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A STUDY ON FLOOD SUSCEPTIBILITY ANALYSIS OF SYLHET SADAR USING GIS

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Abstract

Flooding is a natural occurrence in Bangladesh with devastating effects on significant areas, including Sylhet. This study aimed to summarize the flood susceptibility of different areas of Sylhet Sadar. This study is based on an approach that relies on free and open datasets rather than data obtained on the ground. NASA Earth Data was utilized to acquire satellite images of the study area (DEM at 30m resolution). The Surma River shapefile was obtained from humandata.org or HDX. Six individual maps were created, i.e., land cover, flow direction, precipitation, elevation, slope, and Topographic Wetness Index and each of the maps was then reclassified. Then the six reclassified maps were overlaid, summarized, and our final output came out as the Flood Susceptible Map of Sylhet Sadar. ArcGIS 10.8 version was used to create a flood-prone area, which was divided into five zones (very high, high, moderate, low, and very low). From this final flood susceptible map, we can identify the vulnerable zones or the flood-prone areas of the Sylhet Sadar and can take precautions or actions during the flood season. The study area's low-lying plains are particularly susceptible to flash floods. The result shows that Kazir Gaon, Kurir Gaon, and Umairgaon are in a very high flood susceptible zone. South Surma is in a highly susceptible area. Khadimnagar is the least susceptible zone. This research can aid in the development of appropriate flood management strategies and policies to minimize the risk of future flood-related damages and losses in the region.

Keywords: Flood Susceptibility, Sylhet Sadar, GIS, Satellite Image, Surma River, Vulnerable.

Introduction

When the natural bed of a river, a stream, or an artificial canal overflows, it is referred to as a flood. As a result, normally dry areas are flooded. Although they are a natural occurrence and a significant component of a river basin's hydrological processes, floods are more frequent and have more severe effects due to human activity and climate change (Anna Karkani, 2021). Floods are among the worst natural calamities, inflicting destruction on the economy, society, and human life in approximately 43 percent of all-natural disasters (Indira Bose, 2016). The most significant causes of floods are heavy downpours, the melting of ice, high water levels (caused by either natural or artificial obstacles in the riverbed), the destruction of forests due to fires or deforestation, and the collapse of dams (Anna Karkani, 2021).

The Ganges, the Brahmaputra, and the Meghna are the three major rivers that drain into Bangladesh's deltaic area, which is situated in the bottom section of their respective basins (Md Abdullah Al Baky, 2019). As a result, flood is the kind of natural catastrophe that occurs most often in Bangladesh. The country's unique geographic position, in which it is encircled on three sides by mountainous regions, in conjunction with its exceptionally flat and low-lying floodplain landscape, its low-lying shoreline, and its high degree of unpredictable climatic nature, has made it particularly susceptible to natural disasters such as floods (Md Abdullah Al Baky, 2019). An in-depth examination of the flood's characteristics is essential to the process of formulating an appropriate adaptation strategy and conducting efficient flood management. Each year, floods affect an area of over 26,000 km² (10,000 square miles), which accounts for approximately 18 percent of Bangladesh. As happened in 1998, the impacted region during catastrophic floods might reach up to 75% of the country. This amount represents 95% of the overall yearly inflow. Floods have wreaked havoc on Bangladesh in the past, particularly in 1951, 1987, 1988, and 1998 (Talukdar S. G., 2020).

Flooding has devastated the Bangladeshi city of Sylhet, affecting hundreds of people. People are returning to their homes as the floodwaters recede, only to find that their homes, possessions, and livelihoods have been shattered by this merciless natural disaster. (Janizadeh, 2021) In reality, the floods have affected over 50,000 people in over 30 locations in Bangladesh (Islam, 2021).

Flood susceptibility mapping is a quantitative or qualitative evaluation of the categorization, area, and geographical distribution of floods that exist or might occur in a given region (Ahmed, 2021). The purpose of conducting flood susceptibility analyses is to raise awareness of the risk of flooding among the general people, government agencies, and other institutions (Talukdar S. G., 2020).

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For the past two decades, GIS and remote sensing (RS) have become common decision-support tools for acquiring, storing, and analyzing environmental data (Siam, 2021). Because the incidence and effect of natural disasters, such as floods, are spatially intrinsic, RS and GIS are increasingly playing a crucial role in their management (Pérez, 2021). In addition, spatial technologies such as GIS not only allow for the visual representation of the spatial distribution of flood events but they additionally allow for the assessment and calculation of potential flood damages (Sachdeva, 2021).

The aim of this study is to determine which parts of Sylhet Sadar are more and less likely to be drowned during floods. As a result, the local areas, farmers, vegetative and cultivable lands will be much more in observance due to the monsoon season as well as the devastations to those areas can be minimized by taking the general flood hazard precautions. Furthermore, Sylhet is a highly flood prone zone for being in a basin area. So this research will be helpful for the future researchers and data analysts'.

Materials and Methods

Study Area

Sylhet Sadar is one of the upazilas that makes up the Sylhet District in the Sylhet Division of Bangladesh. The coordinates for Sylhet Sadar are 24.8917°N 91.8833°E (Figure 1). Sylhet Sadar has a total area of 323,17 km^2. The average annual temperatures at their lowest and highest are 17.6 and 33°C, respectively. The total population reach 554,412 (1071 persons per km^2). It is bordered by the upazilas of Companiganj, Gowainghat, and Jaintiapur to the north, Dakshin Surma to the south, Jaintiapur and Golapganj to the east, and Chhatak and Bishwanath to the west.

