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Research article

Flash Flood Susceptibility Mapping in Phuket Province, Thailand: An Integrated Geo-Information Technology and Logistic Regression Approach

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Abstract

In the past 2 years, Phuket has experienced more frequent flash floods, resulting in significant damage to life and property for the people of Phuket. This research aimed to assess flash flood susceptibility using Geo-information technology (GIS) and logistic regression analysis in Phuket Province. The statistical results from the logistic regression analysis were subsequently processed using the geographically weighted regression method within GIS. The results of the study found that the factors with the most influence on flash flood occurrence were Topographic wetness index (TWI), Stream frequency (SF), Drainage density (DD), Infiltration number (IN), Slope, Distance to road, Mean annual precipitation, Elevation, Land use, Sediment transport index (STI), Stream power index (SPI), Distance to stream, and Geology, respectively. All these variables are shown from the exp β value coefficient, when compiled into a flash flood susceptibility map, it was found that very high flash flood susceptibility level covers an area of up to 43.40 km^2 (8.04% of the total area). Most of it covers the areas along the major rivers of Phuket Island. The most obvious is the mountainous terrain with rivers flowing through it, the piedmont and intermontane plains in the northern part of Phuket, which is the Thalang District and Kathu Sub-district. The coastal plain landscape of the eastern part of Phuket Island also shows areas of very high flash flood susceptibility level scattered along major waterways in the Ko Kaew, Talat Yai, Talat Nuea, Wichit, Chalong, and Rawai sub-districts. However, the top three variables influencing flash flood occurrences in Phuket were the TWI, SF, and DD. This highlights the high susceptibility of the study area's coastal foothill regions to flash flooding, primarily due to their function as a confluence point for multiple stream branches. The findings of this research indicate that the TWI, SF, and DD are significant variables contributing to flash flood occurrences in terrains characterized by narrow coastal plains adjacent to major mountain ranges. The results of this research are to creat a flash flood risk map, intended to inform and enhance upcoming flood monitoring strategies.

Keywords: Flash Flood; Coastal Tourist City; Geo-Information Technology; Logistic Regression; Phuket.

1. Introduction

In the Tropical Climate area, the weather is hot and humid all year round. The average temperature throughout the year is higher than 18 degrees Celsius. It usually rains all year round with an average rainfall of more than 2,500 mm/year, so there is no dry season. (Chen *et al.,* 2020; Archana *et al.,* 2024; Tolentino *et al.,* 2025). With such weather conditions that are influenced by monsoon winds, it is likely that the amount of rainfall accumulated will be higher than in other areas, causing coastal areas to often experience convergence rain and orographic rain. (Gascón *et al.,* 2016; Nagamani *et al.,* 2024; Váš *et al.,* 2025). Such rainfall patterns often result in prolonged rainfall, which can cause flash floods in mountainous coastal areas with relatively steep slopes. In 2024, floods worldwide claimed more than 8,700 lives and cost the global economy more than $550 billion. (Van Dijk *et al.,* 2024). Flash floods are one of the most dangerous disasters that cause damage to life and property. It also had an immediate, severe and shortterm impact on buildings and damage to crop fields in the area.

In recent years, various statistical and machine learning methods have been used to enhance flood susceptibility mapping in coastal tourist cities. These methods include analytical hierarchy process (AHP) (Elkhrachy, 2015; Riaz & Mohiuddin, 2025), weight of evidence (Costache & Zaharia, 2017; Lin *et al.,* 2020), frequency ratio (Youssef *et al.,* 2016; Popa *et al.,* 2019), multiple criteria decision (Costache *et al.,* 2019; Taherizadeh *et al.,* 2023), artificial neural networks (Shahabi *et al.,* 2021; Oddo *et al.,* 2024), support vector machine (Hoang & Liou, 2024), decision tree (Yukseler *et al.,* 2023; Wang *et al.,* 2024), random forest (Long *et al.,* 2025), and logistic regression (Yao *et al.,* 2022; Chen *et al.,* 2023). Such studies often use flash flood conditioning factors such as average rainfall, elevation, slope, land use, geology, soil drainage, distance from waterways, etc (Waiyasusri *et al.,* 2023). This is evident from the wellknown research studies that have studied flash flood susceptibility in various large coastal cities. This passage highlights several recent global research studies that applied various spatial modeling and machine learning techniques to map flood susceptibility in diverse coastal and urban areas. The research process for identifying flood susceptibility areas frequently utilizes methods such as the analytical hierarchy process and the frequency ratio technique (Hadipour *et al.,* 2020; Arnous *et al.,* 2022; Luo *et al.,* 2023). As for the methods of studying flash flood prediction using machine learning, applied techniques include classification and regression tree, support vector machine, logistic regression, and deep 1D-convolutional neural networks (Mekkaoui *et al.,* 2025; Rifath *et al.,* 2024; Wahba *et al.,* 2024; Hao *et al.,* 2024). It can be seen that the research has used statistical techniques and machine learning methods that focus on testing the system in various methods. However, the analysis did not focus on the factors related to flash flood conditioning factors, which led to a lack of connection between the spatial and geographical contexts of that area, as to what the real cause of flash flood disasters was. Therefore, it is necessary to develop research that identifies the factors that affect the occurrence of flash floods in order to find ways to cope with and prevent areas that are prone to flash floods regularly. Geo-information technology represents the fusion of Geographic Information Systems (GIS) and Remote Sensing to be used in flash flood susceptibility research significantly, by collecting spatial data accurately and efficiently. As the research of Ramadan *et al.* (2025) showed the empirical research result in analyzing urban flood vulnerability in Al-Ain City, UAE using geo-information technology. Produced flash flood hazard mapping using GIS In the Barzan Area of Iraqi Kurdistan Region. Al–Shwani *et al.* (2025) identified flash flood susceptible areas using GIS in Erbil Sub-Basin, Northern Iraq. It can be seen that such technology is a good tool for analyzing flash flood susceptibility areas.

However, a key component for flash flood susceptibility analysis is the digital elevation model data (Sahid, 2024). Digital elevation model data is a crucial component for effective flash flood susceptibility analysis, as it allows for the calculation of vital morphometric parameters, including slope, flow accumulation, Topographic Ruggedness Index (TRI), Topographic Wetness Index (TWI), and Stream Power Index (SPI) (Leeonis *et al.,* 2024). Recent empirical research consistently emphasizes the importance of these spatial datasets across various global regions. For instance, studies utilized Digital elevation model data for watershed analysis and prediction in Southwest Saudi Arabia (Masoud *et al.,* 2024), while others relied on GIS ground data—incorporating variables like storm duration, Topographic Wetness Index, and land use—to assess flood hazards in areas like Dallas Fort Worth (Wilkho *et al.,* 2024). Furthermore, GIS remains an essential decision making tool in coastal cities, with research using digital eleva-tion model, geology, and land cover to identify low-lying flood prone areas in Central Evia Island, Greece (Mazarakis *et al*., 2025). Finally, variables derived from remote sensing, such as Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI), are increasingly integrated with GIS parameters (e.g., curvature, Topographic Wetness Index) to enhance the efficiency of susceptibility mapping in locations like Bangladesh and Vietnam (Chowdhury, 2024; Viet *et al.,* 2025). These variables can be used to forecast flash floods very well. In summary, geo-information technology is an important basic tool for data collection, data selection, data analysis, and data visualization as disaster risk maps in research. It is necessary to apply such technology in this research, to prepare for flash flood disasters and also to plan cities to manage flash flood risks that may occur in the future.

The highlight of this research is the application of logistic regression analysis to study the variables that affect the occurrence of flash floods in Phuket, in order to obtain the results of the real flash flood problem and in line with the principles of the United Nations Sustainable Development Goals (SDGs), particularly SDG 11: Sustainable Cities and Communities, and SDG 13: Climate Action. Goal 11 aims to make cities and human settlements inclusive, safe, resilient and sustainable. In particular, Goal 11.1 addresses ensuring access to adequate and safe housing and basic services for all. And, Goal 13 aims to take urgent action to combat climate change and its impacts. In particular, Goal 13.1 addresses strengthening resilience and adap-tive capacity to climate-related hazards and natural disasters in all countries (Effat *et al.,* 2022; Ramadan *et al.,* 2025) The approach will focus on assessing the hazards posed by flood disasters as an important baseline data that can support decision making in implementing appropriate disaster mitigation measures. Research related to areas susceptible to flash floods has often been neglected and undervalued in this country.

Most flooding in Thailand occurs during May – October of each year because it is the monsoon season, causing the southern region of Thailand to often experience orographic rain. During October – January of each year, the southern region of Thailand is influenced by Tropical Cyclone and The Intertropical Convergence Zone (ITCZ), resulting in a pattern of prolonged rainfall for several days (Chanalert *et al.,* 2022). With such rain patterns, it is a major factor that occurs naturally on a regular basis. However, at present, there are additional factors that make coastal tourist city areas more vulnerable to flash flood disasters, namely human activities such as urbanization, agricultural expansion, land use change, including deforestation, which stimulate the severity of flash floods and increase the frequency of flash floods (Hu *et al.,* 2024; Moukomla & Marome, 2025). On 29-30 June and 7-8 July 2024, major flash floods occurred in Phuket due to the influence of the strong southwest monsoon, which brought moisture from the Indian Ocean to the southern west coast of Thailand and collided with the Nakhon Si Thammarat Rangelands in the central part of the peninsula. Phuket is one of the areas affected by orographic rain, a rain pattern where moist air masses collide with the mountains in the central part of Phuket. This causes the moist air mass to rise along the height of the terrain and condense into rain that remains in the same place for several days, resulting in a cumulative rainfall of up to 320 mm within 4 hours (6:00-9:00 AM), which causes flash floods. In addition, flash floods during that period, instead of the rainfall flowing into important canals in Phuket, it was found that natural canals were transformed into narrow drainage pipes. In some areas, housing estates and buildings were built to block the flow of water, causing frequent flash floods in Phuket Province in Kamala beach, Patong beach, Karon beach, Bang Thao beach, Ko Kaew, Khlong Bang Yai stream, Mueang Phuket subdistrict, etc.

