SPATIAL MODELING AND ANALYSIS ON FLOOD RISK ASSESSMENT USING FUZZY ANALYTIC HIERARCHY PROCESS: A CASE STUDY OF BANG RAKAM MODEL IN THAILAND

APHITTHA YODYING

A Thesis Submitted to the Graduate School of Naresuan University
in Partial Fulfillment of the Requirements
for the Master of Science in (Disaster Management - (Plan A Type A2) International Program)
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By APHITTHA YODYING

has been approved by the Graduate School as partial fulfillment of the requirements for the Master of Science in Disaster Management - (Plan A Type A2) International Program of Naresuan University

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ABSTRACT

Flood events are a common global natural disaster with a high frequency and broader geographical distribution. In 2011, Thailand encountered the worst flood, the Thai government developed the “Bang Rakam Model 54” to be used as a guideline model to solve flood problems at Bang Rakam district in Phitsanulok. Subsequently, on September 20, 2016, the Ministry of Agriculture and Cooperatives (MOAC) and Royal Irrigation Department (RID) collaborated to resolve the menace of flood in the provinces of Sukhothai and Phitsanulok. The main idea of “Bang Rakam Model 60” was to adjust the cropping plan over the low-lying areas by allocating water for irrigation earlier than the usual cropping period. These low-lying areas then will be used as Monkey Cheek areas to retard the floods. The purposes of this study are to prioritize factors influencing flood hazard and flood vulnerability using fuzzy AHP, create a flood hazard map and flood vulnerability map, generate a flood risk map, and analyze the perception of farmers on flood risk. The study area covered the area of the Bang Rakam Model 60 project (2 provinces, 5 districts, 20 sub-districts, 93 villages). The fuzzy analytic hierarchy process (fuzzy AHP) based on Chang’s extent analysis was combined with geographical information systems (GIS). Eight factors were considered for the flood hazard map, i.e. 1) distance from drainage network 2) drainage density 3) elevation 4) flow accumulation 5) land use 6) slope 7) soil water infiltration and 8) average annual rainfall. Five factors were considered for the flood vulnerability map including 1) age group 2) dependency ratio 3) gender ratio 4) population density, and 5) road density. Each factor was weighted to obtain the final maps. The obtained flood hazard map and the flood vulnerability map were used to generate and assess the flood risk map. The opinions of 102 sampled farmers who cultivated in the Phitsanulok and Sukhothai provinces were collected and analyzed with the flood risk map to assess farmers' perception of flood risk.

The result showed that annual rainfall with a weight factor of 0.1879 was the most important factor influencing flood hazard. These were followed by flow accumulation (0.1667), drainage density (0.1611), elevation (0.1423), slope (0.1206), soil water infiltration (0.0988), distance from drainage network (0.0632), and land use (0.0594). Prioritization of factors influencing flood vulnerability revealed that population density and road density were the most important factors and recorded the same fuzzy weights of 0.3107. These were also followed by age group (0.1322), dependency ratio (0.1252), and gender ratio (0.1212). The total study area of 695.55 km^2 was assessed into five flood risk levels of very high, high, moderate, low, and very low. Moderate level covered an area of 225.67 km^2 (32.44%), high level covered 139.60 km^2 (20.07%), very high level covered 119.12 km^2 (17.13%), very low level covered 111.05 km^2 (15.97%), and low level covered 100.11 km^2 (14.39%). The results also showed that most of the very high-risk areas were along the Yom River and the border between Kong Krailat and Phrom Phiram districts. The analysis of the farmers' perception of flood risk revealed that farmers in high-risk level areas have a high-level perception of flood risk.

Flood risk assessment at Bang Rakam Model 60 provided important information to guide future projects aimed at flood prevention, mitigation, preparation, response, and recovery. Additionally, the risk analysis results of the study will serve as baseline information for people to understand the level of damages and losses that can happen during a flood.

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ABBREVIATIONS

ADPC = Asian Disaster Preparedness Center

AHA Centre = ASEAN Coordinating Centre for Humanitarian Assistance on disaster management

AHP = Analytic Hierarchy Process

CFE-DM = Center for Excellence in Disaster Management and Humanitarian Assistance

CI = Consistency Index

CR = Consistency Ratio

DDPM = Department of Disaster Prevention and Mitigation

DEQP = Department of Environmental Quality Promotion

DWR = Department of Water Resource

EU = European Union

FHI = Flood Hazard Index

Fuzzy AHP = Fuzzy Analytic Hierarchy Process

FVI = Flood Vulnerability Index

GIS = Geographic Information System

GISTDA = Geo-Informatics and Space Technology Development Agency

GRASS = Geographic Resources Analysis Support System

ICSU-GeoUnions = International Council for Science-GeoUnions

IDW = Inverse Distance Weighted

ILWIS = Integrated Land and Water Information System

JICA = Japan International Cooperation Agency

LDD = Land Development Department

LIDAR = Light Detection and Ranging

MCA = Multi-Criteria Analysis

MCDA = Multi-Criteria Decision Analysis

MCDM = Multi-Criteria Decision Making

MOAC = Ministry of Agriculture and Cooperatives

MOF = Ministry of Finance

ABBREVIATIONS (CONT.)

NSO = National Statistical Office
RI = Random consistency Index
RID = Royal Irrigation Department
SMCA = Spatial Multi-Criteria Analysis
SPSS = Statistical Package for the Social Sciences
TFNs = Triangular Fuzzy Numbers
THB = Thai Baht
TMD = Thai Meteorological Department
UNESCO = United Nations Educational, Scientific and Cultural Organization
UNISDR = United Nations International Strategy for Disaster Reduction
USD = United States Dollar
WMO = World Meteorological Organization

CHAPTER I INTRODUCTION

This chapter explains the background, statement of the problems, objective of the study, question of the study, scope of the study, and preliminary agreement of this thesis.

1.1 Background

Flood events are a common global natural disaster (Stefanidis & Stathis, 2013). Flood, as defined by UNISDR (2017) is a natural hazard with a high frequency and broader geographical distribution that causes catastrophic damages to lives and the ecosystem. According to the EU (2007), flood means *“the temporary covering by water of land not normally covered by water.”* This includes floods from rivers, mountain torrents, Mediterranean ephemeral watercourses, and floods from the sea in coastal areas. According to ICSU-GeoUnions, JBGIS, and UNOOSA (2013) and Queensland Government (2011), this is mostly caused by ceaseless or hefty precipitation, which surpasses the absorption capacity of the soil and the flow capacity of the river. The global flooding events have caused thousands of deaths and huge socio-economic losses. The data in Figure 1 shows the economic losses incurred due to natural disasters in Asia, a colossal financial loss, and economic in the affected countries. These flood events rendered the victims poorer and incapacitated them beyond restoring normal living conditions for a decade (DDPM, 2015). Most of the economic and social losses incurred from floods are caused by population increase, disordered city systems, persistent urban development, and capricious land use (Hategekimana et al., 2018). Besides, forecasts for future climate change indicate that the risk of flooding will intensify in various regions in the world (Muis, Güneralp, Jongman, Aerts, & Ward, 2015).

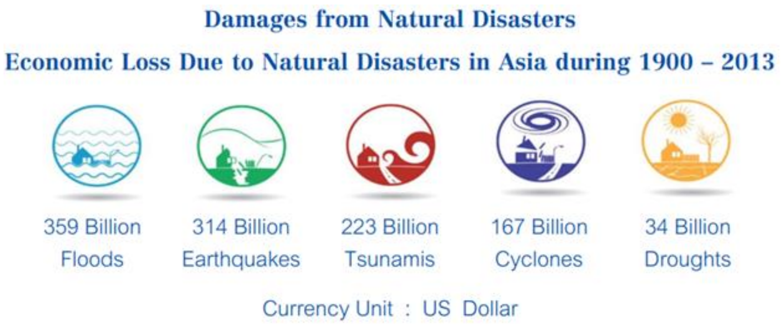


Figure 1 Economic losses caused by natural disasters in Asia

Source: DDPM (2015)

In Thailand, flooding is the most fatal and frequent hazard. It is common and devastating that the impact varies regionally and all provinces in the country struggle with flood-related damages annually (CFE-DM, 2018). Thailand has three climatic seasons naming rainy, winter, and hot. Heavy rains combined with multiple tropical storms all over the extended rainy season contribute significantly to flooding (MOF, Royal Thai Government, & World Bank, 2012). Usually, rainfall intensifies in September causing flooding is in the northern part of the country (Meehan, 2012). Floods and storms contribute 58% and 29%, respectively to the disasters recorded in the country. In 2011 for instance, floods caused 95% of the economic losses attributable to disasters in Thailand (AHA Centre & JICA, 2015). Most flood-related casualties do occur in resource-depleted communities and countries, generally owing to their greater vulnerability to disasters and inferior disaster management systems (Ahern, Kovats, Wilkinson, Few, & Matthies, 2005). The aftermath of floods on health in developing countries are numerous and serious (Fewtrell & Kay, 2008). The effects of the flood on communities may be direct, indirect, and short to long term (Alderman, Turner, & Tong, 2012).

In 2011, the Thai government developed the “Bang Rakam Model 54” to be used as a guideline model to solve flood problems at Bang Rakam district in Phitsanulok before the water flows into the central region and Bangkok (Promma, 2013). Situated at the lower Yom River Basin, the Bang Rakam district is a low-lying area that holds excess water from the upstream districts. The Nan River and Yom River merge at this district and then flows into the Chao Phraya River in Nakhon Sawan province (Kabir & Hasin, 2011). Heavy rains in the upper basin or a large flow of water from the northern sector cause annual floods in this district. An increase in water level in the Nan River restricts water flow from the Yom River causing flooding (Songka & Chaipimonplin, 2018). Many people in the area work as farmers. Therefore, when it comes to disaster prevention and mitigation, they are an important priority. It is necessary to fully understand their perception of disasters. Previously, researchers of flood disasters had focused education on flood risk perception rather than flood perception (Luo, Lone, Jiang, Li, & Berends, 2016). In unsure situations, decisions are depended on farmer's perceptions about the information, preferences, attitudes, and environment (Kitonyo, 2015). Perception of the source of risk is one of the factors that determine the coping method, though perception helps to determine the coping pattern, the basis of perception arises from their local knowledge, experiences, and opportunities to face existing problems (Bormudoi & Nagai, 2017). The Bang Rakam Model 54 was the first project undertaken at the non-irrigation scheme area, right bank of the Yom River at Bang Rakam district. Retarding basins were constructed to hold excess water and these included Bueng Takreng, Bueng Raman, and Bueng Kheerang (Kositgittiwong, Ekkawatpanit, Chiawyonsin, Petpongpan, & Ekkphisutsuntorn, 2017). After this project, in 2017, Thepsitthar and Boonwanno (2018) mentioned that the "Bang Rakam Model 60" took off at the left bank of the Yom River to adopt King Rama IX's Monkey Cheek concept of using lowland paddy fields as expansion zones to amass flood (Trakuldit, 2018). The main target areas for irrigation water in the low-lying areas of Bang Rakam Model 60 were the case study areas in this thesis.

Remote sensing data is the rudiment for many input data layers that are required for risk assessment. High-resolution imagery is a good rudiment for hazard-related aspects of mapping as well as an inventory of the elements-at-risk. The severity of hazard differs from place to place, and the location of the elements-at-risk also varies. Vulnerability is a concept that developed from the social sciences and to date, there is still no clear understanding of it. This makes the concept harder to be measured or quantified, as it is multidimensional, scale-dependent, and dynamic (Alcántara & Goudie, 2010). Appraising flood hazard is a necessity for flood risk appraisal and is of importance to the natural environment, human life, and social economy (Liu et al., 2015). Besides its use for assessment, flood hazard maps are helpful implements for urban development and spatial planning (Büchele et al., 2006). Risk can be described as an amalgamation of the hazard, the disaster likelihood, and the outcomes, which turn to increase the cost and results of flooding (Glas et al., 2017). Hazard, vulnerability, and risk assessments can be conducted effectively by using implements that tackle spatial information, for example, geographic information systems (GIS), e.g. ArcGIS, MAPINFO, GRASS, ILWIS (Alcántara & Goudie, 2010). Wang, Li, Tang, and Zeng (2011) recommended GIS for appraising spatial data on flood risk and has a significant part to perform in natural hazard management, it does not only generate visuals of the flood but also make it feasible to technically estimate the possible flood hazard (Sanyal & Lu, 2006).

Spatial multi-criteria evaluation is a technique that helps stakeholders in decision-making with esteem to a specific goal (Alcántara & Goudie, 2010). It is a suitable tool for decision-making as its integrated and weighted with esteem to the overall goal. Spatial multi-criteria analysis (SMCA) is a reasonable method to combine all pertinent types of results, which help do multi-criteria analysis (MCA) in a spatial character. The spatial data processing together with attributes is the main step to estimate flood risk (Wang et al., 2011). Assessing flood risks with GIS-based MCA was rare until 2000 (Kazakis, Kougias, & Patsialis, 2015). The analytic hierarchy process (AHP) created by R. W. Saaty (1987) forms the basis for the use of multi-criteria evaluation. Papaioannou, Vasiliades, and Loukas (2014) listed the AHP as one of the MCA methods that hierarchically partition the numerous criteria. It is an effective and flexible decision-making technique that helps managers to prioritize and make optimal decisions while considering both quantitative and qualitative features of decisions (Yadav, Jain, Shukla, & Mishra, 2012). Notwithstanding its various implementations, AHP does not usually take into consideration human thoughts. To effectively handle ambiguous information and uncertainties that arise in the multiple criteria, a mathematical tool “fuzzy analytic hierarchy process (Fuzzy AHP)” is used in analyzing decisions (Nguyen, Peterson, Gordon-Brown, & Wheeler, 2008). It has demonstrated with evidence greater pliability, a potentiality to define proper areas, and a further proper feature in decision-making processes compared to the conventional AHP methods (Aruldoss, Lakshmi, & Venkatesan, 2013). According to Erensala, Öncan, and Demircan (2006), beside the complex computations required during the use of fuzzy AHP for complex decision analysis, the judgment of human uncertainties is well captured.

In this study, an assessment of flood risk with a flood risk map obtained from flood hazard and flood vulnerability maps in the Bang Rakam Model 60 project will be done using fuzzy AHP in combination with the GIS process. Since most of the people covered in the study area are farmers, their perception of flood risk will also be analyzed in this study.

1.2 Statement of the Problems

In 2011, Thailand encountered the worst flood ever in more than half a century. The floods began in June in the northern regions with the Haima storm and caused an increase in normal average rainfall by 128%. This was followed by a tropical storm, Nock-Ten in July and August, it also raised the average rainfall of the two months by 150% (MOF et al., 2012). The total yearly rainfall in 2011 was the severest in the country in over 61 years. The movement of four tropical storm remnants; Haima, Haitang, Nesat, and Nalgae from the northern part of the country caused six months to continue to increase in average rainfall, this caused river banks to burst to result in flooding (Gale & Saunders, 2013). The inefficiency management of the major dams and their low capacity led to water spill-over causing damages to houses, historical sites, and industrial estates operated by big multi-national companies such as Honda, Toyota, and Sony. A total of 65 of the 77 provinces in the nation were influenced, leading to 884 casualties and millions left destitute. The World Bank's estimated an economic loss of USD 45.7 billion (THB 1.4 trillion) and was a huge cataclysmic event in recent history (Aon Benfield, 2012).

Yom River Basin covers 10 provinces (4.6%) of the country's area with a catchment area of 5.8 million acres. Yom River is 459 miles long and is the main river basin supporting the livelihood of approximately 1,900,000 inhabitance out of which 612,000 are engaged in agriculture activities (RID, 2011). Spreading wide from Phayao province to Phrae province forms the upper layer of the basin with terraced mountainous topography. The floodplains stretch from Sukhothai, Phichit, and part of Phitsanulok province areas, and this covers the lower part. As wide and long as it is, the basin, unfortunately, lacks a reservoir or a major dam to accommodate excess water flow all year long (Koontanakulvong, Hanittinan, & Suthidhummajit, 2014). Bang Rakam district, Phitsanulok province have located in the lower Yom River Basin as well as Sukhothai province that covers 26.9% of the whole area of the basin, and has been flooded every year.

The Bang Rakam district, Phitsanulok province is one of the significant districts facing recurrent floods annually. Many villages in this area are flooded and are the most affected areas in the province (Kabir & Hasin, 2011; Pittungnapoo, 2013). DEQP (2002) highlighted Si Satchanalai, Sawankhalok, Si Samrong, Mueang Sukhothai, and Kong Krailat districts in the Sukhothai province as flood-prone because the Yom River flows through them. During the flood, most houses, crops, government properties, and even lives are lost in Mueang Sukhothai. Approximately 602,813 of the residents are farmers, 40.3% of which has a mean annual income of US$ 500 (Sriariyawat, Pakoksung, Sayama, Tanaka, & Koontanakulvong, 2013). An individual’s perception is created by the psychological images that are stimulated by the external environment (Luo et al., 2016). Farmer’s attitudes and perceptions of risk are a significant part of decision-making. Timely and precise perception of risks may help farmers evaluate the likelihood and results of the risks. Additionally, timely perception of risk can aid farmers to make smart decisions about crop planning and adaptation (Iqbal, Ping, Abid, Kazmia, & Rizwan, 2016).

On September 20, 2016, the Agriculture and Cooperatives Minister (Chatchai Sarikalaya) was abreast of the situation. The Ministry of Agriculture and Cooperatives (MOAC) and Royal Irrigation Department (RID) were tasked to put efforts together to resolve the menace of flood in the provinces of Sukhothai and Phitsanulok. Among their functions was to adjust the crop plan in the main target areas to allocate water for irrigation in the low-lying areas. Thus farmers will have to sow in early April, a month earlier than the regular period (May) and farmers can harvest within July. These low-lying areas will be used as Monkey Cheek areas to retard the floods. So RID proceed with “Bang Rakam Model 60” with a targeted area of approximately 424 km^2 or 265,000 rai (RID, 2017, 2018). The main purpose was to save the government budget used as compensation fees to flood-affected farms and also create job opportunities for farmers during the flood period (Trakuldit, 2018).

This study will focus on flood risk assessment using the fuzzy analytic hierarchy process at the Bang Rakam Model 60 project. The study is designed to create a flood hazard map and flood vulnerability map, to generate a flood risk map as well as analyze the perception of farmers on flood risk. The fuzzy AHP will also be combined with GIS. Flood risk assessment in the areas covered by the Bang Rakam Model 60 will provide important data that related a reduction in disaster risks to environmental policies, economic, and social. Also, the generated flood map will become a pivotal element for flood risk assessment. This will help create a bench line data for disaster and risk management and provide essential information to guide future projects aimed at prevention, mitigation, preparation, response, and recovery. Moreover, the risk analysis results of the study will serve as baseline information for people to understand the level of damages and losses that can happen to lives, properties, and public services.

1.3 Objective of the Study

For this study, the following objectives are aimed:

1.3.1 Main Objective

To assess flood risk with flood hazard and flood vulnerability maps using fuzzy AHP in combination with the GIS process.

1.3.2 Specific Objectives

1. To prioritize factors influencing flood hazard and flood vulnerability using fuzzy AHP.

2. To create a flood hazard map and flood vulnerability map by applying fuzzy AHP and GIS.

3. To generate a flood risk map from the flood hazard map and flood vulnerability map for flood risk assessment.

4. To analyze the farmer’s perception of flood risk with the obtained flood risk map.

1.4 Question of the Study

1.4.1 Main Question

What are the procedures to assess flood risk using the fuzzy AHP method combination with GIS?

1.4.2 Specific Questions

These questions relate to the four specific objectives:

Specific objectives **(1) to prioritize factors influencing flood hazard and flood vulnerability using fuzzy AHP**

1. What are the factors to be considered for flood hazard and flood vulnerability assessment?
2. What is the procedure for the application of fuzzy AHP?
3. How to design an expert questionnaire for data collection?
4. How are the weights of fuzzy AHP methods?
5. What are the factors influencing flood hazard and flood vulnerability using fuzzy AHP?

Specific objectives **(2) to create a flood hazard map and flood vulnerability map by applying fuzzy AHP and GIS**, and **(3) to generate a flood risk map from the flood hazard map and flood vulnerability map for flood risk assessment**

6. What are the equations for calculating flood hazard maps, flood vulnerability maps, and flood risk maps?
7. How to create a flood hazard map, a flood vulnerability map, and a flood risk map?
8. What is the level of flood hazard, flood vulnerability, and flood risk in each area?
9. How to validate the obtained map?

Specific objective **(4) to analyze the farmer's perception of flood risk with the obtained flood risk map**

10. How to design the survey questionnaires?
11. What are the flood experiences of the farmers?
12. How is the farmer's perception of flood risk?
13. What is the reflection of the farmers on the Bang Rakam Model 60 project?

1.5 Scope of the Study

1.5.1 Area

The Bang Rakam Model 60 project irrigated fields will be selected for this study. The investigation will be performed in two provinces; Phitsanulok and Sukhothai provinces, where the districts of Phrom Phiram, Mueang Phitsanulok, Bang Rakam, Wat Bot, and Kong Krailat will serve as the study sites.

1.5.2 Methods

This study will be conducted using the application of fuzzy analytic hierarchy process and GIS for flood risk assessment at the Bang Rakam Model 60 areas. The processes are as follows:

1. Fuzzy AHP will be used to relieve the inherent uncertainty. The triangular fuzzy numbers (TFNs) based on Chang's extent analysis will be utilized to form the pair-wise comparisons, this is to obtain the preference weights of the alternative decisions. The fuzzy AHP will also be used to prioritize factors influencing flood hazard and flood vulnerability with reference to the weights obtained from the fuzzy AHP method. Therefore, the data collected from the questionnaires will be used to calculate and create a flood hazard map and a flood vulnerability map.

2. GIS will be used to generate the criteria maps, the classification, and the reclassification of the criteria maps, to create a flood hazard map with the help of the flood hazard index (FHI) and a flood vulnerability map with the help of the flood vulnerability index (FVI) to finally generate a flood risk map.

3. The repeated flood area from GISTDA will be used to validate.

4. Questionnaires clustered in two-parts will also be used: (1) questionnaire for pair-wise comparison will be used to consider factors that are being compared under the goal of this study as well as consider a class and a rating for each factor, and (2) questionnaire survey will be used to survey the farmer's perception of flood risk.

1.6 Preliminary Agreement

1. Experts will be considered as those people who have experiences and knowledge on the Bang Rakam Model 60 project, hydrology, flood hazard, flood vulnerability, demography, or related fields.

2. All respondents will answer questions with understanding and sincerity.

3. Data collected from the questionnaires at different times, dates, and places will have no direct effect on the data. They will serve as the baseline information and reference in generating the data presented in this study.

CHAPTER II LITERATURE REVIEW

This chapter discusses the flood, Bang Rakam Model, hazard and vulnerability, risk assessment, and risk perception. It continues with an explanation of the Multi-Criteria Decision Making (MCDM), Analytic Hierarchy Process (AHP), and Fuzzy Analytic Hierarchy Process (Fuzzy AHP) that are used in this study. It also describes the Geographic Information System (GIS) and Spatial Modeling for this study.

2.1 Flood

Floods and flooding often occur over normal drylands and affect households, plantations, property, human lives, and the economy (WMO, 2017). The character and scope of the flood rely on the physical location and topography, and the type of environment (Du, FitzGerald, Clark, & Hou, 2012). Floods have significantly good and bad effects depending on the area and the environment (Queensland Government, 2011).

2.1.1 Definition of flood

As stated by the WMO and UNESCO (2012), flood is defined as a *"rise usually brief in the water level of a stream or water body to a peak from which the water level recedes at a slower rate."* It also defined as *"relatively high flow as measured by stage height or discharge."* and flooding is defined as *"overflowing by the water of the normal confines of a watercourse or other body of water."* It is normally because of heavy rainfall events that cause a large volume of water within a water body. Moreover, human activities can also cause floods (DDPM, 2015).

2.1.2 Causes of floods

Floods are natural events that may occur from many factors, which include hydrological events e.g. south-west monsoons (Figure 2), intertropical convergence zones, tropical storms, and depressions, etc. These occurrences lead to heavy rainfall for an extended period particularly during mid-May until mid-October, which is the rainy season in Thailand (WMO, 2017).

Rainfall is the most important factor in flooding. When rain falls on a catchment, the rainwater amount that reaches the waterways rely on the catchment properties especially land use, size, and shape (Queensland Government, 2011).

Floods can also be caused by human activities such as inappropriate land use, forest land invasion, and deforestation. The rapid growth of urban without appropriate planning, inefficient water management, and inappropriate maintenance of drainage systems including a lack of harmony by water-related agencies are feasible factors that lead to flooding (WMO, 2017).

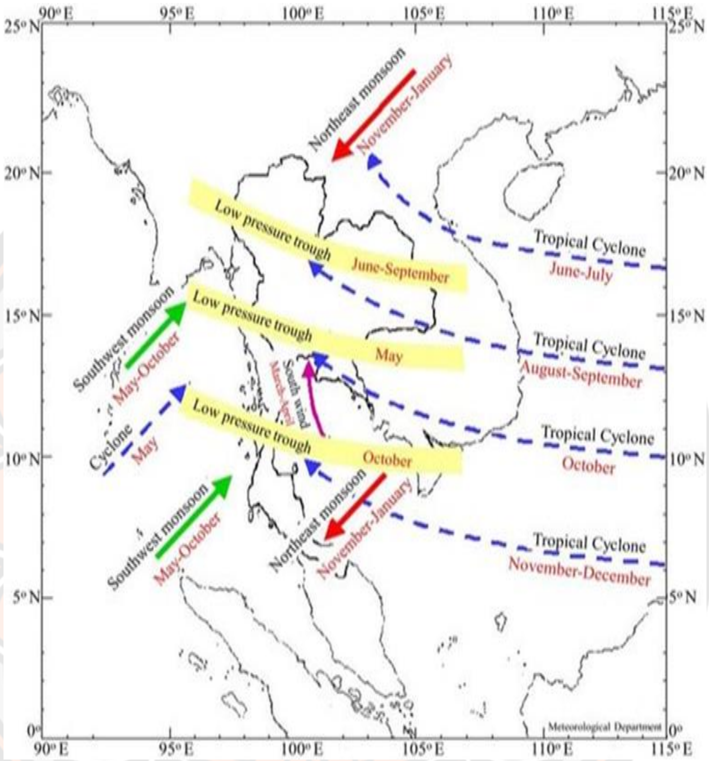


Figure 2 Areas that are influenced by hydrological events in Thailand. Green and red arrows mark are the southwest and northeast monsoon, respectively

Source: Jampanil and Seigo (2017)

2.1.3 Types of floods

Rani, Reddy, Felix, and Mariappan (2018) describes the following types of floods

1. Inland flood: It is the common flooding that happens in inland areas hundreds of miles from the coast. Continuous rainfall, surface runoff, slow-moving tropical cyclones, rapid snowmelt, or ice jams are the cause.

2. Urban flood: Normally caused because of lacking drainage in the urban area. High-intensity rainfall may result in flooding due to the city's sewage treatment system, and drainage canals, which are not capacitated enough to handle the quantity of rain that is falling.

