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Morphometric characteristics of Manas River Basin, Assam

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Abstract

The Manas River Basin in Assam (India) and the Bhutanese Himalayas in the Brahmaputra River system is an ecologically and hydro-geologically vital sub-basin. This paper presents a robust morphometric analysis where the Geographic Information System (GIS) techniques and Digital Elevation Model (DEM) have been utilized in a bid to assess drainage features of the basin, hydrological process and the consequences of various water resource management, flood control, soil conservation, and environment sustainability. The stream order, bifurcation ratio, drainage density, stream frequency, form factor, elongation ratio, and circulatory ratio that are morphometric parameters (these parameters were computed based on geomorphological methods). The findings show that with eight stream orders and majority of streams in ranks of first order, the basin has low drainage density (0.79 km/km^2) and stream frequency (0.49), indicating low infiltration capacity, dense vegetative cover and permeable surface land substance. Longitudinal basin shape (form factor 0.03; elongation ratio ~0.6 0.9) provides longer lag time and reduced flood peak magnitude, and relief/contrast between north-facing steep hills versus the south facing gentle plains affects velocity of runoff flows and erosion and sediment transport. Hydrological study shows powerful rainfall-discharge relations that have lagged in runoff responses as a result of infiltration and storage impacts. Those results reflect the moderate flood vulnerability of the basin in normal conditions and the increased exposure to localized flash floods in the northern tributaries in extreme situations. Morphometric knowledge can be incorporated in planning the basins to implement specific activities like upstream control of floods, stabilization of soil in erosion prone regions, utilization of rainwater in plains, and protection of wet species that are ecologically sensitive. The research would provide the essential baseline morphometric characterization based on which sustainable, climate-resilient water and land management plans would be established in the Manas River Basin.

Keywords: Manas River Basin, Bhutanese Himalayas, Brahmaputra River system, morphometric analysis, water resource management, soil conservation

1. Introduction

The river basins are also crucial hydrological units in which rainwater is gathered, captured and directed via a series of tributaries into a major river system. Their shape, which is formed under the influence of geological, climatic and anthropogenic factors, predetermines the mechanism of hydrological reactions, sediment transportation, floods, and biological mechanisms. Learning about these physical characteristics using morphometric analysis gives us a quantitative relationship to evaluate properties of basins and can be used to postulate how water-related processes may occur. Compared to other Manas river basin tributaries, the Brahmaputra River flow drains in Assam, India and the country of Bhutan, which is both ecologically rich and significant hydrologically, within the greater Brahmaputra drainage system. It nurtures different habitats, such as, the UNESCO World Heritage-listed Manas National Park to support the local agricultural livelihoods. Nonetheless, the disparate physiographic zones of the basin (higher, steep, and erosional Himalayan headwaters to low-gradient flood lands) pose complicated issues of water management. Its geomorphic structure needs integrated underlying as brought about by seasonal monsoon floods, heavy loads of sediments and rising demands due to its development. The paper examines GIS-enhanced morphometric analysis to describe the drainage pattern, shape and relief of the basin thus guiding water resource management and flood management strategies, soil conservation practices and ecological sustainability of Manas River Basin.

2. Study Area

Many decades have been spent on the analysis of the river basins and the analysis of the morphometric features of these rivers (Singh et al., 2020; Abrar et al., 2024). A river basin is the natural hydrological unit in which precipitation is accumulated and drained through the chain of tributaries in the direction of a primary river channel and finally to a large water mass (Tandon & Sinha, 2022). The geological, climatic, anthropogenic factors together give the physical form and structure of this drainage network in terms of its size, shape, slope, and pattern (Jha et al., 2022). Morphometric work would give a quantitative concept in describing these features giving information on functionality and possibility of resource-based management of the basin. Manas River Basin is an ecologically as well as hydrologically important catchment area in the northeastern state of India, Assam, in the larger drainage of river Brahmaputra (Begum & Al Huda, 2023). The river Manas has its origin in the Bhutanese Himalayas and flows to the south into Assam and merging with the Brahmaputra (Pradhan et al., 2021). The basin is hydrologically significant as well as ecologically rich, including areas of the Manas National Park a World Heritage site of UNESCO and is known to have a rich variety of flora and fauna and essential wildlife habitats. Such bipolar significance environmental as well as hydrological makes the Manas River Basin a perfect example to cope with a detailed morphometric analysis.

Geomorphologically, the Manas River Basin can be described as having a diversified physiography (Bhattacharyya, n.d.). At its upper course, the river flows in steep Himalayan environments with high relief that makes it a swift-flowing stream with quite a lot of sediment. At the point of entering the Assam plains, the gradient gets lower, the river is more meandered, and floodplains play a predominant role. Such physiographic differences not only affect the hydrology of the river but also the transport of the sediments, flood capability and the agriculture and settlement feasibility (Juan-Diego et al., 2025; Nayak & Shukla, 2022). The morphometry of such a basin can be revealed by showing how the distribution of streams and slopes determines flow of water and access to resources. Traditionally river basin studies in Assam have paid more attention to flood risk, erosion of the river bank, and the potential of the hydropower (Krishnan, 2023; Pradhan et al., 2021). Morphometric research has been relatively less common, and where they have been done; they tend to concentrate on smaller sub-watersheds as opposed to the whole basin (Pastor et al., 2024). This leaves a missing link in the interpretation of the integrated physical properties of larger basins such as the Manas. The quantitative knowledge of the form of the basin is imperative to the sustainable development work in conditions of climate change, rapid population growth, and rapid increase in developmental pressure in Assam (Gogoi & Debbarma, 2025).

Manas River Basin is subject to seasonal flooding, which occurred especially during the southwest monsoon season of June to September, when torrential rains received in the foothills of the Himalayas caused flooding and rising levels in the Brahmaputra (Nagamani et al., 2024). Moreover, the geomorphology of the basin, steep upper part with a wide and broad lower floodplain, is a dominant factor in flood magnitude, and frequency (Adnan et al., 2019). Due to quantifying morphometric characteristics of the basin including drainage density, bifurcation ratio and relief ratio one could predict the region of high runoff potential, possibility of erosion and the risk of flood. Moreover, the personification of the basin is so socio-economical close to their hydrology. Most residents are mostly farmers and depending on where they are located the access to water resources be it surface water or groundwater- they can only be accessed by the spatial distribution of the drainage system (Sabale et al., 2023). Knowledge of morphometric parameters may help with locating the potential water storage, the optimal places to locate check dams, and the areas susceptible to soil erosion.

