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Geographic Information System for Flood Hazard Area Delineation and Estimation of At-Risk Households at the Community Level: A Case Study of Salaya Sub-District, Nakhon Pathom Province

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Abstract

Every year, Thailand faces flooding, the greatest natural disaster threat for the country. It is at the household level where risk outcomes first materialize. This study delineates flood-hazard areas in Salaya sub-district and provides estimates of at-risk households located in this area by using geographic information system (GIS) technology with Potential Surface Analysis (PSA) and Overlay Analysis. The analysis classifies areas into different levels of hazard, hazard zones and at-risk households. The results show that 41.6% of the sub-district is an area of "moderate" flood hazard, comprising 10.45 square kilometers. "High" flood-hazard areas account for 8.98 square kilometers (35.9%), "low" hazard areas represent 4.28 square kilometers (17%) and "very low" hazard areas account for 1.38 square kilometers (5.5%). As or the number of households in the hazard area, it was estimated that the highest percentage—1,160 households or 50%—are located in moderate flood-risk areas, followed by low flood-risk areas (560 households or 24%), high flood-risk areas (521 households or 23%), and very low flood-risk areas (70 households or 3%). All results are shown on a map of the study area with a 1:50,000 scale.

Keywords

GIS; PSA; flood hazard area; Thailand

Introduction

Thailand is a country at risk of flood disaster. The household is the primary unit of a community to be hit by disaster impacts. Lacking risk analysis at the local level means that households are incapable of taking action in due time. Unexpected and severe flooding occurred in Thailand in 2011. Flood damage was dispersed in every region of the country. In total, 65 out of Thailand's 77 provinces were affected by flooding, with most damage concentrated in the industrial estates and residential areas in the Central Plains (Centre for Research on the Epidemiology of Disasters, 2011).

After the 2011 flooding, the Thai government intensified its attention to water resources and disaster management using proactive disaster management as a strategy, with long- and

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short-term flood prevention plans. This strategy includes measures for disaster preparedness to reduce risk, especially in the pre-flood season (June-October). The concept of risk assessment was considered a tool to evaluate risk especially in vulnerable areas. Key steps in flood-risk reduction include the classification of risk areas and estimating the probability of flooding at the community and societal levels. The analysis will enable a more thorough understanding of the nature of natural disasters, obstacles that effective disaster management, exacerbating environmental factors, and changes in vulnerability in the future. Accurate assessment of risk by level of severity (Department of Disaster Prevention and Mitigation, 2013) relies on both quantitative and qualitative data collection tools of high quality. These tools can be used to depict disaster risk in a variety of ways, such as maps with color-coded risk differentials. Simple displays of complex data help improve understanding by policymakers, local officials and local populations. One such tool is geographic information system (GIS) technology.

GIS, a popular tool used in risk assessment, is a form of computerized spatial data that specifies spatial position. Addresses or house numbers on the map, along with latitude and longitude, are stored in data tables. Data in the spatial database can be analyzed to find time-related changes such as the spread of an epidemic, migration, area invasion and shift of land use. With GIS, data can be very precise by specifying a set or series of geographic coordinates (spatial data) which portray an image of an area. The GIS data can then be merged with other data (e.g., epidemic disease, migration, squatter settlements, types of land usage) and time to portray patterns and trends.

GIS can combine geographical factors and risk assessment models to illustrate risk area mapping related to different natural disasters (Peggion, Bernardini & Masera, 2008). Since 1970, geographers have been using approaches for assessing risk in a spatial context. Imaging of spatial risk quickly conveys existing vulnerability in ways that are accessible to the non-technical population, as well as experts. This form of assessment can also be used to predict future risk based on historical information. Spatial risk imaging generally consists of three main steps: 1) creating a map of risk areas; 2) evaluating vulnerability to damage by the risk; and 3) prioritizing the physical factors, and analyzing the correlation between human land use, natural phenomena and the environment (Hewitt & Burton, 1971).

