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DEM & Morphometric Based Watershed Prioritization & Analysis in Foothill Catchments Area of the Eastern Himalaya: Mountainous Landscapes Promoting for Sustainability

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Abstract

The present study utilized a Digital Elevation Model (DEM)-based approach to explore a Geomorphometric technique for prioritizing watersheds in the hilly areas of the Lish & Gish catchment. This study evaluated Microwatersheds to assess their susceptibility to erosion and hydrological response by employing topographic parameters, as well as drainage density, stream frequency, bifurcation ratio, relief ratio, and ruggedness number. To delineate micro-watersheds and extract linear, areal, and relief morphometric features, 30-meter resolution SRTM DEM data and Survey of India (SOI) topographic maps were utilized. These components were integrated to develop a Composite Priority Index (CPI), which was used to classify the watersheds into high, medium, and low priority categories. Owing to their steep slopes, extensive drainage systems, and rocky landscapes, watersheds 1 and 3 were identified as high priorities in the analysis, highlighting the urgent need for soil and water conservation measures. This study offers a scalable framework for managing watersheds in other mountainous regions and underscores the significance of terrain analysis for resource planning.

Keywords: Watershed Prioritization, Digital Elevation Model, Morphometric Analysis, Lish & Gish Catchment, Sustainable Watershed Management, Composite Priority Index.

Introduction

Watersheds are complex and hierarchical terrains that are in a constant flow of materials and energy (Şerban et al., 2020). This is necessary to understand their distinctive Morphometric features, including shape, size and drainage patterns to manage limited water resources and reduce the effects of flood or erosion (Magesh et al., 2012). Through topography studies, slope distribution, and watershed geometry, we are able to forecast the amount of runoff, seasonal changes and the chances of flash-floods (Saha et al., 2020). By computing particular Morphometric measures (Khan & El Kashouty, 2023), we will be able to prioritize the intervention at the sub-watershed level and lead to the specific restoration and conservation measures. Simply put, mathematical analysis of watershed form and its drainage networks provides the geomorphic processes on which the landscape is constructed and knowledge of the sustainable water-resource management.

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Over the past years, there has been a variety of techniques developed to prioritize and rank watersheds, ranging both in simple analytical tools and more complex, physically-based process models. The most common methods, which include a weighted-sum scoring, fuzzy analytic hierarchy process (Rahaman et al., 2015; Farhan et al., 2018) and principal-component analysis (PCA), have been extensively used on river basins. PCA specifically minimizes the dimensionality by emphasizing the Morphmetric variables that can explain the majority of the have been observed (Arefn et al., 2020; Shekar and Mathew, 2022).

Sub-watershed selection and management studies have also emphasized the selection of erosion prone areas based on indicators like Morphometry, land-use/ land-cover, soil type, and other socio -ecological indices (Adhami ester al., 2019; Sharma ester al., 2020). A well-engineered watershed -management plan can contain a continuum of issues many have been soil erosion, low agricultural output, excessive flooding, as well as insufficient infiltration, and can withstand disastrous circumstances, such as drought and flash flooding (Gajbhiye & Sharma, 2017). Thus, decision-makers should have a good understanding of the nature of watersheds and the hydrological processes that define watersheds.

Combined, Remote Sensing (RS) and Geographic Information Systems (GIS) offer a potent prism through which we can look at the not only multifaceted interaction between Climate, Geology, Geomorphology and Watershed structure, but also structure. With the introduction of high-resolution Digital Elevation Models (DEMs) the watershed analysis has undergone a revolution whereby more accurate and scalable analysis of drainage networks, slope gradient, flow accumulation, streamline delineation and catchment boundaries can be performed. GIS makes these data come alive- big datasets are easily accessed, handled and visualized, complex morphological issues are solved which would have been otherwise uncontrollable. Computer technology has developed, and GIS is a completely digital, high-performance application, which is able to process terabytes of spatial data. By combining the advantages of both RS and GIS, researchers can have an in-depth, operational insight into watershed morphology and dynamics and base a water-resource management strategy, land-use planning strategy, and environmental management approach on this information with confidence and clarity.

Using topographical intelligence provided by Digital Elevation Model (DEM) to examine the Geomorphological processes of the Lish and Gish catchment areas which are two major tributary sub-watersheds in the hilly North Bengal region located in India. Using systematic analyses of their underlying Morphometric features (e.g., drainage density, form factor, elongation and relief ratio), we can uncover the key derived attributes that can tell us about the underlying processes of landscape evolution. The information can help us prioritize the sub-watersheds based on the level of erosion, sediment transportation, or watershed decline. The ensuing hierarchy of Morphometry will guide the prioritization of the target intervention strategies and thus enhance better land-use planning and watershed administration in this ecologically sensitive region.

Study Area

The Lish and Gish catchments areas which is located in the rolling hills of West Bengal at the junction of three districts, Kalimpong, Darjeeling and Jalpaiguri. These catchments are part of the Teesta River system which directs the rich subtropical monsoon climate of the region through a vibrant hydrological rhythm.

The catchments receive an amazing 3,000 mm of rainfall every year with the heaviest downfalls in the months of June to September. This torrent makes the hills a river of runoff, and fills the banks of the rivers, and occasionally causes floods, rolling miles down the bank. During the cooler seasons, winters are not too harsh and provide a short-lived relief to the intensity of the monsoon.

