Application of Geographic Information System for Mapping Population Exposure to Flood Hazards in Thailand

Puvadol Doydee

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* Corresponding Author: Puvadol Doydee, E-mail: puvadol.d@ku.th

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Abstract

The assessment of population exposure to flood hazards in urban riverine areas is crucial to flood risk response and mitigation in Thailand. This study employed a free, open-source QGIS associated with various spatial datasets e.g. administrative boundaries, census data, built-up areas, and flood hazard. The objective was to estimate the population's exposure to flood hazards in Thailand. The analysis focused at the provincial level and estimated the population's exposure to a 25-year flood event. The findings revealed that the percentage of the Thai population exposed to riverine flood hazards ranged from zero to 99.86% and was categorized into five severity levels. Approximately 18.10 million Thai people (25.83%) dwell along rivers that are highly vulnerable to riverine floods. Nakhon Pathom province was the first highest risk of its population being exposed to riverine floods specifically nearby the Tha Cheen River. Concurrently, there were 8 provinces namely; 1) Nonthaburi, 2) Sing Buri, 3) Phra Nakhon Si Ayutthaya, 4) Samut Songkhram, 5) Ang Thong, 6) Pathum Thani, 7) Bangkok and 8) Samut Sakhon were determined as having the highest vulnerabilities to riverine floods, while Phangnga, Krabi and Phuket showed the lowest vulnerabilities. The findings of this study provide valuable insights for policymakers to facilitate preparedness and improve effective strategies to mitigate the flood hazards.

Keywords: Spatial Data Analysis, Open-Source QGIS, Flood Hazards, Population Exposure, Thailand.

1. Introduction

Floods are a natural phenomenon with the potential for devastating loss of life, social and economic disruption, outbreaks of infectious diseases, water and food insecurity, and adverse effects on mental health [1], [2]. Floods and hydrometeorological hazards are the most frequent causes of devastation globally [2], [3], [4]. Floods are among the most catastrophic natural disasters [1], [3], [5]. The rapidity of the havoc floods can cause underscores the serious threat that floods pose to infrastructure, communication systems, crops, livestock, and natural ecosystems [6], [7]. For example, Thailand's devastating 2011 flood shown resulted in numerous casualties which affected millions of people, caused extensive economic loss [8], [9].

Thailand has been highly exposed to and vulnerable to flood risks due to its riverine geography. These phenomena are occurring more frequently due to climate change and the increase in impervious surface area. Thailand is in a region prone to an annual monsoon season. During its rainy season from May to October, the country experiences upwards of 88% of its yearly rainfall [10], [11]. Particularly, riverine floods pose a major threat to agricultural production and urban areas located near principal rivers. However, various climatic and non-climatic dynamics give rise to different types of floods such as riverine, flash, urban, glacial-lake outburst, and coastal floods. This study focuses on riverine floods, as the latest spatial dataset of excessive rainfall, which caused main rivers to exceed their capacity.

* Department of Agriculture and Resources, Faculty of Natural Resources and Agro-Industry, Kasetsart University Chalermphrakiat Sakon Nakhon Province Campus.

Mapping population exposure flood hazards is an essential tool for disaster risk management, especially in the issue of climate change [12], [13]. It helps identify location and situation of population exposure and provides a better understanding of spatial characteristics, which have not yet been studied before. In This study, Geographical Information Systems (GIS) have been applied to map population exposure to flood phenomena with the use of a free, open-source QGIS toolkit. Again, population exposure for this paper refers to the elements of a community affected by a flood such as, population, shelter, amenability and support services [14], [15]. The extent of flood hazards, population and their built environment were chosen to characterize population exposure [16].

2. Theoretical background and related researches

2.1 GIS data models

Data model define how real-world of land use and land cover features are represented in a GIS [17], [18]. Geospatial data are basically represented by two main structures; vector and raster datasets. The representation of real-world spatial information in vector and raster format is shown in Figure 1. The vector data model consists of points, lines, and polygons created using beginning and ending nodes and intervention vertices, each with detailed x,y coordinate information. The raster data model stores the spatial information in a user-defined grid where every pixel has a unique geographic location and attribute value.

