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Multi-hazard Risk Assessment Using GIS and RS Applications: A Case Study of Pak Phanang Basin

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ABSTRACT

Droughts and floods are natural phenomena where risks of occurrence are likely to continue to grow in Pak Phanang Basin. In the southern east coast of Thailand, Pak Phanang Basin covers a total area of 308,000 hectares with a total population of approximately 600,000. In this paper, the risk of drought and flood using GIS and RS is assessed and effective risk assessment process for the studied area is identified. The findings reveal that approximately 75,815 hectares, or 25 % of the total land area, exhibited a high multi-hazard risk. However, approximately 120,737 and 82,710 hectares, equivalent to 39 % and 27 % of the total land area respectively, were estimated to be experiencing medium and low multi-hazard risk. Further analysis revealed that residential areas and shrimp farms, especially in Nakhon Si Thammarat, Huasai, and Pak Phanang Municipality, are under high multi-hazard risk, while agricultural land scattering over the basin is consistent with medium multi-hazard risk. Finally, the swamp, located in the southernmost zone of the basin in Cha-uat District, faces low multi-hazard risk. Moreover, this paper concludes with risk management strategies and public participation integrated with risk assessment.

Keywords: Drought and flood hazards, geographic information system, risk assessment, remote sensing

INTRODUCTION

Pak Phanang Basin, in the southern east coast of Thailand, covers a total area of 308,000 hectares with a total population of approximately 600,000 as shown in **Figure 1**. This area is a fertile yet environmentally degraded coastal embayment in southern Thailand, which is prone to flooding during the monsoon and drought during the dry season every year [1]. Flood risk is among the most severe risks to human lives and properties, and has become more frequent and severe along with local economical development. Drought is broadly defined as "severe water shortage". Low rainfall and ineffective water management has mainly caused drought.

The increased vulnerability of many areas in Pak Phanang Basin, especially to drought and flood is a major reason of concern. Therefore, attempts should be made to the reduce the vulnerability of critical areas, which requires an analysis of potential losses in order to make recommendations for prevention, preparedness and response [2]. To identify and implement these measures, risk assessment based on hazard and vulnerability needs to be conducted.

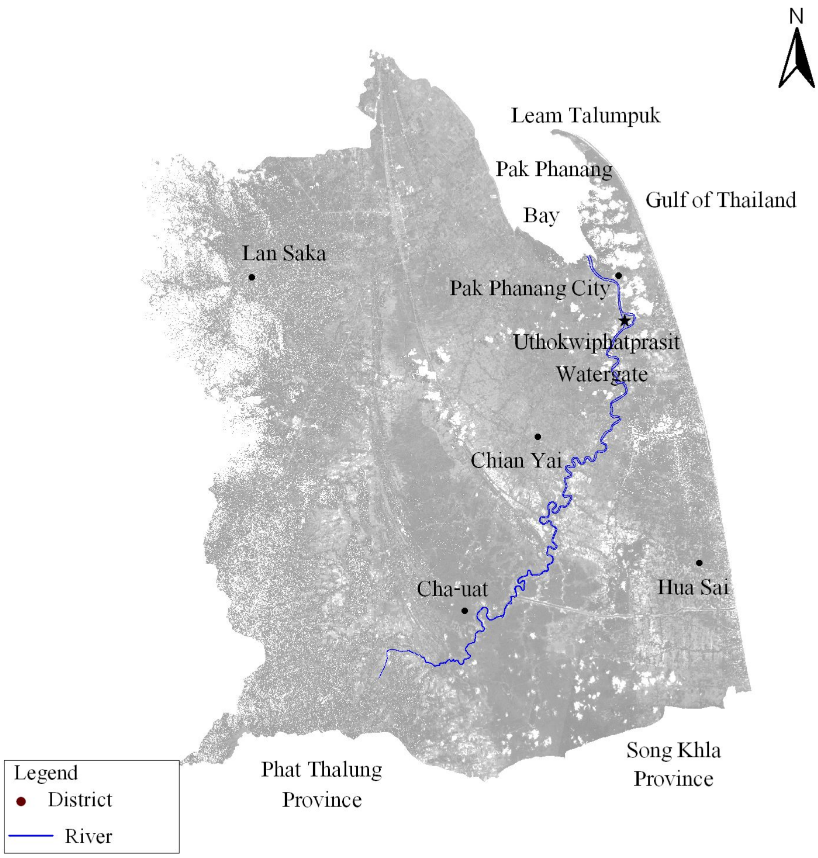

Figure 1 A satellite image showing the boundary of the Pak Phanang Basin.

