Multi-criteria Flood Susceptibility Assessment Using Remote Sensing and GIS-based Approaches in Chi River Basin, Thailand

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Abstract. The flood susceptibility map is a comprehensive resource for forecasting and preventing floods worldwide, particularly where floods occur on a regular basis, which is missing in numerous developing-country basins. The recurring flood hazard in Thailand is an endless problem as there is still a lack of understanding of the underlying causative factors. This research provides an answer of certain flood-causative parameters and the effects on flood susceptibility in Chi River Basin (CRB), Thailand, using an Analytical Hierarchical Process (AHP) method. As the result, total of seven hydrogeomorphological parameters can be ranked by its influence on flood hazard in the CRB, as follows, the distance from the river, elevation, geology, soil type, land use, drainage density, and geomorphology, respectively. Combination of all flood-causative parameters based on their weights and ranks provided the flood susceptibility map. The map was evaluated as accurate relative to previous satellite-based flood maps using a binary classification test, providing a robust flood susceptibility map. The findings of this work have contributed to a decent understanding of the present problem of floods in the CRB in the context of its actual causes, which is beneficial for a water management scheme.

1. Introduction

Flood perceived to be a frequent natural disaster inflicts damage worldwide [1-5]. Changing in flood frequency and magnitude is one of the impacts of global warming [6], which influences the flood control system downstream [7]. Climate change conditions cause these problems. Consequently, the water in the basin increases suddenly [6]. Flood disaster caused by both natural and anthropogenic influences [8], which raises economic agricultural and social losses, also affects housing and agricultural areas of riparian people [2,9-12]. However, there is no single solution provided in terms of a flood management plan, and the warning system is still a real-time foresee warning [13]. Thus, the determination of flood risk area is essential for water management of the basin [14], as the flood-prone area needed to be identified [15]. The flood susceptibility mapping in various techniques is a tool for spatial water management to enhance flood prevention and mitigation strategies [16,17], which is particularly essential for flood-prone areas [18].

The Analytical Hierarchy Process (AHP), as one among other multi-criteria analysis (MCAs) methods, is an efficient, cost-effective, less time-consuming, and convenient multi-criteria decision on which variables are ordered in a hierarchical structure [2,19,20], developed by Saaty [21]. Currently, remote sensing and Geographic Information Systems (GIS) techniques became the key elements for...
multi-criteria decision-making processes, particularly in water resource management [19]. MCA is a method that weights the physical parameters logically in the GIS study [18]. The combination of MCA (AHP method) and GIS is widely used in various research regarding water management issues [2,22,23], especially for flood susceptibility mapping. The AHP and GIS methods can solve problems of water management in various aspects such as identify, assess, and simulate flood-prone areas and its impacts [24], to reduce cost in lives and properties, especially for cities of developing countries [16].

The Chi River is one of the main rivers in Thailand, which flows through several provinces in the north-eastern region of Thailand [25], including Mahasarakham and Roi-Et Provinces. Floods often occurred in the basin [26], such as the flooding from the influence of the tropical storm Sonca in 2017. The floods caused damages to live and properties in the CRB [26]. However, the flood risk and susceptibility of the basin is still not identified. This study aims to assess hydrogeomorphological factors, which influence the occurrence of the flood. The spatial flood susceptibility map of the CRB in Mahasarakham and Roi-Et Provinces was developed and evaluated by utilizing the Analytical Hierarchical Process (AHP) and divided into different flood risk levels, spatially. This flood susceptibility map will be beneficial for flood warning and sustainable water management in the CRB, and further applied in other basins worldwide.

2. Methodology

2.1. The Case Study Area: Chi River Basin

The case study area is a part of the Chi River Basin (CRB) in the northeastern of Thailand, Mahasarakham, and Roi-Et Provinces; consists of 17 districts with the total area of 3,032.87 km$^2$ (Figure 1). Agriculture is a dominant land use activity in the research field. The study area is classified into three main categories according to geomorphological characteristics, which are the gentle plateau in the south and some areas in the north, floodplain in the central region along the Chi river, and the water bodies such as lakes and swamps throughout the area. According to the data from the Department of Mineral Resources of Thailand [27], in 2006, the area endured tropical monsoon conditions with 1,304.7 mm of a mean annual rainfall. Due to heavy rainfall in the study region, several small villages along the Chi River were dramatically affected by flood threats, both physically and economically.