At present, GIS and Potential Surface Analysis (PSA) are two tools that are recognized and widely used in disaster management. These techniques are used to analyze disaster risk and create maps showing the risk of damage potentially caused by a disaster. The analysis prioritizes the target areas by risk of disaster and level of potential impact. Applications of this technique include the research by Mayomi, Dami and Maryah (2013) which involved a risk assessment of 120 communities on the banks of the Benue River floodplains in Adamawa State, Nigeria. The information from that assessment was used to inform recommendations for location of lower-risk settlements and guidelines for flood preparedness in areas of elevated risk (Chumriang, 2008). In Thailand, as part of a flood-risk analysis in 1996, the Forestry Research Center of the Faculty of Forestry, Kasetsart University in collaboration with the Office of Environmental Policy and Planning, developed an assessment model by using a physical database to not only assess the flood and drought situation in the Northeast Region of Thailand, but also to define the boundary of the flood-risk area, using GIS. Furthermore, under a project called GIS Development for Drought and Flood Monitoring and Surveillance, the Information Technology Center, under the Department of Water Resources, applied the geo-informatic and remote sensing technique to monitor and analyze the flood and drought situation in all regions of Thailand. In addition, the Department of Water Resources also adopted GIS for monitoring flash flood risk throughout the country. This information regarding flash flood risk has been disseminated to the relevant communities and offices to help with preparedness, safety and security. In this way, prevention and preparedness resources can be more efficiently allocated. This information improves efficient risk management, especially in the preparation process (Dhanarun & Amonsanguansin, 2010).

The Chao Phraya River Basin covers a broad area with about 20 million people (30% of the total Thai population) (DHI Singapore, 2012). This area has been adversely affected by flooding in the past, especially when the river breeches its banks. Many people living in this area have experienced flooding and are always on guard for the next flood. Many homeowners have built their houses so that the main floor is as high as 13 feet above the surrounding ground level. They also often have small motorboats on hand if road access is cut off (Phisphumvidhi, 2012).

Changing patterns of land use, livelihoods and habitats exacerbated the effect of the large amount of floodwater in 2011 in Thailand. For example, in recent decades, there has been a conversion of land, from agricultural use to the construction of factories, retail outlets and housing developments, thus reducing the ability of the land to absorb excess water. Urbanization that is accompanied by rapid expansion of construction presents a major obstacle to water flow, and often eliminates natural drainage channels that have historically protected settlements over many generations.

The decline in the number of young Thais who pursue careers in agriculture is resulting in a gradual extinction of traditional wisdom about how to cope and prepare for life in a river basin environment. Earlier generations had a special sense of the relation between the direction of the winds and water flow, seasonal change, lunar and solar cycles, and variation in the height of the water level. Based on these observations of natural phenomena, farmers of the past were able to anticipate and adapt to changing patterns of water flow. At the same time, the new generation views the traditional style of construction of houses on stilts as old-fashioned and antiquated. They also view the solution to flooding in terms of dams and other man-made ways of controlling nature (Martin-Breen & Anderies, 2011).

