Evaluating Flood Susceptibility through integrated Geospatial Techniques in Thailand's Monsoon Regions

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ABSTRACT

This study integrated Geographic Information Systems (GIS) with the Potential Surface Analysis (PSA) method to assess and map flood hazards in the repeatedly flooded Khuan Khanun District of Phatthalung Province, Thailand. Amid the escalating global concerns about climate change impacts this research addressed critical gaps in local disaster preparation and resilience strategies demanded to face the increased precipitation and intensified flooding documented in recent IPCC reports. By synthesizing data considering multiple parameters such as slope, elevation, water and road density, land use, and soil drainage, this work delineated flood-prone areas, emphasizing their susceptibilities and the specific environmental dynamics that influence hydrological behavior. The findings revealed that over 66% of Khuan Khanun District fell within high to very high flood risk zones, accentuating the urgent need for enhanced flood mitigation measures. The significance of comprehensive flood risk management is hilighted, having incorporated advanced mapping techniques to inform effective policymaking and community-engaged planning, aiming to bolster regional resilience against recurrent threat of flooding.

Keywords-flood hazard assessment; GIS; potential surface analysis; Khuan Khanun

I. INTRODUCTION

Addressing Sustainable Development Goals (SDGs) poses a formidable challenge considering the significant adverse impacts of climate change-induced extreme events. These events not only inflict direct damage, but also erode the developmental achievements painstakingly accrued by prior generations [1]. Over the past half-century, the incidence of recorded disasters has escalated by five times, largely driven by anthropogenic climate change [2]. This change amplifies the risk of future disasters through its influence on meteorological conditions, such as temperature fluctuations, precipitation patterns, wind velocities, vegetation dynamics, and land surface alterations [3-5]. The changes to the land surface are of particular concern. Although the former are often the result of natural processes, their intensification through human activities presents a critical risk factor [6].

Floods represent the most common natural disaster type worldwide [7]. Over the last three decades, there has been a marked increase in flood incidents globally, with Asia having been particularly affected. This region accounts for over 90% of the flood-related fatalities and more than half of the economic losses due to floods [8, 9]. The socioeconomic and environmental devastation wrought by these floods is immense, highlighting the acute vulnerability of the affected communities [10]. This rising trend in flood frequency within the monsoon Asia region is strongly linked to climatic alterations. The Intergovernmental Panel on Climate Change (IPCC) projects a significant uptick in intense rainfall events over the coming years, which is expected to exacerbate the already perilous flooding scenarios across Asian landscapes [11]. Defining flood hazards and their temporal and spatial exposure is a fundamental aspect of risk analysis [12]. The risk concept is generally understood as a function of hazard, exposure, and susceptibility [13, 14]. In urban environments where flooding occurrence has markedly escalated in recent years, accurate flood risk assessment has become necessary for effective flood mitigation [15]. Such assessments form the bedrock of flood mitigation strategies, empowering urban planners and policymakers to devise and implement targeted flood prevention or mitigation measures, aimed at protecting vulnerable populations and critical infrastructure. Nonetheless, current practices in flood risk management often prioritize the evaluation of economic losses due to asset damage, sometimes at the expense of considering the broader social and environmental impacts [16]. GIS are instrumental in enhancing flood risk management by generating detailed risk and damage assessment maps. These systems analyze flood data and visualize the geographic extent of flooding, which is crucial for accurate hazard assessment [17-19]. Such mappings are essential in identifying areas at high risk of flooding, thereby facilitating more informed decision-making in disaster preparedness and risk management. The PSA method, often employed in these analyses, requires careful weight calibration according to the physical characteristics of the study area. The method ensures that the assessments are not only comprehensive, but also tailored to the specific vulnerabilities of the area under study, enhancing the precision and effectiveness of flood risk management strategies.

