. Moreover, differences in irrigation potentials and irrigated lands, for example, 3.7 million ha and 197,000 ha according to Awulachew research in 2022 (Akalu, 2022a). A recent source claims that between 2011 and 2015, Ethiopia's total irrigated agricultural area increased from 885,000 ha to 2.4 million hectares, to reach 4 million ha by 2020. Nonetheless, by the end of 2019, it is planned to grow the high and medium projects to roughly 954,000 acres.

One way to reduce poverty and encourage economic expansion is through irrigation Assessment. For thousands of years, the Nile Valley in Ethiopia was used for irrigation. Accordingly, traditional irrigation methods using modest river diversion have been practiced for a long time in the nation. The predominant irrigation method in Ethiopia is still basic river diversion(Shitu and Almaw, 2021). The ministry's report states that 466 small, 102 medium, and 9 large irrigation schemes totaling 28,939, 71,924, and 49,675 hectares were created in modern irrigation by the government, non-governmental organizations, and private investors. Most of the food crops in the nation are produced by rain-fed farming. Still, 625,819 hectares of irrigated land were expected to be under cultivation in the nation in 2005–2006, which represents around 18% of its potential(Belachew M, 2022). Ethiopia has an abundance of water resources, with 12 river basins producing 122 billion cubic meters of water in runoff annually and an estimated 2.6 to 2.65 billion cubic meters of potential groundwater(Akalu, 2022b). This information is important because it informs the government and the present study region residents about the previous actions that those same parties took in the same sector. Thus, understanding what has been done in the past, what is being done today, and what the future holds for irrigation developments in Ethiopia in general and in the Gilgel Gibe watershed, in particular, depends on this study's evaluation of the morphometric analysis for surface irrigation.

2.3 Morphometric analysis for surface irrigation Assessment

The morphometric analysis yields useful information pertinent to the ruggedness irrigation potential of the basin, flood, and above all, it provides input for understanding the role of the characteristics of the terrain in the development of the drainage basin. Morphometric is the measurement and mathematical analysis of the configuration of the earth's surface, shape, and dimension of its landforms(Kuntamalla, *et al.*, 2018). There are three components to the morphometric analysis in the study. The parameters of the linear aspects include stream order, stream number, total length streams, mean stream length, bifurcation ratio, mean bifurcation ratio, and stream length. The second component are areal aspect which includes watershed area, perimeter, drainage density, length of overland flow, stream frequency, form factor, circulatory ratio, and elongation ratio and the third component are relief aspect which includes basin relief, ruggedness number, slope map, and aspect map. The three components are listed and discussed below. Even though the growth of surface irrigation depends on watershed analysis, Ethiopia has paid little attention to it and has experienced it without doing a thorough examination of the area's

potential. To develop surface irrigation, the morphometric parameters of the Gilgel Gibe watershed were examined by utilizing RS and GIS tools.

2.3.1 Linear morphometric aspects

The linear aspect is a one-dimensional characteristic of morphometric analysis of a basin. Our analysis accounted for linear parameters which consist of stream order, number of stream order, total stream length, stream length ratio, bifurcation ratio, and mean bifurcation ratio. In a drainage basin, a stream network is a collection of stream segments (Asfaw & Workineh, 2019). The following parameters are some important linear parameters used for the assessment of surface irrigation.

2.3.1.1 Stream orders

Labeling the stream order is the first step in the examination of the morphometric parameters of the watershed. According to (Strahler, 1964) The sequence of streams in the tributary chain of command is stream order. To show the degree of branching in a river system, it is utilized in hydrology and geomorphology (Bogale, 2021). In this study, the stream orders of the watershed are ranked according to Strahler (Strahler, 1964). The first-order stream originates at the stream source and has no tributaries. It is the mainstream source as well as small in number. In linear morphometric analysis, the first stream order is the fundamental parameter. The joining of two first-order segments yields a second-order segment; The joining of two second-order segments yields a third-order segment; The joining of two third-order segments yields fourth order; The joining of two fourth-order segments yields fifth-order segments and the joining of two fifth-order (Strahler, 1964). When a portion of one order is joined by a lower order, there is no rise in order.

2.3.1.2 Stream numbers

Stream number is the total number of different stream order segments. It has an inverse relationship with the stream order (Dwivedi and Tripathi, 2019). The stream number is computed with ArcGIS 10.7. The higher stream order indicates less permeability and infiltration. The effects of increasing stream numbers in surface irrigation Assessment can significantly impact water availability, agricultural productivity, and environmental sustainability. The effects of increasing stream number affect irrigable area expansion. More streams can expand the potential irrigable area. Farmers can access water from additional sources, allowing them to cultivate more land. However, this expansion must be carefully managed to avoid over-extraction and ecological damage. Other

effects of higher stream numbers are the following; Risk of Flooding, and swelling of rivers during wet years due to increased stream numbers can lead to flooding. Excessive water can damage crops, infrastructure, and soil. To mitigate this risk, proper drainage systems and water storage structures are necessary. Crop Productivity; Adequate water supply from multiple streams can enhance crop productivity. Farmers can irrigate larger areas and grow more diverse crops. However, improper management may lead to water wastage or uneven distribution. Environmental Impact; Altering stream patterns affects ecosystems. Increased stream numbers may disrupt habitats, impact aquatic life, and alter sediment transport. Infrastructure Assessment; More streams require additional infrastructure, such as canals, diversion structures, and distribution networks. Investment in well-designed irrigation systems is essential to optimize water use. Climate Change Considerations; Climate change can alter stream patterns, affecting water availability. Incorporating climate projections into irrigation planning is crucial. Adaptation strategies, such as adjusting crop calendars and developing climate-resilient systems, are necessary. Proper environmental assessments and sustainable practices are crucial (Fikadie *et al.*, 2022).

2.3.1.3 Stream lengths

Stream length is another statistic that has a lot of potential for understanding the basin's hydrological characteristics. Generally speaking, longer streams indicate flatter catchments. Typically, a stream segment's cumulative length reaches its maximum in the first order and diminishes as the stream order increases (Bogale, 2021). The computed geometry of GIS tools has been used to measure the total stream lengths of different orders.

2.3.1.4 Total stream length

Total stream length is the summation of all lengths of all stream order. The total length of stream segments decreases as the stream order increases (Gebre *et al.*, 2015). The increase in total stream length plays a significant role in surface irrigation Assessment.

The following points are the role of the impacts of longer stream length on surface irrigation; Favorable surface irrigation conditions: Stream length affects the availability of water for irrigation. Longer streams provide more water resources for agricultural purposes. Increased stream length allows for better distribution of water across fields, enhancing crop growth and yield. Surface irrigation systems benefit from longer streams as they can draw water directly from these sources.

Rainwater Harvesting Potential: Longer streams mean more opportunities for rainwater collection. Surface irrigation relies on capturing and utilizing rainwater efficiently. Increased stream length contributes to better water availability during dry seasons, supporting crop cultivation.

Drainage and Runoff: Longer streams facilitate efficient drainage. Excess water can flow away, preventing waterlogging and soil salinization.

2.3.1.5 Stream Length Ratio

Stream length ratio is the stream's length in one order to its total length in the next lower level. According to the law of stream length, the average length of a stream segment in each subsequent order of a watershed tends to resemble a straight geometric sequence, with the average length of segments in the first order being the first term(Kandekar *et al.*, 2021).

2.3.1.6 Bifurcation ratio

The bifurcation ratio is calculated as the ratio of the number of streams in any two consecutive stream orders. It is a dimensionless morphometric measure in the linear aspect that may be used to analyze the structural control in the geological environment(Mazahir, *et al.*, 2022). A low bifurcation ratio value suggests that the drainage pattern is not impacted by geological formations and structures, whereas a large value of the bifurcation ratio indicates that the geologic structures have an impact on the drainage pattern. Since the patterns are closely related to the topography of the watershed and the climate, it is the fundamental characteristic used to explain the basin's stream patterns. It is a helpful indicator of the basin's form and aids in understanding the watershed's runoff patterns. It also helps identify areas that are prone to folding. A short concentration of time is indicated by a high bifurcation ratio, which also increases the likelihood of folding (Bogale, 2021). Due to random fluctuations in the geometry of the watershed, the bifurcation ratio is not always the same from one order to the next, but it generally remains constant throughout the series. When the drainage pattern of a watershed is not distorted by geologic formations, the bifurcation ratio typically falls between 3 and 5. Under natural conditions, the theoretical minimum feasible value of 2 is rarely approached. The bifurcation ratio varies little from region to region, which is not surprising given that it is a dimensionless characteristic, and drainage systems in homogenous materials typically exhibit geometrical resemblance (Yashas K and Shivakumar, 2019).

2.3.1.7 Mean bifurcation ratio

The mean bifurcation ratio is the average of all bifurcation ratios of all orders. The relatively lower value of mean bifurcation indicates geological heterogeneity, higher permeability, and lesser structural control in the area (Kuntamalla *et al.*, 2018). If the values of mean bifurcation ratio is low it indicates that the drainage system is slope dependent with low water carrying capacity and high water scarcity that affects surface irrigation development(Singh & Singh, 2022).

2.3.2 Areal Morphometric Aspects

It refers to the entire catchment area projected on a horizontal plane that contributes surface flow to the given order's channel section, which includes all tributaries of the least order(Raja & Mathew, 2022). It determines a two-dimensional analysis of the study area such as; drainage density, stream frequency, elongation ratio, form factor, and circularity ratio.

2.3.2.1 Area and Perimeter

To understand how quickly rainwater reaches the desired location, the size of the watershed must be determined. Rainwater will probably reach the main channel more slowly in a larger watershed than in a smaller one (Kandekar *et al.*, 2021). Obtaining the area and perimeter of the watershed are fundamental for computing areal aspects of morphometry.

2.3.2.2 Drainage density

The ratio of the stream's entire length to the contributing area is known as the drainage density. High drainage density, which is often greater than 5 km/km², indicates an exceptionally high stream density and, thus, an excellent response to runoff (Al-Hurban *et al.*, 2021). Drainage density is one of the factors influencing the watershed's hydrological process. Both the duration of concentration and the flow's amplitude may be impacted by drainage density. This is because prolonged periods of concentration provide more chances for infiltration and flow distribution over time.

2.3.2.3 Stream frequency

The ratio of the total number of stream segments in the watershed to the watershed's total area is known as stream frequency(Horton, 1945). For the Assessment of surface irrigation, a higher stream frequency represents greater surface run-off (Journal and Geomatics, 2011). There is a positive correlation between drainage density and stream frequency.

2.3.2.4 Elongation ratio

The ratio of a circle's diameter in the watershed's area to the length of the watershed is called the elongation ratio. The basin's form is shown by the elongation ratio. Due to the short time of concentration, the basin will become more circular and more vulnerable to floods as the Elongation ratio value increases, and vice versa. This affects surface irrigation development. The value of the elongation ratio ranges from 0-1, where a value of near 1 indicates a circular basin and a value near 0 is an elongated basin (Babu, *et al.*, 2016).

2.3.2.5 Circularity ratio

The ratio of the watershed area to the area of a circle whose diameter is equal to the watershed's perimeter is known as the circularity ratio (Farhan *et al.*, 2015). The basin's form is indicated by the circularity ratio value; as the value rises, the basin becomes more rounded and has a higher risk of flooding at the outlet point due to shorter flow durations and may affect surface irrigation. Strongly elongated circularity ratios, ranging from 0.4 to 0.5.

2.3.2.6 Form factor

To understand the drainage basin's flow property, the form factor is crucial. Form factor provides information on a basin's flow strength within a specific area (Jothimani, *et al.*, 2021). It is calculated by dividing the length of the basin squared by its area. The basin is become longer as the form factor value falls. A watershed with a rounded shape and a high form factor value experiences heavy runoff with short concentration times and is more susceptible to flooding, whereas a watershed with a smaller form factor and more elongated shape creates moderate runoff with a long runoff duration. A watershed that is exactly round has a form factor value greater than 0.78. Large form-factor watersheds have enormous peak flows that last for a short while, while tiny form-factor watersheds have modest peak flows that last for a long time (Jothimani, *et al.*, 2021). Which affects surface irrigation development.

2.3.2.7 Length of overland flow

The amount of water flowing across the ground before it condenses into a specific stream is known as the length of the overland flow. The Length of Overland Flow's low value suggests that precipitation may travel a shorter distance before condensing into stream channels (Journal and Geomatics, 2011).

2.3.3 Relief aspects

As (Asfaw & Workineh, 2019) stated relief is a three-dimensional parameter of a drainage basin that is expressed in terms of area, volume, and altitude of watershed landforms. Under this relief aspect, the parameters such as; basin relief, ruggedness number, slope map, and aspects are determined.

2.3.3.1 Basin Relief

The difference in watershed elevation between the highest and lowest places is known as total relief (Gidey *et al.*, 2021). It measures the watershed's total steepness, which reveals the degree of the watershed's effective water flow on its slope.

2.3.3.2 Ruggedness number

Ruggedness number is the output of maximum basin relief and drainage density, where both parameters are in the same unit. Sometimes, both variables are significant, and the slope is steep as well as long, that time ruggedness numbers occur in enormously high values (Devne *et al.*, 2019).

2.3.3.3 Slope map

It is crucial to characterize an area's slope because it influences the balance between the topography's soil infiltration rates and runoff response. Large slope values cause less rainfall infiltration and increased runoff (Ferozur Rahaman, 2017).

2.3.3.4 Aspect map

The aspect map, which shows the direction of the watershed's slope from higher to lower elevation, is crucial for researching how sunlight affects the local climate. The aspect map, which shows the direction of the watershed's slope from higher to lower elevation, is crucial for researching how sunlight affects the local climate. In the afternoon, a west-facing hill tends to be warmer than an east-facing slope (Gidey *et al.*, 2021). The outcome shows a high proportion of slopes facing east. The soil on these slopes is relatively higher.

2.4 GIS application

Tools for organizing and assessing geographically dispersed information will be Geographic Information Systems (Yashas K and Shivakumar, 2019). Data that describe the positions and attributes of spatial features on the surface of the Earth, such as highways, land parcels, and

vegetation stands, are referred to as geographically referenced data. One way that a GIS differs from other information systems is that it can handle and process data that is geographically referenced. The most widely used tool for people to analyze geographic data is a map. Working with geographic data to comprehend slope, morphometric characteristics, land use, land cover, and water bodies is the main purpose of a GIS. As an assortment of layers and other components are displayed in a map view, the map depicts geographic information. A typical map element consists of a data frame with map layers for a specific extent along with a title, north arrow, scale bar, descriptive text, and symbol.

2.5 Watershed delineation

A drainage basin or catchment region that empties into a shared outlet is referred to as a watershed. A specific outlet's watershed is simply described as the area that gathers precipitation and drains it to a single outflow via gullies. Determining a watershed's perimeter, or ridgeline, is the first step in its delineation. The Arc Hydro tools, which are a component of the Arc Hydro Add-on toolbar, produce several datasets that together characterize a catchment's drainage pattern. For their needs, most watershed managers rely more on this service than on other sophisticated hydrologic evaluations. The first phase in creating data is a raster analysis, which is followed by the definition, accumulation, and segmentation of streams, as well as the delineation of watersheds (Baye, 2020).

2.6 Digital elevation model

DEMs are digital computer files that contain point elevation data. The point elevation or z variables and the x, and y grid positions make up these data. They are produced in several methods at various map scales or resolutions. The US Geological Survey (USGS) distributes elevation data from the Shuttle Radar Topographic Mission (SRTM) in an agreement with the National Aeronautics and Space Administration (NASA) and the Department of Defense's National Geospatial-Intelligence Agency (NGA). Digital Elevation Models are a well-liked digital elevation source that is essential for characterizing watersheds (DEM). DEM data with resolutions of 90m, 30m, and 10m are provided by numerous agencies. As a GIS input, the point elevation values are quite helpful. In the process of delineating watersheds, this data is utilized to produce significant derivative products such as slope, aspect, flow accumulation, flow direction, and curvature.