2.1.1 Vector Data

Vector maps represent the most common form of thematic maps e.g. road atlases, GPS navigation devices, and Internet mapping engines display vector maps. The vector data structure uses points, lines, and polygons to represent spatial features. Points object are assigned using simple x, y coordinates; lines consist of connected x,y coordinates called nodes or vertices,; and polygons (areas) are simply enclosed lines where the beginning and ending nodes have the same coordinate value (Figure 1b)

2.1.2 Raster Data

Raster data have a more simple data structure than vector data due to raster data are represented in space by an array or grid of cell (Figure 1c). A raster layer contains cells arranged in rows and columns. Each cell contains a value or digital number that describes the phenomena being examined. The cell in the array are commonly called pixel, and they are usually square (i.e. the sides of a pixel have the same dimension) and in remote sensed raster data called spatial resolution. Unlike the vector data model, the raster data model has remained relatively unchanged since its inception.

Raster data area especially useful to describe spatial phenomena that vary continuously across the landscape. Such phenomena include elevation above sea level, precipitation [10], [11], temperature, etc. [12], [13].

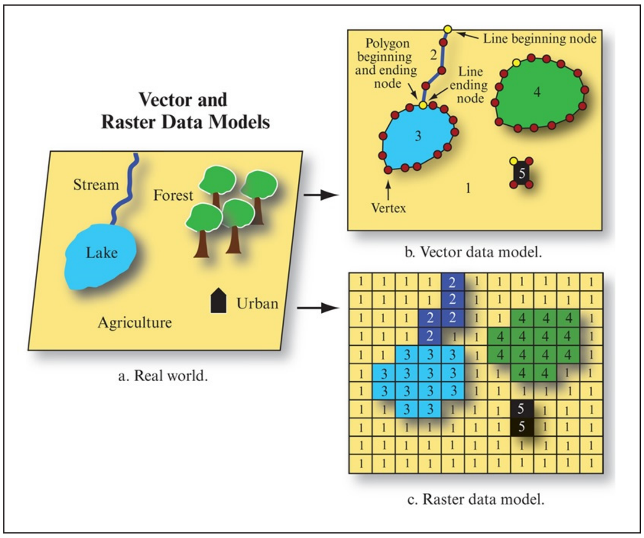


Figure 1. Features in the real world can be represented using vector and raster data model. a) The real world. b) The real world portrayed in vector format. c) The real world portrayed in raster format [18].

2.2 QGIS for mapping population exposure to flood hazards

This study used QGIS, a freely, open-source geographic information system software, to map population exposure to flood hazards in Thailand. QGIS facilitated the creation of flood exposure maps by identifying areas susceptible to flooding and the population residing in those areas.

The percentage of the population exposed to flood hazards for each province was calculated using the total population of the assessed area. The spatial data flow and the geospatial analysis conducted using the QGIS was illustrated (Figure 2). The flowchart showed the sequential steps involved in the processing and analysis of spatial data, highlighting the key stages and relationships within GIS framework.

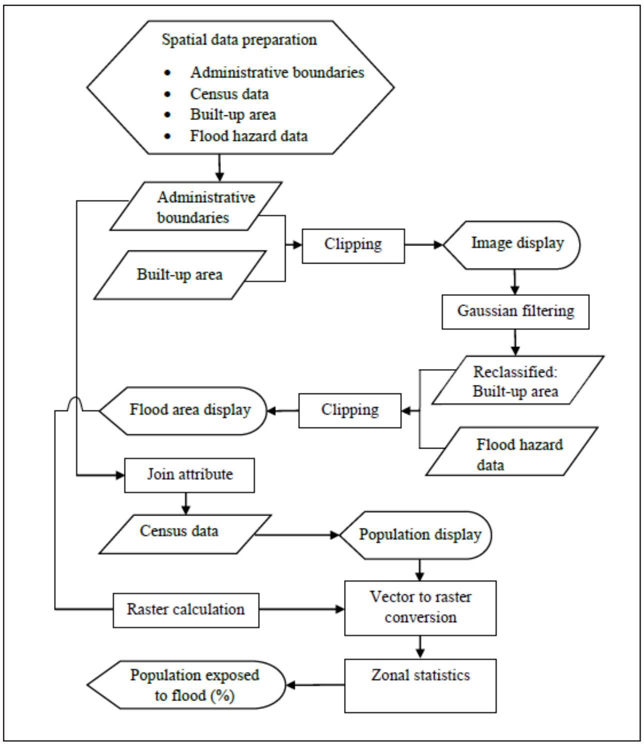


Figure 2. *Flowchart of spatial data preparation and geospatial techniques and analysis using QGIS.*

A Gaussian filter, which assigned weight to the pixel based on their spatial distribution, was utilized to estimate population density [19]. The population density map depicted higher density in central pixels compared to those in the corners of the grid. The population within each administrative boundary was calculated by multiplying the estimated population density with the census data. Riverine flood analysis within each administrative boundary was performed using raster data model of flood hazard.