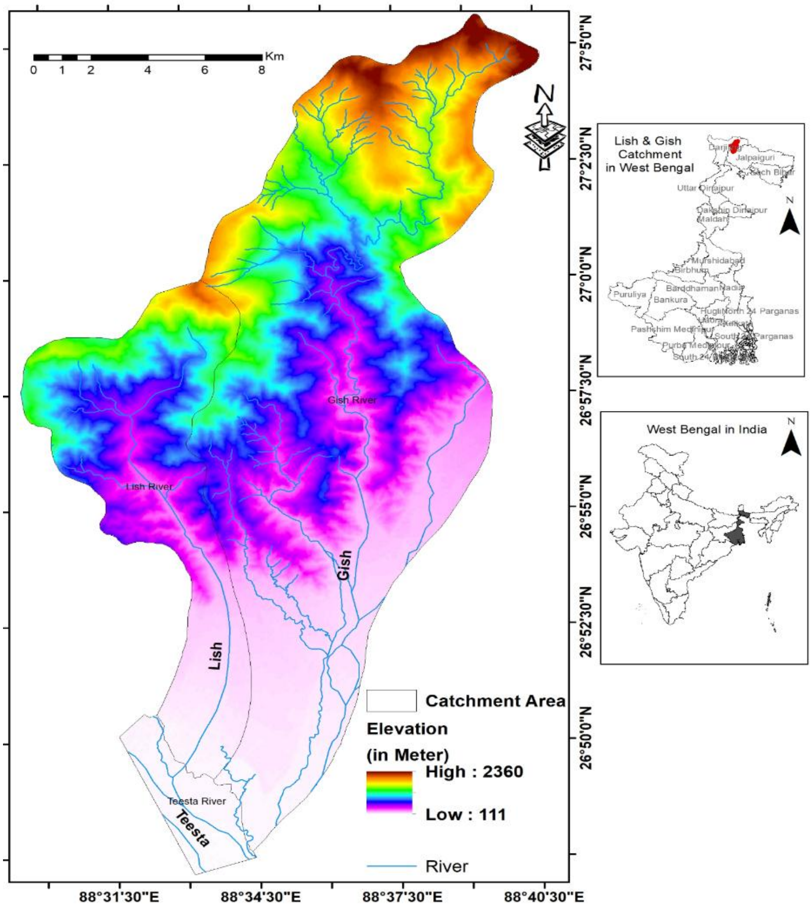


***Figure 1:** Location map of Lish and Gish catchment area*

The rivers are also not without an eventful history, the Lish and Gish are the rivers which originate at the Kalimpong hills, flow down towards the south and join the Murti River, a tributary of the Jaldhaka (*Figure 1*).

The Lish and Gish rivers are the primary freshwater conduits in the region- they supply homes, agricultural lands and day to day activities. At the higher elevations of their basins predominate the sands soil of loam and gravelly nature, which in any case may be readily eroded whenever the steep declivities come in force upon the onslaught of heavy rainfalls. When the rivers reach their lower courses, they have deposited thick loamy alluvium which underlies the fertile lands further down the river.

An assortment of rural peoples, the liveliest of which are the Nepali, the Rajbanshi and the Adivasi, are scattered across hamlets and Nepali villages along these waterways. Small scale farming, horticulture and tea gardens are part of the local economy as they form the backbone of their livelihoods.

But it is a fine balance that is shredding. Environmental stresses are increasing as a result of population growth, uncontrolled deforestation and haphazard development. A watershed management plan that combines traditional knowledge and conservation methods with the modern ones is strongly necessary in order to protect these crucial rivers and individuals who rely on them.

Materials and Methods

Mapping of the Lish and Gish catchments was done by combining the old Survey of India (SOI) Toposheets with the current satellite generated terrain information. In particular, we matched scanned Toposheets (Digitized and Georeferenced in WGS84 datum and UTM projection system) with 30m Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM).

Control points (Latitude & Longitude) on major intersections were used to align the Toposheets. Around every sheet as it was registered we digitized manually the principal hydrographic network, ridgelines and contour lines, so topographical features were recorded in a topographic fashion.

USGS Earth Explorer has SRTM DEM tiles which were downloaded. The 30m resolution offered the advantage of increased vertical resolutions, and we used this to our advantage by automating the watershed delineation. The DEM was pre-processed (void filling, re-gridding to UTM) and then a part of the GIS workflow.

Using standardized measures in the watershed analysis (Javed et al., 2009; Magesh et al., 2012), so that the basins that have been delineated can be compared with the earlier ones and used in downstream hydrologic models and management activities.

Watershed Delineation

The initial pre-processing of the Digital Elevation Model (DEM) was conducted using the Fill tool in ArcGIS to rectify any irregularities or depressions (sinks). This step is crucial for ensuring hydrological continuity, thereby allowing water to flow seamlessly across the terrain. Following this, the Flow Direction tool was applied to determine the path of water flow from each cell to its steepest downslope neighbor, post-hydrological adjustment of the DEM. This information is foundational for further hydrological modeling. In conjunction with the flow direction raster, the Flow Accumulation tool was employed to compute the total flow into each cell. This process identifies areas where water naturally converges, which is essential for pinpointing key drainage pathways. Cells with flow accumulation values surpassing a certain threshold are classified as streams, facilitating the assignment of unique identifiers to stream segments and the establishment of a hierarchical stream order structure (such as the Strahler ordering system).

