การบูรณาการแนวคิดเพื่อกำหนดเขตการใช้ประโยชน์ที่ดินสำหรับการบริหารจัดการอุทกภัยโดยใช้การประเมินมูลค่าความเสียหาย
An Integrated Approach to Determine Land Use Zoning for Flood Management by Using Flood Loss Assessment

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บทคัดย่อ

การกำหนดเขตการใช้ประโยชน์ที่ดินเป็นหนึ่งในมาตรการการจัดการอุทกภัยที่ไม่ใช้โครงสร้าง ซึ่งที่ผ่านมาการกำหนดเขตพื้นที่น้ำท่วมส่วนใหญ่จะกำหนดจากพื้นที่ที่เคยถูกน้ำท่วมหรือพื้นที่ที่เคยได้รับความเสียหายจากน้ำท่วม ส่งผลให้พื้นที่ที่มีอาคารและพื้นที่อื่น ๆ ในเขตพื้นที่เสี่ยงภัยน้ำท่วมนั้นไม่ได้รับการพัฒนาต่อไป การศึกษานี้มีวัตถุประสงค์เพื่อประเมินความเสียหายจากน้ำท่วม โดยประเมินจากการเกิดน้ำท่วมในอดีต บริเวณที่ราบลุ่มแม่น้ำน้อย อำเภอเสนา จังหวัดพระนครศรีอยุธยา เพื่อเสนอแนะแนวทางการกำหนดเขตการใช้ประโยชน์ที่ดิน โดยประยุกต์ระบบสารสนเทศทางภูมิศาสตร์ในการวิเคราะห์เพื่อจำแนกระดับความถี่จำนวนครั้งของการเกิดน้ำท่วมในอดีตที่แบ่งตามเกณฑ์ คือ ความถี่ต่ำ (3 ครั้งต่อ 10 ปี) ความถี่ปานกลาง (4-7 ครั้งต่อ 10 ปี) และความถี่สูง (8-10 ครั้งต่อ 10 ปี) ส่วนการประเมินความเสียหายจากอุทกภัยพิจารณาความเสียหายที่จับต้องได้และจับต้องไม่ได้จาก 6 ปัจจัย ความเสียหายซึ่งเป็นการวิเคราะห์ความเสียหายเชิงปริมาณและความเสียหายเชิงพื้นที่ในช่องกริดขนาด 100x100 เมตร ที่ได้กำหนดเกณฑ์ของมูลค่าความเสียหายเป็น 3 ระดับ คือ ระดับต่ำ (≤ 0.1 ล้านบาท) ระดับปานกลาง (0.1 ถึง 1.00 ล้านบาท) และระดับสูง (≥ 1.01 ล้านบาท) ส่วนการวิเคราะห์เพื่อการกำหนดเขตการใช้ประโยชน์ที่ดิน ใช้วิธีการวิเคราะห์ทางเลือกแบบหลายปัจจัยสำหรับเพื่อเสนอแนะการใช้ประโยชน์ที่ดินประเภทต่าง ๆ ผลการวิเคราะห์พื้นที่น้ำท่วมตามระดับความถี่ของการประสบน้ำท่วมในระยะเวลา 10 ปีที่ผ่านมา (พ.ศ. 2550-2559) พบว่า แต่ละบริเวณมีระดับความถี่ของการประสบน้ำท่วมที่แตกต่างกัน โดยมีขนาดพื้นที่ประสบน้ำท่วมความถี่สูง พื้นที่ประสบน้ำท่วมความถี่ต่ำ และพื้นที่ประสบน้ำท่วมความถี่ปานกลาง คือ 49.64, 27.78 และ 24.79 ตร.กม. ตามลำดับ

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และผลการวิเคราะห์มูลค่าความเสียหายจากน้ำท่วมนั้นมีมูลค่ารวมทั้งสิ้น 2,396.06 ล้านบาท นอกจากนี้ยังพบว่าพื้นที่ประสบน้ำท่วมความถี่สูงส่วนใหญ่เป็นพื้นที่ที่มีมูลค่าความเสียหายอยู่ในระดับต่ำ ในทางกลับกันพื้นที่ประสบน้ำท่วมความถี่ต่ำส่วนใหญ่เป็นพื้นที่ที่มีระดับความเสียหายจากน้ำท่วมอยู่ในระดับสูง จากผลการศึกษาสามารถกำหนดเขตการใช้ประโยชน์ที่ดินเพื่อการบริหารจัดการอุทกภัยได้ 5 เขต คือ เขตทรัพยากรน้ำ เขตเกษตรกรรมสำหรับกักเก็บน้ำ เขตพัฒนาชนบทและเกษตรกรรม เขตควบคุมการพัฒนา และเขตพื้นที่พัฒนาที่ต้องดำเนินโครงการป้องกันน้ำท่วม

