A Flood Damage and Shelter Need Assessment: A Case Study of Mueang Sing Buri, Thailand

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Abstract. Flooding is one of the main disasters in Thailand and Mueang Sing Buri is among those areas hit. Located on the Chao Phraya River Basin, in the central region of Thailand, the area receives a large amount of runoff during monsoon seasons which causes frequent flood disasters. The aims of this research are to create a flood hazard map and to estimate the number of people that may need shelter after the occurrence of a flood, and to evaluate whether the shelter capacity is adequate in Mueang Sing Buri. To explore the potential locations of emergency shelters, the relevant information related to flooding was initially recorded, such as building detail, flood depth, elevation map, and flood risk map. The available space of each building varies by the characteristics of building types. The calculation of shelter capacity thus depends on characteristics of the buildings, accessibility, and percent of vacant area. The emergency shelter assessment benefits many sectors in the design of preparation plans for hazard management.

1. Introduction
Flooding naturally occurs every year in Thailand, around the Chao Phraya River Basin in particular. This basin is the most important basin in Thailand, covering 30% of Thailand’s land area and about 40% of the country’s population [16]. It combines the economic and historical heartlands of Thai settlements, including the capital of Thailand, Bangkok. However, this basin receives a large amount of runoff during monsoon seasons that causes frequent flood disasters. Many communities have suffered from extensive severe flooding, especially in 2011 and 2013. These disasters resulted in a detrimental impact on life and properties. These severe floods have been aggravated by major factors such as rapid urbanisation, reduction of flood retention areas and the intensification of agricultural practices. The Thai government has controlled floods through the construction of multi-purpose reservoirs, dikes (diversions) and other flood control infrastructures. These methods have been successful in reducing the volume of floodwater, however they can still fail when floodwater rises quickly in the areas with no flood-protection infrastructure [3]. Apipattanavis et.al 2018 [1] mentioned that Thailand developed strategic plans for better water management for the next 20 years regarding the Committee on Water Resources Policy and Management, established in 2015. However, the plans do not focus extensively on emergency shelter or early warning.

Emergency shelter is likely to be one of the most important preparations for many hazard management systems. After a devastating flood, the local government should prepare efficient shelters...
for victims. Whitehead et al. (2000) claimed that households with higher incomes tend to evacuate to motels/hotels and households with higher education and/or with pets and children are more likely to stay with family. On the other hand, low-income and minority families with children or elderly members are likely to evacuate to shelters. Flood shelters in three locations along three major rivers were visited, and communities were consulted to address selected issues regarding shelters. To explore the potential locations of emergency shelters, information related to flood management was initially recorded such as building details, flood depth, elevation, and flood risk areas. The available space of each building varies by the characteristics of building types. For example, hospitals and stadiums have more floors and provide a larger floor space than single residential and religious buildings. In Bangladesh, there are 3 major types of flood shelters which are community shelters, school-cum-shelters, and individual homesteads. Each type has different functions and purposes to serve refugees [11]. In terms of mass shelter design framework proposed by London Resilience Group (2018) [8], emergency shelters have been divided into 2 groups; 1) emergency evacuation centres designed for short-term living and large numbers of evacuees (5000+) and 2) emergency rest centres designed for no more than 200 evacuees providing basic facilities for longer stays. The suggested building types for the first group are large public and private spaces such as large exhibition halls, large night club venues, large sports centres, shopping centres and large multiplex cinemas. The possible building types for the second group is dependent on the arrangements of local authorities.

However, some building types for supporting evacuees are occupied by more daytime occupants than night-time occupants. The calculation of shelter capacity thus depends on the use of the buildings, the population occupying the building in the daytime and percent of vacant area which can be used for the construction of temporary camps or tents outside the buildings. Some land uses have large vacant spaces such as recreation areas or parks and public religious zones, while others have few vacant spaces such as hospitals.

The aims of this research were to assess flood-risk buildings and populations affected in the 2011 floods. The second is the finding of shelter availability for evacuation. Ultimately, the results of this research can provide local authorities and policy decision-makers with a baseline flood hazard assessment to design urgent mitigation measures and support local communities through education and preparedness for future flooding.

