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Digital Terrain Analysis to Understand Watershed Characterization Using Aster DEM: A Case Study of Jamuna Watershed of Assam, India

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***Abstract*—Digital terrain analysis with the help of Digital Elevation Model (DEM) is most the common in various watershed related studies. In this study the Aster DEM software has been used because of its high resolution. The Jamuna watershed of Assam is located in remote area therefore this DEM data is quite reliable to delineate some of the thematic layers viz.- extracted DEM of the study area, slope, aspect, hill shade, flow direction, flow accumulation, stream order etc. These thematic layers are represented through cartographic techniques are helpful in analyzing the surface characteristics of the watershed, water concentration and presence of stream patterns. ArcGIS software has been used to complete the digital terrain analysis in the Jamuna watershed. The methodology involves preprocessing of DEM data to ensure accuracy and terrain attributes are computed using spatial analysis tools available in ArcGIS toolbox. The findings from the study contribute to a comprehensive understanding regarding Jamuna watershed's terrain characteristics; which will help in decision-making in various applications like land use planning and most importantly natural resource management in the study area.**

***Index Terms*—DEM, digital terrain analysis, Jamuna Watershed.**

I. INTRODUCTION

The Digital Terrain Analysis (DTA) (Miller, 2014; Hu et al. 2019) is the most important tool in hydro-morphological and environmental studies (Wilson & Gallant. 2000; Xiong et al. 2021); it offers valuable insights into the present topographical features of a particular area; in our case it is the study of a hilly watershed. With the help of high-resolution Aster DEM (30m resolution) (Peter G. et al. 2007), the characterization of watersheds has become more reliable and it has added more accuracy to the work. This study seeks the application of Digital Elevation Models (DEMs) (Richardson & van Oosterom. 2002); particularly derived from Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) data (Yamaguchi et al., 1998; Abrams et al. 2010), for the characterization of various features inside a watershed with the help of digital terrain analysis (Shingare & Kale. 2013; Sofia et al. 2019; Toradmal & Patil., 2020; Xiong, 2021) in ArcGIS software (San & Suzen; 2005) where various tools are available for auto delineation which is quite convenient, accurate and effective.

Whenever we study about a river basin or a watershed, the first thing comes in our mind that how the river looks like, how it is flowing and showing what type of patterns (Berhanu et al. 2015; Chuphal & Mishra, 2023) and how does the watershed look like, how is the slope, elevation, curvature etc (Fuss, 2013; Yang, 2023)- a lot of questions arise in our minds. To answer such questions we do a compact study to understand a river's hydrology (Finlayson & McMahon, 1995; Batelaanet al. 2013; Yang et al. 2021) and surface characteristics prevails in the basin; and for that going for digital terrain analysis with the help of Digital Elevation Model (DEM) data is most reliable (Talchabhadela et al. 2021) and cost effective also for a remote study area.

In watershed characterization, the delineation and understanding of various terrain features such as slope, aspect, curvature, hill shade etc (Mokarram & Hojati,2016; Yang et al. 2020), are crucial for various hydrological and morphological studies (Sarkar & Mathew, 2024). These attributes have direct influences on surface runoff, soil erosion, agriculture and habitat suitability and landform evolution processes (Stetler, 2014). To understand the relationships between surface terrain features and hydrological processes (Van Nieuwenhuyse et al. 2011; Sofia, 2020) in our Jamuna watershed of Assam, we choose Aster DEM (30m resolution) and ArcGIS 10.8to delineate the complex topographic variations present in thewatershed. This study will also help in understanding the condition of water availability and distribution (Lakshmi et al, 2018; Salehie et al. 2022) inside the watershed.

II. STUDY AREA

The study area is confined as a remote region, it is situated in the plateau regions of East Karbi Anglong district -a part of Karbi-Meghalaya plateau; the study area is distant from the Nagaon town by 127.4 km and hard to reach because of topographical challenges. The study area of Jamuna basin has different topographical divisions- the upstream zone is of hilly terrain having sparse settlements, the mid-stream zone has moderate slope where moderate to high concentration of settlements can be seen and the downstream zone is alluvial plain and settlement concentration is very high. In the floodplain zone near the Jamunamukh town three river confluences are seen and these are viz. Jamuna, Nikhari and Kopili. Besides availability of fish this zone is suitable for various agricultural crops. Communities living in this zone are mostly farmers and they mainly practice rice, vegetable and jute cultivation.