คำสำคัญ: *การจัดการเขตน้ำท่วม มูลค่าความเสียหายจากน้ำท่วม แม่น้ำน้อย อำเภอเสนา*

Abstract

Land-use zoning is one of the non–structural flood management measures. In the past, criteria for flood zoning were mostly based on flooding experiences or potential flood damage. The result shows that the built-up land and spaces in flood risk areas cannot undergo further development. This study aims to assess flood loss based on previous flood events in the Noi River floodplain, Sena District, Phra Nakhon Si Ayutthaya Province, to suggest a guideline for land use zoning. This study applies Geographic Information System (GIS) techniques for flood frequency analysis in order to classify flood frequency levels. The applied criteria included low frequency (LF ≤ 3 times/10 years), moderate frequency (MF = 4-7 times/10 years), and high frequency (HF = 8-10 times/10 years). The flood loss is evaluated by considering the tangible and intangible losses of six flood damages in monetary terms. The flood loss is analyzed quantitatively and spatially on a grid size of 100x100 m. The flood loss value is divided into three classes: low (≤ 0.1 million baht), moderate (0.1 -1.00 million baht), and high (≥ 1.01 million baht). To determine the land use zones, multiple criteria decision analysis is employed. The analysis of flooded areas and flooded frequency levels for the past ten years (2007-2016) shows that each flooded area has a different flood frequency level. The flooded area of HF, LF, and MF was 49.64, 27.78, and 24.79 sq km, respectively. The total flood loss stood at 2,396.06 million baht, most of which arose from LF areas. HF areas were also areas of low flood loss level (LL). On the other hand, some areas with LF turned into areas of high flood loss level (HL). As a result of land-use zoning, five flood management zones can be determined, namely a water resource zone (WRZ), an agricultural area for water retention zone (AWZ), a rural and agricultural development zone (RAZ), a development control zone (DCZ) and a developed area for flood prevention projects implementation zone (DAZ).

Keywords: *Flood zoning management, Flood loss, Noi River, Sena district.*

Introduction

Land use planning in floodplains is one of the key flood management measures. It lessens the risk and costs of flood damage control or restricts land use and building structures to mitigate potential flood damage in a particular area. Flood-resilient communities may benefit from zoning or land use planning. Such flood management policies can reduce flood risks by regulating the development of flooded areas and raising public awareness (Botzen et al. 2019; Burby et al. 2000). Zoning regulations achieved by restricting development in floodplain areas can further lower exposure and vulnerability to floods, as evaluated through the number of people or the value of assets that can be affected, which can serve to alter the potential flood hazard (Hudson; & Botzen. 2019).

Risk-based zoning maps have recently been used by global communities and recognized as an essential part of comprehensive flood loss prevention and management programs (ISDR. 2004). A map is created using hydraulic models based on flooding experiences or potential flood damage and takes into account only the extent of the flooded area, not the cost of the flood damage. However, the value of flood damage varies according to the major use of land in the flood risk area. Hence this flood-risk and zone-based classification, which leave the estimation of damage out of the equation, will prevent the existing built-up lands and areas of great potential for investment from undergoing further development.

Flood damages have indicated both tangible and intangible flood damages (Jonkman et al. 2008). Each type of damage is classified as direct or indirect, depending on whether it is related to a direct exposure to flooding or whether it occurs in an area with no previous exposure to flooding (Bre´mond; Grelot; & Agenais. 2013). Direct flood damage results from physical contact with floodwater, while indirect flood damage results from the interruption and disruption of economic and social activities caused by direct flood damage (Dutta; Herath; & Musiake. 2001). Types of flood damage to agriculture fall into five categories: 1) flood damage to agricultural land, with mainly crop loss and opposing effects on plant growth; 2) flood damage to agricultural buildings, machinery and equipment; 3) flood damage to stocks or production stuff; 4) costs for evacuation; and 5) other costs (e.g. costs for repairing damaged agricultural infrastructure and clearing and cleaning-up costs) (Thieken et al. 2008).

