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Geoinformatics-Driven Analysis for Watershed Management: Focus on the Manjara River Basin

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Abstract

This study investigates the morphometric attributes of the Manjara basin in Latur, Maharashtra, India, employing geospatial technology to assess the watershed's hydrological and geomorphological properties. Using satellite imagery and terrain maps, the research evaluates key morphometric parameters, including the bifurcation ratio (1.279), which suggests minimal branching and a more linear network. The drainage density of 2.743 km/km² indicates moderate runoff and infiltration rates, implying balanced erosion and sediment transport processes. A stream frequency of 14 reveals a highly interconnected network of streams, while an elongation ratio of 0.712 points to a compact or rounded watershed shape. Additional findings include a relief value of 0.057, showing minimal vertical elevation variation, an infiltration number of 39.360, suggesting higher runoff with reduced infiltration, and a ruggedness number of 0.1659, reflecting relatively low terrain roughness. The significance of the infiltration number and ruggedness number is in assessing surface runoff, groundwater recharge, erosion patterns, and watershed stability. These morphometric indicators are critical for understanding the watershed's hydrological behaviour, contributing to more effective catchment planning, flood management, and sustainable water resource use. The study's limitations include the reliance on remote sensing data, which may introduce errors in measurement accuracy, and the static nature of morphometric analysis, which may not fully capture temporal variations in hydrological processes. Future research should incorporate dynamic models and real-time data to enhance predictions of flood and drought risks under varying climate conditions. Despite these limitations, the results offer insightful information about how to design effective watershed planning strategies in the current context of mounting environmental issues.

Major Findings: *The study reveals that the Manjara Watershed exhibits moderate drainage density, a compact shape, and minimal relief, indicating balanced hydrological processes. However, a high infiltration number suggests greater surface runoff and reduced groundwater recharge, while a low ruggedness number points to limited terrain roughness, influencing erosion and watershed stability.*

Keywords: *Geospatial Technologies, GIS, Morphometric Analysis, Sustainable Watershed Management*

1.0 Introduction

The application of geoinformatics in analyzing drainage basins is vital for effective watershed management, as it helps in understanding the intricate relationships among various watershed components[1]. While considerable research has been conducted on morphometric analysis, the lack of a universally accepted classification system for geomorphometric factors presents a significant challenge in consistently evaluating these factors[2]. For well-

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informed decision-making in watershed management, accurate geomorphometric assessments are essential. This highlights the significance of exact mapping, appropriate scales for analysis, and high-quality data[3]. A watershed, or drainage basin, is any area of land where precipitation collects and flows into a common body of water, such as a lake or stream[4]. Addressing problems with erosion, water quality, and land degradation requires effective management of these basins[5]. Even with the watershed's ecological and socioeconomic importance, the area struggles with unchecked erosion, recurrent flooding, and ineffective water resource management[6]. These challenges are exacerbated by the absence of a comprehensive morphometric analysis, which limits the understanding of the watershed's geomorphological and hydrological dynamics[7,8]. Without proper insight into these dynamics, efforts to address land degradation, water scarcity, and flood risks remain ineffective. This research aims to pinpoint vulnerable areas prone to erosion, landslides, and flooding, offering crucial insights for effective land management and conservation strategies. By filling these knowledge gaps, this study will promote the sustainable management of the watershed and enhance its resilience to environmental stresses.

The necessity to give a thorough geospatial analysis of the Manjara watershed to comprehend its hydrological behaviour and geomorphological aspects is what drove this work. Given the region's vulnerability to natural hazards, there is an urgent need for data-driven strategies to improve water resource management, enhance land conservation efforts, and mitigate environmental impacts. This research aims to optimize water resource management in the Manjara River basin by employing spatial parameters and prioritizing sub-basins based on current land use, utilizing Geographic Information System (GIS) technologies[9]. The study specifically focuses on analyzing the stream network within the basin to understand flow paths and drainage patterns. Additionally, it seeks to examine how watershed morphology influences hydrological responses to precipitation events, including runoff generation and flow pathways. By leveraging morphometric data, the study aims to predict areas within the watershed that are vulnerable to flooding and drought under varying conditions, contributing to more effective techniques for managing watersheds.