For the above reasons, this research aims to evaluate flash flood susceptibility using Geo-information technology and logistic regression analysis in Phuket Province, Thailand. This re-search approach has collected important physical and socio-economic factors affecting flash flood occurrence, including elevation, slope, SPI, STI, TWI, SF, DD, IN, mean annual precipitation, geology, land use, distance to stream, and distance to road. The expected outcome of this research is a spatial database of flash flood risk areas in Phuket, one of the world's major coastal tourist cities. It will be displayed in the form of a flash flood susceptibility map showing different levels of risk. The geographical databases will be useful for disaster relief agencies and related government and private sectors, for managing areas at risk of flash floods that may occur in the future. It will also be a guideline for planning, monitoring, and preventing such disasters in a timely manner. Phuket Province still lacks flash flood susceptibility mapping, and the results of this research will be clearly beneficial to this coastal tourist city.

2. Research Methods

2.1. Study Area

Phuket, a key urban center in Southern Thailand, spans 539.67 km^2. Geographically, its coordinates are between 7°45' N and 8°15' N latitude, and 98°10' E and 98°30' E longitude. (Figure 1). Phuket is the largest island in Thailand, located in the western part of the southern region in the Andaman Sea, Indian Ocean. It is approximately 700 km from Bangkok. The topography of Phuket is an island that lies from north to south. 70% of the area is mountainous. The highest peak is Khao Mai Thao Sip Song, which is 529 m high and is located in the south of Phuket Island, near Patong Beach. 30% of the area is flat, located in the southeast of the island in Mueang Phuket. This flat area is vast (Ufimtsev, 2011). Historically, Phuket was a major agricultural and tin mining area in Thailand. However, much of the land has now transformed into business districts and residential areas (Moukomla & Marome, 2025). Near the plains lies a large indented coastline, Chalong Bay, which features a mangrove forest at the estuary of Phuket province. To the north of Phuket, a narrow strait called Pak Phra Strait connects the island to the mainland via the Thao Thep Krasattri Bridge and Thao Si Sunthon Bridge. The western part of Phuket is characterized by mountains stretching from north to south, interspersed with narrow coastal plains (Akkajit *et al.,* 2024). This coastline is famous for its beautiful white sandy beaches, including Mai Khao Beach, Nai Thon Beach, Bang Tao Beach, Kamala Beach, Patong Beach, Karon Beach, Kata Beach, and Kata Noi Beach, in sequential order (Akkajit *et al.,* 2021). Patong Beach is the largest and attracts both Thai and international tourists throughout the year.

Since the central part of Phuket Island is a mountainous area and undulating plain, the drainage system is a radial drainage pattern. In the study area, there are 3 drainage patterns from the center: flowing direction to the north, flowing direction to the west, and flowing direction to the east. The stream with a flow direction to the north is found as Khlong Dan Yit stream only in the Nai Yang beach area in the north of Phuket. Stream flowing west of Phuket has 7 important watersheds: The northernmost basin has the main river, Khlong Phama Long. The basin in the Bang Thao beach coastal plain, which is the largest plain in Phuket, has a watershed system with important waterways, namely Khlong Riang, Khlong Thalang, and Khlong Bang Cho, where the three rivers merge to become Khlong Phang before flowing into the sea at Bang Thao Beach. Khlong Bang Thao is a short river in the south of Bang Tao Beach. The basin in Kamala beach has only one Khlong Kamala stream flowing into the sea (Pakoksung *et al.,* 2022). The basin in Patong beach has only one Khlong Patong stream flowing into the sea. The basin in Karon and Kata beach has a short but unnamed river flowing into the sea as well. In the southernmost basin, at Nai Han beach, there is only one stream, Khlong Ya Yai, flowing into the sea.

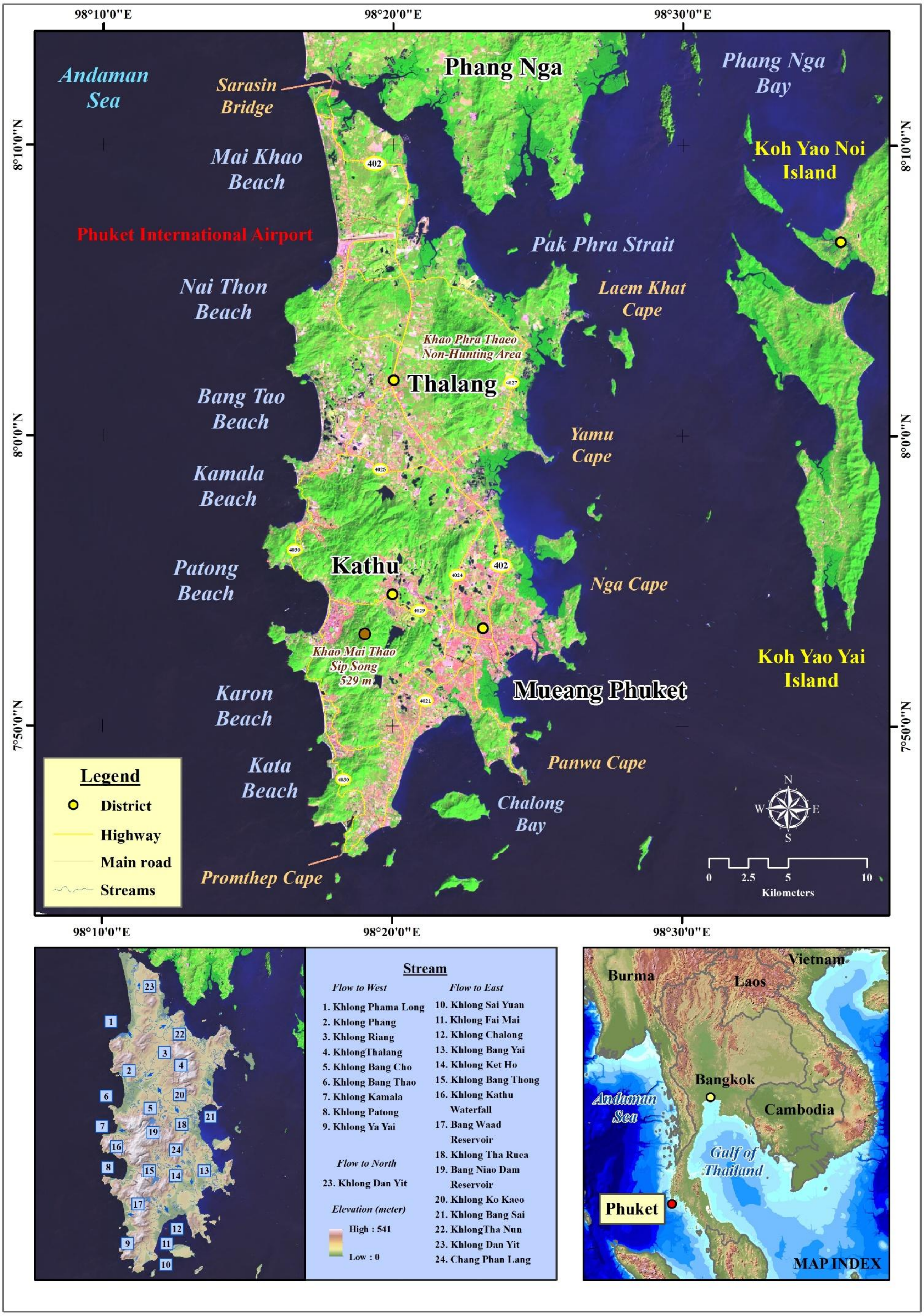

Figure 1. Geographic Map and Drainage Pattern Map of Phuket Province, Thailand.

Stream flowing east of Phuket has 8 important watersheds: Khlong Tha Nun stream is a watershed in the northern part of Phuket. The eastern watershed system in the Khao Phra Thaeo Non-hunting area has Khlong Bang Sai and a short unnamed stream flowing into the sea. Khlong Tha Ruea originates from Kuan Wa Hill and flows into Khlong Ko Kaew.

The headwaters are at Khao Phra Thaeo Hill. The two canals meet to become Khlong Ko Kaew, flowing into the sea near Yamu Cape. Khlong Chang Phan Lang is a short waterway flowing into the sea near Khlong Ko Kaew. Phuket town is the second largest plain on Phuket Island. There is an important watershed system, Khlong Bang Yai, which originates from important rivers in the Kuan Wa Hill and Khao Mai Thao Sip Song mountains, which are the largest mountain ranges in the central part of Phuket (Kulsoontornrat & Puangkaew, 2025). It is the source of important streams, Khlong Kathu Waterfall and Khlong Bang Thong, which flow together to form Khlong Ket Ho, becoming Khlong Bang Yai and flowing into the sea at Sapan Hin Cape. The other three river basins in the south of Phuket Island originate in Khao Mai Thao Sip Song, namely Khlong Chalong, Khlong Fai Mai, and Khlong Sai Yuan, which flow into Chalong Bay.