The Jamuna is a tributary of Kopili River. Jamuna watershed is mainly located in the East Karbi Anglong district and few parts of it falls under Hojai district of Assam. It extends from 25°41′ N to 26°27′ N latitude and from 92°44′ E to 93°40′ E longitude (Fig.1). The Jamuna River rises in Khumbaman hills near Diphu of East Karbi Anglong and joins with Kopili river near Jamunamukh town. Total area of the Jamuna watershed is about 3900 sq. km and maximum of it lies in the East Karbi Anglong district (Borah & Deka, 2019; 2020). The watershed covers five revenue circles of both the districts. It covers few areas of Diphu revenue circle & Phuloni revenue circle of East Karbi Anglong district; few areas of Lanka revenue circle, Doboka revenue circle & a small part of Hojai revenue circle of Hojai District (Dutt, 1979).

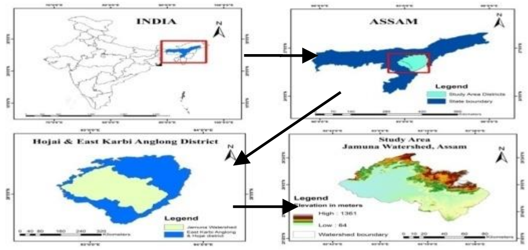

Fig.1 Location map of the study area

III. OBJECTIVE

The main objective of this study is to assess the digital terrain characteristics of Jamuna watershed with the help of Aster DEM in ArcGIS.

IV. DATA BASE AND METHODOLOGY

For this study Aster DEM data of30 meter resolution has been downloaded from NASA’s Earth Data website and processed the same in ArcGIS 10.8 software. Here after the study area has been extracted. With the help of Spatial Analyst tools of Arc tool box, more specifically surface & hydrology tools, we have drawn out various topographic layers like slope, aspect, hill shade, flow direction, flow accumulation, stream network, stream order etc one by one and represented as different maps for the Jamuna watershed (Fig. 2).

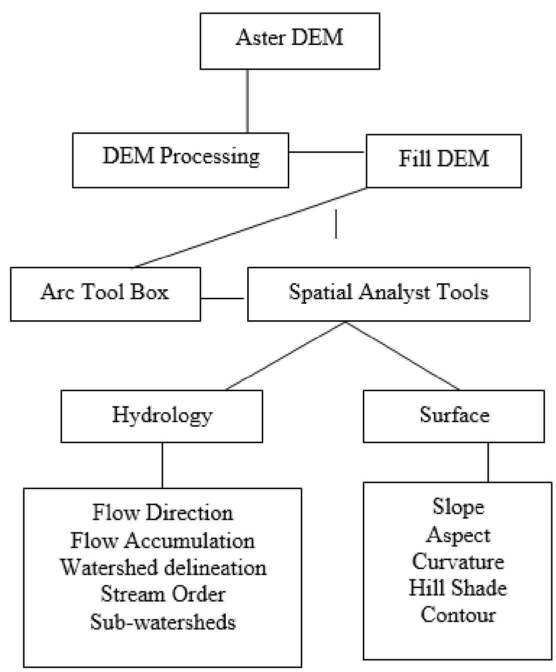

Fig. 2 - Conceptual framework

V. RESULTS AND DISCUSSION

In the context of terrain analysis and visualization of a particular area, there are some parameters like morphological parameters, hydrological parameters etc (Moore et al; 1991) which depends on the DEM representing the surface shapes. Representation of these parameters with the help of hydrology tool and surface tool in Arc tool box of ArcGIS 10.8 is quite convenient and accurate in terms of a remote area like Jamuna watershed. The result from the performed parameters helps us to know about the present morphological and hydrological settings of the watershed in a compact manner.

A. DEM

Digital Elevation Model (DEM) is the first and the most necessary input of digital terrain analysis; it has elevation, slope etc surface information in it. In this study we are using ASTER DEM and clipped our study area from the DEM after processing. In the Jamuna watershed we got the highest elevation 1361 meter and lowest elevation 64 meter from the DEM. The watershed comprises of hilly terrain to gentle slopes, the upstream zone has highlands of Karbi plateau and the downstream zone has fertile flood plains of Jamuna, Nikhari and Kopili river **(Fig.3)**. The DEM mapping clearly shows the terrain conditions of Jamuna watershed in a precise manner with the elevation details (Garbrecht and Martz, 2000).