Numerous regions globally are witnessing increasingly unpredictable precipitation patterns, which contribute to the prevalence of urban flooding due to climate variability [20-22]. In Thailand, the interplay of climate variability and other geographical and infrastructural factors, such as terrain, geomorphology, drainage systems, and engineering structures, exacerbates the frequency and intensity of flooding [23-26]. The strategic mapping of flood-prone areas is substantial for assessing the severity and risk associated with these events and for enhancing disaster preparedness [27]. Effective mapping not only identifies areas susceptible to flooding, but also facilitates risk communication to communities and stakeholders, hence serving as an essential tool for the management, reduction, and mitigation of flood hazards [28, 29]. In regions experiencing rapid development, such as the Khuan khanun District in Phatthalung Province, the risk of flooding poses a substantial threat. The current research in Khuan Khanun District applied GIS and satellite imagery to evaluate flood risks, considering factors like river density, road density, slope, elevation, soil drainage, and land use. The study highlights the impact of land-use changes on flood vulnerability. Despite the frequent flooding events, the utilization of geospatial planning in disaster management remains significantly underexplored in this area. Central to the mitigation, prevention, and preparedness efforts are the local government leaders, whose role is pivotal in coordinating and implementing disaster management strategies and operations. This research underscores the necessity of integrating geospatial data into local governance frameworks to bolster community resilience against the recurrent threat of flooding.

II. MATERIAL AND METHODS

A. Study Area

The designated area for this research was Khuan Khanun, Phatthalung, Thailand. This region was selected due to its flooding events, making it a pertinent subject for investigating flood risk management strategies. Figure 1 defines the study area's boundaries and provides context by illustrating the former's relationship with the surrounding regions. The map serves as a critical tool for understanding the geographical scope and specific environmental characteristics that influence the hydrological dynamics in Khuan Khanun.

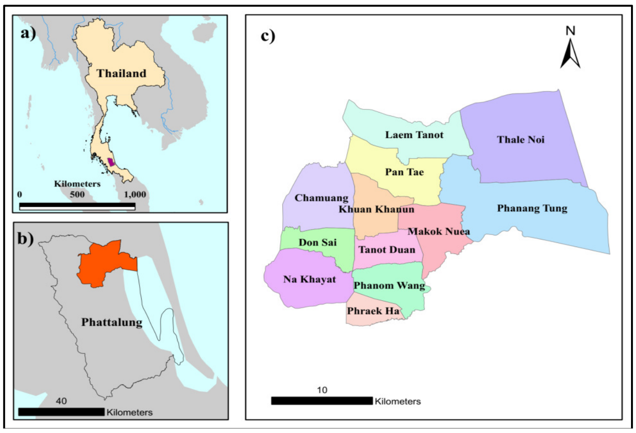

Fig. 1. a, b) Phatthalung Province locations, (c) Khuan Khanun District, and the boundaries of 12 sub-districts.

B. Data Collection and Preparation

Thorough data collection and preparation were conducted using GIS to support the PSA technique for flood risk assessment. As presented in Table I, the data acquisition and processing phase involved multiple datasets: the DEM offered essential topographical data in raster format, crucial for modeling the water flow and identifying flood-prone zones. Additional vector data, collected in 2016 from the Regional Irrigation Office 16 [31], included water density, which maps the distribution of water bodies crucial for predicting flood spread, and road density, which highlights how infrastructure can impact water flow during floods. Soil drainage data, also obtained from the Regional Irrigation Office 2016 [31], detailed the drainage capacities of different soil types, indicating areas prone to rapid saturation and potential flooding. Furthermore, land use data from the Southern Regional Geo-Informatics and Space Technology Center [32] showed how residential, commercial, and agricultural areas differently affect local hydrology and flooding susceptibility.

These datasets were methodically classified and assigned rating values based on their relevance to the flooding potential. Subsequently, weights were allocated to each factor to prioritize their impact on flood susceptibility, establishing a comprehensive, data-driven foundation for accurately mapping flood-prone areas. The importance criteria ranking factors were assigned to determine the rate score, ranging between 1 and 5. All factors were processed in GIS based on the PSA method, and are listed in Table II. Such a comprehensive preparation ensures that the analysis, as illustrated in the methodology diagram in Figure 2, is grounded in quantifiable metrics that reflect the complex interplay of environmental variables affecting flood risks.