For the last 3 decades advancements in the fields of geographic information system (GIS) and remote sensing (RS) have greatly facilitated the operation of risk assessment. Most data required for risk assessment has a spatial component, and also changes over time. Therefore, the use of GIS and RS has become essential. It is evident that GIS has a great role to play in risk assessment because natural hazards are multi dimensional [3]. The main advantage of using GIS for risk assessment is that it not only generates a visualization of hazard but also creates potential to further analyze this product to estimate probable damage due to hazard [4,5]. Risk assessment requires up-to-date and accurate information on the terrain topography and the use of the land. Remotely sensed images from satellites and aircrafts are often the only source that can provide this information for large areas at acceptable costs. This paper develops the application of GIS and RS in multi-hazard risk assessment through the lens of integrated public policy.

In October 1999, the Uthokawiphatprasit Watergate began its operation over the Pak Phanang River in order to prevent salt-water intrusion into the inner area along the river and to keep fresh water for mainly agricultural purposes. Since the Watergate was implemented, debates over the environmental change in the area have raised many issues. One area of debate is that of flood and drought which requires further investigation. The objective of this paper is to determine multi-hazard risk assessment in the Pak Phanang Basin after the operation of the Uthokawiphatprasit Watergate.

MATERIALS AND METHODS

Materials

Both primary and secondary sources of information were used in this study. Secondary sources include data published by many governmental agencies. The following sources of spatial data were used:

- Topographic map on a 1:50,000 scale, pertaining to Pak Phanang Basin.
- Aerial photo of the studied area on a 1:25,000 scale, produced by the Royal Thai Survey Department.
- Soil map for the Pak Phanang Basin on a 1:50,000 scale, produced by the Land Development Department.
- Geohydrology map of southern Thailand on a 1:50,000 scale, produced by the Department of Mineral Resources.
- Irrigation area map of southern Thailand on a 1:50,000 scale, produced by the Royal Irrigation Department.
- Climate map of the studied area on a 1:50,000 scale, produced by the Thai Meteorological Department.
- Slope map of the studied area on a 1:50,000 scale, produced by the Royal Thai Survey Department.

- Watershed classification map of the studied area on a 1:50,000 scale, produced by the National Hydrology Committee.
- Geological map of Nakhon Si Thammarat and Songkhla on a 1:250,000 scale, produced by the Department of Mineral Resources.
- District map of the Pak Phanang Basin on a 1:50,000 scale, produced by the National Statistical Office, the Royal Thai Survey Department, and the Department of Provincial Administration.

Primary data on past natural hazards, socio-economic conditions, vulnerability, response capability and efforts made by local people for mitigation of the hazards in the recent past were collected by field survey.

Methods

Hazard is some threat, natural, technological, or civil to people, property, and the environment. Risk is viewed as the probability that a hazard will occur during a particular time period. Vulnerability is susceptibility to injury or damage from hazards. A disaster is a hazard occurrence resulting in significant injury or damage [6]. As an example, a flood is a natural hazard; flood risk is defined in terms of the hundred-year flood; the people and buildings located within the hundred-year flood zone are vulnerable, and a flood disaster is a flood that injures a number of people, or causes significant damage.

Alexander [6] highlights a formal definition relating risk to hazard and vulnerability originally provided by the Office of the United Nations Disaster Relief Coordinator (UNDRO) where:

$$Risk = element\ at\ risk \cdot (hazard \cdot vulnerablity)$$

Thus, risk is viewed as a function of the elements at risk, the hazard, and the vulnerability to that particular hazard. The elements at risk are mainly the population, property, and economic activities in a given area.

Risk assessment is the process of identifying and evaluating risk as well as selecting, and implementing actions to reduce risk to human health and to ecosystems [7]. Risk assessment has not been given sufficient attention in multi-hazard dimensions because of the complexity of this integrated problem. However, it is absolutely essential to give priority to risk assessment, if we want to counteract the potential negative consequences. In the absence of risk assessment, managers and policy makers frequently respond to the level of realized losses but their response can be disproportionate to the level of risk.

The entire risk assessment comprises 3 equal parts: risk analysis, risk evaluation and risk management [8]. Risk analysis is an objective quantification of risk components such as hazard, exposure, and susceptibility. Risk evaluation is used to quantify and value the losses associated with damage and expected losses which depend on the probability of hazard. Risk management is the process of analyzing, selecting, implementing and evaluating actions to reduce risk. **Figure 2** displays the risk assessment concept.

