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Relief Analysis for Identification of Flood Susceptibility in Khagaria District, Bihar Using Remote Sensing and GIS Techniques

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ABSTRACT

Relief analysis describes an area's relief and landform structure. It is a vital source of information for assessing flood susceptibility in a region. Khagaria is one of the most flood-prone areas in Bihar, where floods significantly affect residents, the environment, and cause economic losses. This study examines seven topographic parameters, namely elevation, slope, hillshade, drainage density, TWI (Topographic Wetness Index), ruggedness number, and relative relief in Khagaria district. These factors provide deeper insights into the flood characteristics of the study area and offer observations on the structural landscape patterns. The relief-related maps have been prepared using satellite data and Digital Elevation Models (DEMs), employing Remote Sensing (RS) and Geographic Information System (GIS) techniques. According to the slope map, the terrain is mostly level, with an average elevation of 36 meters and a slight slope. Due to extensive lowland areas in the northern, north-eastern, and southern regions, along with the general relief characteristics, these areas are more prone to flooding.

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تحليل التضاريس لتحديد قابلية التعرّض للفيضانات في مقاطعة خاجاريا، بيهار باستخدام تقنيات التحسس النائي ونظم المعلومات الجغرافية

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الملخص

تحليل التضاريس يصف الطبوغرافيا وبنية الأشكال الأرضية للمنطقة، ويُعدّ مصدراً أساسياً للمعلومات في تقييم قابلية التعرّض للفيضانات في أي إقليم. تُعدّ مقاطعة خاجاريا إحدى أكثر المناطق عرضة للفيضانات في ولاية بيهار، حيث تؤثر الفيضانات بشكل ملحوظ على السكان والبيئة، وتسبب خسائر اقتصادية كبيرة. تتناول هذه الدراسة سبعة معايير طبوغرافية هي: الارتفاع، الانحدار، تظليل التضاريس (Hillshade)، كثافة التصريف النهري، مؤشر الرطوبة الطبوغرافي (TWI)، معامل الوعورة، والفرق النسبي في الارتفاع داخل مقاطعة خاجاريا. تُسهم هذه العوامل في توفير فهم أعمق لخصائص الفيضانات في منطقة الدراسة، كما تتيح ملاحظات حول الأنماط البنيوية للمشهد الطبيعي. وقد أُعدّت الخرائط المتعلقة بالتضاريس بالاعتماد على بيانات الأقمار الصناعية ونماذج الارتفاع الرقمية (DEMs)، باستخدام تقنيات التحسس النائي (RS) ونظم المعلومات الجغرافية (GIS). ووفقاً لخريطة الانحدار، فإن السطح الطبوغرافي يتسم بالاستواء، بمتوسط ارتفاع يبلغ 36 متراً مع انحدار طفيف. وبسبب الانتشار الواسع للمناطق المنخفضة في الأجزاء الشمالية والشمالية الشرقية والجنوبية، بالإضافة إلى الخصائص العامة للتضاريس، تُعدّ هذه المناطق أكثر عرضة للتعرّض للفيضانات.

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Introduction

Relief features are a primary element of the human environment. Relief analysis describes the relief and landform structure of any area. There is a close, reciprocal relationship between the sciences that study the Earth's surface and relief, and cartography (Bhunia et al., 2012). On the other hand, analyzing an area's relief structure is crucial to understanding its physical characteristics, including its slope. Typically, contour data is used to study an area's slope; where contours are compact, the slope is steep, while sparse contours indicate a gentle slope (Chavare, 2011). Relief aspects are the three-dimensional morphometric parameters of drainage basins (Maiti and Lama, 2021). One hydrological phenomenon impacted by topography is flooding. There is a correlation between specific topographical features and flood occurrences. Areas with flat terrain, slopes, and basins are typically the sites of most flood events (Fitra et al., 2024). Floods significantly affect residents, the environment, and cause economic losses in the region (Febrina et al., 2022). Relief features can be depicted using various techniques, including hachures, contours, form lines, spot heights, benchmarks, trigonometrical points, hill shading, and layer coloring. Each technique for capturing the land's relief has its own advantages and limitations. The growing availability of digital elevation models (DEMs) has driven rapid advancements in the regional-scale characterization and numerical modelling of mountain landscapes (Bishop et al., 2003). The use of GIS has become integral to cartography and data analysis, with applications expanding alongside the rise of remote sensing. In recent years, GIS methodologies and earth observation data have become increasingly effective for morphometric analysis, especially in remote areas (Bhunia et al., 2012). Relief analysis can be performed manually or digitally through a series of successive steps. Traditionally, relief characteristics were estimated from topographic maps of the Survey of India (SoI) using the classic tracing approach. Currently, this process is digitized with the use of advanced GIS software. In digital methods, contour lines and drainage layers are formatted either through a digital elevation model (DEM) or on-screen digitization using GIS software (Karim, 2020).

Numerous studies have evaluated the impact of relief on flood hazards, showing that an area's topography is a primary factor in flood vulnerability (Shettima et al., 2019). For instance, Shettima used remotely sensed data and GIS methodologies to assess the influence of topography on flood risk in the Maiduguri region. Similarly, Xie and Zhao (2013) investigated the relationship between topographic relief and flood disasters, concluding that lower terrains are more vulnerable to flooding. Flood-risk vulnerability detection is based on developing the topographic wetness index tool in GIS (Bety et al., 2024). The primary objective of the present study is to analyse the relief characteristics of Khagaria district using Shuttle Radar Topography Mission (SRTM) data and GIS techniques. Relief analysis using SRTM DEM data will provide insights into the local relief features and structural landscape patterns, which will assist in determining the flood susceptibility of the area.

Study Area

Khagaria and Gogari are the two subdivisions that make up Khagaria district. The district consists of the following seven blocks: Alauli, Beldaur, Chautham, Gogari, Khagaria, Parbatta, and Mansi. The coordinates of Khagaria are 25°30'N, 86°29'E to 25.5°N, 86.48°E, and its total area is 1,485 square kilometres. According to the 2011 census, the population of Khagaria was 1,666,886, with 883,786 men and 783,100 women. Rich alluvial sediment, deposited by the constantly shifting rivers, has formed a vast plain in the northern part of the district. In the southern part (south of the Ganga River), extensive rice fields and forests cover the metamorphic hills, which extend deep into central India from the town of Munger. Much of the alluvial plain forms a saucer-shaped depression, with the central part consisting of marshy hollows that remain waterlogged for most of the year and are further inundated by river overflows during the rainy season.

The Ganga, Burhi Gandak, Bagmati, Kamla, and Ghaghri (the mainstream of the Koshi River) are the district's major rivers. The climate of Khagaria can be described as a transitional zone between the humid atmosphere of Bengal's southern valley and the dry, scorching heat of the northern uplands (Ramasastri, 2015). There are no hills or mineral deposits in the district, and agriculture remains the primary industry. Wheat is the principal crop grown here, reflecting the region’s land-use pattern. Figure 1 represents the study area map of Khagaria, which was created using SRTM DEM data in ArcGIS software. The area has an elevation ranging between 0 and 91 meters.