2.2. Data Requirement and Preparation

This study assessed flash flood susceptibility using secondary data acquired from a variety of sources, especially data on flash flood areas that occurred during 2024-2025 from the National Hydroinformatics Data Center and Geo-Informatics & Space Technology Development Agency (Public Organization). Spatial data for the analysis of factors affecting flash flood occurrence include Elevation, Slope, SPI, STI, TWI, SF, DD, IN, Mean annual precipitation, Geology, Distance to stream, Distance to road, and Land use. As detailed in Table 1, these data represent crucial variables used for evaluating areas prone to flash floods. All spatial data will be generated in raster format with grid cell size of 50 × 50 m.

Table 1. Spatial Data Layers Used in This Research.

Driving factors (Theme)	Year	Sources
Flash flood area	2024-2025	National Hydro-informatics Data Center Geo-Informatics & Space Technology Development Agency (Public Organization).
Elevation (digital elevation model-DEM)	2020	Derived from Royal Thai Survey Department (RTSD)
Slope	2025	Generated using the DEM
Stream Power Index (SPI)	2025	Generated using the DEM
Sediment Transport Index (STI)	2025	Generated using the DEM
Topographic Wetness Index (TWI)	2025	Generated using the DEM
Stream Frequency (SF)	2025	Generated using the DEM
Drainage Density (DD)	2025	Generated using the DEM
Infiltration Number (IN)	2025	Generated using the DEM
Mean annual precipitation	2005-2024	Derived from Thai Meteorological Department (TMD)
Geology	2017	Derived from Department of Mineral Resources
Distance to stream	2021	Derived from Department of Water Resource, Thailand
Distance to road	2024	Derived from Department of Public Works and Town &Country Planning
Land use	2024	Derived from Land Development Department (LDD)

2.3. Data Analysis

The methodology of this research followed these steps: (1) flash flood area analysis, (2) spatial database analysis of driving factors, and (3) statistical approach. Figure 2 illustrates the specifics of each step, which are detailed below.

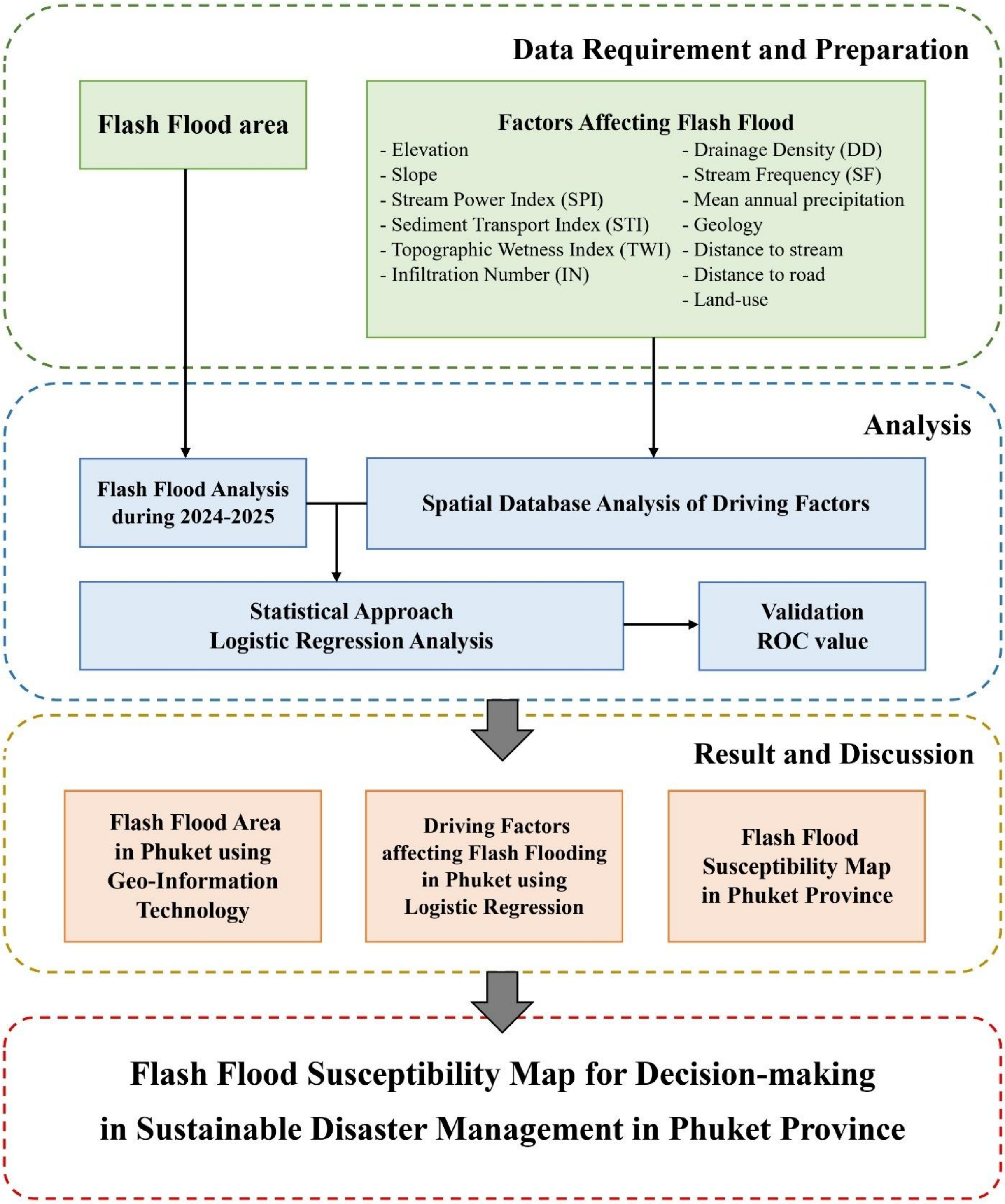

Figure 2. Flow Chart of Methodology.

2.3.1. Flash Flood Area Analysis

Analysis of past flash flood records can predict future recurrences. The steps for analyzing flash flood susceptibility area are to analyze past flash flood events during 2024-2025, which were obtained from the National Hydro-informatics Data Center and Geo-Informatics & Space Technology Development Agency (Public Organization). During 2024-2025, severe flash floods occurred on June 29-30, July 7-8, and September 17, 2024, and again on April 16, 2025. The data of these four events will be recorded as spatial data in vector file format, and then converted to raster file data for use in the next logistic regression analysis.

2.3.2. Spatial Database Analysis of Driving Factors

Selection of factors affecting flash flood occurrence is important for analyzing flash flood susceptibility to obtain accurate spatial data. In this study, the most related and repeated flash flood conditioning factors selection is crucial (Al–Kindi *et al.,* 2024). Spatial data that has been used in many other research studies, and is also used in this research is the Digital Elevation Model (DEM) from the Royal Thai Survey Department (RTSD). The data for this study, initially in vector file format (including elevation points, contour lines, stream lines, water bodies, and watershed boundaries), underwent an initial conversion.

To facilitate spatial analysis and obtain statistics for each grid cell, these vector files were transformed into a raster file format using the Topo to Raster technique within ArcGIS 10.8 software. The result was DEM resolution of 50 × 50 m grid cell size (Figure 3a) for subsequent analysis of other variables. The local topographic slope (Figure 3b), SPI (Figure 3c), STI (Figure 3d), TWI (Figure 3e), SF (Figure 3f), DD (Figure 3g), and IN (Figure 3h), were then calculated from the DEM. It can be seen that in addition to geographical driving factors such as DEM and slope that affect the susceptibility to flash floods, there are also the hydrological driving factors, namely SPI, STI, TWI, SF, DD, and IN that also have influence and are also important physical accelerators in hydrology (Solaimani *et al.,* 2024).

SPI is a widely used driving factor in hydrological research. As it is a variable indicating the potential of river flows to be erosive, it has an impact on the change of the terrain surface. A higher SPI value points to a stronger propensity for erosion, while lower values suggest minimal erosion risk (Singh *et al.,* 2025). The SPI analysis can be calculated from Equation 1.

$$\text{SPI} = \text{As} \tan \beta \tag{1}$$

Where, As indicates the definite watershed area, and β denotes the slope gradient.

STI is a driving factor that determines the movement of sediments along the river. This sedi-ment causes erosion and sedimentation processes. The result of STI, if the STI value is high, it indicates high sedimentation and deposition in that area. Conversely, if the STI value is low, it indicates low sedimentation and deposition in that area (Gebremichael *et al.,* 2025). STI analysis can be calculated from Equation 2.

$$STI = \left(\frac{A_s}{22.13}\right)^{0.6} \left(\frac{sin\beta}{0.0896}\right)^{1.3} \tag{2}$$

Where, As indicates the definite watershed area, and β denotes the slope gradient.

TWI is an index that can forecast the tendency of water to flow into a basin due to the Earth's gravity (). High TWI values indicate areas prone to water accumulation in the basin, which may occur in the combination of a large upslope area and a lower slope or lowland areas (Le Guillou & Niculescu, 2025). The TWI analysis can be calculated from Equation 3.

$$TWI = ln\left(\frac{A_s}{tan\beta}\right) \tag{3}$$

Where, As indicates the definite watershed area, and β denotes the slope gradient.

SF is the ratio of the number of 1st order streams to the area of the watershed. Therefore, if SF shows a high value, it indicates an area with low runoff. On the other hand, if SF shows a low value, it indicates an area with high runoff. In other words, the flow of water in a stream from the headwaters to the downstream is rapid (Sahoo *et al.,* 2024). The SF analysis can be calculated from Equation 4:

$$SF = \frac{\sum N_s}{A} \tag{4}$$

Where, Ns is the total number of 1st order streams and A is the total watershed area (km^2).