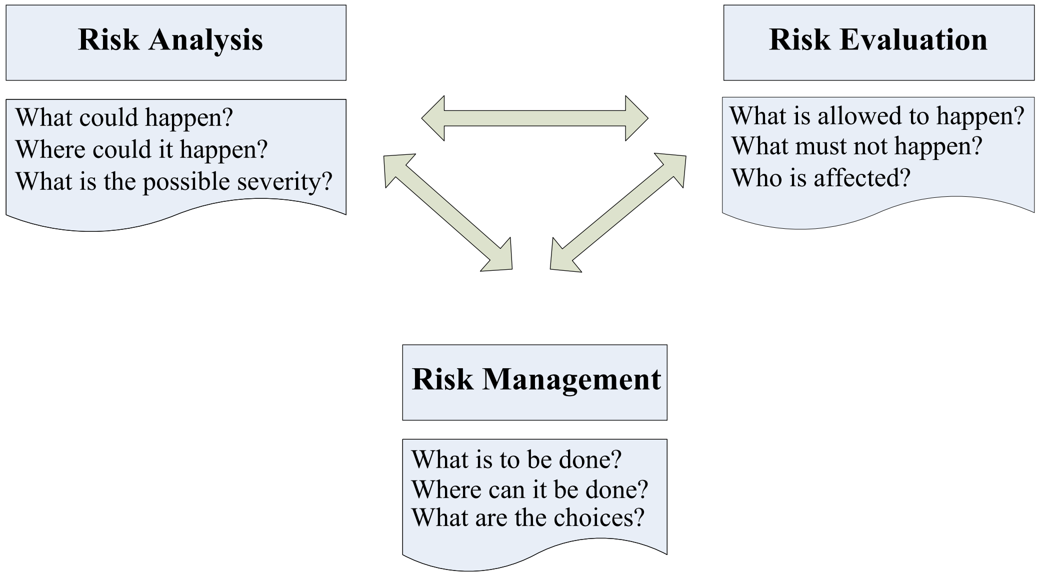

Figure 2 The holistic concept of risk assessment [7,8].

In this study, the multi-hazard risk assessment has been conducted in 3 steps; firstly the hazard assessment for drought and flood, secondly the risk assessment for drought and flood, and thirdly the multi-hazard risk assessment [9]. The methodological sequence of multi-hazard risk assessment is shown in **Figure 3**.

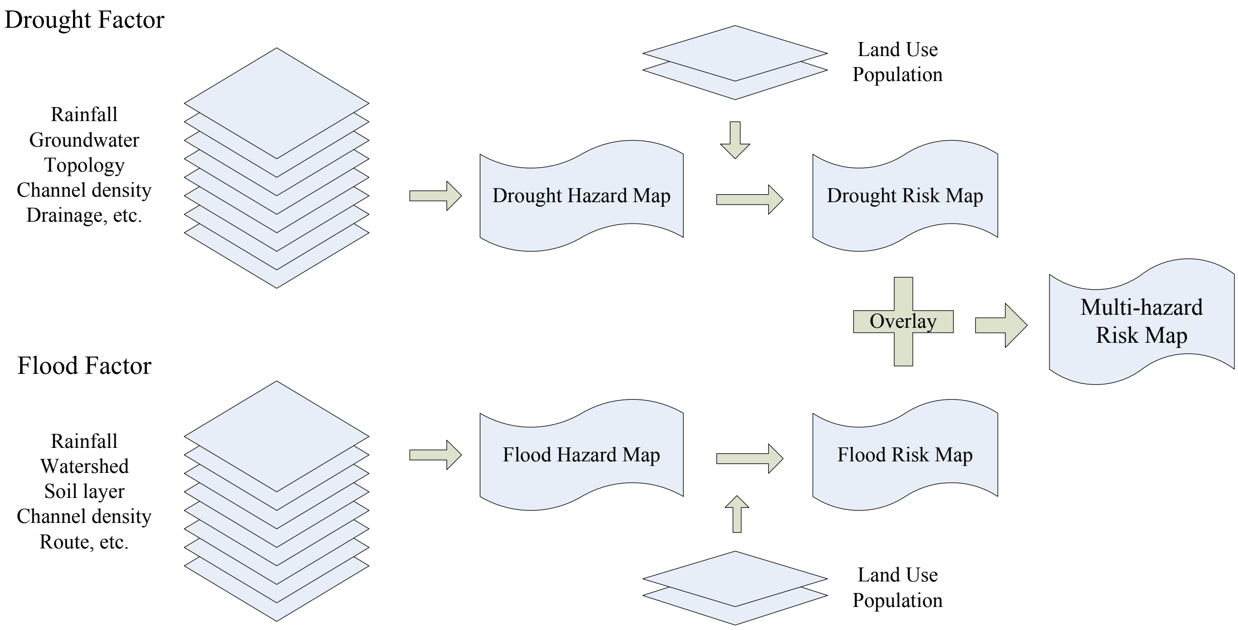

Figure 3 Multi-hazard mapping schemes.