3. Flash flood: It occurs within a very short time about 2-6 hours and may be caused by very-high intensity rain, the sudden break of the dam, or snowmelt. It normally gives no warning signs; hence no preparation is made, and the impact can be very rapid and devastating.

4. River flood: It happens when the level of water in streams, rivers, and lakes increases and flows over to all around banks, shores, and nearby lands. Heavy rain from tropical cyclones, snowmelt, or ice jams is the cause.

5. Coastal flood: A severe storm is a cause; the storm wind shoves the water up and creates high waves with heavy rainfall. Low elevation also plays a role in coastal water flooding. It can occur on the coast and along the banks of large lakes (Nasiri, Yusof, & Ali, 2016).

6. Storm surge: It occurs during a storm, cyclone, or hurricane. It is an enormous water wave that sweeps over the land.

In Thailand, there are two main types of floods (WMO, 2017):

1. Flash flood: It happens because of overabundant rainfall within a short time in the mountainous areas, flat areas near the river mouth, or in any low-lying area next to the rivers, where the soil is incapable of absorbing surplus water. A flash flood may cause following landslides and can cause larger damage than other types of floods on account of its speed and intensity.

2. Riverine flood: It occurs when the level of water in a river exceeding its water retention ability due to high-intensity rainfall. Also happens when a big amount of water is incapable to drain downstream towards the river mouths and flows over the river banks or stream.

2.1.4 Impacts of floods

WMO (2017) describes the following impacts of floods

1. Life of daily: Communities confront increased difficulties in traveling when roads are damaged by floods.

2. Health and hygiene: Expanding possibilities of contracting transmissible diseases or being bitten/stung by poisonous animals.

3. Life and psychosocial well-being: Sudden injury or death, for instance, electric shock, drowning, being hit by floating debris, being incapable to access health care centers, and depression over the loss of a family member, and so on.

4. Property: Damage to or loss of buildings, equipment, tools, and properties, etc.

5. Infrastructure: Damage to roads, and disruption of water supplies and electricity, telephone service and internet, etc.

6. Livestock and agricultural products: Damage to agricultural sites, conveying to the loss of crops and livestock. On other hand, the flood is beneficial as it transports sediments and nutrients onto flood plains as fertilizer and may also intern kill field rats and weeds. Moreover, communities can rising their earnings by selling fish.

2.2 Bang Rakam Model

The Prime Minister (Yingluck Shinawatra) visited the flood-affected area in August 2011 at Bang Rakam district, Phitsanulok province, and nearby areas as well as announced flood management is a national agenda that requires immediate solutions. By raising the problem of flooding in Bang Rakam district as a pilot project to unravel the flood problems (Kositgittiwong et al., 2017) for other areas so-called “Bang Rakam Model” (Promma, 2013).

2.2.1 Bang Rakam Model 54

From the floods event in 2011, the government endeavored to execute flood mitigation measures that are favorable to the life of locals to relieve the impact of floods. Both non-structural and structural measures have been suggested. Non-structural measures are the development of a database, making local knowledge, preparation of disaster mitigation planning, and monetary compensation. Structural measures lead to improving irrigation systems or reservoirs establishing (Trakuldit, 2018).

Kerdsakul (2013) describes that the Prime Minister defined a plan for water management to solving flood problems with Bang Rakam Model project based on 2P2R comprises:

1. Preparation: Preparing for the situation that will occur.

2. Response: Quick response when an incident occurs, send the officer help immediately and report the results of actions.

3. Recovery: Compensation, remedies, and recovery to normal conditions during flooding and after flooding.

4. Prevention: Sustainable protection against possible flood damage by selecting Bang Rakam district, Phitsanulok province as a model.

Bang Rakam Model 54 is a project conducted on Bang Rakam district, right bank of the Yom River with a period starting from 2012-2014. There is a division of responsibility between the Royal Irrigation Department (RID) and the Department of Water Resource (DWR). As for the RID, the budget will be allocated and responsible for the construction of regulator and dredging monkey cheeks as well as dredging various of the canal. DWR will receive a budget allocation and have a duty to dredge the canal to connect the system (Thepsitthar & Boonwanno, 2018). The non-irrigation area (Bang Rakam sub-district) is located on the right bank of the Yom River and the land is higher compare with the left bank, which is the irrigation area (Tha Nang Ngam and Chum Saeng Songkhram sub-districts). After the floods in 2011, the right bank never encountered a flood but on the left bank faces a flood every year due to it is a flood plain that is located between the Yom River and Nan River (Trakuldit, 2018).

In the part of the RID, related to recovery and prevention that focused on prevention by implementing structural measures (Trakuldit, 2018). The main goal is to reduce flood levels, reduce the period time of the flood, and to have water for farming after the water is reduced (Kerdsakul, 2013). There are a total of seven projects namely; the improvement of the floodgate one project, canal-dredging three projects, and monkey cheeks three projects to holding and retarding water, the location as shown in Figure 3 and Table 1. Monkey cheeks projects in Bang Rakam Model 54 comprise Bueng Takreng, Bueng Kheerang, and Bueng Raman to holding and retarding water, the area and amount of water retarding as shown in Figure 4.

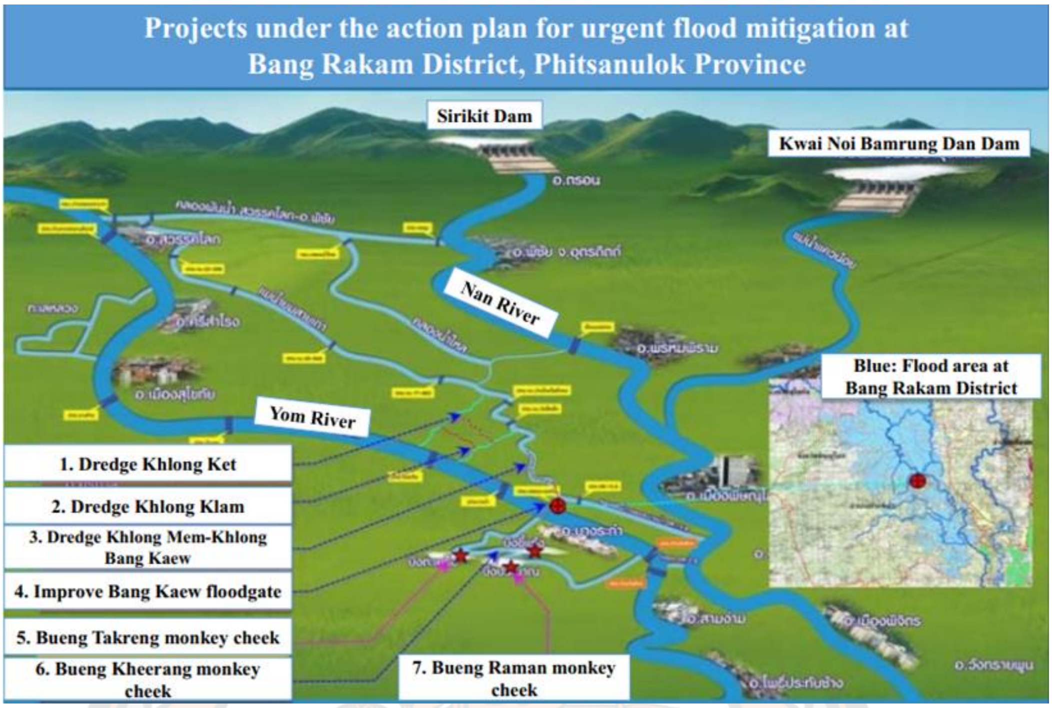


Figure 3 Location of seven projects according to the action plan

Source: Adapted from Kerdsakul (2013)

Table 1 Action plan for urgent flood mitigation of seven projects at Bang Rakam District

No.	Projects	Location
1	Dredge Khlong Ket (5.700 km)	Chum Saeng Songkhram Sub-district
2	Dredge Khlong Klam (5.762 km)	Chum Saeng Songkhram Sub-district
3	Dredge Khlong Mem-Khlong Bang Kaew	Bang Rakam and Tha Nang Ngam Sub-districts
4	Improve Bang Kaew floodgate	Bang Rakam Sub-district
5	Bueng Takreng monkey cheek	Bang Rakam Sub-district
6	Bueng Kheerang monkey cheek	Bang Rakam Sub-district
7	Bueng Raman monkey cheek	Plak Raet Sub-district

Source: Kerdsakul (2013)

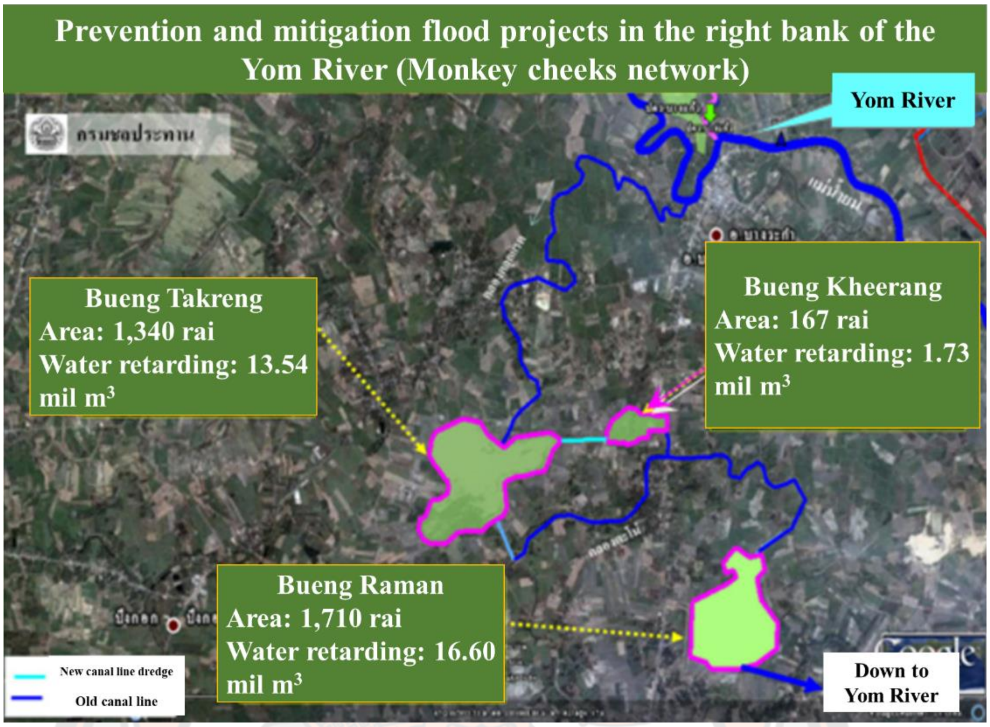


Figure 4 Area and amount of water retarding of Bueng Kheerang, Bueng Takreng, and Bueng Raman

Source: Adapted from Kerdsakul (2013)

2.2.2 Bang Rakam Model 60

After the implementation of Bang Rakam Model 54, the flood problem over the low-lying area in Yom River basin still existed. RID (2017) and RID (2018) stated that on 20 September 2016, Chatchai Sarikallaya (Minister of Agriculture and Cooperatives) authorized the RID and relevant agencies in the Ministry of Agriculture and Cooperatives (MOAC) to cooperate to resolve the flood problems in low-lying areas (Sukhothai and Phitsanulok provinces) because it is high flood risk areas in the flood season. They considered the situation for solving flood problems as follows:

1. Plan the supply of water for rice crop, starting in April and farmers can cultivate products within July (1 April - 31 July 2017) as shown in Figure 5 as well as use that areas as land to support water retarding and holding in the flood season. The amount of water that has been allocated for planting totaled 228 mil m^3. There is a water demand plan for supplying water to farmers by start planting in April total of 61.77 mils m^3 with target areas of 265,000 rai (424 km^2).

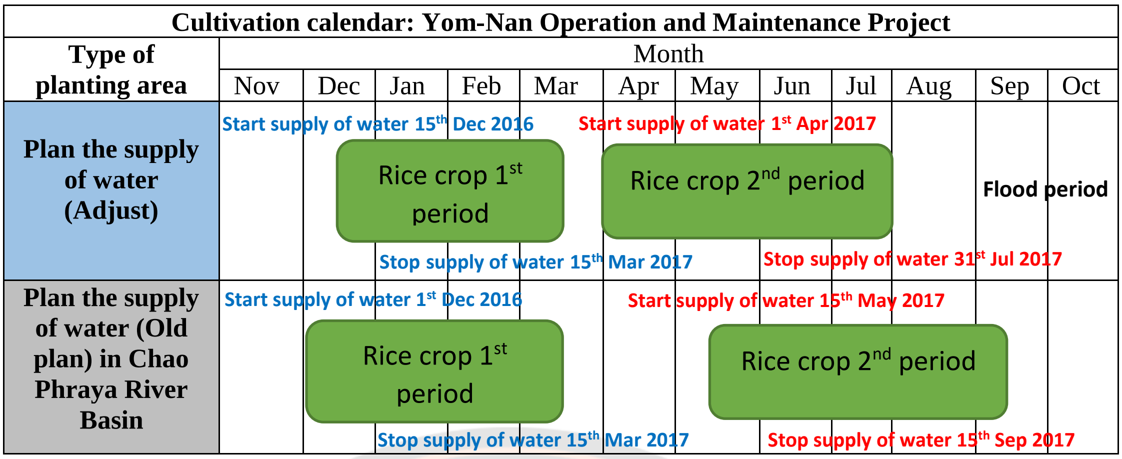


Figure 5 Cultivation calendar

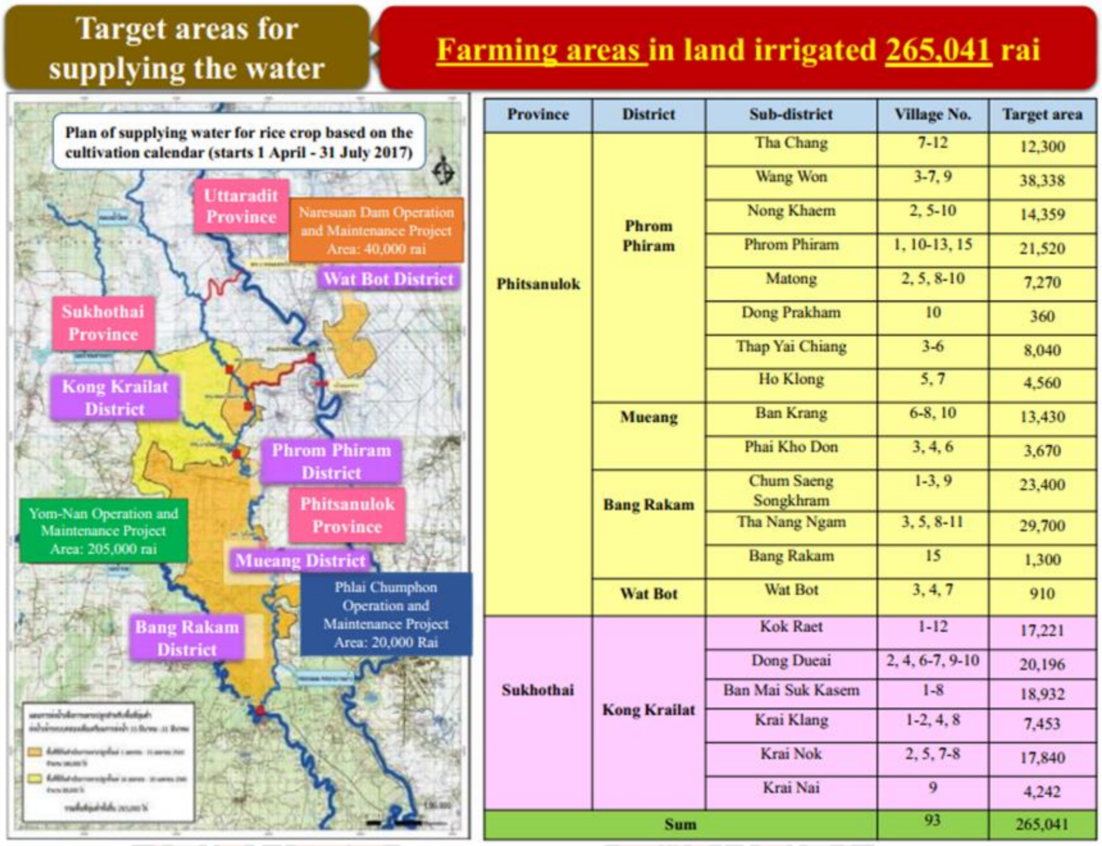
Source: Adapted from RID (2017)

2. Consider diversion of water into the three monkey cheeks (Bueng Kheerang, Bueng Takreng, and Bueng Raman) since the amount of water was low and some feeder canals still did not inter-connect.

The RID, therefore, implemented the project is called "Bang Rakam Model 60". It is the integrated water management project in the extension area that has been officially named similar to Bang Rakam Model 54 (Trakuldit, 2018) with the following project objectives:

1. Make community-based participate in water management. The communities over the low-lying areas that are between Yom and Nan River basin (in Sukhothai and Phitsanulok provinces) must give their consensus on using their land as the retarding fields through the participating process.

2. Establish water management that non-structural measures by adjusting the farmers' cultivation calendar in low-lying areas. Farmers have to earlier crop rice which starts planting in April to July and farmers can harvest products before the flood season inland irrigated (Irrigation Office 3, RID) with approximately is 265,000 rai or 424 km^2 (Yom-Nan Operation and Maintenance Project: 205,000 rai (328 km^2), Naresuan Dam Operation and Maintenance Project: 40,000 rai (64 km^2), and Phlai Chumphon Operation and Maintenance Project: 20,000 rai (32 km^2)). This land irrigated covering two provinces five districts twenty sub-districts ninety-three villages (Figure 6) and retarding a maximum of around 400 mils m^3 in order not to affect the Chao Phraya River Basin.



Target areas for supplying the water

Farming areas in land irrigated 265,041 rai

Province	District	Sub-district	Village No.	Target area
Phitsanulok	Phrom Phiram	Tha Chang	7-12	12,300
		Wang Won	3-7, 9	38,338
		Nong Khaem	2, 5-10	14,359
		Phrom Phiram	1, 10-13, 15	21,520
		Matong	2, 5, 8-10	7,270
		Dong Prakham	10	360
		Thap Yai Chiang	3-6	8,040
		Ho Klong	5, 7	4,560
	Mueang	Ban Krang	6-8, 10	13,430
		Phai Kho Don	3, 4, 6	3,670
	Bang Rakam	Chum Saeng Songkhram	1-3, 9	23,400
		Tha Nang Ngam	3, 5, 8-11	29,700
		Bang Rakam	15	1,300
	Wat Bot	Wat Bot	3, 4, 7	910
Sukhothai	Kong Krailat	Kok Raet	1-12	17,221
		Dong Dueai	2, 4, 6-7, 9-10	20,196
		Ban Mai Suk Kasem	1-8	18,932
		Krai Klang	1-2, 4, 8	7,453
		Krai Nok	2, 5, 7-8	17,840
		Krai Nai	9	4,242
Sum			93	265,041

Figure 6 Land irrigated of Bang Rakam Model 60

Source: Adapted from RID (2017)

Trakuldit (2018) stated that Bang Rakam Model 60 components are as follows:

Regulations:

1. Farmers who suffered must register on the names list at the agricultural office of the district.

2. Registered farmers must begin farming on 1-30 April and must use hybrid rice that is short-term rice species.

Guidances:

1. After the harvest period, registered farmers must not do farming up to November 1, 2017.

2. In case a occurs before August 20, 2017, if the farmers have not completely harvested, the government should pay compensation according to the rate expounded by the Ministry of Finance (MOF) at the national level.

- For residents affected: 33,000 baht per household.
- For rice fields affected: 1,113 baht per rai (not more than 30 rai).

According to RID (2018), the operation of Bang Rakam Model 60 project achieved the following objectives.

1. During flood crisis in Yom River basin, the retarding field can directly reduce the flood impact in lowland in Sukhothai province.

2. The retarding fields can slow down water drained downstream that helps decreasing the impact to the lower Chao Phraya River basin.

3. Saving the compensation budget in helping agricultural disaster victims.

4. Saving budget for preventing floods that will damage agricultural areas.

5. Encourage farmers to earn extra income from fishing activities which is a way of life for farmers in the area. Farmers can earn 300-500 baht per day/household and promote rice and fish products from the results of Bang Rakam Model 60.

2.3 Hazard and Vulnerability

2.3.1 Definitions of hazard and vulnerability

Wisner, Blaikie, Cannon, and Davis (2003), hazard refers to *“the natural events that may affect different places singly or in combination at different times.”* and vulnerability means *“the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard.”*

UNISDR (2009) explains a hazard as *“a dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.”* The same reference defines vulnerability as *“the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.”*

According to the UNISDR (2017) stated that hazards can be anthropogenic, natural, or socio-natural in origin. Human-induced hazards or anthropogenic hazards are mainly or completely by human choices and activities. Natural hazards are eminently related to natural phenomena and procedures. In the same reference, vulnerability is the situations defined by procedures that expand the individual susceptibility, assets, a community, or systems to the impacts of hazards or social, economic, environmental, and physical factors. DDPM (2015) described that vulnerability is a condition or factor that makes society or communities unable to protect themselves, incapable of handle disaster situations, or recover from hazards effects in a performance manner and timely.

2.3.2 Flood hazard

According to the WMO (2017), the assessment of hazards is the process of participation to identify hazards. The outcomes ought to be can identify the hazard nature in the sense of their location, causes, seasonality, probability, intensity, impact area, and the probability estimate or future occurrence frequency. Hazards can be able to separate into anthropogenic and natural hazards. Natural hazards can be classified as geophysical, hydro-meteorological, and biological which the hydro-meteorological phenomena are hydrologic and atmospheric processes (Ali, Bajracharya, & Koirala, 2016).

Mapping flood hazards is an important part of land use planning and mitigation in flood-prone areas (Gashaw & Legesse, 2011). Techniques for assessing flood hazards depend on several parameters, for instance, socioeconomic, hydrological, and meteorological (Ali et al., 2016). Flood hazard maps can be used to assess flood dangers to people, thus mapping and predicting flood hazards are important aspects of assessing flood risks (Rani et al., 2018).

The abrupt changes of the flood hazard maps and inundation maps are prominent features that affect the assessment of flood hazard thus a dissimilar methodology is required to determine flood hazard when different scales are regarded (UNISDR, 2017). GIS plays an excellent role in managing natural hazards for the reason that natural hazards are the spatial constituent is inherent and multi-dimensional (Rani et al., 2018).

2.3.3 Flood vulnerability

Vulnerability assessment is a process of participation to identify which components are at risk for each hazard type and the likelihood of them being lost or damaged. This assessment will identify what loss or damage is probable to take place during disasters and the causes it happens (WMO, 2017). Vulnerability assessment depends on processes caused and conditions set by social, physical, environmental, and economic factors that expand the community susceptibility. Vulnerability and risk assessment are interconnected parts and provide an overview related to flood risk assessment (Rani et al., 2018).

The vulnerability concept implies a measurement of risks associated with social, economic, and physical features and the result of the impact from the system's potentiality to manage with the outcome of events (Ali et al., 2016; Nasiri et al., 2016). Vulnerability is a set of consequent or prevailing conditions that are adversely affecting the community's potentiality to respond or prepare, prevent, and mitigate hazard events (Khan, Ali, Ali, & Qasim, 2015). Vulnerability represents a pivotal step in appropriately assessing the impact of floods and all quantitative indexes that are the last product of probabilistic risk assessment (UNISDR, 2017).

Flood vulnerability varies for people in diverse circumstances (Pandey, Singh, & Nathawat, 2010). Vulnerability assessment methods differ in vulnerability explanations, theoretical framework, variables, and methodology as well as vulnerability assessments based on normal indicators but still being challenged for reasons of complications related to standardization, weighting, and aggregation methods (Nasiri et al., 2016).

2.4 Risk Assessment

2.4.1 Definitions of risk and risk assessment

Risk is defined by UNISDR (2009) as *"the combination of the probability of an event and its negative consequences."* In the same reference, risk assessment is defined as *"a methodology to determine the nature and extent of risk by analyzing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm."*

2.4.2 Risk assessment concept

Rani et al. (2018) described risk as a statistical concept and a probability of negative events or conditions that affect people, infrastructure, and the environment. Risk is an occasion of an event happening or probability amalgamation and incident consequences. Consequences are in turn defined by the exposure level to that event and vulnerability of property, infrastructure, and people to the event (Queensland Government, 2011). Wisner et al. (2003) stated that the risk must be seen as a cross-cutting amalgamation of hazard and vulnerability that there incapable of a disaster if there is a vulnerable population but no occurrence of hazard or if there are hazards, but vulnerability is nil. Hazard (H), vulnerability (V), and risk (R) are three elements that relate and can be arranged in equation 2.1 as follows:

$$R = H \times V \qquad \text{Eq. (2.1)}$$

Risk assessment is a methodology or a process to define the extent and nature of risk by diagnosing the liable hazards and assessing the existing conditions of vulnerability and exposure as well as to estimate the alternative coping ability of communities and the effectiveness of prevailing (DDPM, 2015). It is an extremely data-intensive process. Moreover, new valuable data and analyses are made during risk assessments (UNISDR, 2017).

Risk assessment efforts in the present showed that more cooperation and innovation with experts in communications and other disciplines are essential to upgrade the technical information translation into transferable and productive information for practitioners and decision-makers. The risk assessment outputs are inputs to decision-making on strategies, operations, and investments for managing risk (UNISDR, 2017).

2.4.3 Process of risk assessment

The process of risk assessment flow designed in the international standards on risk assessment and risk management is the most commonly used (UNISDR, 2017) described as follows:

1. Establishing context: It is related to understanding the risk management context for determining the scope and purpose of the risk assessment. Also comprises consulting and engaging with stakeholders and determining decision criteria.

2. Risk identification: It is related to a very high-level scoping of vulnerabilities, exposure, and hazard to determine the way for the rest of the assessment procedure. It applies the experience and knowledge of stakeholders, risk information, and data on a past event to draw preliminary conclusions.

3. Risk analysis: It is related to acquiring a more detailed understanding of the risk, it comprises detailed vulnerability analysis, exposure analysis, hazard analysis, and capacity analysis.

4. Risk evaluation: It allows for risk prioritization for the risk managing purpose. The risk prioritization is further adjusted rely on an understanding of risk acceptance, risk perception, and capacities, and by the level and availability of resources.

2.4.4 Geospatial data in a risk assessment

UNISDR (2017) mentioned that location or spatial information, also known as geospatial information is essential for understanding risk. Geospatial information explains a data/information or location that can be referred to a location, which there are two types consist of raster and vector data. Examples of raster data include imagery from scanned maps or digital pictures or satellites, and aerial photographs, etc. Vector data, for instance, point location of a community, geographic contours, topographic road attributes characterized as lines, and polygon-shaped attributes of flooding extent. As presented in Figure 7, geospatial analysis is used in many risk assessment approaches. Analyzing and using geospatial data needs particular enabling technologies such as geographic information systems (GIS).

