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Simulation of flood protection using Hec Ras modeling: A case study of the Lam Phra Phloeng river basin

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ABSTRACT

The Lam Phra Phloeng reservoir, positioned within the Lam Phra Phloeng river basin and situated in Nakhon Ratchasimi province, assumes a substantial role in the realm of regional water management. During severe storms in the reservoir's upper region, excess water flows downstream, occasionally resulting in devastating floods in Pak Thongchai district, as witnessed in 2010 and 2020. Both flooding events have resulted in significant economic, social, and livelihood disruptions to the local population in the affected areas. This study pursues two primary objectives: firstly, to assess the extent of flood-prone areas across various return periods (2, 5, 10, 25, 50, 100, and 500 years); secondly, to employ Hec Ras modeling for an in-depth analysis of strategies aimed at flood prevention and mitigation within the Lam Phra Phloeng river basin. The Hec Ras modeling incorporates both 1D and 2D flow simulations. The findings reveal that the flood-prone areas, corresponding to the specified return periods, occupy 0.20%, 1.10%, 1.60%, 2.08%, 2.39%, 2.66%, and 3.17% of the total area in the Lam Phra Phloeng river basin, respectively. To safeguard against flooding and minimize its impact, a multifaceted approach is recommended, encompassing the construction of water barrier flaps, augmentation of water transmission and drainage capacity, implementation of flood alarm systems along the Lam Phra Phloeng river, installation of runoff stations, and the establishment of a comprehensive database system for flood and drought prevention. Among these measures, constructing water barrier flaps and enhancing water transmission and drainage capabilities stand out as effective strategies to protect the Lam Phra Phloeng river basin from flooding.

Keywords: Flood area, HEC RAS model, Flood protection, Structure measurement, non-structure measurement

INTRODUCTION

In 2010 and 2020, the Lam Phra Phloeng River basin experienced severe flooding, causing significant distress and harm to the local population. The primary cause of these floods can be heavy rainfall in the upstream and downstream areas of the reservoir, resulting in a substantial volume of water accumulating within the Lam Phra Phloeng reservoir, ultimately leading to overflow. These events resulted in widespread flooding, particularly affecting the Pak Thongchai district. Therefore, identifying flood-prone areas is paramount and warrants thorough evaluation [1, 2]. This information is crucial for the development of flood prevention and mitigation policies.

Generally, flood management strategies encompass two critical approaches: structural measures and non-structural measures [3, 4]. Both strategies have been widely adopted, not only in Thailand but also internationally, with their implementation varying based on the suitability for each specific region. Non-structural measures are often used in conjunction with structural measures to ensure a sustainable approach to flood prevention and management. These efforts aim to address and mitigate the challenges posed by flooding, safeguard the well-being of affected communities, and promote long-term resilience in flood management practices [5-11].

Structural measurements pertain to quantifying and assessing physical infrastructure intended to mitigate the repercussions of flooding. These entities encompass levees, dams, floodgates, and stormwater drainage systems. The meticulous measurement and evaluation of structural components are imperative to ascertain their efficacy during inundation events. This entails the continuous surveillance of water levels, structural integrity, and the operational capacity of flood control apparatus. Pervasive technological advancements, notably remote sensing, real-time monitoring, and Geographic Information Systems (GIS) have substantially augmented the precision and temporal relevance of structural measurements. These advancements facilitate informed decision-making by authorities during flood occurrences [12].

Conversely, non-structural measurements encompass the assessment of flood-relevant variables

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that are not directly associated with tangible infrastructure. These metrics predominantly encompass meteorological and hydrological data, such as precipitation patterns, river discharge rates, and soil moisture content. The comprehension of non-structural measurements holds pivotal significance in forecasting flood events, tracking their progression, prognosticating potential ramifications, and managing water. Contemporary tools, including weather radar, river gauging systems, and numerical weather models, have ushered in a paradigm shift in non-structural measurements, affording heightened precision in forecasting and early warning capabilities. These, in turn, are indispensable for the execution of timely evacuations and formulation of emergency response strategies [13].

Structural and non-structural measurements exhibit an intricate interplay, each complementing the other in a mutually reinforcing manner. The veracious non-structural data, such as precipitation forecasts and river discharge metrics, underpin decisions concerning the operational facets of structural elements like dams and floodgates. Simultaneously, structural measurements, encompassing the monitoring of levee conditions and embankment integrity, offer valuable feedback regarding their efficiency in attenuating flooding. Consequently, an integrated approach synthesizing structural and non-structural measurements constitutes an indispensable facet of comprehensive flood management. This confluence permits optimizing flood control systems while ensuring the populace remains well-informed and secure. The measurement and assessment of flooding comprise the dual facets of structural and non-structural measurements. Structural measurements are centered on the appraisal of tangible infrastructure intended for flood mitigation, while non-structural measurements are rooted in monitoring meteorological and hydrological variables. These two symbiotic methodological paradigms provide invaluable insights for flood monitoring, prediction, and emergency response. A holistic grasp of both structural and non-structural measurements is imperative for effective flood management and the amelioration of disaster risk in flood-prone regions within the purview of academic inquiry [14-15].

The objectives of this study are twofold: (1) to assess flood-prone areas at runoff various return periods of 2, 5, 10, 25, 50, 100, and 500 years, and (2) to analyze strategies for flood prevention and damage reduction in the Lam Phra Phloeng river basin using the Hec Ras modeling approach. This study employs the Hec Ras modeling method to simulate one-dimensional and two-dimensional flow conditions. Furthermore, the model can effectively depict areas at risk of flooding due to water volume exceeding the riverbank's capacity.