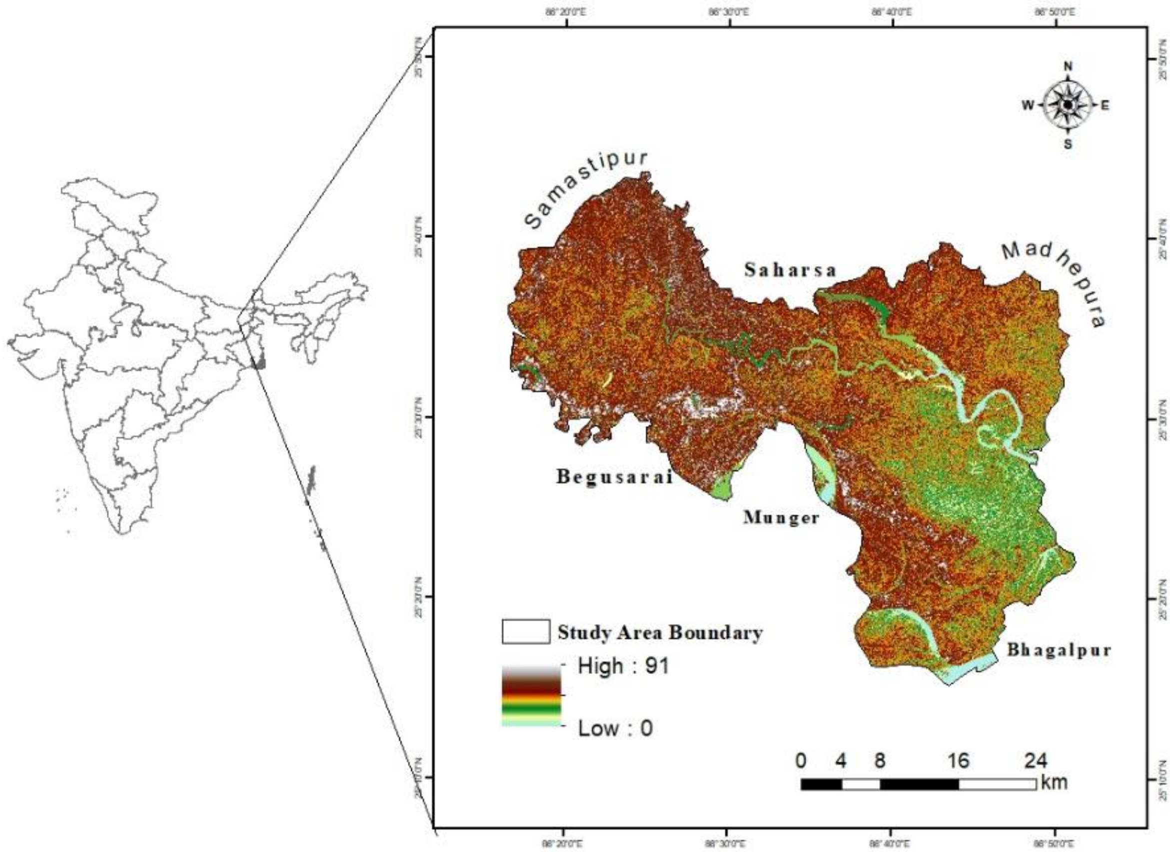

Fig.1. Study Area

The flood history of Khagaria has been devastating, with around 74% of the district's total area being vulnerable to floods (Flood Hazard Atlas Bihar, 2020). Notable floods occurred in 1954, 1957, 1974, 1987, 2004, 2007, and 2017, severely impacting people’s lives, properties, and the district’s agriculture sector. Floodwaters have often submerged agricultural land, causing widespread damage to standing crops. Every year, approximately one lakh hectares of standing crops are destroyed by floods, leading to significant losses, including loss of human lives (Kumar, 2020). A relief analysis of Khagaria can help us understand the landforms and geographic characteristics that contribute to the area’s susceptibility to flooding.

Material

Table 1 contains all the data that has been used in this study. For the relief analysis, an elevation model created using the Shuttle Radar Topography Mission (SRTM) with 30-meter resolution data is employed. The SRTM is an international project by the U.S. National Geospatial-Intelligence Agency and NASA. It obtains elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth. Using ArcGIS 10.8.2 software, the 30-meter resolution SRTM data were converted to point data. The SRTM data were downloaded for free from the USGS website. Data from the Digital Elevation Model (DEM), including elevation, river patterns within the watershed, and the research area's water basins, were used to determine the flow direction and water storage. Additionally, a topographic map with a 1:50,000 scale was downloaded from the Survey of India’s official website. Topographic maps are detailed, accurate graphical representations of features found on the Earth’s surface.

Table 1: Data Types and Sources

Sno.	Data Types	Sources
1.	Topographical Map	Survey of India (1767).
2.	SRTM DEM (30m Resolution)	USGS Earth Explorer https://earthexplorer.usgs.gov/

Methodology

A Digital Elevation Model (DEM) is a representation of terrain or ground surface topography that can be displayed as a Triangular Irregular Network (TIN) or a raster grid. Unlike conventional elevation contours, a DEM provides exact elevation values at each grid point. Applications such as runoff modelling, slope stability analysis, and topographic feature extraction rely on DEM data (Suganthi et al., 2010). DEMs are informative datasets that include terrain elevation data, typically sampled over the ground surface at regular grid intervals. These grid points are always referenced to a specific geographic coordinate system, often using latitude–longitude or Universal Transverse Mercator (UTM) coordinate systems (Kumar et al., 2024). The data used in this study have been georeferenced using the WGS 1984 UTM system. In GIS, image rectification involves transforming images into a common map coordinate system. This process requires matching points in the image with ground control points (GCPs) in the mapping system, which determine the necessary image transformations. Non-topographic maps are used with rectified images. However, topographic distortions may exist in the images being analyzed. Image orthorectification addresses and removes these distortions, ensuring spatial accuracy. Image rectification is a standard feature of GIS software packages (Fogel, 2008).

A subset of the study area refers to a selected portion of a larger dataset chosen for detailed research. It involves isolating a specific area of interest from the entire dataset to enhance analytical precision and improve research findings. After image rectification, the subset of the study area is extracted using the Clip feature in ArcGIS software. The Clip tool allows researchers to cut out a smaller portion of the larger data file for focused study and analysis. Figure (2) shows the flowchart of methods\steps that have been used in this study: -