2.0 Study Area

The Terna River is the primary tributary of the Manjara River, which is the research area's focal point. Covering approximately 7,000 square kilometres, the watershed is located in Shirur Village, Latur District, Maharashtra, India. Geographically, the basin extends from 76°0' E to 19°0' N. The research involves the analysis of geographic data for the Manjara Watershed and the creation of thematic maps to support the study. Topographical maps, specifically toposheets, play a vital role in this analysis, providing a two-dimensional representation of the region's three-dimensional land surface. The toposheets utilised in this study, No. E43K11, with a scale of 1:50000, were downloaded from the Survey of India website and used for the analysis.

3.0 Materials and Methods

The Manjara watershed's morphometric analysis was done using Geographic Information System (GIS) methodologies in this study's approach. Morphometric analysis quantitatively assesses the size, shape, and structure of watersheds, offering insights into their topographical and hydrological characteristics[10,11]. This study focuses on linear, aerial, and relief aspects, enabling a detailed understanding of watershed interconnectivity and development over time[12,13]. The geoinformatics-based watershed management of the Manjara River was conducted using GIS tools, with the ARC GIS 9.0 software utilized for basin delineation and stream digitization. The study employed the WGS 1984 projection system, 43N zone, to geotag maps and delineate the basin's total area. The region's geology is dominated by Deccan Basaltic rock, a volcanic formation from the Deccan Plateau, which affects the hydrological processes such as percolation due to its porosity and permeability[14]. Hydrological data, including streamflow, rainfall, drainage characteristics, and topographic information, were collected to facilitate the morphometric analysis. Rainfall data from the Saigaon rain gauge indicated an average annual rainfall of 60 cm over three years (2020–2022). The morphometric analysis leveraged ArcGIS tools, particularly within the ArcGIS Spatial Analyst extension, to perform hydrological and surface analyses. Key operations included stream network development, watershed delineation, flow direction

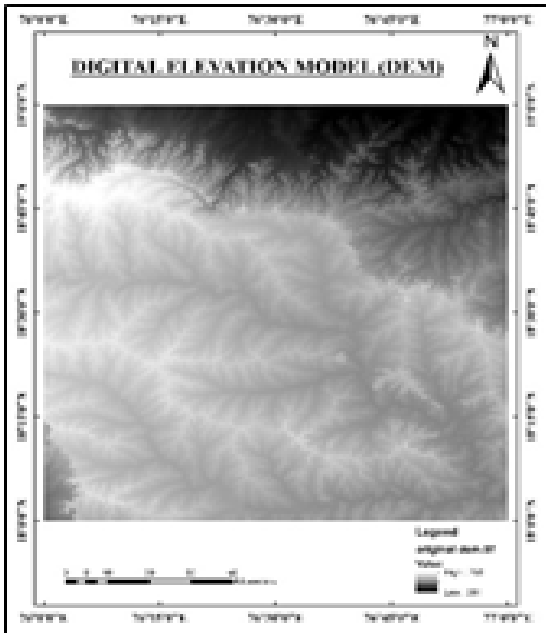


Figure 1. Digital elevation model used for morphometric analysis.

establishment, and flow accumulation analysis using raw Digital Elevation Model (DEM) data[15]. Tools for processing DEM data and evaluating water flow patterns included fill, basin, flow direction, and flow accumulation[16]. Tools for surface analysis, such as contour and slope, assisted in locating elevation features. The clipping tool was essential for defining watershed boundaries and ensuring accurate analysis. Topographic maps were used to create contour lines representing identical elevations, supporting the analysis of stream networks and flow pathways[17]. The topography features of the Earth are represented digitally by Digital Elevation Models (DEMs), which show the elevation of the landscape at regular intervals[18]. Organized in a grid structure, each cell in a DEM contains a specific elevation value, with the resolution determining the level of detail. Higher-resolution DEMs offer more detailed terrain data, but they require greater storage capacity and computational resources[19]. DEMs are fundamental for creating topographic maps, visualizing terrain in GIS applications, and supporting engineering projects such as site selection, infrastructure planning, and environmental assessments. Because of its high resolution and accuracy, the Indian Space Research Organisation (ISRO) used the Cartosat-1 DEM in this investigation (Figure 1). Cartosat DEMs are valuable for topographic mapping, 3D modelling, terrain analysis, infrastructure development, and natural resource management due to their precision in representing elevation data. To ensure accurate terrain analysis and prevent water from being trapped in spurious depressions, a filled DEM was generated from the raw DEM data. This filled DEM corrects elevation errors by eliminating pits and depressions, ensuring accurate and reliable measurements for morphometric analysis[20]. Contour maps, created using the DEM data, connect areas of equal elevation and are critical for visualizing terrain. In this study, a contour interval of 25 km was employed, meaning the distance between contour lines represents changes in elevation[21]. Slope maps, on the other hand, illustrate the gradient of the terrain, showing how steep or gentle the surface is. These maps are crucial for understanding how slope influences water movement, as steeper slopes lead to faster runoff, while gentler slopes promote slower water flow and greater infiltration[22]. Slope analysis is essential for identifying areas vulnerable to high runoff, erosion, and potential flooding, thereby supporting effective watershed management and flood control planning.