2. Study area

Sing Buri province is located in the Chao Phraya River Basin, a major rice production area in the central region of Thailand (Figure 1). The province has been regularly subjected to large flooding events during monsoon seasons in Thailand. In addition, most areas of the province are flood plains, which have elevations ranging approximately from 3.5 to 15 metres [14]. In 2011 there was severe flooding which caused extensive damage to life and property of communities. It ranged from late July 2011 to mid-January 2012, triggered by the landfall of tropical storm Nock-ten. Damaged areas accounted for 9.1% of total land area of the country covering 69 provinces [7]. Many flood victims lost their homes and needed to evacuate to temporary shelter. Particularly, Mueang Sing Buri district was inundated by water up to two metres deep in some residential and commercial areas in 2011. Residents had to move their belongings to higher ground without prior planning, and some families evacuated to emergency shelters.

The total area of the province is 822.48 km². Most land use is agriculture (74.22%), which is mostly paddy rice, accounting for 66.87% of total agricultural areas, followed by built-up areas accounting for 18%. The population of the province was 208,446 with 77,432 households in 2019 [13]. This paper will evaluate the capacity of possible emergency shelters to support the number of residents who may be affected by floods in future disasters.
3. Methodology
The study started with flood inundation mapping by using a set of flood depth points from a field survey. Next, the Kriging interpolation technique was applied to create a flood hazard map from flood inundation data of Sing Buri province though the Geographic Information System (GIS). Kriging is a spatial interpolation method that generates an estimated surface from a scattered set of points with z-values. The principles of Kriging consider both the distance and the degree of variation between surrounding known data points when estimating values in unknown areas [10]. Generally, Kriging has 2 types: point Kriging and block Kriging. The point Kriging estimates parameter at a point and suits smaller amounts of data, while the block Kriging estimates parameter at the centre of a block and suits larger amounts of data [12]. Kriging has been widely applied to interpolate various geographic data such as rainfall, soil and geology operating on GIS environment [2, 10]. Its general formula is calculated using Eq [10]:

\[ Z(s_0) = \sum_{i=1}^{n} W_i Z(s_i) \]

where:
- \( Z(s_0) \) = the measured value at the \( i \)th location
- \( W \) = an unknown weight for the measured value at the \( i \)th location
- \( s = \) the prediction location
- \( N = \) the number of measured values
In addition, the weight \( W \) depends upon the distance between the measured points and the prediction location and also on the overall spatial arrangement of the measured points.

A flood hazard map is an important tool in flood risk management and is used to qualify the levels of flood risk to buildings and estimate building losses using the relevant flood occurrence information. The next step of this study was to analyse flood damage. Regarding the Atlas of Flood Maps proposed by EXICMAP in 2007 published by the Ministry of Transport, Public Works and Water Management, The Netherlands [5], levels of flood damage classified by flood depth classes are as follows (Table 1):

**Table 1. The characteristics of flood damage in effect of inundation depth levels**

| Flood depth (metre) | Flood damage characteristics |
|---------------------|------------------------------|
| 0-0.5               | Most houses will stay dry and it is still possible to walk through the water |
| 0.5-1               | There will be at least 0.5 m. of water on the ground floor and electricity will have failed |
| 1-2                 | The ground floor of houses will be flooded, and the inhabitants have either to move to the first floor or evacuate |
| 2-5 and >5          | Both the first floor and often also the roof will be covered by water. Consequently, evacuation is the logical choice of action now |

Then, the study integrated the consequence of building losses with the hazard map to analyse the total number of people in affected buildings. In the meantime, the land use map, flood map and flood risk building map were overlaid to extract the possible places for offering shelters. The final step was to calculate the capacity of these shelters to support the total number of people suffering from the flood and needing to go to these shelters. Thus, the shelter availability was presented in a map for evacuation preparation.

4. Results

4.1. Flood hazard map

In this study, LiDAR derived Digital Surface Model (DSM) and the set of flood depth data from a field survey of the 2011 flood were analysed to create the flood inundation map using interpolation (Kriging technique) to interpolate flood depth of Sing Buri province (Figure 3).
**Figure 2.** Flood depth data from Sing Buri (data source: the Department of Mineral Resources)
In regard to the field survey after the flood, there were some areas and main streets that had not been affected by flooding due to dikes and flood control infrastructures. Therefore, it was necessary to eliminate those areas from the flood inundation map and to recheck flood magnitude with a specific return period between 50 years and 100 years derived from secondary data calculated from Nays2D Flood program (data source: the Department of Mineral Resources). A flood hazard map was then developed (Figure 4) which was subsequently classified to better depict probability of flood between 0 and 3 corresponding to flood depth interpolation.