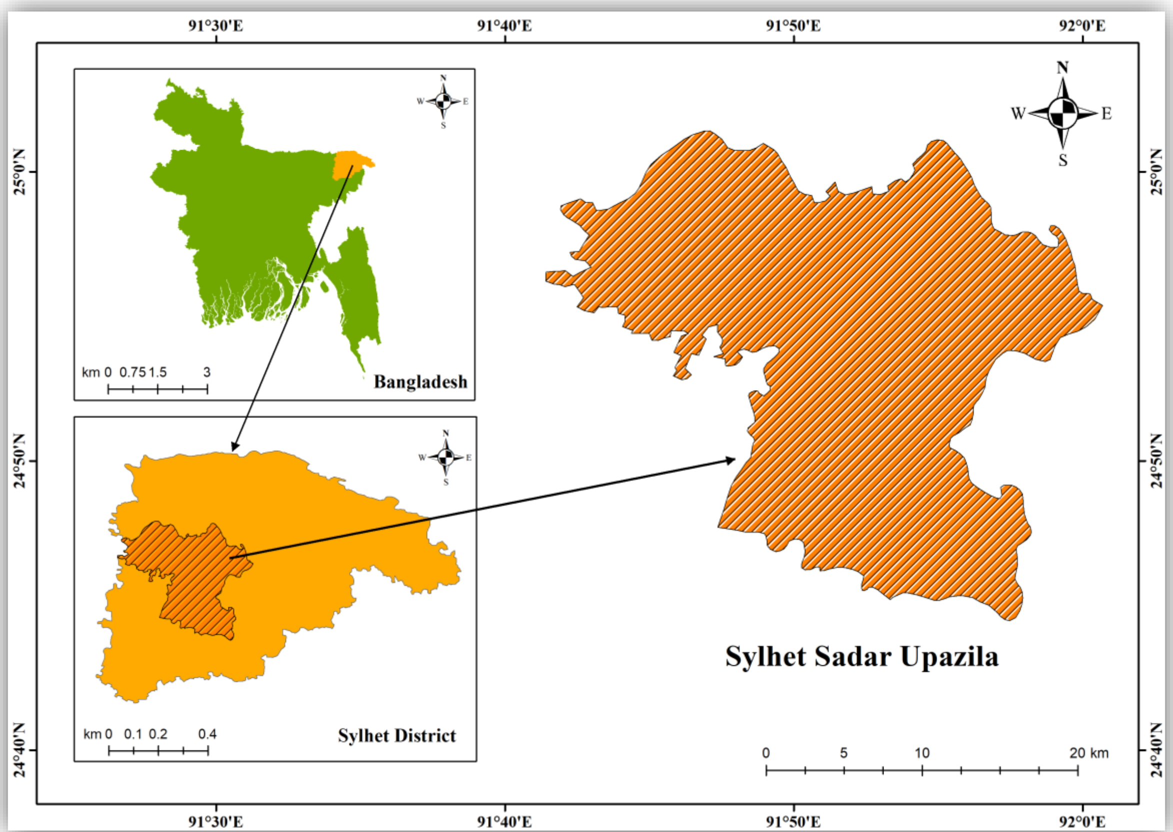

Figure 1: Map of the Study Area.

Materials used

For the GIS data preparation work as well as the implementation of a flood hazard model, we used ArcGIS 10.8 and the accompanying Spatial Analyst extension (Esri). Satellite images were used from the NASA Earth Data website. Other datasets used for flood susceptibility mapping are given in Table 1.

Table 1: Datasets used for flood susceptibility mapping

Sl. No.	Data description	Data-type/resolution	Source
1	Digital Elevation Model	30m	https://earthexplorer.usgs.gov
2	Slope DEM	10m	https://earthexplorer.usgs.gov.
3	Land cover	Satellite imagery of the study area	USGS Earth Explorer
4	Precipitation	Raster layer	https://crudata.uea.ac.uk/cru/data/hrg/

Data collection and data processing methods using GIS

It is usually difficult to choose characteristics that can be used in flood susceptibility mapping universally. We used six different variables to determine a location's vulnerability to flooding: land use/land cover, slope, elevation, precipitation, topographic wetness index (TWI), and proximity to a river. A flowchart summarizing the methods of analysis is provided in Figure 2.