Study area: Lam Phra Phloeng river basin

The Lam Phra Phloeng river basin is entirely located in the Nakhon Ratchasima province and features a significant water reservoir, namely the Lam Phra Phloeng Reservoir. This reservoir, which serves as a dam on the Lam Phra Phloeng river, is a tributary of the Mun river, situated in the Takob sub-district, Pak Thongchai District, Nakhon Ratchasima province. The basin encompasses a total area of 807 square kilometers and is primarily designed for water retention purposes, with a normal retention level of 263 meters above sea level and a minimum retention level of 240 meters above sea level. This river basin covers 40 sub-districts in 7 districts, which are Wang Nam Khiew, Khon Buri, Pak Thong Chai, Chok Chai, Pak Chong, Sung Nein and Mueang districts presented in Figure 1. The reservoir has a storage capacity of approximately 106.30 million cubic meters. It is vital to provide water assistance for agricultural cultivation within the project area, covering 75,524 rai during the rainy season and 40,000 rai during the dry season. Additionally, it supplies water for the municipal water supply in Pak Thongchai district, Chok Chai district, and numerous rural communities, as well as for agricultural purposes outside the irrigation project area through natural water channels on an intermittent basis.

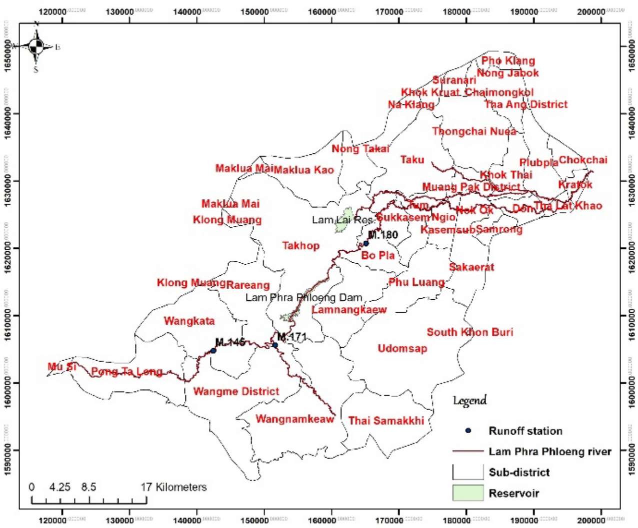

Figure 1 The sub-district in the Lam Phra Phloeng river basin.

This study utilizes land use data for the Lam Phra Phloeng river basin obtained through aerial and satellite imagery from the Department of Land Development. The study categorizes land use into five major types as follows:

1. The agricultural land primarily serves for the cultivation of rice, orchards, and a diverse range of crops, including mangoes, longan, jackfruit, papaya, lychee, guava, corn, sugarcane, various legumes, sesame, watermelon, chili, and others. This land category encompasses an expanse of 839,753.35 rai, representing 58.16% of the total area within the Lam Phra Phloeng river basin.

2. The forested land category encompasses a variety of forest types, including disturbed forests,

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primary forests, bamboo forests, mixed deciduous forests, and dense orchards, and spans across an area of 484,333.81 rai, representing 33.55% of the entire basin's land area.

3. Within the category of grasslands and suitable forests, formed because of human activities like shifting cultivation and road construction, notable plant species found in these areas include Napier grass, cogon grass, and Indian goosegrass. This land classification encompasses 39,156.14 rai, representing 2.71% of the total land area within the basin.

4. The classification of residential and industrial areas within the basin includes small to medium-sized communities, designated villages, religious institutions, educational establishments, government offices, and industrial complexes. This land category spans 63,988.53 rai, accounting for 4.43% of the total area within the Lam Phra Phloeng river basin.

5. The classification of water bodies within the region encompasses various natural water reservoirs, canals, and, notably, significant river confluences. This category extends over an area of 16,518.17 rai, representing 1.14% of the entire basin's geographical extent.

MATERIALS AND METHODS

The process conducted to facilitate flood area assessment using the Hec Ras modeling system consists of three primary phases: data collection, model setup, and model calibration and validation. Data collection involves acquiring relevant data and information necessary for the modeling process. Model setup pertains to configuring the modeling system, which includes defining parameters, establishing boundary conditions, and addressing other critical factors. Model calibration and validation encompass the adjustment and verification of the model to ensure its accuracy and reliability in replicating real scenarios. Following this, the calibrated and validated model is deployed to assess flood-prone areas across runoff various return periods, namely 2, 5, 10, 25, 50, 100, and 500 years. These stages collectively form the basis for a comprehensive and detailed analysis of flood-prone areas within the specified return periods. The specific intricacies of each phase are outlined as follows:

1. Data Collection

Hec Ras modeling employs five distinct methods for data collection, which are outlined as follows:

1.1 Data on the physical characteristics of the river basin area are employed to define the physical attributes of the river basin. These include information on river networks longitudinal river cross-sectional profiles along the entire Lam Phra Phloeng river, from its source to its confluence with the Mun river. Digital elevation maps (DEM) and river cross-sectional data are also collected. The river cross-sectional data is gathered from measurements at the river gauge stations of the Royal Irrigation Department and through additional survey efforts within this study, totaling 32 cross-sectional profiles.

1.2 Hydrological data comprise daily water flow measurements, utilizing data from various water gauge stations within the river basin of the Royal Irrigation Department. This includes the relationship between flow rates and water levels at these gauge stations. Data from station M.180 for the years 2008-2017 is used for the modeling. In cases where data is missing for some periods, the Hec Ras model is employed to generate data for those missing time intervals.

1.3 Data pertaining to the physical attributes of flood control structures holds significant importance in the context of river flow dynamics, as these attributes influence water flow patterns and volume regulation. Accurate information regarding the placement and dimensions of flood control structures positioned within river systems serves as essential input data for modeling processes, striving to replicate flow conditions with utmost fidelity to real scenarios.

1.4 In the domain of multi-purpose water issues and their management, problem data is pivotal in delineating the modeling parameters, particularly in regions susceptible to diverse water-related challenges. Conversely, management data serves to ascertain the constituent elements of the model, encompassing extant water management infrastructures.

1.5 Land use data is used to determine Manning's roughness coefficients and the coefficients for flood control structures in rivers. This data is essential for defining the boundaries and details in modeling, prioritizing flood-prone areas, and studying flood area management strategies.