DD is the ratio of the total length of the river to the basin area. So, if the DD level is more than 3, it means the basin area has good and fast drainage. DD level between 1-3 means the basin area has moderate drainage. And, if the DD level is less than 1, it indicates that the area has poor drainage or slow drainage (Bahrami *et al.,* 2024). The DD analysis can be calculated from Equation 5:

$$DD = \frac{\sum L_s}{A} \tag{5}$$

Where, Ls is the sum of all river basin lengths and A is the total watershed area (km^2).

N is the result of DD and SF analysis in the study area. High IN indicates low infiltration rates, resulting in higher surface runoff. On the other hand, low IN indicates low surface runoff, higher infiltration rates, resulting in lower surface runoff (Sahoo *et al.,* 2024). The IN analysis can be calculated from Equation 6.

$$IN = DD \times SF \quad (6)$$

Mean annual precipitation is obtained from weather stations from the Thai Meteorological Department (TMD) from 2005-2024 (Figure 4a). This research used the inverse distance weighted interpolation technique in spatial analysis tools in ArcGIS 10.8 software. This resulted in an estimate of the annual average rainfall in raster format.

Geology (Figure 4b) and land use (Figure 4c) driving factors, which are nominal data, were converted to raster format. Finally, Distance to stream (Figure 4d) and distance to road (Figure 4e) factors were analyzed using Euclidean distance technique in spatial analysis tools, before being analyzed using logistic regression analysis statistical methods in the following order.

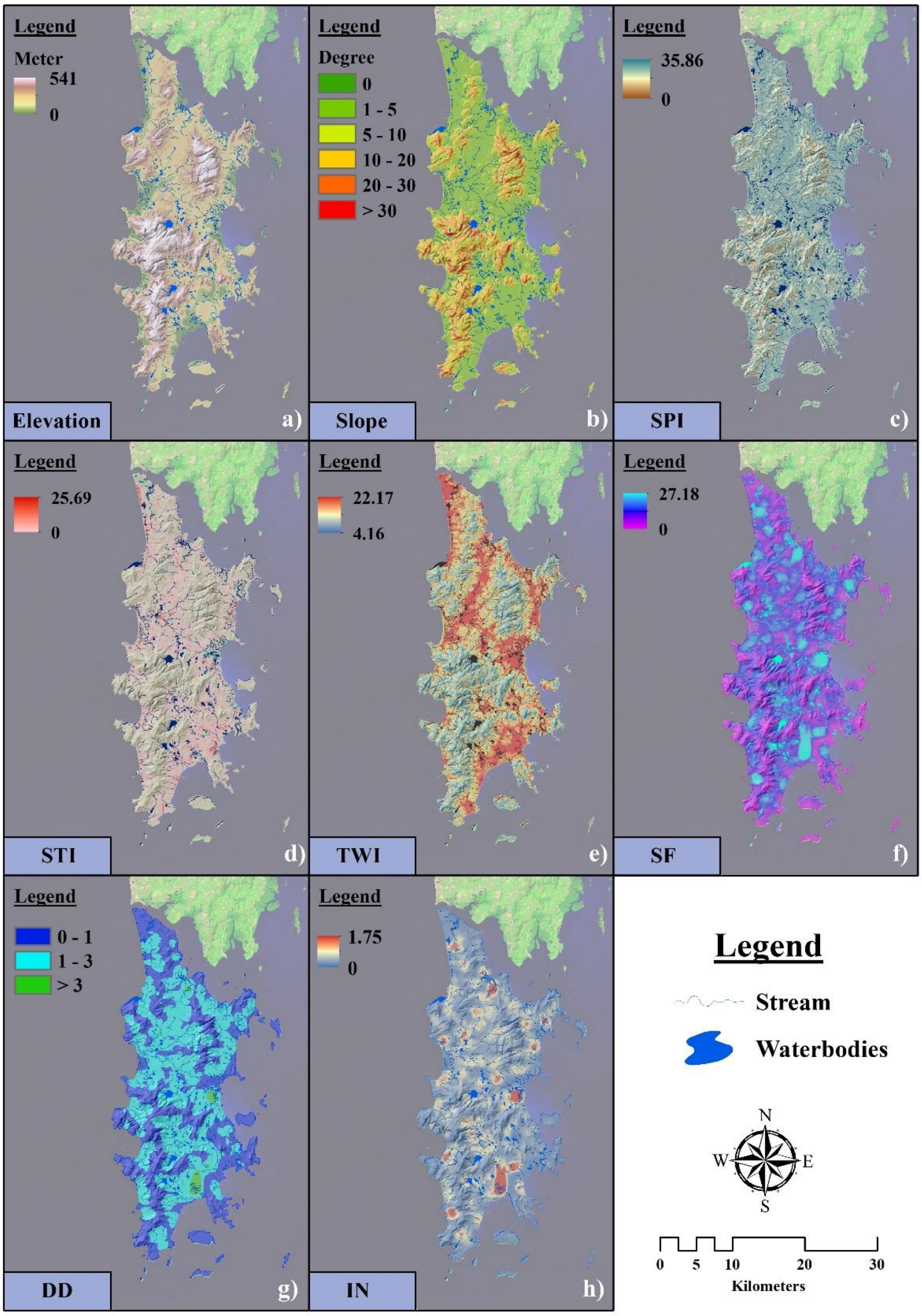

Figure 3. Spatial Database Analysis of Driving Factors: Elevation – DEM (a), Slope (b), SPI (c), STI (d), TWI (e), SF (f), DD (g), IN (h).

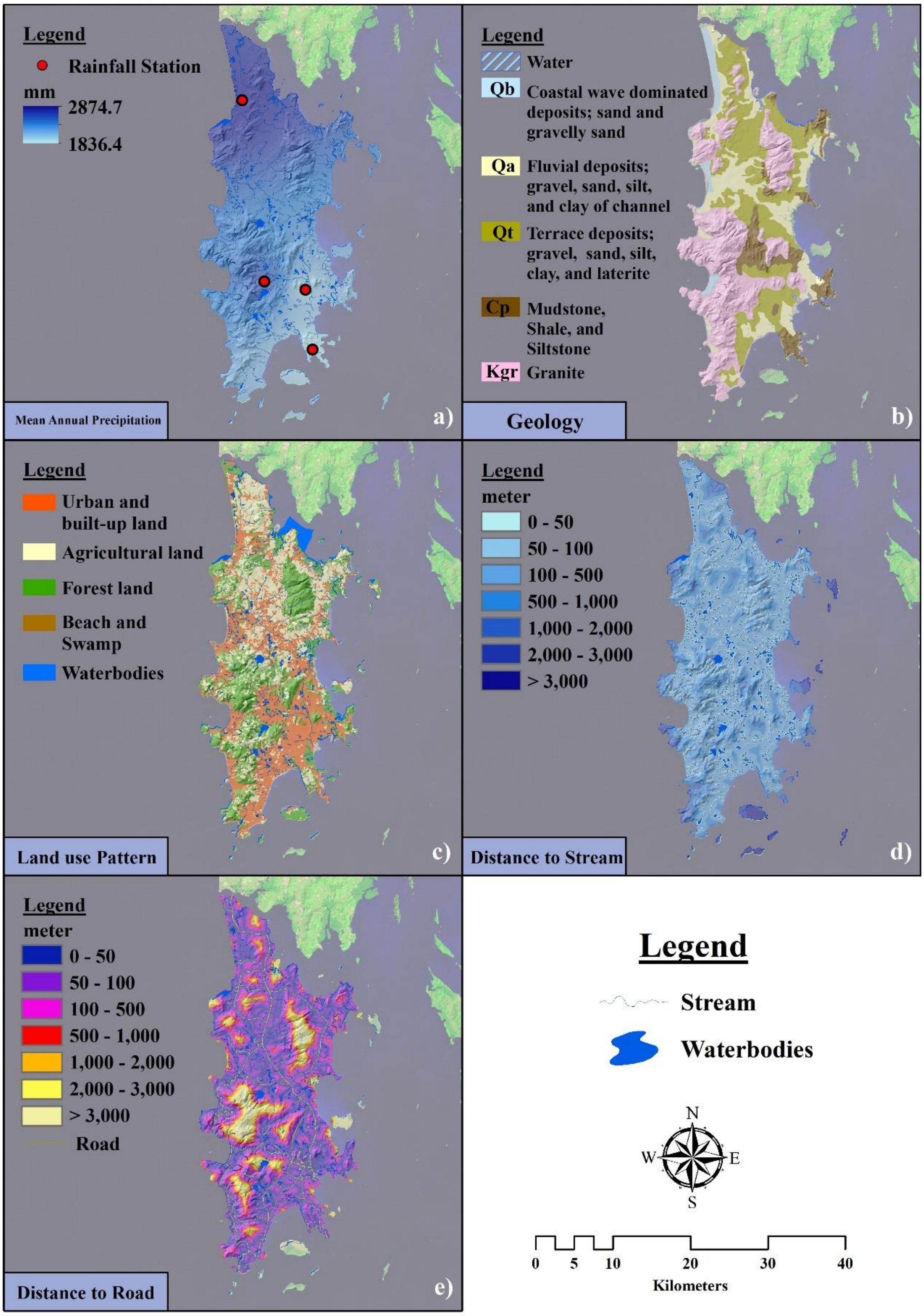

Figure 4. Figure 4. Spatial Database Analysis of Driving Factors: Mean Annual Precipitation (a), Geology (b), Land Use (c), Distance to Stream (d), Distance to Road (e).