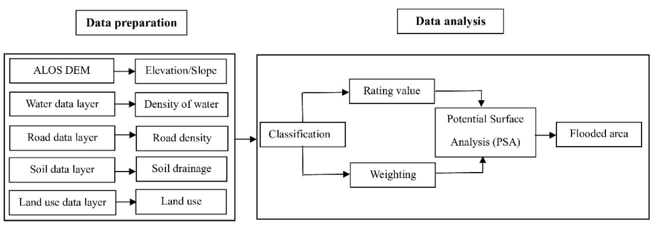

Fig. 2. Research methodology.

The PSA method was employed within GIS to analyze flood-prone areas using satellite imagery and vector data. PSA enabled a comprehensive analysis of six critical factors, namely slope, elevation, water density, road density, soil drainage, and land use, each being crucial for a detailed understanding of the flood dynamics and risk assessment. These factors' integration provides an accurate model of how natural terrains and human modifications contribute to flood risks in the region.

Each dataset was methodically classified and assigned a ranking of 1 to 6 and rating scores from 1 to 5 to quantify its influence on flood risk. This meticulous classification and integration process allowed for a multidimensional analysis of flood risks, providing a nuanced view of how various factors intersect to shape the flood dynamics. By synthesizing these diverse data sources, the current study presents well-informed and targeted flood management services, ensuring that disaster preparedness and mitigation planning are based on precise data, enhancing the effectiveness of interventions aimed at reducing the impact of floods in the region.

TABLE I. DATA SOURCES OF EACH FACTOR

Input Data	Source (year)	Factors	Original formats
ALOS DEM	[30] (2009)	Slope, elevation	Raster (.tif file, resolution 12.5 m.)
Data layer of water	[31] (2016)	Water density	Vector (Shapefiles)
Data layer of road	[31] (2016)	Road density	Vector (Shapefiles)
Data layer of soil	[31] (2016)	Soil drainage	Vector (Shapefiles)
Data layer of land use	[32] (2016)	Land use	Vector (Shapefiles)

C. Potential Surface Analysis

The PSA technique, a cornerstone of suitability analysis in GIS, leverages the overlay mapping method to integrate spatial and attribute data effectively [23]. It facilitates the comprehensive assessment of various environmental and man-made features that contribute to flood risk, such as elevation, slope, road, and water source density. Precise weighting of these factors, tailored to the physical characteristics of the study area, is essential. Each parameter's influence on flood potential is quantified through a robust ranking method that accurately prioritizes their relative impacts, thus enhancing the specificity and usefulness of the flood risk assessments. In the context of this study, a detailed physical database was constructed, encapsulating critical parameters, like water source density, road density, area slope, elevation, land use, and soil drainage capacity. This database supports the creation of a potential flood hazard map through a comprehensive overlay mapping process within GIS. Data manipulation is a calculated process by the potential equation:

$$S = R_1W_1 + R_2W_2 + R_3W_3 + R_4W_4 + R_5W_5 + R_6W_6 \quad (1)$$

where S is the total score of the flood factor, R_1 is the rating score of river density, W_1 is its weighting score, R_2 and W_2 are the rating and weighting scores of road density, R_3 and W_3 the respective scores of slope, R_4 and W_4 the scores of elevation, R_5 and W_5 the respective scores of soil drainage, and R_6 and W_6 the respective scores of land use.

Each term in (1) corresponds to a specific physical factor, processed and integrated to produce an elaborate map of the flood hazards, as illustrated in Figure 3. The total score was classified into five risk ranks: very low, low, moderate, high and very high.