A basic characteristic of geospatial data is that they have the capability to be tied to a reference system or comprise a spatial reference system. Resolution in geospatial data used for a risk assessment ought to sufficient to reflect the level of accuracy and detail essential to evaluate both the scale of analysis and the processes considered.

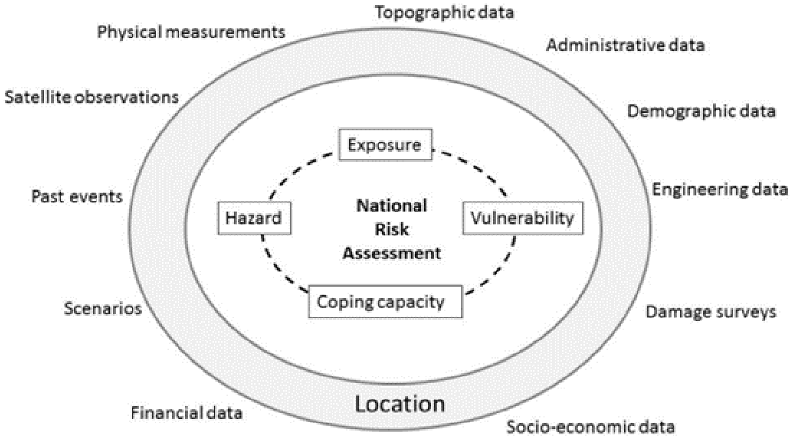


Figure 7 Major roles of spatial information in a risk assessment

Source: UNISDR (2017)

2.4.5 Flood risk assessment

The concept of risk associated with hazard and vulnerability seems to be the most acceptable to manage the risk of flooding, so it is important to know that the risk is completely a human subject (Nasiri et al., 2016). Flood risk is a product and a function of vulnerability and hazard, therefore risk assessment is significant in policies, making decisions, and managing floods (Ali et al., 2016). The flood risk assessment is a compound-complex and multi-disciplinary process (Khan et al., 2015). In each area, there are different methods for assessing flood risk and its vulnerability (Nasiri et al., 2016).

Flood hazard assessment is most often done amid the flood risk assessment process as it relies on the strength of the flood and the probability of flooding scenarios in the affected area. The risk from potential floods can be decreased by reducing the hazard level, vulnerability, and exposure value. Flood vulnerability and hazards directly correspond to the level of risk from floods. When the level of flood vulnerability and the hazard value are higher, then the level of the risk of flooding will also increase (Rani et al., 2018).

Flood risk is defined as the overall levels of flooding impacts. It combines the threat concept to limbs and life, the difficulties and dangers of migrating people, and their properties during floods that may damage the structure and content of social interruption, buildings, damage to public property, and loss of production (Rani et al., 2018). Risk is the results of hazards, statistical aspects, and physical of floods and vulnerabilities is the exposure of properties and people to floods and susceptibility of the elements at risk to encounter from flood damage (Cutter, 1996). Dang, Babel, and Luong (2010) defined flood risk as a product of flood hazard and flood vulnerability as in equation 2.2.

$$\text{Flood risk} = \text{Flood hazard} \times \text{Flood vulnerability} \qquad \text{Eq. (2.2)}$$

Flood risk assessment is used for flood planning and forecasting so that mitigation measures can be done in time (Khan et al., 2015). It requires interdisciplinary approaches and studies (Dang et al., 2010). There are four important steps which are characterizing the area, defining hazard intensity and level, vulnerability assessment, and risk assessment. Flood risk assessment, vulnerability, and hazard require an understanding of the causes of a possible disaster (Ali et al., 2016). Koontanakulvong et al. (2014) recommend that reducing the risk of flooding could be done by conducting a vulnerability assessment and adaptive capacities of communities.

The section of GIS and remote sensing has enormously facilitated the functioning of flood risk assessment and flood mapping. The flood risk map is of two types (Rani et al., 2018) and are as follows:

1. A detailed mapping approach, which is required for hazard assessment for risk maps.
2. A large-scale approach with the purpose of identifying the areas that have the highest risk.

2.5 Risk Perception

2.5.1 Definition of perception and risk perception

Perception is defined by Eidelberg (1968) as *"an internal experience arising from sensations and feelings and an external perception from sensory phenomena that both are controlled by the ego."*

Kristal, Argyle, Davison, Eysenck, and Spielberger (1981) define perception as "*a higher-level process by which the brain makes sense of sensations as* *well as receiving that sense. It enables us to receive and process information about the environment."*

Statt (1981) defines perception as *"the process by which the brain receives the flow of information about the environment from the sense organs and uses this raw material to help an organism make sense of that environment."*

Vesey and Foulkes (1990) stated that perception refers to *"the cognitive apprehension of something. In a narrow sense (sense-perception), cognitive apprehension depends on the stimulation of the sense-organs."*

Department of Psychology (1994) reported perception refers to *"the process of interpreting stimuli that affect our senses and how to interpret depends on our past experiences and current mental state."*

Paek and Hove (2017) highlighted that risk perception refers to *"people's subjective judgments about the likelihood of negative occurrences such as injury, illness, disease, and death."* and Lechowska (2018) defines risk perception as *"an assessment of the probability of a hazard and the probability of the results that most often are negative consequences perceived by society."*

2.5.2 Perception process

According to Eidelberg (1968) stated that internal perception is classified into perceptions from the desires and from feelings of guilt. Internal perception occurs from the remaining memory stored in the psychic apparatus, in the unconscious part of the ego, which must become preconscious and establish a connection to an external presentation to enter consciousness. External perceptions are direct consciousness and arise from assigning meaning to sensory experiences that are not different.

Vesey and Foulkes (1990) explain that based on the representative theory of perception, three philosophical assumptions consist of (1) only judgments (thoughts, propositions, which are non-sensory) be able to be false or true, (2) a person to be justified must have some foundation for judging and (3) the foundation must eventually be a thing other than another judgment. Thus, there must be a component that is not a judgment, which may be in accordance with the sense organs stimulation but are the foundation and be mental for the judgment the perceiver makes. This component is called "sensation" or "idea", which is stated to represent the external object and is an interpretation which is the foundation for judgment that there is an external object. The existing exterior world is hypothesized in the interpreting act thus its knowledge is direct or indirect, while the perceiver is directly or abruptly accustomed to the sensation.

Wonganutarot (2008) stated that perception consists of the following parts:

1. Sensation refers to stimuli that affecting the sensory organs so that people are aware of their surroundings. Interpretation of sensation requires intellect, observing, attention and intention, and quality of mind at that time.

2. Interpretation of sensation: It depends on the clarity of subsistence which can know from sensation by looking at gestures and speech characteristics.

3. Previous knowledge or previous experience: It viz thoughts, knowledge, and actions that have been acting in the past.

Disaster perception covers a wide range of potential research topics. It is significant to differentiate between disaster perception and a disaster risk perception. Perception cannot be regarded as a proven knowledge but is essential for understanding people's behavior during a disaster. People with different social factors, for example, age, culture, gender, and occupation tend to different disaster perceptions (Bormudoi & Nagai, 2017; Luo et al., 2016).

Risk perception is a significant descriptor in the disaster literature. This had a positive influence on the nature of farmers' risk aversion (Saqib, Ahmad, Panezai, & Rana, 2016). Farmers' risk perceptions reveal show many important findings along with that frequently a discrepancy between genuine and perceived risk (Botterill & Mazur, 2004), and not considering the individual accuracy of risk assessment. Intention to vary the way of actions and risk perception cannot ever direct to authentic actions change (Niles, Brown, & Dynes, 2015). Farmers' perceptions assessment and response to risk is very important because of its significance in paying attention to the decision-making manner of the farmers when they face unsure situations (Flaten, Lien, Koesling, Valle, & Ebbesvik, 2005). Well-timed and accurate perceptions of risks can help farmers evaluate the consequences and likelihood of exposed risks that can help farmers make smart decisions about crop management and adaptation measures (Iqbal et al., 2016).

2.6 Multi-Criteria Decision Making (MCDM)

Multi-criteria decision making (MCDM) or multi-criteria decision analysis (MCDA) is a method and technique of finding a compromise solution that has been evolved to advocate decision-makers in a private and exclusive decision procedure. MCDM is different in putting decision-makers at the center of the process which is not an automated method that leads to the identical solving of a problem for everyone nevertheless it will amalgamate subjective information or preference information. MCDM is comprehensive by psychology, management, mathematics, informatics, economics, and social science that can be extended to deal with any issue in which a crucial decision must be taken (Ishizaka & Nemery, 2013).

Aruldoss et al. (2013) stated that MCDM allows good decision-making in the domain where choosing the best solution is highly complexed. The MCDM method assists in the selection of the best choice by comparing existing criteria, analyzing various scopes for the criteria is the best way to go, using any multi-criteria decision-making techniques by selecting and weights of criteria the most suitable.

MCDM relates to the structure and problem solving of decisions, and planning related to multiple criteria. In general, there is the need to use decision-makers to distinguish between solutions, in situations that there is no best unique solution for problems (Albayrak & Erensal, 2005). It deals with selecting the optimal choice from a set of choices. Another way is to select a small set of nice choices or group the alternatives into different preference sets. The best distinctive choice to the MCDM problem can achieve without the incorporation of the desired information. The notion of the best solution is frequently returned to the set of non-dominated solutions. As a consequence, the decision-maker will pick a solution from the non-dominated set with ease. Anything else, the decision-maker could not able to do worse in any of them but could do better in terms of all the criteria.

Many applications use MCDM to determine defects in the system, these defects can be dealt with by using effective problem-solving methods. Figure 8 depicts the hierarchical view of MCDM methods and types. The MCDM methods have been used widely in various applications to assess the best approach for choosing the best alternative (Aruldoss et al., 2013).

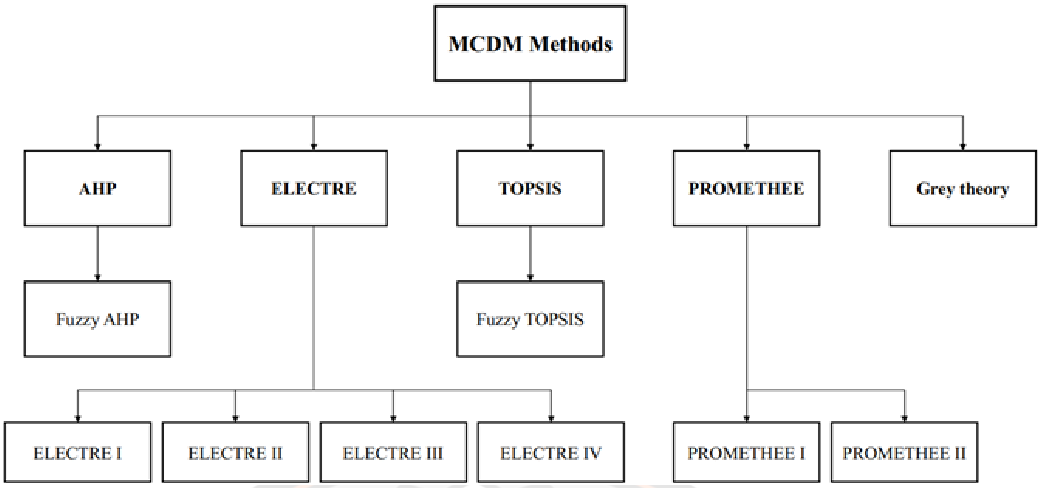


Figure 8 Hierarchical structure of MCDM methods

Source: Adapted from Aruldoss et al. (2013)

2.7 Analytic Hierarchy Process (AHP)

One of the best ways to decide the structure of complicated criteria at various levels is to use the analytic hierarchy process (AHP). It is a multi-criteria decision-making process, it is particularly well suited to complicated decisions that include comparing elements of the decision, which are hard to quantify (Kabir & Hasin, 2011). AHP was introduced and developed by R. W. Saaty (1987), is a powerful tool. Priority or weights vectors of criteria and alternatives are needed for the AHP method. R. W. Saaty (1987) also developed the pair-wise comparison method (Brahma, 2018).

Kabir and Hasin (2011) describes that AHP is based on the premise that when confronted with complicated decisions, the natural human response is to group the decision elements in accordance with their general characteristics. It involves creating a hierarchy of the decision elements (Figure 9) and using a matrix to comparisons between each potential pair in each group. This will give weight for each element within the group or the hierarchy level and the consistency ratio is helpful for testing data consistency.

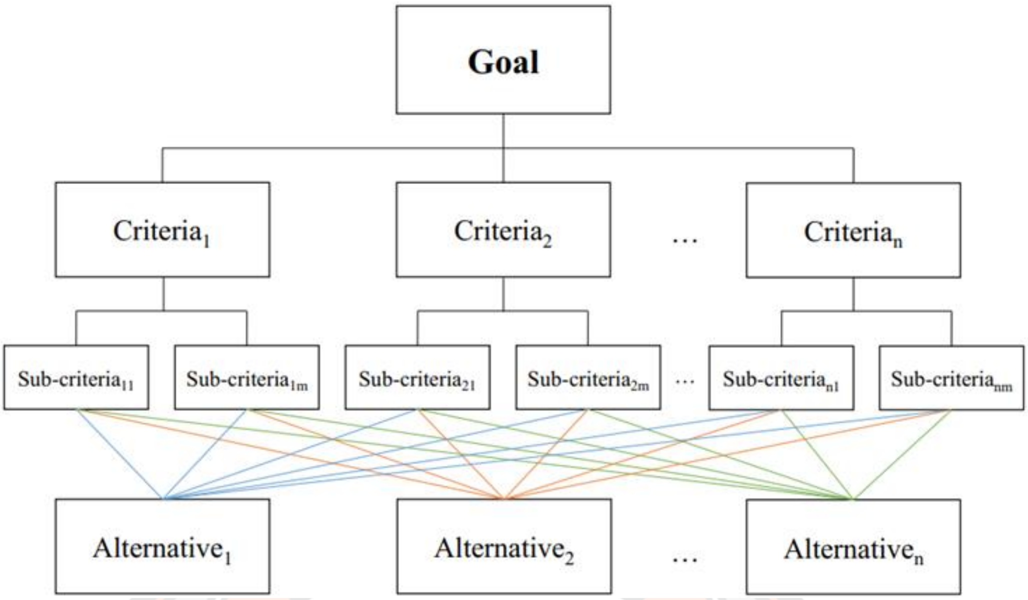


Figure 9 AHP hierarchy structure

Source: Adapted from Jongpaiboon (2015)

Suppose there are *n* criteria in the hierarchy defined, the process generates an *n x n* pair-wise comparison matrix. The pair-wise comparison is performed such that the criterion in row *i (i = 1, 2, 3, ..., n)* is ranked in relation to each of the *n* columns that constitute a criterion. Letting a_{ij} define the element *(i,j)*, in which $a_{ij} = 1$ signifies that *i* and *j* are equally important thus must equal 1 because they ranked *a* pattern criterion against itself (Kabir & Hasin, 2011). Brahma (2018) indicated that the general of the pair-wise comparison matrix is defined by equation 2.3.

$$R = [a_{ij}] = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1j} \\ 1/a_{12} & 1 & \cdots & a_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1j} & 1/a_{2j} & \cdots & 1 \end{bmatrix} \qquad \text{Eq. (2.3)}$$

The pair-wise ratio between the criteria is one of the significant elements of this matrix, which are chosen based on how well each criterion serves the ultimate final goal and how important each is in achieving it. T. L. Saaty (1990) used a scoring system to determine how important one criterion is in comparison to another in the construction of a pair-wise comparison matrix. In the end, a pair-wise comparison yields a square matrix where the value of each element ranges from 1/9 to 9 (Table 2). The matrix's diagonal elements are always equal to one, the non-diagonal elements, on the other hand, reflect the perceived relative importance of the corresponding choices.

The AHP will tolerate inconsistencies via the approach's amount of redundancy. If this consistency index falls short of the goal, it is possible to double-check the comparison. The consistency index (CI) is calculated as in equation 2.4.

$$\mathrm{CI} = \frac{\lambda_{\mathrm{max}} - \mathrm{n}}{\mathrm{n} - 1} \qquad \text{Eq. (2.4)}$$

where; λ_{max} principal eigenvalue and n is the number of criteria of the judgment matrix. The consistency ratio (CR) is calculated as in equation 2.5.

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \qquad \text{Eq. (2.5)}$$

where; *RI* is a random consistency index, as shown in Table 3, and sample size determines it. In the pair-wise comparison, a fair degree of consistency is assumed. For various matrix sizes, the reasonable CR is as follows (Jongpaiboon, 2015): CR ≤ 0.05 for the 3 x 3 matrix, CR ≤ 0.08 for the 4 x 4 matrix, and CR ≤ 0.10 for matrix sizes more than 4 x 4.

Vaidya and Kumar (2006) described some main steps and key related to the AHP method as follows:

1. Identify the problem.
2. Increase the scope of the problem's goals or regard all goals, actors, and outcomes.
3. Determine the criteria that affect behavior.
4. Create a hierarchical structure of different levels for the problem, including an objective, criteria, sub-criteria, and alternatives.
5. Compare and calibrate each part in the corresponding level on the numerical scale. Make sure the diagonal parts are equal or 1, and the rest of the parts are just the reciprocals of the previous comparisons.
6. For each alternative or criterion, calculate the maximum eigenvalue, consistency index (CI), consistency ratio (CR), and normalized values.

7. If the maximum eigenvalue, CI, and CR are appropriate, the decision is made using the normalized values; otherwise, the process is repeated until the values fall within the target range.

Table 2 The fundamental scale ranges from 1 to 9

Intensity of importance on an absolute scale	Determination	Description
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of tile highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals	If activity *i* has one of the above numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	

Source: T. L. Saaty (1990)

Table 3 Random consistency index for various matrix sizes

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Source: Kabir and Hasin (2011)

According to Aruldoss et al. (2013), the basic concept of the AHP is to collect expert knowledge about the phenomena under study. Priority theory underpins AHP. AHP manages complicated problems involving the contemplation of alternatives or multi-criteria at the same time. A matrix is generated for each criterion using the relative importance of the alternatives. AHP distinguishes a tough MCDM problem into hierarchical processes in a systematic manner. An $m \ x \ n$ matrix structure, where m represents the number of alternatives and n is the number of criteria, is the final step in the AHP method. The advantages and disadvantages of AHP methods have been outlined as follows:

Advantages:

1. It is user-friendly, flexible, and it checks inconsistencies.
2. The importance of each component becomes apparent as the issue is organized into a hierarchical structure.
3. There is no prejudice in the decision-making process.

Disadvantages:

1. There are inconsistencies in the ranking.
2. Important information can be lost due to additive aggregation.
3. There is a need for more pair-wise comparisons.

2.8 Fuzzy Analytic Hierarchy Process (Fuzzy AHP)

When considering the decision-makers' fuzziness, the fuzzy analytical hierarchy process (Fuzzy AHP) is a synthetic extension of the traditional AHP system. In general, it is impossible to reflect the uncertain preferences of decision-makers employing sharp values. Accordingly, the fuzzy AHP was proposed to reduce the uncertainty of the AHP method by using fuzzy comparison ratios (Kabir & Hasin, 2011). There are several procedures to prioritize in fuzzy AHP, in this study, Chang's extent analysis (Chang, 1996) was used to evaluate the focus problem.

The fuzzy AHP method can be considered as a more advanced method of analysis derived from traditional AHP (Kabir & Hasin, 2011). Aruldoss et al. (2013) added that AHP includes expert opinions and multi-criteria evaluation that cannot reflect the vague ideas of humans. Pair-wise comparisons are used to assess AHP, several products, and alternatives. For each item evaluation, the weight and evaluation values for each element, as well as alternatives, are determined. However, pair-wise comparisons do not yield a result of 0,1, but rather a numerical value is used to determine the degree. The weight is expressed by possibility measure or essential measure in fuzzy AHP, and aside from that, the normal state that the total of various weights 1 can be relaxed. AHP regards the explicit judgment of decision-makers, thus the fuzzy set theory makes the comparison process more capable of explaining the needs of a wider range of experts and flexible.

Zadeh (1965) developed the fuzzy set theory to deal with unpredictability and the source of ambiguity as well as has been used to incorporating vague data into the decision framework. A fuzzy set *A* of a universe *X* is defined by a membership function μ_A as a result μ_A: $X \rightarrow [0,1]$; where $\mu_A (x)$ *x* is the membership value of *x* in *A*. The universe *X* is always a crisp set. A fuzzy set is a class of objects with a continuum of membership grades. Such a set describes the nature of a membership function that is tasked with each object of membership grade ranging between zero and one. A tilde "~" that if the symbol represents a fuzzy set theory, it will be put above it (Rouyendegh & Erkar, 2012).

Brahma (2018) stated that the most usually utilized fuzzy numbers in practice and theory are triangular and trapezoidal fuzzy numbers, where the characteristics and effortless of calculation, the use of triangular fuzzy numbers is more practical in the application (Figure 10). A fuzzy number *a* is determined by a triplet $a = (l, m, u)$ the membership function, the triangular fuzzy number is assigned by equation 2.6.

$$\mu_a(x) = \begin{cases} \frac{x-l}{m-l} & x \leq m \\ \frac{u-x}{u-m} & x \geq m \\ 0 & x \notin [l, u] \end{cases} \qquad \text{Eq. (2.6)}$$

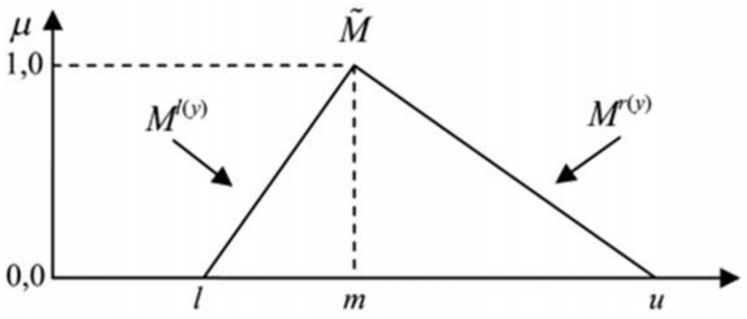


Figure 10 Triangular fuzzy numbers

Source: Rouyendegh and Erkar (2012)

Define two triangular fuzzy number $a_1 = (l_1, m_1, u_1)$ and $a_2 = (l_2, m_2, u_2)$. The algebraic functioning of the triangular fuzzy number can be express as in equation 2.7-2.10.

Summation $\quad a_1(+)a_2 = (l_1 + l_2,\ m_1 + m_2,\ u_1 + u_2) \quad$ Eq. (2.7)

Subtraction $\quad a_1(-)a_2 = (l_1 - l_2,\ m_1 - m_2,\ u_1 - u_2) \quad$ Eq. (2.8)

Multiplication $\quad a_1(\times)a_2 = (l_1 \times l_2,\ m_1 \times m_2,\ u_1 \times u_2) \quad$ Eq. (2.9)

Division $\quad (a_1)^{-1} = \left(\frac{1}{u_1},\ \frac{1}{m_1},\ \frac{1}{l_1}\right) \quad$ Eq. (2.10)

Chang (1996) proposed a new method for dealing with fuzzy AHP based on triangular fuzzy numbers for the pair-wise comparison scale of fuzzy AHP, accompanied by the use of the extent analysis technique for the pair-wise comparison’s synthetic extent value. The first step is to use triangular fuzzy numbers for pair-wise comparisons using the fuzzy AHP scale, followed by the extent analysis approach to obtain priority weights using synthetic extent values. The fuzzy criteria evaluation matrix was generated by pair-wise comparisons using triangular fuzzy numbers and linguistic variables as shown in Figure 11 and Table 4 (Kabir & Hasin, 2011).

Aruldoss et al. (2013) had also compared AHP and fuzzy AHP and stated that AHP is a technique used to rank the aim of choosing, when decision-makers have several criteria, this is the best option. This approach enables decision-makers to choose the best alternatives from every one of them to rank based on the suitability of each alternative. Fuzzy AHP helps humans in quantitative prediction as they are not well versed, uncertainties may arise during decisions, resulting in inconsistency between the alternatives.

There are several criteria, according to fuzzy pair-wise comparisons, but if some are less significant than the others, they can be weighed nil. In this way, AHP can determine and operations do not permit for a situation where zero is weighed, so if the criterion’s evaluation is lower than all other values, the numerical weight of the criteria would be closer to zero. The less important criteria can be ignored by a fuzzy AHP, on the other hand, the AHP will give some weight.

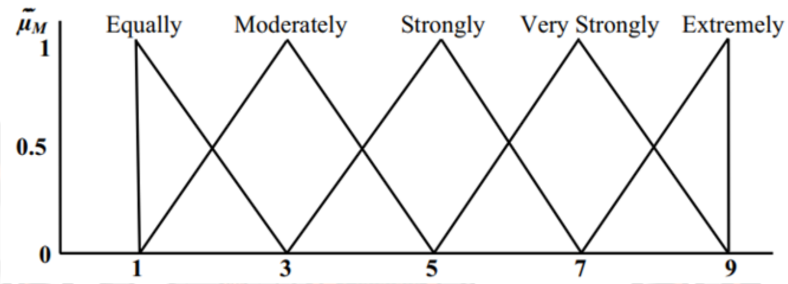


Figure 11 Linguistic variables for each criterion’s important weight

Source: Kabir and Hasin (2011)

Table 4 Weights of the criteria and ratings values are represented by linguistic variables

Intensity of importance	Fuzzy number	Linguistic scale for importance	Triangular fuzzy scale (l, m, u)
1	$\tilde{1}$	Equally important	(1, 1, 3)
3	$\tilde{3}$	Moderately more important	(1, 3, 5)
5	$\tilde{5}$	Strongly more important	(3, 5, 7)
7	$\tilde{7}$	Very strongly more important	(5, 7, 9)
9	$\tilde{9}$	Extremely more important	(7, 9, 9)
If factor *i* has one of the above numbers assigned to it when compared to factor *j*, then *j* has the reciprocal value when compare to *i*			Reciprocals of above $\widetilde{M_1^{-1}} = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right)$

Source: Adapted from Kabir and Hasin (2011), and Yadav et al. (2012)

The key point is to use the AHP approach if the assessments or information are certain and choose the fuzzy approach if the assessments or information are uncertain. The fuzzy AHP method is a natural result of this essentiality. Subjective and linguistic assessments arise in the form of questionnaires. On a predetermined scale, each linguistic variable has its numerical value. These numerical values are certain numbers in AHP, whilst they are intervals between two numbers in the fuzzy AHP method. So, it can be summarized that AHP has the following shortcomings (Kabir & Hasin, 2011):

1. The AHP technique is generally utilized in nearly crisp decision applications.
2. The AHP technique generates and manages a highly unbalanced decision scale.
3. The ambiguity related to the mapping of one’s judgment to a number is not taken into consideration by the AHP process.
4. The AHP method’s ranking is somewhat imprecise.
5. The AHP results are strongly influenced by decision makers’ subjective selection, consideration, and preferences.