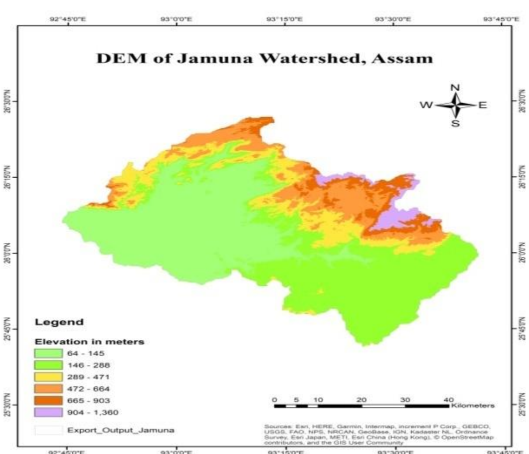

Fig.3- DEM of Jamuna Watershed, Assam

B. SLOPE

The slope characteristics of a particular region shows how the steepness of terrain and runoff pattern prevails in that area, in the case of Jamuna watershed of Assam, the slope variation rangesfrom0 to 67.5 degrees. It shows the suitability of habitat and agriculture practices of the area. In Jamuna watershed, the upstream tribes' practices *Jhum* cultivation (slash and burn method of agriculture) in the hilly terrains. On the other hand, in the downstream, it is observed that the cultivation is done with the help of river water irrigation; various cannels (e.g.-Jamuna irrigation cannel) were made under various schemes to supply water from Jamuna River to the agricultural fields.

The slope variation inside the watershed shows the degree of very gentle, gentle, moderate, moderately steep, steep and lastly very steep (IMSD, NRSA 1995; Ramaprasad, 2016) type of slope, where area wise very gentle slope covers 362.00 sq km (i.e. 9.10 % of the total area of the watershed), gentle slope covers 2503.99 sq km (i.e. 62.96 % of the total area), moderate slope covers 808.57 sq km (i.e. 20.33 % of the total area), moderately steep slope covers 269.64 sq km (i.e. 6.78 % of the total area), steep slope covers 30.63 sq km (i.e. 0.77 % of the total area) and lastly very steep slope covers 2.11 sq km (0.05 %) area of the total area of the whole watershed (Fig.4).

Table 1- Showing slope type with area covered and percentage

Slope type	Slope in degree	Area (in sq km)	Percentage
Very gentle slope	0-3.17	362.00	9.10 %
Gentle slope	3.17-7.67	2503.99	62.96 %
Moderate slope	7.68-12.98	808.57	20.33 %
moderately steep slope	12.99-18.8	269.64	6.78 %
steep slope	18.81-25.95	30.63	0.77 %
very steep slope	25.96-67.53	2.11	0.05 %

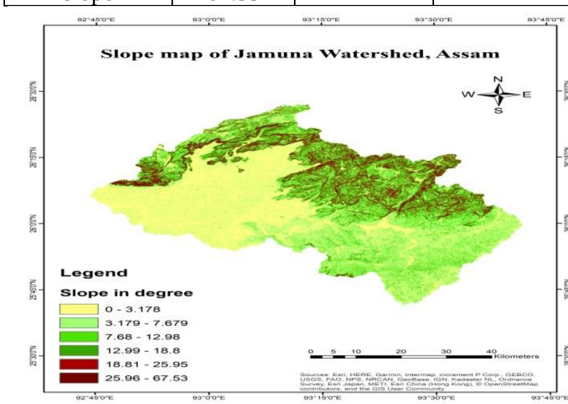

Fig. 4- Slope map of Jamuna Watershed, Assam

C. ASPECT

Aspect map usually shows the directional orientation of down slope (Weisberg & Newcombe, 2014), it helps to know in which way the slope is facing. Aspect map is helpful in terms of availability of sun light, prediction of local climate, agricultural productivity, surface runoff, tendency of landslides etc (Shengwen et al., 2006). The different aspect zones present in Jamuna watershed are- North (0-22.5), North-east (22.5-67.5), East (67.5-112.5), South-east (112.5-157.5), South (157.5-202.5), South-west (202.5-247.5), West (247.5-292.5), North-west (292.5-337.5) **(Fig. 5)**. For flat surface the aspect value is -1.

Importance of Aspect Values for Jamuna Basin:

North (0–22.5 & 337.5–360 degrees):

- North-facing slopes receive less direct sunlight throughout the year, especially in the Northern Hemisphere. These slopes tend to be cooler and retain more moisture, which can affect vegetation and soil stability.
- In the Jamuna Basin, this might mean denser vegetation cover on north-facing slopes, impacting water retention and reducing soil erosion in these areas.