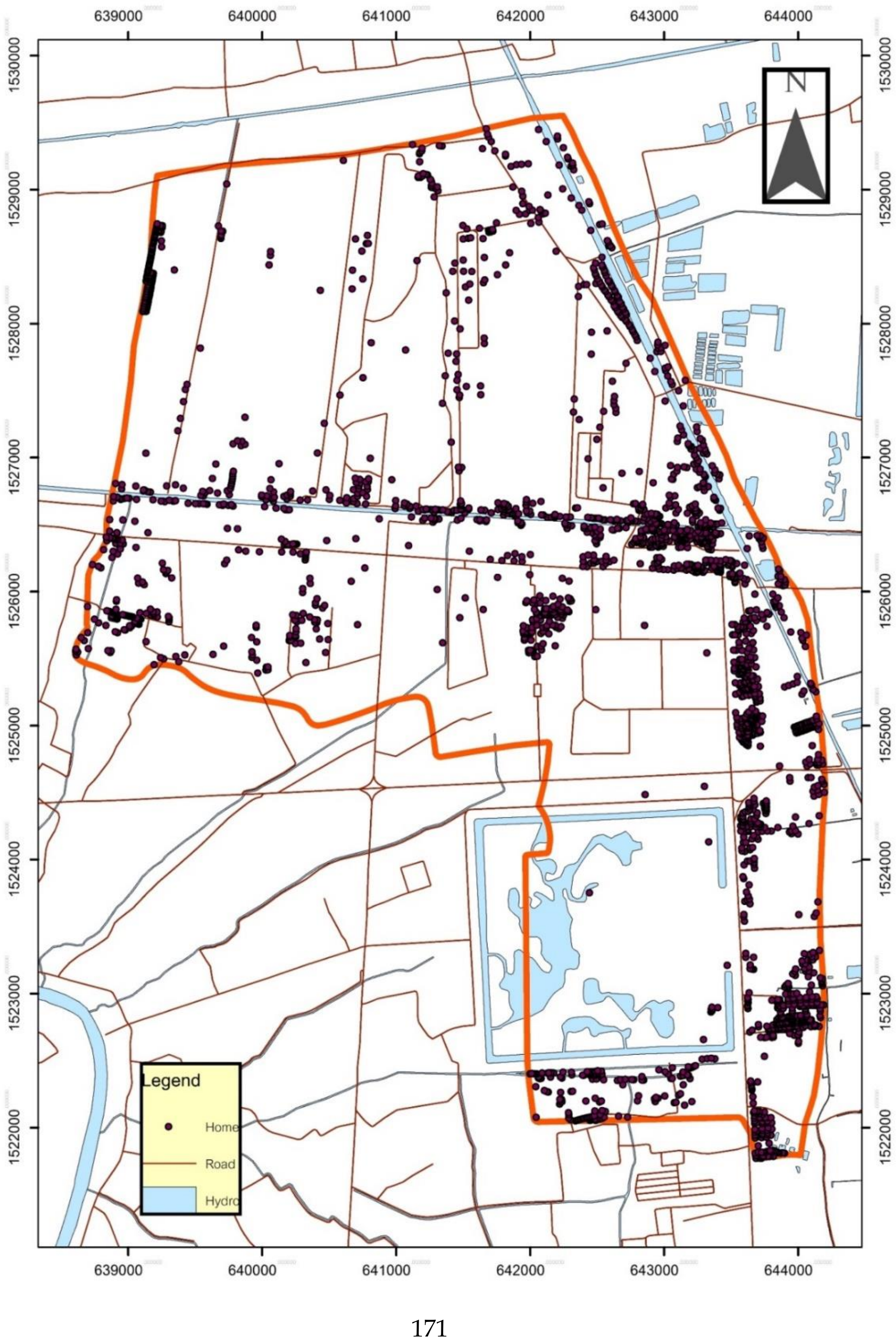
Additionally, demographic changes—such as increases in single families and the older adult population in the community—have also made disaster management more difficult due to the urgent need to move dependents and valuables to higher ground or to sanctuaries (Middelmann, 2002). Often, when flood disaster strikes, it is found that many households hardly knew about their risk in order to be prepared. Therefore, with the increased variability and severity of climate change expected in the future, it will be more important than ever for households to reduce flood risk by understanding their level of vulnerability and make appropriate preparations to mitigate the impact, which are certain to be different than what Thai people have experienced in the past.

In this study, the objective was to delineate flood-hazard areas and produce estimates of at-risk households located in the target area by using GIS technology with PSA and Overlay Analysis. The results were displayed on a map at a 1:50,000 scale, which presents more details and specific attributes of the study area. Mapping flood-hazard areas and households is an important first step in the proper management of future flooding events. It helps reducing the risk of flooding at the community level, which is the first social unit impacted by disaster. Additionally, the results of this study can help small municipalities that wish to conduct a cost-effective flood vulnerability assessment and design appropriate approaches or policies to reduce the risk of future flooding.