2.9 Geographic Information System (GIS)

2.9.1 Nature of GIS

A geographic information system (GIS) is a system that incorporates software, hardware, and data to capture, manage, analyze, and show all types of geographically referenced information. Spatial characteristics are stored in a coordinate system that refers to a specific location on the planet. Spatial characteristics are linked to descriptive attributes in the tabular pattern. For analysis and mapping, spatial data and related attributes in the same coordinate system can be layered together. A GIS keeps the diversity of coordinate systems, geodetic datums, and projection inside the data set itself. As a consequence, a GIS enables data sets with different coordinate systems to be displayed and overlaid seamlessly if necessary data sets are re-projected to amalgamate them for analyses. The geospatial reference system is an important metadata feature to collect for all geospatial data sets (Jakubicka, Vos, Phalkey, Marx, & Sapir, 2010; UNISDR, 2017).

A GIS is more than just a hardware or software product; it helps with decision-making, data collection, and analysis. It can be applied to a variety of disciplines and allows the application of a geographic approach to the methods. A GIS's importance is that it comprehends the spatial nature of information, allowing users to examine trends, patterns, and relationships in relation to other non-spatial and spatial data (UNISDR, 2017). A GIS is a framework that enables users to visualize, interpret, question, understand, and view data in a variety of ways that expose trends, relationships, and patterns in the form of charts, reports, globes, and maps, where visual outputs enable for a simple understanding of issues and the answering of questions in a way that is easily shared and understood. It is helpful to view GIS as a process rather than a thing (Jakubicka et al., 2010).

2.9.2 GIS and flood risk assessment

GIS software tools vary widely with respect to the underlying theory on spatial information, spatial data representation, types of data analysis components included, interfaces, user-friendliness, and costs (Alcántara & Goudie, 2010). GISs have improved in complexity over the past decades, and they are now a very effective decision-making tool utilized for a wide variety of applications (UNISDR, 2017).

GIS plays a significant role in flood risk, vulnerability, and hazard assessment. It is having benefits in determining flood zones, preparing flood hazards, and risk maps. GIS offers a number of tools for assessing flood-affected areas and for predicting areas that are likely to be flooded as a result of increasing river levels (Ali et al., 2016). GIS offers a simple platform for modeling, databases, and the number of variable analyses in flood risk assessment (Khan et al., 2015).

GIS software covers a wide variety of applications that all include the use of geo-referenced data and digital maps between each other, which ESRI ArcGIS is widely used in educational institutions (Khan et al., 2015). The GIS was utilized to map the flooding hazard distribution and process the input spatial data (Liu et al., 2015). GIS creates charts and maps that are easy to read, quick to access as well as administrators and planners may find it easier to define risk areas and prioritize prevention or response efforts (Gashaw & Legesse, 2011).

2.10 Spatial Modeling

Huisman and De By (2009), modeling refers to *"the process of producing an abstraction of the real world so that some part of it can be more easily handled."*

Techopedia (2019) stated that spatial modeling is *"an analytical process conducted in conjunction with a GIS to describe basic processes and properties for a given set of spatial features."*

The most accustomed model in the GIS environment is a map. In practice, modeling means the process of expression, representing key aspects of the real world digitally inside a computer as shown in Figure 12. The GIS can produce visualizations from the computer representation both on-screen and printed on paper or otherwise to better understand the representation of the phenomena and final output from the analysis. However, phenomena in the real world are complex so models cannot be perfect. Therefore, it is possible that some facts or relationships that exist in the real world may not be discovered through the model. Any geographical phenomenon can be represented in a variety of ways, the best way of representation is based on two issues. First, what is the original data, which is raw data from the sensor or others available, and secondly, what sort of data manipulation is required or will be undertaken (Huisman & De By, 2009).

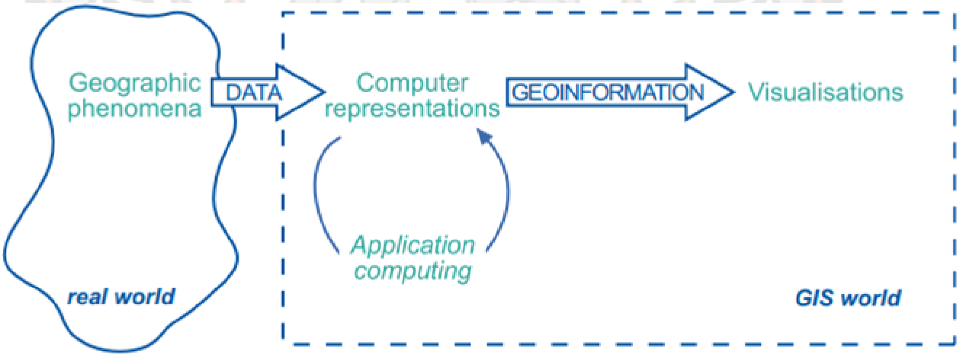


Figure 12 Representation of relevant aspects of real-world phenomena inside a GIS to build models or simulations

Source: Huisman and De By (2009)

Techopedia (2019) also explained that for spatial data analysis, spatial modeling is an important method that uses models or procedures and special rules. It is used in conjunction with a GIS to visualize and analyze layout data for better comprehension. Data management happens in several stages, each of which represents a phase in the complicated analysis process. Since spatial modeling is object-oriented, it is extensive and interrelates with how the physical world appears or functions. The model that emerges depicts either a set of objects or real-world processes. Therefore, spatial modeling can assist in the analysis and simulation of real-world spatial objects or phenomena, as well as planning and problem-solving.

Table 5 Some related studies

Title	Factor/Parameter	Method/Technique	Findings
Hu, Cheng, Zhou, and Zhang (2017) GIS-based flood risk assessment in suburban areas: a case study of the Fangshan District, Beijing.	Hazard Rainstorm intensity, rainstorm frequency, elevation, slope, river network density, and impervious surface. Vulnerability Population, road network density, and fixed assets.	- Analytic hierarchy process (AHP)	The method can be easily extended to most Chinese suburban areas and can quantitatively represent the relative magnitude and spatial distribution patterns of flood risk.
Kazakis et al. (2015) Assessment of flood hazard areas at a regional scale using an index-based approach and Analytical Hierarchy Process: Application in Rhodope-Evros region, Greece.	Flow accumulation, distance from the drainage network, elevation, land use, rainfall intensity, and geology.	- Analytic hierarchy process (AHP) - Flood Hazard Index (FHI) - Sensitivity analysis	The proposed methodology provides accurate results.
Mahmoud and Gan (2018a) Multi-criteria approach to develop flood susceptibility maps in arid regions of Middle East.	Flow accumulation, annual rainfall, slope, runoff, land use/ cover, elevation, geology, soil type, distance from the drainage network, and drainage density.	- Analytic hierarchy process (AHP) - Sensitivity analysis	They found maps to be in good alignment with previous flood events, and to be useful in flood prevention and future land use planning.

Table 5 (Cont.)

Title	Factor/Parameter	Method/Technique	Findings
Rahmati, Zeinivand, and Besharat (2015) Flood hazard zoning in Yasooj region, Iran, using GIS and multi-criteria decision analysis.	Distance to river, land use, elevation, and land slope.	- Analytic hierarchy process (AHP) - Hydraulic model - Weighted linear combination	They found that the AHP technique is a promising method for predicting flood extent with accuracy and reliability.
Stefanidis and Stathis (2013) Assessment of flood hazard based on natural and anthropogenic factors using analytic hierarchy process (AHP).	Natural factors Land use, rock erodibility, watersheds slope, main stream slope, rock permeability, watershed shape, and density of hydrographic network. Anthropogenic factors Encroachments, inadequate technical works, and shaped cross-section.	- Analytic hierarchy process (AHP)	They found that in the majority of watersheds (48 percent), the flood hazard from anthropogenic factors was very high, while the flood hazard from natural factors was medium (43 percent).
Wang et al. (2011) A GIS-Based Spatial Multi-Criteria Approach for Flood Risk Assessment in the Dongting Lake Region, Hunan, Central China.	Hazard Elevation, vegetation cover, drainage network, passing flood, flood control project, and rainfall. Vulnerability Population, production, cropland, and transportation.	- Spatial multi-criteria approach (SMCA) - Semi-quantitative model - Fuzzy analytic hierarchy process (FAHP)	They concluded that the findings can be useful information for decision-makers and insurance companies.

CHAPTER III METHODOLOGY

This chapter explains the study area, data collection, and instrument of the study. It also describes the steps of the study process and methodology that will help to get the result of this study.

3.1 Study Area

This study was targeted at irrigated area in Phitsanulok and Sukhothai provinces based on Bang Rakam Model 60 project. The study area included Phrom Phiram, Mueang Phitsanulok, Bang Rakam, and Wat Bot districts in the Phitsanulok province and Kong Krailat district in the Sukhothai province (2 provinces 5 districts 20 sub-districts 93 villages) as shown in Figure 13 and Table 6. Bang Rakam Model 60 was the integrated water resources management project that was implemented through the community participation process on changing the cropping pattern at the left bank of the Yom River to allow these land been retarding fields during flood season (Thepsitthar & Boonwanno, 2018).

Phitsanulok province is located in the lower northern region of Thailand with an area of 10,815.854 km^2 (6.75 million rai) or 2.1% of the whole country area (Phitsanulok Province Office, 2017). The northern and the central part of the province are of high mountains. Some of the important rivers such as Nan River, Kwai Noi River, and Khek River (Wang Thong River) flow in the northern and eastern sides of the province. The plain areas in Mueang Phitsanulok, Phrom Phiram, Bang Krathum, and Bang Rakam districts are important rice-growing areas that make the main income for this province. The climate of Phitsanulok province is generally hot and humid. The summer season is very hot, especially from March to April. The rainy season is very rainy and occurs between August to September. The winter is quite cold from December to February. Bang Rakam, one of nine districts in Phitsanulok province, is located in the southwest of Phitsanulok and has a total area of 992,043 km^2 (Pittungnapoo, 2013). It holds water in the rainy season and is a source of natural aquatic animals as well as aquaculture sources that make income for people in the area. Bang Rakam district is located in the Yom River Basin and faces a repeated flooding problem every year so the people cannot cultivate crops or raise animals in this period.

For example, Chum Saeng Songkhram sub-district is an old community located in the administrative area of Bang Rakam district and most people there have an agricultural career. The topography of the area is the river basin sloping into the south-west direction. The first part is located over the Yom River. Some rivers flow through (Ket Canal and Klam Canal, etc.) that are the catchment canals gathering water from Yom River and drainage canals for some certain seasons. Therefore, it is quite affected by floods faster than another side of the bank. The second part is the land that is higher than the first part and every canal irrigating there never had enough water throughout the year (JICA, 2013).

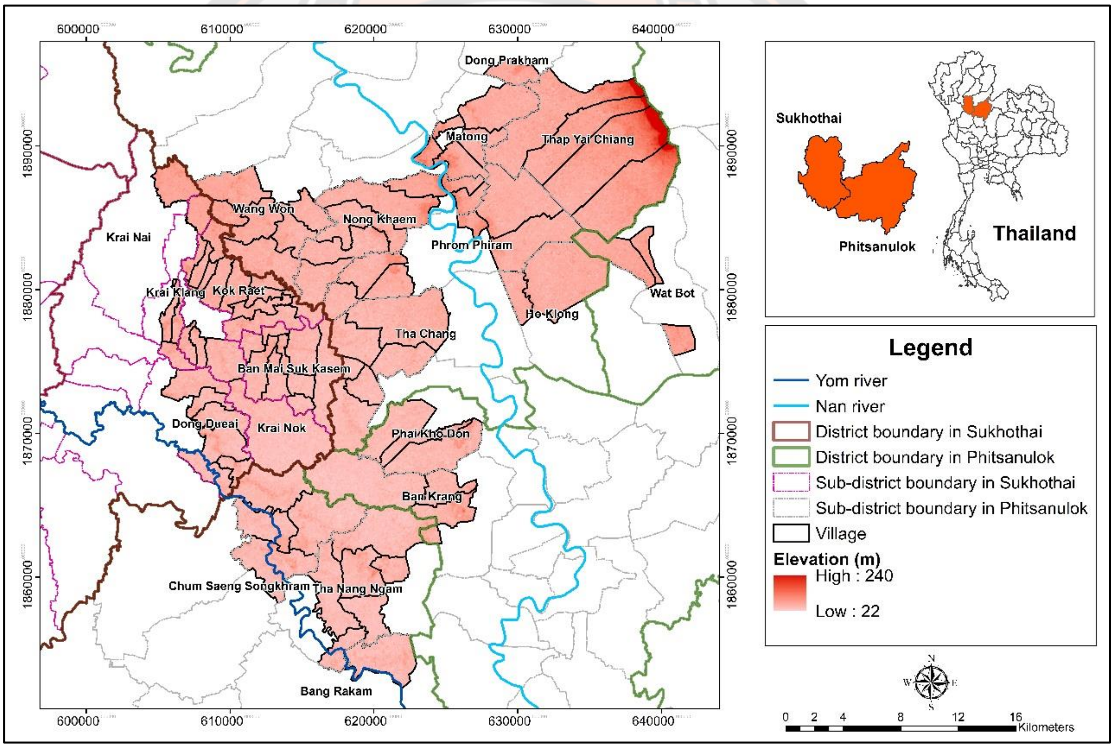


Figure 13 Map of villages in the study location of Bang Rakam Model 60 project

Sukhothai province is located in the lower north of Thailand between the latitudes 16˚ 34’ North to 17˚ 16’ North and longitudes 99˚ 24’ East to 100˚ 01’ East. The area is approximately 6,673 km^2 (4.2 million rai) and is also located in the lower Yom River Basin, which covers 26.9% of the whole area of the basin with most areas being floodplains. The province is subdivided into nine districts and Kong Krailat is one of the districts in this province (DEQP, 2002). The average annual temperature of

Sukhothai province is 27.8 °C and rainfall is registered at an average of 1,179.7 mm (TMD, 2017).

Table 6 Study area based on Bang Rakam Model 60 project

Provinces	Districts	Sub-districts	Village No.
Phitsanulok	Phrom Phiram	Tha Chang	7-12
		Wang Won	3-7, 9
		Nong Khaem	2, 5-10
		Phrom Phiram	1, 10-13, 15
		Matong	2, 5, 8-10
		Dong Prakham	10
		Thap Yai Chiang	3-6
		Ho Klong	5, 7
	Mueang Phitsanulok	Ban Krang	6-8, 10
		Phai Kho Don	3, 4, 6
	Bang Rakam	Chum Saeng Songkhram	1-3, 9
		Tha Nang Ngam	3, 5, 8-11
		Bang Rakam	15
	Wat Bot	Wat Bot	3, 4, 7
Sukhothai	Kong Krailat	Kok Raet	1-12
		Dong Dueai	2, 4, 6-7, 9-10
		Ban Mai Suk Kasem	1-8
		Krai Klang	1-2, 4, 8
		Krai Nok	2, 5, 7-8
		Krai Nai	9

3.2 Data Collection

3.2.1 Primary data

1. Questionnaires of pair-wise comparison

The questionnaires were used to collect data from experts of general information, factors influencing flood hazard evaluation, factors influencing flood vulnerability evaluation, rating of factors influencing flood hazard, and rating of factors influencing flood vulnerability.

2. Questionnaires survey

The questionnaires were used to collect data from farmers in the area of general information, flood experience, flood risk perception, the effect of the Bang Rakam Model 60 project as well as comments and suggestions of the respondents.

3.2.2 Secondary data

The required data and sources used in this study are presented in Table 7. These were gathered from different sources and were used to generate a flood hazard map and flood vulnerability map. Besides, I also validated the flood hazard map to generate a flood risk map using GIS software.

Table 7 Data and sources used in the study

Flood hazard factors				
No.	Data	Year	Sources	Create data layers
1	Land use	2018	Land Development Department (LDD)	Land use
2	Rainfall	1989-2018	Northern Meteorological Center	Average annual rainfall
3	Drainage network	-	Yom-Nan Operation and Maintenance Project, and Water Resources Regional Office 9 (Phitsanulok)	Distance from drainage network and drainage density
4	Soil group	2016	Land Development Department (LDD)	Soil water infiltration
5	SRTM DEM 30 m resolution	-	https://earthexplorer.usgs.gov/	Elevation, flow accumulation, and slope
Flood vulnerability factors				
No.	Data	Year	Sources	Create data layers
6	Demographic statistics	2018	Registration Administration Center 6 (Phitsanulok)	Age group, dependency ratio, gender ratio, and population density

Table 7 (Cont.)

Flood vulnerability factors				
No.	Data	Year	Sources	Create data layers
7	Road	2020	https://download.geofabrik.de/asia.html?fbclid=IwAR1_mQ8eUfuuHLhMAhFOuaBa87EQyxDRnd1XQhTM6nkQUhPveLTnn6zQs4Q	Road density
Boundary				
No.	Data	Year	Sources	Create data layers
8	Boundary data of the study area	-	2nd Office of Agricultural Economics	Boundary of the province, district, sub-district, and village in Sukhothai and Phitsanulok provinces
Validation				
No.	Data	Year	Sources	Create data layers
9	Repeated floods area	2004-2019	https://floodv2.gistda.or.th/	-

3.3 Instrument of the Study

1. Laptop computer Intel(R) Core(TM) i7-6500U CPU @2.50GHz RAM4 GB
2. GIS software
3. SPSS/Statistical software
4. Microsoft spreadsheet
5. Questionnaire

3.4 Steps of the Study Process

1. Study the principles, theory, and research reviews related to factors influencing flood hazard and flood vulnerability.

2. Study fuzzy AHP.

3. Create a hierarchy structure for prioritizing factors influencing flood hazard and flood vulnerability according to the AHP method by identifying the problem and

creating a decision-making pattern to be a hierarchical structure that consists of goal level and criteria level.

4. Create a criteria map and classify map.

5. Create questionnaires for experts to collect data in the form of pair-wise comparison and rating of factors.

6. Check consistency ratio (CR) by using the AHP method.

7. Reclassify the criteria map.

8. Analyze data from the questionnaires according to the fuzzy AHP method for prioritizing.

9. Calculate using the index to create a flood hazard map and flood vulnerability map.

10. Validate the flood hazard map.

11. Generate the flood risk map.

12. Analyze the flood risk perception of farmers using a questionnaire survey and with the flood risk map obtained.

3.5 Methodology

In this study, fuzzy AHP was used to prioritize factors influencing flood hazard and flood vulnerability. GIS was used to create a flood hazard map, flood vulnerability map, and to generate a flood risk map. Moreover, an analysis of the farmer’s perception of flood risk was done. The overall methodology is shown in Figure 14. The process consisted of four parts depending on the specific objectives.

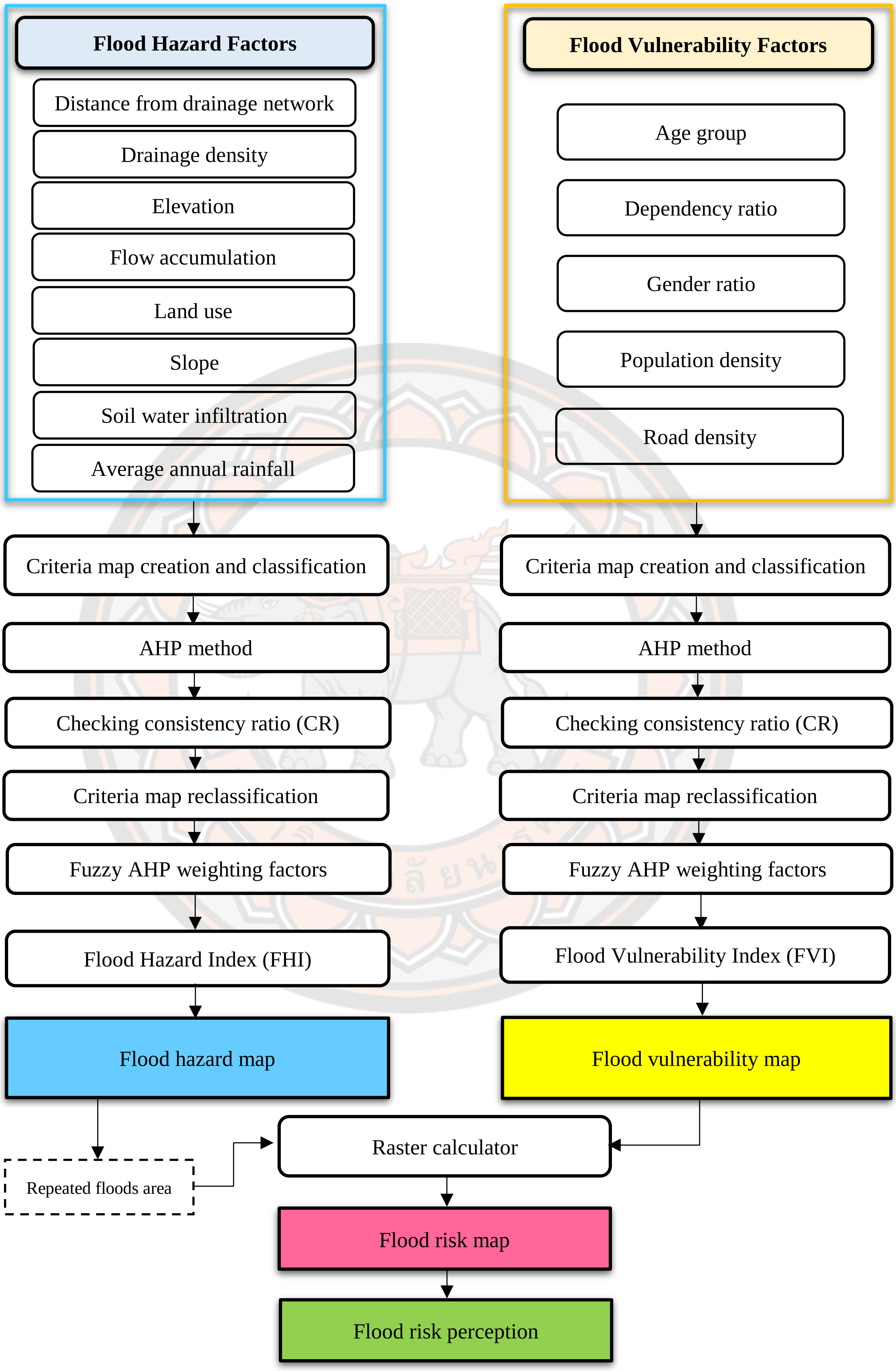


Figure 14 Overall methodology

3.5.1 Priority of factors influencing flood hazard and flood vulnerability

This study used fuzzy AHP as a decide-making tool for prioritizing factors influencing flood hazard and flood vulnerability in which prioritization is according to the structure of AHP.

3.5.1.1 Analytic hierarchy process (AHP) hierarchy structure

1. Factors influencing flood hazard

1) Distance from drainage network

Often the inundation emanates from riverbeds and enlarges into the surrounding area. The distance to the closest water channels is revealed by the distance from the drainage network. At the beginning of flood events is it important to consider the areas that will be affected by river-overflows. Several studies Kazakis et al. (2015), Liu et al. (2015), and Mahmoud and Gan (2018a) explained that as distance increases, the role of the riverbed decreases, and as a result, areas nearer to the drainage network suffers more flooding compared to the areas located further from it.

2) Drainage density

Drainage density deals with water channel length per unit area to describe flooding from multiple and individual water channels. Normally, greater surface runoff generates in high drainage density areas than those with lower drainage density, hence the probability of flooding is greater (Liu et al., 2015; Mahmoud & Gan, 2018a).

3) Elevation

The elevation is an essential factor and has more intensive influences on the flood hazard. Flat areas in lower elevations tend to flood faster and are easier to be inundated by flood than areas in higher elevations because water naturally flows from higher elevations to lower elevations (Kazakis et al., 2015; Liu et al., 2015).

4) Flow accumulation

This is the summation of water flowing from all down-slope cells into the output raster, resulting in an accelerated flow in specific cells. The areas with more flow accumulations tend to flood because those areas act as convergent points for surface runoff. As a result, Kazakis et al. (2015), and Mahmoud and Gan (2018a) revealed that areas of concentrated flow and consequent higher flood hazard are indicated by high values of accumulated flow.

5) Land use

Land use pattern influences infiltration rate. Vegetation cover and forest have a significant impact on infiltration. Unfortunately, urban areas support the overland flow of water. Due to this, vegetation cover and bare soil generate less surface runoff compared to urbanization (Kazakis et al., 2015; Mahmoud & Gan, 2018a).

6) Slope

The slope is one key factor that influences the hazard of any area for flooding. The amount of surface runoff and rate of infiltration is affected by the slope. Water from surfaces with steeper slopes can be easily drained towards the downslope, therefore areas with steep slopes may flood slowly than flat ones (Kazakis et al., 2015; Liu et al., 2015; Mahmoud & Gan, 2018a).

7) Soil water infiltration

During a flood, water is stored in the soil, and as such localized heavy rainfall may influence flooding. Liu et al. (2015) indicated that heavy rains are required for the flood to occur.

8) Average annual rainfall

According to Lyu, Wang, Shen, Lu, and Wang (2016), the major natural factor that causes flooding is rainfall. Higher rainfall depth and events increase surface runoff as well as flood hazards (Mahmoud & Gan, 2018a, 2018b). Mean annual rainfall was collected from the rain gauge situated that the various study areas and neighboring rain gauge stations for this investigation.

2. Factors influencing flood vulnerability

1) Age group

The young (0-14 years) and the elderly (60+ years) are vulnerable to natural hazards due to their physical conditions and financial dependency. The vulnerability of the elderly is reduced according to their experience (Behanzin, Thiel, Szarzynski, & Boko, 2016; Müller, Reiter, & Weiland, 2011).

2) Dependency ratio

It provides insight into the number of people of non-working age in comparison with those of working age (Hayes, 2020). It is a simple calculation to understand society and recognize the potential economic pressures that confront economically dependent populations (Esther -Team forecast, 2013). The non-working age population may not have money to protect themselves (Behanzin et al., 2016). A high dependency ratio means those of working age, and the overall economy faces a greater burden in supporting the aging population.

3) Gender ratio

In general, women are described as being vulnerable to natural hazards than men due to their stronger involvement in family life, sector-specific jobs, and lower wages (Behanzin et al., 2016; Müller et al., 2011).

4) Population density

The concentrated population causes a high level of exposure to a given hazard. The higher the population density, the higher the vulnerability (Behanzin et al., 2016).

5) Road density

The road is an artificial hindrance to prevent flooding. Thereby, the more the density of roads in an area, the less inclination of flooding (Sarkar & Mondal, 2019).

3.5.1.2 Criteria map creation and classification

1. Flood hazard factors

1) Distance from drainage network (m)

The drainage network data (including river and canal) was collected from Yom-Nan Operation and Maintenance Project, and the Water Resources Regional Office 9 (Phitsanulok). The intensity of the distance away from the drainage network analyzed with the Multiple Ring Buffer in GIS software as follows: open ArcToolbox, select Analysis Tools followed by Proximity, and then Multiple Ring Buffer. This criterion was a raster layer, it was created by using the Polygon to Raster in GIS software as follows: open ArcToolbox, select Conversion Tools followed by a To Raster, and then Polygon to Raster, with a resolution of 30 meters.