Flooding in the Noi River floodplain is a natural hazard in central Thailand that causes severe damage to agricultural and residential areas. The flooding is caused by heavy rainfall in the area together with maximum streamflow, especially during the rainy season. The assessment of flood damage in monetary values in Sena district

revealed the average flood loss of 321,643 baht per household. This can be classified as damage to buildings and assets amounting to 31,227 baht per household. The damage from loss of employment opportunities was 87,321 baht per household. The average damage value of prevention, cleaning, and water-borne disease treatment costs was 5,178 baht per household and the average damage value of agricultural flood damage was 208,333 baht per household (DPT. 2019).

There are many government sectors in Thailand that regulate the land and building utilization related to water management for flood prevention. The Comprehensive Plan of the Department of Public Works and Town & Country Planning (DPT) has defined open-space and land use zones for flood management. The open-space plan has determined the following zones: open-space areas for environmental quality conservation along the rivers and canals zone (OEC), open-space areas for preservation of natural drainage conditions zone (OPD), open-space areas as drainage basins for flood prevention zone (OFP) including a zone for rural and agricultural conservation, which is defined as the land use for water drainage or drainage basins; besides, these are preserved as valuable agricultural areas (DPT. 2020a). In addition, The Water Master Plan of Office of the National Water Resources (ONWR) has also defined several other zones, namely floodway areas along the rivers and streams and floodway areas for drainage conservation zone. Wetland and lowland zones are also included (ONWR. 2019). Determination of the various land use zones mentioned above is mainly based on physical conditions and flood situation. However, flood loss is not taken into consideration.

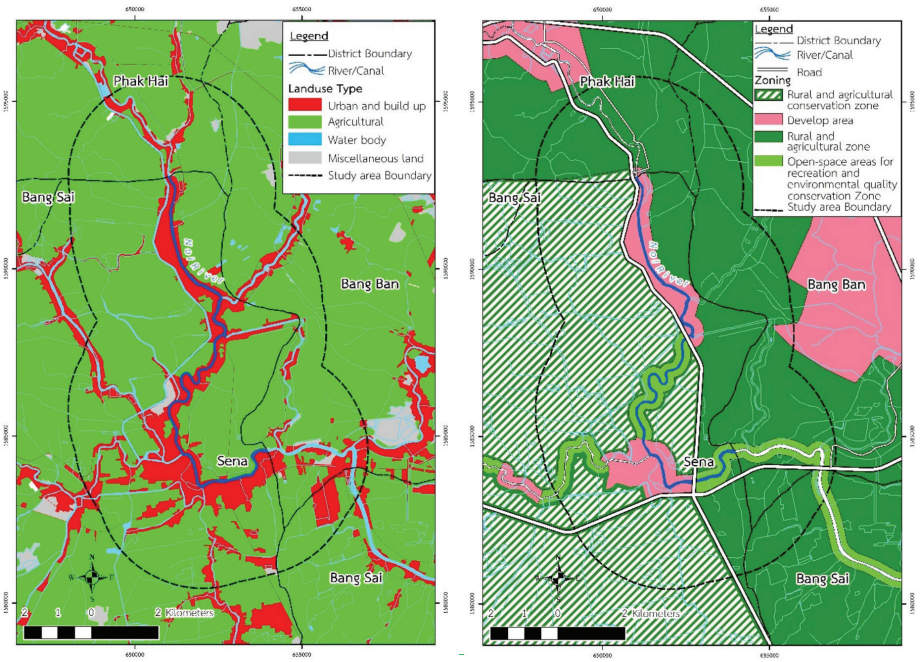
GIS is a decision-making tool for spatial planning, and geospatial decision making derives from computationally complex prescriptive methods. (Milutinović et al. 2021). The data using in this study are complex. Thus, GIS application by using overlay technique in grid cells was employed. These spatial database represents an analysis of flood frequency in the past, damage assessment caused by flood both tangible and intangible aspects, and an analysis of land use zone in order to prepare for flood management.

Research Objectives

The aim of this study was to determine land use zoning under the consideration of the expected flood loss value, to establish a guideline for the control of land use and building utilization that is suitable for the actual conditions of the area.

Study Area

The Noi River is a tributary of the Chao Phraya River, which flows from the north to the south through the eastern area of Sena District, Phra Nakhon Si Ayutthaya Province, central of Thailand. for a distance of 10.15 kilometers, with a river width of approximately 70-80 meters. The land use at 3 kilometers from Noi river, Sena district consists mostly of agricultural areas (97.61 % as peddy field), followed by urban and built-up areas and others, respectively. (LLD. 2016). The Noi River floodplain features zones that are designated as the urban zone, the rural and agricultural conservation zone, the rural and agricultural zone, and the open-space areas for recreation and environmental quality conservation zone of the Phra Nakhon Si Ayutthaya comprehensive plan. Apart from this plan, the Royal Irrigation Department (RID) has also proposed a water management strategy that focuses on designating the study area as a water storage area. Figure 1 illustrates the land use zone of the Phra Nakhon Si Ayutthaya comprehensive plan, which is different from the existing land use because the comprehensive plan considers the factors such as development strategy, physical characteristics, population density, economics, etc. in the analysis and determination of the land use zoning (DPT. 2021).