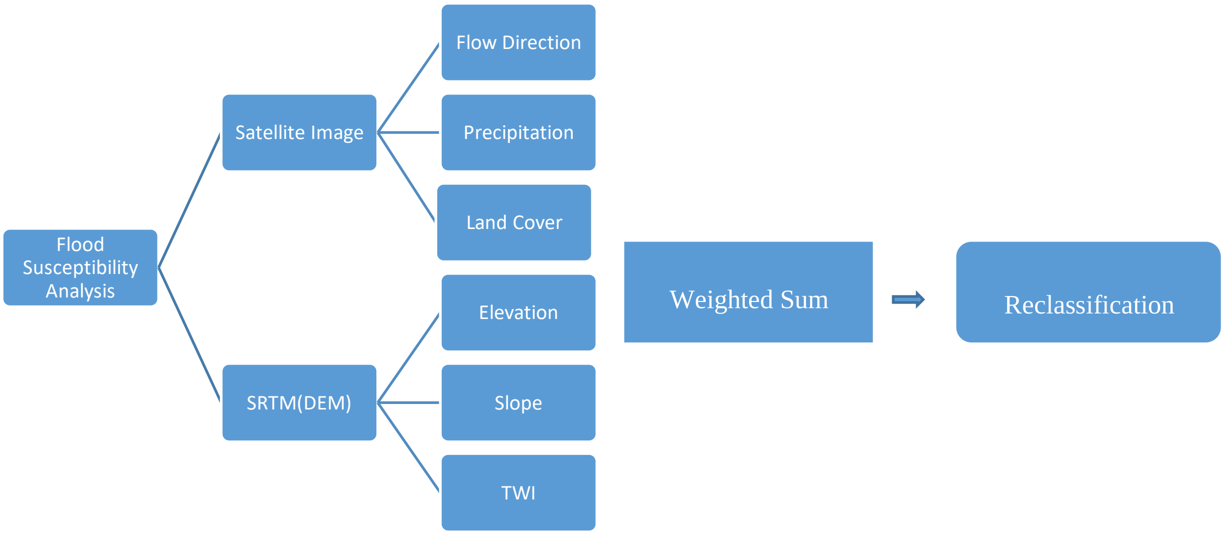

Figure 2: Flow Chart of the Analysis Method

A digital elevation model is a crucial part of any flood research project. The digital elevation model (DEM) data for the study area was provided by the NASA Shuttle Radar Topographic Mission (SRTM). The DEM has 30-meter resolution. The digital elevation data were downloaded from the USGS website - https://earthexplorer.usgs.gov. To generate a high-quality slope map, a DEM with a resolution of 10 meters was obtained from the US Geological Survey. The DEM data was pre-processed using a Gaussian filter with a radius of 3 pixels to remove noise and smooth the terrain. To produce the slope effect, the azimuth angle was set to 315 degrees and the altitude angle to 45 degrees. The resulting slope map had a color ramp ranging from black to white, with white representing the highest elevations and black representing the lowest, which was altered with green to red color ramps, respectively. The accuracy of the slope map was assessed by comparing it to ground truth data collected from GPS surveying, with an overall root-mean-square error of 0.5 meters.

This map was created by taking some steps. Firstly, source data for your study area were collected as a satellite image from the USGS. Then it was georeferenced as .tiff file. Then by using specific operations with the GIS inbuilt tools, a signature file was created of the study area. After that, maximum livelihood classification was performed. In the end, the study area was calculated and represented on the map (Figure: 3).

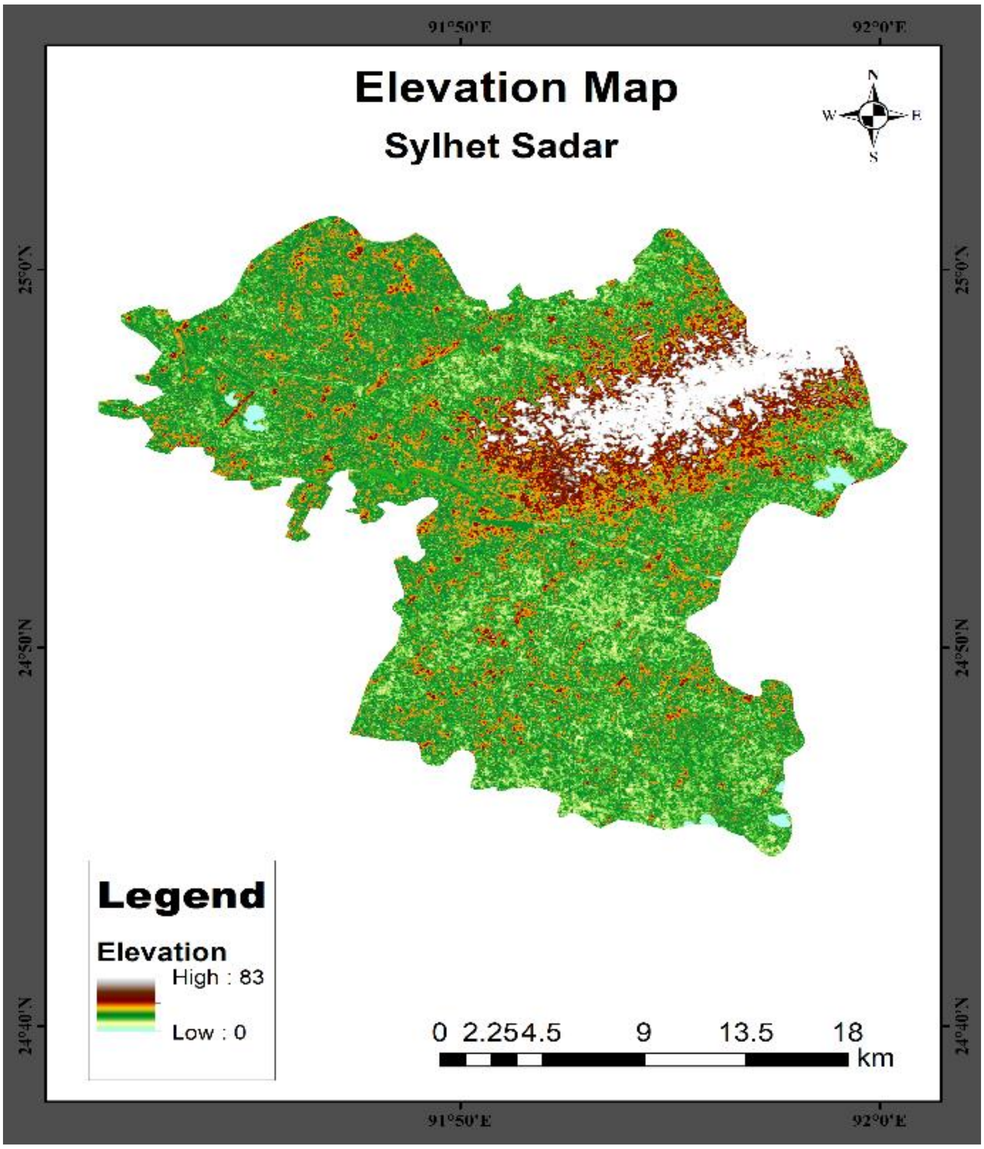

Figure 3: *Elevation Map*

The topographic wetness index (TWI) map was created by taking some steps. First, a high-quality DEM raster file was taken of the study area and ensured that it was properly projected and geo-referenced. Then slope and aspect of the terrain were calculated using the DEM with slope and aspect tools available in the GIS software. After that, the LS (Length-Slope) factor is calculated. This factor represents the effect of slope and length on the movement of water over the surface. It can be calculated using the following formula:

$$LS = \{\sin(slope) / 0.0896\} * \{(flow\ accumulation * cell\ size) ^\wedge 0.6\} \quad \text{(eq. 1)}$$

The final step is to calculate the TWI using the LS factor or (eq. 1) and the flow accumulation raster file. The TWI represents the potential wetness of the terrain and is calculated using the following formula,

$$TWI = \ln \{a / \tan(b)\} \qquad \text{(eq. 2)}$$

Here ‘a’ is the flow accumulation, and ‘b’ is the LS factor (eq.1) (both raster files).