Flow direction determines the path water takes from one cell to another within a terrain, identifying which

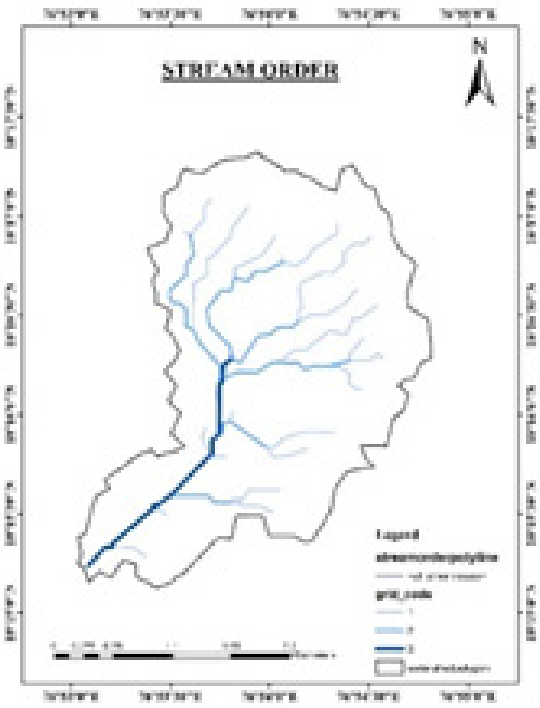


Figure 2. Stream order map of Manjara basin.

neighbouring cell water will flow into based on elevation. Flow accumulation maps are essential for identifying areas where water is likely to concentrate, forming streams, rivers, or other drainage features[23]. Stream order, a classification system in geomorphology, assigns a numerical value to each stream segment, representing its position and branching complexity within the river network. It helps assess the hierarchical structure of a drainage system, considering factors such as distance from the source and confluence with other water bodies (Figure 2). A drainage line map gives important information about the topography, soil properties, and water resources of a watershed by following the pathways taken by streams, rivers, and temporary channels. The longest flow path, defined as the duration required for water to traverse from a watershed's headwater to its outlet, is a critical determinant of the time it takes for water to circulate through the system, influencing runoff and flood responses. To ensure a thorough understanding of water movement within the basin, the boundaries of the watershed and sub-catchments were drawn using topographic parameters such as relief, slope, stream numbers, and flow direction.

4.0 Analysis and Discussion

The integration of morphometric analysis with geoprocessing tools provides a robust approach to watershed management, enabling more accurate predictions of water flow, identification of critical conservation areas, and planning for sustainable land use[24]. This study used Geographic Information System (GIS) methodologies, specifically ArcGIS 10.5 software, to analyse the geospatial parameters of the Manjara watershed. Using this software, key hydrological and structural elements were extracted, providing important insights into the behaviour of the watershed. ArcGIS tools were utilised to derive key morphometric characteristics, including drainage density, basin relief, and stream frequency. These characteristics are essential to comprehending the watershed's general reaction to hydrological processes as well as its flow patterns. For instance, stream order and flow accumulation tools were used to map and quantify the drainage network, while slope analysis and relief ratio calculations were performed to assess the topographical influence on runoff and sediment transport. This analysis is instrumental in identifying vulnerable areas prone to erosion and flooding, guiding future watershed management efforts. In addition to improving the morphometric assessment's accuracy, the use of geoprocessing tools made it easier to create plans for sustainable land use and efficient water resource management[25].

4.1 Linear Aspect

4.1.1Bifurcation Ratio

The ratio of streams in each order to streams in the next higher order is quantified by the bifurcation ratio (Rb). Natural river networks usually have bifurcation ratios between two and five. A lower bifurcation ratio (Rb < 2) indicates less branching, whereas a higher bifurcation ratio (Rb > 5) suggests significant branching. In the case of the Manjara Catchment (CH_1), the bifurcation ratio is calculated as 1.279, which suggests minimal branching within the watershed. This lower ratio reflects a more streamlined network, where fewer tributaries are connected to the mainstream, potentially leading to less complexity in water flow and runoff behaviour.