2.7 Sub-watershed ranking and prioritization-based morphometric analysis.

The process of prioritizing a watershed involves arranging its sub-watersheds in order of suitability for surface irrigation Assessment. Geographic Information Systems (GIS) can be used to measure the linear, areal, and relief features of basins to do this analysis. Nowadays, GIS techniques are employed to evaluate different topography and morphometric aspects of the drainage basins since they offer a powerful tool for manipulating spatial information in a flexible setting (Mazahir *et al.*, 2022). The most effective way to plan for watershed management is through a quantitative morphometric characterization of a drainage basin, which allows the user to assess various drainage basins developed in different geologic and climatic regimes and comprehend the relationships between various drainage basin aspects (Elias, 2019). To be more precise, the results of the morphometric study provide important information on the basin's capacity for flooding, irrigation, and ruggedness. Most importantly, though, the information helps to clarify how the terrain's features contribute to the drainage basin's Assessment (Elias, 2019).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Location

The study area is located in the Oromia regional state in the southwest of Ethiopia, upstream of the Omo Gibe basin. It is 260 kilometers from Addis Ababa and 70 kilometers northeast of Jimma. Gilgel Gibe has a 4309.5km² catchment area and is located between 7°19'07" and 8°12'09" North latitudes and 36°31'42" and 37°25'16" East longitudes. Along with having an average annual rainfall of 1550 mm and an average temperature of 19 °C, it is also known for its rainy climate. The catchment's terrain is diverse, with flat terraces encircling the Gilgel Gibe River in the middle of the catchment and upper plateaus sliced by profound V-shaped valleys on the flanks. The inter-tropical convergence zone (ITCZ) influences the seasonal rainfall distribution, which follows a unimodal pattern with a summer maximum and a winter minimum. The Gilgel Gibe hydropower reservoir is the catchment's outlet for this study.

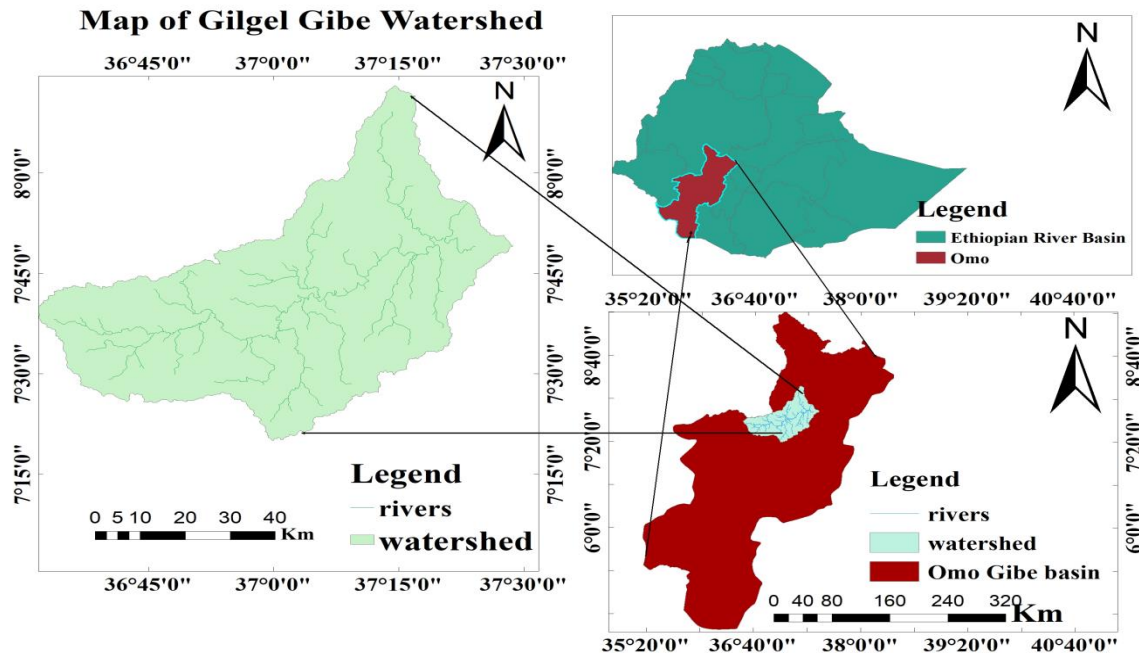


Figure 1 Gilgel Gibe watershed

3.1.2 Topography

The Gilgel Gibe watershed has a topographic variety, with an altitude range of 1414 m to 3359 m a.m.s.l. Naturally, most of the study area topography possesses an undulating nature of the terrain (MAMUD). The rainfall and temperature vary spatially due to the undulating topography of the watershed (Sisay *et al.*, 2022). Gilgel Gibe watershed has uneven topography, characterized by rapid topographical variations. Therefore, the possible spatial variation of coefficient of variation (CV) is attributed to the variation of topography.

3.1.3 Agriculture

An Agro-ecological zone is a kind of land that combines information on abiotic and biotic characteristics of physiography, soils, plants, animals, and human activity with a climate that makes it suited for a variety of crops (Mereta *et al.*, 2023). Ethiopian agroecology is categorized as Wurch, Dega, Weina-Dega, Kolla, and Bereha according to the MoA (2000) categorization (Tessema & Simane, 2019). In the area, crops and cattle are produced on a subsistence basis through agriculture. The land is moderate to intensely farmed due to the pressure of a growing population. Rain-fed cereal crop production is the watershed's most well-known feature. Seldom, wheat, maize, teff, sorghum, and to a lesser extent, oil crops are among the main crop types farmed in the region. Several farmers in this area continue to use perennial rivers and springs for traditional irrigation projects. The four agro-ecological zones of the study area as drawn in the figure below

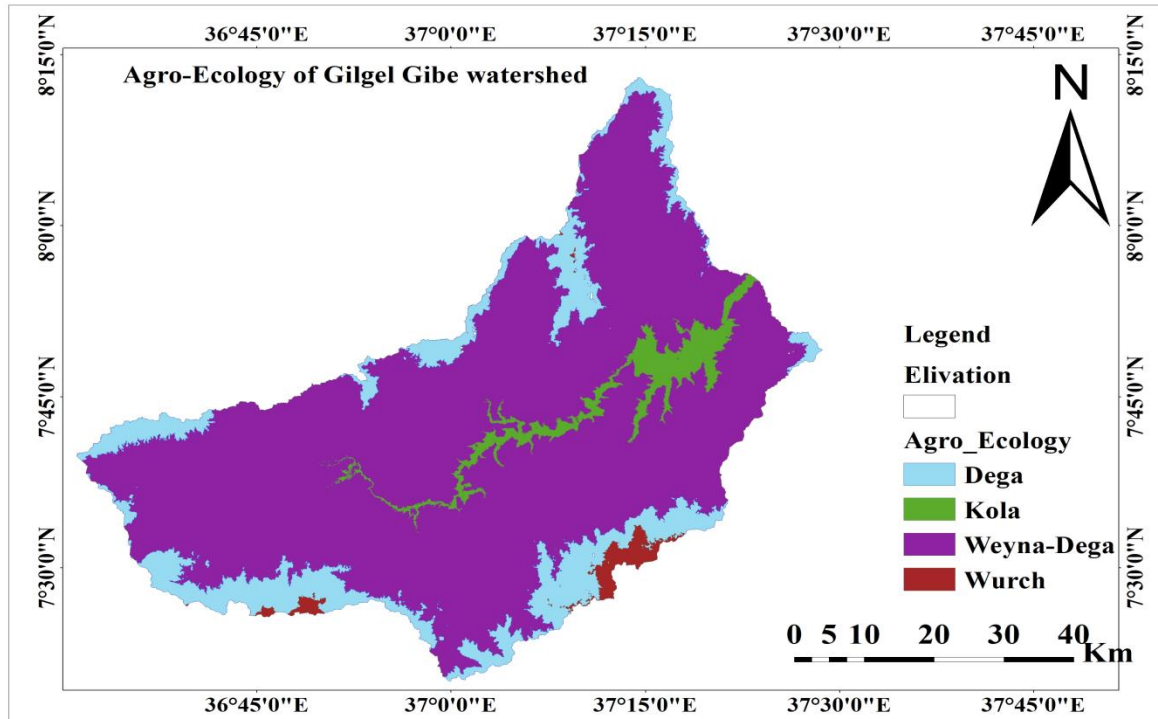


Figure 2 Argo-ecological map of the study area

3.2 Data and software used

The morphometric study of the Gilgel Gibe watershed served as the foundation for this thesis's Assessment of surface irrigation. The data collection processes used in this research are secondary data. The downloaded digital elevation (DEM) data is the important data which is used for this research is downloaded from internet. that come from recorded sources such as the internet, libraries, downloading Digital Elevation Models, and Google Earth. The morphometric parameters were evaluated using DEM data with a resolution of 30 by 30 meters. Dendritic stream pattern digitization was done in a GIS system. Using Strahler's law, the stream order was determined after an analysis of the basin's stream network. Arc GIS software was used to define the boundaries for this watershed. The sub-watershed is characterized by its inlet and outlet. The tools Arc Hydro and GIS Version 10.7 were utilized to create, manage, and generate various layers and maps. For the mathematical calculations, Microsoft Excel was utilized. The software and data listed below were employed in this study.

3.2.1 Digital Elevation Model (DEM)

The digital elevation model (DEM) was one of the crucial inputs needed for the GIS to identify the research area. In remote sensing, one important use of data fusion is DEM fusion. It produces an elevation dataset that is more comprehensive, accurate, and dependable by utilizing the complementing qualities of multiple DEMs (Okolie and Smit, 2022). The primary resources for depicting the surface of the globe are digital elevation models (DEM). Generating digital elevation models (DEMs) with comparatively high levels of accuracy remains a crucial concern (Alahmadi, 2019). The data for this study were obtained from the internet [w.w.w.hydrosheds.org](http://www.hydrosheds.org). using the 30 x 30m shuttle radar topographic mission (STRM) digital elevation model. ArcGIS uses this data as input to create a slope map that can be reclassified as one of the irrigation suitability variables.

3.2.2 GIS (Geographical Information System)

A geographic information system is dedicated to managing, organizing, displaying, and interpreting geographical data. GIS is used to prove a viable method of characterizing the morphometrical behavior of the watershed and also well observed that remote sensing satellite data is emerging as the most effective, time-saving, and accurate technique (Kumar and Chaudhary, 2016). To prepare and visualize input and output, as well as to interact with models, GIS has become an increasingly useful tool for handling both spatial and non-spatial georeferenced data. GIS is a crucial tool to assess a basin's irrigation potential while evaluating its morphometry and it can extract information about spatially distributed phenomena more effectively. Gaining knowledge about a location, making the right decisions, and getting ready for unforeseen circumstances can all be facilitated by this geographical information system. This tool is most typically used for efficiently analyzing geographic data, including mapping the locations of items, mapping the highest and lowest values, as well as the density, for Morphometric analysis to find a good location for surface irrigation Assessment. The three Morphometric aspects; are linear, such as stream order, number of streams, the total length of streams, bifurcation ratio, and areal aspects, such as drainage density, circularity ratio, elongation ratio, form factor, texture ratio, and relief aspects such as; basin relief, aspect map, slope map, and ruggedness numbers are generated and computed by using this tool. In the end, the sub-watershed prioritization and ranks are done by the Arc-GIS tool.

3.2.3 Remote Sensing (RS)

By using remote sensing techniques to monitor irrigated areas, water managers can gain a more dynamic understanding of a watershed (Garrido-Rubio *et al.*, 2019). These performance indicators were derived using field observed data and data from remote sensing (Nikam *et al.*, 2020). When compared to traditional statistical surveys, which may involve aerial photography over large regions, remote sensing lowers the cost and time associated with acquiring datasets. Thus, in developing countries where funding for data collection is few, GIS and remote sensing technologies have become essential. Furthermore, rather than providing only totals inside arbitrary administrative divisions, remote sensing provides meaningful geographical information on the precise locations of irrigated watersheds (Bwambale *et al.*, 2022).

3.3 General watershed delineation

Watershed delineation is the first step in determining the boundaries of a watershed. In general, watershed delineation can be done manually or automatically. For this research, I have used automatic watershed delineation. Methods for automatically delineating watersheds were also referred to as grid-based or DEM-based approaches. The Automatic watershed delineation automatically generates GIS layers needed to set up a model where water flows downward and when computer-generated boundaries are used. The drainage area needed to establish a stream's beginning, as well as the size and quantity of sub-watersheds, are determined by the stream definition. To indicate preferred outlet locations for the delineation of sub-watersheds, it is also possible to manually amend the watersheds' output. Reports on watershed study and characterization made use of the sub-watersheds. Therefore, ArcGIS was used to perform this research utilizing the automatic watershed delineation approach. Moreover, ArcGIS was used to obtain other hydrological parameters in the GIS, such as fill operation, which is used to identify and fill sinks in the DEM; calculation and creation of the flow direction map; calculation and creation of the flow accumulation map; creation of the stream network map from the flow accumulation grid; and creation of the stream order raster from the stream network raster map. In watershed delineation, the digital elevation model (DEM) with a 30-meter pixel size, which provides topographic information about the watershed, was used. The projection was verified by setting the DEM parameters to Adindan UTM zone 37N projection and WGS 1984 datum (Baye, 2020).

3.3.1 Sub-watershed classification

The Arc Hydro Tools 10.7 Extension's automated delineation feature was used to define the sub-watersheds within the study area. For the delineation methods, a patched DEM made from a 30 x 30 m ASTER DEM was utilized. Any internal drainage areas are filled in to produce an elevation grid without depressions. Flow direction and flow accumulation were created from a filled DEM. Seven sub-watersheds were identified based on an iterative method to determine the optimal stream threshold value, as depicted in below figure 3.

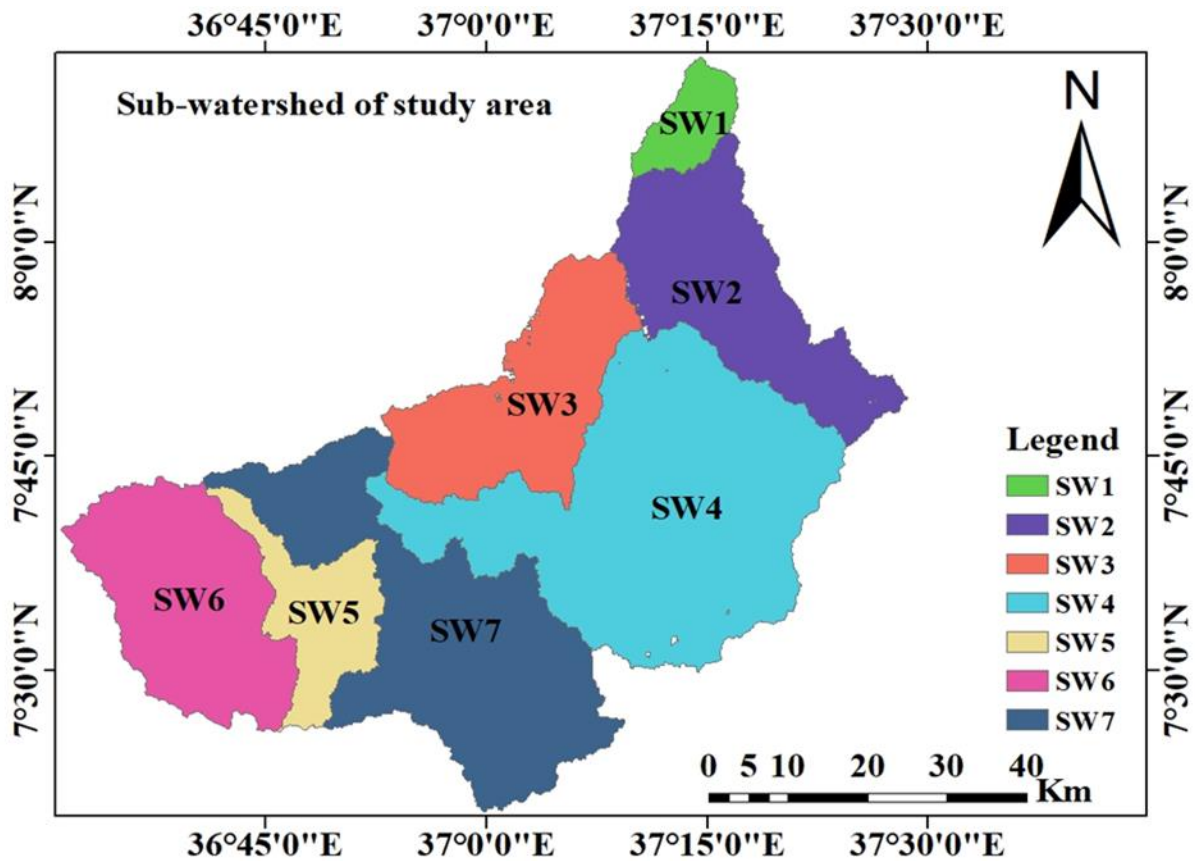


Figure 3 Sub-watershed of study area

3.4 Identifying the morphometric parameter

Morphometric parameters have three basic aspects. Those are linear aspects, areal aspects, and relief aspects. Under those three aspects, different parameters are identified. The Morphometric parameters of the watershed can be useful in combining its hydrological behavior and water balance because they are largely reflective of its hydrological response (Gebre *et al.*, 2015).