2.3.3. Statistical Approach

From the previous steps of flash flood area analysis and spatial database analysis of driving factors, in order to find the factors that affect the occurrence of flash floods in Phuket, it is necessary to analyze the flash flood area together with 13 driving factors, which are Elevation, Slope, SPI, STI, TWI, SF, DD, IN, Mean annual precipitation, Geology, Distance to stream, Distance to road, and land use. These driving factors will be analyzed together with the flash flood area using logistic regression.

Logistic regression is used to assess the probability of a specific event (like a flood) by analyzing its relationship with multiple influencing factors. Through a binary analysis, logistic regression determines the correlation between the flood occurrences (represented as a binary factor of existence/non-existence) and the conditioning factors (independent variables). The output is a flood probability index (p), ranging from 0 to 1 on an S-shaped curve. This index is calculated using the resultant weights, or logistic coefficients, derived from the analysis (Tsumita *et al.,* 2025; Rahman *et al.* 2025) and is presented in the following Equation 7.

$$P = 1 / (1 + e^{-z}) \quad (7)$$

Where P is probability of flooding as a value between 0 and 1 on an S-shaped curve. And z is the linear combination.

Logistic regression is a technique for finding empirical relationships between a binary dependent and several independent categorical and continuous variables (Demissie *et al.,* 2024; Rifath *et al.,* 2024). Logistic regression is calculated using the following Equation 8.

$$Log\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_{1x1,i} + \beta_{2x2,i} + \cdots + \beta_{n\,x\,n,i} \quad (8)$$

Where, P is the flood prone area, xi are independent variables and β is the coefficient value.

This statistical method is used to find the factors that affect the occurrence of flash floods. It is to find out which factors have the most and least influence on the occurrence of flash floods, which is expressed as β value. The statistical principles will consider the underlying and dependent variables according to all grid cell sizes in the study area. Finally, this process will be used to predict the flood risk areas in Phuket Province, which will be divided into 5 classes (classification method), namely very high, high, moderate, low, and very low. It will be displayed as Flash Flood Susceptibility Mapping, as spatial data for sustainable flood disaster management in Phuket Province in the future.

3. Results and Discussion

3.1. Flash Flood Area in Phuket Province

The topography of Phuket Province, which is an island, has a large mountain range in the middle of the island and a narrow plain. Whenever a thunderstorm occurs, the mass of water flows into the canals in Phuket, and is quickly drained into the sea. However, at present, this is not the case. In other words, flash floods occur in many communities, and the water is drained into the sea slowly, due to the structures that block the drainage, resulting in flood disasters in many places on Phuket Island. The results of the analysis of flash flood areas in Phuket found that in the past 2 years (2024-2025), Phuket has experienced major flash floods in 10 years. In the study area, there were 14 flash flood disaster areas, covering a total area of 52.245 km^2 (Figure 5). Most of the flash floods occur in the plains near the foothills of the island around Phuket Island. The areas where flash floods occur regularly in Phuket are as figure 5.

Zone A covers the northern part of Phuket Island, along Mai Khao Beach and Nai Yang Beach. In Nai Yang Beach, flash floods are often experienced around Sakhu Subdistrict Administrative Organization and along the main canal, Khlong Phama Long Stream. In Mai Khao Beach, flash floods are often experienced north of Phuket International Airport.

Zone B covers the area between Thalang District and Choeng Thale Subdistrict, namely where Khlong Riang meets Khlong Thalang to become Khlong Phang. These river basins are often the catchment area for water coming from the Khao Phra Thaeo mountain range, resulting in flash floods around Thep Kasattri Subdistrict Municipality Office.

Zone C is the southern part of Choeng Thale Subdistrict, where Khlong Bang Thao flows from the central mountains of Phuket. This area is prone to flash floods due to its location at the foot of a piedmont hill, causing damage from flooding in the surrounding areas of Choeng Thale Sub-District Administration Organization. Water regularly cuts off major roads such as Srisoonthorn Rd. and Bandon Choeng Thale (Highway 4030).

Zone D has experienced flash floods in the northeastern part of Phuket Island in the Pa Khlok Sub-district. Zone E covers the eastern part of Phuket Island between Si Sunthon and Ko Kaew Sub-districts. This area is prone to flash floods because it receives water from two mountain ranges, Khao Phra Thaeo and Kathu Hill, causing the water to flow into Khlong Ko Kaew, Khlong Tha Ruea and Khlong Bang Sai Stream. This area is prone to flooding on Highway 402 and surrounding communities every year.

Zone F covers Kamala Beach. This area is often flooded, just like Zone G in Patong Beach. Both zones receive water from Kathu Hill that flows into tourist areas regularly. Flash floods are common along the Patong and Kamala Stream canals.

Zone H and Zone I are Karon and Kata Beaches, which are also areas that experience flash floods but have not sustained any damage.

Zone J is an area affected by widespread flash floods, and the impacts are severe. The affected areas include the entire Mueang Phuket District, due to the accumulation of water from many canals, the terrain is steep and is a ravine that receives water from the mountain range, becoming important canals, namely Khlong Bang Thong and Khlong Kathu Stream, which flow into Khlong Ket Ho and Khlong Yai Stream. The major flash floods on June 29-30 and July 7-8, 2024 caused widespread damage in Phuket's Old Town. There are also major damaged zones along the eastern coast of Phuket Island, namely Zones K, L, M, and N, which include Ratsada, Wichit, Chalong, and Rawai Sub-districts.

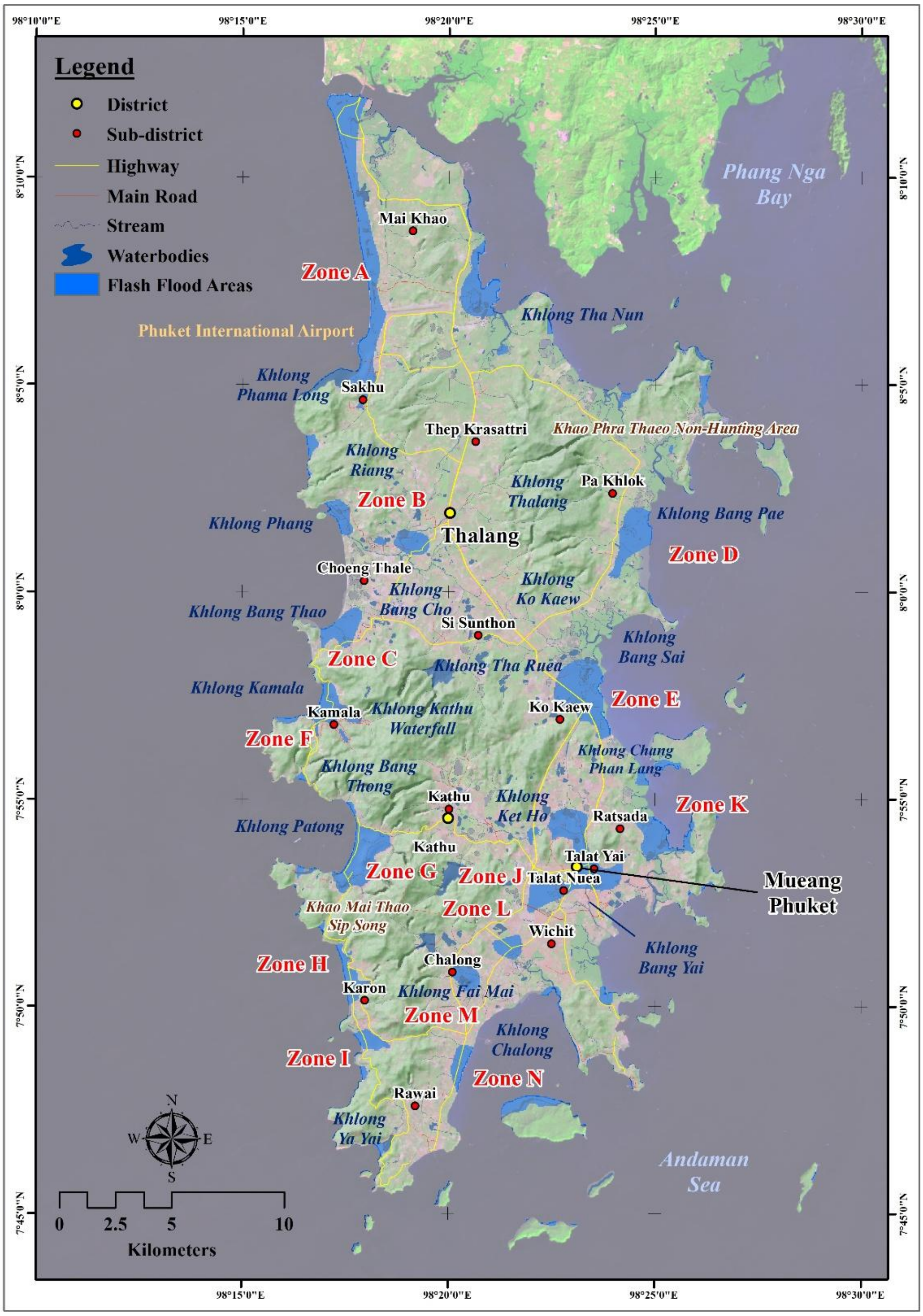

Figure 5. Flash Flood Areas in Phuket Province from the Major Flooding Events in the Past 10 Years in All 14 Zones.