The percentage of population that was exposed to flood hazards was determined through a comprehensive analysis applying open-sources datasets such as the Humanitarian Data Exchange, Copernicus Global Land Cover, the United Nations Environment Programme Global Resource Information Database (UNEP-GRID) associated with various geospatial techniques. The land cover data with spatial resolution of 100 m x 100 m was classified into two categories namely, built-up areas and non-built-up areas. Population density pixels were derived from administrative boundaries and census data, while considering their proximity to accumulated built-up areas. Pixels with higher population density were assigned greater weight in the population density calculations compared to those with lower population densities.

In addition, there are various papers that using QGIS techniques for monitoring and mapping flood disaster and related researches as follows:

Ariyani et al. [20] to assess flood risk in the Bangkok and Masjid watersheds at Riau, Indonesia. Flood hazard map was arranged by slope, land cover, elevation, rainfall, buffer zone, and soil type, which is done with the help of QGIS. The tool integrated with satellite spatial data and classified the vulnerability level being very high, high, medium, low, and very low.

Musunura and Marshall [21] calculated percentage of the population exposed to flood hazard using QGIS case study in Lao People's Democratic Republic. Various open source dataset such as Copernicus Global Land Cover data, Census data and Administrative Boundaries data and Flood Hazard data were imported to QGIS to construct the flood disaster thematic maps.

Samsudin et al. [22] evaluated the impact of dam break scenario under probable maximum precipitation (PMF) condition at Puah hydropower dam using QGIS and open source data for emergency preparedness and early warning systems focusing on rescue work if disaster occurs.

Renjith et al. [23] applied QGIS for delineating the flood prone areas and to create a flood risk map for the Pathanamthitta District of Kerala.

3. Research Methodology

3.1 Spatial data preparation

This study conducted a provincial based mapping of population exposure to flood disasters in Thailand utilizing publicly available datasets. The GIS datasets were obtained from global spatial datasets such as the Humanitarian data exchange and Copernicus global land service [24]. The land cover data provided pixel-level information with a spatial resolution of 100 m x 100 m, representing land areas of 10,000 square meters of each pixel. A global risk data platform was used in conjunction with various geospatial techniques [25].

The administrative boundary with population attribute dataset of Thailand, latest version on January 27, 2022, was incorporated to obtain spatial and geodatabase. Census data in the form of a *.CSV file (Excel) was utilized with the attribute data most updated on April 20, 2021. This information was derived from the sources as indicated in Table 1. It enabled the calculation of the total population within administrative boundaries and facilitated an assessment of population exposure to flood hazards associated with the latest built-up area data in year of 2019.

The percentage of the population exposed to flood hazards was estimated using flood hazard data from UNEP GRID. The flood hazard assessment employed a probabilistic approach, modeling riverine floods from major river basins in Thailand.

This study adopted a 25-year return period for flood hazards [26], [27] due to in community and urban planning, a 25-year return period is often used as a standard for designing flood protection measures. It represents a compromise between frequent smaller floods and very rare, extreme events. This approach helps in creating flood resilience systems that can handle reasonably expected flooding without being excessively conservative or costly.

Hazard maps were developed at a spatial resolution of 1 km x 1 km and were validated against satellite flood footprints from various sources, including the Dartmouth Flood Observatory (DFO) and The United Nations Satellite Centre (UNOSAT) flood portal. These maps coincided with significant events of the 2011 Thailand flood.

3.2 GIS data processing

QGIS was employed for viewing, editing, and analysis of geospatial data [28]. The administrative boundary data were imported into QGIS and analyzed at the provincial level.

Table 1. *Selected GIS spatial open source dataset and related hyperlinks.*

Spatial data	Name	Open Source Dataset
Administrative boundaries	Humanitarian Data Exchange	https://data.humdata.org/dataset/cod-ab-tha
Census data	Humanitarian Data Exchange	https://data.humdata.org/dataset/cod-ps-tha
Built-up area	Copernicus Global Land Service	https://lcviewer.vito.be/download
Flood hazard	Global Risk Data Platform	https://preview.grid.unep.ch/

This spatial data was represented as vector data model consisting of polygons representing GIS features with the WGS84 map projection that encompassed the entire terrestrial area of Thailand.