III. RESULTS AND DISCUSSION

The application of PSA provided critical insights into the spatial distribution and relative importance of various factors influencing flood hazard potential, demonstrating the essential role of GIS in enhancing flood risk management [17-19]. Each critical factor was assigned specific rating and weighting scores, which are fundamental in mapping flood hazards, reflecting the multidimensional nature of flood risk assessment [13, 14]. Table II presents a detailed breakdown of the critical factors, each assigned specific rating and weighting scores essential for flood hazard mapping.

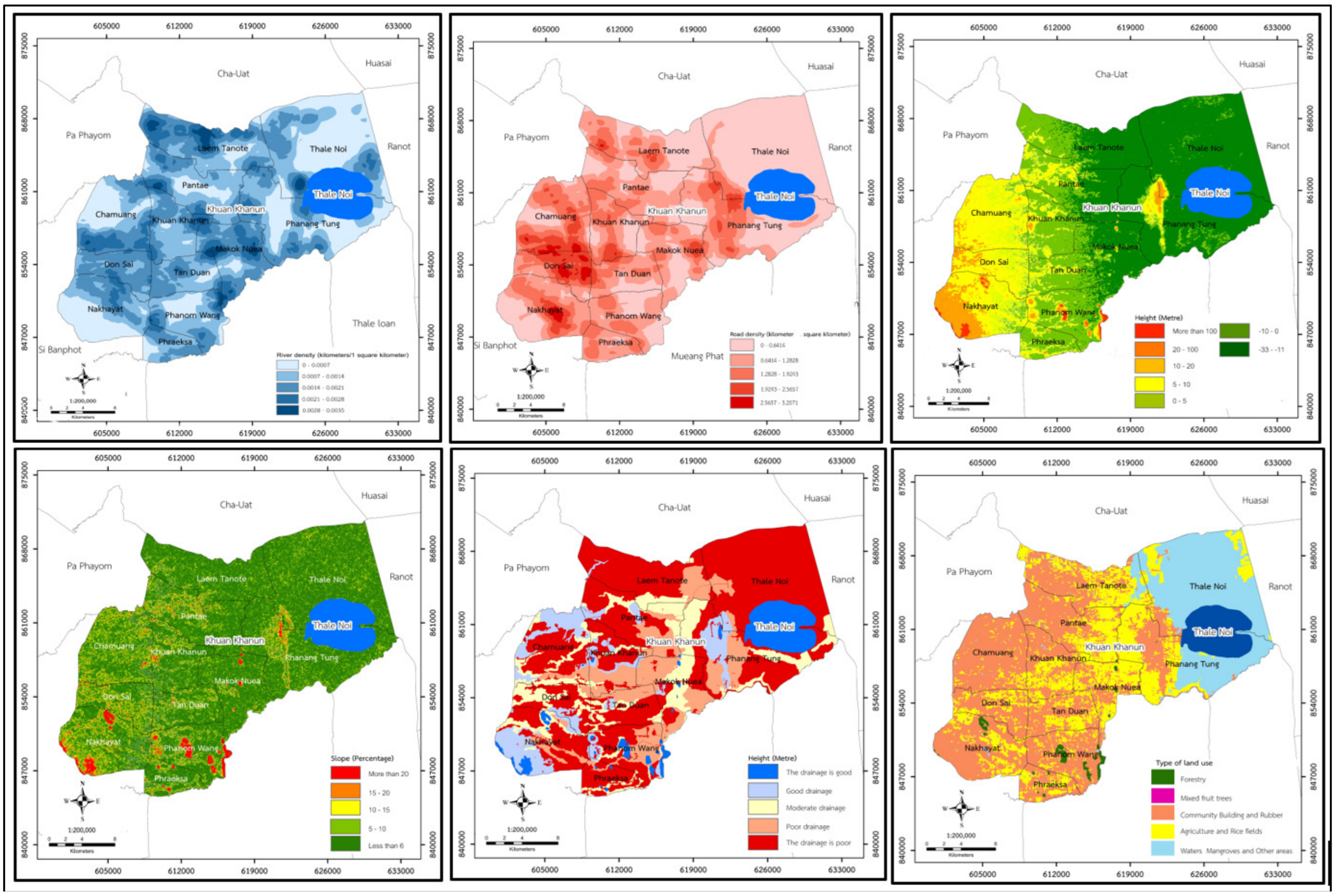

Fig. 3. Input maps for flood hazard assessment including (from left to right and from up to down): (a) river density, (b) road density, (c) slope, (d) elevation, (e) soil drainage, and (f) land use.