3.2. Driving Factors Affecting Flash Flooding in Phuket Province

From the analysis of 13 driving factors, which are important factors affecting the susceptibility to flash floods, when analyzed using the logistic regression statistical process together with the flash flood area data, the results of the study are as shown in Table 2. In this study, each factor has been shown to have an influence on the susceptibility to flash floods with the statistical value β, that is, if β of that factor is shown as a positive value, it means that the higher the value of that factor, the more susceptible it is to flash floods Conversely, a negative β value for a factor indicates that lower values of that factor increase flash flood susceptibility. The Relative Operating Characteristic (ROC) curve indicates the regression equation's effectiveness in predicting sinkhole risk areas based on probability. For the probability of sinkhole areas, the ROC value was 0.822 (Figure 6), which is a high value because the value is close to 1.00, indicating that all 13 factors are very effective in analyzing areas at risk of flash floods.

Table 2. Logistic regression analysis of the flash flood area and affecting factors in Phuket.

Variable	Flash Flooding area			
	β	**Wald**	**Sig**	**Exp (β)**
Topographic Wetness Index (TWI)	1.537	196.45	0	3.412
Stream Frequency (SF)	-1.212	146.23	0	2.783
Drainage Density (DD)	0.795	35.23	0.017	1.214
Infiltration Number (IN)	0.926	10.41	0.006	1.173
Slope (degree)	0.921	15.96	0.004	1.079
Distance to road	0.001	0.087	0.034	0.998
Mean annual precipitation	-0.032	3.785	0.009	0.961
Elevation	-0.046	6.112	0.001	0.953
Landuse	-0.055	1.452	0.001	0.945
Sediment Transport Index (STI)	0.202	0.03	0	0.798
Stream Power Index (SPI)	-0.264	0.001	0.025	0.732
Distance to stream	-0.001	7.63	0.3	0.099
Geology	-0.002	3.212	0	0.097

All variables were significant at the $p < 0.01$ entry and $p > 0.02$ removal levels. ROC relative operating

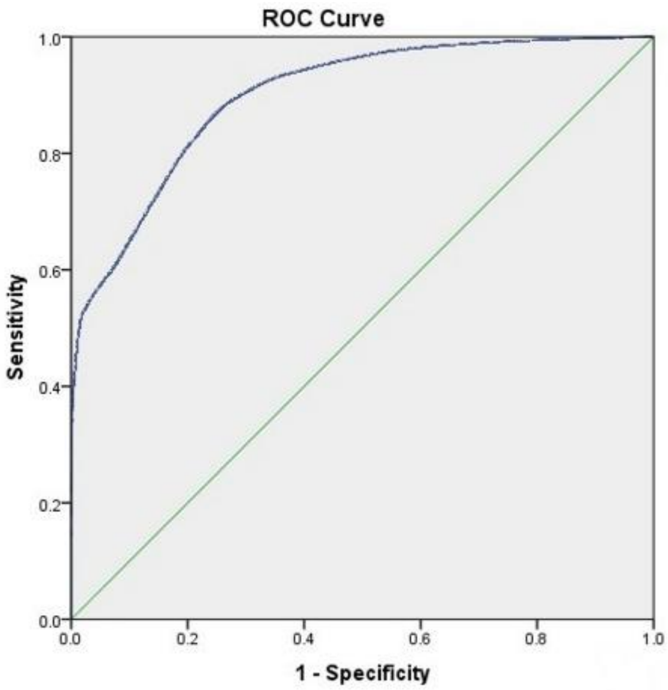

Figure 6. The Relative Operating Characteristic (ROC) Value: Flash Flood Area.

The results of this research found that, the areas susceptible to flash floods have factors that show positive β values, consisting of 6 variables: TWI, IN, Slope, DD, STI, and Distance to road. The factors that show negative β values are 7 variables: SF, SPI, Land use, Elevation, Mean annual precipitation, Geology, and Distance to stream. The Exp β value indicates the level of influence of the factors that affect the occurrence of flash floods, with high Exp β values being the factors that have the greatest impact on the occurrence of flash floods in the study area. When arranged according to the Exp β value, it shows the level of the factors that affect the occurrence of flash floods from most to least as follows: TWI, SF, DD, IN, Slope, Distance to road, Mean annual precipitation, Elevation, Land use, STI, SPI, Distance to stream, and Geology, respectively. The level of Exp β value of each variable is shown as follows: 3.412, 2.783, 1.214, 1.173, 1.079, 0.998, 0.961, 0.953, 0.945, 0.798, 0.732, 0.099, and 0.097, respectively (Table 2).

The factor that affects the most vulnerability to flash floods in Phuket is TWI, which shows a high positive β value. It shows an Exp β value of 3.412, and a High positive β value of 1.537. These factors indicate that high TWI levels are areas with a high chance of water accumulation. In the study area, high TWI levels were found in the coastal plains of Phuket, including the northern part, which is the Mai Khao Beach market area, the central part of Phuket, which is the Thalang district, where the major waterways, Khlong Riang and Khlong Thalang, which receive water from Khao Phra Thaeo Hill, and along the eastern coast of Phuket. Especially in the Phuket Old Town area, which is located in the southeast of the island and the area around Chalong Bay, there are large high TWI areas. These areas are inevitably prone to water accumulation, resulting in flash floods. Currently, flash floods are common in these areas.

The SF factor is the factor that affects the occurrence of flash floods in the next level after TWI. It shows an Exp β value at 2.783 and a High negative β value at -1.212. The results of the study found that if the SF level shows a low value, it indicates that the area has a high runoff and tends to have a rapid runoff. In the study area, the SF level showed a low value along the Phuket mountain range, which is an area with a fairly steep slope and waterways around the mountain range, affecting the rapid flow of water in the river during thunderstorms.

The DD factor is the third influential factor. It shows an Exp β value at 1.214 and a positive β value at 0.795. The results of the study found that the area with DD > 3 appeared in two areas of the eastern coastal plain, namely Ko Kaeo Sub-district, which is the confluence of major rivers, namely Khlong Ko Kaeo and Khlong Tha Ruea. This area is often flooded because there are many tributaries. Another area is Phuket Town, which is the area where tributaries meet from the mountain range in the middle of Phuket Island. The major rivers that meet in the city area are Khlong Ket Ho and Khlong Bang Yai. And, Khlong Fai Mai and Khlong Chalong also found High DD level areas. The area with DD = 1 to 3 indicates a moderately drained watershed area. It appears around major rivers in Phuket Island, indicating that the steep terrain along both sides of the river is at moderate risk of flash flooding.

The IN factor is the fourth factor showing the sensitivity to flooding. It shows an Exp β value at 1.173 and a positive β value at 0.926. The study found that high IN indicates that water infiltrate to the ground at a low level (lower infiltration rates), resulting in higher runoff on the surface of the terrain. The high IN level is distributed in the downstream areas of each river basin, namely Khlong Phama Long, Khlong Tha Nun, khlong Phang, Khlong Bang Thao, Khlong Tha Ruea, Khlong Kamala, Khlong Patong, and the surrounding areas of Chalong Reservoir.

The Slope factor showed a positive β value of 0.921. The results of the study found that areas with high slopes will affect the susceptibility to flash floods, which will occur in the study area at the shoulder of the hill and the foot of the hill. The Distance to road factor is another factor that shows the level of Exp β value = 0.998, ranked 6th. This is a factor that occurs and is influenced by human actions. The study area showed that areas near the road tend to have accumulated flooding, and some areas have overflowing on the road, especially on roads that cut through the foot of the hill, which roads in Phuket tend to block the water mass.

The Mean annual precipitation factor and the Elevation factor showed negative β values at -0.032 and -0.046 respectively. It shows that the low rainfall distribution area is more susceptible to flash floods. This is because the southeastern area of Phuket Island is behind the mountain range and has many waterways flowing through it, making it an area that receives water flowing from the mountain range. This is different from the eastern coastal area along the entire length of Phuket Island, even though it is in front of the mountain, and is directly influenced by the southwest monsoon, but it results in less flash floods than the western coast. This may also be due to other factors. The topographic factor showed a negative β value.

It indicates that areas with an elevation of approximately 0-50 meters are susceptible to flash floods. The Land use factor showed a negative β value at the level of -0.055. This is because the land use type classification was set from 1-5, namely waterbodies, urban and built-up land, agricultural land, forest land, and beach and swamp, respectively. The negative β value can indicate that areas covered by waterbodies and urban and built-up land are susceptible to flash floods. In Phuket Province, there has been a wide expansion of urban areas, especially in the western and eastern coastal areas of the island, which are residential and business areas for tourism. Such areas often have structures encroaching on major canals. Some areas have built residences and resort hotels that obstruct natural waterways. Some have built such structures over canals or natural waterways. This results in flash floods and mudslides along mountainsides and foothills, posing a major problem for water management in Phuket Province.

The four factors that affect flash flooding in Phuket at the final level are STI, SPI, Distance to stream, and Geology, respectively. They are interrelated, STI is the driving factor that deter-mines the movement of sediments along the river. This sediment will cause erosion and sedi-mentation. A high STI indicates high sedimentation and deposition in that area. SPI is the fac-tor that causes erosion in the river. However, the study area showed a negative β value, which is still low in Phuket. The factors of Distance to stream, and Geology will support the first two factors. When flash flooding occurs, there is often a debris flow that deposits in the foothills of the study area. In particular, flash floods and sedimentation along both sides of the river and areas covered by Terrace and Fluvial deposits are often accompanied by alternating flash floods and sedimentation, when thunderstorms repeatedly hit the same area for a long period of time.