Study Area

Salaya, a town west of Bangkok in Nakhon Pathom Province, was selected to be the study area in this research project due to its location in the Central Plains of Thailand, part of the Chao Phraya River Basin. Some flooding occurs annually in this area, though the extent of flooding can vary greatly from year to year, as witnessed by the unprecedented flooding in 2011. In that year, most of the households in Salaya sub-district were adversely impacted by the floods, with different degrees of loss (Department of Disaster Prevention and Mitigation, Ministry of Interior, 2007).

Figure 1: Administrative boundaries and household density for Salaya
(scale of 1:50,000; created by GIS)



There are many canals and rivers passing through the sub-district. Salaya has 29 canals including three major canals (Yong Canal, Narapirom Canal and Thaweewathana Canal) that run through the middle part of Salaya. In the past, Salaya residents preferred traveling by boat and train. Most land was used for agriculture and housing. Salaya's close proximity to Bangkok makes it a target of urban growth and development. Like other towns, the emergence of a development plan for Salaya included new transportation routes, both rail and road, passing through Salaya. Along the roads and waterways, most houses in new communities were concrete houses, without high spaces under them.

The popularity in these new style houses came at a time when the river and canals had much less importance in people's daily lives. Also, the higher price of constructing a wooden house was a deterrent to adhering to the traditional Thai style, especially given the long period without a flood disaster (i.e., pre-2011). In the past, households and communities were clustered along the banks of rivers and canals. Some built houses along roads that connected to local markets. Today, however, urbanization is agricultural area as residential and commercial projects are expanding onto farmland. At present, the majority of settlements are along paved roads. The administrative boundaries of Salaya sub-district and household density are shown in Figure 1.

Methods

This study used GIS technology with PSA and Overlay Analysis. Creating a map of flood-hazard areas in Salaya communities, PSA is a technique to rank spatial factors and calculate factor scores that influence causes of flooding. GIS plays an important role in analyzing the accuracy of spatial factors in PSA technique. To estimate the number of at-risk households based on hazard areas, 2011 household GIS data obtained from the Geo-Informatics and Space Technology Development Agency (GISTDA) were overlaid on flood-hazard levels, from "high" to "very low" risk levels. There were two major steps for this approach: 1) analyzing flood-hazard areas by using GIS and PSA, and 2) estimating the number of at-risk households based on hazard areas.

Analyzing flood-hazard areas by using GIS and PSA

1) Identify the main determinants of flooding

Based on a review of documents from the Office of Natural Resources and Environmental Policy, (ONEP) Ministry of Natural Resources and Environment (1998), there are nine factors that cause flooding: rainfall quantity, slope, altitude from sea level, river density, water flow obstacle (e.g., road density), size of sub-basin, land use, drainage capacity of soil and flood area in the past (Chatphuti, 2012; Yumuang, 2006).

In this study, six experts from the Hydrology and Water Management Center for the Central Region, Meteorological Station, Office of Natural Resources and Environmental Policy, Office of Disaster Prevention and Mitigation, Irrigation Office, Land Development Office, Office of Public Works and Town & Country Planning, and Office of the Salaya Municipality excluded three factors—rainfall quantity, size of sub-watersheds and slope—because the size of the study area is rather small (25 square kilometers). The rainfall quantity and the size of the sub-basin might not be significant enough to influence flood risk in the area. Additionally, the slope variable was dropped because it overlaps with the elevation variable.

Moreover, the study area has a plains topography. Hence the altitude from sea level factor is adequate for the analysis.

After adjusting a number of relevant factors, the analysis was carried out by dividing the area into 1x1 square kilometers according to the recommendations panel of experts. To identify the main determinants of flooding, each factor was assigned a value. The ranking scores of each factor were rated by panel of experts.

2) Data collection and preparation

This step involved collection of spatial data. Data for all factors selected as inputs for assessment of the flood-hazard area were stored in GIS format. The collective geographic information system database was derived from several Thai organizations and analyzed by an ArcGIS program. The spatial data covered in this study are shown in Table 1.