2) Drainage density (km/km^2)

The data was collected from the same sources of distance from drainage network factor, to create drainage density factor. Drainage density was computed in the field calculator of GIS software as follows: open ArcToolbox, select Spatial Analyst Tools followed by Density, and then Line Density, and was calculated by following Ogato, Bantider, Abebe, and Geneletti (2020) with equation 3.1.

$$\text{Drainage density} = \frac{\text{Drainage length (km)}}{\text{Area (km}^2\text{)}} \qquad \text{Eq. (3.1)}$$

Data were classified into five classes by using the Natural Breaks (Jenks) classification method. It is a data classification method for the determination of the optimum arrangement for values into separate classes (Papaioannou et al., 2014).

3) Elevation (m)

The elevation was created from SRTM DEM 30 m resolution and DEM was used to assess the extent of flood effect from the elevation data. The classification was done into five classes by using Natural Breaks (Jenks).

4) Flow accumulation (pixels)

Flow accumulation was created from SRTM DEM 30 m resolution using the Flow Accumulation function in GIS software as follows: open ArcToolbox, select Spatial Analyst Tools followed by Hydrology then Fill. After this step Flow Direction was selected and then proceeded to Flow Accumulation. Data were classified into five classes by using Natural Breaks (Jenks).

5) Land use

Land use was created according to LDD into five classes consisting of agricultural land, forest land, miscellaneous land, urban and built-up land, and water body in GIS software. This criterion was a raster layer, and was created by using the Polygon to Raster in GIS software as follows: open ArcToolbox, select Conversion Tools followed by To Raster, and then Polygon to Raster, with a resolution of 30 meters.

6) Slope (%)

The slope was created from SRTM DEM 30 m resolution by using the Slope function in GIS software as follows: open ArcToolbox, select Spatial Analyst Tools go to Surface, and then Slope (percent rise). Data were classified into five classes by using Natural Breaks (Jenks).

7) Soil water infiltration

Soil water infiltration was created by soil group data in 2016 according to LDD. I grouping again base on water infiltration that was divided into six classes consisting of low, slightly low, moderate, slightly high, high, and other (outcrop, cliff, and water) in GIS software. This criterion was the raster layer, and was created by using the Polygon to Raster in GIS software as follows: open ArcToolbox, select Conversion Tools followed by To Raster, and then Polygon to Raster, with a resolution of 30 meters.

8) Average annual rainfall (mm)

In this study, the average annual rainfall recorded at the study site for 30 years was analyzed using inverse distance weighted (IDW) in GIS software as follows: open ArcToolbox, select Spatial Analyst Tools followed by Interpolation then IDW. The classification was done into five classes by using Natural Breaks (Jenks).

2. Flood vulnerability factors

Flood vulnerability factors consisted of age group, dependency ratio, gender ratio, population density, and road density. Data was collected in .xls format, and all factors are created in GIS software. These criteria were the raster layer, and created by using the Polygon to Raster in GIS software as follows: open ArcToolbox, select Conversion Tools followed by To Raster, and then Polygon to Raster, with a resolution of 30 meters. The classification was done into five classes by using Natural Breaks (Jenks) in GIS software.

1) Age group (%)

The percentage of age group was calculated by using equation 3.2 (National Statistical Office, 2010).

$$\text{Age group} = \frac{\text{Population aged } (0-14 \text{ years}) + (60+ \text{ years})}{\text{Total population}} \times 100 \qquad \text{Eq. (3.2)}$$

2) Dependency ratio

The dependency ratio factor is the ratio of the population not in the work-force group as the dependents, namely children (aged 0-14 years) and elderly population (aged 60+ years). The other population was the working-age population (aged 15-59 years). The dependency ratio was calculated as in the following equation 3.3 (Esther -Team forecast, 2013; Hayes, 2020; National Statistical Office, 2010).

$$\text{Dependency ratio} = \frac{\text{Population aged } (0-14 \text{ years}) + (60+ \text{ years})}{\text{Population aged } 15-59 \text{ years}} \times 100 \qquad \text{Eq. (3.3)}$$

3) Gender ratio

The gender ratio factor is the ratio of males relative to females in a population group and was calculated as equation 3.4 (National Statistical Office, 2010).

$$\text{Gender ratio} = \frac{\text{Male population}}{\text{Female population}} \times 100 \qquad \text{Eq. (3.4)}$$

where; ratio < 100 is more female than male, ratio = 100 is the same number of male and female, and ratio > 100 is more male than female.

4) Population density (persons/km^2)

The population density factor is a measurement of population per unit area as in equation 3.5 (National Statistical Office, 2010).

$$\text{Population density} = \frac{\text{Number of people}}{\text{Area (km}^2\text{)}} \qquad \text{Eq. (3.5)}$$

5) Road density (km/km^2)

The road density factor is the ratio of the length of the village's total road network to the village's area. It was computed in the field calculator of GIS software as follows: open ArcToolbox, select Spatial Analyst Tools followed by Density after that Line Density and was calculated with equation 3.6 (USDA Forest Service, 2019).

$$\text{Road density} = \frac{\text{Length of road (km)}}{\text{Area (km}^2\text{)}} \qquad \text{Eq. (3.6)}$$

3.5.1.3 Questionnaires design for pair-wise comparison

The first step was to find and contact experts who have experience and knowledge in this field. Secondly, I was giving questionnaires to collect data to be used in this study. Finally, I prepared the data according to the answers from experts and analyzed it using the AHP method.

1. Expert sample group

This study employed experts who have experience and knowledge of the Bang Rakam Model 60 project, hydrology, flood hazard, flood vulnerability, demography, or related fields, to create matrix tables for the weighting to each factor as well as ranking for criteria map reclassification. There were two experts groups, the first group worked on questionnaires for factors influencing flood hazard and the second group was for questionnaires for factors influencing flood vulnerability.

2. Questionnaire evaluation

All experts in each group used the same questionnaire form, each person got one set and evaluated by pair-wise comparison as well as considering the class and the rating. The questionnaire was designed for an expert to consider factors that are being compared under the goal of this study such as what factors are important, how is the level, and the rating. The level of pair-wise comparison was categorized into five levels (Jongpaiboon, 2015): (1) equally important, (3) moderately important, (5) strongly important, (7) very strongly important, and (9) extremely important. For rating, it is divided into five rates (Gashaw & Legesse, 2011; Hu et al., 2017; Mahmoud & Gan, 2018a) as (1) very low, (2) low, (3) moderate, (4) high, and (5) very high.

A matrix table of pair-wise comparisons was created according to the AHP method for comparison of factors to designate the relative preference of one element over another. For the method of pair-wise comparison, factors were compared with one another, meaning each factor on the vertical axis was compared with a factor on the horizontal axis to define the priority level. Diagonal elements were equal to 1. The upper of the diagonal were values from the questionnaires and the lower of the diagonal were the inverse values of the pair-wise comparison.

An example is shown in Table 8, a matrix table of pair-wise comparisons, where F_1 (vertical axis) compares with F_2 (horizontal axis) was assigned the level equal to 5 which means F_1 is strongly important than F_2. Conversely, when compare between F_2 (vertical axis) and F_1 (horizontal axis) the value is 1/5 that was the inverse value.

Table 8 Matrix table used to pair-wise comparisons

Factor	F_1	F_2	F_3	→	F_n
F_1	1	5	1/3	→	f_{1n}
F_2	1/5	1	f_{23}	→	f_{2n}
F_3	3	$1/f_{23}$	1	→	f_{3n}
↓	↓	↓	↓	1	↓
F_n	$1/f_{1n}$	$1/f_{2n}$	$1/f_{3n}$	→	1

Priority weighting for each factor was calculated in the following way: (1) sum of the values in each column, (2) divide each element by the column total and (3) average of each row.

3.5.1.4 Consistency Ratio (CR)

The data obtained from the pair-wise comparison was checked for CR (the reason for scoring) before used in the fuzzy AHP data analysis process. CR was calculated (Kazakis et al., 2015; Mahmoud & Gan, 2018a; Rahmati et al., 2015; Stefanidis & Stathis, 2013) as in equation 3.7.

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \qquad \text{Eq. (3.7)}$$

where; *CI* represents consistency index, and *RI* is the mean random index for different size matrix (Table 9). CI was worked out as equation 3.8.

$$\mathrm{CI} = \frac{\lambda_{\mathrm{max}} - \mathrm{n}}{\mathrm{n} - 1} \qquad \text{Eq. (3.8)}$$

where; λ_{max} is eigenvalues. Firstly, the level of pair-wise comparison from the questionnaire was multiplied with weighted factors (by multiplying the whole column with the same weighted factor) and the total of each row summed. Secondly, the sum from each row was divided by the weighted factors and then the total of this column was summed. Lastly, the total of the column was divided by the number of factors. *n* represents the number of factors.

Table 9 Random consistency index for different size of the matrix

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Source: R. W. Saaty (1987)

3.5.1.5 Criteria map reclassification

Rated data by the experts from questionnaires of pair-wise comparison was used in this step. All criteria maps were raster layer, maps which were vector layer were created to raster layer using the Polygon to Raster in GIS software.

Finally, criteria map reclassification for both flood hazard factors and flood vulnerability factors were generated by reclassifying into five levels: (1) very low, (2) low, (3) moderate, (4) high, and (5) very high. It was created by using the Reclassify in GIS software as follows: open ArcToolbox, select Spatial Analyst Tools followed by Reclass, and then Reclassify.

3.5.1.6 Fuzzy AHP analysis

This process was done after CR was acceptable following Chang's extent analysis with triangular fuzzy numbers or TFNs (Chang, 1996) to model the pair-wise comparisons. The steps used to calculate and analyze were applied from the fuzzy AHP that combines the AHP method and fuzzy by still using the pair-wise comparison method of AHP but the TFNs were used to replace single numbers of the AHP method. This study used TFNs as shown in Table 10 and their characteristics in Figure 15.

Table 10 Triangular fuzzy numbers of pair-wise comparison

Intensity of importance	Linguistic scale	Triangular fuzzy numbers (l,m,u)
1	Equally important	(1,1,3)
3	Moderately more important	(1,3,5)
5	Strongly more important	(3,5,7)
7	Very strongly more important	(5,7,9)
9	Extremely more important	(7,9,9)

Source: Jongpaiboon (2015)

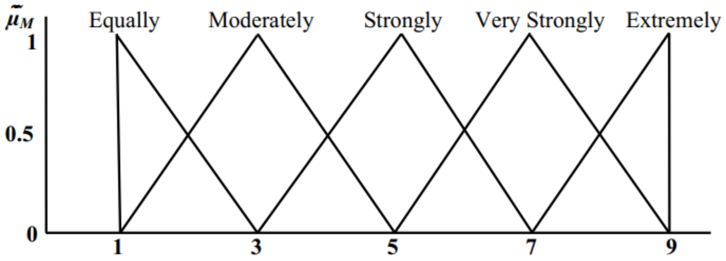


Figure 15 Linguistic variables for the important weight of each criterion

Source: Kabir and Hasin (2011)

Jongpaiboon (2015) method was adopted to calculate the priority weighting for each factor.

1. Calculation of the fuzzified pair-wise comparison matrix: Let $X = \{x_1, x_2, \ldots, x_n\}$ LDD (2014) is an object set and $G = \{g_1, g_2, \ldots, g_m\}$ is a goal set. According to the method of Chang (1996), the analysis of the extent for each goal, g_i was computed for each object. Hence, m extent analysis values for each object was obtained as $M_{g_i}^1, M_{g_i}^2, \ldots, M_{g_i}^m;\ i = 1, 2, \ldots, n$ where; all the $M_{g_i}^j$ $(j = 1, 2, \ldots, m)$ are TFNs.

According to the fuzzy AHP methodology, equation 3.9 can be followed to create a pair-wise comparison matrix based on the fuzzy AHP process.

$$\left(M_{g_i}^j\right)_{n\times m} = \begin{bmatrix} M_{g_1}^1 & M_{g_1}^2 & \ldots & M_{g_1}^m \\ M_{g_2}^1 & M_{g_2}^2 & \ldots & M_{g_2}^m \\ \vdots & \vdots & & \vdots \\ M_{g_n}^1 & M_{g_n}^2 & \ldots & M_{g_n}^m \end{bmatrix}$$

$$= \begin{bmatrix} (1,1,1) & \left(l_{1_2}, m_{1_2}, u_{1_2}\right) & \ldots & \left(l_{1_m}, m_{1_m}, u_{1_m}\right) \\ \left(l_{2_1}, m_{2_1}, u_{2_1}\right) & (1,1,1) & \ldots & \left(l_{2_m}, m_{2_m}, u_{2_m}\right) \\ \vdots & \vdots & \vdots & \vdots \\ \left(\frac{1}{u_{n_1}}, \frac{1}{m_{n_1}}, \frac{1}{l_{n_1}}\right) & \left(\frac{1}{u_{n_2}}, \frac{1}{m_{n_2}}, \frac{1}{l_{n_2}}\right) & \ldots & (1,1,1) \end{bmatrix} \qquad \text{Eq. (3.9)}$$

where; $\left(l_{ij}, m_{ij}, u_{ij}\right) = \left(\frac{1}{u_{ji}}, \frac{1}{m_{ji}}, \frac{1}{l_{ji}}\right)$ for $i = 1, 2, \ldots, n,$ and $j = 1, 2, \ldots, m,$ and $i \neq j$; $\left(l_{ij}, m_{ij}, u_{ij}\right) = (1,1,1)$ for $i = j$

2. Calculation of the fuzzy synthetic extent with regards to the ith alternative: This was calculated using equation 3.10.

$$S_i = \sum_{j=1}^{m} M_{g_i}^j \times \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j\right]^{-1} \qquad \text{Eq. (3.10)}$$

where; S_i is the synthetic extent value of the pair-wise comparison and $\sum_{j=1}^{m} M_{g_i}^j$ is a summation of the TFNs which was express as in equation 3.11-3.13.

$$\sum_{j=1}^{m} M_{g_i}^j = \left[\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right] \qquad \text{Eq. (3.11)}$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \qquad \text{Eq. (3.12)}$$

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} l_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} u_i}\right) \qquad \text{Eq. (3.13)}$$

3. Calculation of the degree of possibility: $S_i \geq S_j$ when $S_i = (l_i,m_i,u_i)$ and $S_j = (l_j,m_j,u_j)$ where; $i = 1,2,...,n$ and $j = 1,2,...,m$ as well as $i \neq j$ was express as equation 3.14.

$$V(S_i \geq S_j) = \begin{cases} 1 & \text{if} \quad m_i \geq m_j \\ 0 & \quad\quad l_j \geq u_i \\ \frac{l_j - u_i}{(m_i - u_i) - (m_j - l_j)} & \text{otherwise} \end{cases} \qquad \text{Eq (3.14)}$$

For S_i greater than S_j was express as equation 3.15.

$$V(S_i \geq S_j | j = 1,2,\ldots,m; i \neq j) = \min V(S_i \geq S_j | j = 1,2,\ldots,m; i \neq j) \qquad \text{Eq. (3.15)}$$

4. Calculation of the weight vector and normalization of the non-fuzzy weight vector: It was done as in equation 3.16 - 3.18.

Assuming that $$w_i' = \min V(S_i \geq S_j | j = 1,2,\ldots,m; i \neq j) \qquad \text{Eq. (3.16)}$$

The weight vector is given by $$w_i = \frac{w_i'}{\sum_{i=1}^{n} w_i'} \qquad \text{Eq. (3.17)}$$

Normalized weight vectors $$W = (w_1, w_2, \ldots, w_n)^T \qquad \text{Eq. (3.18)}$$

where; w_i is a non-fuzzy number.

Finally, the non-fuzzy number that is weights of each factor was obtained. Therefore, factors influencing flood hazard and flood vulnerability using the fuzzy AHP method were prioritized, and a flood hazard map and a flood vulnerability map were created.

3.5.2 Flood hazard map and flood vulnerability map

3.5.2.1 Map creation

Raster overlay analysis was performed in GIS software under Spatial Analyst Tools as follows: open ArcToolbox, select Spatial Analyst Tools followed by Map Algebra, and then Raster Calculator. Go to create the flood hazard map and the flood vulnerability map that use the weights of factors acquire by fuzzy AHP to calculate. Finally, it was classified into five categories ranging from very low, low, moderate, high, and very high to create an easily readable map.

1. Flood hazard map: This was calculated using the flood hazard index (FHI) (Kazakis et al., 2015; Mahmoud & Gan, 2018a) as in equation 3.19.

$$\mathrm{FHI} = \sum_{i=1}^{n} r_i \times w_i \qquad \text{Eq. (3.19)}$$

where; r_i = rating of the factor in each point, w_i = weights of each factor, and n = criteria number.

2. Flood vulnerability map: The calculation was done using the flood vulnerability index (FVI) (Hadi, Naim, Adnan, Nisa, & Said, 2017; Mohamed & El-Raey, 2019) as in equation 3.20.

$$\mathrm{FVI} = \sum_{i=1}^{n} r_i \times w_i \qquad \text{Eq. (3.20)}$$

where; r_i, w_i, and n follow the same definition above.

3.5.2.2 Validation

Repeated floods area in 2004-2019 from GISTDA was used to compare with the flood hazard map.

3.5.3 Flood risk map

Risk is seen as a function of hazard and vulnerability (Ekmekcioğlu, Koc, & Özger, 2020; Wisner et al., 2003) as in equation 3.21. The flood hazard map and the flood vulnerability map obtained were used to assess risk.

$$\text{Risk} = \text{Hazard x Vulnerability} \qquad \text{Eq. (3.21)}$$

In this study, the flood risk map was performed in GIS software under Spatial Analyst Tools as follows: open ArcToolbox, select Spatial Analyst Tools followed by Map Algebra, after that Raster Calculator. Finally, flood risk was categorized in five levels as very low, low, moderate, high, and very high.

3.5.4 Analysis of the farmer’s flood risk perception

This process used a questionnaire survey to analyze the farmer’s perception of flood risk.

1. Population, samples, and sampling

1) Population: All people who have lived in Phitsanulok or Sukhothai provinces (in 5 districts 20 sub-districts 93 villages) of the Bang Rakam Model 60 project were considered as the population. The total population was 59,271 people.

2) Samples and sampling: The sample size was calculated based on Yamane's formula (Yamane, 1967) as in equation 3.22.

$$n = \frac{N}{1+Ne^2} \qquad \text{Eq. (3.22)}$$

where; *n* is the sample size, *N* is the size of the population, and *e* is the level of precision.

Therefore, the sample size of the study was 100 people (the level of precision is 0.1). The sample was specified as 102 and were farmers who have cultivated in the Phitsanulok or Sukhothai province, which a focus on 5 districts, 20 sub-districts, and 93 villages of the Bang Rakam Model 60 project. The samples were chosen by purposive sampling with the head of the household or a household member represented a respondent (1 person/household).

3) Instrument of the Study: The tool used for collecting this data was a questionnaire which consisted of five parts as follows:

Part 1: General information, which was a closed-ended question, consisting of gender, age, education level, household member, and average monthly income.

Part 2: Flood experience, which was an open-ended question and closed-ended questions.

Part 3: Flood risk perception, which was closed-ended questions that have two parts. First, ask about the source of flood news. Second, ask about the flood risk perception of farmers. In the second part, I gave the correct answer a score of 1, the wrong answer gave a score of 0. There were 10 questions in total.

- The correct answers were questions no. 1, 2, 3, 4, 6, 7, 9, and 10 with the following scoring criteria:

Answer yes/correct, the score was 1 point.

Answer no/wrong, the score was 0 point.

- The wrong answers were questions no. 5 and 8 with the following scoring criteria:

Answer yes/correct, the score was 0 point.

Answer no/wrong, the score was 1 point.

In addition, I divided the scores into 5 levels with the equation 3.23. According to the following criteria:

$$\text{Range of a data set} = \frac{\text{Largest value} - \text{Smallest value}}{\text{Number of range}} \qquad \text{Eq. (3.23)}$$

$$= \frac{10 - 0}{5} = 2.00$$

A score of 0 - 2 means the flood risk perception of farmers is a very low level

A score of 3 - 4 means the flood risk perception of farmers is a low level

A score of 5 - 6 means the flood risk perception of farmers is a moderate level

A score of 7 - 8 means the flood risk perception of farmers is a high level

A score of 9 - 10 means the flood risk perception of farmers is a very high level

Part 4: Effect of the Bang Rakam Model 60 project, which was closed-ended questions. Classifying effect level of the Bang Rakam Model 60 project used the Likert Scale by following Kantathong (2013) that divided into 5 levels as follows:

1 point	means a very low level
2 points	means a low level
3 points	means a moderate level
4 points	means a high level
5 points	means a very high level

Criteria for interpreting the effect of the Bang Rakam Model 60 project was as in equation 3.24.

$$\text{Range of a data set} = \frac{\text{Largest value} - \text{Smallest value}}{\text{Number of range}} \qquad \text{Eq. (3.24)}$$

$$= \frac{5 - 1}{5} = 0.8$$

An average score of 1.00 - 1.80 means the effect of the project is a very low level

An average score of 1.81 - 2.60 means the effect of the project is a low level

An average score of 2.61 - 3.40 means the effect of the project is a moderate level

An average score of 3.41 - 4.20 means the effect of the project is a high level

An average score of 4.20 - 5.00 means the effect of the project is a very high level

Part 5: Comments and suggestions

CHAPTER IV RESULTS

This chapter presents the results of the priority of factors influencing flood hazard and flood hazard map. It also presents the results of the priority of factors influencing flood vulnerability, flood vulnerability map, flood risk map as well as farmers perception of flood risk.

4.1 Priority of factors influencing flood hazard

4.1.1 Hierarchy structure of factors influencing flood hazard

The factors were structured in a hierarchy of different levels that comprise goals and criteria. As shown in Figure 16, the goal level is the factors influencing flood hazard, and criteria level (8 factors) include the distance from drainage network, drainage density, elevation, flow accumulation, land use, slope, soil water infiltration, and average annual rainfall.

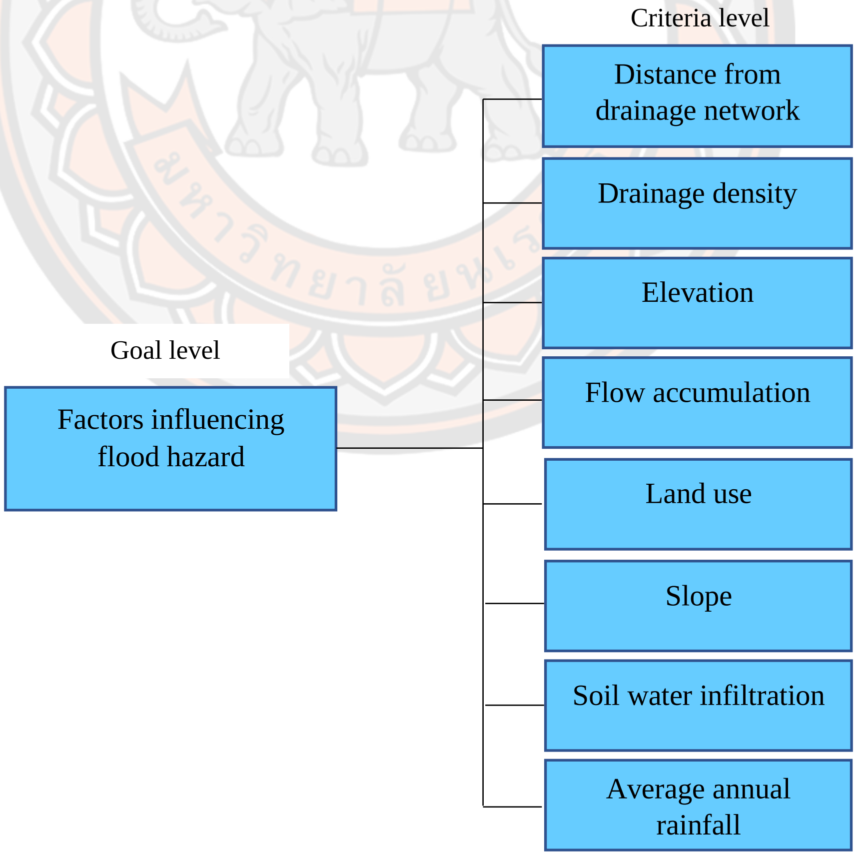


Figure 16 Structuring the hierarchy of factors influencing flood hazard

4.1.2 Criteria maps and classification of factors influencing flood hazard

Criteria maps of factors influencing flood hazard was classified using GIS software as shown in Figure 17. Figure 17(a) showed the distance from drainage network (m) and was classified into five classes, namely 200, 500, 1,000, 2,000, and > 2,000. Drainage density (km/km^2) was classified into five classes, namely 0 - 6.26, 6.26 - 17.20, 17.20 - 29.09, 29.09 - 45.35, and 45.35 - 79.45 (Figure 17(b)). Elevation (m) was classified into five classes, namely 22 - 44, 44 - 55, 55 - 94, 94 - 156, and 156 - 240 as shown in Figure 17(c). Figure 17(d) represents the flow accumulation (pixels), classified into five classes, namely 0 - 5,874, 5,874 - 26,014, 26,014 - 56,224, 56,224 - 82,238, and 82,238 - 213,987. Land use was classified into five classes, namely agricultural land, forest land, miscellaneous land, urban and built-up land, and water body (Figure 17(e)). Slope (%) was classified into five classes, namely 0 - 3, 3 - 5, 5 - 12, 12 - 28, and 28 - 70 (Figure 17(f)). Soil water infiltration was classified into six classes, namely high, slightly high, moderate, slightly low, low, and other (Figure 17(g)). The last one was average annual rainfall (mm) and was also classified into five classes, namely 997 - 1,054, 1,054 - 1,100, 1,100 - 1,157, 1,157 - 1,215, and 1,215 - 1,275 as shown in Figure 17(h).

