



Climate Change and Flood Hazard Assessment in Savar Upazila: Geospatial Analysis of Precipitation and Temperature Trends with Risk Mapping

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Abstract

Flooding is an increasing challenge in the rapidly urbanizing peri-urban areas of Bangladesh due to climate variability, land-use change, and topographic conditions. This study assesses flood hazard susceptibility in Savar Upazila by integrating long-term climate trends with geospatial flood conditioning factors using an Analytical Hierarchy Process (AHP) Geographic Information System (GIS) framework. Six variables elevation, slope, topographic wetness index (TWI), land use/land cover (LULC), normalized difference vegetation index (NDVI), and precipitation were analyzed using 30 m datasets derived from ASTER, SRTM, Landsat-9, and Climatic Research Unit (CRU) data. Climate trends for 1952–2024 were evaluated using LOESS smoothing, Sequential Mann Kendall, Mann Kendall, Sen's slope, and Innovative Trend Analysis. Results reveal a significant decline in monsoon rainfall and increasing monsoon and post-monsoon temperatures, indicating climatic changes that may intensify flood hazards. The flood hazard map identifies Amin Bazar, Kaundia, eastern Biralia, eastern Ashulia, and Yearpur as highly susceptible because of low elevation, high wetness index, dense built up areas, sparse vegetation, and poor drainage. In contrast, Shimulia, Pathalia, and parts of Dhamsana exhibit lower

*susceptibility. The integrated AHP-GIS approach provides valuable information for climate-resilient urban planning, flood mitigation, and sustainable land management in rapidly developing regions of Bangladesh.*

**Keywords:** Flood hazard mapping; Climate change; AHP-GIS; Remote sensing; Mann- Kendall test; Savar Upazila; Bangladesh.

## 1. Introduction

Flood hazard remains one of the most pressing environmental challenges in Bangladesh, especially in peri urban areas where rapid land use change is taking place amidst climatic variability. Savar Upazila, situated on the northwestern fringe entry point of Dhaka, is not only a major gateway to the capital but also a critical hub for the economy of Bangladesh because here lie densely concentrated export-oriented garment industries, an export processing zone, tanneries as the second-largest industry, a growing diverse industry, educational institutes, and rapidly growing residential zones (BBS, 2022). Its geographic position along major transport corridors with a combination of industrial estates, agricultural land, and wetlands makes it socioeconomically significant at both regional and national scales. However, these very factors also increase its risk: low-lying topography, altered drainage patterns and proliferation of impervious surfaces amplify exposure to both pluvial and fluvial flooding events.

Climate change is expected to intensify hazard risks with precipitation variability and temperature patterns, thus affecting hydrological processes like surface runoff, infiltration, and evapotranspiration (PCC, 2021). Damage by water is not the only effect of flooding in Savar. Regular flood occurrences interrupt the industrial activities and supply chains, ruin houses, force the displacement of people, damage the public health situation, and threaten the incomes of those who rely on daily wages (Alam, M., & Rabbani, M. G., 2007). Over time, these disruptions contribute to drive broader economic losses and social unrest, long term shifts in settlement patterns, forcing permanent physical and social change in where and how people live in response to increased flood risk. Historical flood events underscore the severity of this threat. The flood of 1988, one of the deadliest disasters in Bangladesh history, resulting from the synchronized peak flows from the Ganges, Brahmaputra, and Meghna rivers that inundated as much as 75% of the country including vast areas surrounding Dhaka like in Savar region (United Nations, 1988). It led to extensive damage of crops, infrastructure, homes and displaced millions, sparking a national humanitarian crisis (United Nations, 1988). Areas in Savar which were prone to flooding and many comprising low industrial zones as well as informal settlements, suffered significantly, resulting in widespread displacement with long-term economic consequences.

The 1998 flood, thought as the prolonged and most damaging flooding in the history of Bangladesh, driven by extended rainfall during the monsoon period, and increased river inflow from upstream areas that inundated vast areas across 52 districts including Savar and greater Dhaka. More than 30 million people were affected, damaged 800,000 hectares of farmland, industrial activities brought to a standstill, and cities put out of order (OCHA, 1998). This clearly demonstrates the compound nature of flood hazards in the area, where climatic extremes interact with land-use pressures as well as socioeconomic vulnerability. Areas in Savar, the floodwaters disrupted garment production, damaged educational institutions, and drainage systems were disrupted by flood due to extreme hydrological stress revealing such fragility of urban infrastructure (Del Ninno, C., Dorosh, P. A., Smith, L. C., & Roy, D. K., 2001). Flood hazard assessment has been traditionally directed to the largest river basins such as Ganges-Brahmaputra-Meghna (GBM) and other selected rural floodplains in case of Bangladesh Islam, (M. M., & Sado, K., 2000, Dewan, A. M., 2015). However, Peri-urban landscapes such as Savar are less well understood, with heterogeneous land cover, micro-topographic variation, and complex socio-economic drivers of exposure likely to be important. Whereas several studies employ hydrodynamic models or statistical approaches to flood mapping (Rahman, M. M., et al., 2019), there remains a scarcity of research integrating long-term climate trends and geospatial indicators of flood susceptibility at local scales. More specifically, the joint impact of precipitation variability, temperature change, terrain-driven wetness and vegetation dynamics on flood hazard has not been comprehensively studied or quantified for Savar.

Recent advances in remote sensing technologies and Geographic Information Systems (GIS) enable integration of multi-source datasets to generate fine-resolution spatially explicit flood hazard maps (Tehrany, M. S., et al., 2015). The most important parameters which influence the occurrence and also distribution of flood events are: elevation, slope, topographic wetness index (TWI), land use/land cover (LULC) and vegetation indices (e.g., NDVI) (Kazakis, N., et al., 2015). In addition, multi-decadal climate records can be critical to developing an understanding of how shifts in precipitation intensity and temperature trends may alter flood risk patterns over time frames (Kazakis, N., et al., 2015). The Analytical Hierarchy Process (AHP) is a powerful approach to efficiently assigning weights to these numerous factors using expert judgment and empirical evidence, and compute the composite hazard indices accordingly, which can aid in decision-making (Gigović, L., et al., 2017).

In this study, we have analyzed the flood hazard in Savar Upazila using six important factors of elevation, slope, TWI, precipitation, LULC and NDVI with an AHP-GIS environment. We calculated elevation and slope from ASTER and SRTM digital elevation models, land use (LULC) and NDVI from recent Landsat-9 imagery, as well as precipitation trends over the 72-year record (1951–2022) of gridded dataset. This approach facilitates the production of a flood hazard map 30 m resolution, which reflects both the current land-surface conditions and the long-term climatic context. Our study integrates climate change signals with a geospatial model of flood susceptibility mapping which is missing from the peri-urban flood-risk assessment literature in Bangladesh. The key objectives of this research are: (i) to quantify multi-decadal precipitation and temperature trends for Savar; (ii) develop terrain-based and land-surface indicators pertaining to flood susceptibility; (iii) combine these influences to produce a composite flood hazard index using AHP method; and, (iv) identify areas with higher intensity of potential flood risk for implementation of targeted adaptation and mitigation measures. Together, the results will offer data-driven guidance for urban planners, administrators, and disaster response organizations working to improve climate adaptation in increasingly urbanized areas.

## 2. Study Area

### 2.1 Study Area

The study area for this research is Savar Upazila, a key administrative and socioeconomic hub located on the northwestern fringe of the Dhaka metropolitan area in Bangladesh. Situated between approximately 23°50'N and 23°59'N latitudes and 90°12'E and 90°19'E longitudes. Its geographic location, serving as a gateway to the capital, Dhaka, makes it a hub for economic activities, particularly in industries such as the garment sector, tanneries, and diverse manufacturing units. This makes it a significant area on both regional and national scales (Ghai et al., 2024).

Geographically, Savar is characterized by low-lying topography, which makes it inherently prone to flooding. The Upazila's vulnerability is further exacerbated by its altered drainage systems, the proliferation of impervious surfaces, and proximity to key rivers such as the Turag. These factors collectively increase exposure to both pluvial flooding, caused by heavy rainfall, and fluvial flooding from river overflow, especially during the monsoon season. Additionally, the interaction between land use changes, urbanization, and climate-induced weather patterns has heightened the region's susceptibility to flooding (Kalita et al., 2025).