Hazard Assessment for Drought and Flood

Factors that influence the occurrence of drought are selected as input data for assessing drought hazard using ArcInfo GIS. The factor selection was based on quotation frequencies in drought-related reports and authors' experience of past droughts in the studied area. These factors were weighted according to their relative priority to each other and their expected significance in causing droughts. Furthermore, each factor was divided into 5 subfactors and listed in order of susceptibility to the occurrence of droughts (**Table 1**). For each factor, the weighted hazard ranking was obtained by multiplying its weight by the order value for the corresponding subfactor. The total estimated hazard, obtained by adding the weighted drought rankings of all the factors, was classified in 3 levels; low, moderate, and high. The resulting coverage created by the overlay of these data generated the drought hazard map (**Figure 4**). The same process was conducted for flood hazard (**Table 2** and **3**; **Figure 5**).

Risk Assessment for Drought and Flood

Risk assessment requires an understanding of the causes of a potential disaster which includes the hazard, vulnerability, and the element at risk. In this study, the vulnerability was determined by the effective risk mitigation. The risk mitigation in this area was not adequate so, the vulnerability was equal to 1, representing total loss. Regarding the element at risk, land use and population were determined by the authors' experience as the highest impact factor. For land use type, the agricultural area with residents had the highest weighting value (**Table 4**). Risk was determined by calculating specific risk for each hazard type. A drought risk map then was created by overlaying the drought hazard map with the population density and then the land use maps. The total estimated risk, obtained by adding the weighted risk rankings of all factors, was also identified in 3 levels; low, moderate, and high (**Table 5**). The same process was used for the flood risk map.

Table 1 Weighted drought hazard rankings for Pak Phanang Basin.

Factors	Weighting	Subfactors	Ranking
1. Rainfall records (mm)	8	1. < 1,000	5
		2. 1,000 - 1,200	4
		3. 1,201 - 1,400	3
		4. 1,401 - 1,600	2
		5. > 1,600	1
2. Rainfall duration (day)	7	1. < 86	5
		2. 86 - 122	4
		3. 123 - 157	3
		4. 158 - 175	2
		5. > 175	1
3. Distance from water source (m)	6	1. > 500	5
		2. 401 - 500	4
		3. 301 - 400	3
		4. 200 - 300	2
		5 < 200	1
4. Ground water discharge (Gal/min)	5	1. < 30	5
		2. 30 - 50	4
		3. 51 - 100	3
		4. 101 - 500	2
		5. > 500	1
5. Channel density (km/km^2)	4	1. < 0.90	5
		2. 0.90 - 1.05	4
		3. 1.06 - 1.20	3
		4. 1.21 - 1.50	2
		5. > 1.50	1
6. Soil drainage	3	1. very high	5
		2. high	4
		3. moderate	3
		4. low	2
		5. very low	1
7. Slope (%)	2	1. > 35	5
		2. 30 - 35	4
		3. 20 - 29	3
		4. 10 -19	2
		5. 0 - 9	1
8. Topography	1	1. Mixed Fruit and urban area	5
		2. Para rubber and mixed fruit	4
		3. Forest	3
		4. Rice field and shrimp farm	2
		5. Swamp and mangrove	1

Table 2 Weighted flood hazard rankings for Pak Phanang Basin.

Factors	Weighting	Subfactors	Ranking
1. Rainfall records (mm)	9	1. > 1,600	5
		2. 1,401 - 1,600	4
		3. 1,201 - 1,400	3
		4. 1,001 - 1,200	2
		5.< 1,000	1
2. Watershed area (km^2)	8	1. > 600	5
		2. 501 - 600	4
		3. 401 - 500	3
		4. 201 - 400	2
		5. < 200	1
3. Watershed slope (%)	7	1. 0 - 9	5
		2. 10 - 19	4
		3. 20 - 29	3
		4. 30 - 35	2
		5. > 35	1
4. Channel slope (%)	6	1. < 2	5
		2. 2 - 3	4
		3. 3.1 - 4	3
		4. 4.1 - 5	2
		5. > 5	1
5. Channel density (km/km^2)	5	1. > 1.50	5
		2. 1.21 - 1.50	4
		3. 1.06 - 1.20	3
		4. 0.90 - 1.05	2
		5. < 0.90	1
6. Land use	4	1. Paddy field, bush, swamp	5
		2. Fruit trees and residential area	4
		3. Mixed orchards and rubber	3
		4. Para rubber	2
		5. Forest	1
7. Soil type	3	1. Clay	5
		2. Silty sand	4
		3. Sandy Clay	3
		4. Clayey Sand	2
		5. Sand	1
8. Soil layer depth (cm)	2	1. < 25	5
		2. 25 - 50	4
		3. 51 - 100	3
		4. 101 - 150	2
		5. >150	1
9. Transport Route	1	1. 5 routes	5
		2. 4 routes	4
		3. 3 routes	3
		4. 2 routes	2
		5. 1 route	1