The built-up area data was shown as a raster data model, comprised a grid of cells or pixels with assigned values representing information. Built-up areas were assigned a digital number (DN) value of 100 (bright color), while non-built-up areas were assigned a DN value of 0 (dark color). These datasets were overlaid with the Thailand administrative boundaries. Geoprocessing techniques such as merge and clip operations were used to combine four raster files into a single built-up area file, then clipped to fit within the boundaries of Thailand. To estimate the population density for each provincial area, a Gaussian filter was applied to the built-up area layer. This filter facilitated the transformation of pixel population density, taking into consideration the characteristics of each area. Population density tends to be higher in built-up areas, such as cities or urban areas with limited land availability, compared to non-built-up areas or rural zones with more abundant land.

The accumulated built-up areas with the highest population density were situated at the center of the grid, while areas farther away from the administrative boundaries were assigned lower values. The built-up layer was reclassified into two categories namely, 1) built-up areas with a DN value of 1 and 2) non-built-up areas with a DN value of 0.

3.3 Flood hazard mapping

The flood inundation layer was imported into GIS and clipped with the boundary of the built-up area using geo-processing techniques. The census dataset was layered and integrated into the Thailand administrative boundaries. An attribute join was performed using a primary key to integrate the population data from the census spatial database into the attribute of the administrative boundaries.

To distribute the census data within the estimated pixels, either rasterization or vector to raster conversion techniques were employed, resulting in the generation of a population raster. The raster calculator function was utilized to generate the flood hazard calculation layer.

Zonal statistics analysis was conducted to generate the population exposed to the flood hazard map. This analysis determined the percentage of the population exposed to flood hazards for each administrative boundary, utilizing the total population of the assessed area.

4. Results and Discussions

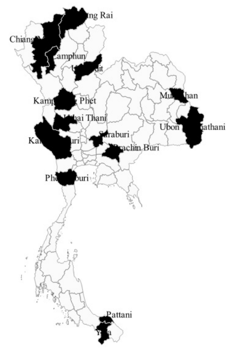
4.1 Population exposed to flood hazards

In 2022, Thailand's population was estimated to be 70.08 million people [29]. In this study, as latest (2022) flood open source dataset available, it was found that in Thailand around 19 million people (27.74% of the population) located in nine of the seventy seven provinces were exposed to a 25-year flood event. This exposure level was classified as extremely high in severity level (SL), ranging from 79.17% to 99.86%. Among these provinces, Nakhon Pathom had the highest risk with 99.86% (Figure 3a) of its population being exposed to river floods specifically, the Tha Cheen River [30]. Though this seems to align with the newspaper and television accounts of the 2022 Nakhon Pathom river flood, no academic studies, in either Thai or English, have been published which analyzed the impacts of the flood that would either confirm or refute this.

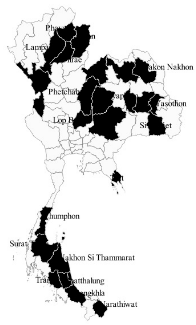
Rivers, streams and riverine communities in Thailand, as they are worldwide, are prone to flooding and adversely impacted due to heavy precipitation or tropical storms [31], [32], [13]. These areas are more susceptible to flood hazards, and it is observed that the exposed population tends to reside in flood-prone zones [6], [7], [21].

a. SL 5: Extremely high (79.17-99.86 %).

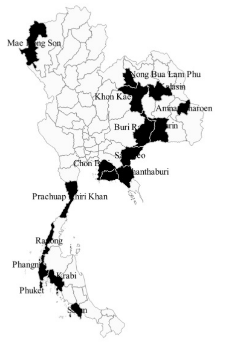
b. SL 4: Very high (50.99-79.17 %).



c. SL-3 High (32.69-50.99 %).



d. SL-2 Moderate (19.30-32.69 %).



e. SL-1: Low (0-19.30 %).