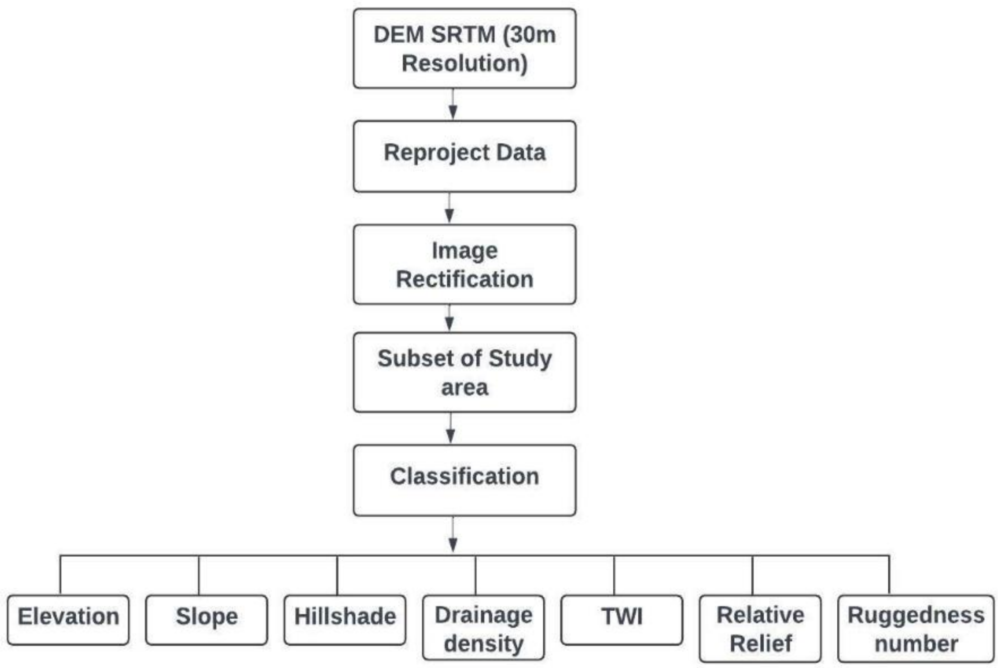

Fig. 2. Flowchart of Methodology

The elevation map is divided into six legend classes, ranging from 0 to 90 meters, representing low to high elevation areas in Khagaia area. To create a slope map, the first step is to import the Digital Elevation Model (DEM) into ArcGIS software. The DEM is then converted into a slope map using the Slope feature available in the Spatial Analyst Tool within Arc-GIS software. In Arc-GIS software, the slope formula is applied to calculate the steepness of the terrain based on elevation data. The slope can be determined using the following formula (1):

Slope Calculation Formula:

$$\text{Slope} = \Delta X / \Delta Z \times 180 / \pi \quad \text{………………………………………} \quad (1)$$

Where:

ΔZ is the change in elevation (vertical distance).

ΔX is the horizontal distance (Esri, 2020).

Geospatial Analysis: The calculation typically uses DEM to derive slope values across the study area (Burrough and McDonnell, 1998). The Slope tool in ArcGIS software calculates the slope in degrees or percent from a raster surface using the elevation values (Esri, 2020). The slope map was stratified into categories based on degrees of inclination, comprising very gentle (0–0.11 degrees), gentle (0.12 -2.2 degrees), moderately steep (2.3-3.6 degrees), steep (3.7-6 degrees), and very steep (6.1-35.3 degrees).

By mimicking the effects of illumination, a GIS-based hillshade map provides insight into the topography and graphically portrays the terrain's surface relief. Like slope map, for creating a hillshade map, we first need to import a DEM into ArcGIS, which is then converted into a hillshade map using the hillshade feature in the Spatial Analyst tool in Arc-GIS software. A hillshade map's legend usually consists of the following parameters such as Light Areas: These are areas that appear brighter when facing the light source, which is typically the sun. Usually, this depicts the slopes that are right in front of the light source. Dark Areas: These are areas that appear darker when viewed from a distance away from the light source. These are frequently the shadowed slopes or the ones that face away from the light source. The hillshade function obtains the hypothetical illumination of a surface by determining illumination values for each cell in a raster. It does this by setting a position for a hypothetical light source and calculating the illumination values of each cell in relation to neighboring cells. It can greatly enhance the visualization of a surface for analysis or graphical display.

By default, shadow and light are shades of grey associated with integers from 0 to 255, increasing from black to white (Smith, 2020). Azimuth is the angular direction of the sun, measured from north in clockwise degrees from 0 to 360 (Johnson and Lee, 2019). An azimuth of 90 is east (Doe, 2021). The default is 315 1W. Altitude is the slope or angle of the illumination source above the horizon (Brown, 2018). The units are in degrees, from 0 on the horizon to 90 degrees overhead. The default is 45 degrees. 90°. The hill shade to the left has an azimuth of 315 and an altitude of 45 degrees (Williams, 2022).

For morphometric relief analysis, specific altitudinal and drainage features are produced. Several significant morphometric variables, including Stream Ordering, drainage density, slope, and Topographic Wetness Index, are chosen for the current study using Arc-GIS software. The drainage map of the study area was created through DEM data using fill, flow accumulation, flow direction, and stream order features in the hydrology tool of Arc-GIS software. After creating a drainage map drainage density map has been created through the line density feature in the Density tool of Arc-GIS software. It is represented in Km/Sq. Km. Drainage Density Categories include: Low Density, Areas where the drainage network is sparse. This is usually indicated by lighter shades or less dense line patterns. Moderate Density: Areas with a moderate amount of drainage features, shown with intermediate colors or line patterns. High Density: Regions with a dense network of drainage features, often depicted with darker shades or closely spaced lines. Equation (2) was used to calculate the drainage density:

$$D = \sum L \setminus A \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where ΣL is the total length of the hydrographic network (km) and A is the hydrographic basin area (km2) (Moeini et al., 2015).

The Topographic Wetness Index (TWI) is also calculated from the drainage map using the Raster calculator. It is commonly used to quantify topographic control on hydrological processes and terrain-driven variation in soil moisture. The index is a function of both the slope and the upstream contributing area per unit width orthogonal to the flow direction. The index is highly correlated with several soil attributes such as horizon depth, silt percentage, organic matter content, and phosphorus. Mathematically, the topographic wetness index is defined as in function (3):

$$W = \text{In } \alpha/\tan \beta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

The slope angle at that particular position is represented by β, and the W value is the wettability index, represented by α, which measures the volume of water gathered from the top slope at each contour unit. The following index illustrates the tendency of water to get stagnant due to gravity, particularly at a location where water continuously flows downward (Quinn, 1991).

For creating TWI, we need a DEM file→ then apply Fill DEM→ followed by Flow direction and Flow accumulation through Hydrology tool in Arc-GIS software → create slope in degree →then calculate, Radians of slope = (Slope in degree *1.570796)/90→Tan slope= con (slope>0, tan(slope), 0.001) → Flow accumulation scaled= (flow accumulation+1) *cell size TWI= Ln (Flow accumulation scaled/Tan slope) using raster calculator feature in Arc-toolbox. TWI is often visualized using color gradients on maps, where higher values are shown in warmer colors and lower values in cooler colors.

Strahler (1964) describes ruggedness number (Rn) as the product of maximum basin relief (R) and drainage density (Dd). It usually combines slope steepness with its length. Extremely high values of ruggedness number occur when slopes of the basin are not only steeper but long, as well. The equation (4) was used to calculate the ruggedness number:

$$Rn = R * Dd \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

River basins with a high ruggedness number indicate higher drainage frequency with high channel gradient, which leads to more erosion. The level of dissection is also very high in such a basin (Karim, 2020). The ruggedness index map has been created through Focal statistics and raster calculator in ArcGIS. Relative relief is denoted by RR as in equation (5):

$$RR = (\text{Maximum Altitude-Minimum altitude}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

The difference between the highest and lowest height in a unit area is known as relative relief (Smith, 1939), and it is used to analyze the general morphological aspects of the terrain as well as the degree of dissection (Khatua, 2022). It is denoted by RR. The relative relief map has been created through Create Fishnet, Zonal statistics, and IDW tools in ArcGIS software.