TABLE II. FACTORS WITH WEIGHTING SCORES AND RATING SCORES FOR FLOOD HAZARD MAPPING

Factors	Rating Score					Weighting Score
	5	4	3	2	1	
Density of water sources (km/km^2)	0.0028-0.0035	0.0021-0.0028	0.0014-0.0021	0.007-0.0014	0-0.007	6
Road density (km/km^2)	2.5657-3.2071	1.9243-2.5657	1.2828-1.9243	0.6414-1.2828	0-0.6414	5
Slope (%)	< 5	5-10	10-15	15-20	>20	4
Elevation (m)	0-5	5-10	10-20	20-100	>100	3
Land use	Water areas, mangrove forests and miscellaneous areas	Agriculture rice fields	Buildings	Mixed fruit trees	Forest	2
Soil drainage	Very bad	Bad	Moderate	Good	Very good	1

The use of rating and weighting scores in this analysis precisely quantified the impact of various factors on flood risk. Each factor was assigned a rating score that quantified its intensity within specific ranges, alongside a weighting score that reflected its relative importance. For instance, the density of water sources was rated from 0.0028 to 0.0035 km/km² in the highest impact category, emphasizing its significant influence on flooding, as evidenced by a weighting score of 6. This high score indicates the critical role that hydrological factors play in flood dynamics, aligning with existing research that emphasizes the substantial impact of water source density on flood occurrence [20-22]. Road density similarly affects flood risk, with its influence reflected by a weighting score of 5. This classification exhibits the complex interaction between man-made infrastructure and natural hydrological pathways, emphasizing the need for comprehensive flood mitigation strategies that integrate both environmental and urban development considerations [23-26]. Other factors such as slope, elevation, land use, and soil drainage were also analyzed with respective ratings and weights. Slopes under 5% were deemed to have the least impact on flooding and were given the lowest rating, whereas areas with slopes greater than 20% were considered to have a more substantial impact, with a corresponding higher rating score and a weighting score of 4. Elevation played a slightly less significant role, with lower areas having been assigned the highest potential for flooding and more elevated areas the lowest, reflected by a weighting score of 3. The categorization of land use highlighted different types of terrain, from water areas and mangrove forests to agricultural fields and urban settings, each with varying impacts on the water runoff and accumulation, having been assigned a weighting score of 2. Finally, the soil drainage capabilities were denoted by the lowest weighting score of 1.

Each factor group was multiplied by its weighted values, and the composite scores were categorized into five risk levels: very high, high, moderate, low, and very low risk of flooding. This categorization employed the natural break classification method to ensure an accurate delineation based on data statistical properties, allowing for a targeted approach in flood management across varying sub-districts and underlining the critical need for effective flood mitigation strategies in these zones [27-29]. The weight overlay command was run in GIS. Subsequently, the scores were combined, culminating in the flood risk map visualized in Figure 3.

The detailed analysis results are presented in Tables III and IV. Table III enumerates the areas at risk of flooding across different sub-districts within Khuan Khanun, providing specific measurements in km² and their corresponding percentages. For instance, Khuan Khanun Sub-District itself had a very high-risk area of 4.097 km², constituting 2.71% of the total area, while Thale Noi Sub-District had a significantly larger very high-risk area of 55.731 km², making up 36.88% of the total area. This detailed breakdown allows for a targeted approach in flood management across varying sub-districts. Table IV further summarizes the flood hazard levels by total area and proportion across the entire Khuan Khanun District, showing that areas of very high and high risk constitute over 65% of the total area, underlining the critical need for effective flood mitigation strategies in these zones. This thorough data assessment provides a comprehensive basis for enhancing flood preparedness and implementing specific, data-driven flood mitigation measures across the district.