Table 3 Maximum and minimum values of the total estimated hazard.

Hazard category	Drought	Flood
Low	< 63	< 142
Moderate	63 - 121	142 - 190
High	> 121	> 190

Table 4 Weighted drought and flood risk rankings for Pak Phanang Basin.

Factors	Weighting	Subfactors	Ranking
1. Drought and flood hazard	1	1. Low	1
		2. Moderate	2
		3. High	3
2. Population density (no./km^2)	1	1. < 100	1
		2. 100 - 500	2
		3. > 500	3
3. Land use type	1	1 Swamp and flat area	1
		2 Paddy field	2
		3 Mixed orchards and rubber	3
		4 Residential area	4

Table 5 Maximum and minimum values of the total estimated risk.

Risk category	Total estimated risk values for drought and flood
Low	1. < 3
Moderate	2. 3 - 7
High	3. > 7

Multi-Hazard Risk Assessment

Two types of hazards were analyzed: drought and flood. These 2 risks were aggregated together. A multi-hazard risk map was then created by overlaying the drought risk map with the flood risk map. The total estimated multi-hazard risk also was classified in 3 levels; low, moderate, and high. The multi-hazard risk assessment based on using GIS and remote-sensing was verified by field inspection. In addition, the aerial photo was interpreted to validate the output of the models.

Recognition of hazard severity in the first step is risk analysis. The second step is risk evaluation in order to determine drought and flood consequences. The third step, being risk management, is proposed in the last section to select and implement the optimal responses for this multi-hazard risk.

RESULTS AND DISCUSSION

Multi-hazard Risk Assessment

A drought generally results from low precipitation over a certain time period. A drought hazard map was calculated based on parameters listed in descending order of priority that induce drought such as rainfall records, rainfall duration, distance from water source, groundwater discharge, channel density, soil drainage, slope, and topography. From the drought hazard map, it was estimated that 352,888 hectares, or 88 % of Pak Phanang Basin's total land areas were subjected to drought. The results also revealed that areas of high drought hazard accounted for 33,713 hectares, or 8 % of the total land area, while 306,130 hectares, or 77 % of the total land area, were of medium drought hazard and low drought hazard areas cover an estimated 13,045 hectares, or 3 % of the total land area (**Figure 4**).

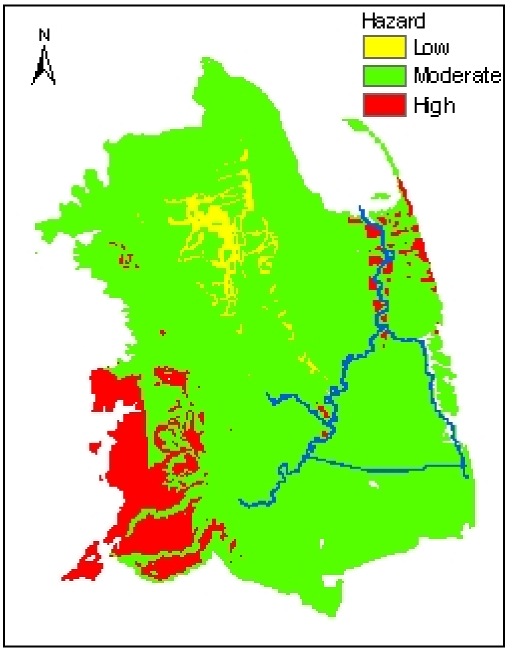

Figure 4 Drought hazard map of the Pak Phanang Basin.