Savar's socio-economic landscape is shaped by a mixture of formal and informal settlements, with a significant portion of the population living in low-lying areas that are prone to flood damage. The industrial zones, informal housing, and agricultural areas are all interspersed with wetlands, contributing to a complex socio-economic structure. Frequent flood events in the past have led to disruptions in industrial activities, public health crises, displacement of populations, and extensive damage to homes and infrastructure. These disruptions are particularly harmful to low-income communities that depend on daily wages and are more vulnerable to the economic impacts of floods (Liu & Wang., 2025).

Historically, Savar has been affected by major flood events, most notably the 1988 and 1998 floods. The 1988 flood, driven by the synchronized peak flows from the Ganges, Brahmaputra, and Meghna rivers, inundated

large parts of the region, causing widespread displacement and destruction of crops, homes, and infrastructure (Shao et al., 2025). Similarly, the 1998 flood, one of the most prolonged and devastating in Bangladesh's history, disrupted industrial activities and further highlighted the fragility of the region's infrastructure in the face of extreme hydrological events. These historical events underscore the compounded risk of flooding due to climatic extremes interacting with socio-economic vulnerabilities and land-use pressures (Ma'rufah et al., 2024).

This study focuses on Savar Upazila as a case study for assessing flood hazards in peri-urban landscapes, where multi-dimensional factors such as climate variability, topography, land use, and socio-economic vulnerabilities intersect. The use of Geographic Information Systems (GIS) and remote sensing technologies, in combination with historical climate data, allows for a comprehensive assessment of flood risks in this region (Choudhury et al., 2025). By integrating multi-decadal climate trends with geospatial indicators, this study aims to create an accurate flood hazard map that reflects both current land-surface conditions and future climatic shifts (Mustafa et al., 2025).

In conclusion, Savar Upazila represents a critical area for flood hazard assessment due to its geographical, socio-economic, and environmental context. This study aims to provide data-driven insights into how long-term climate changes and urbanization dynamics contribute to flood risks, helping inform urban planning and climate adaptation strategies for similar peri-urban areas in Bangladesh (Paudel et al., 2023). The study area is shown in Figure 1.

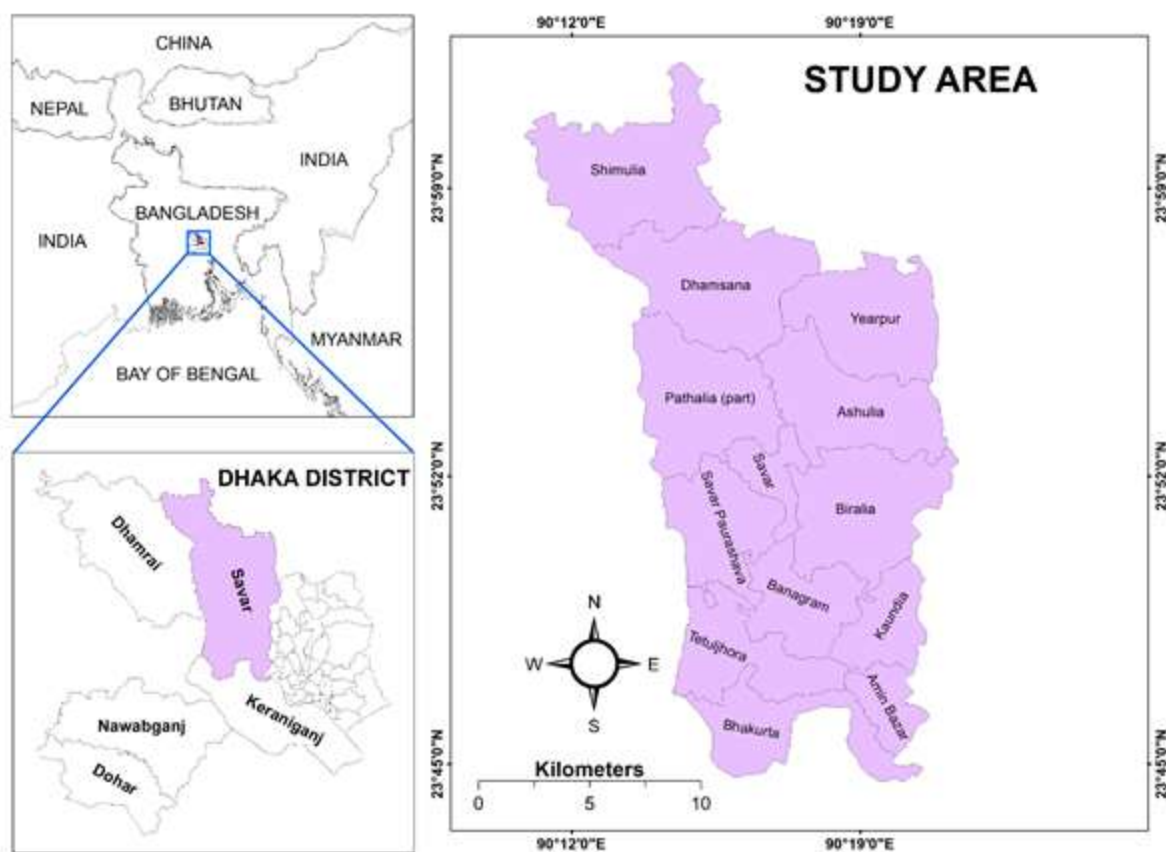


**Fig. 1. Study Area in Savar**

## 2.2 Flood Inducing Factors:

The goal of flood vulnerability assessment is to determine the likelihood and severity of a flood hazard happening over time (Baky et al., 2019; Hoque et al., 2019; Mundhe, 2019). The present research has been carried out to framework the AHP model coupled with GIS using ArcGIS 10.7.1. Six flood influencing parameters have been taken into consideration here, namely:

**I. Topographic Wetness Index (TWI):** It is a metric used to estimate a landscape's wetness or moisture conditions based on topographic parameters such as slope, aspect, and flow accumulation. It is a widely used method for describing the state of wetness at the catchment level (Grabs et al., 2009). The TWI forecasts the possibility for water accumulation and flow, both of which can lead to flood formation. High TWI readings indicate locations prone to water saturation, rendering them more vulnerable to floods during heavy rainfall or snowmelt occurrences.

**II. Elevation:** The height or altitude of a location above sea level is referred to as elevation. It is significant in determining the likelihood of floods. Flooding is more likely in locations with lower elevations because water naturally flows downhill. Higher elevation regions, on the other hand, are less prone to floods since water naturally drains away more quickly.

**III. LANDSAT-9:** LANDSAT-9 multispectral imagery was used to derive land use/land cover (LULC) and vegetation information. The images were pre-processed through atmospheric correction, mosaicking (if necessary), and clipping to the study area before analysis.

**IV. Precipitation:** Long-term precipitation data were obtained from the Climatic Research Unit (CRU). Spatial interpolation techniques were applied to generate a continuous rainfall surface representing the average precipitation distribution across the study area, which serves as a major factor influencing flood susceptibility.

**V. Slope:** Slope was derived from the Shuttle Radar Topography Mission (SRTM GL1) DEM using GIS spatial analysis tools. It represents the rate of elevation change and significantly influences runoff velocity and water accumulation during rainfall events.

**VI. Land Use/Land Cover (LULC):** LULC and NDVI were derived from LANDSAT-9 imagery using supervised classification and spectral band calculations, respectively. LULC identifies different surface features such as built-up areas, agriculture, water bodies, and vegetation, while NDVI measures vegetation density and health, both of which influence infiltration and surface runoff.

### 2.3 Data

We needed various datasets while conducting the study, their names along with sources are presented in Table 1.