The identification of pour points or outlet locations, which function as the starting points for watershed delineation, is an essential step subsequent to defining the stream network's structure. These pour points are typically situated where water exits the drainage basin, specifically at the outlet of interest. The Watershed tool employs pour point data in conjunction with the flow direction raster to delineate the contributing watershed area for each point.

Linear Aspect

Table 1: *Linear aspect of morphometric parameters of watershed*

Morphometric Parameters	Description	Formula	Interpretation	Reference
Stream Order (U)	Hierarchical classification of streams using Strahler's method. First-order streams have no tributaries; when two streams of same order merge, they form a higher order.	$U = \max\{U_1, U_2\} + 1$	Indicates the hierarchy of the drainage network. Higher orders signify mature, well-developed systems.	Strahler (1957)
Stream Number (Nu)	Total number of streams in each order. Follows Horton's law – stream numbers decrease with increasing order.	$N_u = {R_b}^{(U_{max} - U)}$	High stream numbers in lower orders indicate youthful stage and active erosion.	Horton (1945)
Stream Length (Lu)	Total length of all streams in each order.		Helps in understanding the drainage development and topography.	Horton (1945)
Mean Stream Length (Lmean)	Average length of streams in a given order.	$L_{mean} = \frac{L_u}{N_u}$	Longer mean lengths indicate lower gradient and mature topography. Shorter lengths suggest steeper slopes.	Horton (1945)
Length Ratio (RL)	Ratio of mean stream length of a given order to the next higher order.	$R_L = \frac{L_{mean}(U+1)}{{L_{mean}}^{(U)}}$	High RL values indicate increased erosion potential and tectonic influence.	Horton (1945)
Bifurcation Ratio (Rb)	Ratio of number of streams in one order to the next higher order.	$R_b = \frac{N_u}{N_u + 1}$	Lower values suggest uniform geology; higher values indicate structural control or disturbances.	Horton (1945)
Mean Bifurcation Ratio	Average of all bifurcation ratios across the stream orders.	$\overline{R_b} = \frac{\sum R_b}{n}$	Useful for comparing drainage basins; consistent values reflect mature and stable basins.	Horton (1945)

Areal Aspect

An understanding of the area around a micro-watershed is necessary for comprehending its hydrological behavior, vulnerability to erosion, and flood potential. Drainage Density (Dd), Texture Ratio (Rt), Stream Frequency (Fs), Form Factor (Ff), Elongation Ratio (Re), Circularity Ratio (Rc), and Length of Overland Flow (Lg) are some of the key Morphometric criteria used to evaluate watershed features. These parameters are determined using both GIS-based tools and well-known Morphometric computations, as described by Horton (1945), Strahler (1964), and Schumm (1956).

Table 2: *Areal aspect of morphometric characteristics in the study area*

Morphometric Parameter	Formula	Description	Interpretation	Reference
Drainage Density (Dd)	$D_d = \frac{L_u}{A}$	Total stream length per unit watershed area.	• High Dd (>2.0): High runoff, low infiltration. • Low Dd (<1.0): High infiltration, permeable surface.	Horton (1945)
Texture Ratio (Rt)	$R_t = \frac{N_u}{P}$	Measures drainage texture based on number of streams and perimeter.	• High Rt: Rugged terrain, weak lithology, high runoff. • Low Rt: Resistant lithology, smooth terrain, high infiltration.	Horton (1945)
Stream Frequency (Fs)	$F_s = \frac{N_u}{A}$	Number of streams per unit area.	• High Fs (>5.0): High runoff, erosion risk. • Low Fs (<3.0): Better groundwater recharge.	Horton (1945)
Form Factor (Ff)	$F_f = \frac{A}{L_b^2}$	Indicates watershed shape and influence on flood peak.	• Ff > 0.5: Circular basin, high peak discharge. • Ff < 0.5: Elongated basin, low peak discharge.	Horton (1945), Strahler (1964)
Elongation Ratio (Re)	$R_e = \frac{2}{L_b}\sqrt{\frac{A}{\pi}}$	Indicates basin elongation and flood potential.	• Re > 0.8: Circular basin (high flood potential). • 0.5 < Re < 0.8: Oval basin (moderate risk). • Re < 0.5: Elongated (low flood potential).	Schumm (1956)
Circularity Ratio (Rc)	$R_c = \frac{4\pi A}{P^2}$	Compares watershed shape to a circle, influenced by geology.	• Rc → 1: Circular basin, high flash flood risk. • Rc < 0.5: Elongated basin, low flood risk.	Miller (1953), Strahler (1964)

Length of Overland Flow (Lg)	$L_g = \frac{1}{2D_d}$	Average water travel distance before reaching stream channel.	• High Lg: Longer infiltration time, lower runoff velocity. • Low Lg: Steeper slopes, rapid surface runoff.	Horton (1945)

Relief Aspect

To comprehend the dynamics of a watershed, relief features are necessary because they have a significant impact on patterns of surface runoff, erosion, and the growth and development of landforms. Important relief metrics like the Relative Relief (R), the Relief Ratio (Rh), the Dissection Index (Dis), and the Ruggedness Number (Rn) are frequently used in watershed evaluation. These markers are crucial for assessing the degree of erosion, the ruggedness of the terrain, and the likelihood of flooding.