North-east (22.5–67.5 degrees):

- Slopes in this direction receive more sunlight in the morning. The moderate sunlight and cooler temperatures can promote different vegetation types compared to south-facing slopes.
- These areas might be crucial for sustaining crops or forests that require moderate sunlight and cooler conditions.

East (67.5–112.5 degrees):

- East-facing slopes get sunlight in the early morning hours, which can help with the rapid warming of the surface.
- This can be beneficial for crops or plants that thrive with morning light and it may also influence evapo-transpiration rates and water use efficiency.

South-east (112.5–157.5 degrees):

- These slopes receive sunlight for a longer portion of the day.
- In the Jamuna Basin, south-east slopes may be drier and warmer, potentially supporting different types of vegetation and affecting soil moisture content.

South (157.5–202.5 degrees):

- South-facing slopes are exposed to direct sunlight for most of the day, making them the warmest. This can lead to higher rates of evaporation, drier soils and vegetation that is adapted to warmer, drier conditions.
- In the Jamuna Basin, this may affect the type of vegetation cover and soil erosion patterns, as well as the microclimates that develop in the area.

South-west (202.5–247.5 degrees):

- Slopes in this aspect receive intense afternoon sunlight, leading to warmer temperatures and drier conditions, especially during summer.
- These areas may be prone to erosion due to the dryness and vegetation may be sparse or adapted to high levels of sunlight.

West (247.5–292.5 degrees):

- West-facing slopes receive sunlight in the afternoon, which is generally warmer and more intense than morning light. This could lead to increased drying of soils and more arid conditions on these slopes in the Jamuna Basin, impacting vegetation and soil retention.

North-west (292.5–337.5 degrees):

- These slopes experience cooler conditions similar to north-facing slopes but with slightly more sunlight exposure in the late afternoon. This may create a balance between moisture retention and sunlight exposure, supporting diverse vegetation types and influencing local water retention in the basin.

Flat surfaces (Aspect value = -1):

- Flat surfaces have no specific aspect; they don’t face a particular direction. These areas are typically neutral in terms of solar exposure and may retain more water, which could be beneficial for agriculture or settlement.
- Flat surfaces may also be prone to water logging or slower water runoff during heavy rains, which may affect the overall hydrology of the watershed.

The aspect values in the Jamuna watershed influence not only the physical environment but also the local livelihood, agriculture and ecosystem services, playing a crucial role in shaping the sustainability of the region.

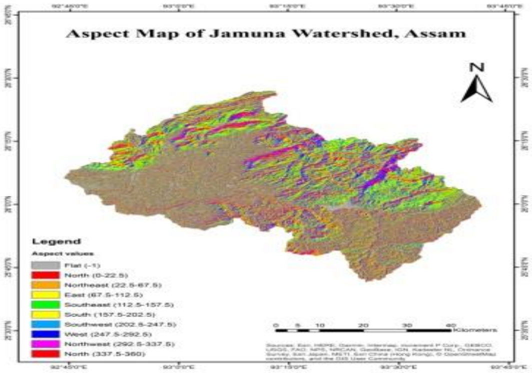

Fig. 5- Aspect map of Jamuna watershed, Assam.

D. CURVATURE

The curvature map shows the curvy shape or curves of the slope; it carries information of surface morphology; it may be convex or concave. With the help of GIS tools we can get the curvature value of a particular surface (Crane, 2021).It helps in better understanding of the local level curves of the slopes which helps in various studies and management purposes. The DEM derived data shows that the high value of curvature of Jamuna watershed is 2.26 and the low value is -3.21 rad/m (Fig. 6).

High curvature values (2.26 rad/m): These positive values indicate convex surfaces, like hilltops or ridges. Water tends to flow away from these areas; those are areas of low water accumulation. Low curvature values (-3.21 rad/m). These negative values indicate concave surfaces, like valleys or depressions. Water accumulates in these areas, making them zones of higher moisture retention, which can promote sediment deposition and influence vegetation growth.

High curvature areas in the Jamuna watershed are more prone to soil degradation and less water retention. Low curvature areas are essential for water collection, sediment deposition and important for agriculture or sustaining water flow during dry periods.