Result and Discussion

Elevation

Typically, elevations are expressed in feet or meters (Singh, 2011). On maps, they can be represented by bands of color, contour lines connecting points of the same elevation, or numbers that indicate the precise elevations of specific locations on the surface of the Earth. Topographic maps are those that depict elevations. Elevation shapes climate and human habitation, with most people living on coastal plains below 150 meters. In Tibet, some live as high as 5,334 meters, but above this altitude, the cold, low oxygen, and lack of crop growth make survival difficult. (National Geographic, 2024). The elevation map of Khagaria is shown in Figure 3.

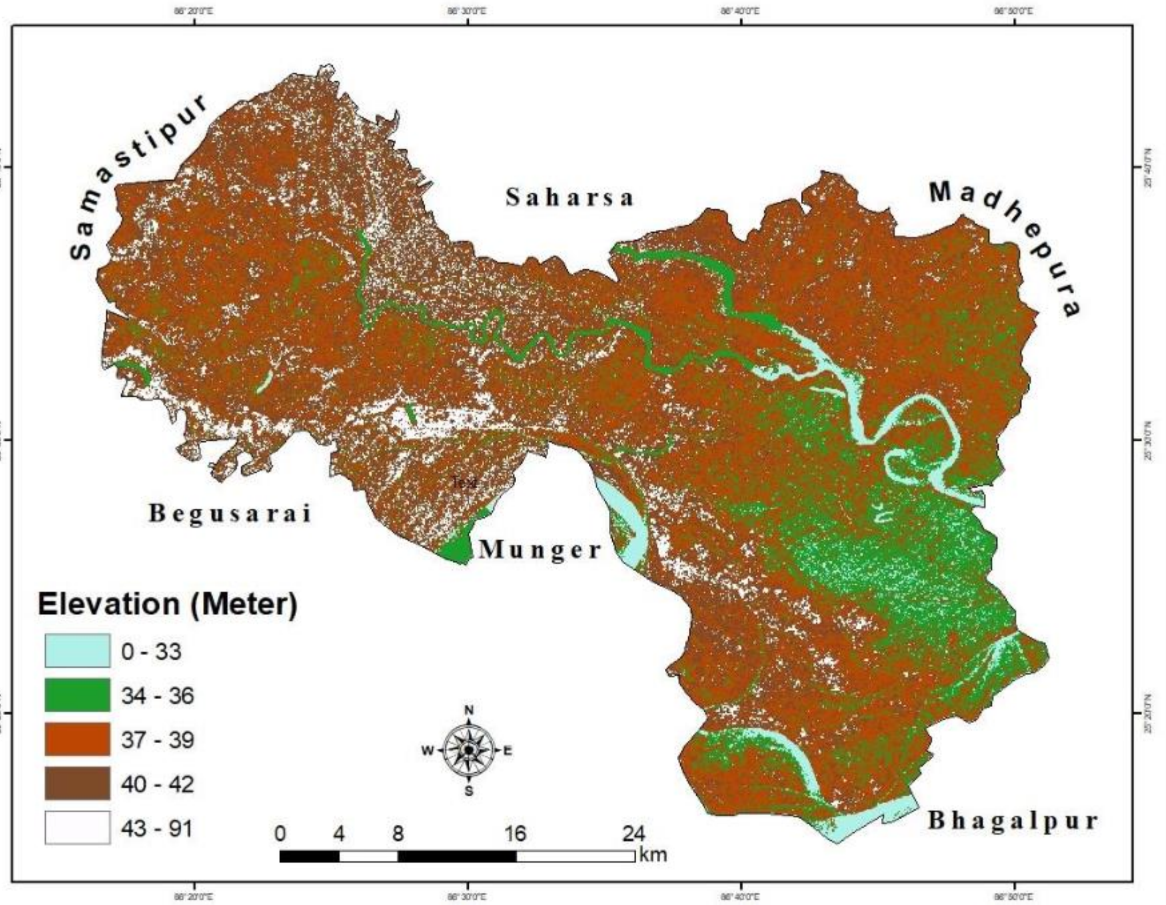

Fig. 3. Elevation Map.

Elevation is also one of the main factors influencing flooding; generally, the likelihood of flooding increases as elevation decreases (Choubin et al., 2019). Elevation affects both flood depth and the generation of surface-water flow. The average elevation of Khagaria district is 36 meters, with most of the area categorized as flat, ranging between 43 and 91 meters at its highest points. The elevation map (Fig. 3) indicates that the terrain is almost flat, with the highest point at 91 meters and the lowest at 33 meters. This low elevation contributes to the area's high susceptibility to flooding, as flat regions are more likely to become submerged under water.

Slope

An essential geospatial characteristic for any geographic investigation is the land's slope. The elevation difference between two points over a unit of distance is referred to as the slope. Slope is expressed as % slopes or degree slopes and is also known as gradient (Mundhe, 2018). Studying land slopes is essential for geography classes. Every geographer needs to have a solid awareness of elevation, altitudinal changes, and the topography of a certain area in addition to a detailed understanding of the slopes of the land in India. (Balasubramanian, 2007). The slope map of Khagaria is shown in Figure 4.