**Table 1: Datasets used in this study**

| Sl. | Datasets                                 | Description          | Resolution             | Source                                                                                             |
|-----|------------------------------------------|----------------------|------------------------|----------------------------------------------------------------------------------------------------|
| 1   | Digital Elevation Model (DEM)/ Elevation | ASTER                | 30 m                   | USGS Earth Explorer<br><a href="https://earthexplorer.usgs.gov">https://earthexplorer.usgs.gov</a> |
| 2   | LANDSAT-9                                | Downloaded           | 30 m                   | USGS Earth Explorer<br><a href="https://earthexplorer.usgs.gov">https://earthexplorer.usgs.gov</a> |
| 3   | Precipitation                            | Interpolation Method | Climatic Research Unit |                                                                                                    |

|   |            |           |                                                                   |                                                                                                |
|---|------------|-----------|-------------------------------------------------------------------|------------------------------------------------------------------------------------------------|
|   |            |           | <a href="https://crudata.uea.ac.uk">https://crudata.uea.ac.uk</a> |                                                                                                |
| 4 | Slope      | SRTM GL1  | 30 m                                                              | Open Topography<br><a href="https://www.opentopography.org">https://www.opentopography.org</a> |
| 5 | TWI        | GIS Steps | 30 m                                                              | DEM                                                                                            |
| 6 | LULC, NDVI | GIS Steps | 30 m                                                              | LANDSAT-9 Band Images                                                                          |

### 3. Methodology

The methodology integrates remote sensing, climate data, and GIS-based multi criteria analysis to assess flood hazard in Savar Upazila. Digital Elevation Model (DEM) data were used to derive elevation, slope, and Topographic Wetness Index (TWI) maps, while Landsat-9 imagery was processed to generate Land Use/Land Cover (LULC) and Normalized Difference Vegetation Index (NDVI) maps. Long-term precipitation data were used to prepare the precipitation map. These six flood-conditioning factors were integrated using the Analytical Hierarchy Process (AHP) to determine their relative importance through pairwise comparison. The consistency of the assigned weights was evaluated using a consistency check, and if acceptable, the weighted thematic layers were combined using GIS overlay analysis to produce the final flood hazard map of Savar Upazila. To achieve the goals of the study, we needed to follow a certain set of steps. The methodology we used is described as a flowchart in Figure 2.

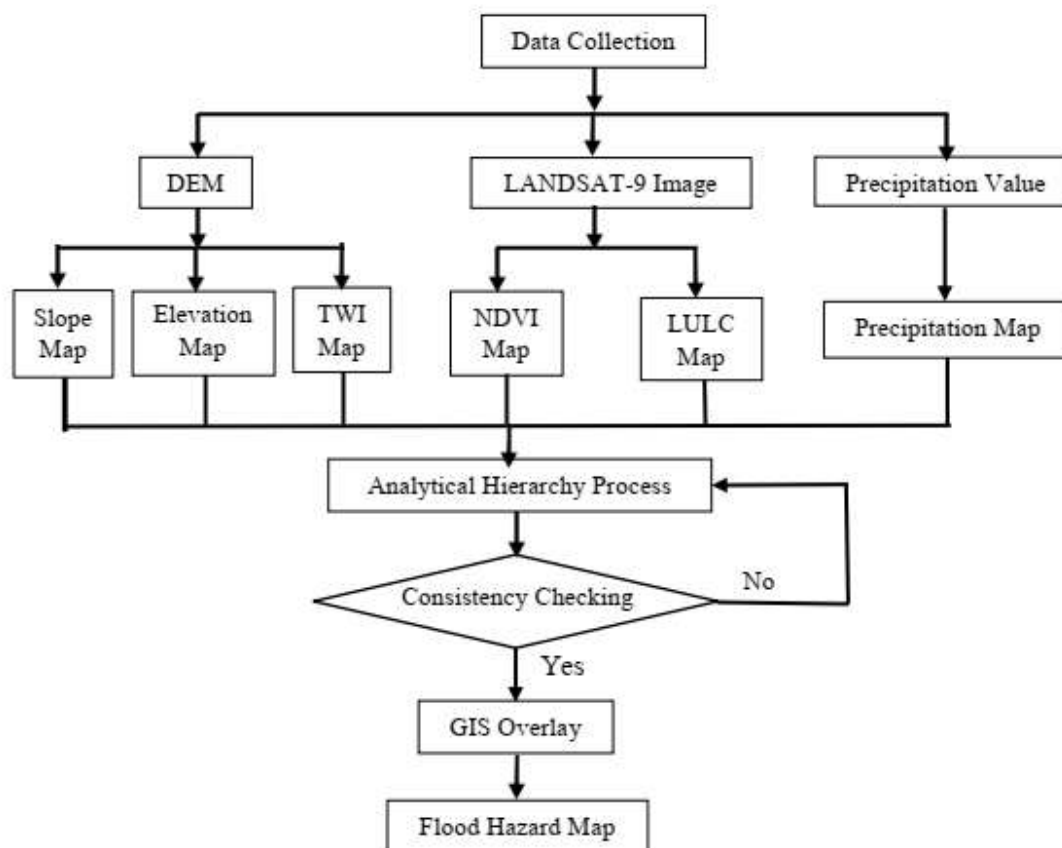


**Figure 2: Flowchart of Methodology**

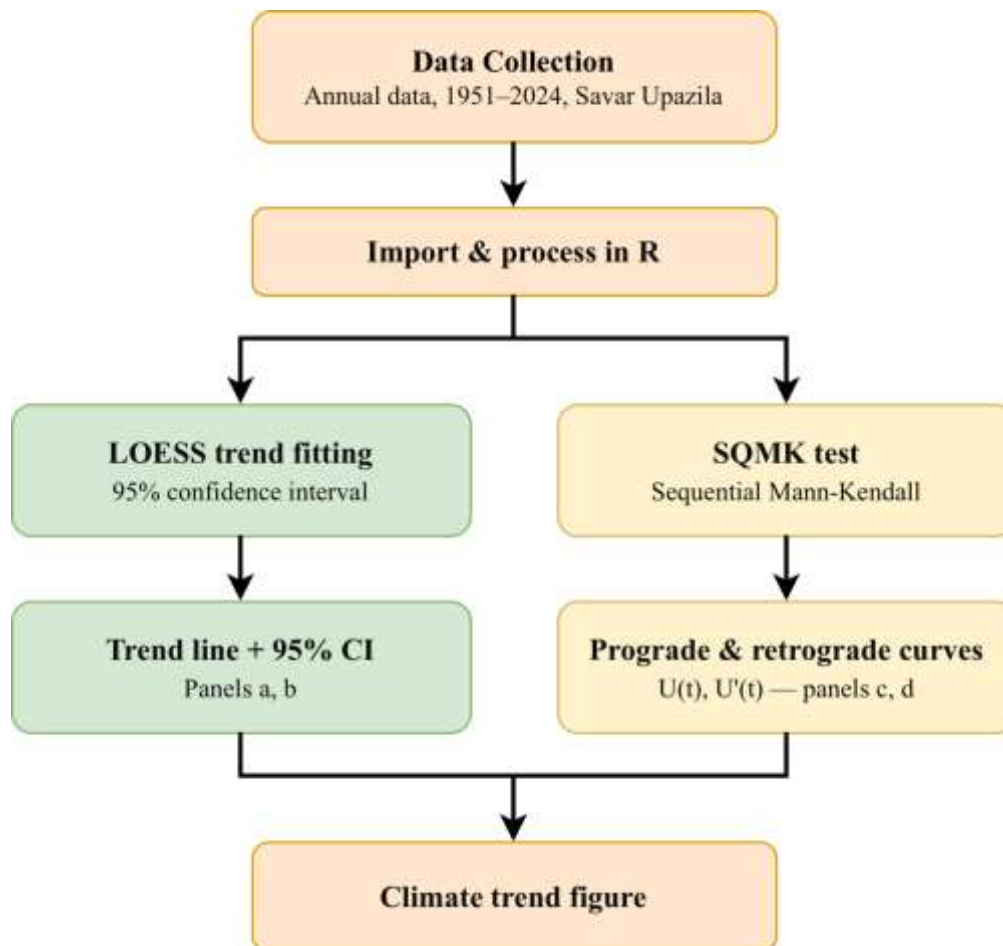


**Figure 3: The flowchart used to generate the climate trend analysis (Figure 6, panels a–d). Annual precipitation and temperature data (1951–2024) were imported and processed in R. Each variable was analyzed using two complementary approaches: LOESS.**

Annual precipitation and mean temperature data for Savar Upazila (1951–2024) were compiled and imported into R for analysis. Two complementary statistical approaches were applied to each variable to characterize long-term climate trends. First, a LOESS (locally estimated scatterplot smoothing) regression was fitted to the raw annual series to visualize the underlying trend, with a 95% confidence interval generated to represent the uncertainty around the smoothed curve. Second, the Sequential Mann–Kendall (SQMK) test was applied to identify the approximate onset of any statistically significant trend. This non-parametric test generates two curves — a prograde series,  $U(t)$ , computed from the original data, and a retrograde series,  $U'(t)$ , computed from the reverse-ordered data — plotted against the 95% confidence limits ( $\pm 1.96$ ). The intersection of the  $U(t)$  and  $U'(t)$  curves within the confidence bounds indicates the point of trend change. The results of both analyses were plotted together to produce the final climate trend Figure 6, with precipitation results shown in panels (a) and (c), and temperature results in panels (b) and (d).