The power of such analysis, including morphometric study, has been amplified by the development of new geospatial technologies like Geographic Information Systems (GIS) and Digital Elevation Models (DEMs) (Saleem et al., 2019). In case of the Manas River Basin, satellite obtained DEM like SRTM or ASTER offer high-resolution elevation data which can further be converted and used to extract such parameters as slope, aspect, flow accumulation, etc. Not only does this make the analysis much faster than it was in traditional methods but also more accurate and reproducible. Therefore, the context of the present study lies in the intersection of various forces: the geomorphic complexity and ecological significance of Manas River Basin, dependence of the associated socio-economic community on water resources, exposure to floods and erosion, and the necessity of the realization of the quantitative, GIS-based perception of its shape and functionality (Singh, 2022). By means of morphometric analysis, the research tends to cover a significant information vacuum and make a scientific contribution to integrated basin management.

The Manas river Catchment records the highest area coverage of 3683.196 sq.km under the elevation range of 19-54 m. The lowest area coverage is under the highest elevation range (238-462 m) which covers an area of only 203.921 sq. km (Fig.-3).

3. Materials and Methods

The method of the study was planned to analyse the morphometric and hydrological properties of the Manas River Basin using a combination of the geospatial and statistical method to perform the analysis in a systematic manner. The drainage network was delineated using high-resolution Digital Elevation Model (DEM) data, topographic maps and satellite imagery through the help of Geographic Information System (GIS) tools in order to extract morphometric parameters. Streams were ordered according to the Strahler classification scheme (thus have a hierarchical characteristic), and linear, areal and relief dimensions of the basin were measured by well-known formulae relevant to geomorphology. The shape of the basin, texture of drainage and basin runoff characteristics were assessed in terms of parameters including stream length, bifurcation ratio, drainage density, stream frequency, form factor, circulatory ratio and elongation ratio. Long term records of rainfall, temperature, and river discharge were used in the hydrological analysis to evaluate the inter-seasonal variability and precipitation-stream flow relationship. To study the dynamics of the rainfall and runoff, the statistical correlation and regression model was used and geospatial analysis has been employed to generate morphometric attributes in a spatial domain. This integrated approach to methodology kept in place a complete and repeatable analysis of the geomorpholotical and hydrological behaviour of the basin, a sound foundation base of future interpretation and management advice.

3.1 Morphometric Analysis

The morphometric analysis of the Manas River Basin was carried out to understand the basin's drainage characteristics and hydrological behavior. Stream ordering was performed following the Strahler (1964) hierarchical method, which classifies streams based on their relative position in the drainage network.

Several morphometric parameters were computed to quantify the basin's geometric and hydrological properties. These included:

- Stream length (Lu): The total length of streams of each order.
- Stream length ratio (Rl): Ratio of lengths of streams of successive orders.
- Bifurcation ratio (Rb): Ratio of the number of streams of one order to the next higher order, indicating structural control.
- Mean bifurcation ratio (Rbm): Average of bifurcation ratios across all stream orders.
- Stream frequency (Fs): Number of streams per unit area, reflecting drainage density.
- Drainage density (Dd): Total stream length per unit basin area.
- Drainage texture (Rt): Measure of the closeness of spacing of streams.
- Form factor (Rf), circulatory ratio (Rc), and elongation ratio (Re): Indices describing the basin shape and its influence on hydrological response.

The primary data sources included Digital Elevation Models (DEM), topographic maps, and high-resolution satellite imagery. Stream networks were delineated using GIS techniques, enabling accurate computation of linear and areal morphometric parameters.