(a) Existing land use in the Noi River floodplain (LLD. 2016).

(b) Land use zoning according to the Phra Nakhon Si Ayutthaya comprehensive plan (Office of the Council of State. 2017).

Figure 1 Existing land use and land use zoning in the Noi River floodplain.

Research Methodology

The methodology of this study consists of four main stages: 1) Flood frequency analysis; 2) Flood damage analysis; 3) Flood loss assessment; and 4) Determination of land use zones. These are illustrated in Figure 2.

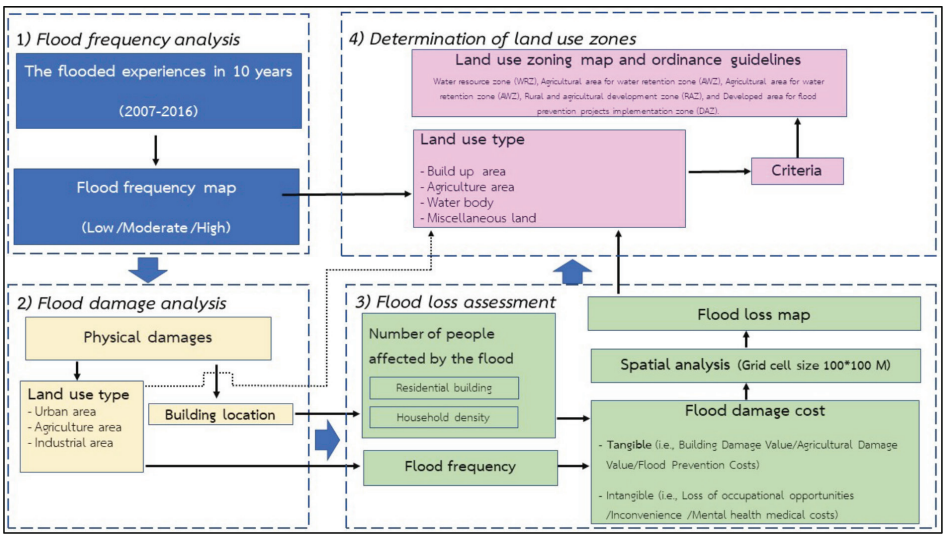


Figure 2 Research methodology framework.

1. Flood frequency analysis

The analysis of flood frequency relied on the overlay technique in the geographic information system provided by GISTDA, which used flood data of the past 10 years (2007-2016) and divided them into 3 levels by using the same criteria as the frequent flooding areas (LLD. 2020). The 3 levels consist of 1) low frequency level (≤ 3 times per 10 years); 2) moderate frequency level (4-7 times per 10 years); and 3) high frequency level (8-10 times per 10 years). The high frequency level represents a high-risk investment opportunity for development.

2. Flood damage analysis

Flood damage analysis deals with the physical damage expected to occur at different levels of flood frequency. The technique uses spatial analysis of 2 considerable data sets, namely Land Use data (LU) and Building Location (BL). LU from LDD in year 2016, was utilized on flood-hit areas. BL was defined by DPT (DPT. 2020b) for the purpose of determining the number of buildings.

3. Flood loss assessment

Since the losses are not exactly predictable, flood losses are assumed by the expected value which can be evaluated from the losses arising from the flood in the specified period. The objective of flood loss assessment in this study was to evaluate the expected economic losses to inform flood frequency with reference to the damage value from previous studies and to the compensation reference value set by a government agency. Flood losses used in the assessment cover both tangible and intangible losses as shown in Table 1. Flood Losses were calculated by combining the damage values on grids using the overlay technique in the Geographic Information System (GIS) Program. In this study, a grid size of 100x100 m was selected due to the limitations of the spatial data resolution using for analysis. In case of using a smaller grid, the spatial damage value of the flood loss map, which divided into three levels, will not much different from the selected grid cells for this study.

Table 1: Types of damage and flood damage value determination.