Seasonal and annual precipitation and mean temperature data for Savar Upazila (1952–2024) were compiled and imported into R for analysis. Two complementary approaches were used to characterize climate variability. First, the annual data were grouped into five seasonal categories — Annual, Pre-Monsoon, Monsoon, Post-Monsoon, and Winter — and boxplots were generated for each category to illustrate the central tendency,

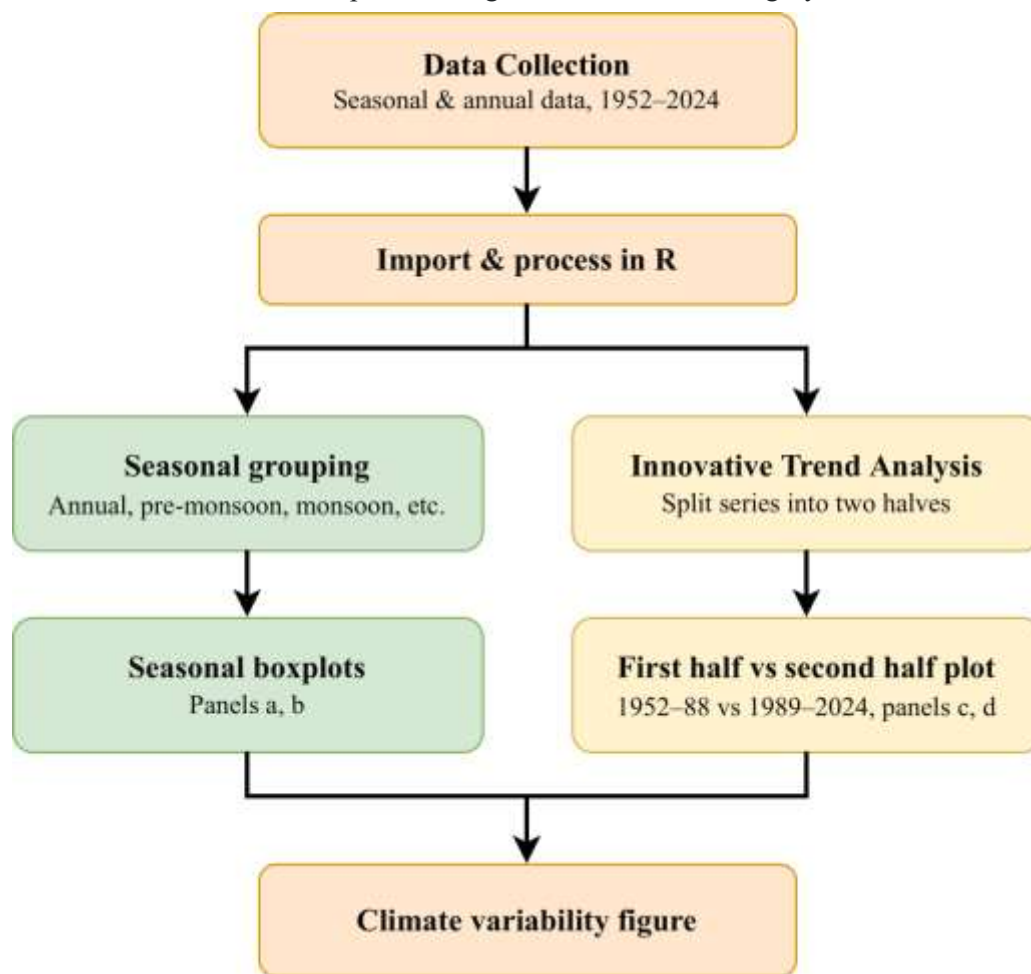


**Figure 4: Flowchart of the methodology used to generate the climate variability analysis (Figure 7, panels a–d). Seasonal and annual precipitation and temperature data (1952–2024) were imported and processed in R. Two complementary approaches were applied to each**

spread, and outliers in long-term seasonal variation. Second, the Innovative Trend Analysis (ITA) method of Şen (2012) was applied to detect shifts in trend behavior. Each time series was divided into two equal halves — an early period (1952–1988) and a later period (1989–2024) — sorted in ascending order, and plotted against each other on a 1:1 scatter plot. Points falling above the no-trend (1:1) line indicate an increasing trend between the two periods, while points below indicate a decreasing trend; a  $\pm 10$ th percentile band was included to assess the significance of the departure from the no-trend line. The results of both analyses were combined to produce the final climate variability Figure 7, with rainfall results shown in panels (a) and (c), and temperature results in panels (b) and (d).

#### 4. Results

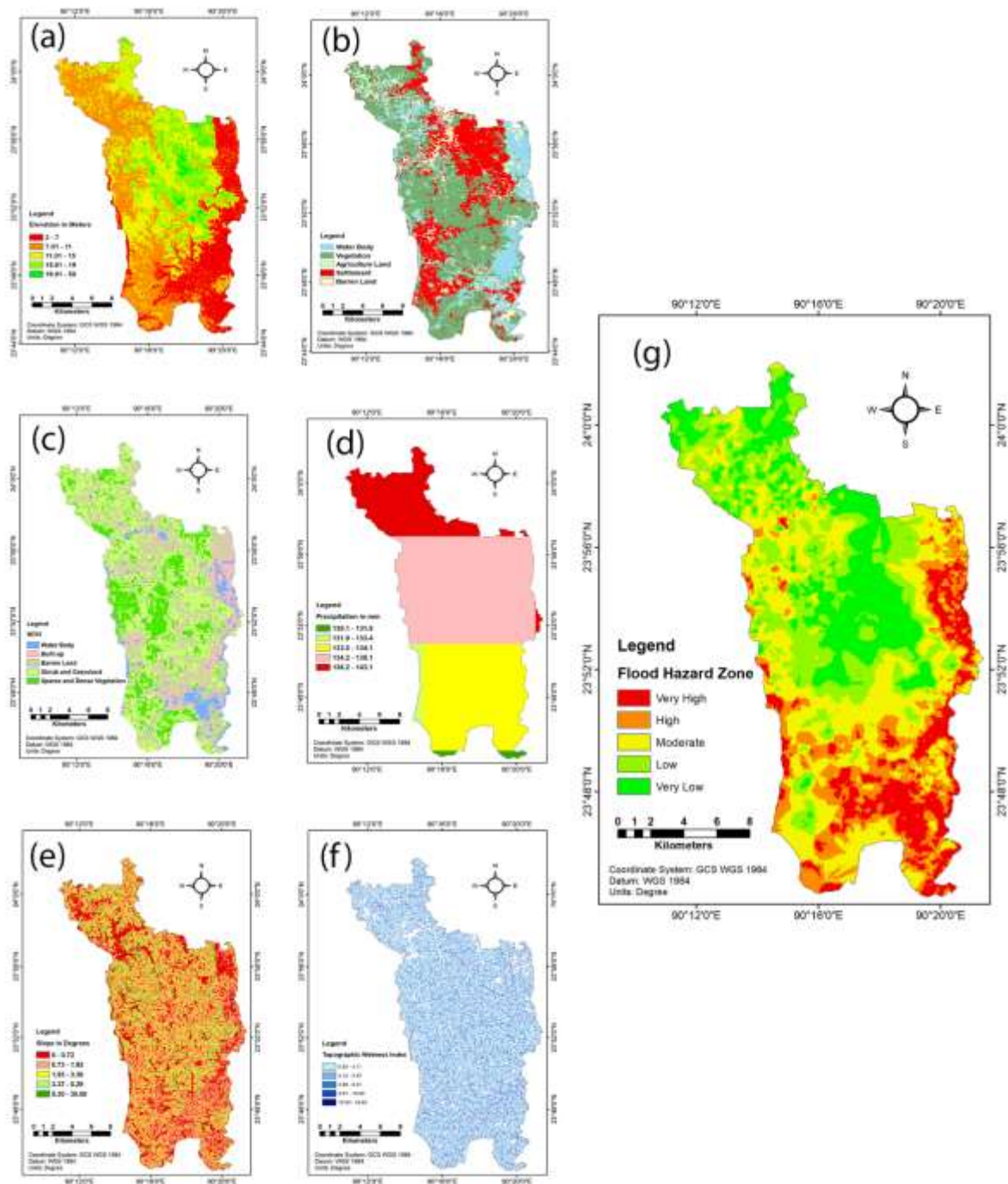


**Figure 5: (a) the elevation, (b) land use and land cover (LULC), (c) normalized difference vegetation index (NDVI), (d) precipitation, (e) slope, (f) topographic wetness, and (g) flood hazard in Savar Upazila.**

The Figure 5 illustrates (a) the elevation, (b) land use and land cover (LULC), (c) normalized difference vegetation index (NDVI), (d) precipitation, (e) slope, (f) topographic wetness, and (g) flood hazard in Savar Upazila.