Initially, the river distance map was created using the fill tool. The *Fill* tool in ArcGIS was used to remove small depressions or sinks in a raster surface. The tool fills these depressions with values from the surrounding cells, which can help to create a smoother and more accurate surface. This was done in order to remove minor data flaws. The direction of flow from each cell was then measured. This is based on the slope of the terrain and the surrounding cell values. The tool outputs a raster where each cell contains a value representing the flow direction from that cell. After that, a flow accumulation map was made. This was based on the flow direction raster created in the previous step. The tool outputs a raster where each cell contains a value representing the total number of cells that flow into that cell. Stream orders were formed as a result of this. The Strahler stream order was used for this case, which assigns an order of 1 to the smallest streams and gradually increases the order as streams merge. Then there was a conditional evaluation. The *Stream to Feature* tool in ArcGIS was used to convert a raster stream network into vector features. This vector layer was useful for visualizing the river distance parameter.

The *Flow Length* tool in ArcGIS was used to calculate the flow length or distance of each cell in a flow accumulation raster to the nearest downstream outlet based on a specified flow direction raster. The tool takes into account the direction and slope of the terrain to calculate the distance along the flow path. The output of the tool is a raster where each cell represents the distance in units of the input raster. The *Euclidean Distance* tool in ArcGIS was used to calculate the straight-line distance from each cell in a raster to the nearest source location, such as river or stream (following eq. 3). The streamlines generated from the flow accumulation raster were used to calculate the Euclidean Distance. The general formula is given in eq. 3

Euclidean Distance = square root $((x^2 - x^1)$ ^2 + $(y^2 - y^1)$ ^2) (eq. 3)

Where, x^1 and y^1 are the coordinates of the starting point, and x^2 and y^2 are the coordinates of the ending point.
High resolution gridded dataset was obtained from https://crudata.uea.ac.uk/cru/data/hrg/

The dataset used here is the 2020 dataset. The first step was to use multidimensional tools to generate a NetCDF raster layer. Then the raster dataset was exported. The data frame was changed to WGS 1984 UTM Zone 46N. Then again, the raster was exported according to the data frame spatial reference. We had a total of 120 bands. The last 12 bands were taken to create a composite band. Then cell statistics tool was used. After that, raster to point was created. Then IDW interpolation was done to create the precipitation map.

Six classes were used to combine all of the maps. In order to get the final map, all the rasters were overlaid using the weighted sum tool. In GIS, the weighted sum tool is used to generate a composite index or raster map by merging numerous input layers or components with different weights. This technique is widely used in a variety of applications, including flood susceptibility mapping the weighted sum tool allows us to assign weights to each factor (Slope, Flow length, Precipitation, River distance, Land cover, Elevation) based on their relative importance in contributing to flood susceptibility. These weights can be determined through expert knowledge or statistical analysis. The tool then combines the input layers by multiplying each factor by its weight, summing up the results, and generating a composite index or raster map that represents the overall flood susceptibility of the area. The parameters used for the weighted sum are given in Table 2. By using this tool, the final flood susceptible map was obtained.

Table 2: Weight used for overlay sum

Raster	Weight value
Slope	40
Flow length	5
Precipitation	15
River distance	5
Land cover	5
Elevation	30

Results

Maps were created to represent the results. These maps include a digital elevation model of the study region, a slope measurement of the study area expressed as a percentage rise, the land cover of the Sylhet Sadar Upazila, the topographic wetness index, precipitation, and a watershed delineation map.

Map Analysis

Elevation Map

The current study looked at the topographical aspects of the study area using an elevation map (Fig. 3). A high-precision global positioning system (GPS) was used to measure the elevation values of the terrain, which ranged from 0 to 83 meters above mean sea level. The region had a mean elevation of 42 meters and a standard deviation of 18 meters. The elevation map's topographical changes showed that the study area contained both high- and low-elevation regions. Flood incidence risk is higher in low-elevation areas because runoff moves from high to low terrains (Paul, 2019). Low-lying areas are particularly vulnerable to flooding since even little floods can inundate them (Shaban, 2006). The study's conclusions show that areas with elevation values below the mean are more likely to have flooding incidents. Due to their proximity to water sources and relatively lower elevation compared to other regions within the research area, the lower elevation areas are more vulnerable to flooding. For future planning and management efforts, the elevation map can be a useful tool for identifying regions that are most susceptible to flooding disasters. After excessive rainfall over the central European alpine region triggered a devastating flood on the Elbe River in 2002, (Henry J. B., 2006) employed improved multi-polarized SAR data to track floods. The findings were compared to a higher-resolution DEM-based GIS flood cover model. The results reveal that the DEM/GIS flood cover model and the RS SAR pictures both delineated the flood event in a similar way.

Slope Map

A steep slope encourages rapid water drainage, while a low slope causes water to stagnate and encourages flooding (Dash and Sar 2020). A slope map (Fig. 4) was used to examine the topographical features of the research region. The slope map divided the terrain into four different categories based on the steepness of the inclination. The study region was separated on the map into four categories: slopes with inclines of less than 10%, between 10% and 15%, between 15% and 20%, and over 20%. Understanding the topographical changes within the research area through this classification is essential to comprehending the geomorphological characteristics of the region. The map shows that most of the areas of Sylhet Sadar have slopes of less than 10% inclination. In contrast to slopes with a lower degree of incline (less than 10%), those with a higher degree of incline (more than 20%) are more sensitive to erosion and landslides. The areas with less slope inclination are also likely to get flooded. To reduce the risk of erosion and landslides within the research region, future management, and conservation efforts can be guided by the slope map.