4.2 Aerial Aspect

4.2.1 Drainage Density

The concentration of river networks within a drainage basin is reflected by drainage density, a crucial morphometric parameter[26]. The calculation involves dividing the total length of the stream by the area of the basin. The drainage density in the Manjara Catchment (CH_1) is 2.743 km/km², which suggests a moderate network of stream channels. This number indicates that the basin experiences moderate levels of erosion and sediment transport processes, as well as a balanced rate of surface runoff and infiltration.

4.2.2 Stream Frequency

The density of stream networks is highlighted by stream frequency (Fs), which is the number of stream channels per unit area in a drainage basin. In the Manjara Catchment (CH_1), the stream frequency is calculated at 14, reflecting a dense network of streams. High stream frequency values indicate the need for effective watershed management, particularly in addressing erosion control,

land-use planning, and infrastructure development to mitigate adverse impacts on water quality and habitat preservation.

4.2.3 Texture Ratio

Through the calculation of the number of stream segments (Ns) per unit length of the basin perimeter (P), the texture ratio (T) offers insights into the surface characteristics of the basin. The Manjara Catchment has a somewhat moderate texture that may affect sediment transport and hydrological processes, as indicated by the texture ratio of 7.

4.2.4 Form Factor

The ratio of the basin area to the square of the basin length is known as the form factor (Ff), and it is used to evaluate the basin's shape. A more compact shape is indicated by a higher form factor value, whereas a lower form factor denotes a more elongated basin. The Manjara Catchment's form factor in this study is 0.034, indicating a somewhat elongated basin.

4.2.5 Elongation Ratio

A drainage basin's shape is determined by its elongation ratio (Re), which indicates whether the basin is compact or extended. Re = 1.128 (A^0.5) / Lb is the formula used to determine it, where A denotes the basin's area and Lb its length. The elongation ratio of 0.712 in the Manjara Catchment suggests that the watershed is more compact or rounded in shape, which can influence hydrological responses, including runoff and peak flow timings.

4.2.6 Circulatory Ratio

By comparing the circumference of a circle with the same area as the watershed's perimeter, the circulatory ratio (Rc), a morphometric quantity, can be used to describe the watershed's shape. A circulatory ratio of 0.448 indicates that the Manjara Catchment has a relatively compact and symmetric form, suggesting that the main river channel follows a linear or gently curving path with limited branching or meandering.

4.2.7 Infiltration Number

When evaluating a watershed's infiltration capacity, the infiltration number (If), which is determined by taking drainage density and stream frequency into account, is a crucial metric. The higher infiltration number signifies the greater potential for runoff. In the case of the Manjara Catchment, the infiltration number is calculated as 39.360, indicating a higher tendency for runoff and lower infiltration.

4.2.8 Overland Flow Length

The average distance that water flows over the ground before entering a river channel is called the overland flow length (LoF). It is calculated using the equation LoF = 1 / 2Dd, where Dd is the drainage density. For the Manjara Catchment, the overland flow length is calculated as 1.396 km, which plays a critical role in understanding surface runoff dynamics and designing erosion control measures.

4.2.9 Constant Channel Maintenance

Constant channel maintenance (C) refers to an effort required to maintain the stability and functionality of a river channel, accounting for both natural processes and human interventions. It is drainage density's inverse. For the Manjara Catchment, the constant channel maintenance value is calculated as 0.349 km^2, indicating the required area per unit length of the channel for maintaining the drainage system. This value provides insights into the channel's resilience to erosion and sedimentation, crucial for sustainable watershed management.

4.3 Relief Aspect

The study of elevation variation within a watershed or drainage basin and the impact of slope orientation on topography and hydrological processes is referred to as the relief element of morphometric analysis[27]. This analysis provides insights into how the directional orientation of slopes affects the watershed's overall terrain features and water flow dynamics.

4.3.1 Basin Relief

By calculating the vertical distance between a watershed's highest and lowest points, basin relief provides a broad picture of the topography and surface roughness of the area. It is computed by deducting the maximum height in the catchment from the lowest elevation, which is usually at the basin outlet. Regarding the examined watershed, the basin relief value of 0.057 denotes a low degree of

height fluctuation, implying primarily level or gently sloping terrain with moderate elevation shifts. Within the watershed, this low relief affects sediment transport, erosion, and water flow.