The elevation above mean sea level in this area varies from 2 meters to 50 meters, as depicted in Figure (a). The central and northern regions of Savar Upazila feature the highest elevation, reaching up to 50 meters. In contrast, the western and southern areas of Savar exhibit the lowest elevation, ranging from 2 meters to 7 meters. As shown in Figure (a), the areas of Amin Bazar, Kaundia, and the western parts of Biralia, Ashulia,

and Yearpur exhibit the lowest elevation levels. Most of Dhamshana, Shimulia, Pathalia, Tetuljhora, Bhakurta, and Banagram have elevations ranging from 7 meters to 19 meters. The elevation of Savar Upazila is highest at the center and then gradually declines towards both the eastern and western sides.

The LULC map is used here to understand and monitor the changes in land use and vegetation within Savar Upazilla, as shown in Figure 5(b). The figure divided the Upazila area into five sections (e.g., Water Body, Vegetation, Agricultural Land, Settlement, and Barren Land). Most of the water bodies can be seen in the eastern side of the Savar upazila, although there are plenty of water bodies also present in the northwestern, western, and southern parts of the upazila. Yearpur, Ashulia, Dhamsana, Savar Paurashava, Tetuljhora, and parts of Kaundia display dense human settlements that are primarily found in the southwestern, central, and northern areas of Savar Upazila.

Savar Upazila is predominantly covered with vegetation, and there is very little agricultural land and barren land present in this area, as shown in Figure 5(b). Vegetation occupies nearly 43% of Savar Upazila's total area, which is the highest percentage among the categories. Settlements account for almost 27% of the total area. Water bodies cover almost 19% of the total area. Agricultural land and barren land have the lowest percentages, at 4.5% and 6.5%, respectively.

Biralia, Pathalia, and Shimulia unions exhibit the highest levels of vegetation, at 6.5%, 6.7%, and 6.12%, respectively. Conversely, among all unions, Amin Bazar, Kaundia, and Yearpur exhibit the least amount of vegetation. Yearpur, Kaundia, Dhamsana, and Biralia Unions exhibit the largest waterbody, accounting for 2.8%, 2.7%, 2.14%, and 2.04% of the total area, respectively. The Savar area contains the smallest water body, accounting for only 0.05% of the total area. Ashulia and Yearpur unions have the highest settlement, accounting for 4.5% and 4.7% of the total area, respectively. Dhamsana, Savar Paurashava, and Tetuljhora also have high settlements, and they comprise 3.8%, 3.4%, and 3.1% of the total area. Almost all the unions of Savar Upazila have a low amount of agricultural land. Among them, Shimulia Union has the highest percentage, which is 2.2% of the total land area. As can be seen in figure 3b, Savar Upazilla has very little barren land, and among all unions, Dhamsana has the highest percentage of barren land, which is 1.6% only. The percentage of barren land in all other unions is relatively low, accounting for only 6.5% of the total area.

To assess and track the health and density of vegetation in Savar Upazila, the NDVI map is employed, as shown in Figure 5(c). The map categorizes the area into five sections: Water Body, Built-up, Barren Land, Shrub and Grassland, and Sparse and Dense Vegetation, each represented by different colors. Most of Savar Upazila exhibits high NDVI values, indicating healthy vegetation, as shown in Figure 5(c). The eastern and southeastern regions of Savar Upazila display the lowest NDVI values, which correspond to the water body and built-up categories. The built-up category represents areas of settlement. Figure 5(c) indicates that the eastern sections of Yearpur, Ashulia, Biralia, Kaundia, and Amin Bazar; the central area of Banagram; Savar Paurashava; and the western part of Tetuljhora have the lowest NDVI values, suggesting dense settlements and water bodies. Certain areas of Shimulia, Dhamsana, and Bhakurta exhibit moderate to low NDVI values, indicating the presence of shrub and grassland in addition to human settlements. The highest NDVI values are found in most parts of Pathalia Union, Savar, the western sections of Tetuljhora, and the eastern areas of Bhakurta, signifying sparse and dense vegetation. Furthermore, much of Savar Upazila shows relatively high NDVI values, indicating shrub and grassland. However, the westernmost part of Savar Paurashava and the central section of Dhamsana present the lowest NDVI values, indicative of water bodies.

The precipitation data for Savar Upazila, covering a span of 73 years (1951–2024), was collected using the interpolation method, as illustrated in the precipitation map (d). This extensive dataset allowed for the calculation of the mean annual precipitation in Savar, which ranges from 130 mm to 143 mm. According to the precipitation map in Figure 5(d), the northern region of Savar Upazila experiences the highest yearly precipitation levels, between 138.2 mm and 143.1 mm. In contrast, the southern area receives the lowest, with precipitation levels between 130.1 mm and 134.1 mm. The overall variation in precipitation across different regions of Savar Upazila is minimal. Among the regions, Amin Bazar, Banagram, Bhakurta, Kaundia, and Tetuljhora receive the least annual precipitation, averaging 133.4 mm, 133.4 mm, 133.0 mm, 133.4 mm, and

133.2 mm, respectively. Conversely, Shimulia records the highest average annual precipitation at 142.8 mm. Additionally, Ashulia, Biralia, Dhamsana, Pathalia, Savar Paurashava, and Yearpur have average precipitation levels ranging from 134.9 mm to 139.5 mm.

The slope map of Savar Upazila (e) illustrates the terrain's gradient in degrees. The slope varies from 0 degrees to a maximum of 30.65 degrees within Savar. The steepest slope, measuring 30.65 degrees, is located in Banagram. The average slope across the entire Savar area is approximately 1.5 degrees. The regions of Kaundia, Savar Paurashava, and Shimulia feature the lowest slopes, with maximum values ranging from 8.3 degrees to 9.8 degrees, indicating that these areas are relatively flat. Conversely, Amin Bazar, Banagram, and Bhakurta are characterized by the highest slopes. Areas with moderate slopes include Dhamsana, Ashulia, Biralia, Pathalia, Tetuljhora, and Yearpur, where the maximum slopes range from 10.5 to 16.2 degrees.

The topographic wetness index of Savar Upazila indicates areas with varying water retention capacities, which are largely consistent across most regions of Savar Upazila. This information is depicted in the topographic wetness index map for Savar Upazila, as shown in Figure 5(f). The index values range from 0.82 to 16.62, with an average topographic index of 5.78 for the area. Both the minimum and maximum values of the topographic index across all regions of Savar Upazila are relatively uniform. Amin Bazar and Banagram exhibit the lowest topographic indices, recorded at 0.94 and 0.82, respectively. The minimum topographic index for other regions falls between 1.1 and 1.9. Conversely, Ashulia, Kaundia, Yearpur, and Dhamsana present the highest topographic index values of 16.62, 16.60, 16.45, and 16.21, respectively. The maximum values in other areas of Savar range from 13.65 to 15.91.

The flood hazard map is used to visualize and identify the areas within Savar upazila that are at risk of flooding, as shown in Figure 5(g). The Savar upazila has been divided into five flood hazard zones. Five different colors represent these zones, which range from very low to very high susceptibility to flooding. Very low susceptibility zones are indicated in green, while very high susceptibility zones are marked in red. Figure 5(g) illustrates that the northern and central parts of Savar upazila have the lowest susceptibility to flooding, whereas the eastern and southern parts exhibit the highest susceptibility.

Most areas within the Shimulia union show the lowest susceptibility to flooding, although some sections have low to moderate susceptibility. The same goes for the Dhamsana and Pathalia unions, but a small portion of these unions have high to very high susceptibility to flooding. The western part of Ashulia and Yearpur has the lowest susceptibility to flooding, and it increases eastward. The eastern areas of these unions have the highest susceptibility, while the central portions display moderate to high susceptibility.