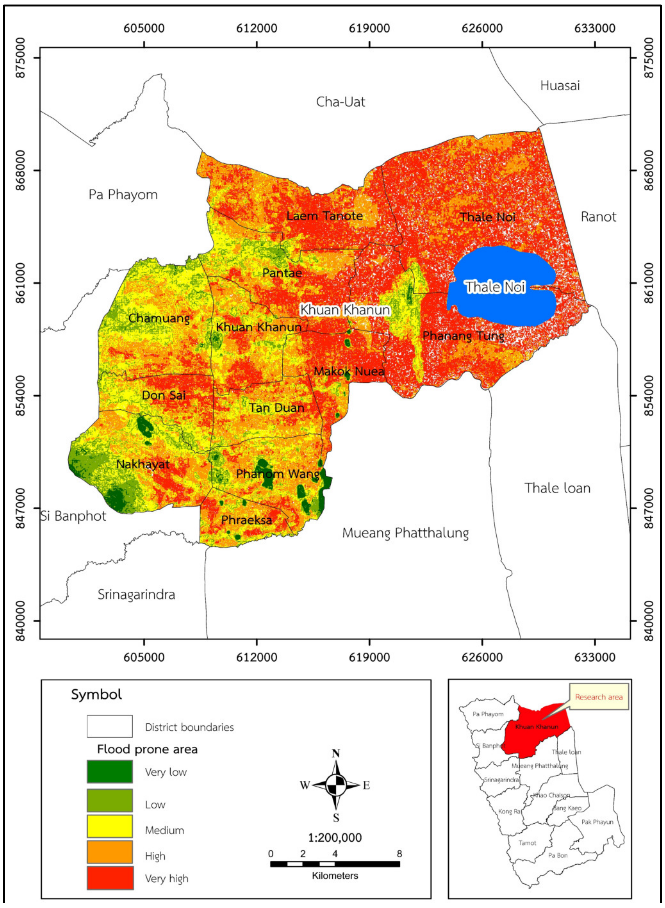

Fig. 4. Flood-prone area map.

TABLE III. AREAS AT RISK OF FLODING

Sub-Districts	Level										Total	
	Very high risk		High risk		Moderate risk		Low risk		Very low risk			
	km^2	(%)	km^2	(%)	km^2	(%)	km^2	(%)	km^2	(%)	km^2	(%)
Khuan Khanun	4.097	2.71	11.755	7.75	8.111	7.76	2.500	5.76	0.149	1.95	26.612	5.81
Thale Noi	55.731	36.88	21.898	14.43	3.239	3.10	0.389	0.90	0.003	0.03	81.260	17.73
Na Khayat	3.307	2.19	10.135	6.68	12.257	11.73	12.029	27.70	3.017	39.46	40.744	8.89
Phanom Wang	1.557	1.03	12.057	7.95	9.044	8.65	3.710	8.54	3.198	41.84	29.567	6.45
Laem Tanot	17.646	11.68	20.526	13.53	4.223	4.04	0.611	1.41	0.016	0.21	43.024	9.39
Pan Tae	11.006	7.28	14.134	9.32	9.666	9.25	4.558	10.50	0.135	1.77	39.500	8.62
Tanot Duan	2.950	1.95	10.347	6.82	17.379	16.63	1.722	3.97	0.025	0.32	32.423	7.07
Don Sai	5.125	3.39	6.197	4.08	7.575	7.25	2.660	6.13	0.024	0.32	21.581	4.71
Makok Nuea	11.825	7.82	8.809	5.81	2.723	2.61	0.672	1.55	0.373	4.87	24.401	5.32
Phanang Tung	33.908	22.44	13.583	8.95	6.470	6.19	3.063	7.05	0.223	2.92	57.248	12.49
Chamuang	2.151	1.42	12.969	8.55	19.123	18.30	9.550	21.99	0.222	2.90	44.014	9.60
Phraek Ha	1.816	1.20	9.304	6.13	4.700	4.50	1.963	4.52	0.259	3.39	18.043	3.94
Total	151.120	100.00	151.715	100.00	104.509	100.00	43.427	100.00	7.645	100.00	458.417	100.00