Landform dimensions and shapes can be measured and analyzed using Morphometric analysis. Morphometric analysis is carried out by identifying and computing drainage basin shape, derived, and basic parameters using Arc-GIS tools, DEMs, and mathematical equations.

By using geographical information systems (GIS) and remote sensing (RS), Morphometrical parameters are identified for the physiographic status of the sub-watershed. A drainage property linear, areal, and relief features can utilize Morphometric analysis of the basin. (Mani, *et al.*, 2022). Stream order, stream number, stream length, basin area, basin perimeter, and basin length are the basic parameters for analyzing Morphometric parameters. Total stream length (Lu), mean stream length (Lsm), stream length ratio (Rl), bifurcation ratio (Rb), and mean bifurcation ratio (Rbm) are further divisions of linear aspect. Drainage density (Dd), drainage texture ratio (Dt), stream frequency (Fs), form factor (Rf), circularity ratio (Rc), elongation ratio (Re), and length overland flow (Lof) are analyzed under aerial aspects. Finally, the relief aspect is broken down into four categories. Those are total relief (Rr), ruggedness number (Rn), slope map, and aspect map. The table below provides a detailed discussion of the formula used to compute those Morphometric parameters. After a thorough review of the literature, expert knowledge integration, and data availability assessment, a subset of 18 parameters is selected. These parameters are carefully chosen based on their relevance, effectiveness, and ability to capture the characteristics and process the sub-watersheds under consideration. These 18 parameters are determined using a variety of empirical methods, as illustrated in the Table below. The rank of each parameter in each watershed is determined after all Morphometric values for individual sub-watersheds have been calculated. The overall Morphometric parameters, generated and computed in the research are listed in the below table.

3.4.1 Linear morphometric parameters

Linear Morphometric parameters represent information about one-dimensional Morphometric parameters, including mean bifurcation ratio, stream order, number, and length (Singh 2022). It displays the drainage system's channel layouts and stream segments' topological features. A drainage basin's linear features show spatiotemporal fluctuations, which affect the basin's hydrological behavior (Vineethkumar, 2022).

3.4.2 Areal morphometric parameters

Areal parameters are focused on two-dimensional quantitative Morphometric metrics, including drainage texture, elongation ratio, circularity ratio, drainage density, stream frequency, form factor, basin area and shape, and more. These variables are largely influenced by the lithology and hydro-geomorphic characteristics of the basins and are related to overland flow in various stream orders (Singh, 2022). A basin's area refers to a horizontal plane that is surrounded by water, separated by ridgelines, and contains streams of all basin orders that flow to a single outlet. Areal aspect parameters describe the watershed's shape.

3.4.3 Relief morphometric parameters

Relief is an important aspect of any drainage system. It denotes the difference of elevation between the lowest and highest point in any region. It represents three-dimensional Morphometric parameters like basin relief, ruggedness number, slope map, and aspect map.

3.5 Analysis of Morphometric parameters

The analysis of all morphometric parameters can be based on the identified morphometric aspects. Firstly, analysis of linear morphometric parameters the stream number, total and mean stream length, bifurcation ratio, and its mean bifurcation ratio of all sub-watersheds are identified. Secondly for analysis of areal parameters, stream frequency, drainage density, drainage texture ratio, circularity ratio, elongation ratio, form factor, and length of overland flow of all sub-watersheds are identified. Thirdly for analysis of relief morphometric parameters, basin relief, slope map, aspect map, and ruggedness number of all sub-watersheds are identified. Finally based on the analyzed parameters the suitability of all watersheds for surface irrigation Assessment is put under each parameter. All analyzed morphometrical parameters are listed in Table 3.1.

Table 3. 1 All morphometric parameters with their formulas

Morphometric Parameter	Methods /Formulas	References
Linear morphometric parameters		
Stream Order (U)	Hierarchical rank	Strahler, 1964
Stream number	Computed by Arc-GIS	
Total Stream Length (L _u)	$L_u = L_1 + L_2 + \dots + L_n$	Horton, 1945
Mean Stream Length (L _{sm})	$L_{sm} = L_u / N_u$	(Strahler, 196)
Stream Length ratio	$R_l = L_{u-1} / L_u$	(Strahler, 196)
Bifurcation ratio (R _b)	$R_b = N_u / N_{u+1}$	Schumm 1956
Mean Bifurcation ratio (R _{bm})	The average bifurcation ratio of all orders	Strahler, 1964
Areal morphometric parameters		
Drainage Density (D _d)	$D_d = L_u / A$	Horton, 1945
Stream Frequency (F _s)	$F_s = N_u / A$	Horton, 1945
Drainage texture ratio (D _t)	$D_t = N_u / P$	Smith, 1950
Form Factor (R _f)	$R_f = A / (L_b)^2$	Horton, 1945
Circulatory Ratio (R _c)	$R_c = 4\pi A / P^2$	Miller, 1953
Elongation Ratio (R _e)	$R_e = (2/L_b) * (A/\pi)^{0.5}$	Schumm, 1956
Length of Overland flow (L _{of})	$L_{of} = 1 / 2D_d$	Horton, 1945
Relief morphometric parameter		
Basin Relief (B _h)	B _h = Max. - Min. elevation of sub-watershed	Schumm, 1956
Ruggedness number (R _n)	$R_n = (B_h * D_d) / 5280$	Schumm, 1956
Slope map	Generated by GIS	Hart, 1986
Aspect map	Generated by GIS	Schumm, 1956

3.6 Sub-watershed ranking and prioritization according to morphometric Analysis

result

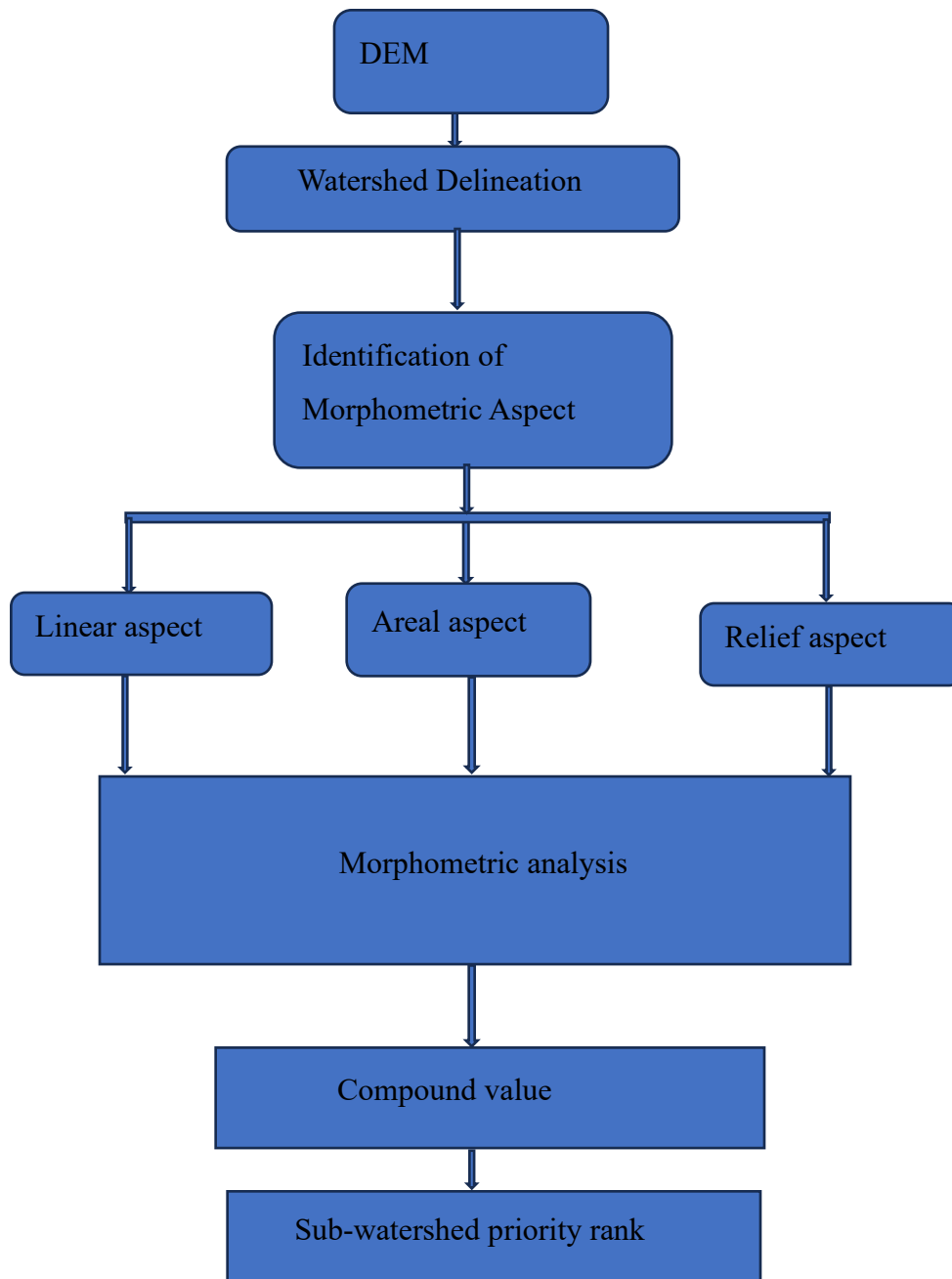
Every Morphometric characteristic is treated as a single parameter in morphometric analysis, and knowledge-based priority ranks are assigned based on the morphometric result and the feature's significance for irrigation Assessment. High values have been given a lot of weight in the linear and relief aspects. Each sub-watershed's highest value of the morphometric parameters Mean

stream length, mean bifurcation ratio, length of overland flow, basin relief, and stream frequency was rated as 1, the next highest value as 2, and so on. Similarly, the aerial aspects were assigned high weightage for high values of form factor, circularity ratio, elongation ratio, and compactness constant. The high value was given a rating of 1, the next high value was given a rating of 2, and so on as the areal aspect parameters generally show positive co-relation with surface irrigation (Das, 2014; Panhalkar *et.al*, 2012).

3.6.1 Determination of compound value and final priority

After assigning ranking based on every single parameter, rated values for each watershed were averaged to arrive at a composite value. Based on the average value of these parameters, the sub-watershed having the high value of composite rating is assigned the highest priority denoted by 1; the sub-watershed with the next highest value of composite rating is assigned a priority denoted by number 2, and so on. The sub-watershed that got the highest value of a composite number is assigned the last priority number. Lastly, the final priority classifications were given into three major classes i.e. High priority, medium priority, and Low priority. The high priority of the sub-watersheds indicates the most suitable areas for surface irrigation (Das, 2014).

Figure 4 Flow Chart showing the framework



CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

4.1 Classification of Sub-watershed and their area coverage

Classification of sub-watersheds for analyzing morphometrical aspects is important. This watershed is classified into seven sub-watersheds. The sub-watersheds total area varies from 113 km² (SW-1) to 1317 km² (SW-4) and perimeters of 52km to 246km. From this delineated sub-watershed SW-4 and SW-7 have covered a large area of this watershed. While SW-1 and SW-5 covered a small portion of these watersheds. The left watershed covers the medium area. In the case of perimeters SW-7 and SW-4 have larger perimeters, while SW-1 is small perimeters from all seven sub-watershed perimeters.

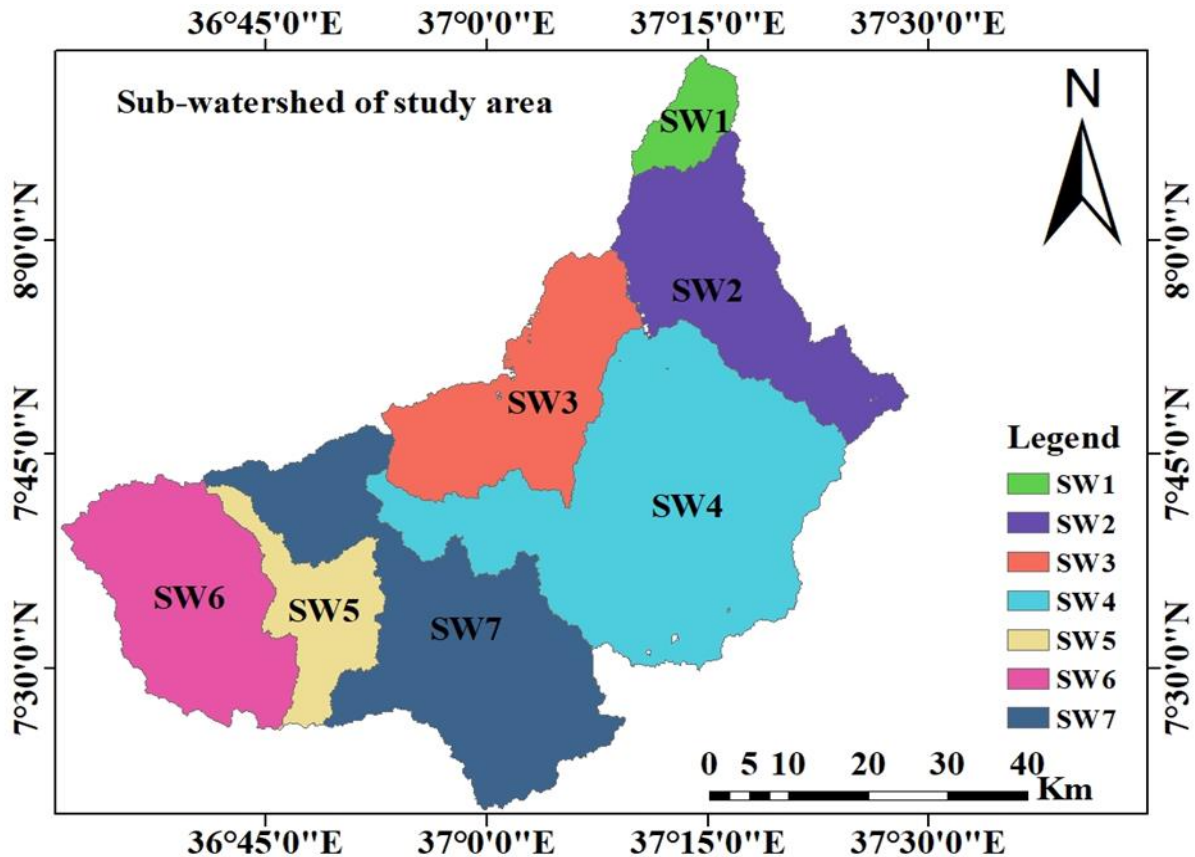


Figure 5 delineated Gilgel Gibe sub-watershed

4.2 Identification of Morphometric Aspects

Morphometric analysis is carried out by measuring and computing drainage basin shape, derived, and basic parameters using GIS tools, DEMs, and mathematical equations created specifically for this purpose. Any watershed's Morphometric parameters are essential for understanding its hydrological response, which indicates the generation of runoff and determines whether or not the land is appropriate for surface irrigation. For this research, the three morphometrical aspects that were identified are the linear, areal, and relief aspects.

4.2.1 Basic parameters

The area (A), perimeter (P), and basin length are the important parameters for determining another parameter. For obtaining area and perimeter, a geometric function of ArcGIS was used. The basin length (L_b) parameter, according to (Patel *et al.*, 2012), is essential for hydrological computation and rises as drainage does as well. It is defined as the distance from the basin divide to the watershed outlet along the main river. Consequently, the principal flow path is used to determine the basin length, which serves as a fundamental input parameter for determining the major form parameters. Using the following formula, the variance in each micro-watershed basin length was determined for this study:

$$L_b = 1.321 \times A^{0.568}$$

Where: L_b = basin length

A = area of basin

For all sub-watersheds obtained area, perimeter, and basin length are listed in table 4.1.

Table 4. 1 Area and perimeter of all sub-watershed

Name	SW-1	SW-2	SW-3	SW-4	SW-5	SW-6	SW-7
Area (Km ²)	113	574	522	1317	261	587	935
Perimeter (Km)	52	161	153	244	124	126	246
Basin Length (Km)	19.4	48.7	46.2	78.1	31.1	49.4	64.3

From this obtained area and perimeters of all sub-watersheds, sub-watershed SW-1 covered a smaller area and it has a smaller perimeter than another sub-watershed. While sub-watershed SW-7 covered a larger area and had a larger perimeter than another sub-watershed. From the calculated basin length SW-4 is longer than another sub-watershed while, SW-1 is shorter in length.