2. Model Setup

The model setup process involves several steps to create the hydrological model of the study area.

2.1 Establish the river network of the Lam Phra Phloeng river by defining the relevant river network boundaries within the study area, from the Lam Phra Phloeng Dam to the confluence with the Mun river.

2.2 Specify boundary water conditions for the model, dividing them into inlet conditions at the upstream boundary and outlet conditions at the downstream boundary. These inlet conditions should include the flow rate discharged from the Lam Phra Phloeng Dam. The depth of flow is assumed to be constant.

2.3 Incorporate physical data, such as river cross-sectional profiles obtained from estimates based on surveyed cross-sectional data and ground elevation data for flood-prone areas. The river cross-sectional profiles are derived from data collected by the Royal Irrigation Department and the project's surveys.

2.4 The Hec Ras model is utilized to compute steady and unsteady flow conditions over time, represented by the following equations [16-19]:

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$$Y_2+Z_2+\frac{a_2V_2^2}{2g} = Y_1+Z_1+\frac{a_1V_1^2}{2g}+h_e \qquad (1)$$

where Y is depth at the considered cross-section, Z is the elevation of the riverbed at the considered cross-section, V is average water flow velocity, a is the weight coefficient of velocity, g is gravitational acceleration and h_e is energy loss resulting from resistive forces due to compression and expansion of the cross-section.

$$h_e = L\bar{S}_f + C\left|\frac{a_2V_2^2}{2g} - \frac{a_1V_1^2}{2g}\right| \qquad (2)$$

where L is the weight of the flow within the considered range, $\bar{S}_f$ is the slope of the frictional resistance force between two cross-sections and C = Coefficient of loss due to expansion or contraction of the flow path. The variable "L" can be calculated using Equation (3).

$$L = \frac{L_{lob}\bar{Q}_{lob}+L_{ch}\bar{Q}_{ch}+L_{rob}\bar{Q}_{rob}}{\bar{Q}_{lob}+\bar{Q}_{ch}+\bar{Q}_{rob}} \qquad (3)$$

where L_{lob}, L_{ch}, and L_{rob} are the lengths of the cross-sectional areas defined for flooding on the left, the main river, and the right, respectively. $\bar{Q}_{lob}$, $\bar{Q}_{ch}$, and $\bar{Q}_{rob}$ represent the flow rates of the specified cross-sectional lengths for flooding on the left in the main river and on the right, respectively.

The Saint-Venant equations, which result from the combination of the continuity equation with the momentum conservation equation, are as follows:

$$\frac{1}{A}\frac{\partial Q}{\partial t} + \frac{1}{A}\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + g\frac{\partial y}{\partial x} - g(S_0 - S_f) = 0 \qquad (4)$$

3. Model Calibration and Validation

The calibration and validation phases are fundamental and integral components in the refinement and improvement of the modeling process, serving as the bedrock for reliable and accurate simulations [20]. The dataset utilized for calibration and validation includes crucial parameters such as water levels, flow rates, and flood extent. Ensuring this input data's quality, accuracy, and spatial authenticity is a fundamental requirement for achieving dependable results within the Hec Ras modeling framework. The calibration process employed in this study is distinguished by its comprehensive methodology, which involves the integration of both graphical and numerical metrics for assessing model performance. The evaluation of simulated and observed hydrographs involves a rigorous graphical analysis, while the numerical performance evaluation is based on the overall water balance error [21]. This error is determined by quantifying the disparity between the average simulated and observed discharge, measuring the model's accuracy and dependability [22].

Model calibration was conducted after creating the model and importing data into the Hec Ras model. During the calibration process, the focus was on the flow rate data from station M.180, specifically for the year 2551. Adjustments were made to Manning's roughness coefficient (Manning's n) to ensure the model's realism and accuracy. The calibration results yielded a correlation coefficient (R^2) of 0.869, representing 86.90% and a Nash-Sutcliffe Efficiency (NSE) index of 0.816, indicating an accuracy of 81.60% [23-25].

To further evaluate the model's performance, model validation was performed using flow rate data from station M.180 for the year 2554. The validation results showed a high correlation coefficient (R^2) of 0.995, signifying 99.50% accuracy, and a Nash-Sutcliffe Efficiency (NSE) index of 0.993, indicating an efficiency of 99.30%. It's important to note that this study conducted a calibration and validation comparison for a limited two-year period due to complete data availability. These outcomes demonstrate R^2 values exceeding 0.5, indicative of a commendable level of agreement, further underscoring the fidelity of the model [26].

Table 1 The result of the confusion matrix.

GISTDA data (Reference data)	Hec-Ras Model		Row total
	Flood	Non-Flood	
Flood	3,451,600	1,929,600	5,381,200
Non-Flood	2,327,600	85,278,000	87,605,600
Column Total	5,779,200	87,207,600	92,986,800

The extent of flooding derived from the model was compared to the extent from a floodplain map that was generated using satellite imagery by the Geo-Informatics and Space Technology Development Agency (GISTDA). It was observed that the maximum flood extent determined by the model covered an area of 144.48 square kilometers. This was overlaid with the floodplain map from the year 2553 (B.E.) provided by GISTDA, which covered an area of 134.52 square kilometers. The model's accuracy was assessed using a confusion matrix [27], and the results are presented in Table 1. Statistical accuracy comparison using the confusion matrix revealed that the overlap accuracy between the flood extent obtained from the model and the GISTDA floodplain map was 95.40%.