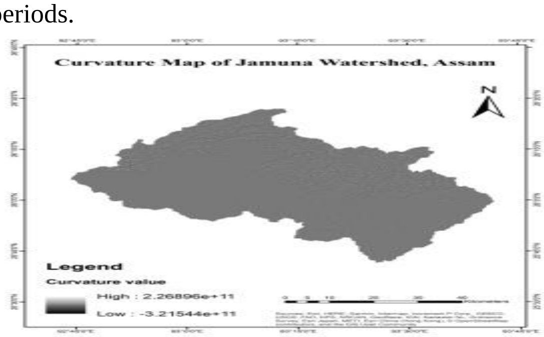

Fig. 6- Curvature map of Jamuna Watershed, Assam

E. HILL SHADE

The hill shade of a particular area shows the grayscale 3D representation of topography of the place, here sun's relative position is taken into consideration to delineate the hill shading of the area. It helps in visualizing the depth and dimensions of the study area by taking the light and shadow patterns of the area to understand the prevailing landscape (Buckley, A. 2018). The hillshade model helps to understand the topographic features like slopes, ridges, valleys and water flow patterns. By adjusting the azimuth angle of the light source, we can simulate how the sunlight affects different parts of the watershed, allowing you to observe shadows and highlights, which help identify the elevation differences and landscape structure (Burrough & McDonnell, 1998; Wilson & Gallant, 2000).

The Jamuna watershed has an integer value range of 0 to 180 azimuth angle of the light source; the azimuth measured clockwise from north **(Fig.7)**. In this study area hillshade analysis would allow us to visualize how the terrain might influence water flow, erosion patterns and how different parts of the watershed are exposed to sunlight. This can be critical for sustainability studies, especially for understanding soil degradation, vegetation growth etc. The azimuth angle in hillshade represents the direction of the light source and adjusting it helps create a more detailed view of the watershed's topography, which is essential for understanding the watershed's physical characteristics and potential environmental impacts.

In this study the derivation of hill shade is done with the help of surface analysis tool of ArcGIS.

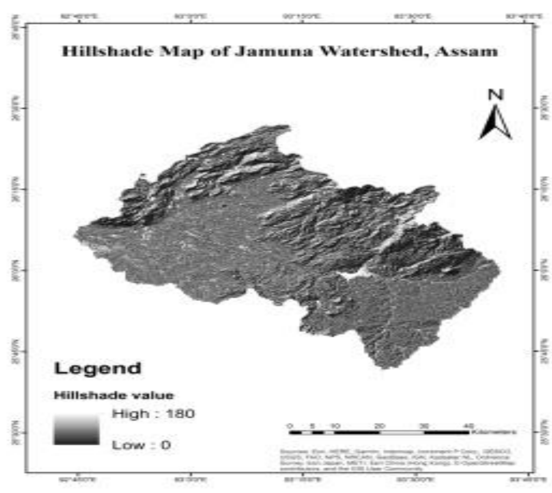

Fig. 7– Hillshade map of Jamuna watershed, Assam

F. CONTOUR

The contour lines of an area show the elevation above sea level and the surface features present in that particular area, these lines connect the pointof equal elevations (Shary, 1991; Florinsky. V. I., 2016). The Jamuna watershed has contours from 200m to 1200 m and interval is 400 m for the clear visualization purposes in the map (Fig.8). Although the area has highest elevated point of 1361 meter, the upstream has a few hills and elevated plateau areas which prevail till the upper part of the mid-stream.

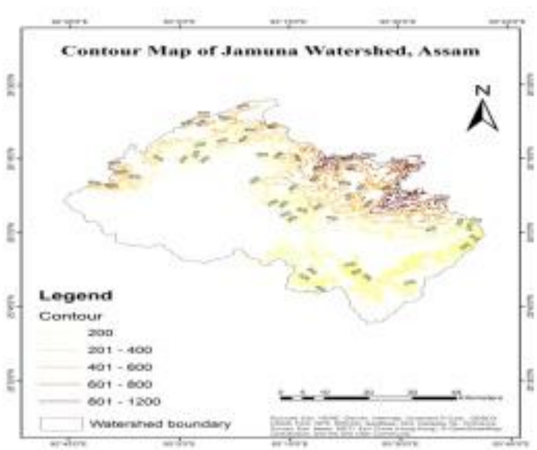

Fig.8 – Contour map of Jamuna Watershed, Assam

G. FLOW DIRECTION

The flow direction map shows the direction in which water is flowing; it determines the prevailing topography of the watershed (Bajjali, 2023). Hilly small streams usually follow the path of having least resistance and necessary slope; it makes a network of channels leading to an outlet. Understanding flow direction is important for managing water resources, it is measured by calculation of the DEM cells which are having a steepest descent in every cell of the DEM; it is an angle of radians and the maximum drop is calculated by checking the change in Z value divided by distance.