Figure 3. *Maps display flood severity level (SL) in Thailand at the provincial level. a. SL-5: Extremely high (79.17-99.86%). b. SL-4: Very high (50.99-79.17%). c. SL-3: High (32.69-50.99%). d. SL-2: Moderate (19.30-32.69%). e. SL-1: Low (0-19.30%).*

In Thailand, these nine provinces, Nakhon Pathom, Nonthaburi, Sing Buri, Phra Nakhon Si Ayutthaya, Samut Songkhram, Ang Thong, Pathum Thani, Bangkok and Samut Sakhon exhibited an SL-5 flood hazard exposure level classified as "Extremely high," ranging from 79.17% to 99.86% (Figure 3a,

Figure 4). Additionally, these thirteen provinces, Nong Khai, Chai Nat, Phichit, Nakhon Phanom, Sukhothai, Chachoengsao, Bueng Kan, Phitsanulok, Suphan Buri, Ratchaburi, Nakhon Sawan, Samut Prakan and Nakhon Nayok were classified as SL-4 (Very high) with exposure ranging from 50.99% to 79.17% (Figure 3b, Figure 4).

Fourteen provinces, Uttaradit, Kanchanaburi, Kamphaeng Phet, Mukdahan, Prachin Buri, Pattani, Phetchaburi, Lamphun, Chiang Mai, Chiang Rai, Ubon Ratchathani, Yala, Saraburi and Uthai Thani were designated as SL-3 (High) with exposure levels ranging from 32.69% to 50.99% (Figure 3c, Figure 4).

Twenty-four provinces, Surat Thani, Lampang, Narathiwat, Trang, Yasothon, Phayao, Roi Et, Phrae, Tak, Songkhla, Chumphon, Chaiyaphum, Lop Buri, Udon Thani, Trat, Nakhon Si Thammarat, Maha Sarakham, Loei, Nakhon Ratchasima, Nan, Phatthalung, Sakon Nakhon, Si Sa Ket and Phetchabun were categorized as SL-2 (Moderate) with exposure levels ranging from 19.30% to 32.69% (Figure 3d, Figure 4).

Finally, seventeen of Thailand's provinces exhibited an SL-1 (Low) flood hazard exposure, ranging from 0% to 19.30%. These were Nong Bua Lam Phu, Chanthaburi, Khon Kaen, Mae Hong Son, Kalasin, Surin, Rayong, Satun, Sa Kaeo, Prachuap Khiri Khan, Buri Ram, Ranong, Chon Buri, Amnat Charoen, Phangnga, Krabi and Phuket (Figure 3e, Figure 4). In addition, Phuket is not significantly affected by riverine floods, but still be susceptible to coastal floods or tsunamis [33], [34].

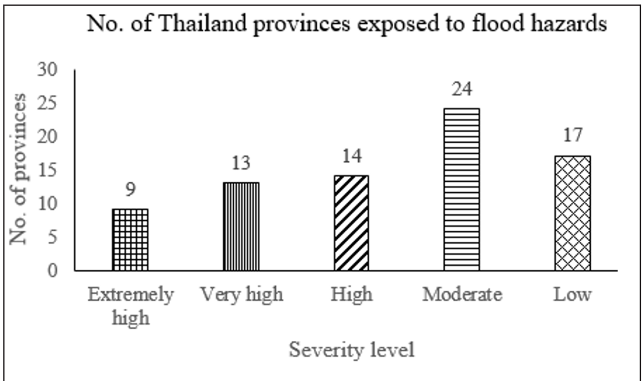


***Figure 4.** Number of provinces exposed to flood hazards.*

Population exposure was categorized into five distinct severity level, ranging from low to extremely high [35]. These levels of exposure are visually represented through a color scheme, wherein variations in color intensity signify varying degrees of vulnerability. Specifically, darker shades correspond to higher levels of exposure to riverine flood hazards and shown in Figure 5.