Finally, the calibrated and validated model is deployed to assess flood-prone areas across runoff various return periods, namely 2, 5, 10, 25, 50, 100,

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and 500 years. This study calculated water levels and flooded areas under current conditions for return periods of 2, 5, 10, 25, 50, 100, and 500 years to predict the impacts of flooding. Various water data from hydrological analysis were used to create water level graphs for each return period. The maximum flow rate data measured annually at station M.180 from 2002 to 2018 was utilized for the Gumbel distribution method to calculate the recurrence intervals. This method was developed by the Lower Northeaster Region Hydrological Irrigation Center, Royal Irrigation Department, as Table 2. shows that the flow rate at the 2-year return period is 61.40 m^3/s, which is smaller than the flow rate at the 5-year return period by almost three times. Additionally, as we move from the 5-year return period to the 10, 25, 50, 100, and 500-year return periods, the flow rate increases by 100 m^3/s or 0.2-0.4 times. This observation indicates that the Lam Phra Phloeng river basin does not experience an immediate and drastic increase in water volume; instead, it gradually increases over time.

Table 2 The runoff/flow rate of return periods 2, 5, 10, 25, 50, 100, and 500 years.

Return period	Flow rate (m^3/s)
2	61.40
5	178.90
10	256.80
25	355.10
50	428.10
100	500.0
500	667.8

RESULTS AND DISCUSSION

The investigation outcomes involving flood simulations at different return periods employing the Hec Ras model, as well as flood event simulations post-implementation of barrier flaps and river dredging, are presented hereinafter.

1. The study of flood risk areas in various return periods in the Lam Phra Phloeng watershed reveals important insights. Figures 2 through 8 illustrate the calculated flood areas without additional flood protection structures in the current conditions, utilizing the flow rates at various return periods of 2, 5, 10, 25, 50, 100, and 500 years. The Gumbel distribution frequency analysis is employed to predict the probability of flood impact on specific areas. These flood areas result from the flow rates within the river system, leading to overflow and inundation of different areas. It's important to note that the model does not consider rainfall quantities within the watershed but focuses on the flow rates entering the watershed or flowing into the river/canal, as shown in Table 3.

Table 3 shows the extent of areas impacted by flooding in different return periods. Most flood-affected areas are in Pak Thong Chai district, with some parts of Chok Chai district also experiencing flooding. These flooded areas are closely situated along the Lam Phra Phloeng river. The Lam Phra Phloeng river overflow contributes to these areas' inundation. The findings of this study are consistent and aligned with the results of the floodplain study using the MIKE FLOOD model in the same area [28].

The flooded area in the 2-year return period is only 4.62 km^2, occurring along the river's natural course. However, with the increased water volume corresponding to the 5-year return period, the flooded area expands significantly to 5.5 times that of the 2-year return period. When examining Table 2, it is evident that the inflow into the river at the 5-year return period is 2.9 times that of the inflow at the 2-year return period. This observation indicates that an increase in water volume from the 2-year return period to the 5-year return period has a substantial impact on the occurrence of flooding.

2. Flood Prevention Plan using Structural measurement and non-structural measurement.

2. 1 Construction of water barrier flaps

In the context of mitigating flood impacts due to river overflow within the Lam Phra Phloeng river Basin, it is recommended that water barrier flaps be constructed. To make these plans actionable, detailed surveys of the affected areas should be conducted to design the barrier flaps effectively. In this investigation, initial evaluations of the locations and elevations of these flood control structures were considered, as detailed in Table 4. The study findings suggest that it is advisable to establish flood control structures along the river. Subsequently, the inundated areas post-construction of these flood control structures are delineated in Table 3 and Figure 9 to Figure 15, considering various return periods. The areas benefiting from the construction of these water barriers are as follows:

- For return period 2-yr: Tha Lad Khao sub-district, Phlapphla sub-district, Chok Chai district, Mueang Pak sub-district, Takhoo sub-district, Sam Rong sub-district, Pak Thong Chai district.
- For return period 5-yr: Phlapphla sub-district, Chok Chai district, Mueang Pak sub-district, Takhoo sub-district, Sam Rong sub-district, Pak Thong Chai district.
- For return period 10-yr: Phlapphla sub-district, Chok Chai district, Mueang Pak sub-district, Takhoo sub-district, Sam Rong sub-district, Pak Thong Chai district.
- For the return period 25-yr to 500-yr, the study area's affected flood extent is similar in both scenarios, with or without the water barriers. However, the magnitude of the affected area is reduced due to the presence of the water barriers.

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Table 3 shows that the construction of water barrier flaps significantly reduces the flooded area from the 2-year return period to the 100-year return period, with a reduction of over 40%. However, for the 500-year return period, considered an extreme and unlikely scenario, there is only a marginal 2% reduction in the flooded area. This minimal reduction is due to the high volume and topography of the Lam Phra Phloeng river, which cannot adequately accommodate the excess water. Therefore, the construction of water barrier flaps is paramount for flood prevention and damage reduction and should be given top priority.

2.2 Increasing Water Conveyance and Drainage Capacity

As the collective water drainage capacity of the Lam Phra Phloeng river can handle a 100-yr return period flood [29], it is imperative to augment the river's capacity at sections where it falls short of the 100-yr return period to ensure it can handle such floods. The details of these improvements are presented in Table 5.

Table 5 shows that the Lam Phra Phloeng river has segments where river dredging is necessary, a total 5 segments. Dredging these river segments allows for increased water conveyance. However, in segments km 20+535 and 79+861, the flow rate increases by only 5-7% due to the topographical conditions that limit dredging in more expansive areas. For segments km 84+757, 89+653, and 90+034, dredging results in a significant increase in flow rate of over 32%.

Table 3 Comparison of flood impact in cases with and without water barricades in the Lam Phra Phloeng river.

Return Period	Current Conditions		Water Barricades Conditions	
	Flood area (km^2)	No. of sub-district	Flood area (km^2)	No. of sub-district
2	4.62	14	1.88	9
5	25.53	16	15.09	12
10	37.28	16	18.85	12
25	48.42	16	38.51	15
50	55.63	16	50.94	16
100	61.83	16	48.07	16
500	75.10	17	73.74	17

Table 4 Positions and Heights of Water barrier flap in the Lam Phra Phloeng river.