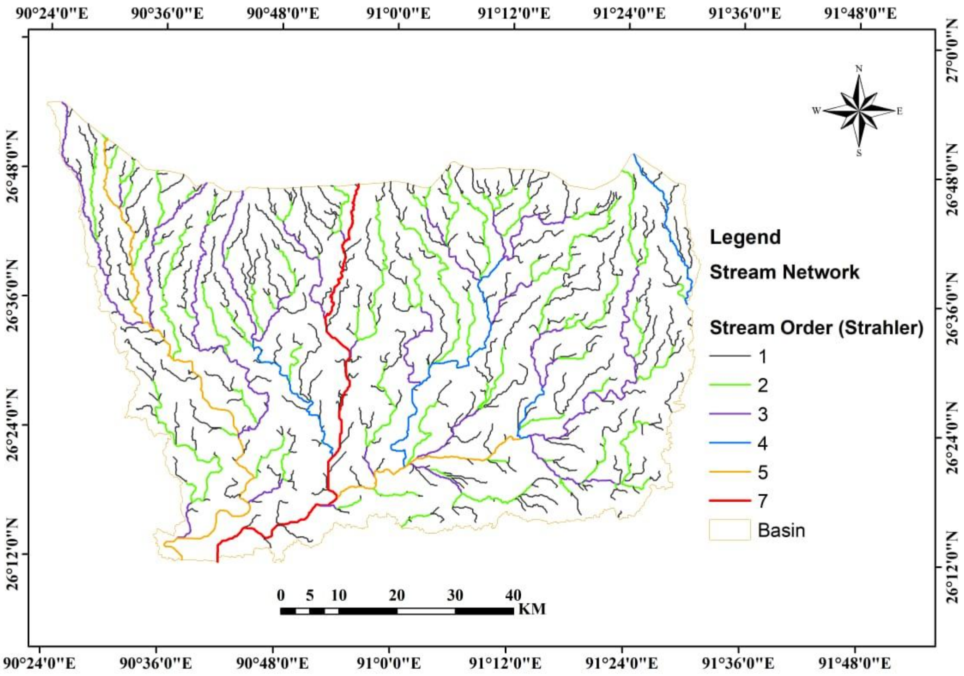

Fig.-1 Drainage Network of Manas River Basin

Table-1: Morphometric Parameter Computation Formula

Sl. No.	Morphometric Parameters	Formulae	References
1	Stream Order (u)	Hierarchical rank	Strahler (1964)
2	Stram length (L_u)	Length of the stream	Horton (1945)
3	Mean Stream Length (L_{sm})	$L_{sm} = L_u/N_u$ Where, L_{sm} = mean stream length L_u=total stream length of order ‘u’ N_u=total no. of stream segments of order ‘u’	Strahler (1964)
4	Stream length ratio (R_L)	R_L = Lu/L_u-1 Where R_L = Stream length Ratio L_u = The total stream length of the ‘u’ L_u-1 = The total stream length of the next lower order.	Horton (1945)
5	Bifurcation ratio (R_b)	R_b=N_u/N_u+1 Where R_b = Bifurcation Ratio N_u = Total no of stream segments of the order ‘u’ N_u+1= No of segments of the next higher order	Schumn (1956)
6	Mean bifurcation ratio (R_{bm})	R_{bm}= average of bifurcation ratios of all orders.	Strahler (1957)
7	Stream Frequency (F_s)	F_s=N_u/A Where F_s=Stream Frequency N_u= Total no of Streams of all order A= Area of the basin(km^2)	Horton (1932)
8	Drainage texture (R_t)	R_t=N_u/P Where R_t= Drainage texture N_u= Total no of streams of all orders P= Perimeter (km)	Horton (1945)
9	Form Factor (R_f)	Rf= A/L_b^2 Where Rf= Form Factor A= Area of the basin (km^2) L_b^2=Square of basin length	Horton (1932)
10	Circulatory Ratio (R_c)	R_c=4*Pi*/P^2 Where R_c= Circulatory Ratio Pi=’Pi’ value i.e. 3.14 A= Area of the basin (km^2) P_2= Square of the perimeter (km)	Miller (1953)
11	Elongation Ratio (R_e)	R_e= 2√(A/Pi)/L_b Where R_e= Elongation ratio A=Area of the basin(km^2) Pi=’Pi’ value i.e. 3.14 L_b=Basin length	Schumn (1956)

3.2 Hydrological Data Analysis

Hydrological characteristics of the basin were assessed using long-term climatic and streamflow data.

- Rainfall: Annual and seasonal rainfall data were analyzed to determine spatial and temporal distribution patterns across the basin.
- Temperature: Monthly and seasonal variations were studied to evaluate their influence on evapotranspiration and runoff generation.
- Discharge: River discharge data were obtained from gauge stations, documenting seasonal fluctuations, peak flow during the monsoon, and low flow during the dry season.

3.3 Data Analysis Techniques

- Geospatial analysis: GIS software was employed to map drainage networks and compute morphometric parameters accurately.
- Statistical analysis: Rainfall and discharge data were analyzed using correlation and regression methods to assess rainfall-runoff relationships and hydrological response of the basin.

These integrated methods provided a comprehensive understanding of the geomorphological and hydrological characteristics of the Manas River Basin.

4. Results and Discussion

The results of the morphometric analysis carried out of the Manas River Basin along with the hydrological analysis of the same is provided with the combination of GIS based measurements along with the statistical analysis of the climatic and the discharge data. Linear, areal and relief morphometric outcomes are arranged accordingly and provide points of insight regarding the configuration of the drainage network of the basin, its shape and its slope. The Hydrological patterns are investigated basing on seasonal distribution of rainfalls, temperature regimes and stream flows behaviour with focus on the rainfalls-runoff systems. Relief and geomorphology characteristics are mentioned with an acccent to notice spatial change in slope in erosion potential as well as the transport of sediments. The overall integration of these parameters gives a platform towards evaluation of the basin in terms of hydrological reaction, and its implication on the management of the water resources, mitigation of floods, soil conservation and ecological sustainability.

4.1 Morphometric Analysis

The morphometric parameters computed for the Manas River Basin are summarized in Table-2 (linear aspects) and Table-3 (areal aspects). The basin exhibits eight stream orders following the Strahler (1964) classification, with a predominance of first-order streams (12,121), which together account for a total stream length of 15,597.09 km.

Table-2: Linear Aspects of Manas River Basin

Stream Order (u)	Number of Streams (N_u)	Total Stream Length (L_u)	Log N_u	Log L_u	Mean Stream Length	Bifurcation ratio (Rb)
1	12121	15597.09	4.08	4.19	1.28	4.77
2	2537	4305.37	3.4	3.63	1.69	4.08
3	621	2354.75	2.79	3.37	3.79	3.8
4	163	1211.51	2.21	3.08	7.43	5.6
5	29	670.77	1.46	2.83	23.13	5.8
6	5	413.29	0.7	2.62	82	1.66
7	3	91.14	0.48	1.96	30	1
8	3	131.70	0.48	2.12	43.72	

The bifurcation ratio (Rb) varies between 1.0 and 5.8, with a mean bifurcation ratio (Rbm) of approximately 3.81. This moderate value indicates that while the drainage network is primarily controlled by topography, there is some influence from underlying geological structures.

The drainage density (0.79 km/km^2) is low, reflecting a coarse drainage texture. This suggests the presence of permeable soils, vegetative cover, and low relief gradients in large parts of the basin. The stream frequency (0.49) is also low, reinforcing the inference of permeable surface materials and low runoff potential.

The form factor (0.03) and elongation ratio (~0.6–0.7, estimated) reveal that the basin is elongated in shape. Such a geometry produces longer lag times between rainfall and peak discharge, lowering the likelihood of sudden flood peaks. The circulatory ratio (0.44) also confirms the elongated character, suggesting moderate infiltration and storage capacity.