3.3. Flash Flood Susceptibility Map in Phuket Province

The findings of this study involve a flash flood susceptibility map for Phuket Province, developed through the statistical analysis of logistic regression. The derived β values were instrumental in building a spatial database to aid in the management of flash flood events in Phuket. (Figure 7). The study's findings were derived from analyzing spatial data within GIS, as outlined in Equation 8.

$$Y = 34.326 + (1.537 \times \text{"TWI"}) + (-1.212 \times \text{"SF"}) + (0.926 \times \text{"IN"}) + (0.921 \times \text{"Slope"}) + (0.795 \times \text{"DD"}) + (-0.264 \times \text{"SPI"}) + (0.202 \times \text{"STI"}) + (-0.046 \times \text{"Elevation"}) + (-0.055 \times \text{"Land\_use"}) + (-0.032 \times \text{" Mean\_annual\_precipitation "}) + (-0.002 \times \text{"Geology"}) + (-0.001 \times \text{"Distance\_to\_stream"}) + (0.001 \times \text{" Distance\_to\_road"}) \quad (8)$$

The β values derived from various factors in this research reveal the level of flash flood sensitivity as spatial data across Phuket. In particular, the classification of the level of sensitivity to floods is shown in 5 levels: very high sensitive areas, high sensitive areas, moderate sensitive areas, low sensitive areas, and very low sensitive areas, respectively (Table 3).

Table 3. Flash Flood Susceptibility Area in Phuket Province (km²).

Flash flood susceptibility level	Area	
	km²	%
Very high	43.40	8.04
High	86.38	16.01
Medium	121.27	22.47
Low	130.97	24.27
Very Low	157.66	29.21
Total	539.67	100.00

In Phuket Province, areas with very high flash flood susceptibility level were found covering an area of 43.40 km^2 (8.04% of the total area). Most of them cover areas along major rivers in Phuket Island. The most obvious areas are the mountainous terrain with rivers flowing through, the foothills and the plains between the valleys (piedmont and intermontane) in the north of Phuket, which is the Thalang District and Kathu Sub-district. In addition, the coastal plains in the east of Phuket Island also have very high flash flood susceptibility level areas, distributed along major rivers in the Ko Kaew, Talat Yai, Talat Nuea, Wichit, Chalong, and Rawai Sub-districts.

The high flash flood susceptibility level area covers an area of 86.38 km^2 (16.01% of the total area). It has appeared in the area near the very high level continuously, the topography that has the characteristics of the foothills and coastal plains, such as the northern part of Phuket Island, Mai Khao Beach area. In the central part of Phuket Island, which is a plain between the valley and the foothills, such as Thep Krasattri, Choeng Thale, and Si Sunthon Sub-districts. And, the topography along the eastern coast of Phuket Island, Ko Kaew, Ratsada, Talat Yai, Talat Nuea, Wichit, Chalong, and Rawai Sub-districts.

As for the narrow plains on the western coast of the island, there are high flash flood susceptibility level areas in important tourist areas, such as Kamala, Patong, Karon, and Kata. The Medium flash flood susceptibility level area covers an area of 121.27 km^2 (22.47% of the total area). It has appeared along the coastlines of both the western and eastern parts of the island and the piedmont. Low and very low flash flood susceptibility levels mostly cover the mountain ranges of Phuket, which cover more than 50 percent of the island.

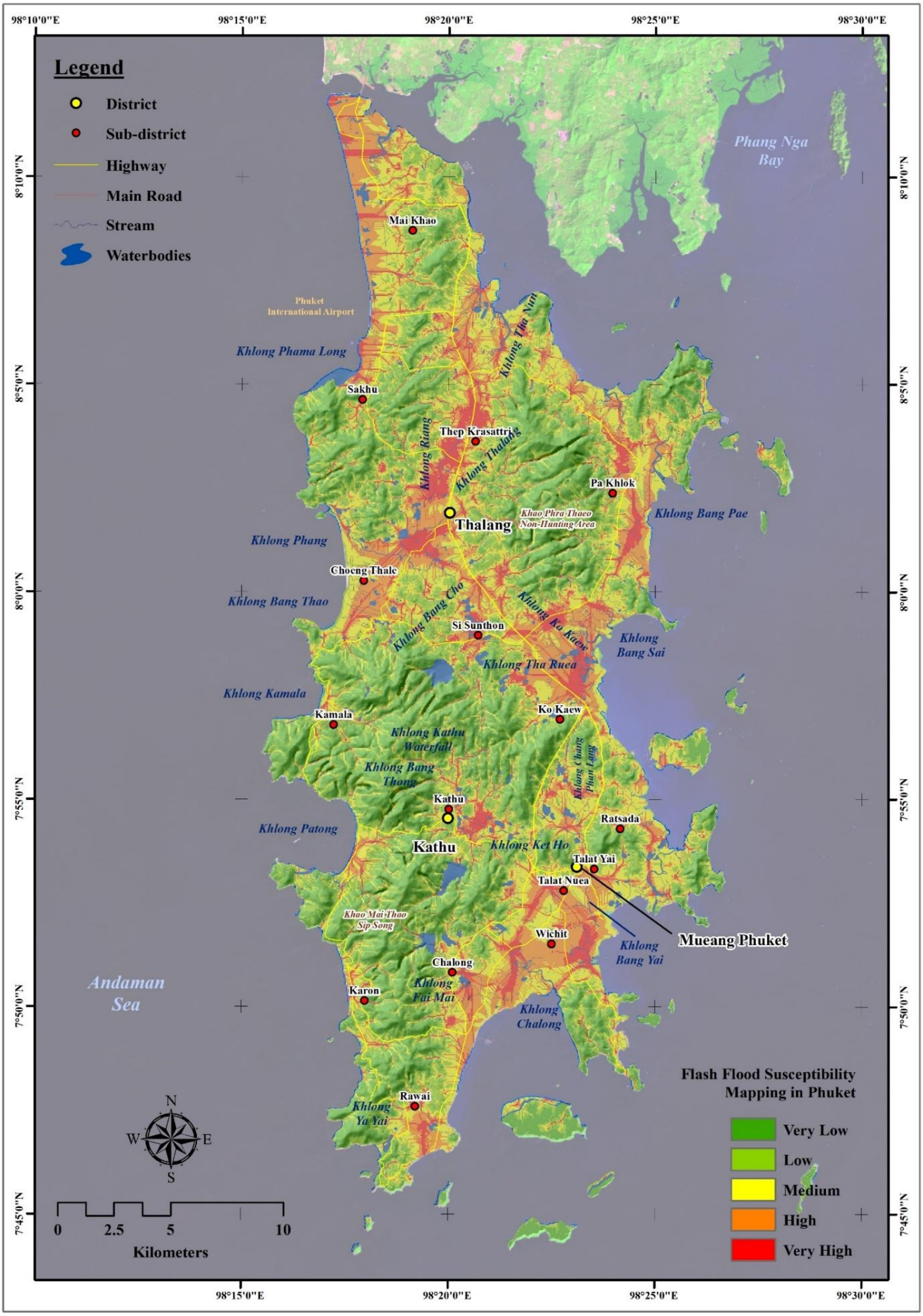

Figure 7. Flash Flood Susceptibility Map in Phuket Province.

3.4. Discussion

Urbanization in coastal tourist city areas without concrete planning has resulted in the city being at risk of flash floods and landslides. The expansion of the city in any direction has caused the infrastructure system to be disorderly, especially the sewage system built after the expansion of the city. If thunderstorms last for a long time, flash floods are inevitable. Moreover, the current climate change has resulted in the rain patterns in Phuket in 2024-2025 that are more frequent and longer lasting.

This is similar to major cities around the world that are experiencing frequent flash flood disasters along coastal areas, such as Madhya Pradesh (Nandam & Patel, 2025), Surat, Mumbai, Chennai, and Kolkata in India (Dhiman *et al.,* 2019), Haikou (Luo *et al.,* 2024), Zhuhai (Zhong *et al.,* 2024) and Xiamen City in China (Xu *et al.,* 2024), Cap-Haïtien City in Haiti (Jean Louis *et al.,* 2024), and North-West Galala City in Egypt. Therefore, researchers need to find tools and methods to study and assess flash flood susceptibility in the most accurate spatial data.

Phuket is a coastal tourist city without systematic urban planning. Urban and built-up land has expanded rapidly and directionless. Buildings such as houses and resorts have encroached on natural waterways. Moreover, some areas have been built over natural streams, causing natural waterways to change their course. In addition, buildings in Phuket often have small and narrow drainage pipes, which often cause flooding in Phuket during thunderstorms. This is different from large cities that have built drainage systems with networks of water drainage to the sea quickly, such as Guangdong in China (Chen & Huang, 2024), Chennai (Andimuth *et al.,* 2019), and Norfolk in the USA (Barbosa *et al.,* 2025).

From the statistical analysis of logistic regression, which is a popular statistical method used in studying flood disasters in Phuket, it shows the factors that affect the occurrence of flash floods effectively (Allegri *et al.,* 2024). The results of this research show the values of the fac-tors that influence the occurrence of flash floods with β value. This research show that the factors that affect the occurrence of flash floods in Phuket from most to least are as follows: TWI, SF, DD, IN, Slope,

Distance to road, Mean annual precipitation, Elevation, Land use, STI, SPI, Distance to stream, and Geology, respectively. It is consistent with the Rheraya watershed in Morocco, stating TWI and DD factors have the most influence on flooding, but the difference is the Distance to stream factor that the research has a low influence on flooding (Elghouat *et al.,* 2024). However, in Tetouan, it was found that the rainfall factor had the most influence, even though it is also in Morocco (Sellami & Rhinane, 2024). In terms of flash flood susceptibility assessment in northeastern Bangladesh and Tafresh Watershed in Iran, it was found that rainfall and slope factors have the greatest impact on flash flood occurrence in these areas (Islam & Chowdhury, 2024; Janizadeh *et al.,* 2019), which is different from this research.