4.3.2 Relief Ratio

A dimensionless metric called the relief ratio (Rh) is used to describe how difficult or steep the terrain is inside a drainage basin. The calculation involves dividing the horizontal distance across the basin by the relief of the basin. For the Manjara Catchment, the relief ratio is 0.013, signifying relatively gentle slopes and a smooth terrain. This low relief ratio suggests limited elevation changes and gradual slopes, which have implications for runoff velocity and erosion potential.

4.3.3 Ruggedness Number

The drainage density and basin relief are combined to create the ruggedness number (Rn), which measures the overall roughness of the terrain. It is a unitless value that indicates the degree of topographic irregularity. For the Manjara Catchment (CH_1), the ruggedness number is 0.1659, which suggests that the landscape is relatively smooth, with gradual elevation changes and minimal topographic complexity. This lower ruggedness value is indicative of a landscape with limited relief features, where erosion processes and sediment transport are likely to moderate.

4.4 Integrated Value of Morphometric Parameters

4.4.1 Integrated Value of Linear Aspect

The integrated value of the linear aspect of the Manjara watershed is calculated by analyzing various morphometric parameters, including the bifurcation ratio. In the Manjara Catchment, the bifurcation ratio is 1.279, which also serves as the integrated value for the linear aspect (Figure 3(a)). This number gives information about the general structure and evolution of the drainage network and represents the branching features of the watershed. As per Table 1, A relatively low bifurcation ratio of 1.279 indicates limited stream branching within the watershed, suggesting that the hydrological response to precipitation and runoff events may be less complex, with reduced potential for extensive stream formation or diversion. This analysis aids in understanding the watershed's capacity for water flow management and its susceptibility to surface runoff.

Table 1. Integrated values for linear aspect

Sr. No.	Morphometric Parameters of Linear Aspect	Manjara Catchment
1	Bifurcation Ratio	1.279
	Integrated Value of Linear Aspect	1.279

4.4.2 Integrated Value of Aerial Aspect

The integrated value of the aerial aspect of the Manjara Catchment is derived through the analysis of several key morphometric parameters. These parameters include drainage density (2.743), stream frequency (14.121), texture ratio (6.997), form factor (0.034), elongation ratio (0.712), circulatory ratio (0.448), infiltration number (39.360), overland flow length (1.396), and constant channel maintenance (0.349) (Figure 3(b)). A thorough picture of the surface hydrological features and landscape dynamics of the watershed is provided by the total

Table 2. The integrated value of the aerial aspect

Sr. No.	Morphometric Parameters of Aerial Aspect	Manjara Catchment
1	Drainage Density	2.743
2	Stream Frequency	14.121
3	Texture Ratio	6.997
4	Form Factor	0.034
5	Elongation Ratio	0.712
6	Circulatory Ratio	0.448
7	Infiltration Number	39.360
8	Overland Flow Length	1.396
9	Constant Channel Maintenance	0.349
	Integrated Value of Aerial Aspect	66.16

Table 3. Integrated values for the relief aspect

Sr. No.	Morphometric Parameters of Relief Aspect	Manjara Catchment
1	Basin Relief	0.057
2	Relief Ratio	0.013
3	Ruggedness Number	0.165
4	Melton Ruggedness Number	0.155
	Integrated Value of Relief Aspect	0.390

integrated value of 66.160 for the aerial aspect, which is the result of assessing these factors collectively (Table 2). This value reflects the catchment's runoff potential, infiltration capacity, and overall drainage network efficiency.

4.4.3 Integrated Value of Relief Aspect

The integrated value of the relief aspect for the Manjara Catchment is calculated by analyzing key morphometric parameters, including basin relief (0.057), relief ratio (0.013), ruggedness number (0.165), and Melton ruggedness number (0.155) (Figure 3(c)). These parameters, which reflect the catchment's elevation variation, surface roughness, and landscape ruggedness, collectively result in a total integrated value of 0.390 for the relief aspect (Table 3). This value sheds light on the intricate topography of the catchment and how it affects hydrological cycle events like runoff and soil degradation.