Table-3: Areal Aspects of Manas River Basin

Sl. No	Areal Aspects	Values
1	Area (Sq. Km.)	31480
2	Perimeter (Km)	1053
3	Elongation Ratio	147
4	Drainage Density	0.79
5	Stream Frequency	0.49
6	Length of overland flow	0.64
7	Form Factor	0.03
8	Circulatory Ratio	0.44

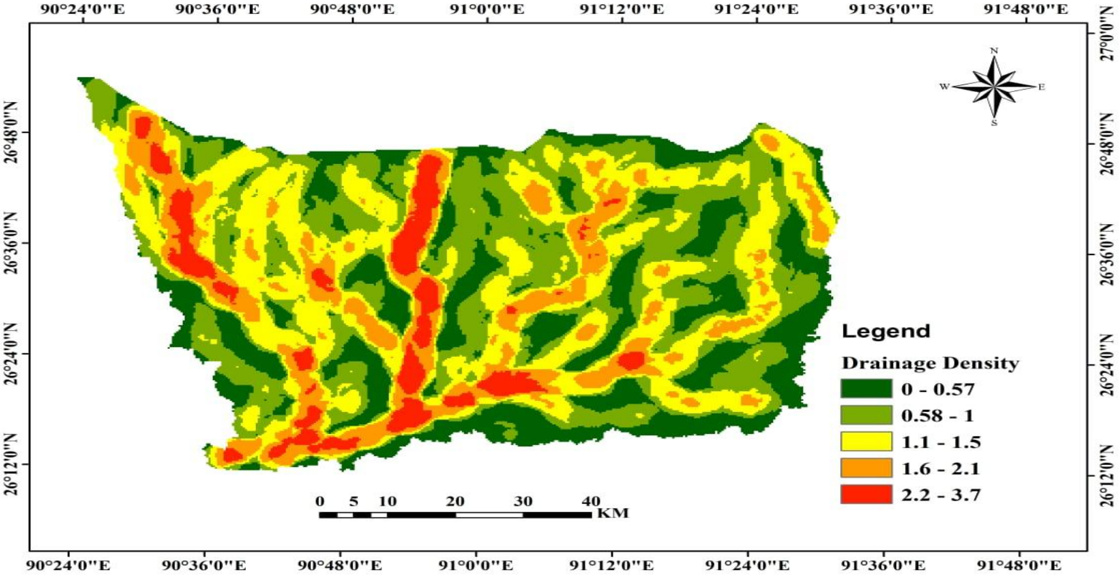

Fig.-2: Drainage Density of Manas River Catchment

4.2 Hydrological Analysis

Rainfall: The basin experiences a monsoonal climate with the bulk of annual precipitation falling between June and September. The northern hilly areas record the highest rainfall due to orographic lifting, while the southern plains receive relatively less.

Temperature: Seasonal variation in temperature directly influences evapotranspiration. High summer temperatures promote water loss through evaporation, while winter's cooler conditions reduce evapotranspiration, stabilising baseflows.

Discharge: Streamflow analysis reveals significant seasonal variation, with monsoon-driven peak discharges and markedly low flows during the dry season. The elongated basin shape and low drainage density contribute to attenuated flood peaks and a slower hydrological response.

Rainfall–Discharge Relationship: Statistical correlation between rainfall and discharge data indicates a strong seasonal linkage but with a time lag in runoff generation. This is attributed to infiltration, subsurface storage, and channel transmission losses.

4.3 Relief and Geomorphology

The Manas River Basin's relief can be divided into two broad physiographic units:

- Northern Hilly Zone: Steep slopes, high relief, and dense stream networks result in high runoff velocities and enhanced erosion potential.
- Southern Plains: Gentle slopes, low relief, and meandering streams encourage sediment deposition and floodplain development.

Relief plays a decisive role in drainage density distribution. The higher drainage density and shorter stream lengths in the hilly north contrast with the low drainage density and longer channels in the plains.

4.4 Implications for Water Resources and Flood Management

- Runoff Response: The elongated basin and low drainage density moderate peak discharges, lowering flash flood potential under normal conditions.
- Flood Risk: Localised flash floods remain a possibility in the steep northern tributaries during extreme rainfall events.
- Soil Erosion Vulnerability: The hilly northern sector is prone to significant soil erosion; soil conservation and afforestation programmes are necessary.
- Water Management Strategy: Rainwater harvesting in the plains, flood control measures in vulnerable upstream areas, and integrated watershed management can improve water security.

4.5 Digital Elevation Model (DEM)

The Digital Elevation Model (Fig. 3) of the Manas River catchment reveals significant variation in elevation, ranging from 19 m to 462 m above mean sea level. The largest area (3683.196 sq. km) is concentrated within the 19–54 m elevation range, representing the extensive alluvial plains that dominate the lower basin. These plains are agriculturally fertile but also flood-prone due to the flat terrain and heavy monsoonal rainfall. In contrast, the smallest area (203.921 sq. km) lies in the 238–462 m elevation range, corresponding to the hilly terrain in the northern and northeastern part of the catchment. These higher elevations are associated with steep slopes, dense forest cover, and serve as important sources of runoff and sediment transport. This elevation gradient strongly influences drainage behavior, land use, and hydrological responses of the basin.