4.2.2 Linear aspect

These parameters provide the flow characteristics and channel network of the watershed, which are essential for designing efficient surface irrigation systems. It expresses one-dimensional features of the study area. Every linear feature found inside a drainage basin, including stream order, stream number, total stream length, mean stream length, stream length ratio, bifurcation ratio, and mean bifurcation ratio is represented by the linear aspect.

4.2.2.1 Stream order

The morphology of a watershed causes the stream order to grow from upstream to downstream, with the main channel through which all discharges, runoff, and sediment pass having the highest order among stream segments (Abdeta *et al.*, 2020). Stream order analysis provides essential information for sustainable water management, efficient planning of surface irrigation, and improving agricultural yield. Higher-stream orders that are closer to the outlet have a more reliable water supply, making them suitable for large-scale irrigation, and lower-stream orders that are near headwaters are less reliable but still contribute to localized irrigation.

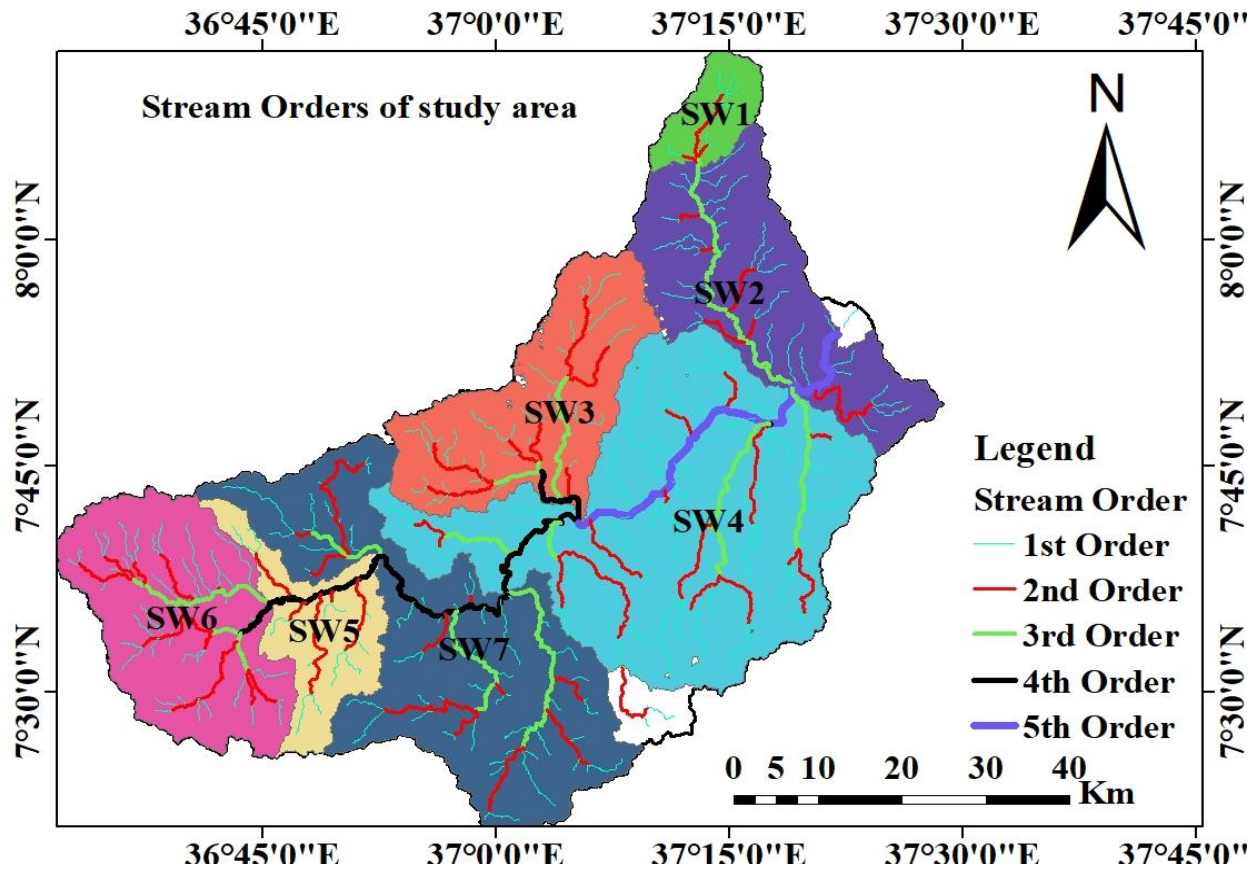


Figure 6. All stream orders for all sub-watershed

By using the Arc-GIS tool five stream orders are identified. Those are 1st order, 2nd order, 3rd order, 4th order, and 5th order.

4.2.2.2 Stream number

Determining stream numbers is essential for optimizing water use, planning infrastructure, and promoting sustainable surface irrigation practices (Dobriyal *et al.*, 2017). As discussed before the effects of increasing stream numbers in surface irrigation Assessment can significantly impact water availability, agricultural productivity, and environmental sustainability. As the number of streams increases, the overall water availability for irrigation also rises. More streams mean a larger catchment area, potentially leading to higher water supply. However, it's essential to consider the dependable flow to minimize flow available during dry periods. Increasing stream numbers may improve dependable flow, ensuring a stable water supply for irrigation.

For this study area, the stream numbers of all sub-watersheds are determined by using the Arc GIS tool and listed in the below table. In summary, while stream numbers are high it can enhance irrigation potential, it must be done thoughtfully, considering ecological balance, flood risk, and long-term sustainability. From Gilgel Gibe watershed 1961 total number of streams were identified, of which SW-4(23.56%), SW-2 (20.40%), SW-7 (17.54%), SW-6 (11.12%), SW-3 (10.25%), SW-5 (9.59%) and SW-1 (7.55%), streams belong to first, second, third, fourth, fifth, and sixth order, respectively. From those SW-4 sub-watershed has higher numbers of streams in this watershed, the SW-2 sub-watershed contains the second highest percentage of stream numbers and SW-7 contains the third-stream number when compared with other sub-watersheds. Those three sub-watersheds are providing more water for this watershed. The other four sub-watersheds have smaller stream numbers and provide less water for this watershed.

Table 4. 2 Stream number and orders of the study area

Sub-Watershed	Stream numbers (Nu) of all order in sub-watershed					
	1 st	2 nd	3 rd	4 th	5 th	Total
SW-1	109	29	10	-	-	148
SW-2	307	73	19	-	1	400
SW-3	149	38	12	1	1	201
SW-4	366	87	6	2	1	462
SW-5	181	5	1	1	-	188
SW-6	166	48	3	1	-	218
SW-7	286	54	3	1	-	344
Total of all stream orders in this study area = 1961						

4.2.2.3 Total length of streams (Lu)

To compute the overall stream length in the watershed Arc-GIS was used. You must add a field and project the feature class first. The length can then be obtained by using the compute geometry function. A stream with a comparatively shorter length is found in places with steeper slopes and finer textures. The identified Gilgel Gibe watershed's total stream length is tabulated in (table 4.4).

Table 4. 3 Total stream length of Gilgel Gibe

Sub-Watershed	Total Stream length (Lu) of all orders in sub-watershed					
	1 st	2 nd	3 rd	4 th	5 th	Total
SW1	15.18	5.50	15.82	2.48	0.31	39.30
SW2	158.70	96.76	1.66	2.53	0.31	259.97
SW3	97.72	92.11	1.85	3.59	2.67	197.93
SW4	408.69	107.68	26.72	10.34	0.49	553.92
SW5	28.41	11.83	0.25	2.60	1.17	44.25
SW6	289.09	30.92	8.77	1.25	0.37	330.40
SW7	209.54	77.26	21.29	7.42	0.67	316.18
Total	1207.33	422.06	76.36	30.21	5.99	1741.95

4.2.2.4 Mean stream length

When identifying possible irrigable land for surface irrigation, one of the drainage morphometric factors that can be used is the mean stream length(Mahala, 2020). The mean stream length is crucial for surface irrigation since it facilitates the identification of potentially irrigable areas.

Table 4. 4 Mean stream length

Sub-Watershed	Mean stream length of all order in sub-watershed					
	1 st	2 nd	3 rd	4 th	5 th	Total
SW1	0.14	0.2	1.76	0.83	1.31	0.27
SW2	0.52	1.36	0.10	0.63	0.31	0.65
SW3	0.66	2.42	0.19	1.20	2.67	0.98
SW4	1.16	1.30	1.41	1.72	0.49	1.20
SW5	0.20	0.37	0.03	1.30	1.17	0.24
SW6	1.80	0.74	0.80	0.42	0.37	1.52
SW7	0.80	1.21	1.64	1.86	0.67	0.92
Total	5.28	7.60	5.93	7.96	6.99	5.78

4.2.2.5 Stream length ration

The stream length ratio is the ratio of the lengths of streams in one order to the total length of streams in the lower order that follows. Generally, it tends to be similar throughout the different

orders (Mahala, 2020). The values of the stream length ratio of Gilgel gibe watershed range from 0.27 to 0.66.

Table 4. 5 Stream length ratio

Sub-Watershed	Stream length ratio of all orders			
	between 1 st & 2 nd	Between 2 nd & 3 rd	between 3 rd & 4 th	between 4 th & 5 th
SW-1	0.26	0.32	0.33	0.33
SW-2	0.23	0.24	0.24	0.25
SW-3	0.26	0.26	0.3	0.33
SW-4	0.24	0.23	0.32	0.17
SW-5	0.22	0.25	0.25	0.5
SW-6	0.26	0.26	0.27	0.33
SW-7	0.24	0.20	0.31	0.25

The overall stream length ratio of the Gilgel Gibe watershed starts with 0.22 to 0.26 from 1st to 2nd order, 0.20 to 0.32 from 2nd to 3rd order, 0.24 to 0.33 from 3rd to 4th order, and 0.17 to 0.5 from 4th to 5th order. This implies that SW-4 has a small stream length ratio which can result in some areas receiving too much water while others receive too little. From those results the stream length ratio between 1st and 2nd order is minimal, reducing available water for surface irrigation. This sub-watershed is more elongated than another order, as seen by the larger stream length ratio between the 4th and 5th order for SW-5. This could result in unequal water distribution during surface irrigation(Mahala, 2020). The shorter stream lengths concerning the drainage area are indicated by the decreased stream length ratio for SW-4 between the 4th and 5th stream orders. The following are some possible effects: -

Reduced Water Distribution Efficiency: Shorter stream lengths may lead to less efficient water distribution across the field, potentially causing uneven irrigation.

Increased Water Loss: With shorter streams, there might be higher water loss due to evaporation and infiltration before the water reaches the end of the field.

Potential for Waterlogging: In some cases, shorter stream lengths can cause water to accumulate in certain areas, leading to waterlogging and negatively affecting crop growth.

Higher Maintenance Requirements: Smaller stream length ratio values might require frequent maintenance to ensure the irrigation system functions properly and distributes water.

4.2.2.6 Bifurcation ratio

The bifurcation ratio is essential for surface irrigation Assessment since it can provide information about a basin's potential for flooding (Mahala, 2020). A basin with a high bifurcation ratio is likely to be mountainous and prone to flooding. In contrast, a basin with a low bifurcation ratio is likely to be flat and less likely to flood which less affects surface irrigation(Bogale, 2021). It can be inferred from certain publications that lower than five can be categorized as low, and more than five as high. The low bifurcation ratio implies the watershed has a regular and dendritic drainage pattern, which is suitable for surface irrigation Assessment.

Table 4. 6 Bifurcation ratio

Sub-Watershed	Bifurcation ratio of all order			
	between 1 st & 2 nd	between 2 nd & 3 rd	between 3 rd & 4 th	between 4 th & 5 th
SW-1	3.82	3.11	3.00	3.00
SW-2	4.32	4.18	4.25	4.00
SW-3	3.92	3.80	3.33	3.00
SW-4	4.25	4.37	3.17	6.00
SW-5	4.53	4.00	4.00	2.00
SW-6	3.83	3.82	3.67	3.00
SW-7	4.09	4.92	3.25	4.00

The result shows that the bifurcation ratio is different for all orders. Geological and lithological Assessment of the drainage basin may be the reason for this variation. Based on this outcome, the only SW-4 bifurcation ratio that is high is between the 4th and 5th stream orders. This suggests that the drainage network is well-developed and that water from upstream sources or rainfall is promptly removed from the basin. As a result, during dry spells, there can be less water available for irrigation. All sub-watershed stream orders have a low bifurcation ratio, though. Shows that certain stream orders' regular, dendritic drainage patterns which are appropriate for surface irrigation are unaffected by the geological structure. However, SW-5's bifurcation ratio between the 4th and 5th order is quite low. This suggests that over an extended length of time, more water is

retained between these orders than another order. Improving groundwater recharge and infiltration, resulting in a more dependable supply of water for irrigation.

4.2.2.7 Mean bifurcation ration

The mean bifurcation ratio (R_{bm}) measures the stream network's degree of distribution (Obeidat & Awawdeh, 2021). The lower the mean bifurcation ratio, the greater the branching in the stream network within a watershed and vice-versa. The mean bifurcation ratio (R_{bm}) value for each sub-watershed and the bifurcation ratio for the different stream orders within each watershed were estimated. Their analysis reveals that the mean bifurcation ratio (R_{bm}) value differs noticeably among the various orders in each watershed, reflecting the variations in local physiography and geological conditions within each watershed. The research area's watersheds have mean bifurcation ratio (R_{bm}) values ranging from 3.23 (for SW-1) to 4.45 (SW-4). For surface irrigation systems, such as basin, furrow, or border irrigation, if the values of mean bifurcation ratios are high it means that there is a higher risk of runoff and potential waterlogging if the system is not designed to handle the increased water flow. This could lead to inefficient irrigation, where water is not evenly distributed or is lost due to runoff, and could also increase the risk of soil erosion. To control excess water and avoid harming crops and soil structure, well-designed drainage systems are crucial in areas with high bifurcation ratios. Further steps that can be taken to lessen the impact of possible flooding on surface irrigation systems include contour plowing, terracing, and the operation of retention basins. Generally, to guarantee that surface irrigation is efficient and sustainable, rigorous planning and management are essential in regions with high mean bifurcation ratios.

Table 4. 7 Results of all mean bifurcation ratios for all sub-watersheds.

Sub-watershed	1st & 2 nd	2nd & 3 rd	3rd & 4 th	4th & 5 th	Mean bifurcation ratio
SW-1	3.82	3.11	3.00	3.00	3.23
SW-2	4.32	4.18	4.25	4.00	4.19
SW-3	3.92	3.80	3.33	3.00	3.51
SW-4	4.25	4.37	3.17	6.00	4.45
SW-5	4.53	4.00	4.00	2.00	3.63
SW-6	3.83	3.82	3.67	3.00	3.58
SW-7	4.09	4.92	3.25	4.00	4.07

4.2.3 Identification of Areal Aspects

The areal aspects of a drainage basin reflect the influence of lithology, geological structure, climatic conditions, and denudation history of the basin(Tukura *et al.*, 2021). In addition, those parameters help in understanding the shape and size of the watershed, which influence the distribution and availability of water resources for irrigation purposes. Under the areal aspect, the following characteristics are taken into account.

4.2.3.1 Drainage density

High drainage density can lead to irrigation system water loss, which can reduce agricultural yields and increase irrigation water requirements. On the other hand, a basin's low drainage density indicates minimal runoff and significant infiltration(Ma, 2019). A high Dd value would be indicative of a fast runoff rate, rapid stream response, and subsequently poor infiltration rate due to a comparatively high density of streams. Conversely, low runoff and high infiltration are implied by a basin's low drainage density (Table 4.10). The amount of vegetation and the soil's capacity to retain rainfall have an impact on the pace of surface runoff, which in turn has an impact on the drainage patterns in a particular location. Generally, drainage density and flood volume are directly correlated. Every sub-watershed has a drainage density that ranges from 0.17 to 0.56.