**Figure 3.** Flood inundation model computed by the Kriging interpolation of flood depth
4.2 Calculation of building damage and losses

The flood damaged area and elements at risk in this study were developed from the overlay of the built-up area/land use map and flood hazard map. The percentage of buildings affected by flooding of 1 metre or more was calculated. With at least 1-metre flood depth, the ground floor of houses will be flooded, and the inhabitants have either to move to the first floor or evacuate. The main land use type of Sing Buri is agriculture followed by residential area and commercial area respectively. Generally, most people affected by flooding live in the residential and commercial built-up areas. Thus, this study selected damaged commercial and residential buildings and then estimated the number of flood victims. The total number of buildings affected by flooding is shown in Table 2, however records of the amount people who live in each building/house was not available. Therefore, the average number of occupants per household in Sing Buri was calculated. In 2011 the total population was 52,867 and total households was 15,289 [13]. The average number of people living in each dwelling was 3 people/dwelling. The number of flood victims that required emergency shelter was estimated to be around 33,132 people (Table 2).

Table 2. Number of affected buildings and people in Mueang Sing Buri

| Building type    | Number of affected buildings | Number of people affected by flood (homeless) |
|------------------|------------------------------|----------------------------------------------|
| Commercial area  | 1265                         | 5060                                         |
| Residential area | 7018                         | 28072                                        |
4.3 Shelter capacity

The Sphere Project [15] conducted by the London School of Hygiene and Tropical Medicine recommends that residents have at least 3.5 m² of indoor living space per person as minimum standards in a disaster response. The available space of each building was obtained from the area of floorspace. Therefore, shelter capacity was calculated from the floorspace, the number of occupants who use the buildings daily, and vacant area. However, the entirety of this floorspace cannot be used to support shelters. In this study, it was assumed that 60% of total could function as vacant areas for shelters. Therefore, the maximum capacity of each shelter was calculated as:

\[
\text{Maximum capacity (number of people) = \left( \frac{\text{Building area} \times 0.6}{3.5 \text{ m}^2} \right)}
\]

Shelter availability was initially analysed through the integration of land use map, elevation map, and flood risk building map as the base maps for extraction of non-flooded areas. Then, these extracted possible areas were linked with the flood damage map to show possible buildings for shelters on the building map. Then, the selection of possible shelters was overlaid with the non-affected hazard map to find potential shelters that were not affected by flooding. The basic criteria were concentrated on the high land and non-flooding areas which focused on the land-use types of public places and recreation parks. In addition, the potential shelters should be close to the road access. According to the criteria above, the map result was generated using on GIS (Figure 5).

Figure 5. Selected candidate buildings for emergency shelter
Next, these non-damaged buildings were selected in built-up areas to apply as shelters, which included schools, recreation parks, and stadium/multi-purpose buildings. Areas that were located on high land at an altitude more than 6 metres (about 2 floors) were prioritised for selection as available shelters. The results showed that 37 buildings located in unaffected-flood areas were selected as candidates for setting emergency shelters which combined could accommodate around 18,807 people (Table 3).

| No. | Schools | Capacity | No. | Temples | Capacity | No. | Multi-Purpose Buildings | Capacity |
|-----|---------|----------|-----|---------|----------|-----|--------------------------|----------|
| 1   | Wat Phrom Sakhon School | 353 | 19 | Wat Phrom Sakhon | 1,164 | 36 | Chak Si Village Multi-Purpose Building Phra Non Village Multi-Purpose Building | 23 |
| 2   | Wat Khlong Sam Yaek School | 159 | 20 | Wat Khlong Sam Yaek | 360 | 37 | |
| 3   | Wat Phu Langka Mitraphap 22 School | 325 | 21 | Wat Chaeng Phrom Nakhon Phitak Phrom Nakhon | 761 | |
| 4   | Phrom Nakhon School | 376 | 22 | Wat Klang Phrom Nakhon Phitak Phrom Nakhon | 798 | |
| 5   | Wat Rat Prasit School | 162 | 23 | Wat Chaksi | 573 | |
| 6   | Wat Srisakorn School | 476 | 24 | Wat Daowadueng | 819 | |
| 7   | Wat Sawang Arom School | 182 | 25 | Wat Buddha | 403 | |
| 8   | Wat Sao Thong Thong School | 268 | 26 | Wat Phranon Chaksi Worawihan Wat Pho | 2,134 | |
| 9   | Thetsaban 3 Kindergarten | 200 | 27 | Kaeo Noppaphakhu Wat Yuat | 432 | |
| 10  | Pho Rat Waranunon Kindergarten Sing Buri Kindergarten | 46 | 28 | | 440 | |
| 11  | Saeng Thien Kindergarten | 2,156 | 29 | Wat Rat Prasit Wat Si Sakhon | 665 | |
| 12  | Sing Buri Kindergarten | 264 | 30 | Wat Sala Bap | 431 | |
| 13  | Vocational Education College Sing Buri Non-Formal Education Center | 921 | 31 | | 415 | |
| 14  | | 466 | 32 | Wat Sathian Watthanadit | 31 | |
According to the calculations of the maximum capacity of the 37 available shelters, shelter no.11, a school, had the largest capacity to support the victims, followed by the religious buildings no.26 and no.19 respectively. Most schools had lower capacity in the daytime as they are full of students. However, students may not attend school during a flood in reality, so these schools could support affected people to their maximum capacities without subtraction of occupants.