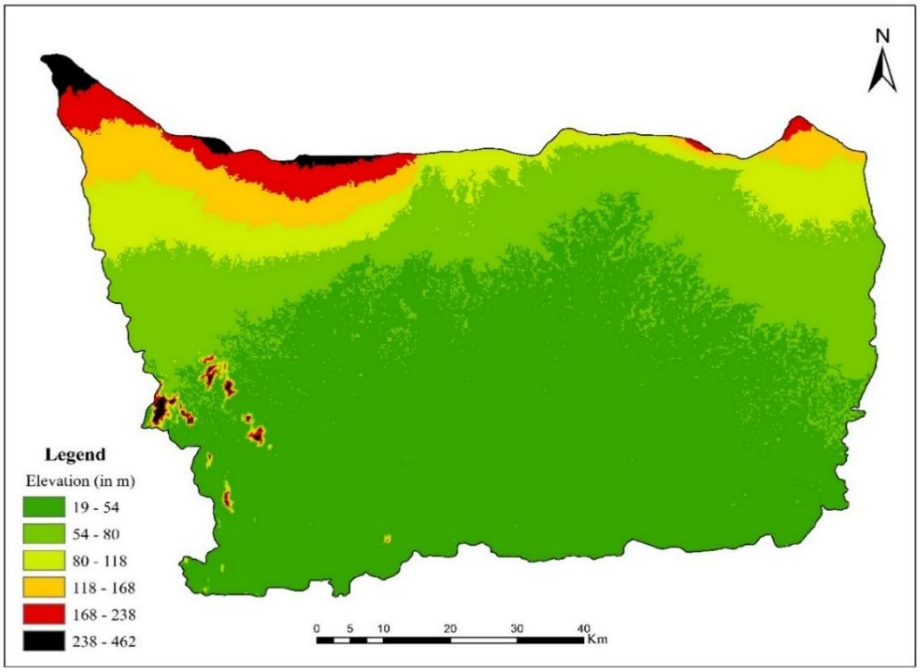

Fig.-3: DEM (Digital Elevation Model) of Manas River Catchment

4.6 Slope Analysis

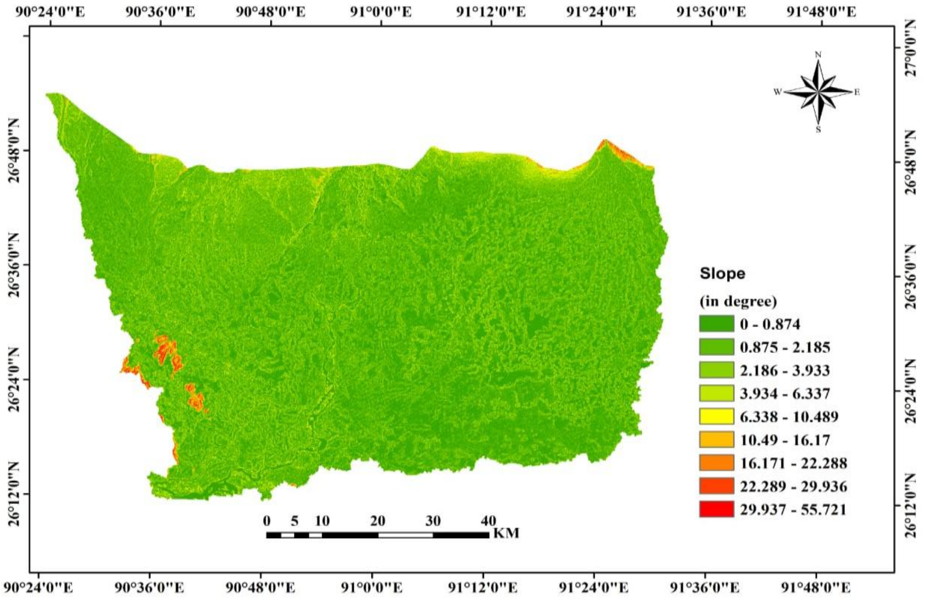

Fig.-4: Slope Map of Manas River Catchment

The slope map (Fig. 4) indicates a clear contrast between the upper and lower reaches of the catchment. The upper catchment is dominated by steep to very steep slopes, which promote rapid surface runoff, soil erosion, and gully formation. These slopes also restrict agricultural expansion but support dense vegetation and forest cover. Conversely, the lower catchment is characterized by gentle slopes, favorable for agriculture, settlement, and infrastructure development. The slope distribution demonstrates how terrain controls land use patterns and the spatial distribution of hydrological hazards such as erosion and flooding.

4.7 Relative Relief

The relative relief map (Fig. 5) highlights the ruggedness of the terrain. High relative relief values in the upper catchment signify intense dissection of the landscape and high erosion susceptibility. These areas contribute significantly to sediment yield in the downstream channels. In contrast, low relative relief zones in the lower basin are indicative of flat alluvial plains, which act as depositional environments and support large-scale cultivation. The relief variations thus reflect the geomorphic transition from rugged highlands to depositional lowlands within the catchment.

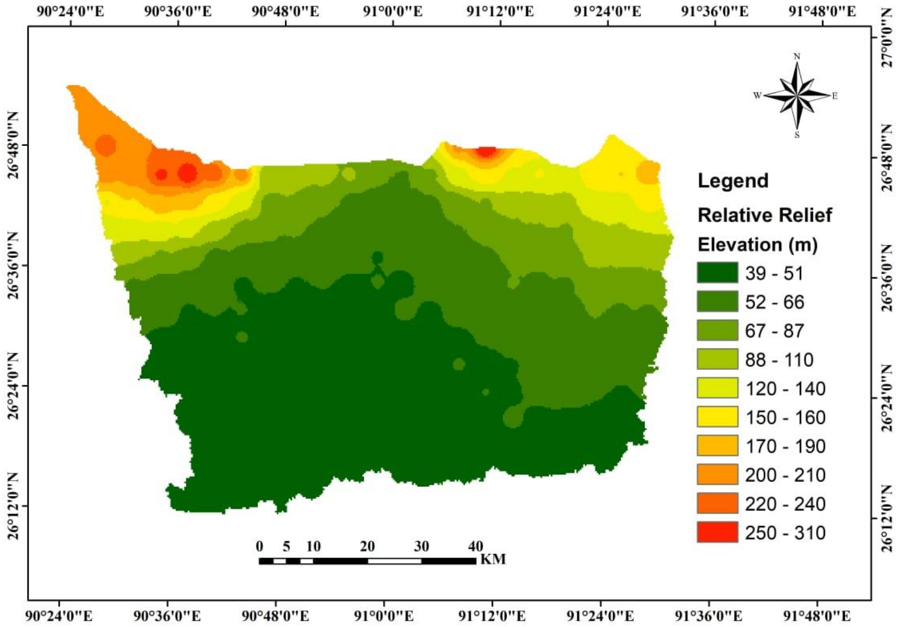

Fig.-5: Relative Relief of Manas River Basin

4.8 Aspect Analysis

The aspect map (Fig. 6) illustrates the orientation of slopes across the catchment. Slopes facing north and east receive comparatively less solar radiation, influencing microclimatic conditions such as soil moisture retention and vegetation growth. Conversely, south and west-facing slopes are more exposed to sunlight, leading to faster drying of soils and potential land degradation if not adequately vegetated. Aspect analysis, therefore, provides insights into ecological diversity, forest growth patterns, and agricultural suitability across different parts of the catchment.