Table 4. 8 Drainage densities of all sub-watershed

Sub-watershed	Area (km ²)	Total stream length (km)	Drainage densities (km/km ²)
SW1	113.09	39.3	0.35
SW2	573.66	259.97	0.45
SW3	522.00	197.93	0.38
SW4	1316.75	553.92	0.42
SW5	260.71	44.25	0.17
SW6	586.74	330.4	0.56
SW7	934.54	316.18	0.34

4.2.3.2 Stream frequency

Larger sub-watershed regions have lower stream frequencies, which suggests extremely permeable subsurface conditions and a dense canopy of plants(Farhan, 2017). The stream frequency can be

classified as low (0-5), moderate (5-10), moderately high (10-15), high (15-20), and very high (20-25). The computed stream frequency of all sub-watersheds is between 0.35-1.31 (Table 4.11)

Table 4. 9 Stream frequency of all sub-watershed

Sub-watershed	Nu (km)	Area (km ²)	Stream frequency
SW-1	148	113.1	1.31
SW-2	400	573.7	0.70
SW-3	201	522.0	0.39
SW-4	462	1316.8	0.35
SW-5	188	260.7	0.72
SW-6	218	586.7	0.37
SW-7	344	934.5	0.37

4.2.3.3 Drainage texture ratio

A high drainage texture ratio denotes a strong infiltration capability and rapid water absorption by the soil (Mahala, 2020). A low drainage texture ratio indicates that the soil has a low infiltration capacity and cannot absorb water quickly. A low drainage texture ratio suggests that water cannot be readily absorbed by the soil due to its low infiltration capability. This means that to prevent runoff and waterlogging, the irrigation system needs to be built with a reduced water application rate (Karimi *et al.*, 2022). In irrigation systems drainage texture ratio may affect how effectiveness of the system. According to (Devne *et al.*, 2019), there are five classes of drainage texture; very coarse texture (<2), through coarse texture (2-4), moderate texture (4-6), fine texture (6-8), and very fine texture (>8) classes.

Table 4. 10 Drainage texture ratio of all sub-watershed

Sub-watershed	Nu (Km)	Perimeter (Km)	Drainage texture ratio
SW-1	148	52	2.85
SW-2	400	161	2.48
SW-3	201	153	1.31
SW-4	462	244	1.89
SW-5	188	124	1.52
SW-6	218	126	1.73
SW-7	344	246	1.40

From this table SW-3, SW-4, SW-5, SW-6, and SW-7 have a drainage texture ratio of less than 2. This indicates that those five sub-watersheds have very coarse drainage texture and the two sub-watersheds SW-1 and SW-2 have a drainage texture ratio of between 2 and 4 which identifies a through coarse texture.

4.2.3.4 Form factor

The form factor plays a critical role in understanding the flow property of the drainage basin. Form factor gives information on the strength of the flow within a basin in a particular (Jothimani, *et al.*, 2021). The form factor in an irrigation system can affect the system's efficiency. A higher peak flow of shorter duration and a longer elongated watershed is indicated by a high form factor. A low form factor suggests that the watershed is shorter in length and has a longer duration peak flow. This indicates that a higher water application rate for the irrigation system can be planned without resulting in runoff or waterlogging. Large form-factor watersheds have enormous peak flows that last for a short while, and tiny form-factor watersheds have modest peak flows that last for a long time (Jothimani, *et al.*, 2021). A circular basin with a high form factor has a high peak flow and short runoff period, which can result in flooding and water scarcity and hinder the Assessment of irrigation (Elias, 2019).

Table 4. 11 The form factor of all sub-watershed

Sub-watershed	Area (Km)	Basin Length (Km)	(Lb) ²	Form Factor =A/(Lb) ²
SW1	113.1	19.4	376.36	0.301
SW2	573.7	48.7	2371.69	0.242
SW3	522	46.2	2134.44	0.245
SW4	1316.8	78.1	6099.61	0.216
SW5	260.7	31.1	967.21	0.270
SW6	586.7	49.4	2440.36	0.240
SW7	934.5	64.3	4134.49	0.226

From this table, the values of all sub-watersheds are between 0.22 (SW-4) to 0.30 (SW-1), which indicates that low form factor and this study area is elongated in shape. But when we compare those sub-watersheds SW-1 has a higher form factor than other sub-watersheds and is also shorter in length than other sub-watersheds which implies this sub-watershed is less elongated than other sub-watersheds.

4.2.3.5 Circulatory ratio

It is useful for measuring basin shape and varies from zero for elongated and one for circular basins. The circulatory ratio in an irrigation system can impact the system's effectiveness. A higher peak flow with a shorter period is indicative of a longer watershed, as indicated by a high circulatory ratio. A low ratio of circulation suggests that the watershed is shorter in length and has a longer time of peak flow. This indicates that more water can be applied to the irrigation system without resulting in runoff or waterlogging(Tukura *et al.*, 2021). The basin's form is indicated by the circularity ratio value; as the value rises, the basin becomes more rounded and has a higher risk of flooding at the outlet point due to shorter flow duration. Strongly elongated circularity ratios, ranging from 0.4 to 0.5. The circularity ratio for all sub-watersheds is listed in the below table.

Table 4. 12 The circularity ratio of all sub-watershed

Sub-watershed	Area (Km ²)	Perimeter (Km)	P ² (km ²)	Circularity ratio= $4\pi A/P^2$
SW-1	113.1	52	2704	0.525
SW-2	573.7	161	25921	0.278
SW-3	522	153	23409	0.280
SW-4	1316.8	244	59536	0.278
SW-5	260.7	124	15376	0.213
SW-6	586.7	126	15876	0.464
SW-7	934.5	246	60516	0.194

From this table SW-6 and SW-1 have circularity ratio values of between 0.4 and 0.5, therefore, those two sub-watersheds are more strongly elongated than another sub-watershed.

4.2.3.6 Elongation ratio

The effect of the elongation ratio on irrigation Assessment is not straightforward. The long basins with high elongation ratios are more likely to have a higher potential for surface runoff because of their higher runoff coefficient. This may help or hurt irrigation Assessment. Based on the elongation ratio, a watershed can be classified as circular (0.9-1.0), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (<0.5)(Turkey, 2021). As shown in the table below the computed values of the elongation ratio for all sub-watershed is between 0.52 (SW-4) to 0.62 (SW-1). This indicates that this study area is elongated in shape and has permeable subsoil circumstances that can contribute to favorable conditions for surface irrigation.

Table 4. 13 The elongation ratio of all sub-watershed

Sub-watershed	Area (Km)	$\sqrt{(A/\pi)}$	Basin Length (L _b) (Km)	2/L _b	Elongation ratio =(2/L _b) * $\sqrt{(A/\pi)}$
SW1	113.1	6.00	19.4	0.103	0.619
SW2	573.7	13.52	48.7	0.041	0.555
SW3	522	12.89	46.2	0.043	0.558
SW4	1316.8	20.48	78.1	0.026	0.524
SW5	260.7	9.11	31.1	0.064	0.586
SW6	586.7	13.67	49.4	0.040	0.553
SW7	934.5	17.25	64.3	0.031	0.537

4.2.3.7 Length of overland flow

This is the typical amount of time that water flows across the surface of the land before entering a stream. It has an impact on the basin's runoff and infiltration rates. Minimum overland flow length results in minimum runoff and high infiltration rates in the basin, both of which are advantageous for irrigation. This element is largely associated with the length of sheet flow and is inversely related to the average slope of the channel. The faster the surface runoff from the streams, the shorter the overland flow length(Kumar *et al.*, 2022a).

Table 4. 14 Length of overland flow for all sub-watershed

Sub-watershed	Drainage densities (km/km ²)	Length of overland flow=1/(2Dd)
SW-1	0.35	1.43
SW-2	0.45	1.11
SW-3	0.38	1.32
SW-4	0.42	1.19
SW-5	0.17	2.94
SW-6	0.56	0.89
SW-7	0.34	1.47

From this result, the length of overland flow for SW-6 is low when compared with another sub-watershed.

4.2.4 Identification of Relief Aspect

A drainage basin's roughness and surface pattern can be seen by examining its relief or gradient characteristics or relief aspects (Devne *et al.*, 2019). The three-dimensional characteristics of a drainage basin, including the size, volume, and height of its vertical landform dimensions, are associated with its relief aspects. The relief aspect includes basin relief, ruggedness number, slope map, and aspect map. Those parameters provide information about the terrain characteristics, which can affect the design and layout of surface irrigation systems.

4.2.4.1 Basin relief

Basin relief is the difference in watershed elevation between the highest and lowest points (Wagh, 2021). It measures the overall steepness of the watershed and the power of the effective water flow on the slope. Proper basin relief ensures uniform water distribution across the field. It prevents water stagnation in low-lying areas and ensures adequate coverage. The maximum and minimum elevation of the Gilgel Gibe watershed are 3359m and 1414m respectively. The specific basin relief of this watershed is 1945m (1.945km).

Table 4. 15 Basin relief of all sub-watershed

Sub-watershed	Max elevation (m)	Min Elevation (m)	Basin relief (km)
SW1	2784	1981	0.80
SW2	2892	1470	1.42
SW3	2890	1690	1.20
SW4	3210	1640	1.57
SW5	3285	1640	1.65
SW6	3050	1730	1.32
SW7	2994	1688	1.31

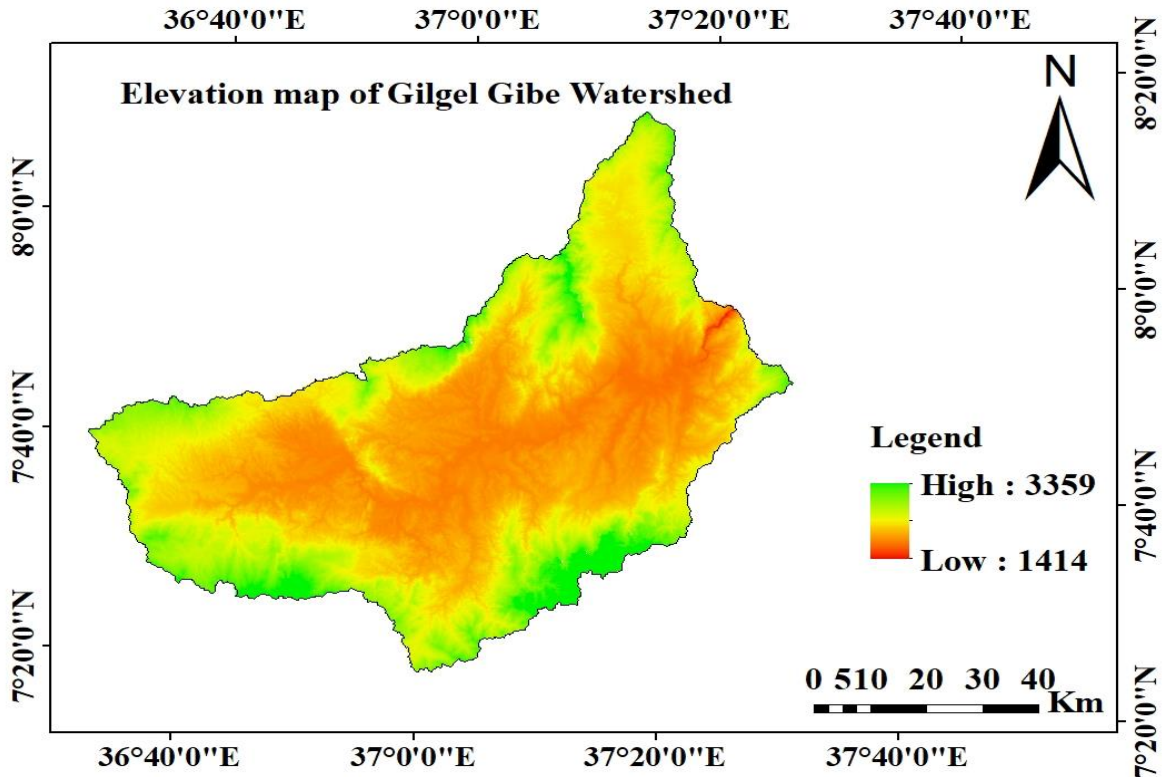


Figure 7 The elevation map of the Study area

4.2.4.2 Ruggedness number

The ruggedness number affects the uniformity of water distribution. A high ruggedness number indicates that the field is more irregular, which can lead to uneven water distribution and lower irrigation efficiency. The identified values of ruggedness number are high for sub-watersheds SW-2, SW-4, and SW-6. However, the values of ruggedness number for other sub-watersheds are low ruggedness number.

Table 4. 16 The ruggedness number of all sub-watershed

Sub-watershed	Basin relief (km)	Drainage densities	Ruggedness number
SW-1	0.80	0.35	0.28
SW-2	1.42	0.45	0.64
SW-3	1.20	0.38	0.46
SW-4	1.57	0.42	0.66
SW-5	1.65	0.17	0.28
SW-6	1.32	0.56	0.74
SW-7	1.31	0.34	0.44

4.2.4.3 Slope map

The slope suitability map was made using the digital elevation model of the research region, which has a river basin resolution of 30 meters. The management of the relationship between runoff response and soil penetration rates in various geographical contexts is contingent upon the slope of a particular location. Reduced rainfall and greater runoff are caused by a high slope value (Ferozur Rahaman, 2017). Based on the percentage of surface irrigation, the study's watershed's slope map was divided into five classes: near-flat (0–3%), gentle (3.1–5%), moderately steep (5.1–8%), high (8.1–16%), and extremely steep (>16%) circumstances (Gidey *et al.*, 2021).

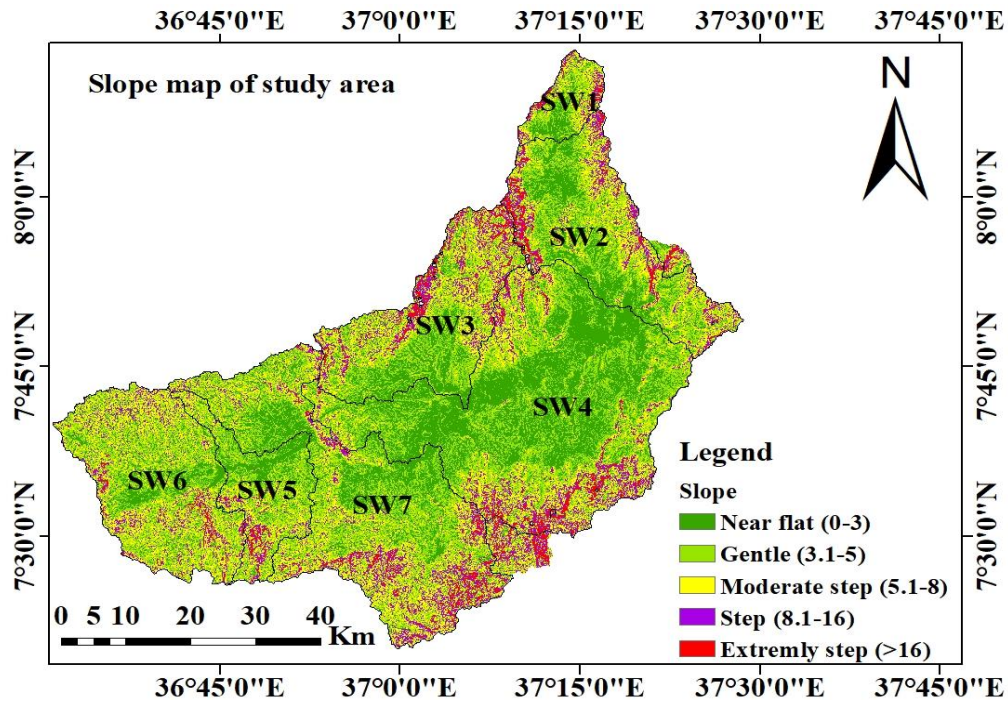


Figure 8 Slope map of Gilgel Gibe watershed

4.2.4.4 Aspect map

The aspect map shows the watershed's slope direction. It is crucial to research how heat or sunlight affects the local climate (Jahan *et al.*, 2018). An aspect map is used to assess how the land's topography affects the effectiveness of surface irrigation systems. The effect of an aspect map is used to determine the optimal location for surface irrigation systems and to design them to maximize their efficiency (Nikam *et al.*, 2020). The Gilgel Gibe watershed's aspect map was generated using DEM data as figure below.