The capacities of available shelters (no.1-37) were compared to the number of affected people who need shelters after flooding. According to the previous results of vulnerable people made homeless in this scenario, they amount to 33,132 people. Therefore, the proposed shelters showed not enough capacity to support evacuees at this time. It is necessary to consider other potential shelters including temporary emergency shelter such as tents in public open spaces.

5. Conclusion

Emergency shelter is likely to be one of the most important preparations for many hazard management systems because it is the basic need of the homeless after an emergency event. An application of GIS is its use as a tool to perform not only the hazard risk assessment but also identify shelter availability. The results revealed that there were some public places with the potential to serve as flood shelters such as public recreation spaces, schools, and temples. In addition, the temple had the largest capacity to support flood victims. As the results of this study show, the capacity of emergency shelters analysed was insufficient for the number of victims. However, according to the information from the Disaster Prevention and Mitigation Centre of Sing Buri province, 18 evacuation centres for flood victims were established in 2011. Among these, only two places, Sing Buri Vocational Education College and Wat Sala Bap, were located in our proposed shelters. Therefore, the list of unaffected buildings from this study could be taken into consideration for establishing more emergency shelters within the Mueang Sing Buri area so that in the case of future flood occurrence, there would be enough space for those who need it. Furthermore, suitability shelter assessments may be used with the existing shelters for more effective management. For example, the assessment of the suitability of a location, and whether it is located in a high risk area for landslides due to a high volume of water in the soil [9], accessibility of the shelter within a short period of time during flood occurrence, nearest route from the shelter to other vital facilities such as hospitals or command centres [6]. A Thiessen Polygon could be used to analyse coverage of the shelter [4] because these shelters

| Shelter                | Capacity/building use | Total capacity |
|------------------------|-----------------------|----------------|
| Chaksi School          | 544                   | 10,928         |
| Wat Sao                | 869                   |                |
| Chom Chon              | 304                   |                |
| Wat Na Phra            | 145                   |                |
| Wat Phra Non           | 204                   |                |
| Thong Thong            | 33                    |                |
| Wat Na Phra            | 34                    |                |
| That                   |                       |                |
| Wat Sawang             | 488                   |                |
| Arom                   |                       |                |
| Tessaban 4 School      | 7,820                 | 18,807         |
| Pho Rat                |                       |                |
| Commercial School      | 414                   |                |
|                         |                       |                |

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can be used not only to provide temporary accommodation but also serve as centres for providing essential needs within the area as well.

In addition, further research is suggested to consider available daytime and night-time shelter capacity separately. Most daily occupants at schools use these spaces during the daytime only. The night-time occupants are the priority for shelters because they are residents and need emergency shelters for sleeping. However, this study presented maximum capacity of shelters in general without considering the number of temporary daytime occupants at schools in particular. Therefore, these available shelters with fluctuating occupancy can support as many night-time occupants as the floorspace allows without the subtraction of daytime occupation. In addition, the study considered the outdoor shelter through the vacant space of each shelter building. These places can be used for constructing mobile shelters or erecting tents. In reality, several factors should be considered when calculating the specific space of living per person in the shelter. It may vary based on the type of land use and financial support from the government to prepare proper shelters.

Acknowledgements
This research paper was supported by the Chulalongkorn University-Faculty of Arts research fund. We would like to thank Mr Surasak Boonlue at the Department of Mineral Resources, Thailand for providing the set of flood depth data from a field survey of the 2011 flood and other information related to flood events.

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