The flow direction map of Jamuna watershed **(Fig.9)** shows the highest value of drop out is 128 and lowest value decreases up to 1. Maximum drop of flow is calculated by the following formula:

Maximum drop = Change in Z value / Distance*100 (Toradmal, 2020)

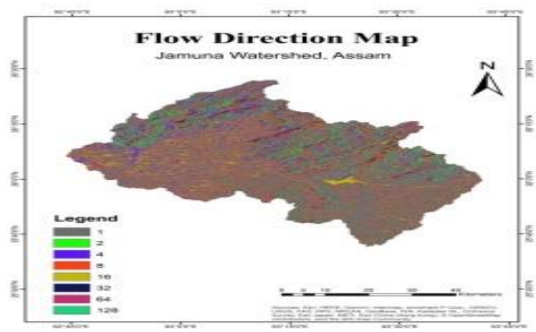

Fig.9- Flow direction map of Jamuna watershed, Assam

H. FLOW ACCUMULATION

Flow accumulation is the process in which water from multiple sub-tributaries accumulates and flows towards downstream; water from various sources joins through channel and gradually increasing in volume as smaller streams merge into the larger ones. This process of accumulation is influenced by some factors like prevailing topography, slope and permeability of soil and land use land cover patterns also (Winkler et al., 2021). Flow accumulation maps help in assessing water availability and distribution in the watershed, flood potentiality, managing resources effectively in the watershed. While flow accumulation deriving from DEM, the cells has a high flow accumulation of 0 are local topographic ridges; cells with high accumulation shows area of flow concentration and recognizes as streams (Esri; Jenson, 1988; Tarboton, 1991). In the case of Jamuna watershed, a few locations are very important in terms of flow accumulation as various tributaries joins in those points; the river has more than twelve tributaries of its own and hundreds of sub-tributaries and a lot of small streams inside the watershed boundary which provides water to the main stream (Fig.10).

Fig. 10- Flow accumulation map of Jamuna Watershed, Assam

I. WATERSHED DELINEATION

Watershed is a zone which contains a common set of streams those channels into a single bigger body of water as master stream for that specific watershed (Kaviya, 2017). In ArcGIS with the help of DEM we can easily delineate a watershed by giving a pour point at the end of the master river, where it is drains in another huge body of water. Jamuna Watershed has almost 3,900 sq. km. of total area (Borah & Deka, 2019; Borah & Deka, 2020). It is a huge watershed comprises with five revenue circles and maximum areas are from Phuloni revenue circle (Fig. 11). In this watershed, Jamuna River has 14 tributaries with their own sub watershed regions which collaboratively form the whole watershed (Wang, et al. 2016).

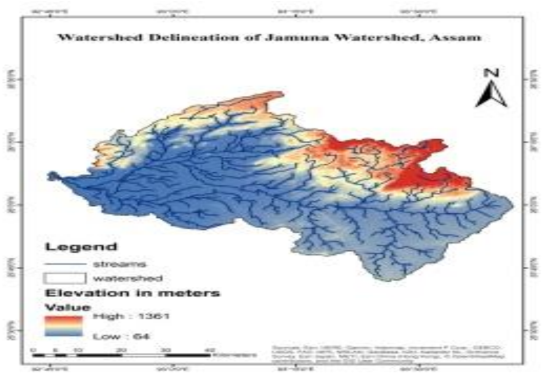

Fig. 11- Watershed delineation of Jamuna River, Assam

VI. CONCLUSION

In this study, we tried to utilize the DEM data for the digital terrain analysis of Jamuna watershed and the outcomes were presented as maps; these maps help in understanding the terrain related characteristics of the watershed which can be utilized for various planning purposes. The terrain analysis of hilly remote region like Jamuna watershed is tough without the help of DEM data; ASTER DEM has global coverage and it is freely available for research purposes in NASA's earth data site; with the help of GIS the ability of work exceeds and watershed characterization related studies needs precise data and software to work with; ASTER DEM has significant promise due to its high spatial resolution and multi-spectral capabilities. These attributes of ASTER DEM enable us to conduct detailed analyses of terrains present within the watershed.

VII. ACKNOWLEDGEMENT

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