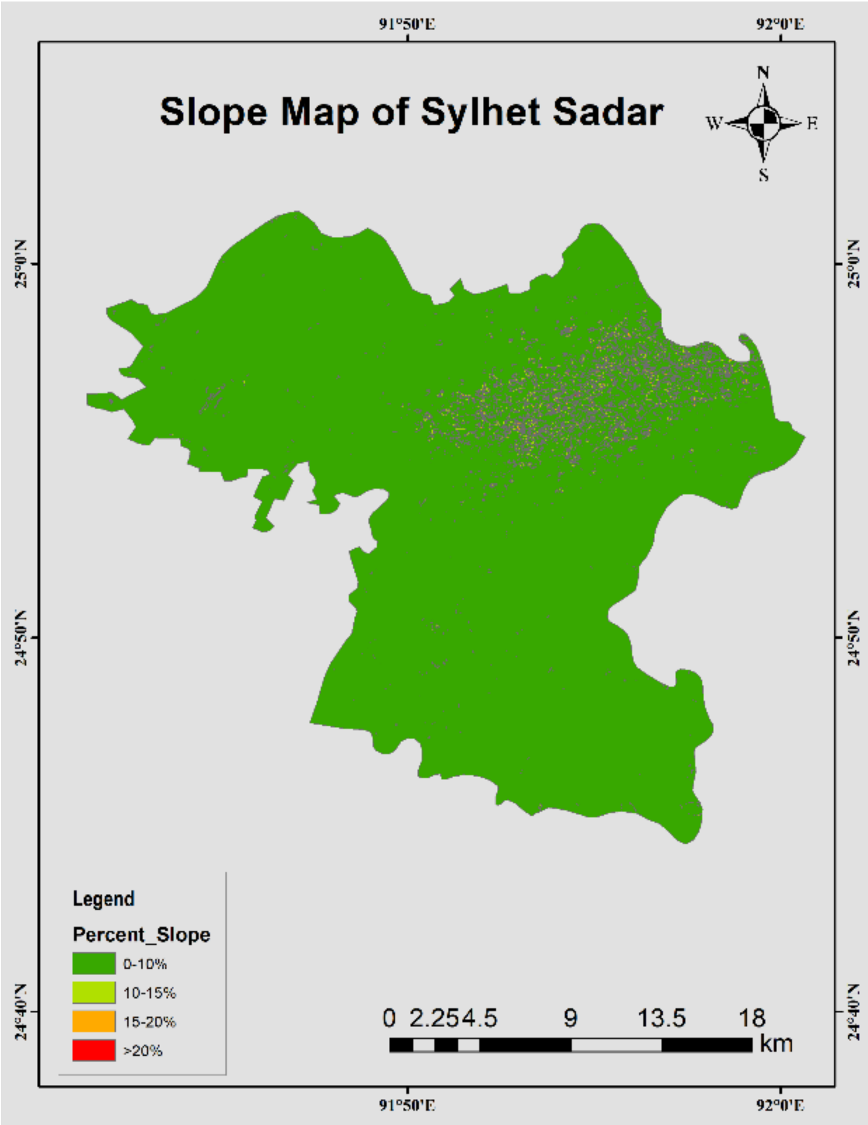

Figure 4: Slope Map.

Land Cover

Land cover has an impact on infiltration rate, the interaction of surface and groundwater (Kazakis et al. 2015), evapotranspiration, and surface runoff generation (Samanta et al. 2018). A land classification map (Fig. 5) that showed the geographic distribution of various land types was used to investigate the land features of the research area. According to the properties of the area, the map divided it into three distinct categories: river land, agricultural land, and hilly land. The chart showed that 88 km^2 were designated as river land, 226 km^2 as agricultural land, and 202 km^2 as hilly land (Table 3). The land categorization map can be an essential tool for comprehending how different land types are distributed spatially within the study region and for guiding future research and management initiatives. The amount and distribution of agricultural land, for instance, can be used to inform land-use planning and agricultural production methods. Similarly to this, knowledge of where hilly land is found might help conservation and management activities that attempt to reduce the risk of landslides and erosion in regions with steep topography.

Table 3: Land Cover

Value Class name or description	Area (sq.km)	% Land
Land use/land cover		
1 River Land	88	17.05
2 Crop Land	226	43.79
3 Hilly Area	202	39.15