Station (km.)	Barrier flap (m)		Station (km.)	Barrier flap (m)		Station (km.)	Barrier flap (m)	
	Left	Right		Left	Right		Left	Right
98+607.34	-	-	65+434.97	0.73	-	33+914	0.72	0.72
96+027.43	-	-	64+045.18	1.34	-	31+423.49	0.19	0.58
94+086.22	-	-	61+841.17	1.62	0.9	30+032.92	-	0.18
91+716.34	-	-	59+206.14	0.48	0.82	28+128.04	-	0.86
89+894.2	-	-	57+258.74	0.76	1.22	26+000	1.39	1.38
88+081.13	-	-	55+922.32	1.86	2.12	23+411.6	1.01	0.98
84+874.48	-	4.56	54+000	2.82	2.69	22+000	1.21	1.01
83+578.36	-	2.83	51+767.07	3.15	3.07	20+000	1.36	1.89
81+107.22	3.89	3.53	50+763.81	0.88	0.89	17+844.62	1.18	0.53
79+830.1	3.55	3.61	48+410.13	1.55	1.9	16+444.98	0.58	0.62
78+379.25	2.66	2.38	46+253.15	1.06	0.92	14+000	0.19	0.27
75+900.99	-	-	43+737.25	2.21	0.77	12+000	1.72	1.62
73+940.95	2.39	-	41+834.26	2.02	1.1	9+930.664	0.84	3.59
72+677.6	1.43	-	40+000	2.06	1.18	7+306.1	1.12	2.08
70+063.51	0.99	-	38+064.14	3.1	1.42	5+789.655	0.77	0.62
68+707.44	1.37	-	36+000	0.45	0.45	4+000	0.95	0.91
						1+588.808	0.41	0.28

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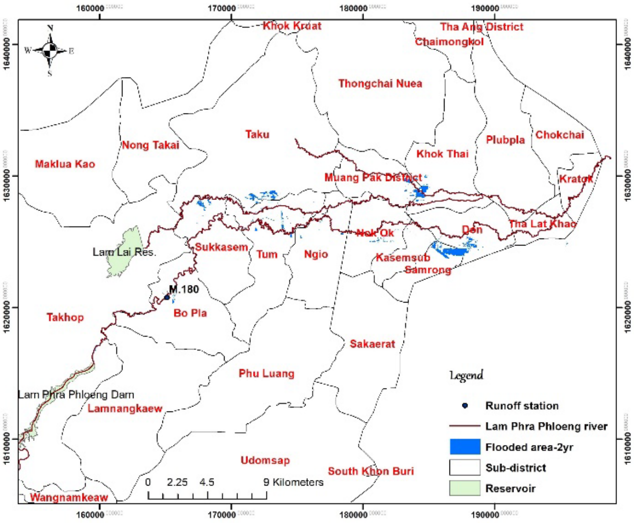

Figure 2 Flooded area in return period 2-yr.

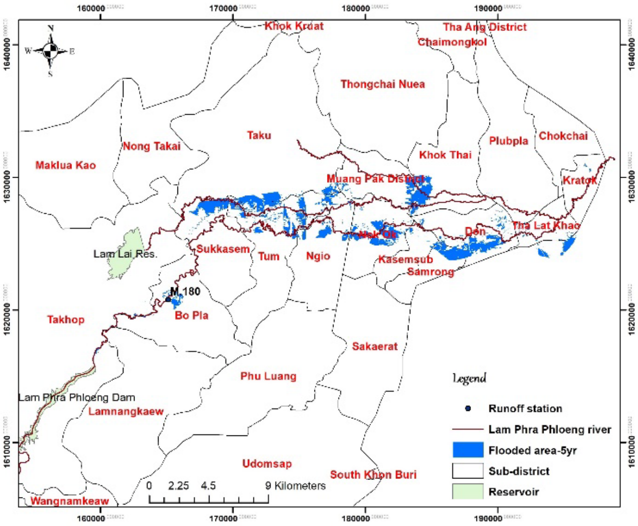

Figure 3 Flooded area in return period 5-yr.

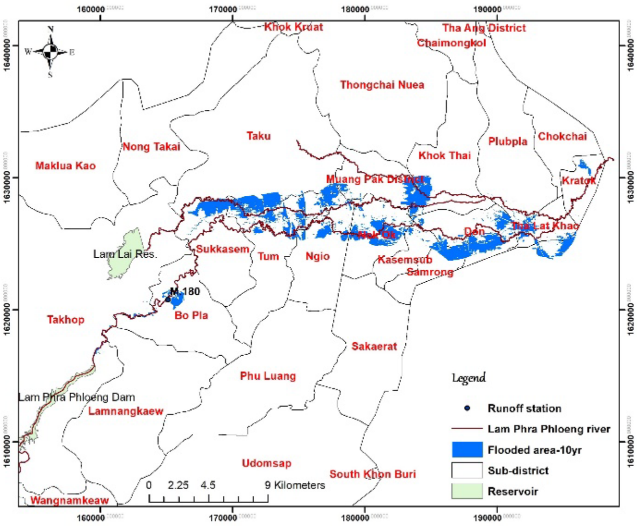

Figure 4 Flooded area in return period 10-yr.

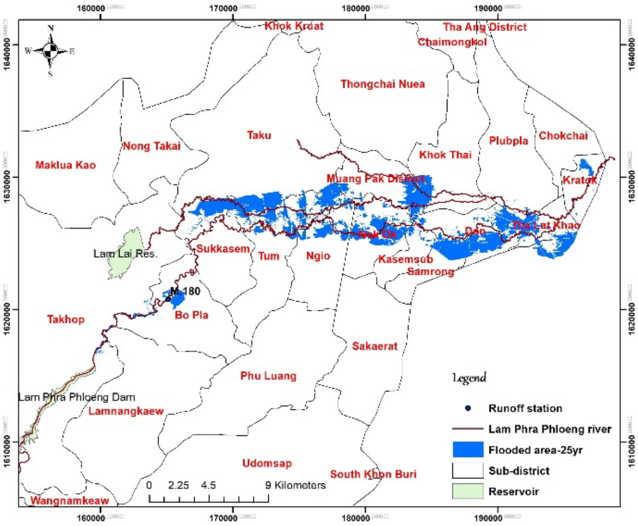

Figure 5 Flooded area in return period 25-yr.