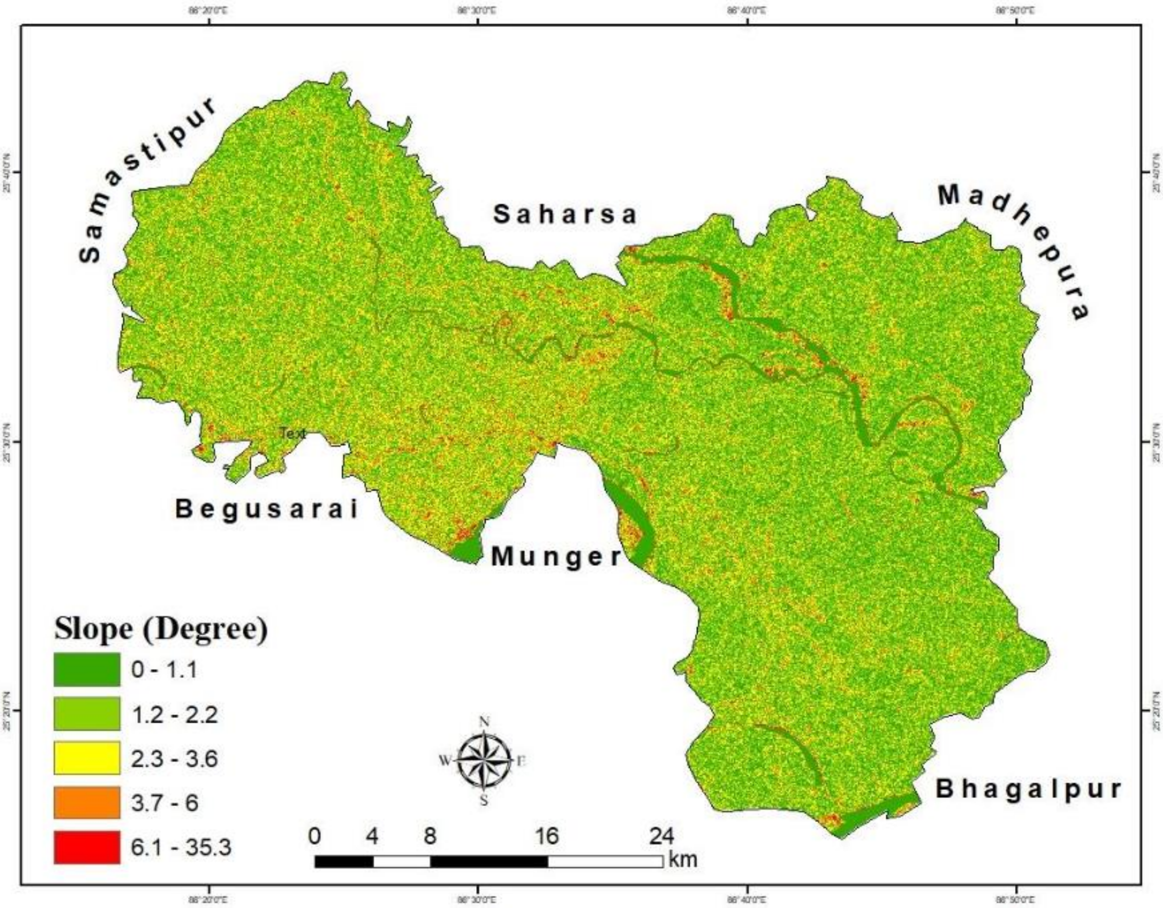

Fig. 4. Slope Map.

The most important aspect in hydrology is slope, which affects floods since it is directly correlated with surface runoff (Meraj et al., 2015). Since steep slopes generate greater velocity than flatter or gentle slopes and may therefore dispose of runoff faster, locations with low elevation typically have gentle or flat slopes, making them more vulnerable to floods and water logging. Runoff accumulates over an area on a mild to moderate slope and eventually dissipates (Tehrany and Kumar, 2018). In contrast to high gradient slopes, low gradient slopes at lower reaches are therefore much more susceptible to flooding. (Ramesh and Iqbal, 2022). A rise in slope directly causes surface runoff to grow more quickly, which affects flood hazards. There is a negative association between flood-prone sites and terrain curvature in lowland/gentle slope (LL/GS) zones, suggesting that topography influences flood features. (Zhang et al., 2023). The slope aspect has a substantial impact on flood risk in different areas. There is little to no variation in the slope across the entire district. Most of Khagaria district lies on gentle slopes, with values ranging from 0 to 35.3 degrees and an average slope of 5.2 degrees. The prevalence of gentle slopes indicates that the district is highly susceptible to flooding.

Hillshade

The process of making relief maps involves a technique called "hill-shading," which uses shading, or different shades of grey, to depict the topographical features of hills and mountains, such as relative slopes and mountain ridges. Additionally, hill-shading maps are frequently utilised to give a 2D map's varied terrain an objective yet artistic representation (Maguire et al., 1991; Robinson et al., 1995; Wilson and Gallant, 2000; Slocum et al., 2004; Li and Du, 2004; Kennelly, 2008). The hillshade map of Khagaria is shown in Figure 5.

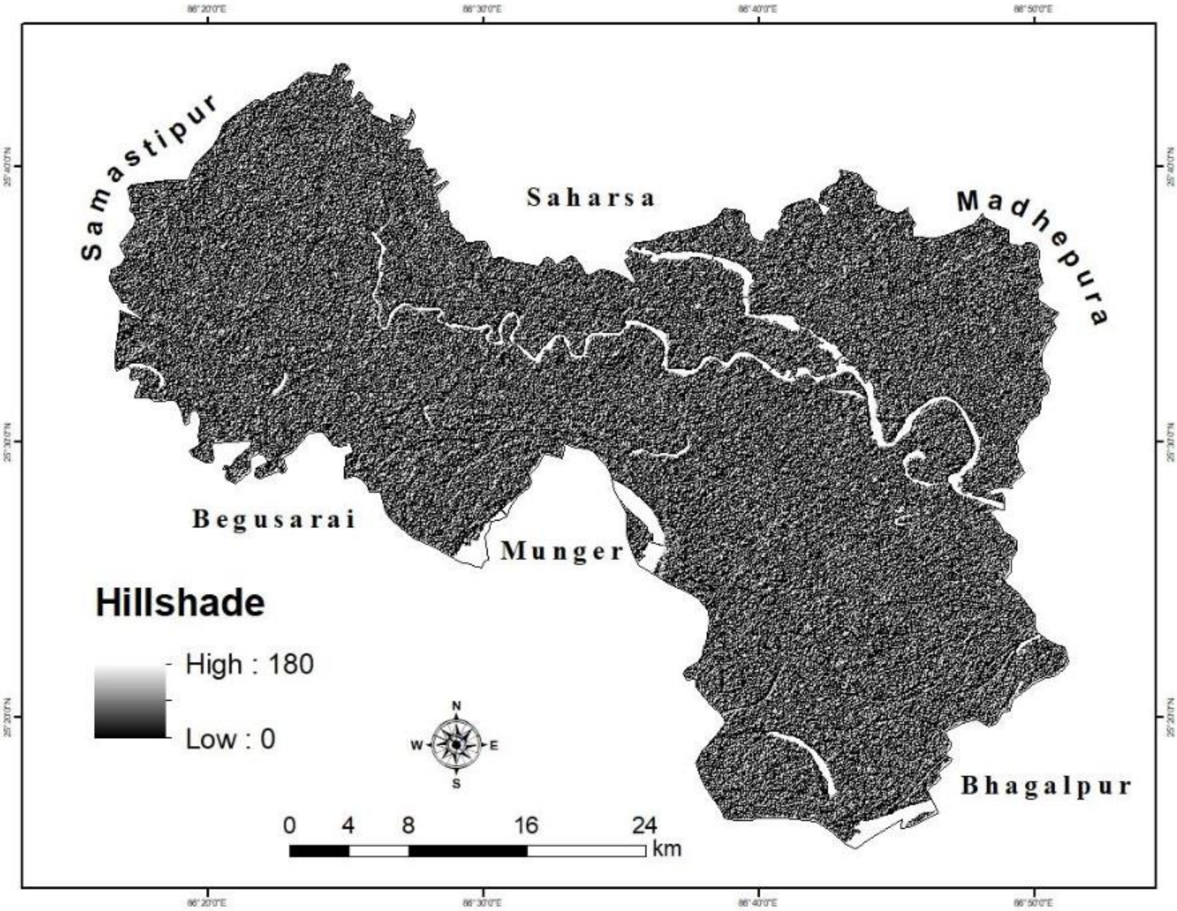

Fig. 5. Hillshade Map.

With consideration for the sun's relative location, the hillshade function creates a grayscale three-dimensional depiction of the terrain surface. The process of "hillshading" involves using a light source, the aspect and slope of the elevation surface, and other factors to represent the terrain. It is a qualitative approach to topographical visualisation and does not provide precise elevation estimates. (Esri Support GIS dictionary, 2024). With the advancements in computer cartography and remote sensing, digital hill-shading mapping has focused on hill-shading techniques supported by DEM (Hongyun et al., 2021). The hillshade map of Khagaria indicates that the area lacks hills or mountains. It is predominantly flat, making it highly prone to flooding.