Type of damage	Value used in the assessment	Source
Building damage Value - Residential and commercial buildings - Other buildings	 49,500 Baht/Building 5,700 Baht/Building	Ministry of Finance (2013)
Agricultural damage Value (Calculated from rice farming investment costs)	4,710 Baht/Rai	Sena District Agriculture Extension Office (2016)
Flood prevention costs	5,178 Baht/Household	DPT (2019)
Loss of occupational opportunities	87,321 Baht/Household	
Inconvenience (Comparable to the cost of Relief Supplies Bag)	3,800 Baht/Building	Ministry of Finance (2013)
Mental health medical costs (Comparable to general assessment of therapeutic activities, individual consultation (by multidisciplinary team) and individual psychotherapy)	950 Baht /time X 6 time	KhonKaen Rajanagarindra Psychiatric Hospital (2020)

4. Determination of land use zones

To determine the suitable zone for each land use, the spatial data of a grid cell was used. Multi-Criteria Decision Analysis was employed under the criteria of three main factors which are 1) Existing land use (built-up or agricultural areas and miscellaneous land); 2) Flood frequency levels (low, moderate, and high); and 3) Flood loss levels (low, moderate, and high). This flood management zoning can be applied to correspond the physical characteristics of the area, and way of life of the locals, allowing them to stay in the area while minimizing the impact on their livelihood.

Zone 1 Water resource zone (WRZ): The environment surrounding this area should be protected and maintained, as it is a state resource area, to allow the water in its original natural conditions to be drained. The flood management zoning needs to present WRZ in order to preserve water body area as well as to promote local occupations; which are mainly dominated by agriculture.

Zone 2 Agricultural area for water retention zone (AWZ): Agricultural or miscellaneous areas at a high frequency flooding level with low losses. These areas should be preserved for the benefit of drainage or as an area for water detention.

Zone 3 Rural and agricultural development zone (RAZ): The areas in this zone are miscellaneous and agriculture land at low frequency flooding but characterized by high or moderate losses and urban areas at high frequency flooding with moderate or low losses. They must be conserved for natural water drainage.

Zone 4 Development control zone (DCZ): Areas in this zone can be developed under a defined zoning ordinance or building code. They are areas of low frequency flooding where low loss value will occur.

Zone 5 Developed area for flood prevention projects implementation zone (DAZ): This is a dense urban area that represents the center of activities. If flooding occurs, it will cause a great deal of damage.

When the zones were arranged in a geometrical pattern, the final step was to adjust the zone geometry to enable the description of the physical characteristics of the area. The zones are defined according to the chart in Figure 3.

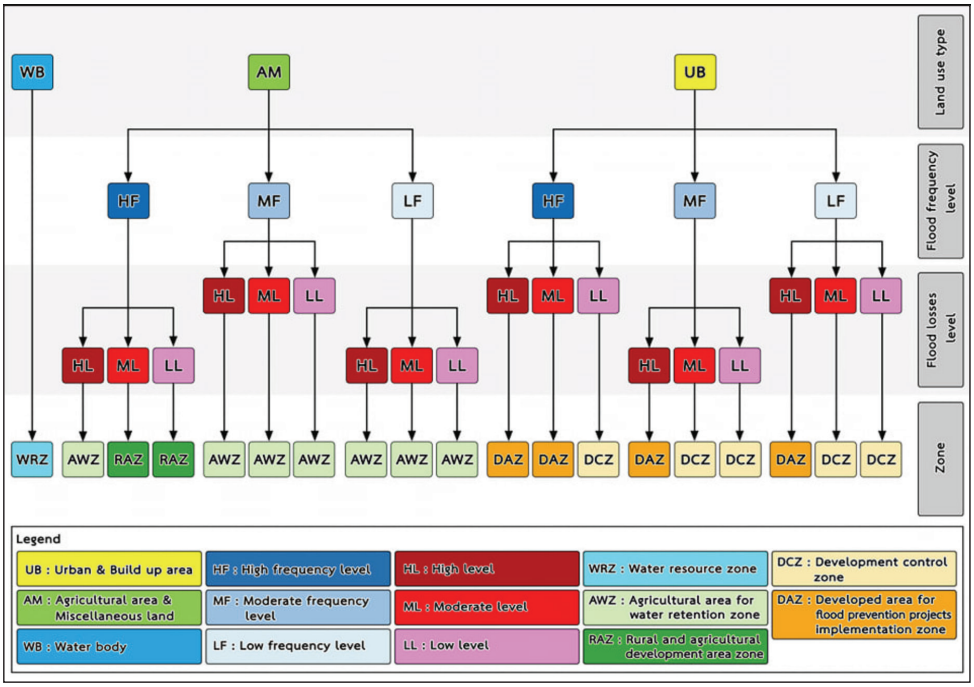
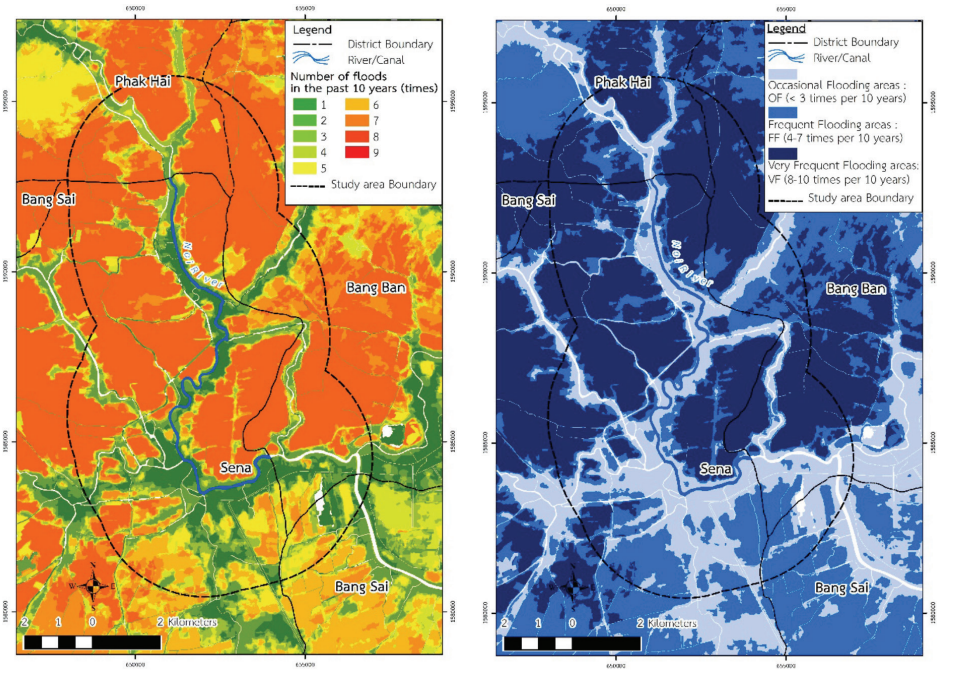