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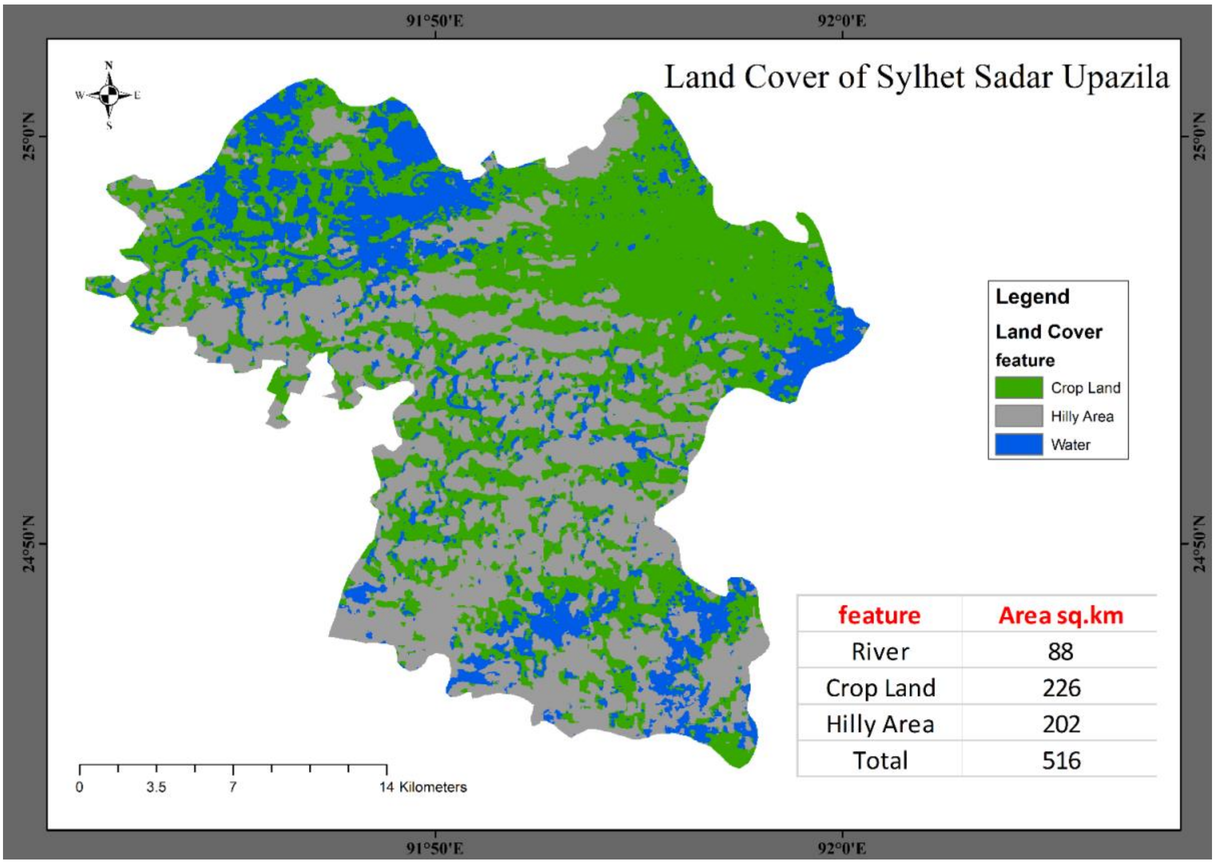

Figure 5: Land Cover Map.

Topographic Wetness Index

Based on the topographic wetness index (TWI) values for the study area, the findings were divided into seven different categories (Fig. 6). They ranged from 2.0 to 6.0, 6.0 to 6.5, 6.5 to 7.0, 7.0 to 7.5, 7.5 to 8.0, 8.0 to 8.5, and over 8.5. A color scale was used to indicate the TWI values, with greater values displayed in red and lower ones in green. Higher TWI values indicate locations that are more likely to be wetter, with greater water accumulation and slower water runoff. Conversely, lower TWI values indicate drier locations, with less water accumulation and faster water runoff. The classification of TWI values offers important insights regarding the topography and hydrological parameters of the studied area. The likelihood of flooding is increased in locations with high TWI values because they have poor drainage and greater soil moisture levels. Future research and management initiatives aimed at reducing the risk of flooding within the study region can therefore be informed by the TWI categorization. The color-coded map's color scale makes it simple and quick to see how the TWI values vary across the study region. Color can be used to help identify places with high or low TWI values, which can guide additional research or management efforts to address areas with a high risk of flooding.

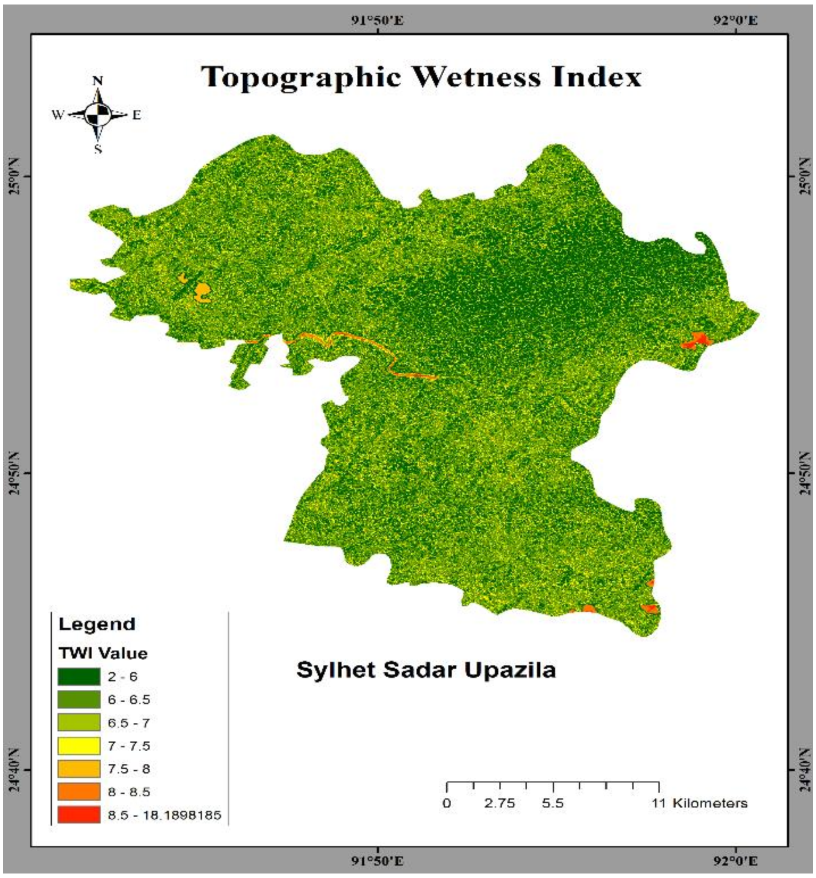

Figure 6: TWI (Topographic Wetness Index) Map.