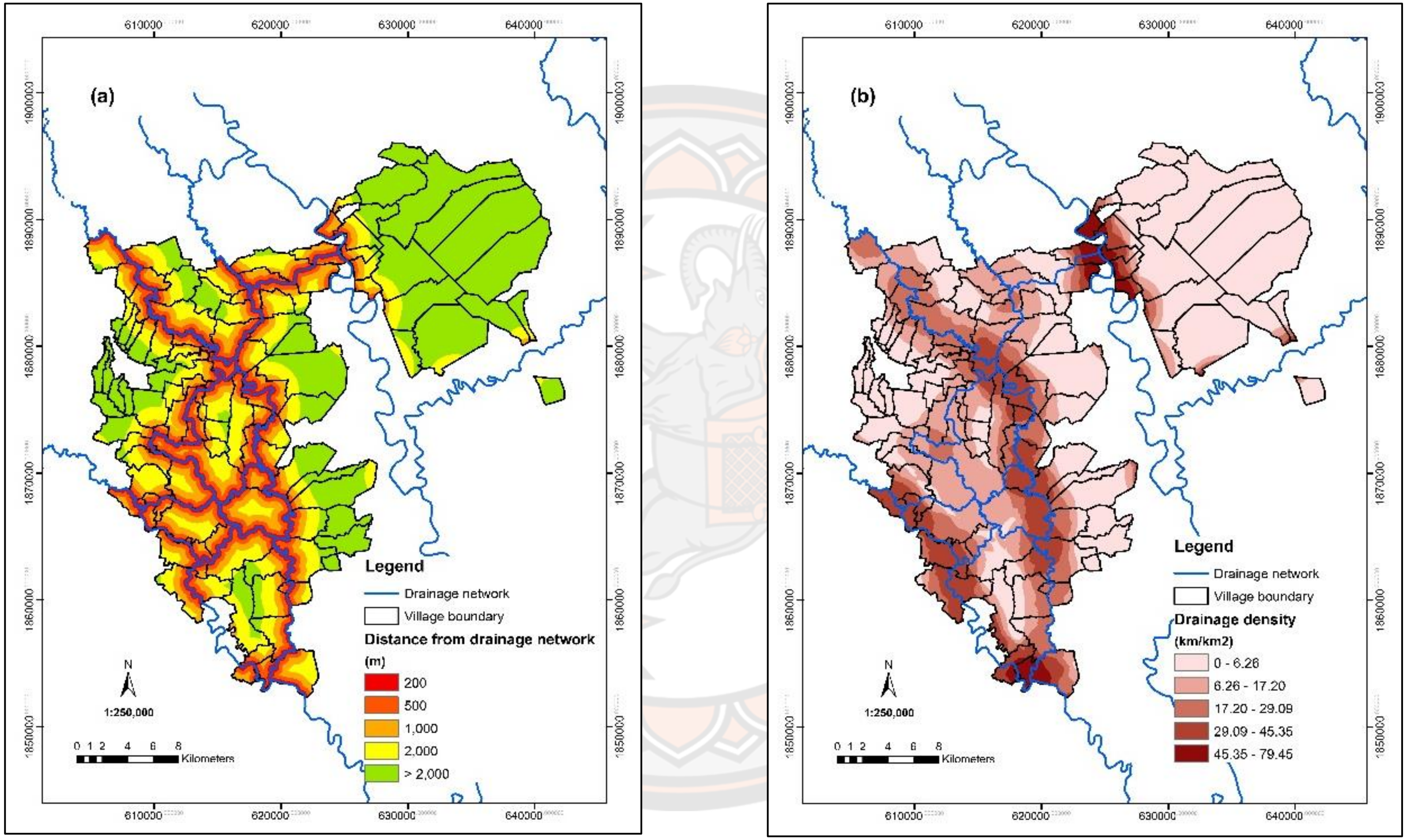


Figure 17 Criteria maps and classification of factors influencing flood hazard: (a) distance from drainage network, (b) drainage density, (c) elevation, (d) flow accumulation, (e) land use, (f) slope, (g) soil water infiltration, and (h) average annual rainfall

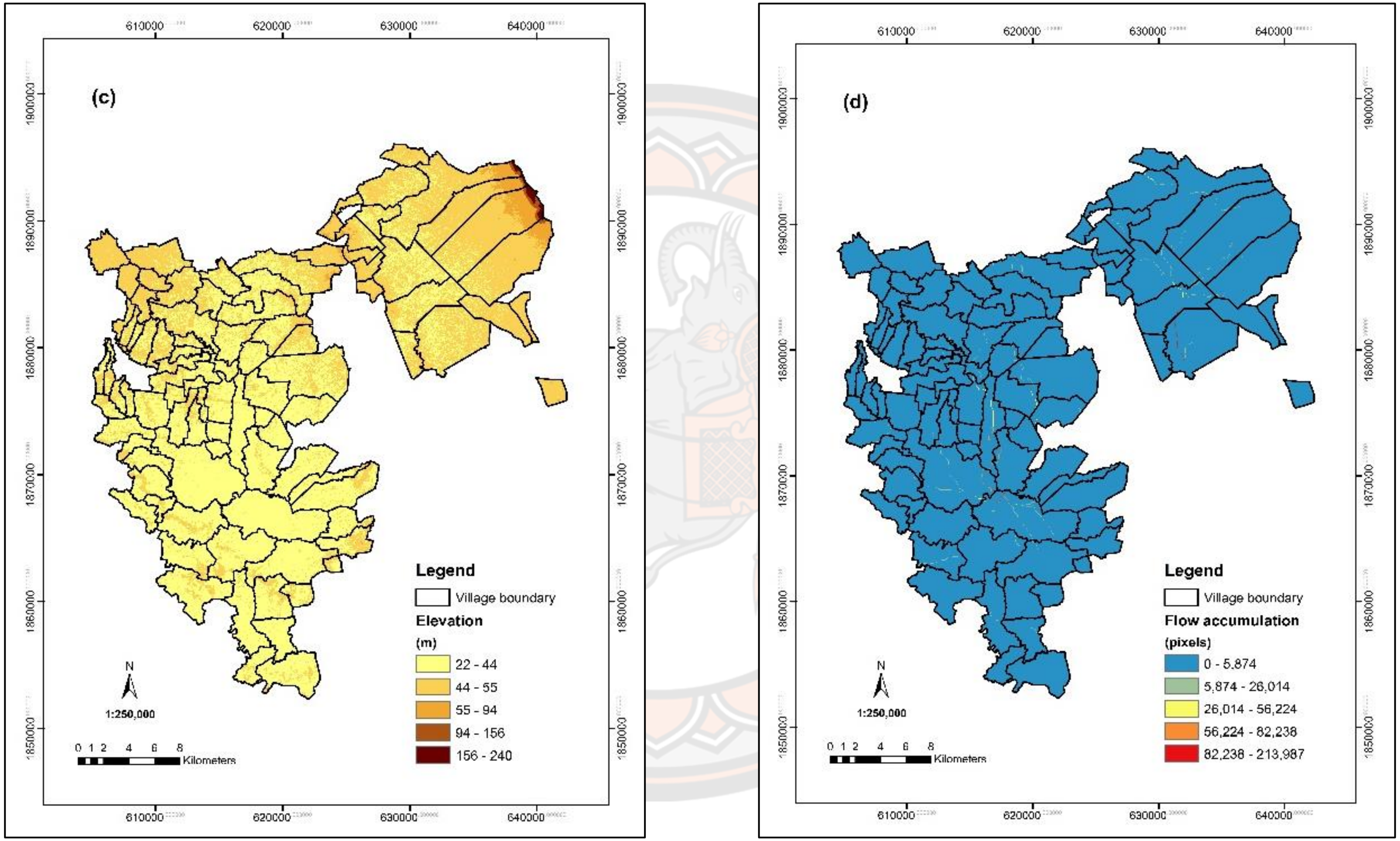


Figure 17 (Cont.)

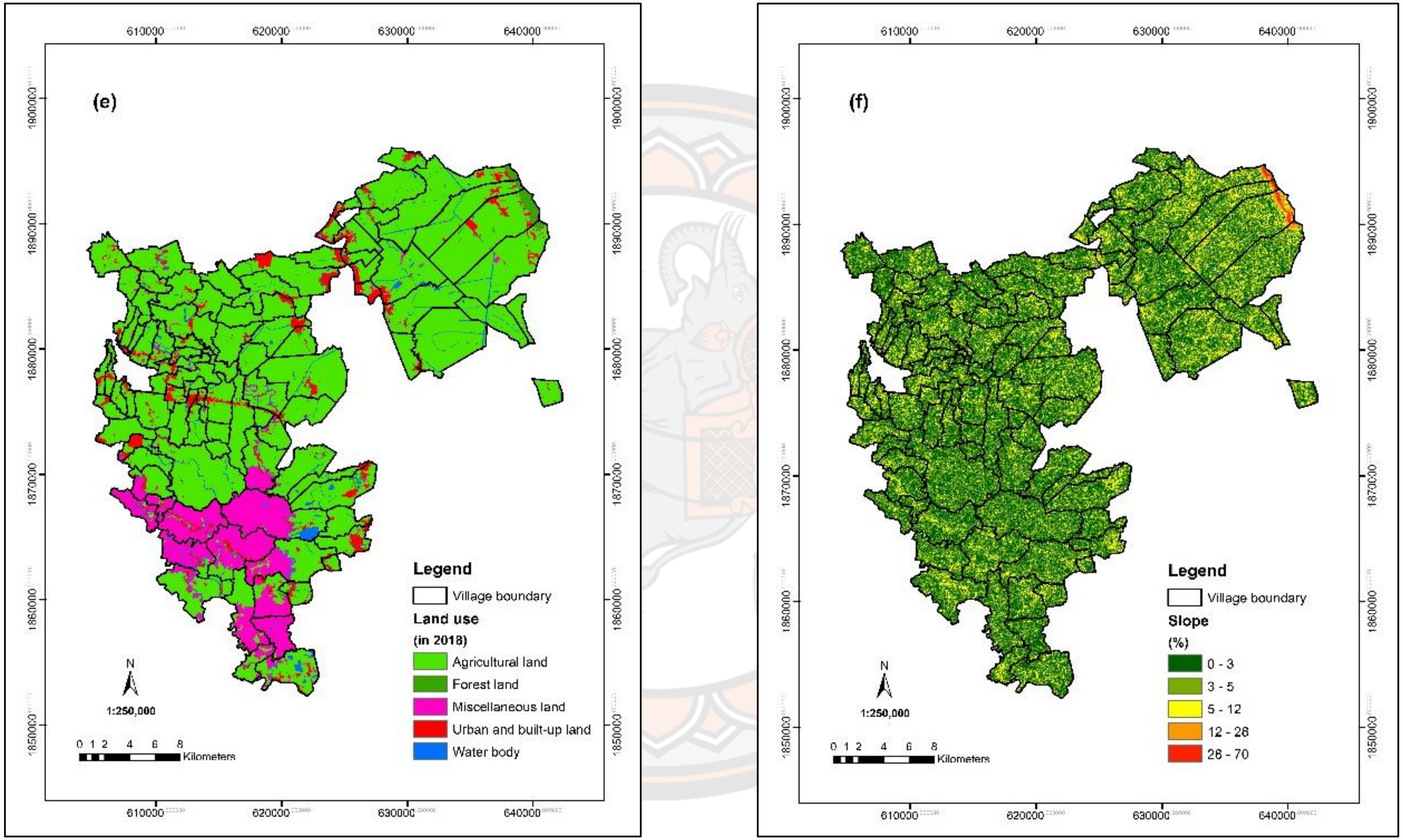


Figure 17 (Cont.)

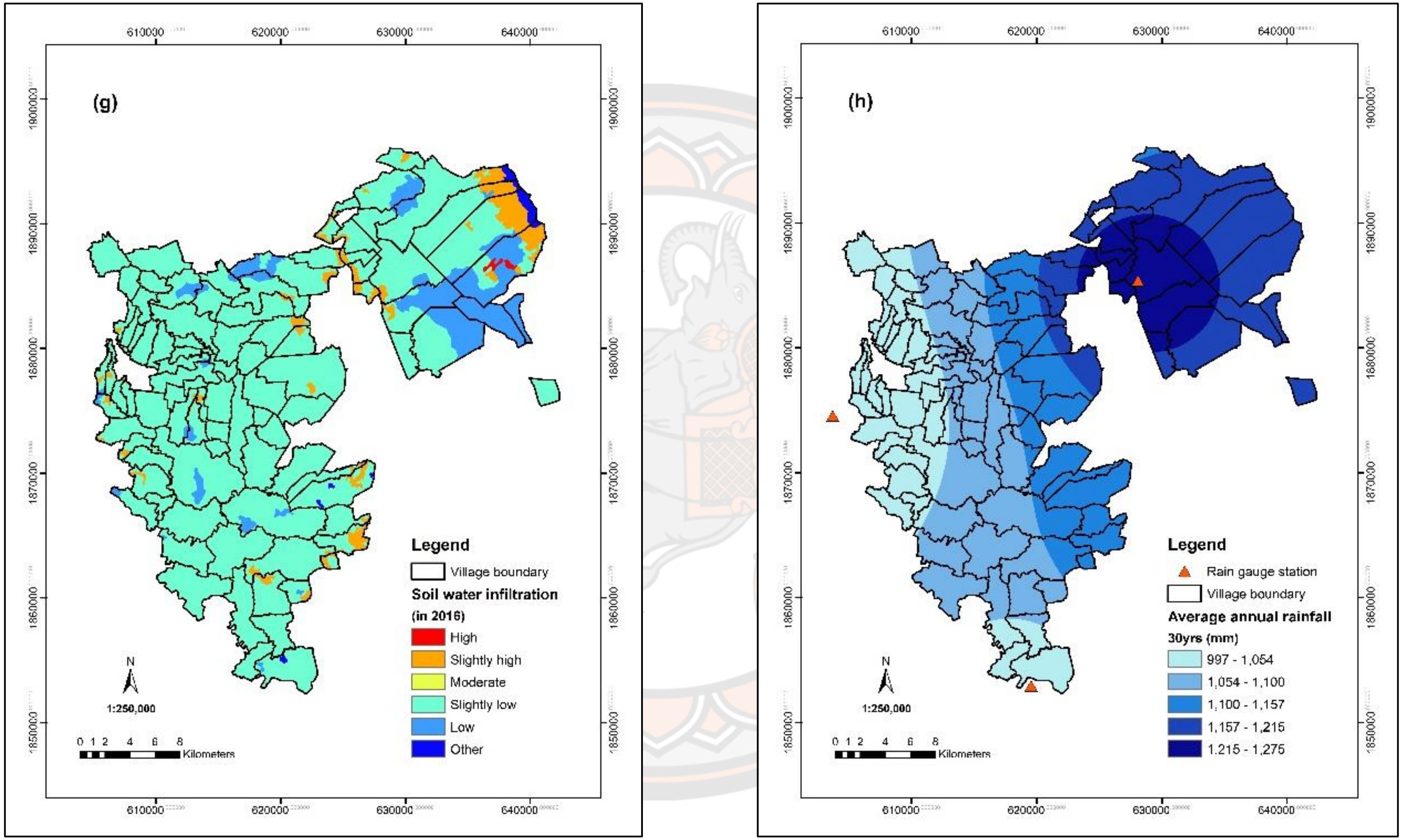


Figure 17 (Cont.)

4.1.3 Pair-wise comparison of factors influencing flood hazard

Experts were considered as those people who have experience and knowledge of the Bang Rakam Model 60 project, hydrology, flood hazard, or related fields. This section was determined by using the answers from the experts (Table 11) through questionnaires.

Table 11 Expert lists for questionnaires of pair-wise comparison (Hazard)

No.	Position	Workplace	Work experience (years)
1	Director of Meteorological Station	Phitsanulok Meteorological Station	36
2	Chief of Strategy and Management	Disaster Prevention and Mitigation Office (Phitsanulok)	30
3	Director of Naresuan Dam Operation and Maintenance Project	Naresuan Dam Operation and Maintenance Project, Regional Irrigation Office 3	33
4	Director of Phlai Chumphon Operation and Maintenance Project	Phlai Chumphon Operation and Maintenance Project, Regional Irrigation Office 3	30
5	Irrigation Engineer	Yom-Nan Operation and Maintenance Project, Regional Irrigation Office 3	19
6	Lecturer	Faculty of Engineering, Naresuan University	42
7	Lecturer	Faculty of Agriculture, Natural Resource and Environment, Naresuan University	22
8	Irrigation Engineer	Engineering Division, Regional Irrigation Office 3	29

Comparisons between each pair using a numerical scale. The data was obtained from questionnaires that were evaluated by the experts as shown in Table 12 and were calculated following the theoretical concept of AHP described in section 3.5.1.3.

Table 12 Pair-wise comparison of factors influencing flood hazard from eight experts

No.	Factors		Experts No.							
	Criteria 1	**Criteria 2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	Distance from drainage network (m)	Distance from drainage network (m)	1	1	1	1	1	1	1	1
2	Distance from drainage network (m)	Drainage density (km/km^2)	1/3	1/3	1/7	1/3	1/3	1/3	1/3	1/3
3	Distance from drainage network (m)	Elevation (m)	1/7	3	1/3	1/3	1/3	1/3	3	1/9
4	Distance from drainage network (m)	Flow accumulation (pixels)	1/3	1/3	1/3	1	1/3	1/3	1/3	1/5
5	Distance from drainage network (m)	Land use	1/7	3	1/5	1/3	1/5	1/9	3	3
6	Distance from drainage network (m)	Slope (%)	1/5	3	1/5	3	1/5	1/5	3	1/9
7	Distance from drainage network (m)	Soil water infiltration	1/3	3	3	3	3	1/5	1/3	1/3
8	Distance from drainage network (m)	Average annual rainfall (mm)	1/9	1/5	1/9	1	1/9	1/9	1/3	1/5
9	Drainage density (km/km^2)	Drainage density (km/km^2)	1	1	1	1	1	1	1	1
10	Drainage density (km/km^2)	Elevation (m)	1/7	9	3	5	1/3	1/3	7	1/3
11	Drainage density (km/km^2)	Flow accumulation (pixels)	1/5	3	3	3	1/3	1/3	1/3	3
12	Drainage density (km/km^2)	Land use	1/5	9	1/3	3	1/5	1/7	7	3
13	Drainage density (km/km^2)	Slope (%)	1/3	5	3	5	1/3	1/3	7	1/5
14	Drainage density (km/km^2)	Soil water infiltration	1/3	7	5	3	3	1/3	3	1
15	Drainage density (km/km^2)	Average annual rainfall (mm)	1/7	3	1/5	5	1/9	1/9	3	1/3
16	Elevation (m)	Elevation (m)	1	1	1	1	1	1	1	1
17	Elevation (m)	Flow accumulation (pixels)	5	1/5	3	1/3	1/3	1	1/9	5
18	Elevation (m)	Land use	3	1/3	1/3	1/3	1/3	1/5	3	7
19	Elevation (m)	Slope (%)	3	1/3	1/3	1	1/3	1/3	3	1
20	Elevation (m)	Soil water infiltration	3	3	5	1	3	1	1/5	5
21	Elevation (m)	Average annual rainfall (mm)	1/3	1/9	1/3	1	1/7	1/9	1/3	1/3

Table 12 (Cont.)

No.	Factors		Experts No.							
	Criteria 1	Criteria 2	1	2	3	4	5	6	7	8
22	Flow accumulation (pixels)	Flow accumulation (pixels)	1	1	1	1	1	1	1	1
23	Flow accumulation (pixels)	Land use	3	5	1/5	1/3	1/3	1/7	9	3
24	Flow accumulation (pixels)	Slope (%)	3	3	1/5	1/3	1/3	1/3	9	1/5
25	Flow accumulation (pixels)	Soil water infiltration	1	3	3	1	3	1/3	3	3
26	Flow accumulation (pixels)	Average annual rainfall (mm)	1/3	1/3	1/5	1	1/7	1/9	5	1
27	Land use	Land use	1	1	1	1	1	1	1	1
28	Land use	Slope (%)	3	1/3	3	3	3	3	3	1/9
29	Land use	Soil water infiltration	3	1/3	7	3	5	3	1/5	1/3
30	Land use	Average annual rainfall (mm)	1/3	1/9	1/3	3	1/5	1/7	1/3	1/7
31	Slope (%)	Slope (%)	1	1	1	1	1	1	1	1
32	Slope (%)	Soil water infiltration	1/3	3	5	1	5	1/3	1/7	7
33	Slope (%)	Average annual rainfall (mm)	1/3	1/5	1/5	1	1/5	1/7	1/3	1
34	Soil water infiltration	Soil water infiltration	1	1	1	1	1	1	1	1
35	Soil water infiltration	Average annual rainfall (mm)	1/3	1/7	1/7	1	1/7	1/3	1/3	1/5
36	Average annual rainfall (mm)	Average annual rainfall (mm)	1	1	1	1	1	1	1	1

Experts considered the class and gave the appropriate rating to each factor, the data was obtained from questionnaires as shown in Table 13. Most experts gave ratings to each factor according to the literature reviews. Seven factors; distance from drainage network, elevation, flow accumulation, land use, slope, soil water infiltration, and average annual rainfall were considered. The experts also considered drainage density and gave the different ratings as below.

Table 13 Rating of factors influencing flood hazard from eight experts

No.	Factors (Criteria)	Classes	Experts No.							
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	Distance from drainage network (m)	200	5	5	5	5	5	5	5	5
		500	4	4	4	4	4	4	4	4
		1,000	3	3	3	3	3	3	3	3
		2,000	2	2	2	3	2	2	2	2
		> 2,000	1	1	1	3	1	1	1	1
2	Drainage density (km/km^2)	0 - 6.26	1	1	5	5	5	5	1	1
		6.26 - 17.20	2	2	4	5	4	4	2	2
		17.20 - 29.09	3	3	3	4	3	3	3	3
		29.09 - 45.35	4	4	2	3	2	2	4	4
		45.35 - 79.45	5	5	1	2	1	1	5	5
3	Elevation (m)	22 - 44	5	5	5	4	5	5	5	5
		44 - 55	4	4	4	4	4	1	4	4
		55 - 94	3	3	3	3	3	1	3	3
		94 - 156	2	2	2	2	2	1	2	2
		156 - 240	1	1	1	1	1	1	1	1
4	Flow accumulation (pixels)	0 - 5,874	1	1	1	1	1	1	1	1
		5,874 - 26,014	2	2	2	2	2	1	2	2
		26,014 - 56,224	3	3	3	3	3	1	3	3
		56,224 - 82,238	4	4	4	4	4	1	4	4
		82,238 - 213,987	5	5	5	5	5	1	5	5
5	Land use	Agricultural land	5	4	3	5	3	4	4	3
		Forest land	1	3	2	3	1	1	2	1
		Miscellaneous land	4	3	4	3	4	1	3	4
		Urban and built-up land	4	5	5	5	5	5	4	2
		Water body	5	5	1	1	2	1	5	5

Table 13 (Cont.)

No.	Factors (Criteria)	Classes	Experts No.							
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
6	Slope (%)	0 - 3	5	5	5	5	5	4	5	5
		3 - 5	4	4	4	4	4	1	4	4
		5 - 12	3	3	3	3	3	1	3	3
		12 - 28	2	2	2	2	2	1	2	2
		28 - 70	1	1	1	1	1	1	1	1
7	Soil water infiltration	High	1	1	1	1	1	1	1	1
		Slightly high	2	2	2	2	2	1	2	2
		Moderate	3	3	3	3	3	1	3	3
		Slightly low	4	4	4	4	4	1	4	4
		Low	5	5	5	5	5	2	5	5
		Other	2	2	2	1	5	1	1	1
8	Average annual rainfall (mm)	997 - 1,054	1	1	1	1	1	1	1	1
		1,054 - 1,100	2	2	2	1	2	1	2	2
		1,100 - 1,157	3	3	3	1	3	1	3	3
		1,157 - 1,215	4	4	4	2	4	1	4	4
		1,215 - 1,275	5	5	5	2	5	2	5	5

4.1.4 Consistency Ratio (CR)

Factors influencing flood hazard in this study were eight. A matrix table of pair-wise comparisons was created using an 8×8 matrix. In the method of pair-wise comparison, the factors were matched one-on-one with each other. The diagonal elements were equal to 1. Checking the consistency ratio (CR) under section 3.5.1.4, it was acceptable when CR ≤ 0.10 for matrix 8×8. The random consistency index (RI) was 1.41 as shown in Table 14. If this CR cannot reach the desired level, the answer for comparison was re-check.

Table 14 The consistency ratio (CR) from eight experts using the AHP method (Hazard)

Experts No.	Consistency ratio (CR)
1	0.098
2	0.098
3	0.096
4	0.096
5	0.090
6	0.088
7	0.089
8	0.097

4.1.5 Criteria map reclassification

Experts considered and gave different ratings to the drainage density factor. Therefore, I divided the experts into two groups according to the expert lists in Table 11. Experts No. 1, 2, 7, and 8 gave a rating of drainage density in class 0 - 6.26 was very low (1) and the second group made of experts No. 3, 4, 5, and 6 gave a rating of drainage density in class 0 - 6.26 was very high (5). Each factor map was reclassified in GIS software according to the average rating as shown in Table 15 for the first expert group, and the second expert group in Table 16.

Table 15 Average rating of the first expert group (No. 1, 2, 7, and 8)

No.	Factors (Criteria)	Classes	Experts No.				Average rating
			1	2	7	8	
1	Distance from drainage network (m)	200	5	5	5	5	5
		500	4	4	4	4	4
		1,000	3	3	3	3	3
		2,000	2	2	2	2	2
		> 2,000	1	1	1	1	1
2	Drainage density (km/km^2)	0 - 6.26	1	1	1	1	1
		6.26 - 17.20	2	2	2	2	2
		17.20 - 29.09	3	3	3	3	3
		29.09 - 45.35	4	4	4	4	4
		45.35 - 79.45	5	5	5	5	5

Table 15 (Cont.)

No.	Factors (Criteria)	Classes	Experts No.				Average rating
			1	2	7	8	
3	Elevation (m)	22 - 44	5	5	5	5	5
		44 - 55	4	4	4	4	4
		55 - 94	3	3	3	3	3
		94 - 156	2	2	2	2	2
		156 - 240	1	1	1	1	1
4	Flow accumulation (pixels)	0 - 5,874	1	1	1	1	1
		5,874 - 26,014	2	2	2	2	2
		26,014 - 56,224	3	3	3	3	3
		56,224 - 82,238	4	4	4	4	4
		82,238 - 213,987	5	5	5	5	5
5	Land use	Agricultural land	5	4	4	3	4
		Forest land	1	3	2	1	2
		Miscellaneous land	4	3	3	4	4
		Urban and built-up land	4	5	4	2	4
		Water body	5	5	5	5	5
6	Slope (%)	0 - 3	5	5	5	5	5
		3 - 5	4	4	4	4	4
		5 - 12	3	3	3	3	3
		12 - 28	2	2	2	2	2
		28 - 70	1	1	1	1	1
7	Soil water infiltration	High	1	1	1	1	1
		Slightly high	2	2	2	2	2
		Moderate	3	3	3	3	3
		Slightly low	4	4	4	4	4
		Low	5	5	5	5	5
		Other	2	2	1	1	2
8	Average annual rainfall (mm)	997 - 1,054	1	1	1	1	1
		1,054 - 1,100	2	2	2	2	2
		1,100 - 1,157	3	3	3	3	3
		1,157 - 1,215	4	4	4	4	4
		1,215 - 1,275	5	5	5	5	5

Table 16 Average rating of the second expert group (No. 3, 4, 5, and 6)

No.	Factors (Criteria)	Classes	Experts No.				Average rating
			3	4	5	6	
1	Distance from drainage network (m)	200	5	5	5	5	5
		500	4	4	4	4	4
		1,000	3	3	3	3	3
		2,000	2	3	2	2	2
		> 2,000	1	3	1	1	2
2	Drainage density (km/km^2)	0 - 6.26	5	5	5	5	5
		6.26 - 17.20	4	5	4	4	4
		17.20 - 29.09	3	4	3	3	3
		29.09 - 45.35	2	3	2	2	2
		45.35 - 79.45	1	2	1	1	1
3	Elevation (m)	22 - 44	5	4	5	5	5
		44 - 55	4	4	4	1	3
		55 - 94	3	3	3	1	3
		94 - 156	2	2	2	1	2
		156 - 240	1	1	1	1	1
4	Flow accumulation (pixels)	0 - 5,874	1	1	1	1	1
		5,874 - 26,014	2	2	2	1	2
		26,014 - 56,224	3	3	3	1	3
		56,224 - 82,238	4	4	4	1	3
		82,238 - 213,987	5	5	5	1	4
5	Land use	Agricultural land	3	5	3	4	4
		Forest land	2	3	1	1	2
		Miscellaneous land	4	3	4	1	3
		Urban and built-up land	5	5	5	5	5
		Water body	1	1	2	1	1
6	Slope (%)	0 - 3	5	5	5	4	5
		3 - 5	4	4	4	1	3
		5 - 12	3	3	3	1	3
		12 - 28	2	2	2	1	2
		28 - 70	1	1	1	1	1
7	Soil water infiltration	High	1	1	1	1	1
		Slightly high	2	2	2	1	2
		Moderate	3	3	3	1	3
		Slightly low	4	4	4	1	3
		Low	5	5	5	2	4
		Other	2	1	5	1	2

Table 16 (Cont.)