Table 1: Spatial data used in the study

Layer	Scale	Source
Governing boundary	1:50,000	Department of Provincial Administration, 2004
Contour	1:50,000	Royal Thai Survey Department, 1999
Water trail	1:50,000	Office of Natural Resources and Environmental Policy, 1995
Basin boundary	1:50,000	Office of Natural Resources and Environmental Policy, 1995
Transportation route	1:50,000	Department of Highways, 2001
Land use	1:50,000	Land Development Department, 2010
Soil series	1:50,000	Land Development Department, 1993
Rainfall	1:50,000	Thai Meteorological Department, 2001-2010
Flooded areas in the past	1:50,000	Flood data from Geo-Informatics and Space Technology Development Agency, 2012

3) Weighting and rating factors

To weight and rate factors that influence causes of flooding, the PSA technique is employed. Each factor was rated by the panel of experts, who weighted the data for each factor and ranked them from one to six, according to the importance of the factor in causing the area to flood. The severity of each factor was rated from 1 to 4, where 1 means the factor has the least influence on flooding and 4 means the factor has the most influence.

4) Data manipulation

The relevant factors were entered into the GIS for processing by computer software. The formula of the equation below generates the scores after data analysis and rating.

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

When S = Total score of risk factor of flooding
R_1 = Rating score of flooded areas in the past
W_1 = Weighting score of flooded areas in the past
R_2 = Rating score of river density
W_2 = Weighting score of river density
R_3 = Rating score of water flow obstacle (road density)
W_3 = Weighting score of water flow obstacle (road density)
R_4 = Rating score of altitude from sea level
W_4 = Weighting score of altitude from sea level

R_5 = Rating score of drainage capacity of soil
W_5 = Weighting score of drainage capacity of soil
R_6 = Rating score of land use
W_6 = Weighting score of land use

5) Classification of value

The total score of factors (S) were classified into four categories: very low, low, moderate and high by using analysis of standard deviation.

6) Data presentation

The results of the analysis are displayed on a map with a scale of 1:50,000.

Estimating the number of at-risk households based on hazard areas

This process involved the overlay of household data from Geo-Informatics and Space Technology Development Agency (GISTDA) (2011) on flood-hazard level, from 'high' to 'very low' risk level in order to estimate the number of at-risk households by hazard level.

Results

By weighting and rating data of each factor according to the PSA technique, the selected factors, with weighting and rating values, are shown in Table 2.

Table 2: Selected factors with weighting and rating values

Factor	Weighting	Sub-factors	Rating
Flood area in past year	6	flooded ≥ 3 years ago	4
An important physical factor as there is risk		flooded ≥ 2 years ago	4
of flooding again		flood in past year	3
		never flooded	2
River density	5	0.1 – 0.35 km. / 1 sq.km	2
Also an important factor in analyzing the		0.36 – 0.70 km. / 1 sq.km	2
drainage condition of the soil surface		0.71 – 1.00 km. / 1 sq.km	2
		> 1.00 km. / 1 sq.km	3
Water flow obstacle (road density)	4	> 0.60 km. / 1 sq.km	3
Roads are likely to obstruct the river or		0.41 – 0.60 km. / 1 sq.km	2
water flow to the river.		0.21 – 0.40 km. / 1 sq.km	2
		0.00 – 0.20 km. / 1 sq.km	2
Altitude from sea level	3	<2.75 m.	4
Plains or flat areas are at risk for floods		2.75 - 7.25 m.	3
		>7.25 m.	2
Drainage capacity of soil	2	very low	4
Water drainage under the soil surface not		low	3
addressed in this study, therefore this		moderate	2
factor is not considered significant.		high	2

Factor	Weighting	Sub-factors	Rating
Land use The case study area is located in a river basin, likely to experience flooding even if there is vegetation on the soil surface.	1	rice fields farm plants perennials, fruit trees	4 2 2

The total scores from the hazard area equation (S) were entered into the GIS to analyze, then classified into four categories—very low, low, moderate and high—by using analysis of standard deviation. The very-low flood-hazard area (dark green) covers approximately 1.38 square kilometers (5.5%), the low flood-hazard area (green) covers 4.28 square kilometers (17%), the moderate flood-hazard area (orange) covers 10.45 square kilometers (41.6%) and the high flood-hazard area (red) covers 8.98 square kilometers (35.9%). The results from analysis are shown in Table 3 and Figure 2.