***Table 3:** Analyzing morphometric parameters of relief aspect in the study area*

Parameter	Formula	Components	Interpretation	Hydrological Implication
Relative Relief (R)	$R = H_{max} - H_{min}$	- Hmax: Maximum elevation (m)	- **>1000 m**: Highly dissected, steep terrain	- Higher R: Steep slopes, rapid surface runoff
		- Hmin: Minimum elevation (m)	- **<500 m**: Gently sloping terrain	- Lower R: Slow runoff, increased infiltration
Relief Ratio (Rh)	$R_h = \frac{R}{L_b}$	- R: Relative Relief (m)	- **>0.5**: Steep watershed	- High Rh: Intense erosion, rapid flow
		- Lb: Maximum basin length (m)	- **<0.2**: Gentle watershed	- Low Rh: Low erosion potential, better water retention
Dissection Index (Dis)	$Dis = \frac{R}{H_{max}}$	- R: Relative Relief (m)	- **~1.0**: Highly dissected, unstable terrain	- High Dis: Intense vertical erosion
		- Hmax: Maximum elevation (m)	- **~0.3 or less**: Moderately dissected	- Low Dis: More stable slopes and lower erosion intensity
Ruggedness Number (Rn)	$R_n = R\ x\ D_d$	- R: Relative Relief (m)	- **>2.0**: Very rugged terrain	- High Rn: Susceptible to landslides, erosion, and flooding
		- Dd: Drainage density (km/km^2)	- **<1.0**: Smooth terrain	- Low Rn: Lower geomorphic and flood risk

Estimation of Prioritization of Micro-watershed

Morphometric analysis, which quantifies the watershed's physical shape and drainage characteristics, serves as the primary foundation for this ranking. Linear, areal, and relief are the three main types of morphometric characteristics, according to Patel et al. (2012). These parameters aid in comprehending the possible flow dynamics and erosion intensity while also reflecting the drainage system's maturity and intricacy. Using metrics such as drainage density, stream frequency, texture ratio, form factor, elongation ratio, circularity ratio, and length of overland flow, the Areal aspects describe the watershed's shape, drainage texture, and surface features. The risk of flooding, the rate at which rainfall is converted into surface runoff, and the watershed's capacities for infiltration are all affected by these factors. Using relative relief, relief ratio, ruggedness number, and dissection index, the relief aspects take into consideration the watershed's vertical dimension and topographical variation. When evaluating the movement of water and sediments across the landscape, these factors are crucial because they determine slope steepness, terrain ruggedness, and erosion potential (Nag, 1998). By ranking micro-watersheds according to a composite prioritization index that is created by computing and evaluating these variables using GIS and remote sensing techniques, planners can determine which regions are most vulnerable and require immediate conservation and development interventions.

***Table 4:** Demarcation of parameters for micro-watershed prioritization*

Aspect	Morphometric Parameter	Impact
Linear Aspects	Stream Order (U)	Higher-order streams indicate a mature drainage system.
	Stream Number (N_u)	High number → Denser drainage, more erosion risk.
	Stream Length (L_u)	Long streams indicate higher runoff potential.
	Mean Stream Length (L_m)	Indicates permeability and infiltration capacity.
	Bifurcation Ratio (R_b)	High R_b → Structural control, lower infiltration.
	Mean Bifurcation Ratio (R_{bm})	Helps in understanding overall branching complexity.
Areal Aspects	Drainage Density (D_d)	High D_d → High runoff, low infiltration.
	Texture Ratio (R_t)	High R_t → High erosion susceptibility.
	Stream Frequency (F_s)	High F_s → High surface runoff.
	Form Factor (F_f)	High F_f → Compact basin, flash floods risk.
	Elongation Ratio (R_e)	Near 1.0 → Circular, more runoff; Near 0.5 → Elongated, better retention.
	Circularity Ratio (R_c)	Near 1.0 → High flood risk, compact basin.

Aspect	Morphometric Parameter	Impact
	Length of Overland Flow (L_g)	Small L_g → High runoff, short infiltration time.
Relief Aspects	Relative Relief (R)	High R → Higher erosion risk.
	Relief Ratio (R_h)	High R_h → Steep terrain, more runoff.
	Dissection Index (Dis)	High Dis → Highly dissected, rugged terrain.
	Ruggedness Number (R_n)	High R_n → High erosion risk, unstable terrain.

Advanced GIS and Remote Sensing methods are used to calculate each morphometric parameter, allowing for precise and in-depth spatial analysis. After that, these parameters are evaluated and ranked according to how much of an impact they have on watershed behavior. Using methods like Multi-Criteria Decision Analysis (MCDA), appropriate weights are assigned to ensure a balanced evaluation. Finally, the following formula is used to generate the Composite Priority Index (CPI), which is used to quantify and ascertain the overall priority level of each micro-watershed:

$$CPI = \sum W_i \; x \; R_i$$

Where,

W_i represents the weight that is given to a parameter, and R_i is the parameter's rank.

Based on the CPI values, watersheds are classified into high, medium, and low priority categories. Due to a higher risk of erosion, flash floods, or poor drainage, high-priority watersheds require immediate conservation measures, whereas low-priority watersheds require minimal intervention. This GIS-based prioritization approach provides a scientific, objective, and data-driven framework for effective watershed management, erosion control, and sustainable resource planning.