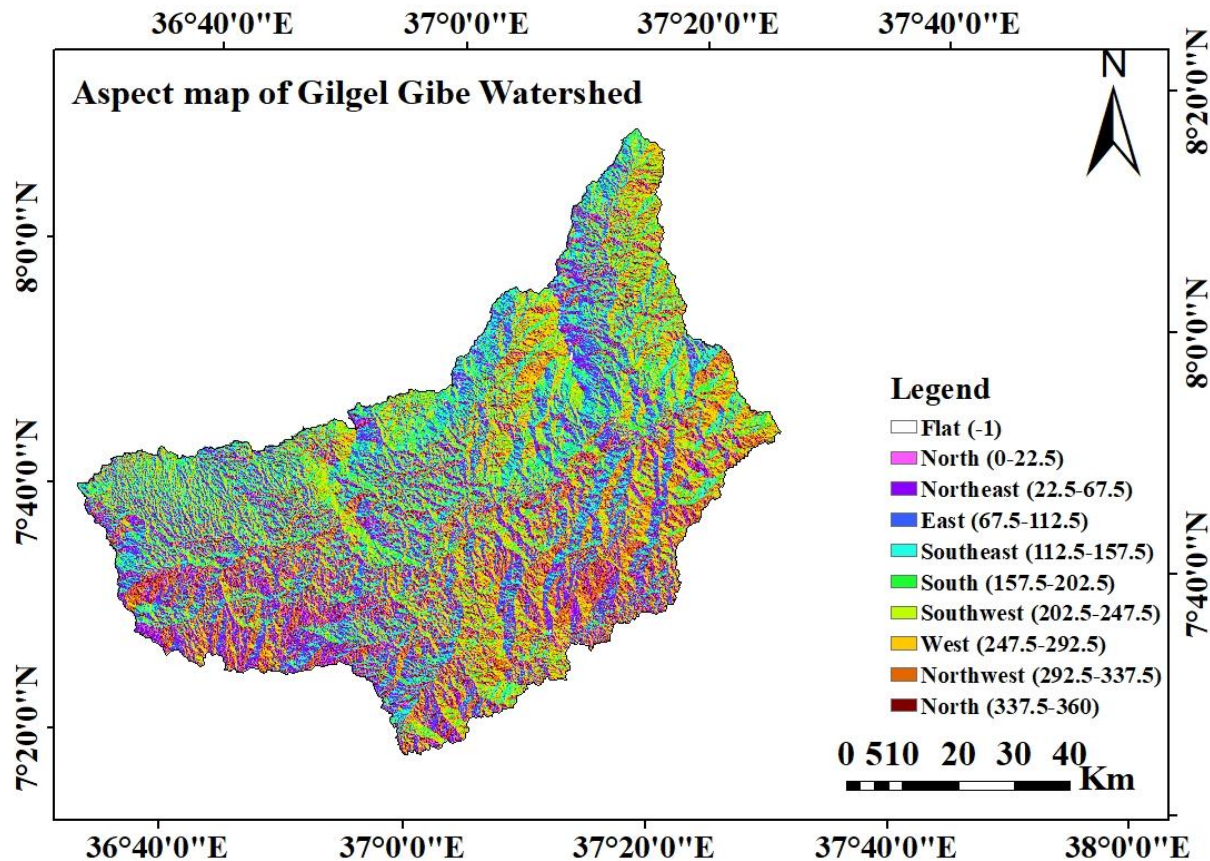


Figure 9 Aspect map of Gilgel Gibe watershed

4.3 Morphometric analysis for the Assessment of surface irrigation

4.3.1 Linear morphometrical analysis

4.3.1.1 Analysis of stream order and stream numbers of all sub-watershed

When analyzing the evolution of surface irrigation in the Gilgel Gibe watershed, numerous morphometric factors are investigated. The examination of stream order is generated by the Arc-GIS program. The total number of streams in the Gilgel Gibe watershed in 1961 was analyzed. Based on the stream order analysis, the first, second-, and third-stream orders are lower, indicating that surface irrigation Assessment may be difficult, particularly in dry weather. The fourth and fifth stream orders are higher, available around the main river, and therefore reliable for surface irrigation Assessment because of their longer water flow and consistent water availability.

Table 4. 17 Analyzed stream numbers of all sub-watershed

Sub-watershed	Total number of streams	Percentage covers (%)
SW-1	148	7.55
SW-2	400	20.40
SW-3	201	10.25
SW-4	462	23.56
SW-5	188	9.59
SW-6	218	11.12
SW-7	344	17.54
Total	1961	100%

As the number of streams increases, the overall water availability for irrigation also rises. More streams mean a larger catchment area, potentially leading to higher water supply.

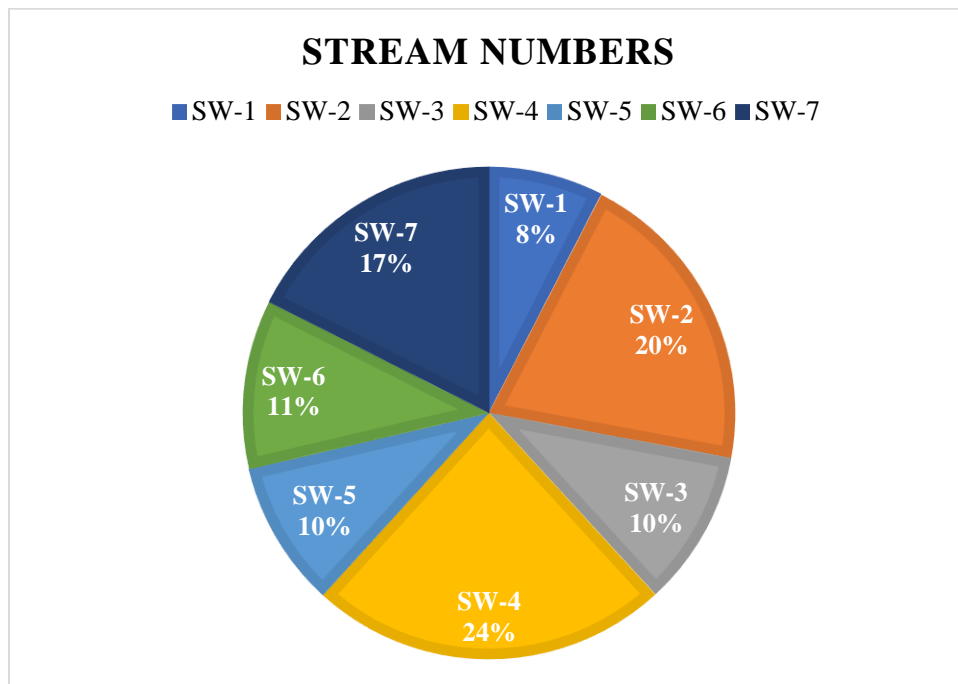


Figure 10 Stream number available in all sub-watershed

From the total of all stream numbers SW-4 sub-watershed has a larger number of streams than other sub-watersheds and SW-1 has a smaller stream number. Generally, when we observe the number of streams available in this watershed, there is sufficient stream number for the Assessment of surface irrigation.

4.3.1.2 Analysis of total stream length

The total stream length for the Assessment of surface irrigation, the stream number, and the total stream length has a direct relationship. The sub-watershed has many streams number have larger total stream length and provides more water for surface irrigation. Conversely, the sub-watershed which has a smaller number of streams has a smaller total stream length and provides a small amount of water for the irrigation Assessment.

Table 4. 18 Analyzed total stream length of all sub-watershed

Sub-Watershed	Total Stream length (Lu) (km)	Percentage (%)
SW1	39.3	2.26
SW2	259.97	14.92
SW3	197.93	11.36
SW4	553.92	31.80
SW5	44.25	2.54
SW6	330.4	18.97
SW7	316.18	18.15
Total	1741.95	100

Graphically the results of all total stream length for all sub-watershed are shown on below figures.

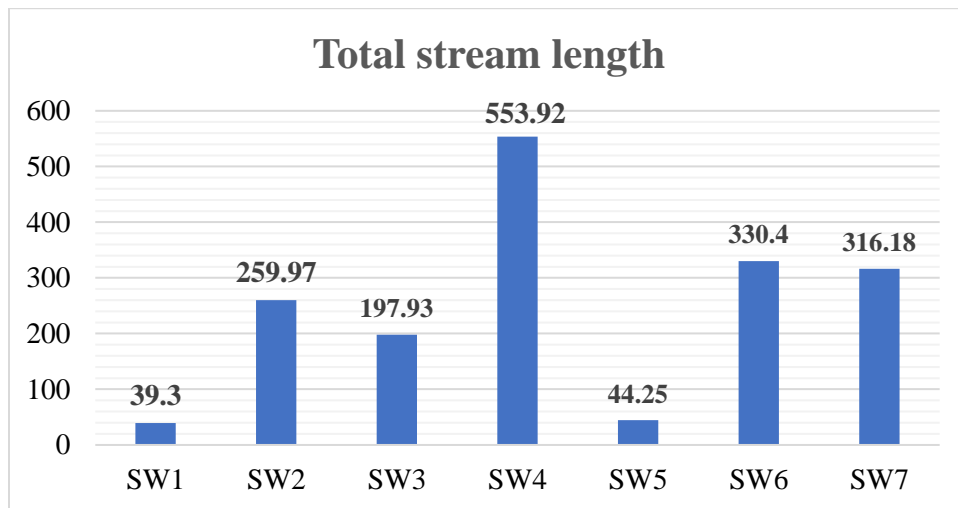


Figure 11 Total stream length of all sub-watershed

The analysis shows that in the case of Gilgel Gibe sub-watersheds SW-4 has larger total stream lengths, and SW-2, SW6, and SW-7 have medium total stream lengths. Those sub-watersheds provide more water for surface irrigation. Conversely, SW-1 and SW-5 have shorter total stream lengths and provide a small amount of water for surface irrigation. When we observe the total stream length of this watershed it is sufficient and good for surface irrigation Assessment.

4.3.1.3 Mean stream length

The analyzed mean stream length of all sub-watersheds are given on below graph.

Table 4. 19 Percentage of total Mean stream length

Sub-Watershed	Total Mean stream length	Percentage (%)
SW1	0.27	4.67
SW2	0.65	11.25
SW3	0.98	16.95
SW4	1.20	20.76
SW5	0.24	4.16
SW6	1.52	26.31
SW7	0.92	15.92
Total	5.78	100.00

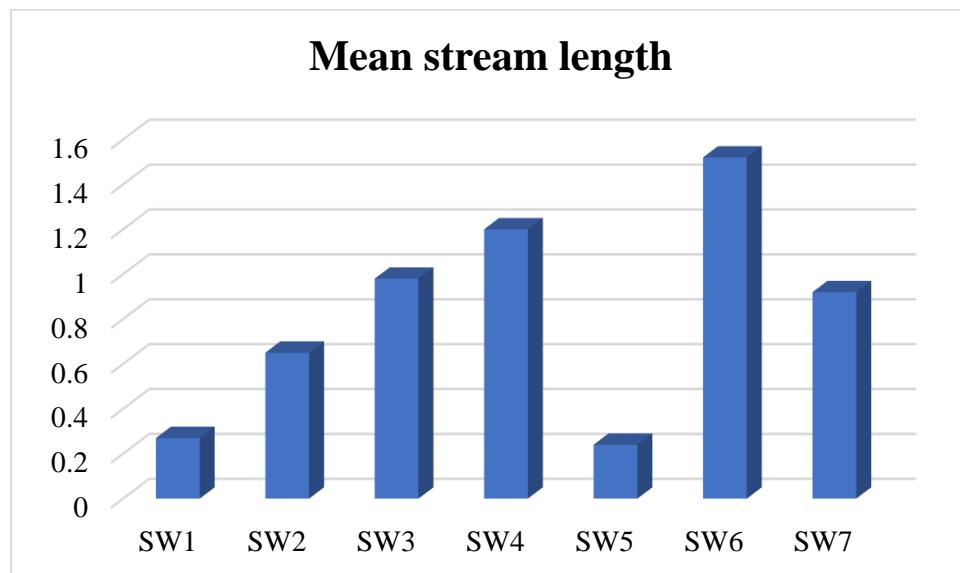


Figure 12 Mean stream lengths of all watershed

From this graph the mean stream length of the study area is more for SW-6 and SW-4, those two provide more water, ensuring better coverage for surface irrigation than other Sub-watershed in this catchment. The mean stream length of SW-5 and SW-1 is minimal therefore affecting water available for irrigation during the dry season.

4.3.1.4 Mean bifurcation ratio

From the results of the bifurcation ratio of all sub-watersheds, only a high bifurcation ratio appears on SW-4 in between stream orders of 4th and 5th therefore there are structural disturbances at this sub-watershed and affects irrigation suitability. But for another sub-watershed, there is a moderate bifurcation ratio for surface irrigation Assessment.

Table 4. 20 Percentages of Mean bifurcation ratio for all sub-watershed

Sub-watershed	Mean bifurcation ratio	Percentage (%)
SW-1	3.23	12.12
SW-2	4.19	15.72
SW-3	3.51	13.20
SW-4	4.45	16.70
SW-5	3.63	13.62
SW-6	3.58	13.43
SW-7	4.07	15.30
Total	26.66	100.00

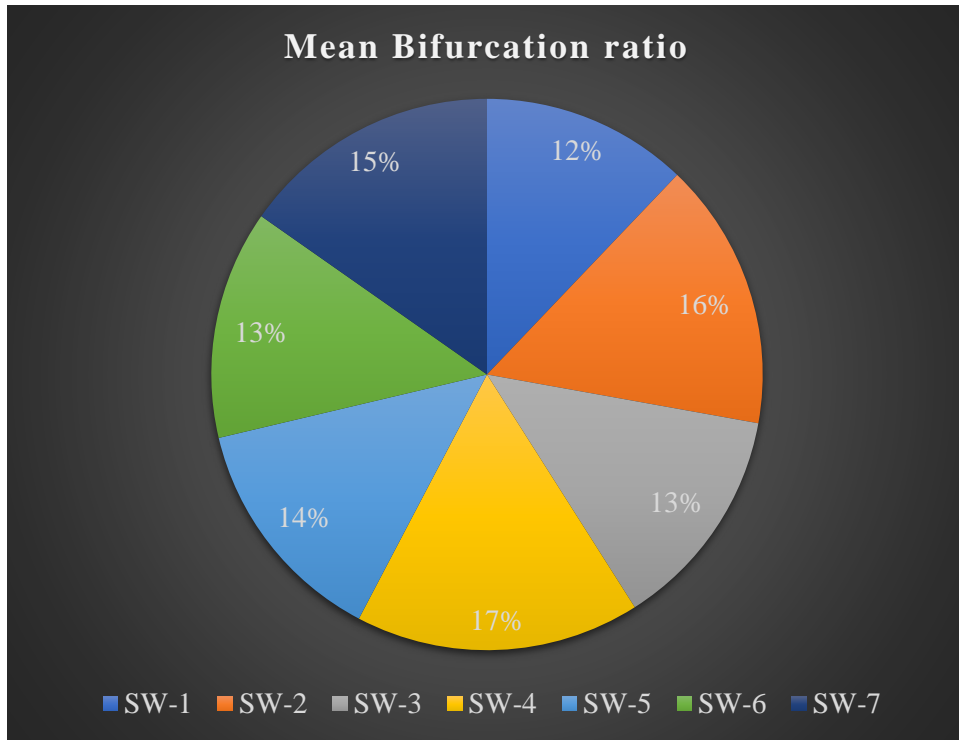


Figure 13 Mean bifurcation ratio of all sub-watershed.

The mean bifurcation ratio of all sub-watersheds is a nearly equal percentage. This indicates this watershed has a moderate mean bifurcation ratio, which expresses the no structural disturbance along these different sub-watersheds.

4.3.2 Analysis of Areal Morphometrical Aspects

Those areal aspects help in understanding the shape and size of the watershed, which influence the distribution and availability of water resources for irrigation purposes. From the area coverage of all sub-watersheds, SW-4 covers larger areas where whereas SW-1 covers smaller areas.

Table 4. 21 Area division of all sub-watershed

Sub-watershed	Area (km ²)	Percentage (%)
SW1	113.09	2.63
SW2	573.66	13.32
SW3	522.00	12.12
SW4	1316.75	30.57
SW5	260.71	6.05
SW6	586.74	13.62
SW7	934.54	21.70
Total	4307.49	100.00

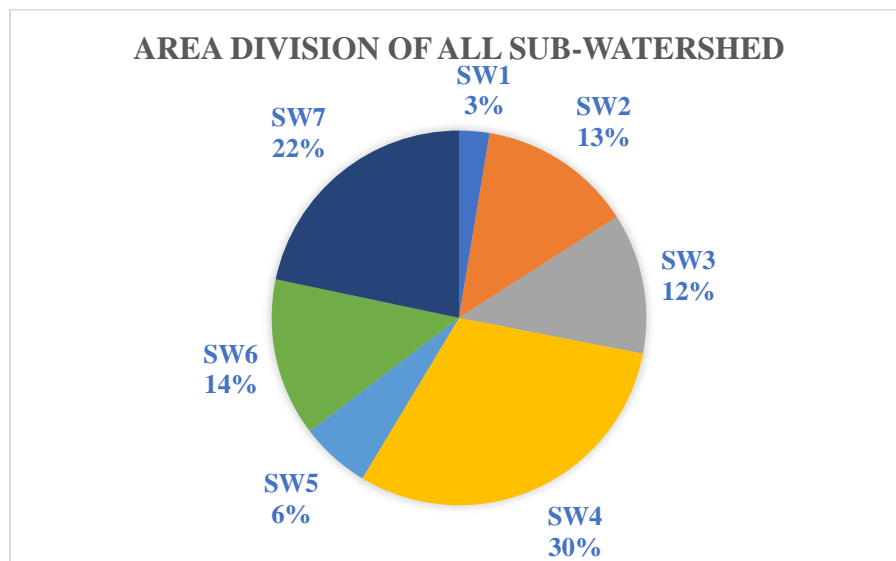


Figure 14 Area of all sub-watershed

From this sub-watershed SW-4 covered the largest area where whereas SW-1 and SW-5 covered the smallest area.