2.2. Preparation of thematic layers

This study applied a GIS-based AHP technique for generating flood susceptibility map, as shown in Figure 2. Data for this study has been acquired from various sources such as government organizations and satellite images for delineating different flood hazard zones in the CRB. The 30 m-resolution of a Digital Elevation Model (DEM) acquired from the USGS online database and processed in ArcGIS Software version 10.5 for the CRB delineating, preparation of elevation, and geomorphology maps. The drainage density map has been calculated and generated through ArcGIS software version 10.5, using the hydrology tools. The DEM has been processed in the buffering function of the ArcGIS software version 10.5 for developing a distance from the river map with 500 m-interval. The Department of Mineral Resources (DMR) of Thailand was a geologic data source for preparing the CRB geologic map. The Landsat 8 images with 30 m-resolution from the USGS online database have been acquired for a supervised land use classification technique in ERDAS Imagine software to generate a land use map of the study area. Data for the soil type mapping has been compiled from the Land Development Department (LDD) database. After preparing all seven thematic layers, which converted to raster format with 30 m resolution, and reclassified using AHP ranks.
2.3. Multi-Criteria Decision Analysis: Analytical hierarchy process (AHP)

The parameter weights can be assigned through the AHP technique which is multi-criteria decision analyses. The AHP method divides the problem into sections in the form of a hierarchical model by imitating the human brain's complex concepts to achieve the right decision based on the information available. The pairwise comparison process is the main part of AHP technique, that assigns numbers for representing data to determine each parameter weight. The values and criteria of the parameters are given for indicating its relative importance between two parameters. The next step is the weighted arithmetic mean for calculating the Eigenvalue. The goal of this process was to measure the weights in a pairwise comparison matrix. Each parameter weight was determined in a pairwise comparison matrix using the mean row approach.

3. Results

The results of this study consist of four sections. The first is a pairwise comparison, which provides the weight of each parameter as the results. The second section is thematic maps, which illustrate flood-causative parameter maps along with the result of rating scores of each parameter class. The third section is an assessment of a spatial flood risk via a flood susceptibility map of the CRB. The last section is an evaluation of the flood susceptibility map. The detail of each result section is explained as follows.

3.1. Pairwise comparison matrix

The pairwise comparison provides the weight of each flood-causative parameters for an AHP method of a flood susceptibility assessment. The results of weighted arithmetic mean are also shown in Table 1.

![Table 1. The weight values and normalized rating of the flood-causative parameters from the pairwise comparison technique](image)

| Parameters          | Distance from river | Elevation | Geology | Soil Type | Land-Use | Drainage Density | Geomorphology | Weight |
|---------------------|---------------------|-----------|---------|-----------|----------|------------------|---------------|--------|
| Distance from river | 0.403               | 0.534     | 0.472   | 0.290     | 0.318    | 0.282            | 0.217         | 0.360  |
| Elevation           | 0.134               | 0.178     | 0.283   | 0.194     | 0.238    | 0.235            | 0.174         | 0.205  |
| Geology             | 0.081               | 0.059     | 0.094   | 0.290     | 0.159    | 0.094            | 0.174         | 0.136  |
| Soil Type           | 0.134               | 0.089     | 0.031   | 0.097     | 0.159    | 0.141            | 0.087         | 0.106  |
| Land use            | 0.101               | 0.059     | 0.047   | 0.048     | 0.079    | 0.188            | 0.130         | 0.093  |
| Drainage Density    | 0.067               | 0.036     | 0.047   | 0.032     | 0.020    | 0.047            | 0.174         | 0.060  |
| Geomorphology       | 0.081               | 0.045     | 0.024   | 0.048     | 0.026    | 0.012            | 0.043         | 0.040  |

Figure 1. The study area of Chi River Basin, Mahasakham and Roi-Et Provinces, Thailand
3.2. Thematic maps

The total of seven flood-causative thematic maps (Figure 2) are discussed as follows; (1) the distance from the river: the thematic map was created and converted to the raster image (Figure 2a). The distance from the river is a significant factor for flood disasters in the study area with a normalized weight of 0.360, (2) elevation: the elevation is generally low in the middle of the area along a floodplain next to the river mainstream in the study area as illustrated in Figure 2b with the normalized weight of 0.205, (3) geology: Influence flood disasters in terms of its permeability geologic distribution of the study area is illustrated in Figure 2c, which has a normalized weight of 0.136, (4) soil type: the clay content in soil causes a lower infiltration rate, which enhances flood risk of the area. The soil type map is shown in Figure 2d. The normalized weight of soil type had been assigned as 0.106, (5) land use: the CRB land use map is presented in Figure 2e, with the normalized weight of 0.093, (6) drainage density: the drainage density map is shown in Figure 2f. The drainage density parameter has a normalized weight of 0.060, and (7) geomorphology: Among these landforms, the floodplain along the mainstream has the highest flood risk than other landforms in the CRB. The geomorphological types map is illustrated in Figure 2g. The geomorphology has been assigned 0.040 for the normalized weight.