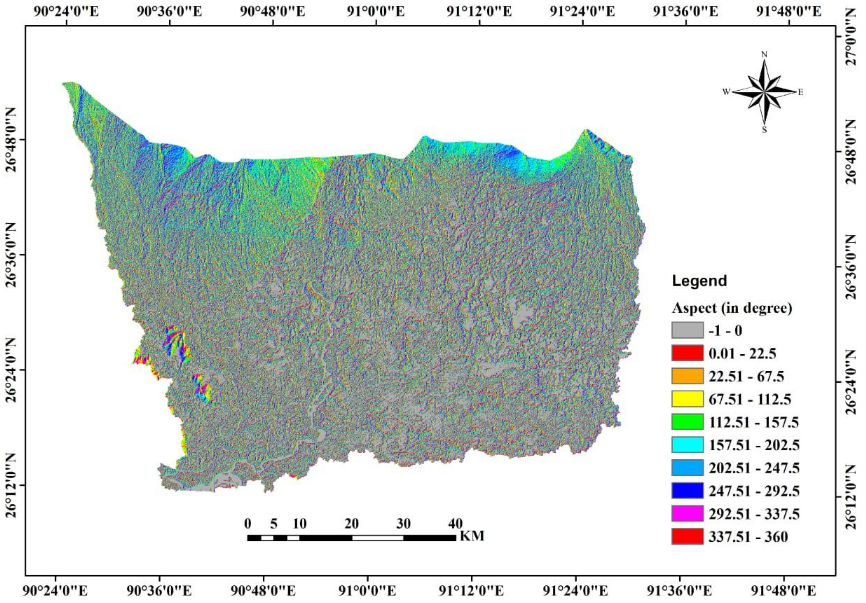

Fig.-6: Aspect Map of Manas River Catchment

4.9 Morphometric Characteristics

The morphometric parameters of the Manas River basin provide a quantitative understanding of its hydrological and geomorphological behavior:

- Area (31,480 sq. km) & Perimeter (1053 km): Indicate a large and structurally complex basin.
- Elongation Ratio (147) & Form Factor (0.03): Suggest the basin is highly elongated, which reduces peak flood risk but extends the runoff duration.
- Drainage Density (0.79) & Stream Frequency (0.49): Indicate coarse drainage texture, moderate surface runoff, and substantial subsurface percolation.
- Length of Overland Flow (0.64): Reflects moderate travel distance of water before joining streams, influencing infiltration rates.
- Circulatory Ratio (0.44): Suggests the basin deviates from circular form, highlighting structural and geological control over drainage.

These parameters collectively demonstrate that the Manas basin is elongated with moderate hydrological response, low flood susceptibility in uplands, but high vulnerability to inundation in the low-lying plains.

5.1 Importance of Morphometric Analysis for River Basin Planning, Flood Management, Soil Conservation, and Ecological Sustainability

Morphometric analysis is a crucial segment in most watershed and river basin analysis since it provides a quantitative model to assess the physical shape of drainage basin (Oruonye & Abbas, 2011; Obiefuna & Sheriff, 2011). Basin shape, the characteristics of the stream network, slope, and relief are all variables that can be expressed numerically which makes it possible to compare any two basins objectively or predict the hydrological behavior. Morphmetric analysis proves to be a useful tool in the Manas River Basin as it lies in a geographical region where the high rainfall, floods and erosion may serve as the reason of integrated basin planning, flood management, soil protection, and ecological control (Kumar et al., 2011; Chopra et al., 2005).

5.1.1 Basin Planning and Water Resource Management

The problem of planning river basins is strategically allocating and managing the water resources to meet the needs of other ecological issues and human needs to support agriculture, industry, and domestic use. Such planning prerequisites are critical as basin area, drainage density, and elongation ratio are morphometric parameters to aid the planning. An instance is the high drainage density which might suggest lack of sufficient infiltration capacity and propensity to lots of surface runoff which would imply water storage structures to store season flow would be necessary. On the same note, ratios of elongation and form factor hint on the rate of runoff to attain the main channel during storm periods which determine the operation of reservoirs operation and irrigation scheduling. In Manas River Basin, farming at the Assam plains depends mostly on seasonal rainfall; monsoons are erratic and may result in water scarcity in dry months and flooding in wet months (Ghosh et al., 2015; Bhatt & Ahmed, 2014). A morphometric study may also assist in indicating the sub-watersheds having high runoff effectiveness to develop small-scale rainwater harvesting or check dam schemes to enhance availability of water. In addition, the relief and slope gradients of the basin help in identifying the favourable locations of irrigation canals that reduce on the cost of construction, as well as the losses involving the flowing water.

5.1.2 Flood Management

In the Manas River Basin, the frequent and serious threat is floods. In Bhutanese Himalaya and foothills, the discharge of rivers rises quickly due to heavy rain during monsoon seasons (Kale, 2003; Goswami, 2008). This is in addition to the fact that there is a high load of sediment transported by the upper catchment which further restricts the channel capacity in the plains, which mean worsening flood conditions. Flood response is directly related to morphometric parameters that include, among others, bifurcation ratio, stream frequency and relief ratio. A low bifurcation ratio shows that tributaries have been generally appropriately dispersed, and floods are rather less steep, but a high ratio shows that runoff is concentrated rapidly in the main tube, because of which the floods are sharper. In the Manas Basin the testing of such values, by stream order, can assist in forecasting flood susceptible sub-catchments and help in prioritizing these areas with flood mitigation actions such as embankments, flood plain zoning, and up-stream retaining basins (Sarma, 2013). Moreover, the examination of drainage textures a measure of stream spacing proximity can be applied to determine the areas where high density of surface runoff is prone. The zones can be afforested or bunded by contours as a means of eliminating peak flows. Morphometric analysis using GIS can also be used in mapping flood inundation through the usage of slope and drainage parameters in relation to the historical flood data (Mishra et al., 2007).