Results & Discussion

Delineation of micro-watershed characteristics in the study area

There is a significant variation in the total length of watercourses within each catchment, ranging from 11,211.76 meters to 34,749.24 meters, indicating variations in the study area's drainage network density. The wide range of stream lengths found in various catchments is shown by the average lengths of these watercourses, which range from 398.79 meters to 1,121.17 meters ***(Figure 2).*** In addition, the watershed's Geomorphological complexity and heterogeneity are exemplified by the fact that the standard deviation of watercourse lengths ranges from 444.60 meters to 890.12 meters, indicating a wide range of stream length variability.

Linear Aspect

The linear Morphometric parameters that are associated with the micro-watersheds in the Lish and Gish catchment area were examined in order to comprehend the characteristics of the stream network as well as the consequences for the behavior of the hydrological system. Stream order, number, length, mean length, length ratio, bifurcation ratio, and mean bifurcation ratio were all incorporated into the analysis. Stream orders ranged from first to fourth in all five micro-watersheds, with first-order streams dominating, indicating the beginning of geomorphic growth and development. The number of streams varied greatly due to slope, lithology, and land use; Watershed 1 had 192 first-order streams in total, whereas Watershed 4 had only 21. Variations in drainage initiation were reflected in this variation. The total lengths of streams within each order generally decreased as stream order increased, indicating a naturally occurring development of hierarchical drainage, as stated by Horton's (1945) law of stream lengths. The mean stream lengths, which ranged from as little as 0.302 kilometers in Watershed 1 (1st order) to as much as 1.016 kilometers in Watershed 4 (1st order), ***(Table 5),*** showed different patterns of stream development and elongation.

Each watershed had a mean bifurcation ratio between 1.55 and 3.26, and the bifurcation ratio (Rb), which gauges the level of branching in the drainage network, varied from 0.323 to 6.8. These values, which typically fall within the typical natural range of 3–5, as proposed by Strahler (1964), indicate a structurally regulated drainage system with few geological disturbances.

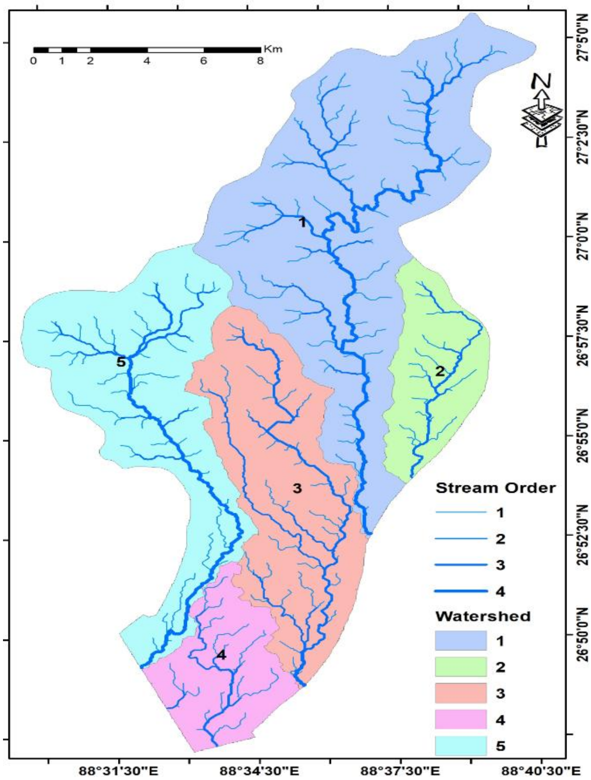


Figure 2: *Delineation of micro-watershed in the Lish and Gish catchment area*

Steeper terrain or potential structural controls are suggested by higher bifurcation ratios, such as 6.8 in Watershed 3 between the third and fourth order. Nag (1998) found that a decreasing length ratio might indicate mature geomorphic development and minimized erosional intensity. The length ratio values, which indicated the proportionate change in stream length across subsequent orders, varied between 0.668 to 1.836.

Table 5: *Linear aspect of micro-watershed in Lish and Gish catchment area*

Watershed	Stream Order	Stream Number	Stream Length	Mean Length	Length Ratio	Bifurcation Ratio	Mean Bifurcation Ratio
1	1	192	58.021	0.302	-	5.053	2.425
	2	38	21.089	0.555	1.836	1.900	2.425
	3	20	11.190	0.559	1.008	0.323	2.425
	4	62	31.474	0.508	0.907	-	2.425
2	1	44	14.810	0.337	-	2.588	1.680
	2	17	7.403	0.435	1.294	0.773	1.680
	3	22	7.024	0.319	0.733	-	1.680
3	1	65	33.785	0.520	-	2.031	3.257
	2	32	22.609	0.707	1.359	0.941	3.257
	3	34	20.524	0.604	0.854	6.800	3.257
	4	5	2.075	0.415	0.688	-	3.257
4	1	21	21.341	1.016	-	2.100	1.550
	2	10	7.239	0.724	0.712	1.000	1.550
	3	10	4.833	0.483	0.668	-	1.550
5	1	80	39.053	0.488	-	3.478	1.783
	2	23	12.942	0.563	1.153	1.438	1.783
	3	16	6.223	0.389	0.691	0.432	1.783
	4	37	19.958	0.539	1.387	-	1.783

Because they are more likely to experience erosion, watersheds 1 and 5 have the highest average weight in this study (3.07), making them high-priority locations that require immediate soil and water conservation measures. With a moderate weight of 2.93, Watershed 3 is classified as medium priority, indicating the necessity of periodic management. With the lowest weight (2.64), watersheds 2 and 4 are classified as low priority, demonstrating minimal erosion risk and generally stable hydrological circumstances ***(Figure 3).***