Drainage Density

Drainage density refers to the total length of the streams per unit area governed by the law of R.E. Horton (1945). The drainage basin's physical features and climate both affect drainage density (Devne et al., 2019). A watershed's runoff is influenced by the underlying rock type and soil permeability, or the difficulty of infiltration. Exposed bedrock or impermeable land will increase surface water runoff, which will result in more frequent streams. If the other features of the drainage basin remain the same, rugged or highly elevated areas will also have a higher drainage density than other drainage basins. (Horton, 1932). The drainage density map of Khagaria is shown in Figure 6.

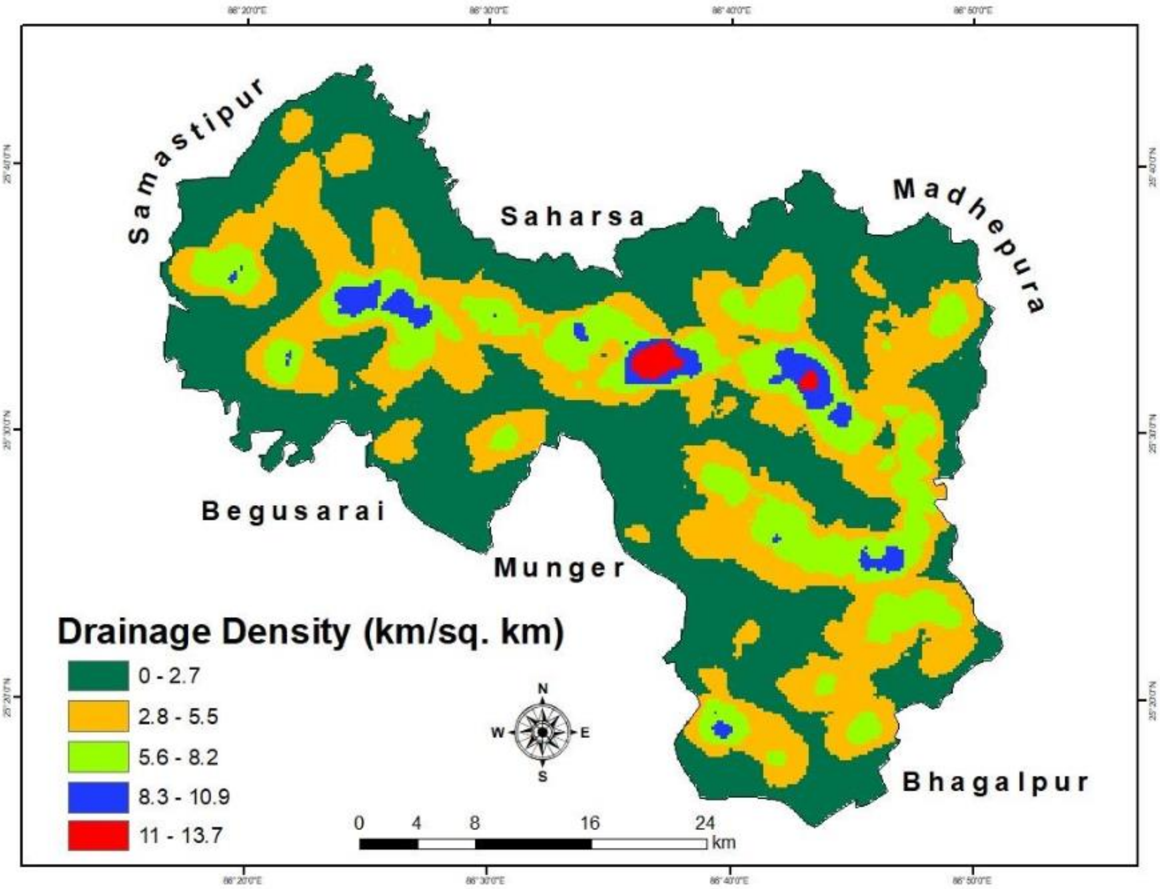

Fig. 6. Drainage Density Map.

Weak and impermeable subsurface materials, sparse vegetation and high relief are related to higher drainage density values, while coarse drainage texture is related to low drainage density values. Areas with high drainage density have high runoff, coarse drainage texture and higher erosion potential. (Strahler, 1964). Humid regions typically have lower densities for the same geology and slope angle because of the presence of lush vegetation that facilitates infiltration. Given the same geology, an arid region would have tended to have a larger density. A high drainage density number denotes a comparatively high stream density and, hence, a quick storm process (Mundhe et al, 2017). Drainage density is an important aspect that indicates that the higher the drainage density (DD), the higher the flood susceptibility. Flood probability is directly correlated with higher drainage density, which results in increased surface runoff and hence increased flood (Geetha et al, 2024). In the study area, most parts exhibit high drainage density values, with nearly 70% of the region characterized by high drainage density, leading to increased flood susceptibility. Both the northern and southern boundaries of the district predominantly have high drainage density, making them particularly prone to flooding.

Topographic Wetness Index (TWI)

The TWI indicates the soil's moisture retained due to poor drainage and other factors. If the soil moisture is high, a maximum amount of precipitation will turn into surface runoff, thus increasing flood susceptibility. The measurement of topographic influence over hydrological processes is generally accomplished using the TWI, ln (a/tanβ), which combines slope and local upslope contributing area. The upslope contributing area is determined differently in each method of calculating this index (Sørensen et al., 2016). The topographic wetness index map of Khagaria is shown in Figure 7.