Table 3: Flood-hazard level by area and proportion of the sub-district

Flood-hazard level	Area (sqkm)	Percent (%)
Very low	1.38	5.5
Low	4.28	17.0
Moderate	10.45	41.6
High	8.98	35.9
Total	25.09	100.00

To estimate the number of at-risk households, data from GISTDA in 2011 were overlaid on flood-hazard levels. The results show that about half of households fall into "moderate" flood zones (1,160, or 50%). The "high" zones were estimated to contain 521 households (23%), whereas 560 households (24%) are located in "low" zones, and 70 households (3%) are located in "very-low" zones, as shown in Table 3. The results from the analysis with overlay of households on a scale of 1:50,000 and THEOS satellite data (acquired on December 9, 2012) are illustrated in Figures 2 and Table 4.

Table 4: The number of households by hazard level

Hazard level	Number of households	Percent (%)
Very low	70	3
Low	560	24
Moderate	1,160	50
High	521	23
Total	**2,311**	**100**

Figure 2: Household density based on flood-hazard level on a scale of 1:50,000

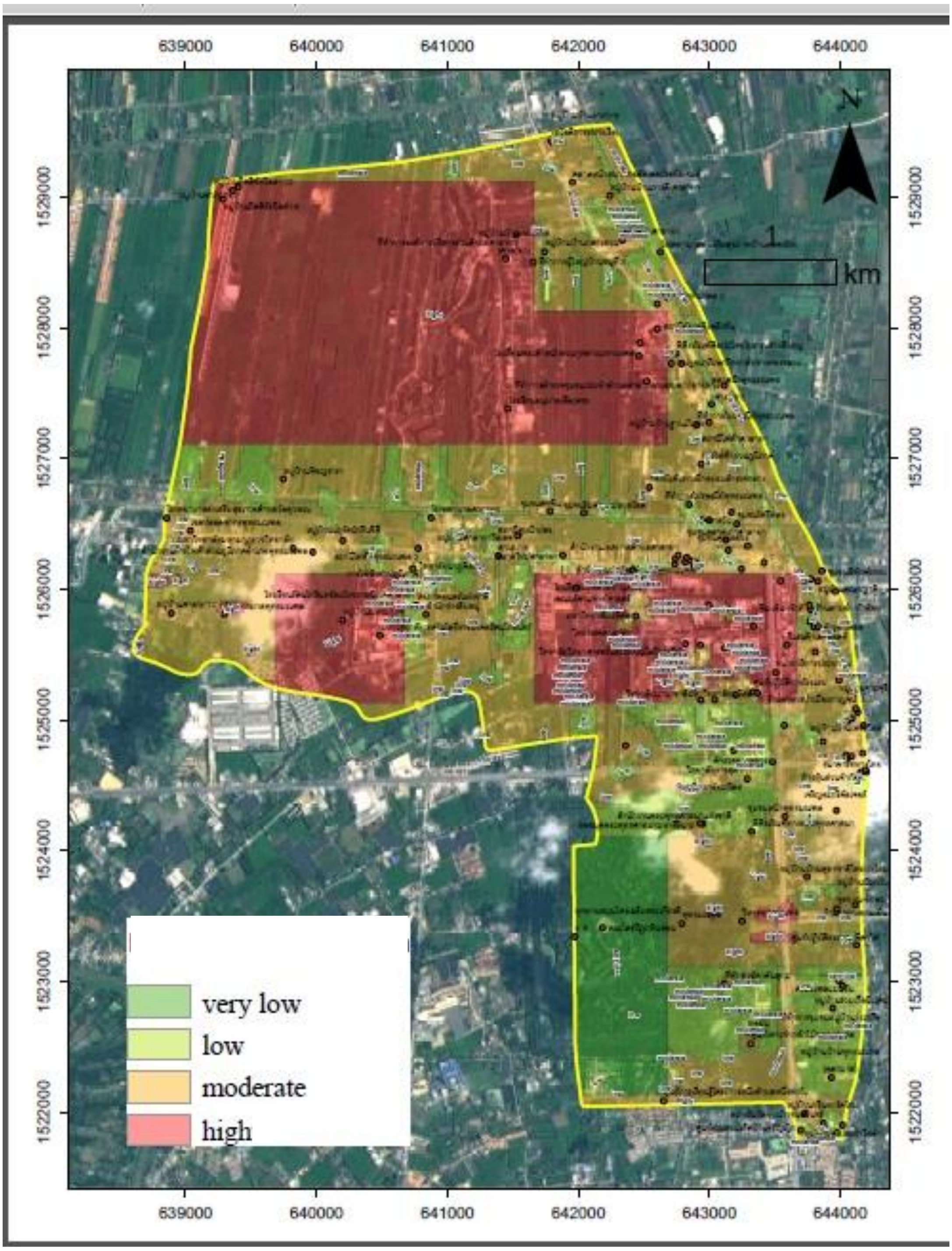
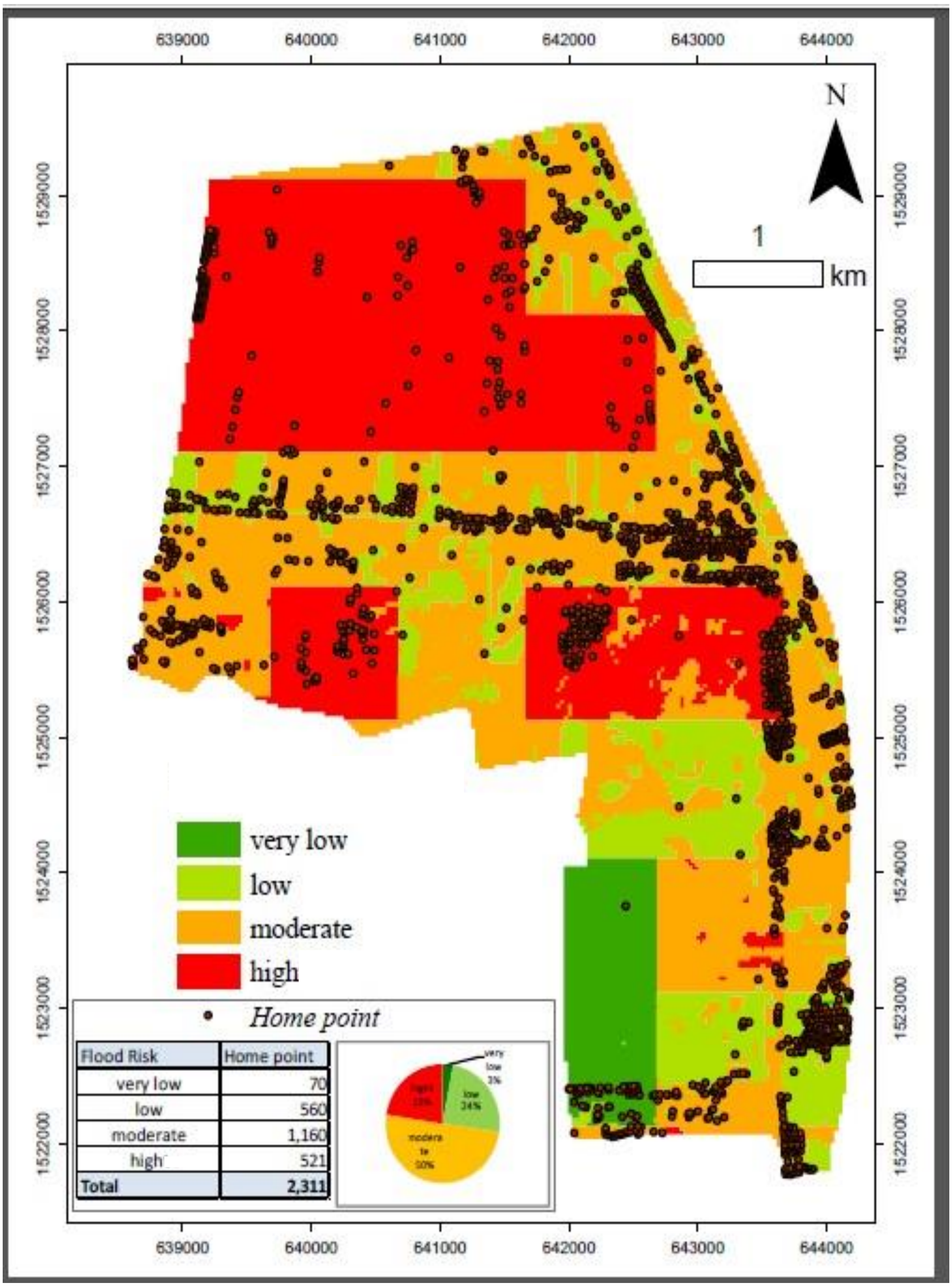