Precipitation

Precipitation data gathered over a predetermined time period were used to assess the research area's precipitation features, which indicated a variety of precipitation values. 3660 mm and 4970 mm, respectively, were the lowest and highest amounts of precipitation that were measured (Fig. 7). The precipitation data were divided into six different categories, including 3660-3880mm, 3890-4100mm, 4110-4310mm, 4320-4530mm, 4540-4750mm, and 4760-4970mm, in order to better understand the distribution of precipitation throughout the research area. The areas with higher precipitation are more likely to get affected by flood events. The spatial distribution of precipitation within the study region can be better understood by the reclassification of precipitation data into several classes, which can be used to guide future research and management initiatives. Planning for land use and agricultural production might be influenced by the identification of regions with high or low precipitation rates. Similarly, it can be used to identify places that may require more storage or conservation efforts, and information on precipitation levels can be utilized to establish strategies for managing water resources.

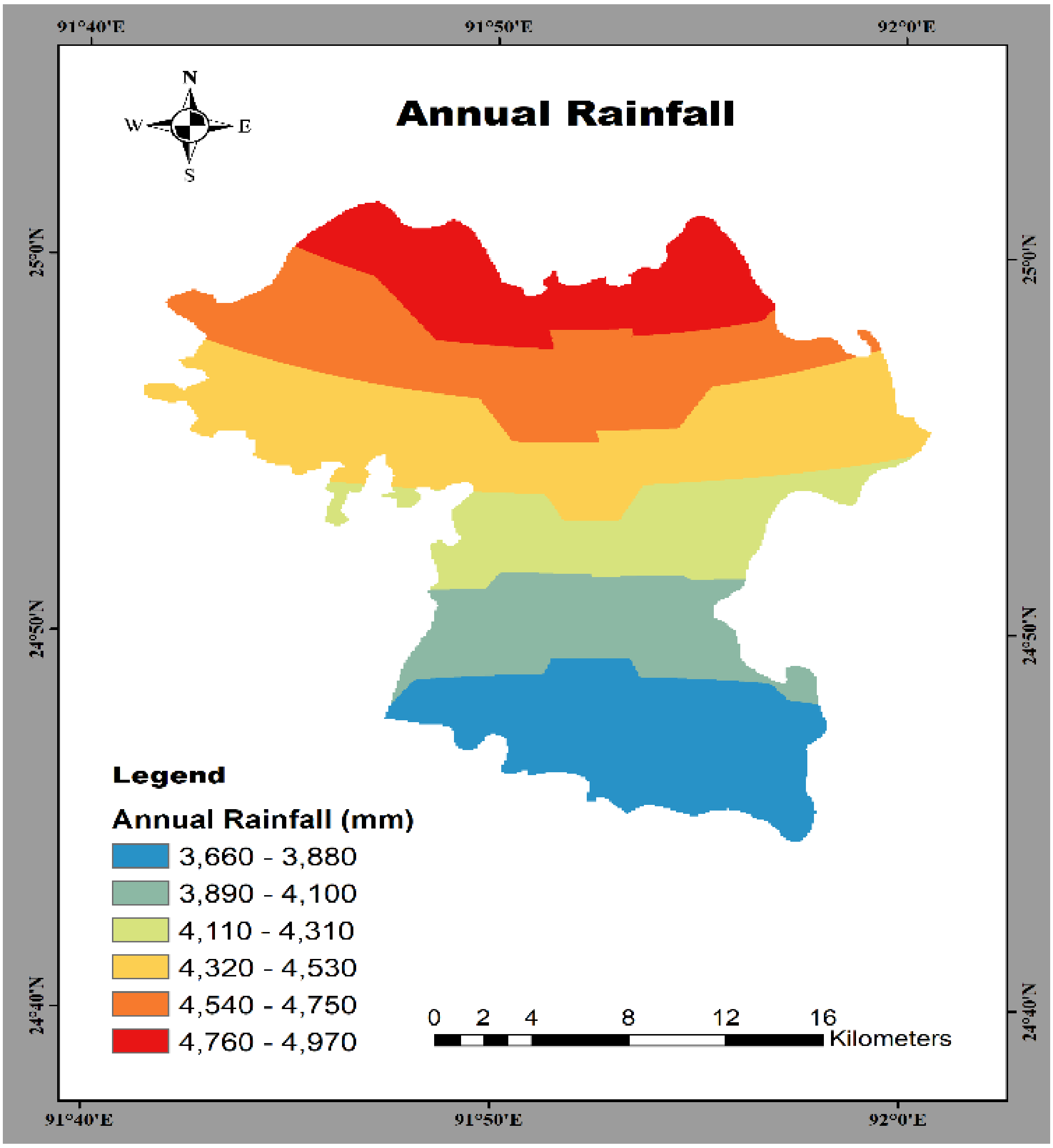

Figure 7: Precipitation Map.

Flood Hazard Map

The complex process of mapping a region's flood inundation takes into account many topography factors, including slope and elevation, precipitation, the topographic wetness index (TWI), land cover, and distance from the river. All of these traits were taken into consideration when creating the map shown in this study (Fig. 8). The map shows a comprehensive division of the research area into five separate zones (very high, high, moderate, low and very low) according to how susceptible they are to flooding. A color scheme that highlights areas of very high susceptibility in red, high susceptible zones in orange, moderate susceptible zones in yellow, low susceptible zones in green, and areas of very low susceptibility in dark green. This serves as a visual representation of the classification scheme, which distinguishes between high and low-sensitive zones. Understanding the geographic distribution of flood risk throughout the research region requires the use of the classification method shown on the map. Land-use planning and development decisions, as well as flood preparedness and response operations, can be influenced by the identification of highly vulnerable zones. On the other hand, pinpointing low-vulnerable areas can direct efforts more effectively and efficiently allocate resources. The map shown in Fig. 6 is an invaluable tool for flood management stakeholders and can be used to guide future studies and management initiatives focused on resolving flood-related issues. Additionally, the inclusion of different terrain features during the map-development process emphasizes the value of a multifaceted strategy for mapping flood inundation and the ongoing need for research into the intricate processes that underpin flood risk.