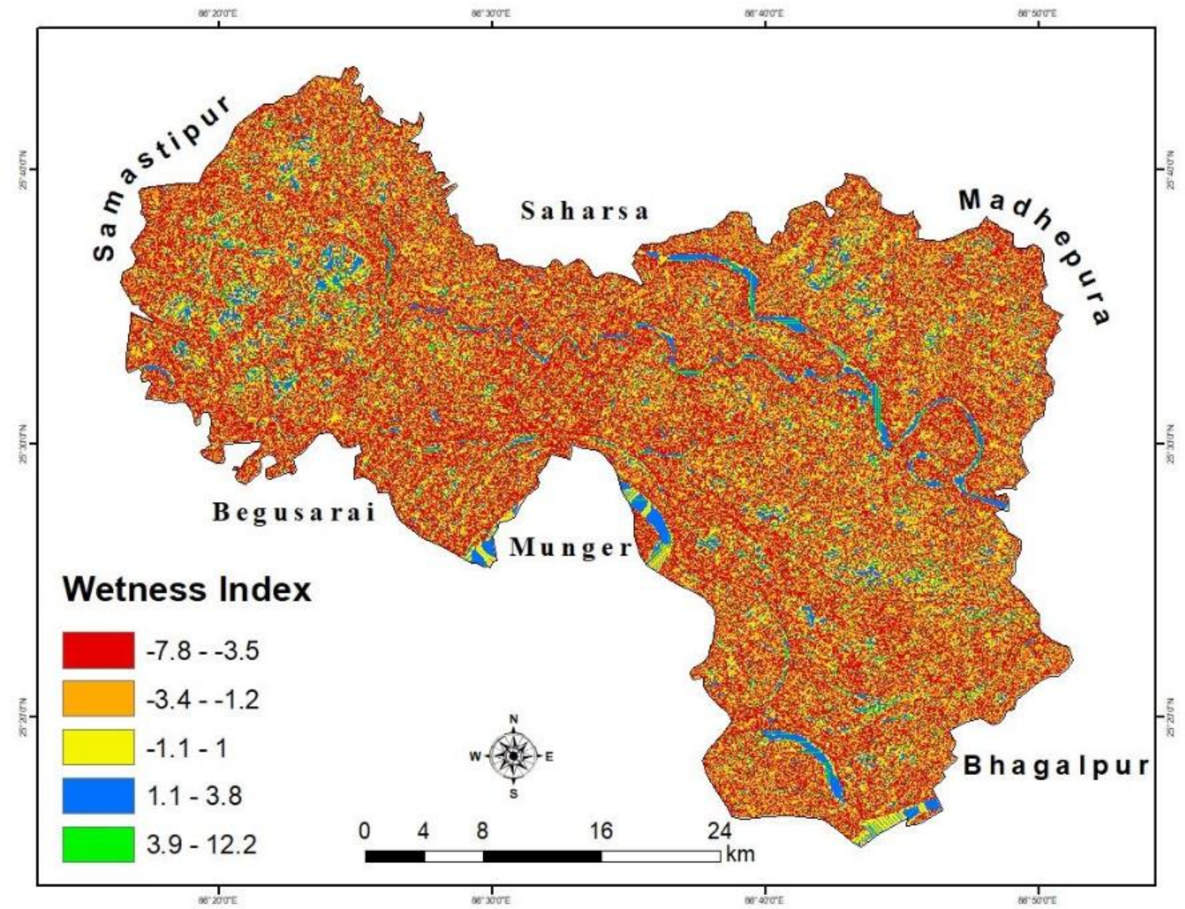

Fig. 7. Topographic Wetness Index Map.

One of the parameters that determines the hydrological settings of the area is TWI, which is likewise derived from the secondary derivative of the DEM. TWI is a commonly used metric to locate and quantify areas that are saturated with water. Since topography is a crucial factor in determining how water is distributed both above and below the surface, its influence on water processes is typically measured by computing this parameter (Kaya et al., 2023). High soil moisture results in a greater proportion of precipitation becoming surface runoff, thereby increasing flood susceptibility. The green and blue patches indicate areas with high Topographic Wetness Index (TWI), highlighting them as more vulnerable to flooding compared to other regions. The northwestern, eastern, and central-southern parts of the district exhibit high TWI values, making these areas particularly prone to flooding.

Ruggedness Index

Strahler (1968) describes the ruggedness index as the product of maximum basin relief (R) and drainage density (Dd). The topographic ruggedness index indicates the extent of instability of the land surface (Strahler, 1950). The available sharpness of the local relief and the amplitude of the available drainage density, along with other environmental factors like slope, precipitation, weathering, soil texture, natural vegetation, etc., have long interacted to produce this derivative. Ruggedness index is measured by taking into account both relief and drainage (Shankar et al., 2014). The ruggedness index map of Khagaria is shown in Figure 8.

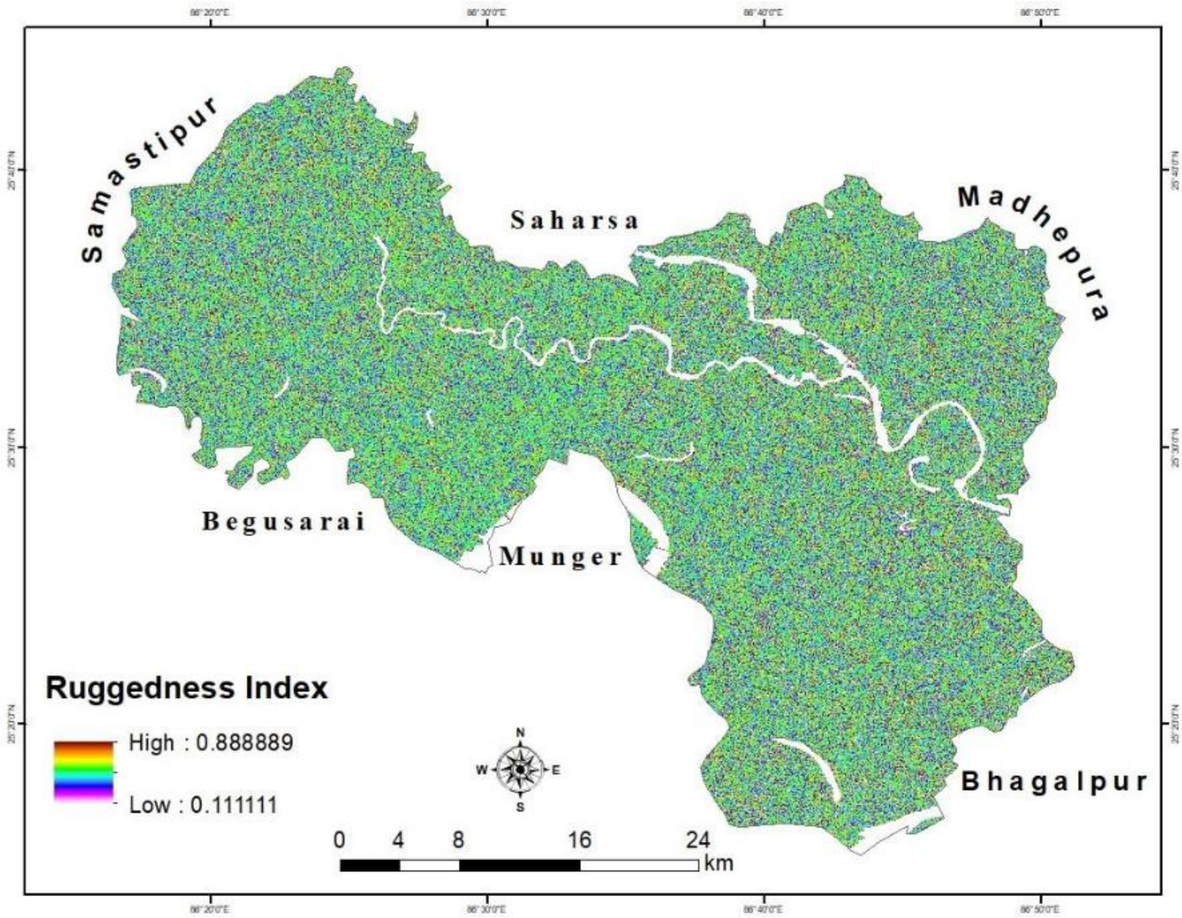

Fig. 8. Ruggedness Index Map.

Steep slopes and irregular surfaces in rugged terrain can lead to faster runoff, potentially causing localized flooding (Montgomery and Dietrich, 1994). Diverse vegetation in rugged landscapes aids in soil retention and reduces erosion, affecting water absorption and runoff (Peters et al., 2013). In rugged areas, limited floodplain availability can lead to rapid water accumulation in valleys during heavy rainfall (Hewitt and Kargel, 2001). Rugged terrain often lacks adequate flood management infrastructure, increasing susceptibility to flood damage (Riley et al., 2016). The overall impact of ruggedness on flooding risk is also influenced by factors like soil type, land use, and precipitation patterns (Morrison et al., 2017). Red/Orange/Yellow areas correspond to higher ruggedness (more uneven). Green/Blue areas represent lower ruggedness (flatter terrain). Khagaria district has a medium-range ruggedness index, with most of the area exhibiting moderate surface roughness. The terrain is neither very smooth nor extremely rough, making it a significant factor contributing to flood risk.