Figure 3: Household density based on flood-hazard level using THEOS satellite data, acquired on December 9, 2012



Conclusions and Discussion

This study was conducted to delineate flood-hazard areas and to produce estimates of the number at-risk households located in this area by using GIS technology with PSA and Overlay Analysis. By combining GIS data with PSA, the analysis classified areas into different levels of hazard. The analysis also overlaid household data, collected in 2011 by the GISTDA, in areas of four risk levels to produce a map indicating households and important sites located in flood-risk areas.

This study illustrates the overall risk in Salaya. The results can be used to assign risk priorities to different zones. The Salaya Municipality should consider formulating appropriate policies and strategies to reduce risk of future flooding and conduct a cost-effective flood vulnerability assessment. One way to reduce the potential threat on lives and property is to restrict development in locations with high flood risk, and relocate residents in high-risk areas to lower-risk zones. For example, recommendations should be to avoid locating a household in an area designated as a hypothetical flood-risk zone. At the micro level, households that remain in higher-risk zones need to better prepare for flooding, and to design appropriate approaches for reducing the loss of life and damage to property from future flooding in their locality.

It should be noted that the weights assigned to the different factors were based on expert opinions and, thus, potentially contain some subjectivity or bias. Likewise, designation of flood-hazard areas is an approximation based on probabilities. Thus, the delineated areas should not be taken as absolute certainties because they are based, in part, on numerical approximations. However, the GIS and PSA techniques can provide useful information for planning and development, especially in flood-risk areas.

Finally, it is also important to note that, at present, physical factors are not the main determinants of the extent of damage from flood hazards; socioeconomic factors are increasingly influential. For example, the location of settlements makes households more or less prone to disasters. The houses situated close to rivers and canals are at elevated risk of flash floods and high-tide effects compared to houses on the main road. But also, risk of damage is related to the type of house. For example, one-story concrete houses, semi-concrete houses and houses made out of less durable materials have greater potential for loss of life and property damage than two-story, concrete houses. Additionally, age, gender and other socio demographic and experiential characteristics are related to disaster preparedness. For example, men are more likely to adopt prevention behaviors than women, given the cultural role and expectation that men are the primary protectors of the household. Advance information about floods influence perception, response and flood management. For example, a community that has recently been affected by flooding is more likely to take preventative action against future flooding than a community that has never experienced a flood. The estimation of the number of households in flood-risk areas, then, should be assessed in combination with other factors, such as socioeconomic characteristics, in order to develop guidelines for disaster preparedness for communities in flood-risk areas.

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