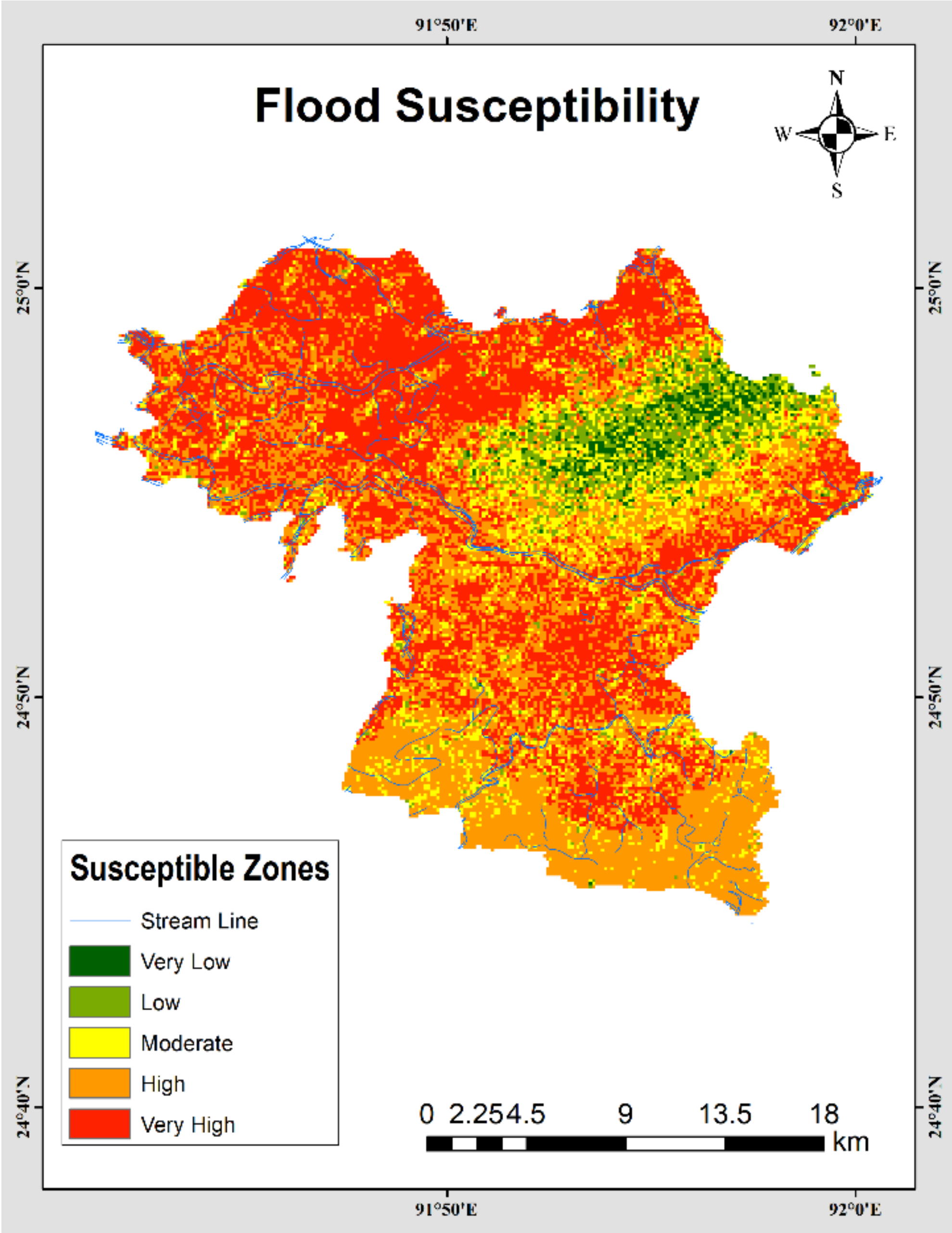

Figure 8: Flood Hazard Map.

Discussion

The primary goal of this study is to get a better knowledge of the temporal flood extents in Sylhet Sadar, with the purpose of acquiring baseline data to aid in prioritizing flood mitigation activities for disaster risk reduction. In this study, we created flood susceptible zones using Arc GIS 10.8 version. We classified the study area into five zones (very high, high, moderate, low, and very low). This study helped us find the areas which are more likely to be affected during flooding events.

Sailesh (2018) conducted this research was conducted to investigate the usefulness of remote sensing, geographic information system and the frequency ratio (FR) for food susceptibility mapping. FR model was used to handle different independent variables via weighted-based bivariate probability values to generate a plausible food susceptibility map. Ten independent conditioning factors, like LULC, elevation, slope, TWI, surface runoff, landform, lithology, distance from the main river, soil texture and soil drainage were derived from the geospatial data sets and used as input into the FR model towards food prone area mapping.

For this study, we analyzed the flood susceptibility zones of Sylhet Sadar by using Arc GIS. We used six independent parameters, namely land use/land cover, slope, elevation, precipitation, topographic wetness index (TWI), and distance from the river for Flood Susceptibility mapping. From this final Flood Susceptible map, we can identify the vulnerable zones or the flood-prone areas of the Sylhet Sadar and can take precautions or actions during the flood season. The study area's low-lying plains are particularly susceptible to flash floods. This study shows that Kazir Gaon, Kurir Gaon, and Umairgaon are in a very high flood susceptible zone. South Surma is in a highly susceptible area. Khadimnagar is the least susceptible zone. The installation of a competent stormwater drainage system facility throughout Sylhet City Corporation and flood control structures in highly susceptible zones is required to make the city less prone to flooding events.

This study demonstrates that the unique capability of satellite imagery, such as that provided by NASA Earth Data and Bangladesh River shapefile from the HDX, can be used to detect vulnerable parts and their extent in order to create Flood Hazard or Flood Susceptible Maps, which are especially useful in a developing nation like Bangladesh. For this kind of study or research purpose works, ArcGIS is the most suitable software to do some real data analysis works and clearly visualize the datasets or information.

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