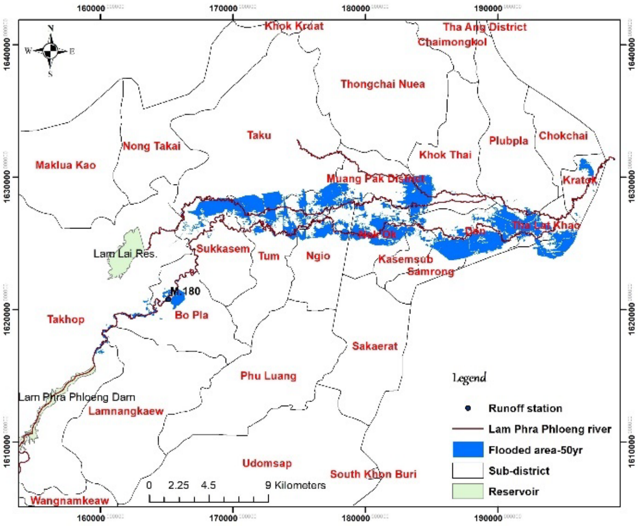

Figure 6 Flooded area in return period 50-yr.

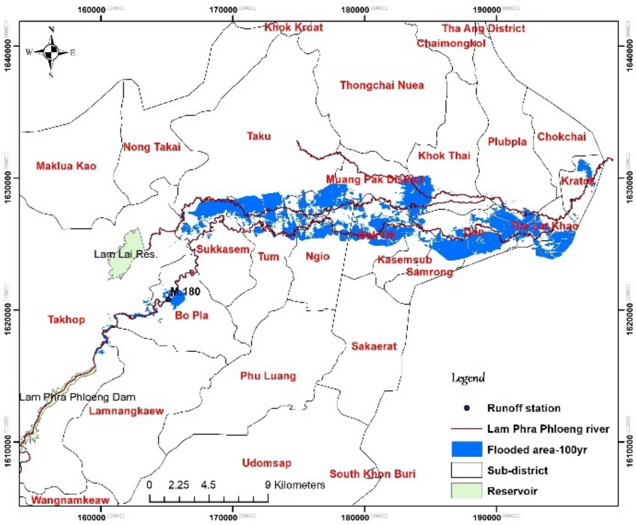

Figure 7 Flooded area in return period 100-yr.

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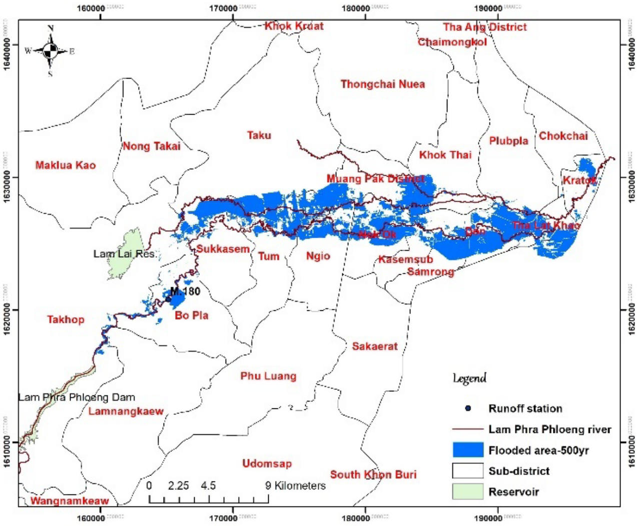

Figure 8 Flooded area in return period 500-yr.

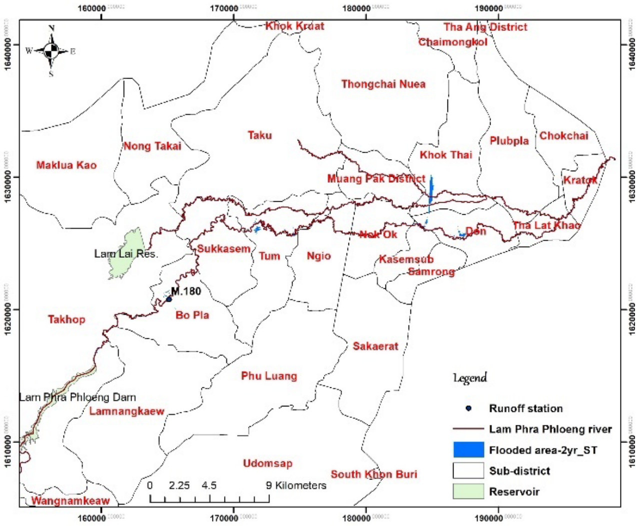

Figure 9 Flooded area in return period 2-yr with water barrier flaps.

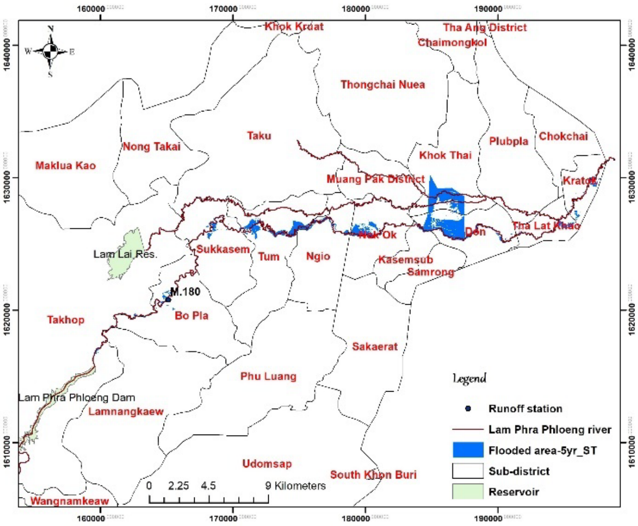

Figure 10 Flooded area in return period 5-yr with water barrier flaps.