Between 2022 and 2024, Phuket experienced major flash flood disasters. The majority of the affected areas were lowlying urban regions, specifically Thalang, Phuket Old Town, Ko Kaew, and Choeng Thale (Figure 8). Consequently, this research collected the locations of flash flood occurrences during that period to validate the results obtained from the logistic regression model. The sampling of flash flood location data utilized 183 realworld, ground truth flood locations (97 flood samples and 86 non flood samples).

The validation was performed using the Accuracy Assessment method (Chen *et al.,* 2024). This methodology involved the use of the 'tabulate area' command within the Geographic Information System (GIS). The results from the model validation demonstrated an overall accuracy of 86.89% and a Kappa coefficient of 0.74, indicating that the model's performance is highly satisfactory (Table 4).

Table 4. Accuracy Assessment for Logistic Regression Model Validation.

	Class	Ground Truth		
		Flooding area	**Non-flooding area**	**Total**
Model results	Flooding area	86	11	97
	Non-flooding area	11	73	84
	Total	97	84	183
	Overall accuracy (%)			86.89
	Kappa coefficient			0.74

Figure 8. Images Illustrating the Major Flash Flood Events in Phuket Province During 2022 and 2024 (Matichon, 2022; Thaipost, 2022; MGR, 2022; Bangkokbiznews, 2024; Hydro Informatics Institute, 2024).

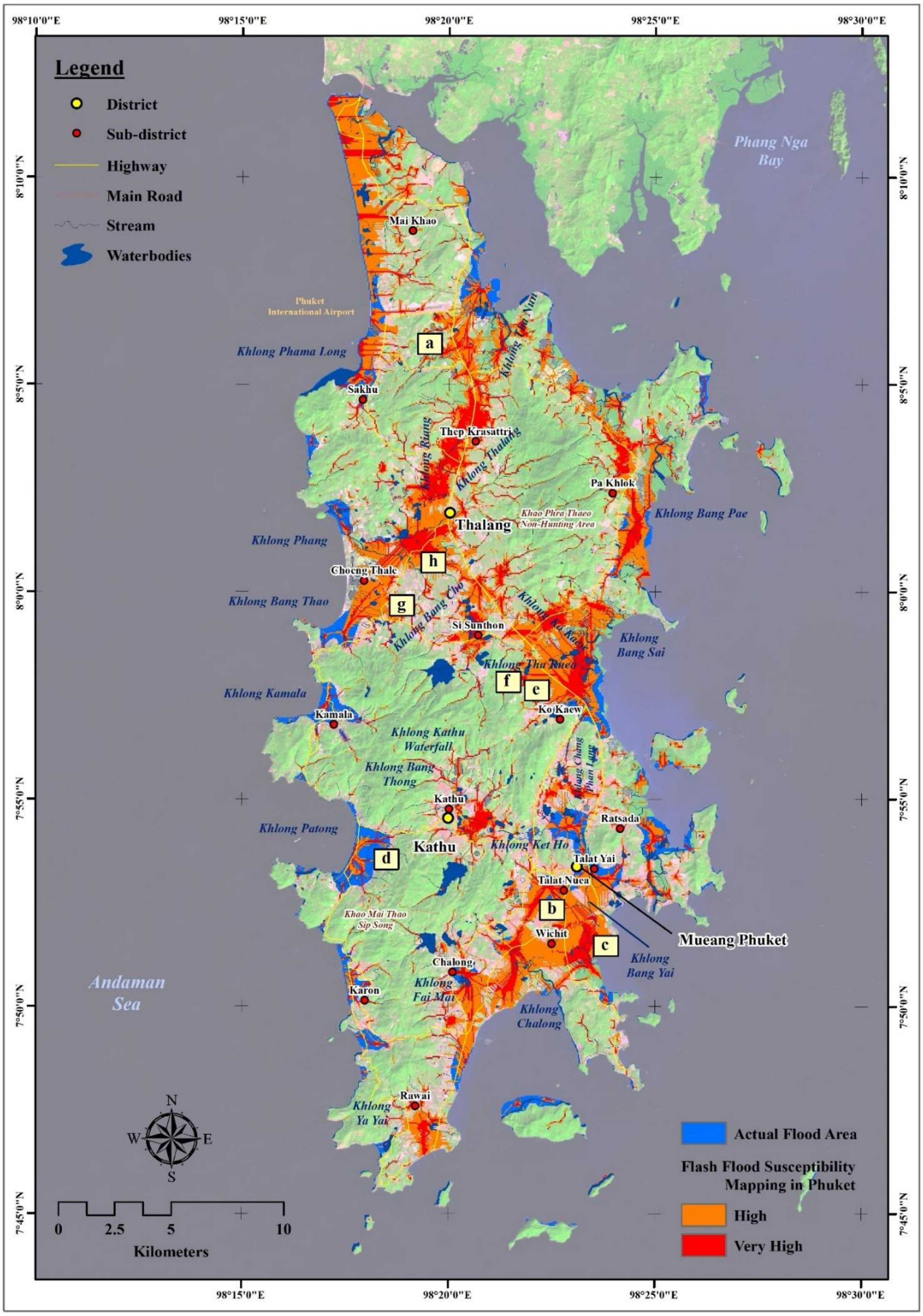

Figure 9. Flash Flood Susceptibility Map Shows Areas With Very High and High Susceptibility in Urban Areas and Important Economic Districts in Phuket Province for Preparing for Flash Flood Disasters.

During the monsoon season, flash floods in Phuket often occur during June-September of each year. However, such disasters are only reported in news reports about flood affected areas and specifying the areas in writing. The relevant government or private agencies have no proactive disaster prevention and mitigation policies. There is only a defensive response to disasters, that is, when a disaster occurs, they go to help the victims, alleviate suffering by providing relief supplies to the victims, and repair the infrastructure damaged by the disaster, etc., which is done every year. However, the spatial data showing the risk areas showing each level of flash flood susceptibility at the provincial or local level that should be displayed in the form of a map, was never found in this research area. If searching for information online about the flood disaster in Phuket, it was found that there was no map showing the susceptibility of flash floods in Phuket to warn villagers to be careful during the period of prolonged thunderstorms. This research gathered and analyzed flash flood related factors to produce a map illustrating Phuket's flash flood susceptibility levels. The results of this study will be useful for government agencies and private sectors, as well as local communities in sensitive areas. Figure 9 shows the areas with the high and highest flash flood susceptibility in urban areas and important economic districts. This is a preparation for dealing with climate change events that cause flood disasters to occur more frequently, so that Phuket can become a coastal tourist city that is ready to deal with flash flood disasters sustainably.

This research has certain limitations and presents avenues for future improvement. Firstly, a key challenge was the difficulty in acquiring data on actual flood events in Phuket using re-mote sensing techniques. This study did not incorporate such data because flash floods typically occur during the monsoon season, which hinders passive remote sensing satellites from ac curately recording the real-time flood extent. Consequently, future work may need to integrate active remote sensing satellite techniques for research applications in Phuket or other study areas situated within monsoon affected regions. Secondly, the research findings identified a total of 13 variables influencing flash flood susceptibility. It was found that the top three vari-ables (Topographic Wetness Index, Stream Frequency, and Drainage Density) exhibited the highest susceptibility in areas characterized by foothills extending into coastal plains, particularly on islands featuring a high mountain range in the center. However, future research or applications leveraging this methodology should adjust certain variables to align with the specific geographical conditions of each locality. Finally, given that flash flood hazards are increasing in frequency due to current climate change, responsible governmental and private sector agencies should prioritize research and the development of comprehensive flash flood hazard maps for each sub-watershed. This should be coupled with the establishment of realtime water level monitoring stations. These measures are crucial for preparedness and for ensuring a timely response to potential flood events, thereby safeguarding the lives and property of local populations.

4. Conclusion

The current climate change phenomenon has resulted in more severe flash flood disasters, such as the incident in Phuket in the past two years. This research attempts to solve the problem and alleviate the impact of such disasters by analyzing individual factors to find the answer to the cause of flash floods in the study area. The statistical principle used in this research is logistic regression combined with Geo-information technology, to create a flash flood susceptibility map in Phuket Province. The results of the study reveal the factors that influence the occurrence of flash floods, which are TWI, SF, DD, IN, Slope, Distance to road, Mean annual precipitation, Elevation, Land use, STI, SPI, Distance to stream, and Geology, respectively. All of these variables are shown by the exp β value coefficient, which will be analyzed and created as a flash flood susceptibility map. It can be seen that in the disaster, more than 1/4 of the study area is covered by very high and high flash flood susceptibility level. The results of this research empirically show that the flash flood disaster data has been compiled into a spatial database, to show the areas susceptible to flash floods at each level. The recommendation for future research is to accelerate the research guidelines on flash flood susceptibility. to cover coastal areas in Thailand, as there is little research in this area. In this regard, agencies related to disaster work should urgently study and research disasters to cover the entire country, in order to be prepared and able to deal with flash flood disasters promptly, and create safety for life and property of local communities sustainably in the future.

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Author Contributions

Conceptualization: Waiyasusri, K., Wetchayont, P.; **methodology**: Waiyasusri, K., Wetchayont, P.; **investigation**: Waiyasusri, K.; **writing—original draft preparation**: Waiyasusri, K., Wetchayont, P.; **writing—review and editing**: Waiyasusri, K.; **visualization**: Waiyasusri, K. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

All authors declare that they have no conflicts of interest.

Data availability

Data is available upon Request.

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