Figure 3 Guidelines for determining land use zone

Results and Discussion

1. Flood frequency level and flood damage analysis

The analysis of flood frequency in the study area found that the high frequency level (HF) often accompanied the upper part of the study area. There were lowland areas reserved for paddy fields and other agricultural practices. While areas with the moderate frequency level (MF) were small and in the connectivity area of the Noi River and tributaries, the areas adjacent to the Noi River and tributaries, the road, and the areas adjacent to the road were of the low frequency level (LF) because of their high elevation than that of other areas. The business center area or the Sena municipality was also in an LF area as shown in Table 2 and Figure 4



(a) The number of flooded. (b) Flood frequency in the past 10 years.

Figure 4 The frequency of flooding in the area around the Noi River in Sena District.

Table 2: The expected damage according to the flood frequency level.

Flood Frequency Level	Area (km^2)				Number of Buildings Affected (N)					Number of Affected People (people)
	Urban & build up area	agricultural area	Miscellaneous land	Total	Residential Buildings	Buildings in Agriculture	Commercial and Industrial Buildings)	Other Buildings	Total	
LF	16.28	7.22	4.29	27.78	12,514	943	948	1,879	16,284	46,084
MF	1.60	22.42	0.77	24.79	534	590	48	213	1,385	3,920
HF	0.13	49.21	0.31	49.64	6	119	1	27	153	433
total	**18.00**	**78.84**	**5.37**	**102.21**	**13,054**	**1,652**	**997**	**2,119**	**17,822**	**50,436**

According to Table 2, although HF areas were the largest, only LF areas were significantly affected by floods that ravaged buildings and people. Overall, the areas affected by flooding at all frequency levels included a total of 17,822 buildings, most of which were 13,054 residential buildings in urban areas and 1,652 agricultural buildings. These eventually affected 50,436 people in all areas (calculated from the density 2.83 people per household (DPT. 2019).

2. Flood loss

Flood loss assessment was conducted in two steps: 1) The analysis of the total flood loss by weighing up the relevant factors and 2) The analysis of spatial flood loss. The details are outlined as follows.