TABLE IV. FLOOD HAZARD LEVEL BY AREA AND PROPORTION IN KHUAN KHANUN DISTRICT

Level	Area (km^2)	Percent (%)
Very high risk	151.12	32.97
High risk	151.72	33.10
Moderate risk	104.51	22.80
Low risk	43.43	9.47
Very low risk	7.65	1.67
Total	458.42	100.00

Besides the aforementioned flood generating factors, global warming is expected to intensify the hydrological cycle, significantly increasing the likelihood of heavy precipitation events and the consequent risk of flooding [30]. An assessment of flood-prone areas in the Khuan Khanun District revealed that the Thale Noi, Phanang Tung, and Laem Tanot Sub-Districts face the highest flood risks, with very high-risk areas accounting for 55.731 km², 33.908 km², and 17.646 km², respectively. Collectively, the areas categorized as of very high risk and high risk encompass 302.84 km², accounting for over 66% of the total area of Khuan Khanun District, indicating a significant vulnerability to flooding.

The city's geographical characteristics greatly increase its vulnerability to frequent and severe flooding [31], with its proximity to Thailand's largest natural lagoon, the Songkhla Lake Basin (SLB), exacerbating its vulnerability. The local communities, deeply intertwined with and dependent on the resources of the SLB, often find themselves excluded from the governance and decision-making processes concerning the lake's management [32]. This oversight affects not only those directly connected to the lake, but also a broader range of stakeholders including local residents. In response to the rising water levels, local farmers are forced to relocate their livestock to higher ground, and the youth engage in fishing during holidays to support their families financially, adapting to the immediate economic impacts of frequent flooding. These community responses highlight the urgent need for inclusive governance that incorporates the local insights and needs into the SLB's management strategies to mitigate the profound and recurring flooding impacts.

IV. CONCLUSIONS

Although hazard mapping has been the main focus of many previous studies, the present research expands on that focus by highlighting practical findings for planning and policy. It provides local governments with a strong tool to prioritize flood mitigation measures by mapping different levels of susceptibility. This research stands out because few studies specifically relate their findings to such a broad range of policy applications. For example, recommendations, like building better drainage systems in flood-prone areas, enforcing stricter zoning laws to prevent development in high-risk areas, and encouraging community-based flood preparedness programs to increase local resilience, have all been influenced by the identification of high-risk zones. The significance of this research lies in both its application to Khuan Khanun District—a region with unique flood challenges—and the development of a novel methodological framework that integrates Geographic Information Systems (GIS) with Potential Surface Analysis (PSA), the combination of which contributes to advancing the flood risk management locally, offering a transferable model for other flood-prone areas. The analysis of flood hazard areas is fundamentally reliant on GIS and mapping data, which facilitate spatial analysis. The latter is substantial for decision-making in disaster management and local government planning, concerning flood risk management and disaster preparedness. This study's findings revealed that approximately 66% of the examined areas fell within high and very high flood risk zones, with a notable concentration in the eastern region adjacent to the Thale Noi and Songkla Lake basins. The substantial risk in these areas underscores the importance of integrating flood prediction models, early warning systems, and effective management practices into routine disaster response efforts.

The findings of the current work may act as a valuable tool for future research, enabling urban planners, and disaster management authorities make informed decisions to reduce the urban flooding impact and enhance urban communities' resilience.

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