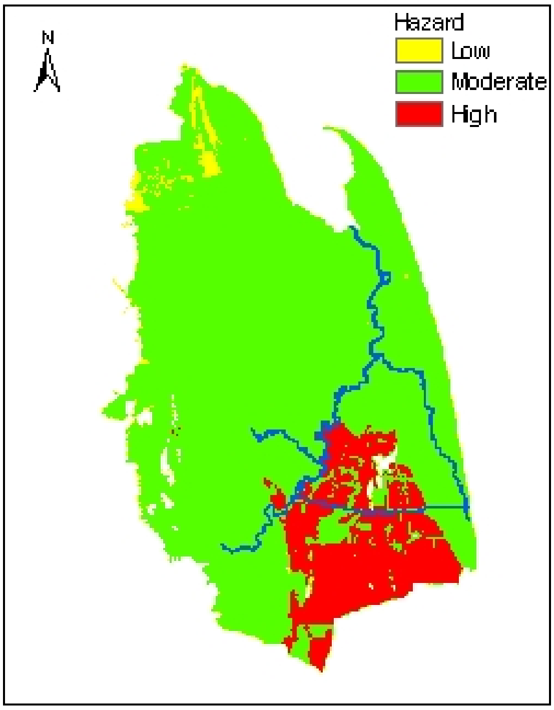

Figure 5 Flood hazard map of the Pak Phanang Basin.

Similarly, a flood hazard map has been developed for the Pak Phanang Basin where inundation is a severe problem during prolonged monsoonal rain. Areas prone to floods were assessed based on these parameters listed in descending order of significance such as rainfall records, watershed area, watershed slope, channel slope, channel density, land use, soil type, soil layer depth, and transport route. With the capacity provided by the ArcInfo GIS, it was estimated that 299,113 hectares, or 75 % of the total land area was prone to flooding. Findings also revealed that 46,113 hectares, or 11 % of the total land area, exhibited high flood hazard. Further analysis showed that approximately 248,954 and 4,046 hectares, equivalent to 63 % and 1 % of the total land area were subject to medium and low flood hazard, respectively (**Figure 5**).

The risk map was obtained by the overlaying the hazard map, land use map and population map. From the drought risk map, it was estimated that 101,592 hectares (26 %), 154,784 hectares (39 %), and 96,548 hectares (24 %) of the total land area were subject to low, medium, and high drought risk, respectively (**Figure 6**). The flood risk map showed that 79,440 hectares (20 %), 139,642 hectares (35 %), and 76,024 hectares (19 %) of total land areas faced low, medium, and high flood risks, respectively (**Figure 7**).

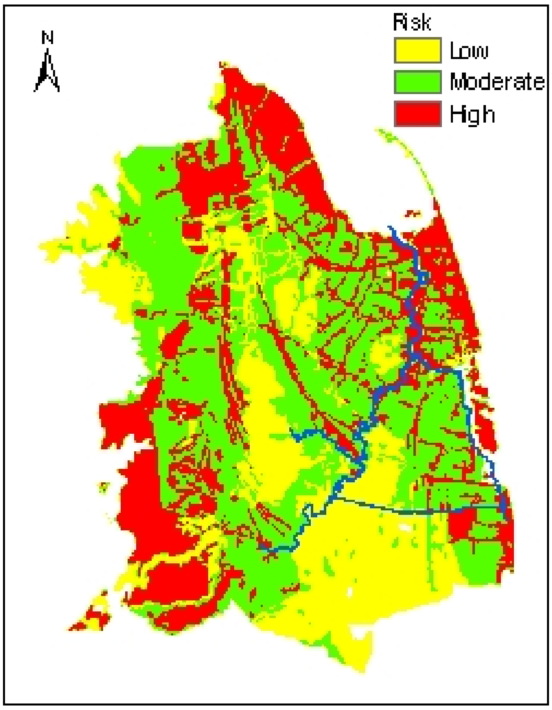

Figure 6 Drought risk map of the Pak Phanang Basin.

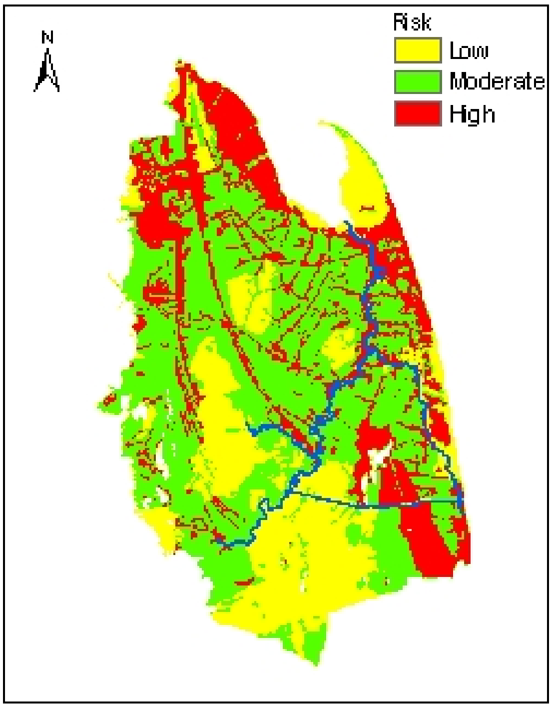

Figure 7 Flood risk map of the Pak Phanang Basin.