2.1 Assessment of the expected flood loss

Flood loss obtained from the analysis was assumed in a hypothetical flooding scenario and calculated at the specified damage value of each factor. The analysis results showed that, if all areas were affected by floods, the flood loss would be 2,396.06 million baht. This could be specified as the loss of occupational opportunities for the greatest amount due to farmers in the area having other occupations. Thus, compensation value would be high when this factor is counted, followed by the building damage value in urban areas and agricultural damage value, respectively. The results suggested that 83.52 percent of the total flood loss were in low frequency level areas. These areas had a small chance of flooding; however, if they were inundated, the effect from flood loss would be substantial, as shown in Table 3.

Table 3: The expected flood loss under the flood frequency level.

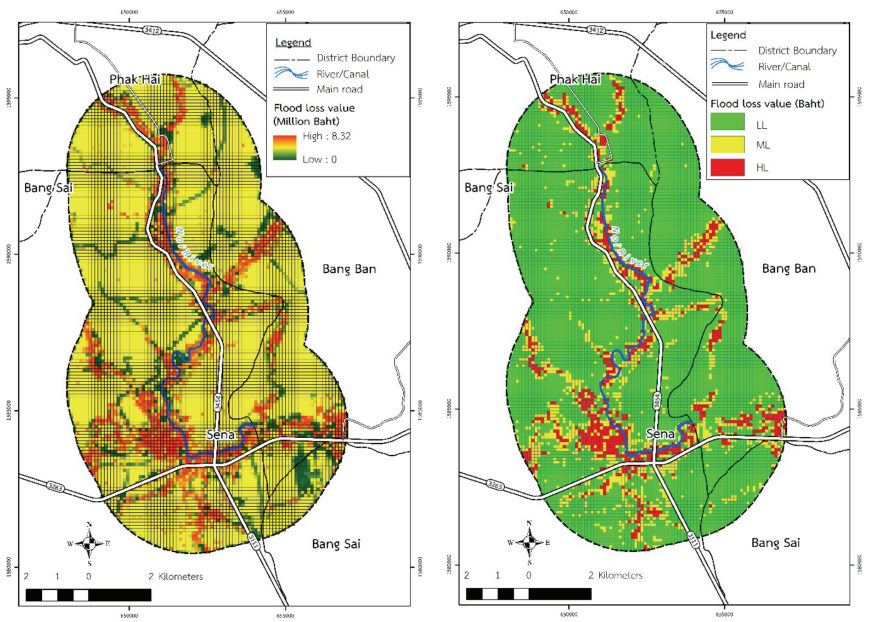
Flood Frequency Level area	Flood losses (million baht)							
	Building Damage Value							
	Urban area	Agriculture area	Agricultural Damage Value	Flood Prevention Costs	Loss of Occupational Opportunities	Inconvenience	Mental Health Medical Costs	Total
LF	666.12	10.71	21.25	74.59	1,175.08	51.14	2.39	2,001.28
MF	55.64	1.21	65.98	6.07	98.15	4.27	0.20	231.53
HF	6.19	0.15	144.85	0.65	10.92	0.48	0.02	163.25
Total	**727.95**	**12.08**	**232.08**	**81.31**	**1,284.14**	**55.88**	**2.61**	**2,396.06**

2.2 Spatial flood loss analysis

Flood loss evaluation was calculated by combining all flood losses on 100 x 100 m grids in the GIS Program. This study divided flood risk into three levels including low (LL ≤ 0.1 million baht), moderate (ML = 0.1 -1.00 million baht), and high (HL≥ 1.01 million baht). The analysis showed that in one grid, the highest flood loss was 8,320,672 baht (Figure 5 (a)). And almost half of the grids used for analysis were grids located in the HF and LL coordination, followed by grids located in the MF and LL coordination. Clearly, although the overall flood loss was the highest in the LF level, the spatial damage value was higher in the MF and HF levels, as shown in Table 4 and Figure 5 (b).

Table 4: Calculation of flood loss level on grid cell.

Flood Frequency Level	flood losses (million baht)	flood loss level (Number of grids) (Number of grids)			
		HL	ML	LL	Total
LF	2,001.28	762	1,106	928	2,796
MF	231.53	38	363	2,042	2,443
HF	163.25	2	123	4,850	4,975
Total	**2,396.06**	**802**	**1,592**	**7,820**	**10,214**



(a) Flood loss on grid cell. (b) Flood loss level after data grouping.

Figure 5 Flood loss value of the study area.

Figure 5 shows that the HL found in 3 areas consisted of 1) the southern part of the area, which served as the business center area; 2) the area adjacent to the river or canal, which has been the settlement area since the past; and 3) the area along the main road, designated to support the expansion of buildings. The HL areas were surrounded by the ML areas because of the low density of buildings and residences. The LL areas were mostly found to be paddy fields. Nonetheless, some parts of the agricultural areas were also found to contain ML areas.