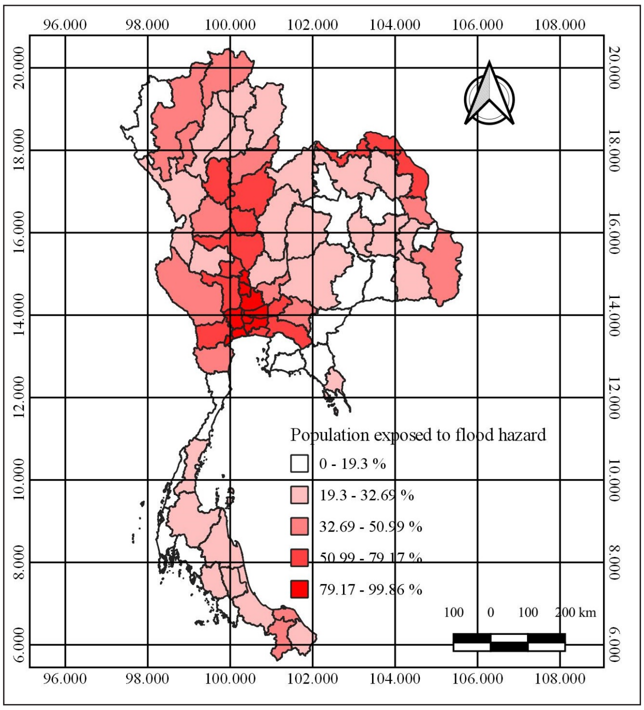


***Figure 5.** Map showing the percentage of population exposure to flood hazards in Thailand.*

4.2 Flood risks and impacts

Annually, global flooding affects approximately 350 million people [36]. Extreme flood events, such as the 2011 floods, have impacted over 13 million people in Thailand [37]. Urbanization and the expansion of impervious infrastructure contribute to increased flood severity level. In Thailand, agricultural lands with high chemical fertilizer usage can contaminate nearby water bodies during floods. Wu et al. [38] reported the role of precipitation and flood events in transporting microplastics, which pose risks to freshwater ecosystems and the food chain.

Thus, there is a need for a holistic approach to river management by considering both flood prevention and the preservation of river habitats [39]. Floods have both positive and negative impacts, such as creating fish habitats and increasing groundwater depth [40], but also causing landslides, crop and livestock losses, and waterway pollution [41] - [44].

Floods not only cause physical damage but also have mental and social implications, particularly in challenging circumstances like the COVID-19 pandemic [45]. In the recovery stage, it is essential for local governments to consider flood insurance payouts to support affected farmers [46]. Flood hazard maps can aid local governments, national and international organizations in reducing flood risk, obtaining financial support and the planning of flood shelters [47].

Recent research suggests that global extreme precipitation and changes in land use contribute significantly to flood damage. Despite data challenges, global datasets have proven valuable in hydrological and climate impact studies [31]. Remote sensing technique was importance of measuring and assessing flood impacts for mitigation practices [48]. Given the significance of flooding in Thailand, a community-based approach is crucial for effective flood management and preparedness, involving all stakeholders in the planning and implementation of flood mitigation strategies to secure national infrastructure in the future [7].

The limitation of the study is the reliance on spatial datasets and free, open-source software, which may not always provide the most up-to-date or comprehensive data. Therefore, it is important to consider commercial spatial datasets and ArcGIS software. This could affect the accuracy of exposure estimates and flood risk categorization. Furthermore, the study's focus on a specific flood return period (25 years) might not account for more extreme or less frequent events, potentially underestimating risk in some areas. The variation in flood exposure across provinces highlights the need for more granular data and localized analysis to enhance the precision of risk assessments. Despite these limitations, the findings offer valuable insights for policymakers, emphasizing the need for targeted flood preparedness and mitigation strategies tailored to the specific vulnerabilities of different provinces. This study provides a foundation for improving flood risk management by identifying high-risk areas and informing more effective flood response strategies.

5. Conclusions

The findings of this study offer a benefit of information technology (IT) such GIS approach to map population exposure to flood risk, serving as a valuable reference for national-level flood risk management, prevention and disaster reduction. Floods pose threats to food security, nutrition, and the livelihoods of vulnerable communities leading to reduced food production.

In conclusion, GIS proves to be a robust tool for mapping population exposure to flood hazards in Thailand. By overlaying flood hazard and population distribution data on a geographic base map. GIS enables the identification of high-risk flood areas and vulnerable populations. The resulting maps inform decision-makers and aid in the development of mitigation strategies to minimize flood impacts on the population. These study findings facilitate a comprehensive understanding of flood risks in Thailand and support the implementation of measures to mitigate its effects. The utilization of GIS for mapping population exposure to flood hazards represents a crucial advancement in ensuring the safety and well-being of Thailand's population.

Legislators and the officers in charge should conduct public awareness campaigns regarding community preparedness and education related to organized early warning systems, emergency response, and improving flood defenses. Nature-based solutions, such as wetland restoration, reforestation, and creating floodplains to absorb excess water, are recommended for incorporation in high-risk communities.

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