The multi-hazard risk map (**Figure 8**) is prepared by integration of the drought risk and flood risk maps. The findings revealed that approximately 75,815 hectares, or 25 % of the total land area, exhibited a high multi-hazard risk. However approximately 120,737 and 82,710 hectares, equivalent to 39 % and 27 % of the total land area, respectively were estimated to be experiencing medium and low multi-hazard risk. Further analysis revealed that residential and shrimp farm areas, especially in Nakhon Si Thammarat, Huasai and Pak Phanang Municipality, were under high multi-hazard risk, while agricultural land scattered over the basin exhibits medium multi-hazard risk. Finally, the swamp, located in the southernmost zone of the basin in Cha-uat District, faced low multi-hazard risk.

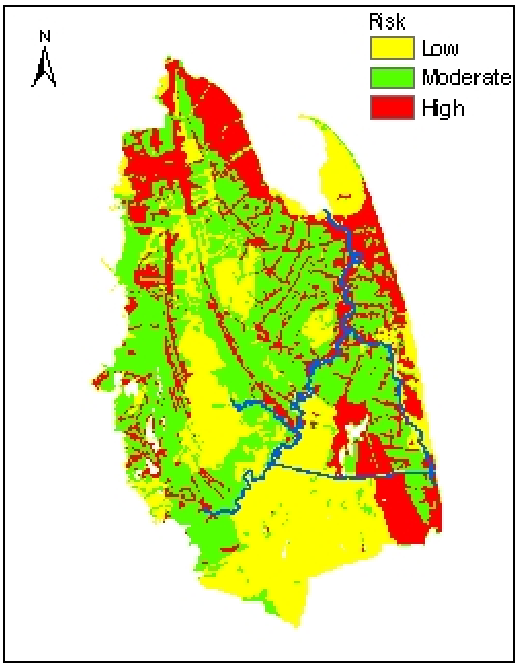

Figure 8 Multi-hazard risk map of the Pak Phanang Basin.

It is important that related government agencies should publish hard copy hazard and risk maps and distribute them to the communities in order to enhance public awareness about the levels of hazard and risk they are likely to confront. This paper concludes with risk management strategies and public participation integrated with risk assessment.

Risk Management Strategies

As the zero risk situation does not exist, there is no other choice than to live with them, however we can respond proactively regarding management of risks. The theoretical range of measures available to manage drought and flood hazards is large. It can include structural (watergates, levees, diversion channels, embankments) and non-structural measures (land use planning, warning systems, evacuation, and insurance). It is possible for a combination of these measures to be implemented. This involves complex institutional and decision-making frameworks to arrive at the compatibility of these measures.

Risk management can be implemented by decision makers through various strategies, consisting of risk acceptance, risk avoidance, risk reduction, and risk transfer. Risk can be accepted if the expected loss is low in that area such as a deserted shrimp farm or swamp area. Risk avoidance consists of a wise land use policy to avoid as much as possible areas highly exposed to hazard. For example, allocating less vulnerable land uses to the most hazardous areas or by avoiding development in those locations. Relocation of the residents of high risk areas would reduce their vulnerability.

Risk can be reduced by decreasing hazards, reducing or eliminating the vulnerability of the elements at risk, or a combination of both actions [10]. Adoption of risk reduction measures, including installation of warning systems, construction of diversion channels to prevent and mitigate flood disasters, and assembly of levees throughout low-lying areas in flood risk areas can effectively reduce the consequences of flood on lives and property. Recently, action plans to reduce drought have shifted from provision of additional water (supply management), to effective demand management of the finite and scarce freshwater resource. Risk transfer is the sharing of potential losses between various stakeholders, through adapted mechanisms such as insurance and public compensation policies.

Public Participation Integrated with Risk Assessment

The understanding of how people evaluate and respond to natural hazards, and how this knowledge can be integrated in the planning and management process, are becoming very crucial elements of a comprehensive and participatory approach to multi-hazard risk assessment.