4.3.2.1 Drainage density

The efficiency of the irrigation system during surface irrigation is influenced by the drainage density. The drainage density map indicates that the drainage density of all sub-watersheds is a low figure (10).

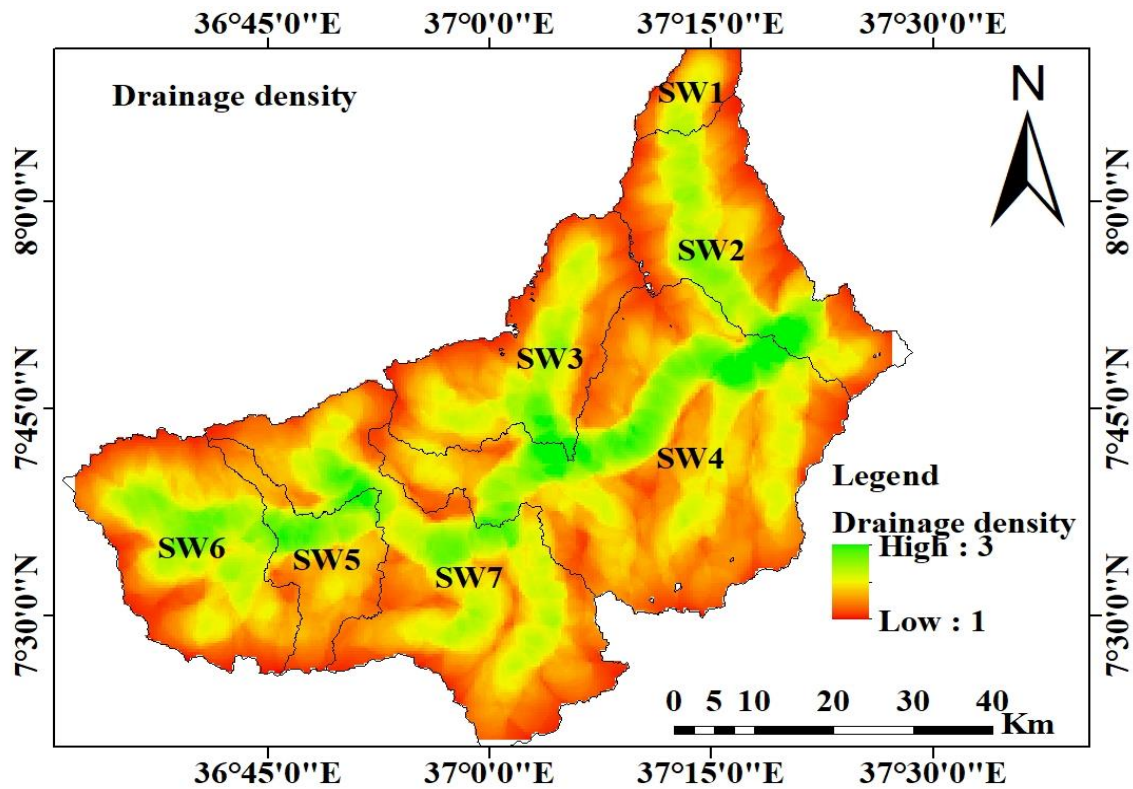


Figure 15 Drainage density map

The drainage density of all sub-watersheds is low, this shows the drainage density of this study area is extremely coarse and highly granular texture. Therefore, this result shows that drainage densities of the study area are low. This leads to a loss of water is small shows this study area is suitable for surface irrigation.

4.3.2.2 Stream frequency

The compute stream frequency of the Gilgel gibe sub-watershed is between 0.35 and 1.31. this is found in classes of low stream frequency. Generally high stream frequency is related to impermeable sub-surface material, sparse vegetation, high relief, and low infiltration capacity of the region. The highest and lowest stream frequencies occurred in SW-1 and SW-4 respectively.

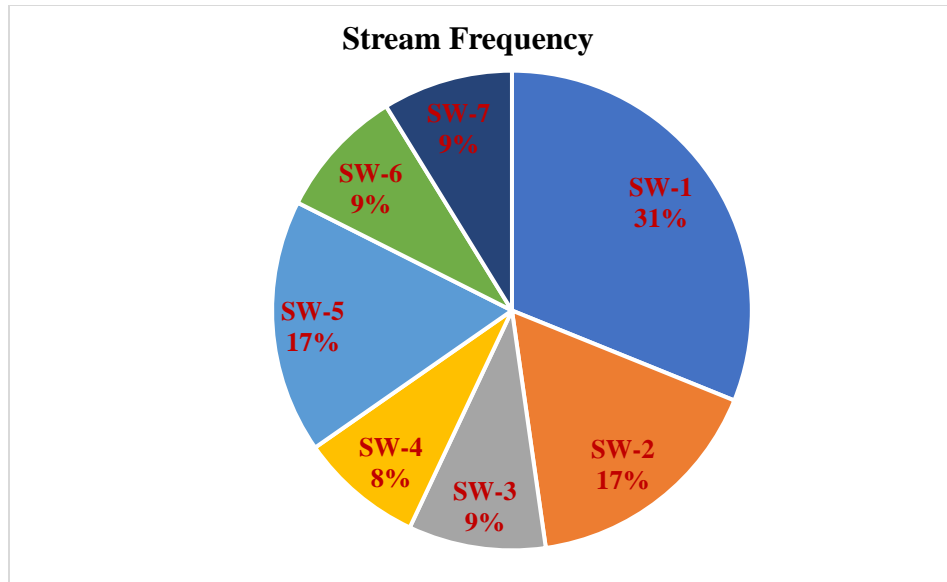


Figure 16 Stream frequency

This graph shows that SW-1 has a larger stream frequency than other sub-watersheds and SW-4, SW-3, SW-6, and SW-7 have lower stream frequency. SW-2 and SW-5 have a medium percentage of stream frequency.

4.3.2.3 Drainage texture ratio

A high drainage texture ratio denotes a strong infiltration capability and rapid water absorption by the soil (Mahala, 2020). A low drainage texture ratio indicates that the soil has a low infiltration capacity and cannot absorb water quickly.

Table 4. 22 Drainage texture ratio

Sub-watershed	SW-1	SW-2	SW-3	SW-4	SW5	SW-6	SW-7	Total
Dt value	2.85	2.48	1.31	1.89	1.52	1.73	1.40	13.18
Percentage	21.62	18.82	9.94	14.34	11.53	13.13	10.62	100.00

The sub-watersheds SW-3, SW-4, SW-5, SW-6, and SW-7 have drainage texture ratios less than 2, and also, they have smaller percentages of drainage texture ratio. But two sub-watersheds SW-1 and SW-2 have drainage texture ratios of between 2-4 and also, those have a higher percentage of drainage texture ratio.

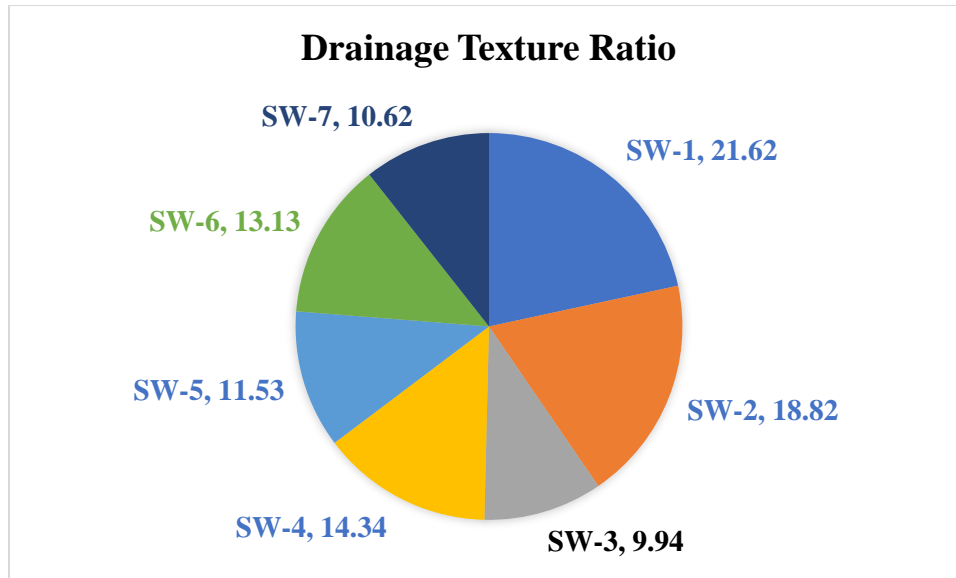


Figure 17 The percentage of drainage texture ratio

This illustrates that sub-watersheds SW-1 and SW-2 contain higher drainage textures than other sub-watersheds. Due to this the SW-3, SW-4, SW-5, SW-6, and SW-7 have smaller drainage texture ratios and fall in ranges of very coarse drainage texture i.e. their drainage density is less than 2. For SW-1 and SW-2 the results of the drainage density ratio fall between 2 and 4 indicating that the drainage texture ratio affects the effectiveness of surface irrigation Assessment.

4.3.2.4 Form factor

The computed form factor values between 0.216 and 0.301 imply the Gilgel Gibe watershed is elongated in shape Table (4.13). The type and extent of layering might affect the lateral dispersion and percolation of applied water. Because higher borders or furrows may be required in soils with low input rates to prevent crust Assessment, the shape element can also have an impact on irrigation efficiency. In contrast, a watershed with a smaller form factor and a more elongated shape produces moderate runoff with a longer runoff duration which is favorable for surface irrigation.

4.3.2.5 Elongation ratio

The computed elongation ratio of all watersheds has been between 0.52 and 0.62 (Table 4.15). This indicates that this study area is elongated in shape and has permeable subsoil circumstances that can contribute to favorable conditions for surface irrigation.

4.3.2.6 Length of overland flow

The average channel slope and the length of overland flow (Lo) have an inverse relationship (Patel *et. al.*, 2012). Longer flow channels, less surface runoff, and low relief with gentle slopes are implied by greater Lo values, whereas shorter flow paths, high surface runoff, and high relief with steep slopes are indicated by lower Lo values. In a basin, a longer overland flow value indicates that the water has traveled farther before accumulating in the stream channels(Singh & Singh, 2022). All sub-watersheds have estimated Lov values ranging from 0.89km (SW-6) to 2.94 km (SW-5) (Table 4.24). Lower Lo values indicate locations of high relief with steep slopes and short flow routes with little infiltration.

Table 4. 23 Length of overland flow.

Sub-watershed	Length of overland flow= $1/(2Dd)$	Percentage (%)
SW1	1.43	13.82
SW2	1.11	10.72
SW3	1.32	12.75
SW4	1.19	11.50
SW5	2.94	28.40
SW6	0.89	8.60
SW7	1.47	14.20
Total	10.35	100.00

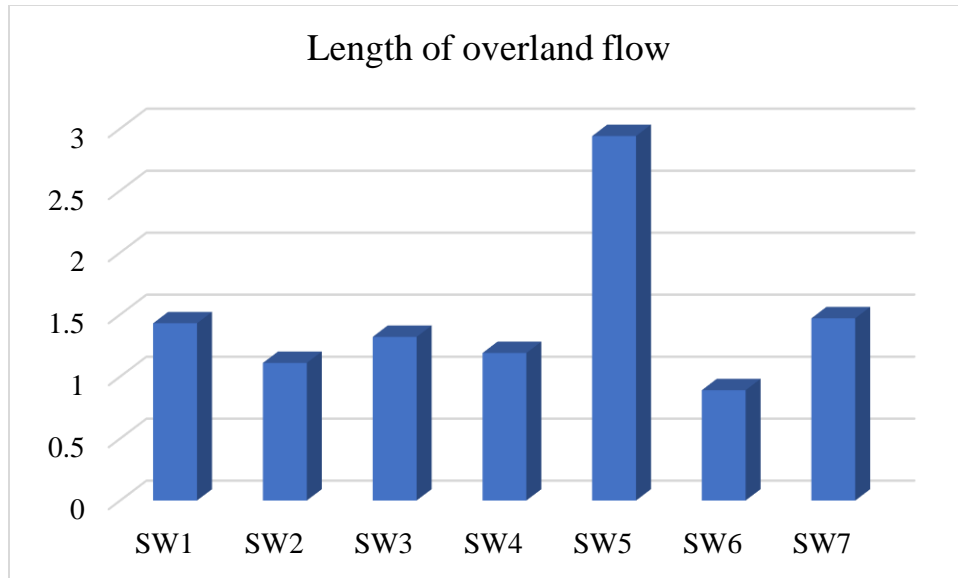


Figure 18 Length of overland flow

These graphs show the SW-5 has the longest length of overland flow, whereas the SW-6 has a smaller length of overland flow. This indicates that the SW-6 sub-watershed has a high infiltration rate and a low runoff rate, which is more beneficial for irrigation and SW-5 has a longer length of overland flow than other sub-watersheds. Therefore, this basin (SW-5) represents a longer distance covered by the water before getting accumulated into the stream channels.

4.3.3 Analyzing relief morphometric aspect

The overall results of basin relief of all sub-watersheds indicate indicating the runoff conditions inside the watershed are sufficient and can't affect surface irrigation Assessment.(Ferozur Rahaman, 2017). Under this relief analysis the three-dimensional characteristics of a drainage basin, including the size, and height of its vertical landform dimensions, are analyzed.

4.3.3.1 Basin relief

The computed overall results of basin relief of all sub-watersheds indicate the runoff conditions inside the watershed are sufficient and can't affect surface irrigation Assessment (Ferozur Rahaman, 2017).

Table 4. 24 Basin relief of all sub-watershed

Sub-watershed	SW-1	SW-2	SW-3	SW-4	SW5	SW-6	SW-7
Basin relief (Km)	0.80	1.42	1.20	1.57	1.65	1.32	1.31

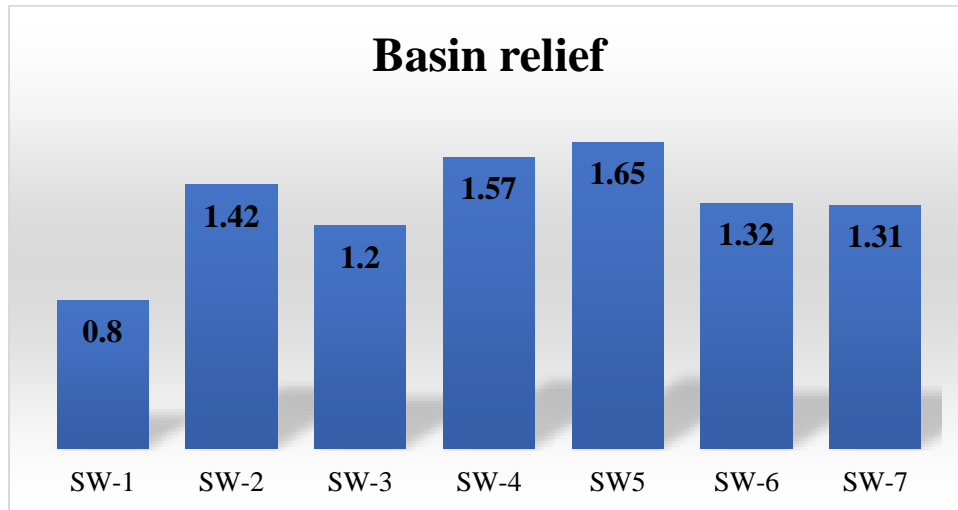


Figure 19 Graphs basin relief

From this graph, we observe that SW-5 has the highest basin relief and SW-1 has the lowest basin relief. The general elevation maps of this watershed show the basin relief is moderately suitable for surface irrigation Assessment.

4.3.3.2 Ruggedness number

Ruggedness numbers explain the ideas of the overall roughness of a watershed. It also indicates the structural complexity of the terrain in association with the relief and drainage density.