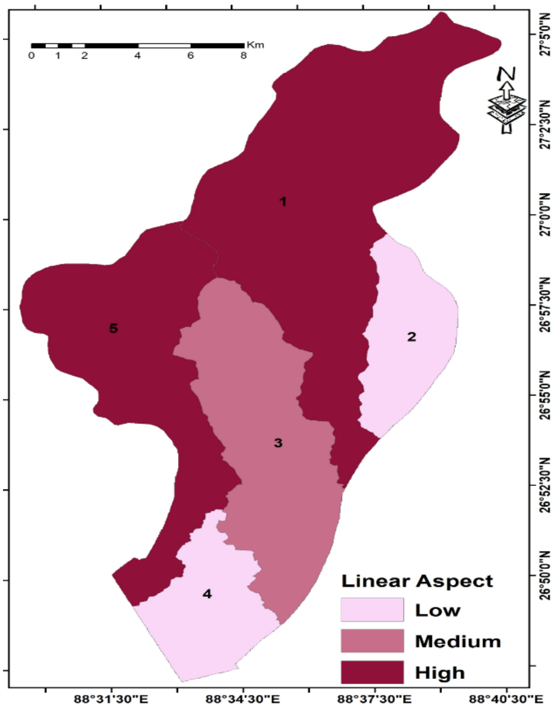


Figure 3: *Micro-watershed prioritization based on linear aspect*

Areal Aspect

This strategy is in line with previous research's methods. Using comparable Morphometric criteria and linear parameters, Nooka Ratnam et al. (2005) prioritized sub-watersheds in the Gudelair watershed, placing an emphasis on.

Table 6: *Areal aspect of micro-watershed in Lish and Gish catchment area*

Watershed	**Area (sq.km.)**	**Perimeter (km.)**	**Watershed (km.)**	**Dd**	**Rt**	**Fs**	**Ff**	**Re**	**Rc**	**Lg**
1	114.108	66.996	1.932	1.067	2.866	2.734	30.561	6.238	0.319	1.874
2	24.523	25.254	2.541	1.192	1.742	3.385	3.798	2.199	0.483	1.678
3	5.967	47.389	2.097	13.240	1.372	22.794	1.357	1.314	0.033	0.151
4	25.572	27.773	3.178	1.307	0.756	1.603	2.531	1.795	0.417	1.531
5	65.603	56.525	3.778	1.192	1.415	2.378	4.597	2.419	0.258	1.678

Dd- *Drainage Density;* ***Rt-*** *Texture Ratio;* ***Fs-*** *Stream Frequency;* ***Ff-*** *Form Factor;* ***Re-*** *Elongation Ratio;* ***Rc-*** *Circularity Ratio;* ***Lg-*** *Length of Overland Flow*

Both Watersheds 2 and 5 have stream frequencies of 3.385 and 2.378, respectively, and moderate drainage densities of 1.192 km/km². With moderate elongation ratios of 2.199 and

2.419 and higher circularity ratios of 0.483 and 0.258, their relatively compact shapes suggest a more balanced hydrological behavior with controlled runoff and reasonable infiltration. Watershed 4 has a similar area to Watershed 2, but it has a drainage density that is slightly higher (1.307) and a texture ratio that is lower (0.756), indicating a variety of soil permeability and dangerous conditions (***Figure 3***).

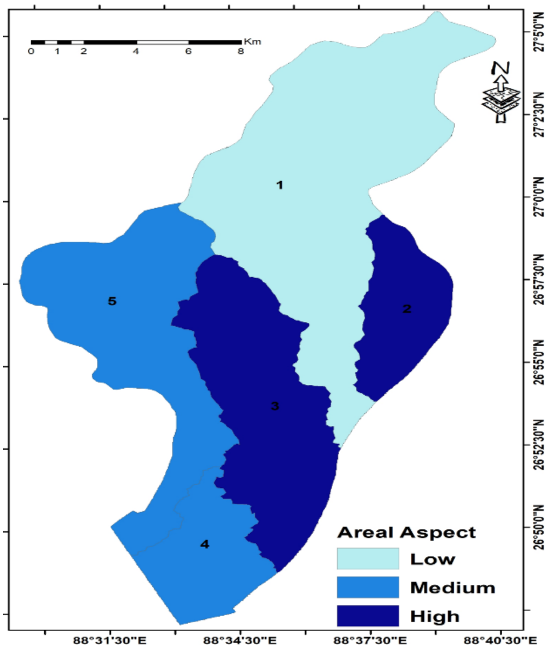


Figure 4: *Micro-watershed prioritization of Lish and Gish catchment area based on areal aspect*