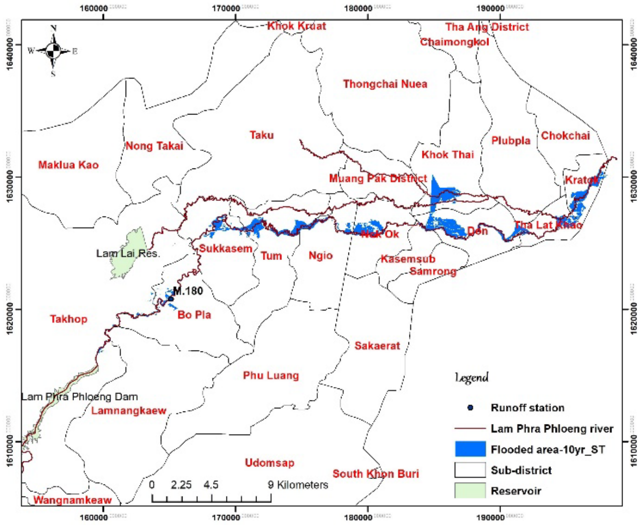

Figure 11 Flooded area in return period 10-yr with water barrier flaps.

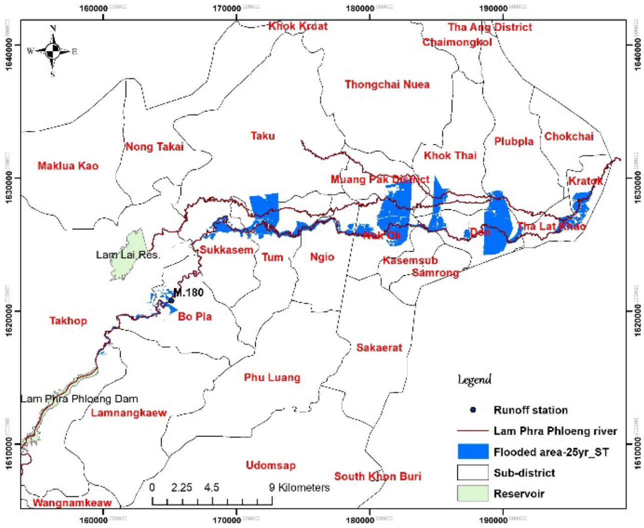

Figure 12 Flooded area in return period 25-yr with water barrier flaps.

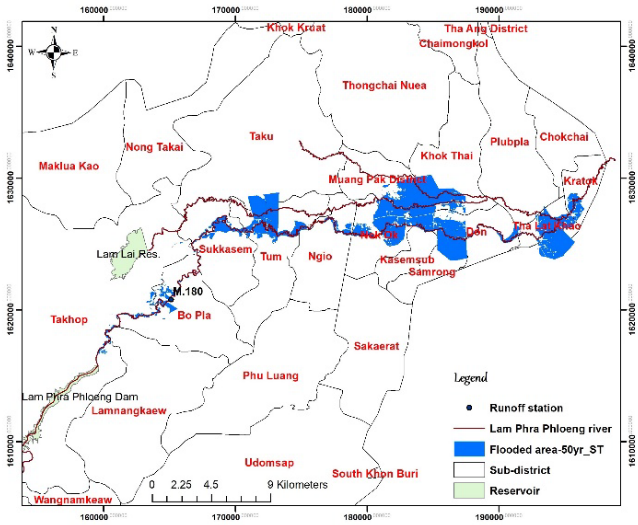

Figure 13 Flooded area in return period 50-yr with water barrier flaps.

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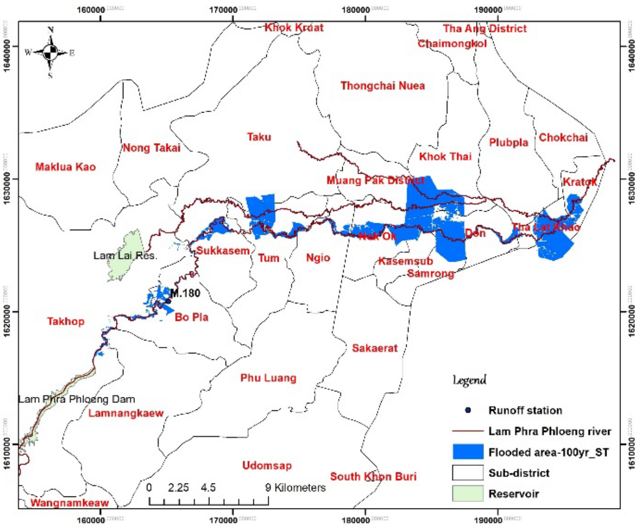

Figure 14 Flooded area in return period 100-yr with water barrier flaps.

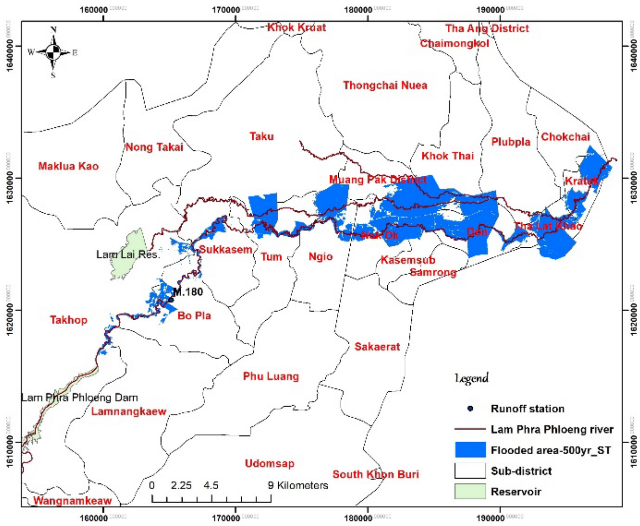

Figure 15 Flooded area in return period 500-yr with water barrier flaps.