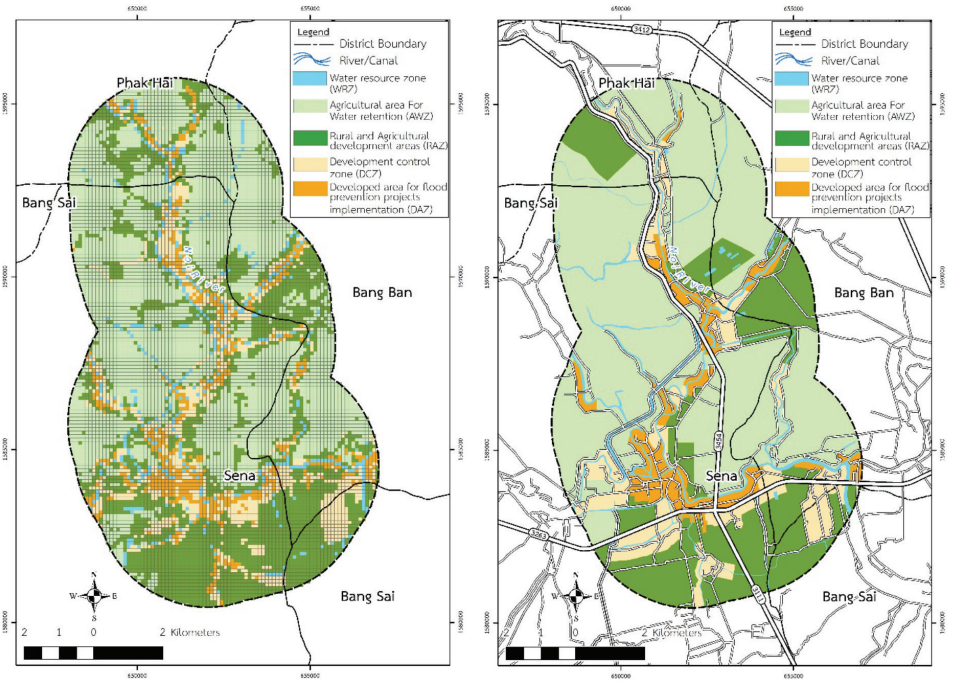
3. Land use zoning for flood management

The results of the flood mitigation zoning, under certain conditions, suggested that most areas should be designated as AWZ, followed by RAZ and DCZ, respectively. The determination of the areas in this manner would add more particularized details to the land use zoning approach by the Phra Nakhon Si Ayutthaya comprehensive plan, providing a better association with the basic information of the area, as shown in Figure 6. and Table 5.

Determination of land use zoning for flood management is vital in order to present suggesting methods for damage reduction from floods in the future. Land use zoning for flood management based on the expected flood loss in this study. Results lead to the comparison of the spatial damage value with the investment cost in flood prevention and mitigation projects, both structural and non-structural measures.

Table 5: Land use zoning area size.

Zone No	Zone Name	Number of grids	Zoning adjusted	
			km^2	%
1	Water resource zone (WRZ)	455	5.22	5.11
2	Agricultural area for water retention zone (AWZ)	4,931	57.94	56.69
3	Rural and agricultural development zone (RAZ)	2,990	23.10	22.60
4	Development control zone (DCZ)	1,166	9.88	9.67
5	Developed area for flood prevention projects implementation zone (DAZ)	672	6.07	5.94
	Total	**10,214**	**102.21**	**100**



(a) Zoning on grid cell. (B) Zoning adjusted to the physical.

Figure 6 Land use zoning for flood management.

Conclusions and Suggestions

Land use zoning for flood management by using flood loss assessment takes into account flood risk through flooding experiences and the current conditions of the area. Remarkably, this approach of zoning provides a clearer insight than the one that relies on the risk level alone. Land use zoning must accurately define the building code according to the purpose of the zones, including the definition of the open-space areas along the river for proper drainage based on the river size or the flood return period. Importantly, land use zoning for flood management can specify the areas for implementing projects for flood prevention and mitigation. Zoning, where the initial flood loss was assessed, is also essential for preparing a budget for flood prevention and mitigation. It can also be useful for flood risk management strategies, transfer development rights (TDRs), flood insurance and other flood mitigation measures in the future. Finally, it is vital that zoning incorporate the expected damage value. For a special development plan, this technique might be applied in a multidisciplinary fashion by integrating public policy, demography, economy and other social factors into the implementation in accordance with the principles of urban planning and through the participation of local communities.

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