Table 4. 25 Ruggedness number

Sub-watershed	SW-1	SW-2	SW-3	SW-4	SW-5	SW-6	SW-7	Total
Percentage of Rn (%)	8.00	18.30	13.14	18.86	8.00	21.14	12.60	100.00

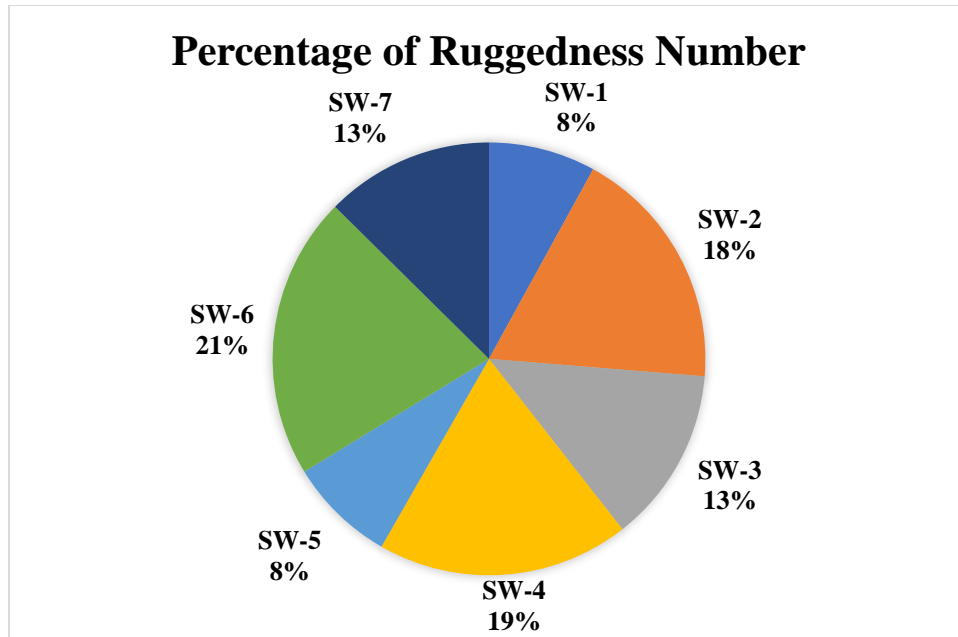


Figure 20 The percentages of ruggedness number

From this graph, we observe that SW-1 and SW-5 have equal ruggedness numbers. In addition to this SW-7 and SW-3 have also equal ruggedness numbers. The three sub-watersheds SW-2, SW-4, and SW-6 have higher ruggedness numbers than other sub-watersheds, due to this reason the watershed indicates that the field is more irregular than another sub-watershed.

4.3.3.3 Slope map

The land sections that are more prone to erosion, waterlogging, and other issues that can lower the effectiveness of surface irrigation systems are shown on the slope map Figure (8). From the analysis of this slope map large portion of the watershed is near flat and can be categorized as a good category for surface irrigation Assessment.

4.3.3.4 Aspect map

Aspect map analysis of the Gilgel Gibe watershed was done using DEM and the outcome shows a significant proportion of slopes facing east. This east-facing slope has a large amount of vegetation and soil moisture when compared with west-facing slope and is suitable for surface irrigation development.

4.4 Developing prioritization rank and compound value

4.4.1 Prioritization rank of sub-watershed

The morphometric measure (stream number, mean bifurcation ratio, mean stream length, stream frequency, drainage density, length of overland flow, ruggedness number, and drainage texture ratio) is higher in each sub-watershed. A sub-watershed revealed that the lowest value in the area/shape parameters was ranked first, followed by a lower value that was ranked second, and so on, with the greatest value being ranked last. This study employed the compound approach of averaging values because it anticipated that all morphometric factors would have equal weight in the final ranking (Obeidat & Awawdeh, 2021).

Table 4. 26 The values of all morphometric parameters used for prioritization and rank for all sub-watersheds.

Sub-watershed	SW-1	SW-2	SW-3	SW-4	SW-5	SW-6	SW-7
Mean bifurcation ratio	3.23 [1]	4.19 [6]	3.51 [2]	4.45 [7]	3.63 [3]	3.68 [4]	4.07 [5]
Stream number	148 [7]	400 [2]	201 [5]	462 [1]	188 [6]	218 [4]	344 [3]
Mean stream length	0.27 [6]	0.65 [5]	0.98 [3]	1.20 [2]	0.24 [7]	1.52 [1]	0.92 [4]
Stream frequency	1.31 [1]	0.7 [3]	0.39 [4]	0.35 [7]	0.72 [2]	0.37 [5]	0.37 [6]
Drainage density	0.35 [5]	0.45 [2]	0.38 [4]	0.42 [3]	0.17 [7]	0.56 [1]	0.34 [6]
Drainage texture	2.85 [1]	2.48 [2]	1.31 [7]	1.89 [3]	1.52 [5]	1.73 [4]	1.40 [6]
Length of overland flow	1.43 [3]	1.11 [6]	1.32 [4]	1.19 [5]	2.94 [1]	0.89 [7]	1.47 [2]
Basin relief	0.80 [7]	1.42 [3]	1.2 [6]	1.57 [2]	1.65 [1]	1.32 [4]	1.31 [5]
Ruggedness number	0.283 [2]	0.64 [5]	0.46 [4]	0.66 [6]	0.28 [1]	0.74 [7]	0.44 [3]
Circularity ratio	0.525 [7]	0.278 [4]	0.280 [5]	0.278 [3]	0.213 [2]	0.464 [6]	0.194 [1]
Elongation ratio	0.619 [1]	0.555 [4]	0.558 [3]	0.524 [7]	0.586 [2]	0.553 [5]	0.537 [6]
Form factor	0.301 [1]	0.242 [4]	0.245 [3]	0.216 [7]	0.270 [2]	0.240 [5]	0.226 [6]

4.4.2 Compound values parameter

The final weights, or compound values, were calculated by summing the ranking values of all the attributes. The priority rank of the morphometric analysis results for each Gilgel Gibe sub-watershed served as the basis for determining the compound values parameter. These compound values were computed for the sum of all ranks of the morphometric data to evaluate the suitability

of each watershed for the application of surface irrigation Assessment. Each sub-watershed was given priority to enable the phase-by-phase execution based on the results of the morphometric research(Jothimani *et al.*, 2021). The analysis of the compound values led to a preliminary classification of the sub-watershed priorities into three priority classes: high, medium, and low (Iyasu B.*et al.*, 2020).

Table 4. 27 Compound values for priority classes

Compound value	Priority classes
≤ 3.55	High priority
3.55-4.36	Medium priority
≥ 4.36	Low priority

High Priority: Sub-watersheds that fall under this category are classified as being very suitable for surface irrigation Assessment.

Medium Priority: Sub-watersheds with moderate slopes and reasonably moderate linear and form parameter values are found in classes with medium priority. These sub-watersheds fall under the category of moderate surface irrigation Assessment.

Low Priority: Sub-watersheds with lower slopes, very low linear parameters, and low shape parameters are classified as low priority. These watersheds may require agronomic practices for the Assessment of surface irrigation. Calculations of compound parameters, prioritization, and ranking of all sub-watersheds are given in (Table 4.31).

Table 4. 28 Compound values and prioritization rank of Gilgel Gibe sub-watersheds

Sub-watershed	SW-1	SW-2	SW-3	SW-4	SW-5	SW-6	SW-7
Mean bifurcation ratio	1	6	2	7	3	4	5
Stream number	7	2	5	1	6	4	3
Mean stream length	6	5	3	2	7	1	4
Stream frequency	1	3	4	7	2	5	6
Drainage density	5	2	4	3	7	1	6
Drainage texture	1	2	7	3	5	4	6
Length of overland flow	3	6	4	5	1	7	2
Basin relief	7	3	6	2	1	4	5
Ruggedness number	2	5	4	6	1	7	3
Circularity ratio	7	4	5	3	2	6	1
Elongation ratio	1	4	3	7	2	5	6
Form factor	1	4	3	7	2	5	6
Sum of ranking	42	46	50	53	39	53	53
Total number of parameters	12	12	12	12	12	12	12
Compound values	3.50	3.83	4.17	4.42	3.25	4.42	4.42
Ranking	6	5	4	1	7	1	1
Final priority	High	Medium	Medium	Medium	High	Medium	Medium

The results show that the sub-watersheds SW-1 and SW-5, from all sub-watersheds that had a compound value of ≤ 3.55 and categorized under high priority rank, were much more suitable for surface irrigation. Sub-watershed SW-2, SW-3, SW-4, SW-6, and SW-7 having a compound value of between 3.55 to 4.36 received the next, medium priority classes. Figure 21 shows the map of priority classes for all sub-watersheds.

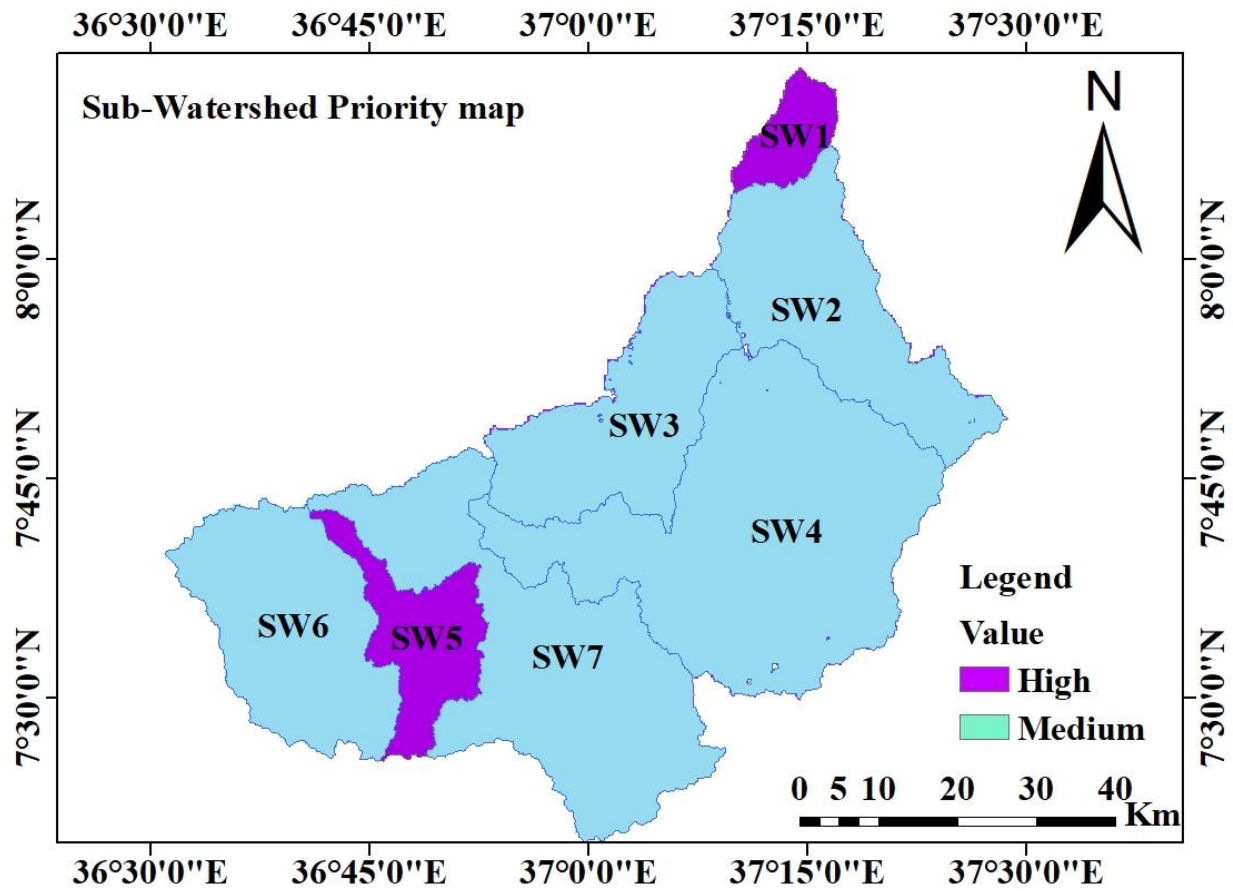


Figure 21 Sub-watershed priority map of Gilgel Gibe watershed

Additionally, the final priority map shows that high-priority classes of this watershed cover an area of 374 km², whereas the larger area of this watershed is covered by medium classes, which cover an area of 3935 km². The overall priority classes of all sub-watersheds based on a percentage of area covered major portions are medium classes.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The main objective of this study is morphometric analysis for the Assessment of surface irrigation in the case of the Gilgel Gibe watershed. Numerous problems relating to watersheds, such as surface irrigation Assessment, droughts, soil erosion, watershed evaluation, flooding, groundwater potential analysis, etc., can be effectively and precisely resolved through the study of morphometric analysis with the aid of the GIS technique. Robust data on the morphometric parameters of watersheds serve as a foundation for making informed decisions about the appropriate use and administration of land resources. The selection of suitable land for irrigation Assessment is made possible by the significance of morphometric analysis. With the use of DEM as an input to characterize the watershed system, Hydrology in the GIS context focuses on flow modeling and watershed delineation. The shape and topography of the specified watershed are reflected in the assessed and analyzed morphometric characteristics, which include area, length, stream pattern, flow direction, and perimeters. The following is a summary of the main thesis.

- ✓ The sub-watershed of this research region is divided into seven sub-watersheds, and the DEM data of the Gilgel Gibe watershed is delineated using the GIS tool.
- ✓ GIS software is used to count the number of streams of different orders in a watershed and measure the length of each stream from the mouth to the drainage divide. i.e. total of 1961 numbers of streams are counted and five stream orders are generated by using Arc-GIS software.
- ✓ The morphometric parameters' linear, areal, and relief components were examined.
- ✓ The mean bifurcation ratio (R_{bm}) values of the watersheds in the research region vary from 3.23 (for SW-1) to 4.45 (for SW-4). This suggests a well-developed drainage network and falls within the ranges of mean bifurcation ratios explained by Strahler, i.e., between 2 and 5. It show appropriate for the of surface irrigation.
- ✓ The analysis of stream frequency for the Gilgel gibe sub-watershed is between 0.35 and 1.31. this is found in classes of low stream frequency.
- ✓ The computed drainage densities of all sub-watersheds are between 0.17 and 0.56.

- ✓ The elongation ratio, circulation ratio, and form factor values for each sub-basin indicate that all of the watersheds were elongated in shape.
- ✓ The basin relief of the watershed is longest for SW-5 i.e. 1.65Km and shortest for SW-1 i.e. 0.8Km.
- ✓ SW-6, SW-4 and SW-2 have largest ruggedness number. while SW-1 and SW-5 have smaller ruggedness numbers.
- ✓ The priority classes of watersheds show that larger areas of watersheds are in the range of medium classes while smaller areas are the highest classes.
- ✓ For Assessments of surface irrigation determining the priority of surface irrigation is mandatory since it affects crop production, the number of waters needed for irrigation, and generally morphometric parameters of the watersheds.

5.2 Recommendations

A key method for describing the quantitative and physical features of a watershed is morphometric analysis. Additionally, it has been applied to sub-watershed prioritization to manage natural resources effectively. Watershed morphometric characteristics can be estimated using Geographic Information System applications and Remote Sensing, as compared to traditional methods. The elements should be taken into account to develop the area for irrigation sustainably more hydrogeological research and details are required in addition to morphometric analysis. Controlling stream length is also essential to surface irrigation in a sustainable manner. Determining the number of streams in the watershed is very mandatory since reducing the water available for irrigation Assessment can lead to water scarcity. The minimum mean stream length develops competition between farmers and raises a conflict between farmers for using water, therefore increasing the mean stream length is important i.e. it solves all farmers getting water equally. For the sub-watershed with a high mean bifurcation ratio, rigorous planning and management are essential. Since the values of form factor affect the irrigation efficiency it is very important to investigate deeply. In surface irrigation Assessment ensuring proper basin relief is very crucial for ensuring uniform water distribution across the field and it prevents water stagnation in low-lying areas and ensures adequate coverage. For the sub-watersheds which have low priority classes it is, increasing the drainage texture ratio by planting trees over it as well as increasing stream number, total, and mean stream length will improve the irrigation suitability of this watershed. However, for a more comprehensive evaluation, further investigation into the physical land suitability of the watershed is necessary. This provides additional insights into the feasibility and effectiveness of surface irrigation in the specific context of the elongated watershed.

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