No.	Factors (Criteria)	Classes	Experts No.				Average rating
			3	4	5	6	
8	Average annual rainfall (mm)	997 - 1,054	1	1	1	1	1
		1,054 - 1,100	2	1	2	1	2
		1,100 - 1,157	3	1	3	1	2
		1,157 - 1,215	4	2	4	1	3
		1,215 - 1,275	5	2	5	2	4

4.1.6 Fuzzy AHP analysis

CR from the AHP method reached the desired level, hence the fuzzy AHP described in section 3.5.1.6 was used to calculate for factors influencing flood hazard (8 factors) as shown in Table 17 from the two expert groups.

Table 17 Fuzzy weights of factor from two expert groups

No.	Factors (Criteria)	Fuzzy weights	
		First group (Experts No. 1, 2, 7, 8)	**Second group** (Experts No. 3, 4, 5, 6)
1	Distance from drainage network (m)	0.0632	0.0224
2	Drainage density (km/km^2)	0.1611	0.1457
3	Elevation (m)	0.1423	0.1019
4	Flow accumulation (pixels)	0.1667	0.0843
5	Land use	0.0594	0.2130
6	Slope (%)	0.1206	0.1464
7	Soil water infiltration	0.0988	0.0306
8	Average annual rainfall (mm)	0.1879	0.2556

The result from the first expert group, found in an order of importance, average annual rainfall (0.1879), flow accumulation (0.1667), drainage density (0.1611), elevation (0.1423), slope (0.1206), soil water infiltration (0.0988), distance from drainage network (0.0632), and land use (0.0594) as factors influencing flood hazard. The second expert group arranged the factors in an order of importance as average annual rainfall (0.2556), land use (0.2130), slope (0.1464), drainage density (0.1457), elevation (0.1019), flow accumulation (0.0843), soil water infiltration (0.0306), and distance from a drainage network (0.0224). Thus, from the two expert groups, average annual rainfall was the most important factor influencing flood hazards.

4.2 Flood hazard map

4.2.1 Map creation

The flood hazard map was created using rating (in Table 15 for the first expert group and Table 16 for the second expert group) and fuzzy weights factor (in Table 17).

Therefore, two different flood hazard maps were created as shown in Figure 18 and Figure 19. The map of the first expert group found that flood levels at Phrom Phiram, Mueang Phitsanulok, and Bang Rakam districts were mostly very high level while at of Kong Krailat district was very low to moderate level. Table 18 showed the flood hazard of the first group at each level with a moderate level covering an area of 211.94 km^2 or 30.47% of the total area, low level of 184.44 km^2 (26.52%), high level of 165.78 km^2 (23.83%), very low level of 75.59 km^2 (10.87%), and very high level 57.81 km^2 (8.31%), respectively. The flood hazard map from the second expert group largely found flood hazards at the left side in very low to moderate levels and that on the right side in high to very high levels, with the very high level occurring mostly in Phrom Phiram district. Table 19 represents the flood hazard of the second group. Most areas of about 218.90 km^2 or 31.47% were found to be in the high level, moderate level accounted for 175.58 km^2 (25.24%), very high level of 161.91 km^2 (23.28%), low level of 100.22 km^2 (14.41%), and very low level of 38.93 km^2 (5.60%), respectively.

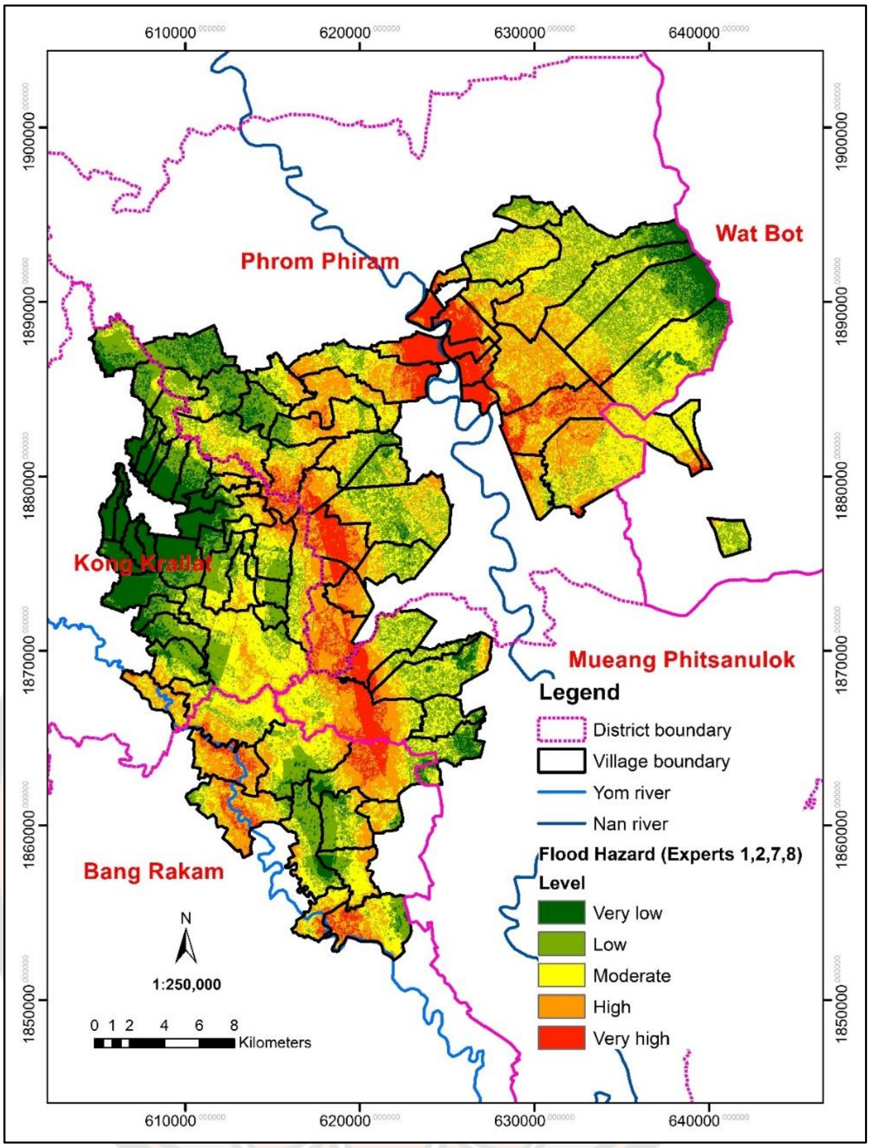


Figure 18 Flood hazard map of the first expert group (No. 1, 2, 7, and 8)

Table 18 Flood hazard area in each level of the first expert group (No. 1, 2, 7, and 8)

Hazard level	Area (km^2)	Percent of area (%)
Very low	75.59	10.87
Low	184.44	26.52
Moderate	211.94	30.47
High	165.78	23.83
Very high	57.81	8.31
Total	695.56	100.00

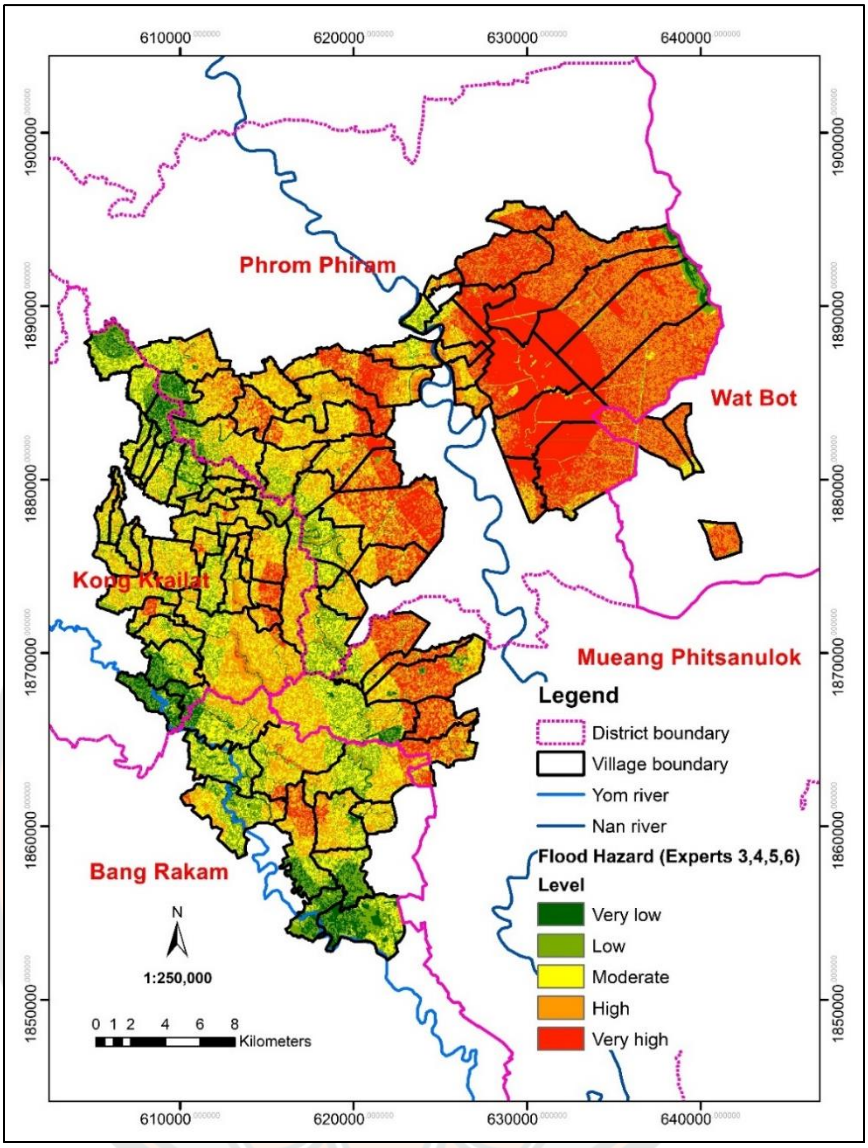


Figure 19 Flood hazard map of the second expert group (No. 3, 4, 5, and 6)

Table 19 Flood hazard area in each level of the second expert group (No. 3, 4, 5, and 6)

Hazard level	Area (km^2)	Percent of area (%)
Very low	38.93	5.60
Low	100.22	14.41
Moderate	175.58	25.24
High	218.90	31.47
Very high	161.91	23.28
Total	695.54	100.00

4.2.2 Validation

Repeated flood areas in 2004-2019 from GISTDA were used to validate the flood hazard maps obtained in section 4.2.1. Under this flood levels were classified into three classes according to as shown in Table 20. The classes were; high (i.e. very high and high group), moderate, and low (i.e. very low and low group).

Table 20 Repeated floods classification according to LDD

Flood level	Repeated flood (times in 10 years)
Low	1 - 3
Moderate	4 - 7
High	> 8

Repeated flood areas and flood hazard maps were validated by shape factor (f) as in equation 4.1 following the method of Sriariyawat et al. (2013).

$$f = \frac{A_{sat} \cap A_{fh}}{A_{sat} \cup A_{fh}} \quad \text{Eq. (4.1)}$$

where; $A_{sat} \cap A_{fh}$ is the intersection of areas from GISTDA by satellite (A_{sat}) images and flood hazard map (A_{fh}). $A_{sat} \cup A_{fh}$ is union area for both satellite images and flood hazard map. If f = 1 meant the flood hazard maps match satellite data completely. Table 21 represent the validation of repeated flood areas and flood hazard map from the first expert group, whereas that of the second expert group is shown in Table 22. It was observed that shape factors from the first expert group at low, moderate, and high levels were 0.34, 0.18, and 0.21, respectively. While, those of the second expert group at low, moderate, and high levels were 0.13, 0.16, and 0.10, respectively. The result showed that shape factors of the first expert group were high and closer to 1 than that of the second expert group. Therefore, the flood hazard map in Figure 18 was used for analysis in the next step.

Table 21 Shape factors (f) of the first expert group (No. 1, 2, 7, and 8)

Flood level	Intersection	Union	Shape factors (f)
Low	134.09	393.92	0.34
Moderate	64.22	356.47	0.18
High	63.35	297.58	0.21

Table 22 Shape factors (f) of the second expert group (No. 3, 4, 5, and 6)

Flood level	Intersection	Union	Shape factors (f)
Low	49.17	373.74	0.13
Moderate	52.41	334.22	0.16
High	47.49	452.55	0.10

4.3 Priority of factors influencing flood vulnerability

4.3.1 Hierarchy structure of factors influencing flood vulnerability

The factors were structured in a hierarchy of different levels, i.e. goal, and criteria. As shown in Figure 20, the goal level is factors influencing flood vulnerability, and criteria level (5 factors) include age group, dependency ratio, gender ratio, population density, and road density.

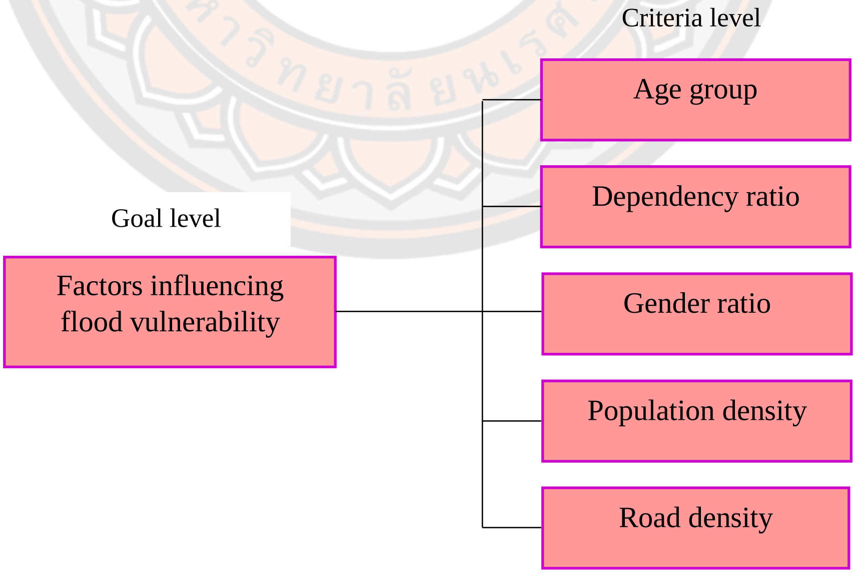


Figure 20 Structuring the hierarchy of factors influencing flood vulnerability

4.3.2 Criteria maps and classification of factors influencing flood vulnerability

Criteria maps of factors influencing flood vulnerability was classified into five classes using GIS software as shown in Figure 21. Firstly, age group (%), namely 29.01 - 30.99, 30.99 - 34.85, 34.85 - 37.37, 37.37 - 41.14, and 41.14 - 51.92 (Figure 21(a)). Figure 21(b) shown dependency ratio, namely 40.87 - 44.82, 44.82 - 53.51, 53.51 - 59.56, 59.56 - 69.83, and 69.83 - 108.00. Next is gender ratio, namely 73.68 - 89.17, 89.17 - 96.05, 96.05 - 101.71, 101.71 - 112.28, and 112.28 - 136.36 (Figure 21(c)). Figure 21(d) shown population density (persons/km^2), namely 3 - 46, 46 - 94, 94 - 184, 184 - 318, and 318 - 610. Lastly, road density (km/km^2), namely 0.48 - 4.28, 4.28 - 6.50, 6.50 - 8.96, 8.96 - 12.84, and 12.84 - 20.68 as shown in Figure 21(e).

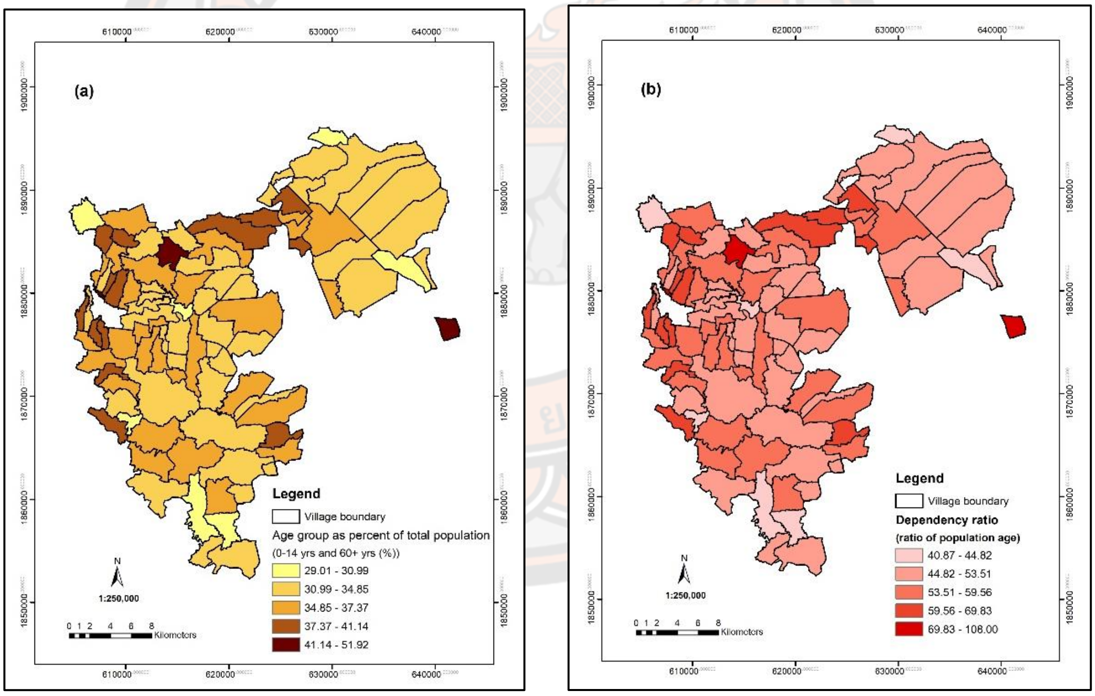


Figure 21 Criteria maps and classification of factors influencing flood vulnerability: (a) age group, (b) dependency ratio, (c) gender ratio, (d) population density, and (e) road density

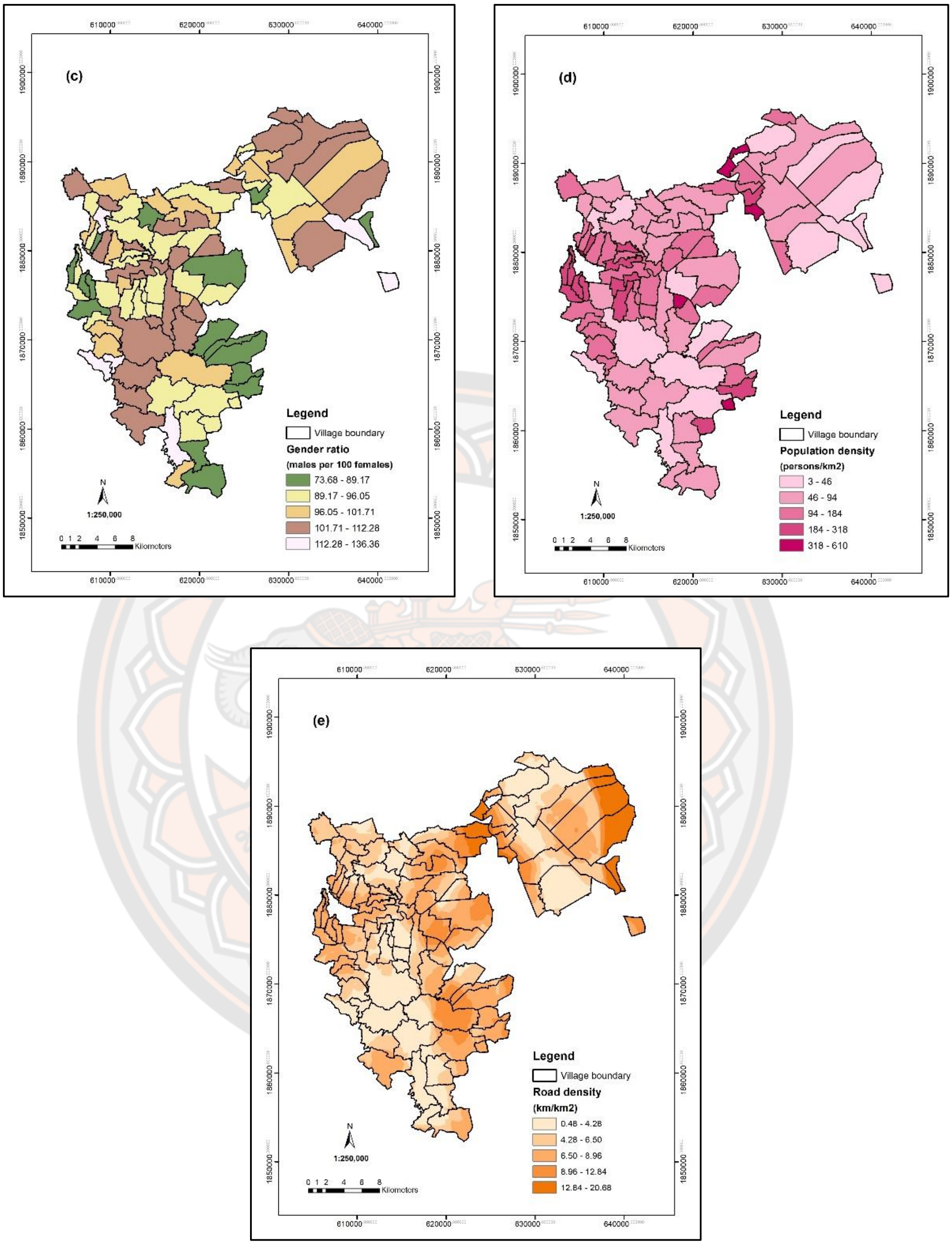


Figure 21 (Cont.)

4.3.3 Pair-wise comparison of factors influencing flood vulnerability

Experts were considered as those people who have experience and knowledge of the Bang Rakam Model 60 project, flood vulnerability, social, or related fields. This section was determined by using the answers of the experts (Table 23) through questionnaires.

Table 23 Expert lists for questionnaires of pair-wise comparison (Vulnerability)

No.	Position	Workplace	Work experience (years)
1	Lecturer	Faculty of Social Sciences, Naresuan University	12
2	Lecturer	Faculty of Agriculture, Natural Resource and Environment, Naresuan University	23
3	Director of Meteorological Station	Phitsanulok Meteorological Station	36
4	Director of Naresuan Dam Operation and Maintenance Project	Naresuan Dam Operation and Maintenance Project, Regional Irrigation Office 3	33

Comparisons between each pair using a numerical scale. The data was obtained from questionnaires that were evaluated by experts as shown in Table 24, to calculate following the theoretical concept of AHP described in section 3.5.1.3.

Experts considered the class and gave the appropriate rating for each factor, the data was obtained from questionnaires as shown in Table 25. All experts gave ratings to the factors according to the literature reviews.

Table 24 Pair-wise comparison of factors influencing flood vulnerability from four experts

No.	Factors		Experts No.			
	Criteria 1	Criteria 2	1	2	3	4
1	Age group (%)	Dependency ratio	3	1	1/5	1
2	Age group (%)	Gender ratio	1/5	9	1/5	1
3	Age group (%)	Population density (persons/km^2)	1/3	7	1/9	1/5
4	Age group (%)	Road density (km/km^2)	1/5	5	1/9	1/7
5	Dependency ratio	Gender ratio	1/5	7	1	1
6	Dependency ratio	Population density (persons/km^2)	1/7	5	1/5	1/5
7	Dependency ratio	Road density (km/km^2)	1/7	5	1/7	1/7
8	Gender ratio	Population density (persons/km^2)	3	1/5	1/3	1
9	Gender ratio	Road density (km/km^2)	3	1/3	1/5	1/7
10	Population density (persons/km^2)	Road density (km/km^2)	1	1/3	1/5	1/5

Table 25 Rating and an average rating of factors influencing flood vulnerability from four experts

No.	Factors (Criteria)	Classes	Experts No.				Average rating
			1	2	3	4	
1	Age group (%)	29.01 - 30.99	2	3	2	2	2
		30.99 - 34.85	3	3	2	2	3
		34.85 - 37.37	3	3	2	3	3
		37.37 - 41.14	4	4	2	4	3
		41.14 - 51.92	5	5	4	5	5
2	Dependency ratio	40.87 - 44.82	3	3	3	3	3
		44.82 - 53.51	3	3	3	3	3
		53.51 - 59.56	4	3	3	4	3
		59.56 - 69.83	4	4	4	4	4
		69.83 - 108.00	5	5	5	5	5
3	Gender ratio	73.68 - 89.17	2	4	5	4	4
		89.17 - 96.05	2	4	4	3	3
		96.05 - 101.71	2	2	4	2	3
		101.71 - 112.28	1	1	3	1	2
		112.28 - 136.36	1	1	3	1	2

Table 25 (Cont.)

No.	Factors (Criteria)	Classes	Experts No. 1	2	3	4	Average rating
4	Population density (persons/km^2)	3 - 46	1	1	1	1	1
		46 - 94	2	2	2	2	2
		94 - 184	3	3	3	3	3
		184 - 318	4	4	4	4	4
		318 - 610	5	5	5	5	5
5	Road density (km/km^2)	0.48 - 4.28	5	3	5	5	4
		4.28 - 6.50	4	3	4	4	4
		6.50 - 8.96	3	2	3	3	3
		8.96 - 12.84	2	2	2	2	2
		12.84 - 20.68	1	1	1	1	1

4.3.4 Consistency Ratio (CR)

Five factors influenced flood vulnerability in this study. A matrix table of pair-wise comparisons was created by the 5×5 matrix. The consistency ratios (CR) were acceptable because CR ≤ 0.10 for matrix 5×5 (section 3.5.1.4), and the results are shown in Table 26. The random consistency index (RI) was 1.12.

Table 26 The consistency ratio (CR) from four experts using the AHP method (Vulnerability)

Experts No.	Consistency ratio (CR)
1	0.074
2	0.089
3	0.095
4	0.081

4.3.5 Criteria map reclassification

Experts considered and gave ratings to factors in the same trend as above. Each factor map was reclassified in GIS software according to the average rating as shown in Table 25.