Relative Relief

The real change in altitude inside a unit region compared to its local base level is represented by the relative relief (RR). The RR is more expressive and helpful in understanding the morphogenesis of this region, but it ignores the dynamic potential of the terrain because it is intimately related with slopes. It is described as the height differential between the highest and lowest locations in grid regions of 100 km² (Bhunia et al.2012). Relative relief is one of the significant techniques that is effectively capable of presenting the relief characteristics without considering the sea level. Initially, a scientific and systematic study of relative relief was done by Smith (1935). The relationship between relative relief and flooding involves the interplay of topography and water flow. Relative relief refers to the difference in elevation between high and low areas within a specific landscape (Pielke, 2001). In areas with high relative relief (steep slopes), water can flow rapidly downhill, which might lead to flash floods, especially if the terrain is saturated or if heavy rainfall occurs over a short period (Miller and Haan, 2008). Low-relief areas, such as floodplains, are more prone to flooding during heavy rain or snowmelt, as they can easily accumulate water. Rivers often overflow their banks in these regions, causing widespread inundation (Wolman and Gerson, 1978). The relative relief influences drainage patterns. Steeper terrains may direct water quickly into rivers, while flatter areas may allow water to pool, increasing the risk of flooding (Bates and De Roo, 2000). Areas with varying relative relief may have different soil types and vegetation, affecting water absorption and retention. Poorly draining soils in low-relief areas can exacerbate flooding (Baker, 1998). Red/Brown areas indicate high relative relief – these regions likely contain hills or steep slopes. Green areas represent low relative relief, signifying flat plains or gently sloping areas. Yellowish/Intermediate colors indicate moderate relief zones. The relative relief map of Khagaria is shown in Figure 9.

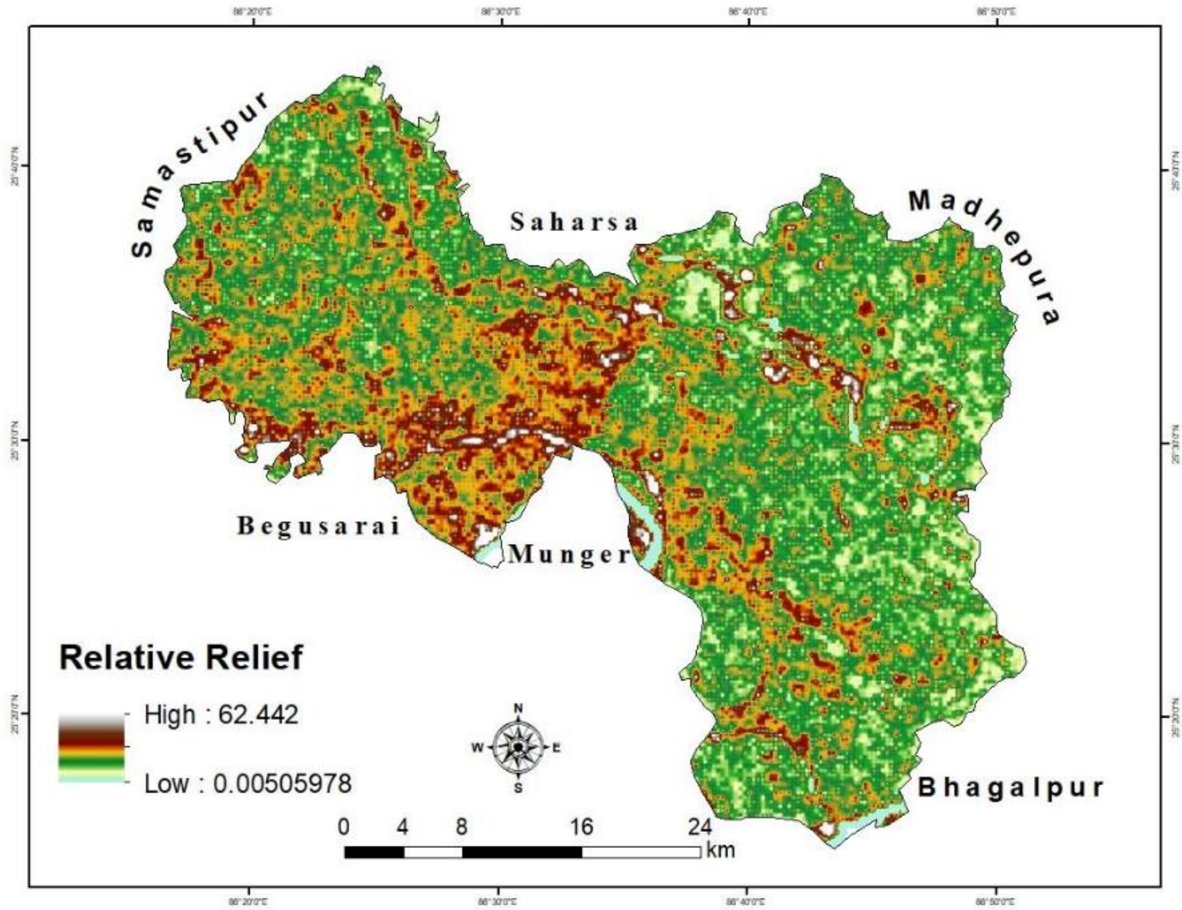

Fig. 9. Relative Relief Map.

The map shows a predominance of green areas, suggesting that most of this region is relatively flat or gently sloping, which aligns with the general topography of Bihar, known for the Gangetic plains. Red zones appear along certain linear features, possibly along river channels or elevated ridges. These areas may correspond to: Terraces or levees formed by river systems and small hills or undulating terrain in parts of the region. Since the area is flat and gentle sloping, Flood inducing chances are high.

Conclusion

An extensive relief analysis of Khagaria district was conducted using SRTM DEM data in ArcGIS, focusing on parameters such as elevation, slope, hillshade, drainage density, TWI, Ruggedness Number and Relative relief. These factors are critical in determining the relief and landform characteristics of the area, which, in turn, help assess its flood susceptibility. The district has an average elevation of 36 meters and a mean slope of 5.2 degrees, indicating a flat terrain with gentle slopes. Drainage density is low in most areas, and there are no hills or mountains present. The average TWI value is 1. Khagaria has a medium-range ruggedness index, with most of the district displaying moderate surface roughness. The relative relief map predominantly shows green areas, reflecting the flat or gently sloping landscape typical of Bihar, known for its Gangetic plains. Based on the parameters studied, the northern, northeastern, and southern regions are identified as highly vulnerable to flooding, with additional flood-prone zones observed in patches of the eastern and southeastern areas. The study concludes that Khagaria district's flat topography, high drainage density, and unique topographic characteristics significantly increase its flood susceptibility, emphasizing the need for strategic flood control measures and effective planning.

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Conflict of Interest

The author proclaimed no conflict of interest.

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