Most regions of the Biralia Union have a moderate susceptibility to flooding, with the lowest levels found in the central area. The highest susceptibility is located in the eastern and southeastern parts of Biralia Union. Banagram, Kaundia, and Amin Bazar are the three unions that largely exhibit the highest susceptibility to flooding. Tetuljhora Union displays the lowest susceptibility in its central part, which peaks in the eastern section. The central portion of Bhakurta Union has high to very high susceptibility to flooding, while the eastern and northwestern parts show moderate susceptibility.

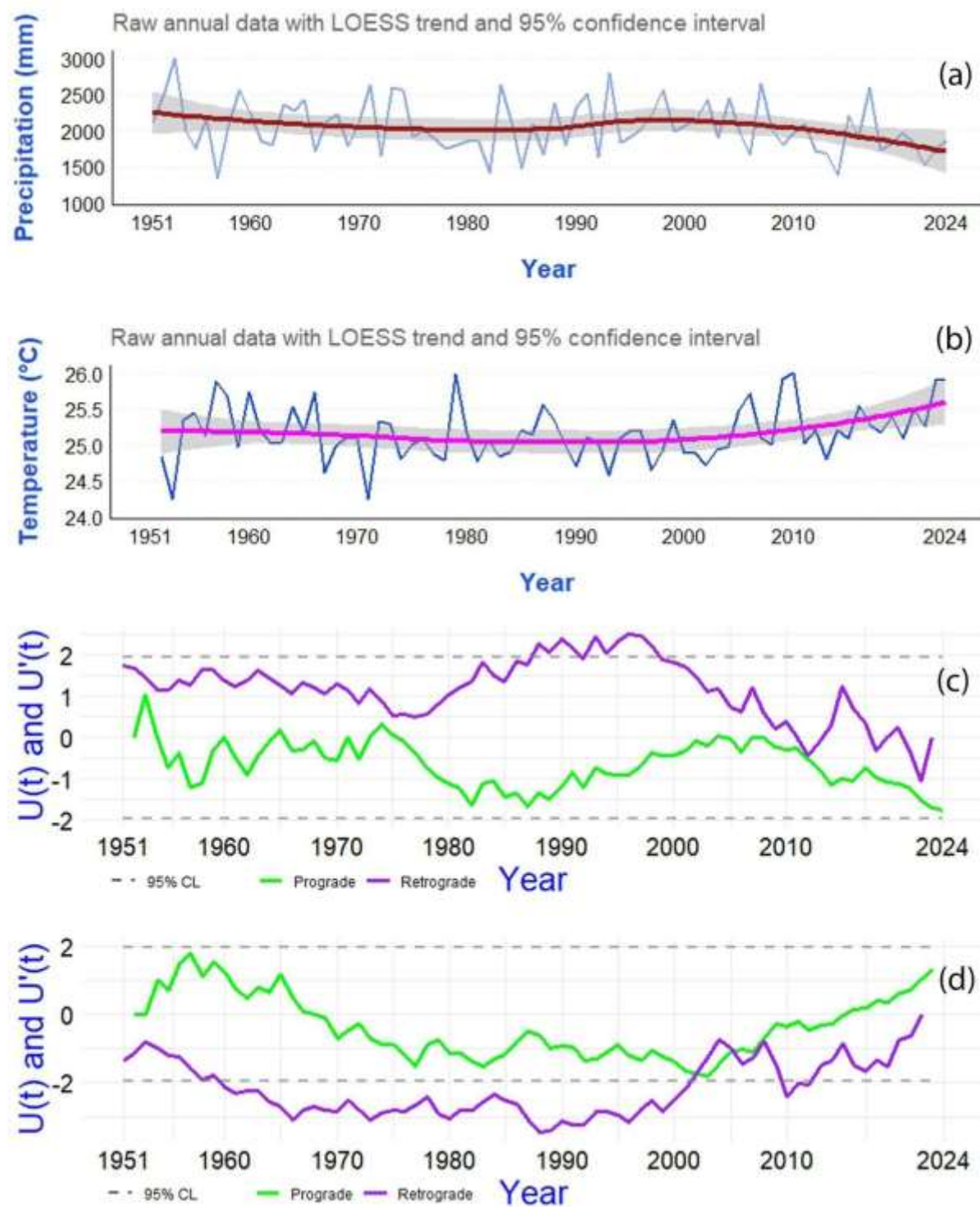


**Figure 6: Climate trends detailing in Savar Upazila (1952–2024).** Panel (a) features the raw annual precipitation data with a LOESS trend line and a 95% confidence interval. Panel (b) shows the annual mean temperature with a U-shaped LOESS trend. Panel (c) presents the Sequential Mann–Kendall (SQMK) test for annual rainfall, illustrating prograde ( $U(t)$ ) and retrograde ( $U'(t)$ ) curves. Panel (d) displays the SQMK test for annual mean temperature.

From 1952 to 2024 the annual precipitation data demonstrated considerable interannual variability and they were seen through the peaks and troughs in the figure. A non-linear decreasing trend was seen in the rainfall data through the LOESS trend line with a 95% confidence interval over the study period of 72 years. The figure shows a relatively high rainfall during the early 1950s to mid- 1960s. The maximum rainfall can also be seen during the early 1970s, 1980s, 1990s and in the late 2000s. Precipitation in Savar Upazila decreased to its

minimum value during the late 1950s and early 1980s. A steady decline in the annual precipitation was seen from the 2000s onward and it suggests a long-term downward trend in rainfall intensity in Savar Upazila.

On the contrary, a relatively stable behavior was seen in the early decades in annual mean temperature data series and the temperatures fluctuated between 24.5 °C and 26.5 °C. A U-shaped pattern was revealed through the LOESS trend line. It indicated a mild cooling phase between 1952 and the mid-1980s which was followed by a steady warming trend from the 1990s onward. A clear temperature rise was visible in the recent decade (2010–2024). During this period, the upper 95% confidence interval suggested increased variability and possible intensification of warming.

The sequential Mann Kendall test is a non-parametric statistical test that was used to identify the shifting points of 72 years' time series data in this study. To identify the trends of annual rainfall and average precipitation, this SQMK test was applied. Multiple intersections were shown by the prograde ( $U(t)$ ) and retrograde ( $U'(t)$ ) curves. They indicated periodic trend reversals rather than a consistent directional change. During the late 1970s to early 1980s and again after 2000, a pronounced negative deviation of  $U(t)$  below the 95% confidence limit can be seen which suggests the presence of statistically significant downward trends in rainfall during those periods.

The warming tendency that was seen in the Figure 6(b) was further validated by the sequential Mann kendall test Figure 6(d). During the early 1990s, the  $U(t)$  and  $U'(t)$  curves intersected and it marked the presence of a statistically significant positive trend in temperature thereafter. As the  $U(t)$  curve consistently remains above the 95% confidence limit from the mid-2000s to 2024 it confirmed that a strong and persistent warming trend was present in the recent decades. Thus, these trend analyses suggest that the Savar upazila has undergone climatic shifts over the past 72 years. The Figure 6 shows that the rainfall of Savar Upazila had a declining tendency, particularly after the 1980s. On the other hand, annual temperatures exhibited a significant warming trend that began in the late 20th century and continued into the present.