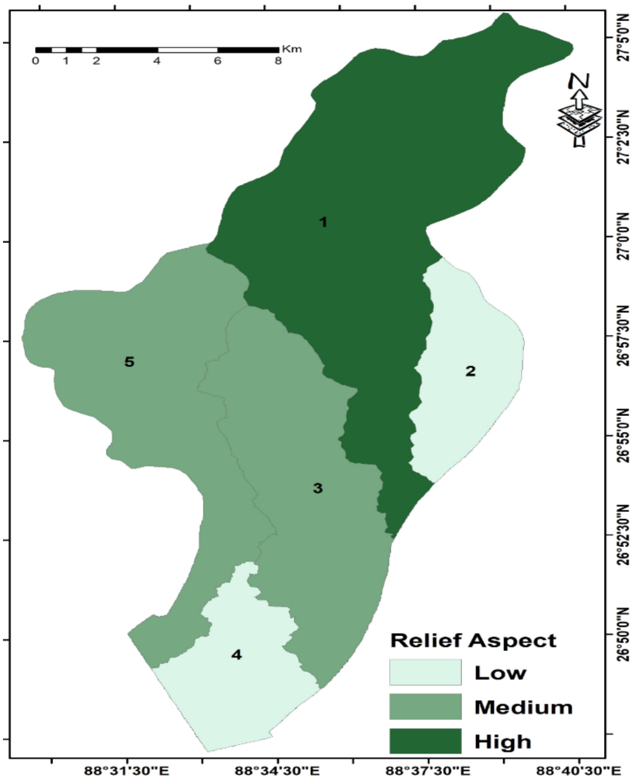
The statistics show that the surface water's distance before it cascades into streams is determined by the slope and topography. With Watershed 3, we only get 0.151 kilometers of overland flow, which tells us that the topography is steep and that the water flows easily in the direction of the channel. On the other hand, Watershed 1 spans a much further distance of 1.874 kilometers, indicating gentler slopes, more vegetated buffers, and runoff that is slower and more diffuse. These dissimilar lengths emphasize the speed at which water can be directed to the stream network in certain catchments and the fact that in other catchments, a slower journey may result in an increased infiltration and evapotranspiration of water which is then released.

Using areal Morphometric parameters like drainage density, texture ratio, stream frequency, form factor, elongation ratio, circularity ratio, and length of overland flow, Microwatershed prioritization gives important insights into watershed shape, drainage efficiency, and surface runoff behavior. These parameters are essential for assessing vulnerability to erosion and for guiding sustainable water resource planning. Based on the average weight age derived from these factors, Watersheds 2 and 3 are identified as high priority due to their greater susceptibility to runoff and erosion, warranting immediate conservation efforts. Watersheds 4 and 5 fall into the medium priority category, indicating moderate risk and the need for regular monitoring. Because of its low weight, Watershed 1 is given a low priority because of its stable geomorphic conditions and lower potential for erosion.

Relief Aspect

A comprehension of the relief component of the micro-watersheds in the Lish and Gish catchment areas is required to comprehend the landscape's topographic variability, erosional potential, and runoff behavior. Watershed 1 has the highest relative relief (2201 m) and the highest ruggedness number (2.349). It has steep slopes and a highly dissected terrain that is susceptible to soil erosion and rapid runoff. Similar to this, Watershed 5 has a ruggedness number of 2.125 and a relative relief of 1783 meters, both of which indicate a significant level of relief and terrain complexity. These watersheds urgently require slope stabilization and erosion control measures due to their increased susceptibility to surface runoff. Despite having a moderately lower relative relief (1222 m) and relief ratio (0.583), Watershed 3 has a very high ruggedness number (16.179). This is due to the combination of moderate relief and very high drainage density ***(Table 7).***

Due to the compound effect of steep slopes and dense drainage, it is an essential zone for erosion control. Watershed 2 depicts an intermediate terrain with moderate erosion susceptibility and balanced relief conditions with moderate values for all parameters. On the other hand, Watershed 4 has the lowest values for all relief metrics, such as the relative relief (67 meters), relief ratio (0.021), dissection index (0.376), and ruggedness number (0.088). These metrics indicate that the terrain is flat and that there is little slope instability.



According to the findings of Kanth and Hassan, geologically and hydrologically active zones with higher relief and ruggedness values necessitate prioritizing soil and water conservation. Similar to this, Sreedevi et al. (2005) demonstrated that ruggedness and relief ratio, which reflect hydrological response and erosion vulnerability in arid and semi-arid landscapes are essential indicators for watershed priority determination.

Table 7: *Relief aspect of micro-watershed in Lish and Gish catchment area*

Watershed	Relative Relief (R)	Relief Ratio (Rh)	Dissection Index (Dis)	Ruggedness Number (Rn)
1	2201	1.139	0.933	2.349
2	979	0.385	0.844	1.167
3	1222	0.583	0.910	16.179
4	67	0.021	0.376	0.088
5	1783	0.472	0.939	2.125

Composite Priority Index

Three important Geomorphometric factors-linear, areal and relief parameters-are combined to create the Compound Priority Index (CPI), which offers an integrated assessment of micro-watersheds. Effective prioritization for conservation and management interventions is made possible by this thorough index, which enables a balanced evaluation of runoff potential, erosion vulnerability, and watershed response to hydrological processes.

With a leading rank in the relief aspect (4.50) as well as significant values for the linear (3.07) and areal (2.71), Watershed 1 in the Lish and Gish catchment area has a high CPI value of 3.43. It falls into the high-priority category, indicating a landscape that is prone to erosion and has a rough geomorphology. With a CPI of 3.37 and 3.23, Watersheds 3 and 5 are also considered to be of medium priority. These watersheds are characterized by steep slopes, extensive drainage systems, and high relief values. As a result, efforts to conserve soil, control drainage, and restore watersheds are urgently required. Watersheds 2 and 4, on the other hand, are categorized as low priority due to their respective CPI values of 2.79 and 2.17. Because of their stable topographic profile, less dissected terrain, and decreased runoff risk, these watersheds have comparatively lower average ranks in relief and linear parameters ***(Table 8).*** As a result, they only require minimal conservation efforts and routine monitoring.