Table 5 Positions for enhancing the potential of the Lam Phra Phloeng river in Pak Thongchai.

Km.	Coordinate		Location	Drainage Capacity (m^3/s)	
	UTM_N	UTM_E	Sub-district	Current	New
20+535	1625589.05	190231.50	Don	147.68	157.90
79+861	1622272.95	165919.48	Bo Pla Tong	412.68	434.73
84+757	1620773.17	165105.37	Bo Pla Tong	170.95	379.16
89+653	1619553.17	162908.27	Takhop	163.17	309.15
90+034	1619420.16	162632.48	Bo Pla Tong	497.11	656.18

Table 6 Surveillance flow rate for flooding.

Km.	UTM-N	UTM-E	Sub-district	Surveillance flow rate (m^3/s)
98+615	1615794.38	159864.06	Takhop	61.40
64+246	1626038.14	170494.48	Sukkasem	61.31
50+016	1626300.66	175841.20	Tum	56.07
43+438	1625923.28	178150.24	Ngio	61.40
33+328	1626345.08	183438.04	Nok Ok	54.85

2.3 Studying of river alarm system.

Implementing an alarm system in areas vulnerable to flooding can significantly reduce flood-related damages. In the Lam Phra Phloeng river Basin, the flood risk starts to materialize at the 2-yr return period or when water levels rise significantly either at the Lam Phra Phloeng Dam or in the vicinity of Tak Kho sub-district, Pak Thong Chai district, reaching 61.40 m^3/s. Relevant authorities should inform the residents of affected communities as well as those living near riverbanks and floodplain areas. These guidelines are presented in Table 6.

Table 6 shows that the Lam Phra Phloeng river has a total of 5 flood warning station locations. The average flow rate for flood warnings is 59 m^3/s. This study has identified the UTM-N and UTM-E coordinates for these station locations, enabling their utilization in determining the installation points for flood warning stations.

2.4 Additional location of runoff station

Due to the insufficient number of runoff stations and the missing data in some areas, increasing the quantity of these runoff stations and emphasizing the efficient and continuous collection of data is paramount. Also, these additional runoff stations can be applied to flood monitoring stations. Following the successful calibration and validation of the model, data collected from water level monitoring stations were incorporated into the model. Trial and error methods were applied to determine the suitable distances between these

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stations. The distances to install runoff stations along the river were identified as follows:

- Kilometer 0+530 in Krathok sub-district, Chok Chai district, which serves as the point where water from Lam Phra Phloeng river flows into the Mun river.
- Kilometer 30+166 in Don sub-district, Pak Thong Chai district.
- Kilometer 60+077 in Tum sub-district, Pak Thong Chai district.
- Kilometer 98+615 in Tak Kho sub-district, Pak Thong Chai district.

These runoff stations should be automated and equipped with data lockers to ensure systematic data collection and data continuity.

To effectively mitigate and minimize the repercussions of flooding in the Lam Phra Phloeng river Basin, it is imperative to implement a combination of structural and non-structural measures, as recommended by the research findings. Additionally, a heightened emphasis on enhancing the water network infrastructure and the establishment of a robust, comprehensive database system in the foreseeable future will play a pivotal role in proactively averting and alleviating flood-related damages within the Lam Phra Phloeng river basin. The water network, connecting primary rivers, tributaries, and reservoirs, will redirect surplus water to storage areas for regions facing water shortages. Furthermore, it is essential to consider flood mitigation measures that focus on minimizing flood-related destruction and storing excessive water during the rainy season for later use during dry periods.

Regarding the database system for flood and drought prevention, developing a comprehensive database system is paramount. This database should encompass various data types, including records of water levels, rainfall data, data from rain gauge stations, water level monitoring stations, meteorological information, land use data, elevation contours, river discharge capacities, reservoir storage volumes, flood-prone areas, areas with recurrent floods, and drought-prone regions, in addition to telemetry systems. These data should be made available in diverse formats, such as Geographic Information Systems (GIS), tabular representations, and textual descriptions. Furthermore, easy accessibility to this information must be ensured for all relevant agencies, with data updates conducted regularly, based on different update frequencies, ranging from hourly to yearly contingent upon the nature of the data.

CONCLUSIONS

In conclusion, this study has illuminated critical insights into assessing flood-prone areas within the Lam Phra Phloeng river Basin, offering valuable information for water management and disaster preparedness. The major findings of this research are as follows:

Firstly, the analysis of various return periods, spanning from 2 to 500 years, has revealed the extent of flood-prone areas within the Lam Phra Phloeng river Basin. These flood-vulnerable regions encompass 0.20%, 1.10%, 1.60%, 2.08%, 2.39%, 2.66%, and 3.17% of the total basin area, respectively. Predominantly, these areas encompass the majority of Pak Thong Chai District and extend into some parts of Chok Chai District.

Secondly, it has been established that the Lam Phra Phloeng river Basin experiences flood events primarily in its downstream agricultural lands. Notably, flooding occurs when the flow rate reaches 61.4 cubic meters per second at the river's starting point, corresponding to a 2-yr return period. It is essential to underline that flood-prone areas at this return period are relatively limited and do not significantly damage the Lam Phra Phloeng river Basin. However, the flood-prone areas at a 5- yr return period, with a water flow rate of 178.9 m^3/s, witness considerable expansion, signifying a critical range for flood monitoring.

Thirdly, it is imperative to implement strategic measures to mitigate the impact of flooding in the Lam Phra Phloeng river Basin. These measures should encompass the construction of water barriers and the augmentation of water transmission and drainage capacities. These initial projects hold the potential to considerably diminish the severity of flood events and reduce the ensuing damage to the basin. These insights form the foundation for informed decision-making and proactive flood management in the Lam Phra Phloeng river Basin.

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