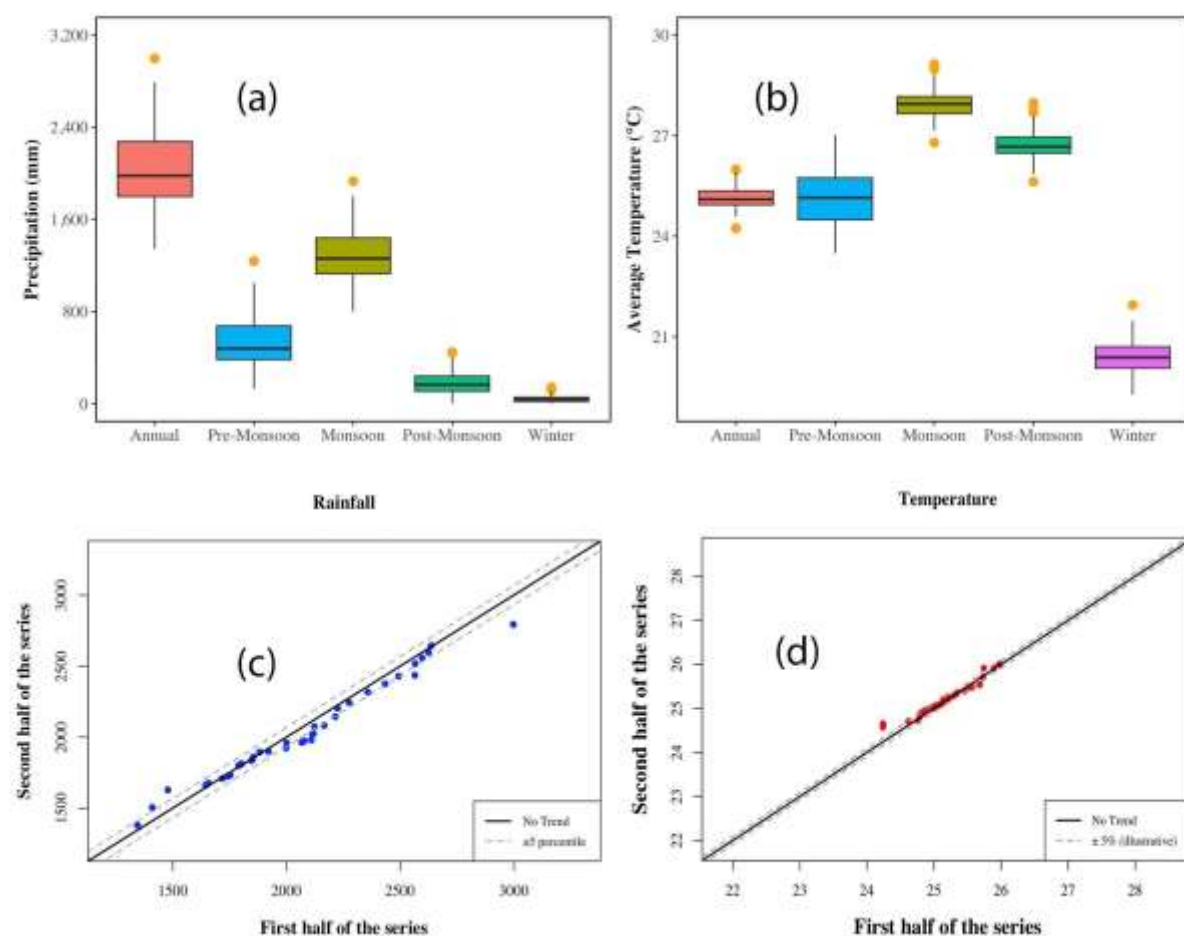


**Figure 7: Climate variability in Savar Upazila. Panels (a) and (b) present boxplots illustrating long-term seasonal variations. Panel (c) shows the Innovative Trend Analysis (ITA) graph for rainfall, comparing 1952–1988 vs. 1989–2024. Panel (d) displays the ITA graph for temperature, comparing 1952–1988 vs. 1989–2024.**

## 4.2 Boxplot

Figure 7 illustrates the long-term variations in average temperature and precipitation for Savar Upazila from 1952 to 2024. It highlights different seasonal climatic characteristics of the tropical monsoon climate of Bangladesh. The spatial variations in precipitation and temperature of 72 years are shown in this figure. Approximately 2000 mm of annual precipitation is exhibited in this figure and the annual rainfall values range from about 1000 to over 3000 mm. It is clear from this figure that the monsoon season contributed the majority of total annual rainfall and the median value of monsoonal rainfall lies between 1400-1600 mm. The pre-monsoon season showed moderate rainfall values where the median is around 600-700 mm. The post-monsoon season showed much less rainfall than the annual, pre-monsoon, and monsoon seasons, with a median value around 200 mm. The winter season showed the least rainfall among all these seasons. The median value lies around 50 mm. The results from these two seasons indicate prolonged dry conditions during the cooler months.

A distinct and consistent pattern of seasonal variations in temperature over 72 years in the savar region is also shown in this figure. The figure clearly shows that the monsoon is the warmest season in the last 72 years, where the median temperature lies near 28 °C. The median temperature of post-monsoon season lies close to that of monsoon season which is around 27 °C. The pre-monsoon season is much cooler than the monsoon and post-monsoon seasons, with the median temperature lies around 25 °C. The winter season is the coldest season bearing a median temperature of about 21 °C and the occasional outliers indicate colder years. The annual mean temperature values show relatively less variations over the years, with the median value lies around 25 °C.

## 4.3 ITA:

To compare the results with the MK-Sen slope estimator test, the study used Innovative Trend Analysis (ITA). The ITA method serves as an alternative for identifying trends in time series data although the MK and Sen slope tests are applied most commonly for trend analysis. In this ITA method, the whole time series data is divided into two equal parts and the trend is calculated through the graph. The figure illustrates the trend analysis for temperature and precipitation through an ITA graph over 72 years (1952-2024) in Savar Upazila.

The mean precipitation of the first half (1952–1988) and the second half (1989–2024) of the dataset is compared through the ITA graph for rainfall in the figure. All the data points lie closely to the 1:1 line, indicating that there is an absence of a significant long-term trend in total rainfall over the last 72 years. As it can be seen from the figure that most points fall within the  $\pm 5$  percentile boundary (gray dashed lines), it suggests that rainfall variations within decades remain within a natural variability range rather than reflecting a directional change. A few minor deviations are observed above the “no-trend” line which indicate that the later decades contain slightly higher rainfall but to suggest a consistent upward trend, these differences are not substantial enough. So, stable annual rainfall patterns are suggested through the rainfall ITA graph from the figure in Savar over the past seven decades where the increase or decrease in annual precipitation is not statistically significant. The ITA graph for temperature in the figure exhibits a similar relationship between the two parts of the dataset. Most data points lie close to the “no-trend” 1:1 line which indicate that the average temperatures of the first and second half of the series are largely comparable. Very few data points are positioned slightly above the 1:1 line, indicating minimal variations among the decades through this narrow dispersion of points. It also indicates a marginal warming in the recent decades. This ITA temperature graph in the figure suggests no statistically significant long-term warming trend over the 72 years study period as the deviation remains within the  $\pm 5\%$  confidence range.

The ITA graphs for both the temperature and rainfall indicate a relatively stable climate of Savar Upazila over the past 72 years study period from 1952 to 2024. Although there are some short time fluctuations observed for both the rainfall and temperature data, the overall analysis suggests no statistically significant increasing or decreasing trend in Savar over the past 72 years study period.

**Table 2: Mann–Kendall and Sen’s slope for rainfall and temperature**

| Variables           | MK test & Sen’s slope value | Annual  | Pre-Monsoon | Monsoon       | Post-Monsoon  | Winter |
|---------------------|-----------------------------|---------|-------------|---------------|---------------|--------|
| Sum of Rainfall     | Z                           | -1.7547 | 0.2613      | -2.3520       | 0.1773        | 0.4293 |
|                     | P value                     | 0.0793  | 0.7938      | <b>0.0187</b> | 0.8592        | 0.6677 |
|                     | Slope                       | -3.5705 | 0.2268      | -3.2275       | 0.0495        | 0.0631 |
| Average Temperature | Z                           | 1.3382  | -1.0811     | 2.1771        | 4.9301        | 1.0098 |
|                     | P value                     | 0.1808  | 0.2797      | <b>0.0295</b> | <b>0.0000</b> | 0.3126 |
|                     | Slope                       | 0.0026  | -0.0067     | 0.0057        | 0.0114        | 0.0031 |

#### 4.4 Mann–Kendall and Sen’s slope (Table)

Mann-Kendall and Sen’s slope estimator have been used to calculate rainfall and average temperature on a seasonal and annual basis for Savar Upazila. The trends that were statistically significant were determined using p-value ( $<0.05$ ). Bold numbers were used to indicate the significant trends in the table 2.

Mixed but generally insignificant trends were indicated using MK z-values across most seasons. A weak negative trend was seen in the annual rainfall data ( $Z = -1.7547$ ,  $p = 0.07931$ ) that is not statistically significant. The pre-monsoon ( $Z = 0.26134$ ,  $p = 0.7938$ ), post-monsoon ( $Z = 0.17734$ ,  $p = 0.8592$ ), and winter ( $Z = 0.42934$ ,  $p = 0.6677$ ) seasons also showed statistically insignificant trends in rainfall. On the contrary, a significant decreasing trend ( $Z = -2.352$ ,  $p = 0.01867$ ) was seen in the monsoon season data. The Sen-slope was found at  $-3.227$  mm/year for monsoon which indicates that the rainfall intensity gradually decreased during the monsoon period.