Table 8: *Estimation of CPI value of Lish and Gish catchment area*

Watershed	Average Rank Linear	Average Rank Area	Average Rank Relief	CPI	Priority
1	3.07	2.71	4.50	3.43	High
2	2.64	3.71	2.00	2.79	Low
3	2.93	3.43	3.75	3.37	High
4	2.64	2.86	1.00	2.17	Low
5	3.07	2.86	3.75	3.23	Medium

The use of CPI for micro-watershed prioritization has been established by previous research investigations. For example, Biswas et al. (1999) highlighted that CPI is useful for combining several Geomorphometric parameters to systematically identify areas that are susceptible to erosion. Similar to this, Nooka Ratnam et al. (2005) demonstrated that a sensible and balanced prioritization strategy that is especially useful in hilly and semi-arid regions can be achieved by giving equal weight to linear, areal, and relief parameters. In a number of catchments across India and abroad, these strategies have been utilized to maximize resource allocation and watershed development.

Summary and Conclusion

To measure the micro-watersheds of the Lish and Gish catchments, a thorough Morphometric analysis, which includes such measures as linear, areal, and relief, was carried out. We were able to establish a direct connection between topography and hydrologic processes like sediment transport, erosion potential, and runoff generation by measuring slope, basin form, and stream network complexity. The review revealed that the micro-watersheds differed significantly in relief, basin geometry, and stream pattern. The differing urgency of conservation interventions and the varying susceptibility of each region to environmental degradation are what differentiate these variations. Consequently, watershed management strategies can be adapted to the Morphometric realities of a specific micro-watershed, ensuring that resources are allocated to the areas where they will have the greatest impact.

Among the linear aspects, drainage density, bifurcation ratio, and stream frequency were identified as primary indicators of erosion prospective and drainage effectiveness. Due to their high drainage density and stream frequency scores, which indicate extensive drainage systems that are susceptible to surface runoff and sediment transport, watersheds 1 and 5 are categorized as high-priority conservation areas. Due to its extremely rugged terrain and high ruggedness number, Watershed 3 was also found to be susceptible to rapid runoff and severe erosion, requiring prompt action.

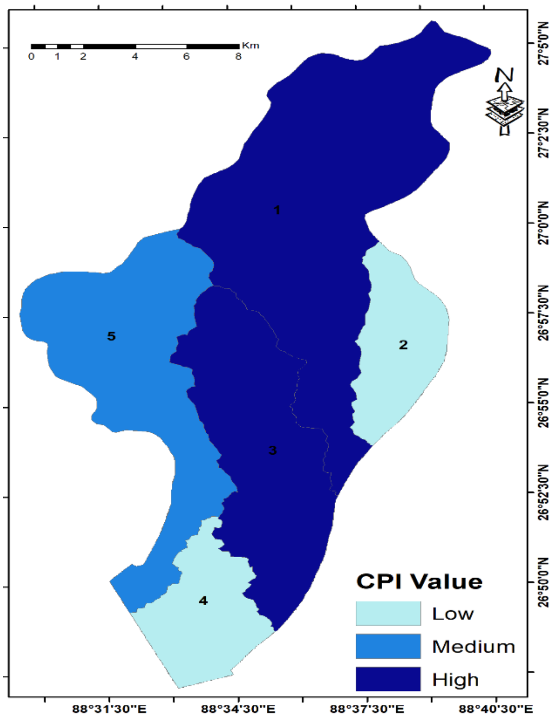


Figure 5: *Composite Priority index of micro-watershed in Lish and Gish catchment area*

The areal parameters form factor, elongation ratio, and circularity ratio revealed the micro-watersheds shape and flow characteristics. The discovery of highly circular and extended watersheds 2 and 3 suggests a shorter lag time, faster flow concentration, and increased vulnerability to flooding. These geometric characteristics influenced their designation as high-priority areas. The steepest slopes of the landscape were the most interesting feature of the relief analysis as they highlight the susceptibility of the soil to gravity-based erosion. The most vulnerable watershed was Watershed 1, the most relative relief and ratio of relief. In the meantime Watershed number 3 deserved its conservation priority due to its remarkable ruggedness, its Number of Ruggedness is the highest in the chart at 16.179, a clear indication of a landscape that cannot be kept without close attention.

This study Using the Composite Priority Index (CPI), which averages ranks from the required linear, areal, and relief parameters, the study determined that Watersheds 1 and 3 are extremely susceptible to degradation and require urgent soil and water conservation measures, such as check dams, contour bunds, Afforestation, and sustainable land management techniques. Given their comparatively stable Geomorphometry and reduced risk of erosion, Watersheds 2 and 4 were categorized as low priority, while Watershed 5 was assigned medium priority.

Both Biswas et al. (1999) and Nooka Ratnam et al. (2005) emphasized the significance of Morphometric-based prioritization in watershed management programs for directing resource allocation and identifying vulnerable zones. The study suggests that future research incorporate soil characteristics, climatic factors, and data on land use and land cover for a more sophisticated approach to prioritization. All things considered, this prioritization framework offers a useful and scientifically sound instrument for erosion control and sustainable watershed development in the Lish and Gish catchment area.

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