3.3. Assessment of flood susceptibility

All flood-causative parameter maps were combined using an overlay technique in ArcGIS software version 10.5 to generate the study area's flood susceptibility map. The parameters were overlaid by using a weight linear combination method according to each parameter weight and rank. The study area’s flood susceptibility map was categorized into five different flood susceptibility levels using the natural break (Jenks) method. The spatial flood susceptibility levels are very high flooding (16.93%), high flooding (17.76%), moderate flooding (22.40%), low flooding (29.08%), and very low flooding (13.83%), that spread throughout the area as illustrated in Figure 3. The very high flooding mostly concentrates along the Chi river floodplain in the central part, indicated in a red area on the map. In contrast, dark green regions on the map represent very low flood susceptibility, spreading on the high elevation regions of the northern, southwestern, and south-eastern part of the study area, shown in Figure 3.

3.4. Evaluation of flood susceptibility map

The flood susceptibility map has been evaluated for its accuracy and reliability by comparing it with a compiled historical flood data of the study area, using a statistical evaluation method of the confusion matrix and binary classification test. The compiled historical floods of the study area in 2005-2016 has been acquired from the Geo-Informatics and Space Technology Development Agency of Thailand (GISTDA) [31]. The accuracy of the map shows a correct determination of flood and non-flood area as compared with an observation data (in this case is a compiled flood area map from GISTDA). The map has an accuracy of 73% according to a binary classification test.

4. Discussion

Although the AHP method was successfully applied for the flood susceptibility mapping in the Chi River Basin, Mahasarakham, and Roi-Et Provinces of Thailand as confirmed by a good accuracy, there are remarks, uncertainties, and limitations that need to be addressed for the study. The first discussable point is a selection of flood causative parameters for the AHP analysis, as it is an adjustment of the experts. There are various numbers of parameters included in different studies of flood susceptibility determination using AHP. The number of parameters of four has been applied in the various studies, such as the studies of [8,22,23]; six parameters in [11,14,15,32]; seven parameters in [17,33]. A different list of parameters for flood susceptibility assessment should be determined according to specific physical characteristics of each basin [17], as well as social and economic aspects. The flood-causative parameters in our study can be grouped into categories as follows; (1) hydrography
parameters: distance from the river, and drainage density, (2) hydrological parameters: geomorphology, and elevation, (3) permeability parameters: geology, land use, and soil type.

Figure 2. Flood-causative parameter thematic maps; (a) distance from river, (b) elevation, (c) geology, (d) soil type, (e) land-use, (f) drainage density, and (g) geomorphology.
In this research, seven flood-causative parameters are in categories (1) – (3), which involved only physical characteristics of the basin. All parameters were considered as static parameters which are not changeable or not like to change through time, reflecting physical flood susceptibility of the basin. Rainfall is a factor that has been excluded in the study since we considered it as a dynamic parameter which can change rapidly through time. This study determined a flood susceptibility spatially over the basin. However, the magnitude of flood disaster, i.e., flood depth; was not included in flood susceptibility levels. Thus, a combination of other various flood susceptibility assessments with the AHP is highly recommended for higher accuracy of flood risk studies. Final remark, the most effective flood susceptibility mapping can be generated by two factors, which are data and method. The AHP technique is a convenient and effective method for multi-criteria analysis. However, this flood susceptibility map can be improved if there are better data availability, as well as if other more effective methods can be evaluated as compared to the AHP.

5. Conclusions
The flood susceptibility evaluation using the Analytical Hierarchy Process (AHP) is successful in assessing the regions vulnerable to spatial floods in the Chi river basin, Mahasarakham and Roi-Et provinces, Thailand. The AHP is a cost and time-effective method. Seven hydrogeomorphologic parameters have been determined as the flood-causative parameters in the CRB; which are the distance from the river, drainage density, elevation, geology, soil type, land use, and geomorphology. The highest normalized weight in the study is a distance from the river, followed by elevation, geology, soil type, land use, drainage density, and geomorphology, respectively. The result reveals that 16.93 percentages of the entire study area have been identified as a very high flood zone in the central of the CsRB; along with 17.76 percentages of a high, 22.40 percentages of a moderate, 29.08 percentages of a low, and 13.83 percentages of a very low flood susceptibility regions. The fluvial flood is a dominant flood type.
in the study area because the weightiest parameter on flood susceptibility is a distance from the river. The flood susceptibility map has an accuracy of 73 percentages as compared to compiled previous flood maps from GISTDA by using the binary classification test. The AHP method is well-performed for the flood susceptibility mapping of the CRB, which can be utilized in other basins. However, an adjustment of parameters is recommended. The method can be further applied for other multi-criteria studies such as drought study, groundwater potential assessment, and so on.

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