Table 4 summarizes the finalized integrated morphometric parameters for the Manjara Catchment (CH_1). The integrated value for the linear aspect is 1.279, for the aerial aspect is 66.16, and for the relief aspect is 0.3949. These values together yield a total integrated morphometric parameter value of 67.829. This comprehensive assessment provides a detailed understanding of the catchment's hydrological and

Table 4. Finalized integrated morphometric parameters

Sr. No.	Integrated Morphometric Parameters	Manjara Basin (CH_1)
i	Integrated Value of Linear Aspect	1.279
ii	Integrated Value of Aerial Aspect	66.16
iii	Integrated Value of Relief Aspect	0.390
Total Integrated Morphometric Parameters Value		67.829

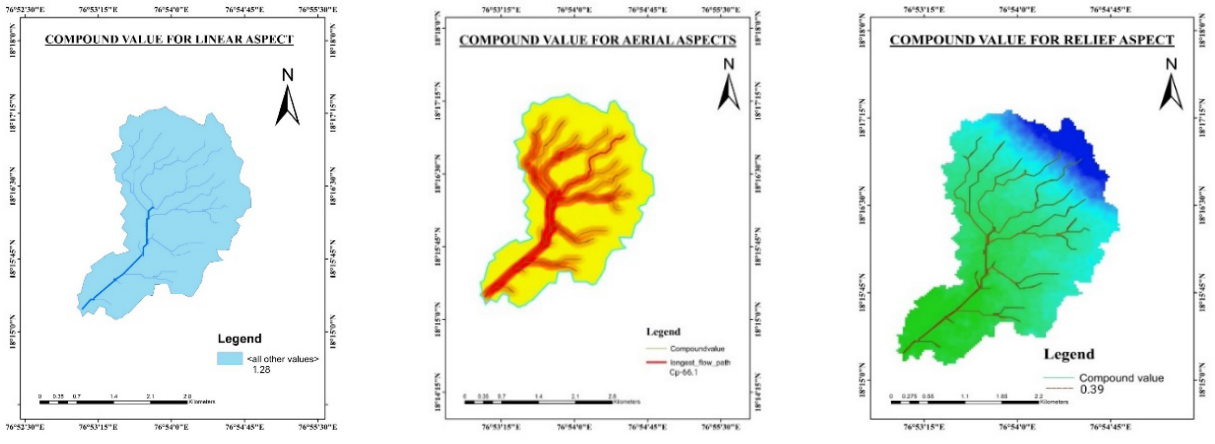


Figure 3. Integrated value of linear, aerial and relief aspect parameters of Manjara basin.

topographical characteristics, contributing to effective watershed management and planning.

5.0 Conclusion

The Manjara Watershed's morphometric study provides important information for sustainable watershed management by shedding light on the hydrological and geomorphological behaviour of the watershed. To understand the structure of the study of water, the study quantified important morphometric parameters using geospatial techniques and GIS-based tools. These parameters reveal the potential for erosion, runoff, and flood risks, and their collective analysis helps elucidate the watershed's hydrological cycle and geomorphological processes. A bifurcation ratio of 1.279, which is lower than typical natural river networks, indicates minimal stream branching and a more linear network, suggesting faster water flow and heightened flood risk. The moderate drainage density of 2.743 reflects balanced runoff and infiltration, while a high stream frequency of 14 indicates an efficiently interconnected drainage network, enhancing water movement. The elongation ratio of 0.712 suggests a more compact basin shape, potentially leading to quicker runoff and higher peak flow events. The relief value of 0.057 points to a relatively flat terrain, which may slow flow velocity and influence sediment deposition, while the infiltration number of 39.360 indicates greater surface runoff potential with lower groundwater recharge. While the infiltration number highlights the potential for surface runoff versus groundwater recharge, its implications for water conservation and flood management in regions prone to hydrological extremes require further exploration. A ruggedness number of 0.1659 reveals a smooth landscape with reduced erosion potential. The ruggedness number, which reflects terrain roughness, offers valuable insights into erosion patterns, sediment transport, and overall watershed stability. However, the study can be enhanced by elaborating on how these parameters directly influence hydrological responses and their practical application in sustainable watershed management. This study offers a comprehensive understanding of the hydrological features and drainage efficiency of the Manjara Watershed to inform plans for water sustainability, flood control measures, and ecological preservation. The moderate drainage density, compact shape, and minimal relief reflect efficient drainage within the watershed, though the low bifurcation ratio and high infiltration number suggest a need for enhanced water management and flood control measures. These results add crucial information for the region's long-term preservation of watersheds.

6.0 Acknowledgements

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7.0 Declaration of Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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