Whether responses to each hazard take a structural, non-structural or both approaches, there remains a need for mechanisms for public participation in decision-making. A structural approach - diversion channel improvements or the construction of floodwalls or watergates for example, can be effective but can have major impacts on the environment and be difficult, therefore, to obtain public acceptance or a consensus of agreement. If non-structural measures, such as flood warning systems are adopted, their efficiency is likely to be impaired if the needs and response capabilities of the public have not been incorporated into the system design. Thus, in all cases, public involvement and participation is required for effective implementation.

GIS can be an important tool for involving the public in the different steps of risk assessment. It allows a representation of reality and the simulation of different scenarios such as different flood or drought levels. In this vein, the public has the opportunity of seeing and understanding some of the technical aspects of these hazard problems. In addition, the simulation of different risk management responses can create the possibility of active participation in the decision process [11].

CONCLUSION

The risk of water-related extreme events, floods and droughts, is likely to grow in the Pak Phanang Basin. To reduce human vulnerability to water related extreme events, a general change of paradigms is need for parties concerned. The risk assessment provides the basis for long-term management decisions regarding flood and drought preparedness systems. In this study, the multi-hazard risk assessment is generated using GIS and RS, based on overlays of hazard, land use and population maps. Multi-hazard risk maps can serve to identify vulnerable areas for the adoption of prevention and mitigation measures, or indicate a need for action, which may lead to an improvement of the system. Nowadays it is increasing necessary to involve the public in the decision making process in order to attempt to achieve consensus on what can be controversial issues in the implementation of water resources policy.

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บทคัดย่อ

วรินธ์ู วิปุลานุสาสน์ สรายุทธ์ นาครอด และ พิภพ ปราบณรงค์

การประเมินความเสี่ยงภัยธรรมชาติโดยใช้ระบบสารสนเทศภูมิศาสตร์และการรับรู้ระยะไกล: กรณีศึกษาลุ่มน้ำปากพนัง

ภัยแล้งและอุทกภัยเป็นปรากฏการณ์ธรรมชาติที่มีความเสี่ยงในการอุบัติขึ้นได้ โดยมีแนวโน้มเพิ่มสูงขึ้นในบริเวณลุ่มน้ำปากพนัง ลุ่มน้ำปากพนังตั้งอยู่ในชายฝั่งทะเลด้านตะวันออกของภาคใต้ของประเทศไทยครอบคลุมพื้นที่ 1,925,000 ไร่ โดยมีประชากรประมาณ 600,000 คน บทความนี้ประเมินความเสี่ยงต่อภัยแล้งและอุทกภัยโดยใช้ระบบสารสนเทศภูมิศาสตร์และการรับรู้ระยะไกล และเสนอกระบวนการประเมินความเสี่ยงที่มีประสิทธิผลสำหรับพื้นที่ศึกษา โดยผลการศึกษาพบว่าพื้นที่ 470,000 ไร่หรือร้อยละ 25 ของพื้นที่ทั้งหมดเผชิญกับความเสี่ยงสูงต่อภัยธรรมชาติ ส่วนพื้นที่ 750,000 ไร่และ 520,000 ไร่หรือร้อยละ 39 และ 27 ประสบกับความเสี่ยงปานกลางและความเสี่ยงต่ำต่อภัยธรรมชาติ ตามลำดับ จากการวิเคราะห์เพิ่มเติมพบว่าพื้นที่พักอาศัยในเขตเทศบาลนครศรีธรรมราชและเทศบาลปากพนังตกอยู่ภายใต้ความเสี่ยงสูงต่อภัยธรรมชาติ ขณะที่พื้นที่เกษตรกรรมซึ่งกระจายอยู่ทั่วพื้นที่ลุ่มน้ำมีความเสี่ยงปานกลางต่อภัยธรรมชาติ สำหรับป่าพรุซึ่งอยู่บริเวณด้านใต้ของพื้นที่ลุ่มน้ำในเขตอำเภอชะอวดมีความเสี่ยงต่ำต่อภัยธรรมชาติ ยุทธศาสตร์การจัดการความเสี่ยงและการบูรณาการการมีส่วนร่วมของประชาชนผสานกับการประเมินความเสี่ยงได้นำเสนอไว้ในบทความนี้สำหรับการวางนโยบายการจัดการน้ำอย่างมีประสิทธิภาพและประสิทธิผล

สำนักวิชาวิศวกรรมศาสตร์และทรัพยากร มหาวิทยาลัยวลัยลักษณ์ อำเภอท่าศาลา จังหวัดนครศรีธรรมราช 80161