5.1.3 Soil Conservation

In the Manas River Basin, soil erosion is classified as a critical issue there with the steep slopes and heavy rainfall of the upper and middle parts of the basin contributing to the fast pace of detachment and transportation of soil particles (Sharma et al., 2011). Erosion-prone areas can be mapped with morphometric indicators ruggedness number, slope ratio and drainage density. The increasing grades of relief, the uneven broken country, are frequently themselves signs of increased power of erosion. Morphometric analysis in the upper catchment can reveal the existence of dangerous slopes where soil stabilization (vegetative cover, terracing or bioengineering techniques) should be undertaken (Kiran et al., 2013). The analysis in the floodplains could show the areas prone to deposition of silt, which has the potential of changing the texture and fertility of the soil. This associative analysis of morphometric data and database on soil type and land use can result in the development of integrated soil conservation plan that can enlist both erosion in uplands and sediment in the lowlands (Yasmin et al., 2015). Moreover, the characteristics, such as the length-width and basin shape, contribute to the comprehension of the potential of sediment yield. Long-extended basins are more inclined to slower delivery of sediment and circular basins tend to move more and faster sediment loads during floods. These findings can be helpful in the design of check dams, silt traps, and training structures of rivers.

5.1.4 Ecological Sustainability

Manas River Basin has unique ecological importance; it is home to sections within the Manas National Park and its buffer zones where rare and endangered species the Bengal tiger, the pygmy hog, the golden langur, and several species of hornbills can be found (Talukdar et al., 2019). The ecological integrity of the basin is important where forces of nature dictate that the natural hydrological regimes are upheld by the nature of a basin in terms of morphometric characteristics. Morphometric analysis helps the spatial distribution of water availability, floodplain dynamics, and sediment distribution that all directly relate to habitat quality. Examples of species affected in this way include those that rely on seasonal flooding frequencies as a breeding or feeding opportunity; shifts in the timing, frequency or extent of flooding relating to altered runoff patterns can alter a species life cycles. There is also the possibility to prioritize sensitive change-responsive sub-basins, and thus, conservation managers can focus specific areas on protection or restoration. As an example, those of low drainage density and low slopes might simply be natural wetlands or flood cushions that play a vital role in terms of biodiversity. Keeping these areas off-limits to agricultural activities or construction of infrastructure is a way of ensuring ecological sustainability as well as mitigating disaster risk.

5.1.5 Integration with Climate Change Adaptation

Future climate change modeling in northeastern India has indicated greater rainfall variability, greater occurrence of extreme events, and a transformation in season water supplies. Morphometric analysis gives a pattern where changes in hydrology in the future can be compared against the baseline. Observation of parameters such as drainage density (through land-use- land cover change or through channel migration) or relief ratio (through erosional processes) therefore allows the planners to evaluate the effects of variations in climate. In Manas River Basin, the combination of the morphometric observations and climatic models will enable designing of adaptive initiatives that would include increasing the amount of flood storage space, strengthening of the embankments, and popularizing climate-resilient farming (Sarma et al., 2020).

5.1.6 Policy and Planning Relevance

Among the best reasons why morphometric analysis is applied is the fact that they can be used in evidence-based policymaking. In the case of a transboundary river such as the Manas river, where it runs through Bhutan to India, morphometric data backs international water management prospects due to a shared scientific background of the characteristics of the basin (Dutta & Goswami, 2021). Information like this can be used to arrive at decisions on warning of floods, sediment management and ecological protection.

The morphometric statistics and maps made at the state and the district level can be incorporated in the floodplain zoning rules and land use policies in Assam and the disaster management plans. Moreover, the connection to the morphometric data and the socio-economic indicators are beneficial in defining priorities in the interventions community.

6. Significance of the Study

6.1 Role of Morphometric Studies in Understanding Hydrological Response

Hydrological response describes the way a river basin will respond to rainfall or snowmelt and other sources of water supply in regards to the quantities of runoffs, the timing of the runs, maximum discharge and the transport of sediments (Smith et al., 2018). This is not the blind answer; it is basically determined by the morphometric properties of the basin the size, shape, slope, drainage network and the relief. Morphometric works form a well-defined and quantifiable method of linking these physical aspects of land with hydrological attitude, and help scientists and planners with better control of water movements and their prediction. The Manas River Basin is the example, where the hydrological response has been complicated by variable physiographic zones of steep, high relief headwaters in the Himalaya; undulating piedmont foothills; and extensive alluvial floodplains in Assam (Pradhan et al., 2021; Sharma et al., 2020). Morphometric characteristics peculiar to each zone affect the velocity of the runoff, infiltration rates, sediment load, and flood peak features. These differences can be interpreted and modelled more precisely by allowing a systematic analysis of morphometric parameters.

6.1.1 Basin Shape and Flow Concentration

The shape of the basin is a fundamental measure of morphometry in terms of the form factor, elongation ratio and circularity ratio and is particularly significant in terms of how a basin responds hydrologically (Miller & Gupta, 2019; Kumar et al., 2021). Circular basins are more likely to experience less lag time, which implies that the time required to achieve runoff of rainfall events is shorter, and in many cases, it leads to more significant peak flows found at the outlet. On the contrary, longer basins tend to possess slower and more gradual runoff, and this decreases peak floods. In the case of the Manas River Basin, the shape parameters are critical to appreciate since the flash floods of the upper catchment may aggregate with the prolonged inundation in the floodplains to present a compound hazard. When upper reaches have more round sub-basins they tend to exhibit more peaked floods hence need to be warned in advance and upstream storage is needed. On the other hand, the bottom reaches could contain long sub-basins that could be used to alleviate floods and therefore could be used as agricultural fields or could be maintained as wetlands (Patel et al., 2020; Singh & Rao, 2019).

6.1.2 Drainage Network and Runoff Pathways

The structure and density of the drainage network captured through parameters such as drainage density, stream frequency, and bifurcation ratio strongly influence how precipitation is converted into streamflow.

- **High drainage density** typically means that water travels quickly over short distances to reach streams, leading to rapid runoff and higher flood peaks.
- **Low drainage density** suggests greater infiltration and slower runoff, often associated with more permeable soils or dense vegetation.