A general warming tendency was seen in the MK and Sen-slope’s estimator results for average temperature. The trends for annual, pre-monsoon and winter temperatures were found statistically insignificant as the p values were greater than 0.05. The Z-values and P values for monsoon ( $Z = 2.1771$ ,  $p < 0.05$ ) and post-monsoon ( $Z = 4.9301$ ,  $p < 0.05$ ) seasons showed a significant increasing trend in mean temperature during these periods. This pattern was confirmed by Sen’s slope estimates as the results suggest that consistent warming trends were present particularly in the second half of the year.

## 5. Discussion

This study provides a comprehensive assessment of flood susceptibility in Savar Upazila by integrating long-term climatic trends with geospatial variables using an Analytical Hierarchy Process (AHP)-GIS framework (Rahmati, O., et al., 2019). The results demonstrate that flood hazards in the study area are controlled by the combined effects of topography, hydrological characteristics, land use dynamics, vegetation cover, and climate variability rather than by a single environmental factor (Kia, M. B., et al., 2012). The integration of 72 years of climatic observations (1952–2024) with high-resolution spatial datasets provides a more realistic representation of flood susceptibility in a rapidly urbanizing peri-urban environment.

Elevation and slope were identified as the primary physical controls of flood susceptibility. The western and southern portions of Savar, where elevations range between 2 and 7 m and slopes are generally below 2°, exhibited the highest flood susceptibility. Low-lying terrain promotes surface water accumulation and reduces runoff velocity, resulting in prolonged inundation during intense rainfall events. Similar findings have been reported in Bangladesh and other deltaic regions where elevation consistently represents the most influential flood-conditioning factor in AHP-based flood hazard assessments (Rahmati, O., et al., 2019). Recent GIS-based studies in Bangladesh also identified elevation and slope as the dominant variables controlling flood occurrence, confirming the robustness of terrain-based flood susceptibility modelling (Islam, M. M. & Sado, K., 2021).

The Topographic Wetness Index (TWI) further explained the spatial variability of flood susceptibility. High TWI values recorded in Ashulia, Kaundia, Yearpur, and Dhamsana indicate greater soil moisture accumulation and poor drainage conditions, making these areas highly vulnerable to flooding. The strong agreement between high TWI values and mapped flood-prone locations supports previous studies showing that TWI is one of the most reliable hydrological indicators for identifying flood-prone landscapes because it combines slope and upstream contributing area to estimate potential water accumulation (Sorensen, R., et al., 2006).

Land use and vegetation significantly influenced flood susceptibility throughout Savar Upazila. The LULC analysis showed that settlements occupy approximately 27% of the study area, whereas vegetation covers nearly 43%. Areas characterized by dense settlements and low NDVI values correspond closely with the high and very high flood hazard zones. Rapid urbanization replaces natural permeable surfaces with roads, buildings, and other impervious infrastructure, substantially increasing surface runoff while reducing infiltration capacity (Shuster, W.D., et al., 2005). Consequently, storm water rapidly exceeds the capacity of existing drainage systems, increasing the frequency and severity of urban flooding. Similar observations have been reported for Dhaka and other rapidly expanding cities where urban growth has intensified pluvial flooding through uncontrolled land-use conversion and wetland encroachment. Recent national-scale flood studies have likewise demonstrated that LULC and NDVI are among the most influential variables controlling flood susceptibility in Bangladesh (Carlson, T.N. & Ripley, D.A., 1997).

The long-term climate analysis reveals important evidence of climatic change in Savar Upazila. Although annual rainfall exhibited only a weak decreasing trend, the Mann–Kendall analysis identified a statistically significant decline in monsoon rainfall, while monsoon and post-monsoon temperatures increased significantly. These findings indicate that climate change is altering regional hydrological processes through increased atmospheric temperatures, enhanced evapotranspiration, and shifts in rainfall distribution rather than simply increasing annual rainfall totals (Mann, H.B., 1945). Similar warming trends have been documented across Bangladesh, where increasing temperatures have modified monsoon characteristics and intensified hydrological extremes. Consequently, future flood hazards in Savar are expected to be increasingly influenced by rainfall intensity, short-duration extreme precipitation, and urban drainage limitations rather than total annual rainfall alone (Sen, P.K., 1968).

The combined application of LOESS smoothing, Sequential Mann–Kendall (SQMK), Innovative Trend Analysis (ITA), and Sen's slope provided complementary insights into regional climate variability. The SQMK and Mann–Kendall analyses detected statistically significant warming trends and declining monsoon rainfall, whereas ITA indicated relatively stable long-term climatic conditions. These differences arise because each statistical technique measures different characteristics of temporal variability. Mann–Kendall identifies monotonic trends, SQMK detects temporal change points, and ITA evaluates distributional changes between two halves of the time series. Therefore, the combined use of multiple statistical approaches improves confidence in climate trend interpretation and minimizes uncertainty associated with relying on a single statistical method (Mann, H.B., 1945) (Kendall, M.G., 1975).

The final flood hazard map identified Amin Bazar, Kaundia, eastern Biralia, eastern Ashulia, and Yearpur as the most vulnerable areas. These regions combine low elevation, gentle slopes, high TWI values, extensive built-up areas, sparse vegetation, and proximity to drainage channels, creating highly favorable conditions for flood occurrence. In contrast, Shimulia, Pathalia, and portions of Dhamsana exhibited relatively lower flood susceptibility due to higher elevations, greater vegetation cover, and better drainage characteristics. The spatial distribution of flood-prone areas corresponds well with historical flood records and recent urban waterlogging events in the greater Dhaka region, demonstrating the effectiveness of the AHP-GIS framework for identifying localized flood hazards (Shahid, S., 2010).

A major strength of this study lies in integrating multi-decadal climate records with remote sensing-derived environmental variables within a unified GIS framework. While many previous flood susceptibility studies have focused primarily on topographic or land-use variables, this study incorporates long-term precipitation and temperature trends to account for the influence of climate change on flood hazard. Such integration provides a more comprehensive understanding of evolving flood susceptibility and offers valuable information for urban planning, climate adaptation, and disaster risk reduction in rapidly urbanizing regions (Basak, J.K., et al., 2013).

Despite these strengths, several limitations should be acknowledged. The AHP weighting procedure relies partly on expert judgement, introducing some degree of subjectivity into the analysis. Furthermore, the study evaluates flood hazard rather than comprehensive flood risk because socioeconomic variables such as population density, infrastructure exposure, drainage capacity, and economic vulnerability were not incorporated. The climate assessment was limited to historical observations and did not include future climate projections under different greenhouse gas emission scenarios. Future research should integrate hydrological modelling, climate projections, socioeconomic indicators, and machine learning techniques to improve flood prediction accuracy and support climate-resilient urban development (Arabameri, A., et al., 2020). Recent studies have demonstrated that hybrid GIS-AHP, machine learning, and artificial intelligence approaches can substantially improve flood susceptibility prediction and provide stronger decision-support tools for disaster management (Tien Bui, D., et al. 2020).

## 6. Conclusion

This study integrated long-term climate analysis with an AHP-GIS framework to evaluate flood hazard susceptibility in Savar Upazila. The results indicate that flood occurrence is controlled by the combined influence of topography, hydrological conditions, land use, vegetation cover, and climate variability. Low-lying areas with gentle slopes, high topographic wetness, dense settlements, and limited vegetation were identified as the most flood-prone, particularly Amin Bazar, Kaundia, eastern Biralia, eastern Ashulia, and Yearpur, whereas Shimulia, Pathalia, and parts of Dhamsana showed comparatively lower susceptibility. The 72-year climate analysis revealed significant warming during the monsoon and post-monsoon seasons and a decline in monsoon rainfall, suggesting that future flood hazards will be driven by changing rainfall characteristics together with rapid urbanization and expanding impervious surfaces. The generated flood hazard map provides a useful decision-support tool for urban planning, drainage improvement, wetland conservation, and disaster risk reduction. Future studies should incorporate hydrodynamic modeling, socioeconomic vulnerability, climate projections, and machine learning techniques to improve flood prediction and support climate-resilient development in Bangladesh.

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