The mountainous areas in Manas River Basin might exhibit moderate and high drainage density because of high topography and non-permeable rock units that might cause rapid runoff of rainfall during heavy monsoons. In the lower floodplains, in the meantime, the drainage density could be lower but flooded owing to Brahmaputra backwater energy and intense deposition of sediments that lessen the channel carrying capacity. Morphometric analysis of stream orders also demonstrates the flow routing of runoff through the tributary systems that is required in order to model travel times of the flood wave (Das et al., 2021).

6.1.3 Relief and Slope Effects on Flow Velocity

Direct indicators of potential energy of a drainage basin are relief parameters namely basin relief, relief ratio and ruggedness number (Verma & Sahu, 2021; Gupta et al., 2022). More inclined slopes have greater velocity of surface runoff and erosive energy, and their sediment yield is usually increased. The steep, Himalayan reaches of the Manas River Basin enhance runoff, which poses flood danger not just downstream in the plains, but also carries high loads of sediment into the plains. Measuring the rate of slope-gradient using DEM-based morphometric analysis, the hydrologists will be able to calculate the overland flow velocity and the resulting time that a peak discharge will likely occur during particular rainfalls. This is very essential in the design of early warning systems. Moreover, ruggedness number provides an indication of where landslides or debris flows are likely to occur and these can severely change downstream hydrological conditions by damming rivers (momentarily) or providing pulse loads of materials.

6.1.4 Hydrological Lag Time and Peak Flow Prediction

Morphometry research plays an important role in calculating lag time that is the difference between the time when the peak of rainfall occurred and peak discharge (Ali et al., 2020; Bhatt & Jain, 2022). This depends on the area of the basin, length, slope as well as drainage density. The smaller lag times normally imply that fewer times can be given to issues flood warnings. The knowledge of the linkage between morphometric parameters and the lag time empower a more conclusive hydrological modeling especially in the flood-prone basins such as the Manas. To illustrate, large relief, small compact versions sub-basins are likely to result in rapid runoff responses; thus, they should be given priority in terms of monitoring of real-time rainfall and prompt emergency response. In comparison, longer-lag sub-basins give more lead time and thus may act as natural filtering so long as they are not overdeveloped.

6.1.5 Sediment Yield and Channel Stability

Another factor that is part of hydrological response but related closely with morphometrics property is the sediment yield. Steep slopes, high relief, and some lithologies promote a higher erosion rate whereas areas with low relief would tend to get sediment deposition. Sediment loads of Bhutanese hills have contributed to aggradation of Assam floodplains in the Manas River Basin, and further shaped the flood hydraulics by decreasing the channel capacity. The correlation of morphometric parameters including slope, drainage density and elongation ratio with the sediment yield allows the planners to forecast areas within the basin that are going to be net contributors vs the net receptors of sediment. This dictates river training, dredging or installation of a sediment trap (Rao et al., 2018).

6.1.6 Floodplain Connectivity and Wetland Hydrology

There is also use of morphometric analysis in ascertaining the role of rivers in their floodplains and wetlands. Variable like basin asymmetry and stream network bifurcation parameters can provide an insight on the chances of the flow being spilt and hence find itself on the floodplains. This has both ecological and hydrological implication in the Manas River Basin since most of the wetlands and grasslands in the Manas National Park relies on seasonal floods to preserve the quality of the habitat. The realization of the nature of morphometric control of the hydrology of floodplains makes it easy to aggregate the objectives of flood management and ecological sustainability. Case in point, flood protection embankment constructed with no input of morphometric and ecological data may interfere with the natural hydrological connectivity vital in biodiversity (Kumar & Roy, 2019; Phukan et al., 2021).

6.1.7 Integration into Hydrological Models

Morphometric measurements are also fundamental in parameterization of many hydrological models, including the empirical equations of flood forecasting and the physically based rainfall- runoff models. They assist in estimation of parameter values of the models like time of concentration, curve numbers, channel roughness coefficients. In the case of Manas River Basin, by amalgamating morphometric information into the hydrological modeling, it will be feasible to model various rainfall regimes, even the extreme monsoons, and impacts of climate change. That said provides the formulation of adaptive water management, infrastructure design and disaster preparedness plans (Lal et al., 2020; Singh et al., 2021).

6.1.8 Role in Climate Change Impact Assessment

With changes in precipitation pattern under climate change over northeast India, morphometric analysis can be considered as a baseline to identify and interpret the impacts on changes in hydrological response. As an example, in a situation where the post event analysis indicates a faster runoff response on the same rainfall intensity, this may be the effect of land cover changes, soil compaction or drainage network modifications. The Manas Basin has a continuous morphometric monitoring supported by hydrological observations which can be used in the separation of the influences of climate variability to those of human interventions like the deforestation and construction of embankments, or through agricultural expansion (Das & Baruah, 2022; Gogoi et al., 2023).

7. Conclusion

In conclusion, Morphometric analysis of Manas River Basin has given a good understanding of the drainage basin, hydrological role of the river as well as geomorphic governing factors. Long shape, low drainage density and stream frequency suggest system with moderate infiltration capacity and attenuated flood peak and moderate speed of response to runoff when hydrologic conditions are normal. The high relief and steep slopes of the northern Himalayan sector, however, develop areas of precipitous runoff zones, high erosional potential and localised flash flooding hazard during extreme monsoonal weather. On the other hand, the southern plains that possess gentle gradients and twining channels are significant floodplains and zones of sediment deposition that facilitate agriculture and biodiversity. When morphometric parameters are integrated into the hydrological statistics, it is possible to notice that the management differentiation in the basin is necessary. Soil conservation, slope stabilization along with upstream flood control structures should be given priority in the upstream ones in the north. In the southern plains, the focus must be on rainwater harvesting, groundwater recharge, and floodplain zoning so that agricultural efficiency and environment conservation will be balanced with one another. Also, biodiversity and flood effects are important factors that need to be taken care of by preserving natural wetlands and floodplain ecosystems. The study provides a baseline morpometric quantification of the Manas River Basin that could be incorporated into hydrological modelling, disaster planning, and related climate change adaptation. The findings support the significance of evidence-based watershed management whereby the community is resilient to change, and the environmental sustainability of the basin is preserved to be passed on to the future generations, maintaining its ecological and hydrological integrity.

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