4.3.6 Fuzzy AHP analysis

The CR result from the AHP method reached the desired level, hence the fuzzy AHP was used to calculate the flood vulnerability factors (in section 3.5.1.6) and the results shown in Table 27.

Table 27 Fuzzy weights of factor influencing flood vulnerability

No.	Factors (Criteria)	Fuzzy weights
1	Age group (%)	0.1322
2	Dependency ratio	0.1252
3	Gender ratio	0.1212
4	Population density (persons/km^2)	0.3107
5	Road density (km/km^2)	0.3107

The result from the experts indicates that population density and road density are the most important factors influencing flood vulnerability as they recorded the same weight of 0.3107. This was followed by the age group (0.1322), the dependency ratio (0.1252), and the gender ratio (0.1212).

4.4 Flood vulnerability map

The flood vulnerability map was created using the average ratings in Table 25 and fuzzy weights factor in Table 27. The flood vulnerability map in Figure 22 showed that most areas were at moderate and high vulnerability levels. Very high levels were found in Kong Krailat, Phrom Phiram, Mueang Phitsanulok, and Bang Rakam districts. Wat Bot district ranged from very low to moderate level. The most vulnerable district was Kong Krailat and it lied within moderate to a very high level. Table 28 showed the area cover of flood vulnerability for each level. The high level covered an area of 314.56 km^2 or 45.13% of the total area, moderate level covered 205.31 km^2 (29.45%), low level covered 85.78 km^2 (12.31%), very low level covered 52.87 km^2 (7.58%), and the very high level was 38.52 km^2 (5.53%), respectively.

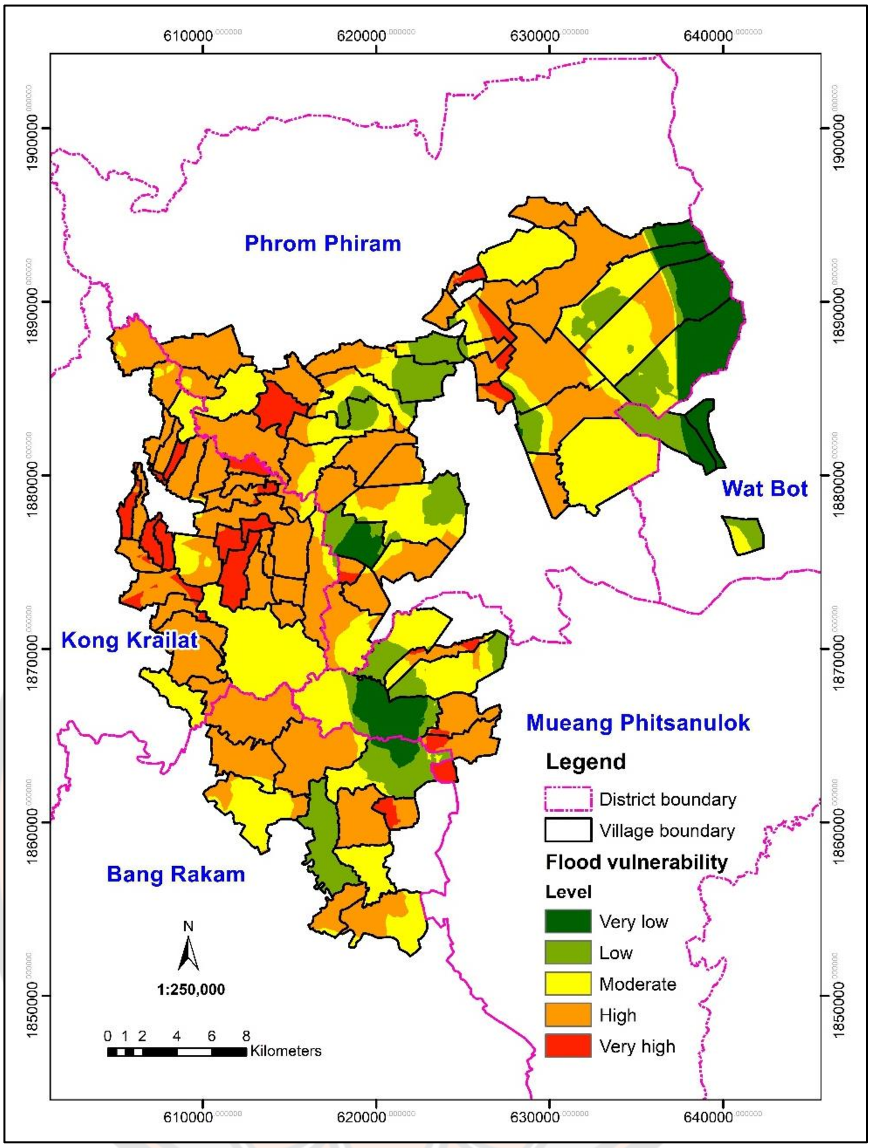


Figure 22 Flood vulnerability map

Table 28 Flood vulnerability area at each level

Vulnerability level	Area (km^2)	Percent of area (%)
Very low	52.87	7.58
Low	85.78	12.31
Moderate	205.31	29.45
High	314.56	45.13
Very high	38.52	5.53
Total	697.05	100.00

4.5 Flood risk map

The flood risk map was generated from the flood hazard map and the flood vulnerability map by the use of the GIS software as shown in Figure 23. Four districts had all the levels of flood risk. This included Kong Krailat, Phrom Phiram, Mueang Phitsanulok, and Bang Rakam. The result showed that Wat Bot district lied only in the very low to moderate level. Out of the 695.55 km^2 total flood risk area, 225.67 km^2 (32.44%) was in the moderate level, 139.60 km^2 (20.07%) was in the high level, 119.12 km^2 (17.13%) was in the very high level, 111.05 km^2 (15.97%) was in the very low level, and 100.11 km^2 (14.39%) was in the low level, respectively as shown in Table 29.

The very high-risk level was mostly at areas along the river and the border between Kong Krailat and Phrom Phiram districts. The map was identified very high flood risk areas at Kong Krailat district in the Sukhothai province (i.e. Kok Raet sub-district-village no. 4, 5, 6, 9, 10), Dong Dueai sub-district (village no. 7, 9), and Ban Mai Suk Kasem sub-district (village no. 2, 4, 5, 6, 7). In the Phitsanulok province, very high flood risk areas were identified at Phrom Phiram, Mueang Phitsanulok, and Bang Rakam districts. In Phrom Phiram district, the catchment areas included; Tha Chang sub-district (village no. 7, 9, 10, 12), Wang Won sub-district (village no. 4, 7), Nong Khaem sub-district (village no. 2, 5, 6, 8, 9), Phrom Phiram sub-district (village no. 1, 10, 11, 12, 15), Matong sub-district (village no. 2, 8, 9, 10), Thap Yai Chiang sub-district (village no. 5), and Ho Klong sub-district (village no. 7). In the Mueang Phitsanulok district, the spotlight was on Ban Krang sub-district (village no. 8) and Phai Kho Don sub-district (village no. 4). Also, in the Bang Rakam district the areas covered were Chum Saeng Songkhram sub-district (village no. 1, 2, 3, 9), Tha Nang Ngam sub-district (village no. 3, 5, 10), and Bang Rakam sub-district (village no. 15).

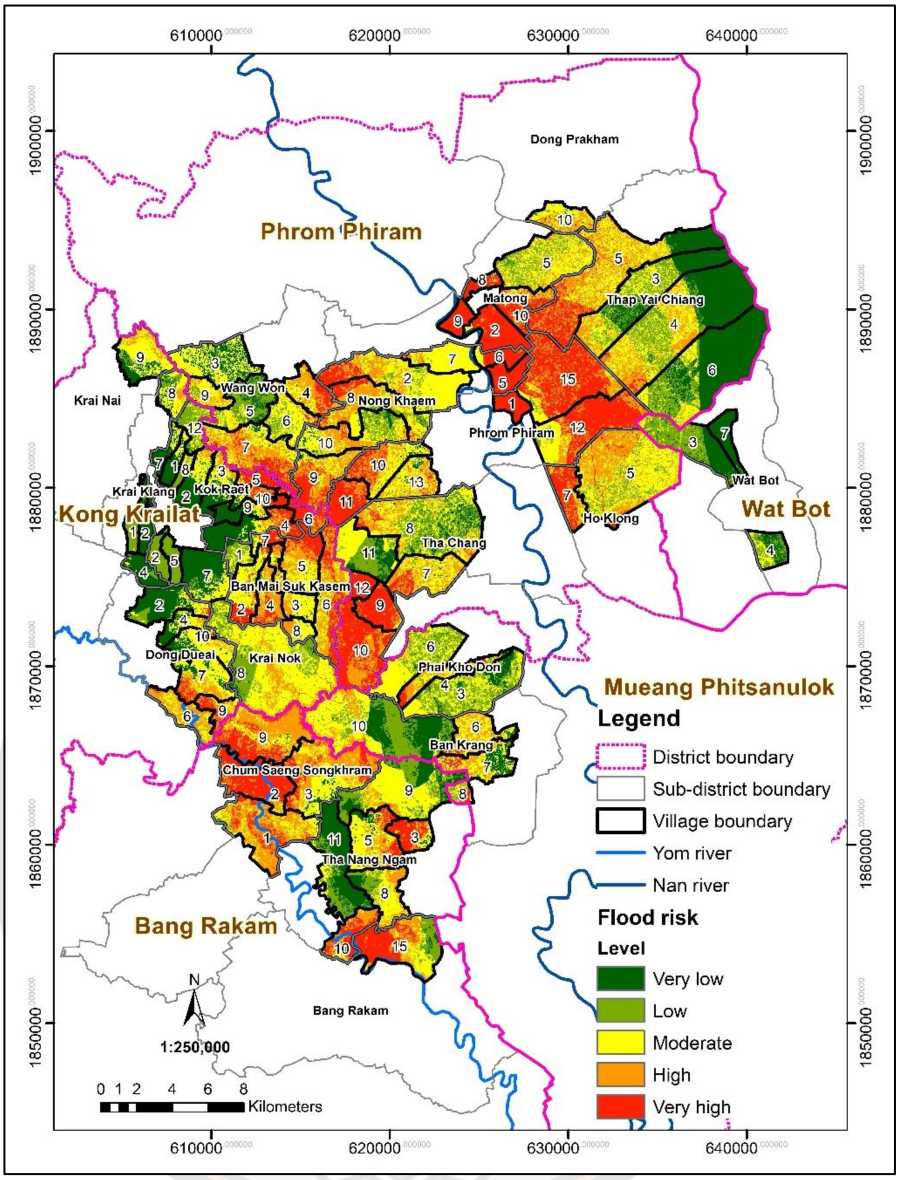


Figure 23 Flood risk map

Table 29 Flood risk area in each level

Vulnerability level	Area (km^2)	Percent of area (%)
Very low	111.05	15.97
Low	100.11	14.39
Moderate	225.67	32.44
High	139.60	20.07
Very high	119.12	17.13
Total	695.55	100.00

4.6 Farmers perception of flood risk

4.6.1 Analyzing survey results from respondents

The study was conducted on farmers who have cultivated within the area of the Bang Rakam Model 60 project in Phitsanulok and Sukhothai provinces by questionnaire (Table 30). The respondents were composed of heads of the household (77 persons) and household members (25 persons).

Table 30 Number of samples collected in each district

Districts	Number of samples
Phrom Phiram	46
Mueang Phitsanulok	10
Bang Rakam	13
Wat Bot	1
Kong Krailat	32
Total	102

The questionnaire was divided into five parts as follows; general information, flood experience, flood risk perception, the effect of the Bang Rakam Model 60 project, and comments and suggestions.

Part 1: General information

1) Gender

A majority of the respondents (71.6%) were males while females were 28.4% as shown in Table 31.

Table 31 Gender of respondents

Gender	Frequency (persons)	Percentage (%)
Male	73	71.6
Female	29	28.4
Total	102	100

2) Age

Most of the respondents, about 63.7% were age 51 years and older. Those between 41 - 50 years were 24.5%, then 20 - 30 years were 5.9%, 31 - 40 years were 4.9%, and below 20 years were 1.0%, respectively as shown in Table 32.

Table 32 Age of respondents

Age	Frequency (persons)	Percentage (%)
Below 20 years	1	1.0
20 - 30 years	6	5.9
31 - 40 years	5	4.9
41 - 50 years	25	24.5
51 years and older	65	63.7
Total	102	100

3) Education level

The result in Table 33 showed that most of the respondents (27.5%) had senior high school education. This was followed by primary school (grade 4-6) education (26.5%), primary school (grade 1-3) education (18.6%), bachelor degrees (14.7%), junior high school (6.9%), high vocational certificate (3.9%), and vocational certificate and uneducated (1.0%).

Table 33 Education level of respondents

Education level	Frequency (persons)	Percentage (%)
Uneducated	1	1.0
Primary School (Grade 1-3)	19	18.6
Primary School (Grade 4-6)	27	26.5
Junior High School	7	6.9
Senior High School	28	27.5
Vocational Certificate	1	1.0
High Vocational Certificate	4	3.9
Bachelor Degrees	15	14.7
Higher than Bachelor Degrees	0	0.0
Total	102	100

4) Household member

The majority of members per household was 3 - 4 persons and this formed 53.9% of the respondents. It was followed by 5 - 6 household members (29.4%), 1 - 2 household members (15.7%), and lastly, more than 6 household members formed 1.0% as presented in Table 34.

Table 34 Household member respondents

Household member	Frequency (persons)	Percentage (%)
1 - 2 persons	16	15.7
3 - 4 persons	55	53.9
5 - 6 persons	30	29.4
More than 6 persons	1	1.0
Total	102	100

5) Average monthly income (Gross income)

The average gross monthly income of the respondents is shown in Table 35. Most of the respondents (41.2%) earned about 5,001 - 10,000 baht. 31.4% earned 10,001 - 20,000 baht while 24.5% earned over 20,000 baht. The income of less than or equal to 5,000 baht was earned by 2.9% of the respondents.

Table 35 Average monthly gross income of the respondents

Average monthly gross income	Frequency (persons)	Percentage (%)
Less than or equal 5,000 baht	3	2.9
5,001 - 10,000 baht	42	41.2
10,001 - 20,000 baht	32	31.4
Over 20,000 baht	25	24.5
Total	102	100

Part 2: Flood experience

From question no. 1: How long have you been living here?

The average number of respondents have lived there for 42 years.

From question no. 2: Who were you living with at the time of the flood?

During the flood, most of the respondents 41.5% were with their spouse or partner, 28.4% were with their children, 16.5% were with their parents or father/mother, 12.5% were with others, and the remaining 1.1% lived alone (Table 36).

Table 36 Who the respondents lived with at the time of the flood

Who were living with	Frequency (persons)	Percentage (%)
Living alone	2	1.1
Spouse or partner	73	41.5
Children	50	28.4
Parents or father/mother only	29	16.5
Other	22	12.5
Total	176	100

Note: Select all that apply

From question no. 3: What type of flooding have you experienced?

The result in Table 37 showed that a majority of the respondents (52.0%) did experienced flood at the farm, followed by 21.5% who experienced it on the road for 1 week or longer. Also, 18.6% experienced a flood at their primary residence while 5.6% experienced other types. The remaining 2.3% have experienced a flood at some parts of their primary residence (e.g., open space, parking lot).

Table 37 Types of flood the respondents have experienced

Type of flooding	Frequency (persons)	Percentage (%)
Flooding on road for a long time (1 week or longer)	38	21.5
Farm was flooded	92	52.0
Primary residence was flooded	33	18.6
Some parts of the primary residence were flooded (e.g., open space, parking lot)	4	2.3
Other	10	5.6
Total	177	100

Note: Select all that apply

From question no. 4: What was the water depth at your primary residence?

A large number (63.7%) of the respondents indicated that they experienced no significant flood water depth at their primary residence. 22.5% of respondents experienced a water depth of over 50 cm at their primary residence while 13.7% experienced a flood depth of 1 - 50 cm (Table 38).

Table 38 Water depth at respondents primary residence

Water depth	Frequency (persons)	Percentage (%)
No significant flood at the primary residence	65	63.7
1 - 50 cm.	14	13.7
Over 50 cm.	23	22.5
Total	102	100

From question no. 5: What was the water depth at your farm?

Table 39 depicts the depth of water at the respondents' farm. A total of 84.3% of the respondents experienced a flood depth of over 50 cm while 9.8% recorded no significant flood depth at their farms. 5.9% of them also experienced depths of 1 - 50 cm.

Table 39 Water depth at respondents farms

Water depth	Frequency (persons)	Percentage (%)
No significant flood to farm	10	9.8
1 - 50 cm.	6	5.9
Over 50 cm.	86	84.3
Total	102	100

From question no. 6: How have you been affected by the flood in this location?

Table 40 represents the impact of flooding on the respondents' livelihood. A large percentage of the respondents (30.4%) lost income and crops. The physical health of about 8.3% of the respondents was affected. 7.6% also suffered a monetary loss due to repair of damages caused by the flood. Some respondents (6.9%)

lost time (off work) to clean up and a partial loss of access to the property (e.g., public health center, hospital). Also, 6.3% recorded a monetary loss due to lost valuables or equipment, while 3.3% experienced no significant effect.

Table 40 Effects of flood on respondents livelihood

Affected by flooding	Frequency (persons)	Percentage (%)
Monetary loss due to repair of flood damages	23	7.6
Monetary loss due to lost valuables or equipment	19	6.3
Time took off work to clean up	21	6.9
Partial loss of access to the property (e.g., public health center, hospital)	21	6.9
It affected the physical health of someone in my home	25	8.3
Lost income	92	30.4
Loss of crops	92	30.4
No significant effect	10	3.3
Other	0	0.0
Total	303	100

Note: Select all that apply

From question no. 7: Please, estimate your total cumulative loss in baht. If you suffered a monetary loss due to flooding in the last year (2019) such as damage to a primary residence, farm, crops, income, etc.

From Table 41 the highest percentage of the respondents recorded zero cumulative loss about 43.1%, followed by 30.4% recorded a loss of 50,001 - 100,000 baht and 14.7% recorded 20,001 - 50,000 baht. Also, 6.9% suffered a cumulative loss of 5,001 - 20,000 baht while 3.9% and 1.0% suffered a loss of less than or equal 5,000 baht, and over 100,000 baht, respectively.

Table 41 Cumulative losses incurred by respondents

Cumulative loss	Frequency (persons)	Percentage (%)
Zero, I had no monetary loss from flooding over the last year	44	43.1
Less than or equal 5,000 baht	4	3.9
5,001 - 20,000 baht	7	6.9
20,001 - 50,000 baht	15	14.7
50,001 - 100,000 baht	31	30.4
Over 100,000 baht	1	1.0
I don't know	0	0.0
I prefer not answering	0	0.0
Total	102	100

Part 3: Flood risk perception

From question no. 1: What source of flood news have you received?

The source of flood information varied among the respondents. Most of the respondents (32.5%) got information through radio/television, this was followed by village broadcasting (21.3%), village headman/village committee (19.5%), household members/neighbors (13.4%), internet (9.0%), document/brochures (2.5%), other (1.1%), and newspaper/posters (0.7%) as shown in Table 42.

Table 42 Respondents source of flood news

Source of flood news	Frequency (persons)	Percentage (%)
Radio/Television	90	32.5
Newspaper/Posters	2	0.7
Document/Brochures	7	2.5
Village broadcasting	59	21.3
Village headman/Village committee	54	19.5
Household members/Neighbors	37	13.4
Internet	25	9.0
Other	3	1.1
Total	277	100

Note: Select all that apply

From question no. 2: Do you perceive flood risk in the following sentences?

The answers were analyzed. For each question, respondents answered as shown in Table 43. The questions that were answered correctly were sorted and shown in descending order as follows:

(1) If the amount of water in the river increases rapidly and flows strongly, it is an indication that there could be severe flooding in the village. Most of the respondents (93.1%) answered correctly while the remaining 6.9% answered incorrectly.

(2) The watershed without a dam increases its risk of flooding, and (3) floods cause a rise in contagious diseases e.g., conjunctivitis, leptospirosis, etc. Most of the respondents (87.3%) answered correctly while 12.7% answered incorrectly.

(4) Low-lying areas are at risk of flooding every year. Most of the respondents (86.3%) answered correctly while 13.7% answered incorrectly.

(5) If it continually rains for several hours in the village, it might cause a flood. Most of the respondents (82.4%) answered correctly while 17.6% answered incorrectly.

(6) The area where rivers flow through is at risk of flooding easily. Most of the respondents (81.4%) answered correctly while 18.6% answered incorrectly.

(7) Planting trees to increase forest cover can reduce the risk of flooding. Most of the respondents (62.7%) answered correctly while 37.3% answered incorrectly.

(8) Flooding affects the quality of water used for consumption. Most of the respondents (51.0%) answered incorrectly while 49.0% answered correctly.

(9) Building/expanding roads in the village is likely not a contributor to flooding. Most of the respondents (60.8%) answered incorrectly while 39.2% answered correctly.

(10) Water network systems for water management may not reduce the risk of flooding in villages. Most of the respondents (64.7%) answered incorrectly while 35.3% answered correctly.

Table 43 Respondents perception of flood risk

Flood risk perception	Answer correctly		Answer incorrectly	
	Frequency (persons)	Percentage (%)	Frequency (persons)	Percentage (%)
1) Low-lying areas are at risk of flooding every year.	88	86.3	14	13.7
2) The area where rivers flow through is at risk of flooding easily.	83	81.4	19	18.6
3) The watershed without a dam increases its risk of flooding.	89	87.3	13	12.7
4) Planting trees to increase forest cover can reduce the risk of flooding.	64	62.7	38	37.3
5) Building/expanding roads in the village is likely not a contributor to flooding.	40	39.2	62	60.8
6) If it continually rains for several hours in the village, it might cause a flood.	84	82.4	18	17.6
7) If the amount of water in the river increases rapidly and flows strongly, it is an indication that there could be severe flooding in the village.	95	93.1	7	6.9
8) Water network systems for water management may not reduce the risk of flooding in villages.	36	35.3	66	64.7
9) Flooding affects the quality of water used for consumption.	50	49.0	52	51.0
10) Floods cause a rise in contagious diseases e.g., conjunctivitis, leptospirosis,etc.	89	87.3	13	12.7

The overall level of flood risk perception is shown in Table 44. The results showed that 55.9% of respondents were at a high level, 26.5% were at a moderate level, 12.7% were at a very high level, 4.9% were at a low level, and none of the respondents was at a very low level.

Table 44 Overall level of flood risk perception

Flood risk perception level	Frequency (persons)	Percentage (%)
Very low (score of 0 - 2)	0	0.0
Low (score of 3 - 4)	5	4.9
Moderate (score of 5 - 6)	27	26.5
High (score of 7 - 8)	57	55.9
Very high (score of 9 - 10)	13	12.7
Total	102	100

Part 4: Effect of the Bang Rakam Model 60 project

Table 45 depicts the overall effect of the Bang Rakam Model 60 project. The effect was at a moderate level with a mean ($\bar{X}$) of 2.80 and a standard deviation (S.D.) of 0.62. From each question, the Bang Rakam Model 60 project effect was at a moderate level while those of questions no. 6 and 11 were at a low level. The highest mean was 3.36 (questions no. 2) and the lowest mean was 2.43 (questions no. 6).

Table 45 Level of the Bang Rakam Model 60 project effect on the respondents

Questions	Level of effect (frequency and percent)					$\bar{X}$	S.D.	Interpretation
	Very low	Low	Moderate	High	Very high			
1) Is the irrigation water enough for cultivation?	6 (5.9%)	28 (27.5%)	36 (35.3%)	27 (26.5%)	5 (4.9%)	2.97	0.99	Moderate
2) Can you harvest the product before the flood season?	-	9 (8.8%)	51 (50.0%)	38 (37.3%)	4 (3.9%)	3.36	0.70	Moderate
3) Has the quantity of products obtained increased compared to the periods without Bang Rakam Model 60 project?	5 (4.9%)	31 (30.4%)	45 (44.1%)	16 (15.7%)	5 (4.9%)	2.85	0.92	Moderate
4) Is the quality of products obtained better compared to that before the Bang Rakam Model 60 project?	7 (6.9%)	26 (25.5%)	43 (42.2%)	23 (22.5%)	3 (2.9%)	2.89	0.93	Moderate
5) After the commencement of the Bang Rakam Model 60 project, do the previously inundated areas still experience flooding?	13 (12.7%)	34 (33.3%)	28 (27.5%)	22 (21.6%)	5 (4.9%)	2.73	1.09	Moderate
6) Are you encouraged to earn extra income during the flood season (Aug-Nov) through fishing, fish sauce making, etc?	20 (19.6%)	37 (36.3%)	29 (28.4%)	13 (12.7%)	3 (2.9%)	2.43	1.04	Low

Table 45 (Cont.)

Questions	Level of effect (frequency and percent)					$\bar{X}$	S.D.	Interpretation
	Very low	Low	Mode-rate	High	Very high			
7) Is your understanding of Public relations, building perception, and the Bang Rakam Model 60 project thorough?	17 (16.7%)	18 (17.6%)	23 (22.5%)	37 (36.3%)	7 (6.9%)	2.99	1.22	Moderate
8) Is the compensation for damages and allowance sufficient for you?	11 (10.8%)	35 (34.3%)	39 (38.2%)	17 (16.7%)	-	2.61	0.89	Moderate
9) Is there sufficient support for sandbags, water blocking equipment, etc. to you?	24 (23.5%)	24 (23.5%)	23 (22.5%)	26 (25.5%)	5 (4.9%)	2.65	1.23	Moderate
10) Are there are improvements in bridges, roads, and paths that were damaged by the flood?	9 (8.8%)	28 (27.5%)	41 (40.2%)	19 (18.6%)	5 (4.9%)	2.83	0.10	Moderate
11) Are there mobile health units and medical personnel to treat the various diseases caused by the flood?	21 (20.6%)	27 (26.5%)	31 (30.4%)	18 (17.6%)	5 (4.9%)	2.60	1.15	Low
12) Do authorities visit, assess the damage, and give encouragement?	18 (17.6%)	27 (26.5%)	33 (32.4%)	17 (16.7%)	7 (6.9%)	2.69	1.15	Moderate
Overall of the Bang Rakam Model 60 project effect						2.80	0.62	Moderate

Part 5: Comments and suggestions

The comments and suggestions from the respondents were summarized as follows;

According to some respondents, compensation for damages and allowance were not sufficient. Some of the respondents liked the Bang Rakam Model 60 project because they get enough water for cultivation which increased their yield. However, some of the respondents do not like the Bang Rakam Model 60 project because the amount of water they received was dependent on the RID supply.

4.6.2 Analysis of farmers' perception of flood risk with the flood risk map

In this section, the maps shown in Figure 24 were classified with mean values in the GIS software. The mean of the flood risk level at each sub-district for Figure 24(a) was obtained from section 4.5 while Figure 24(b) used the mean of the flood risk perception level at each sub-district obtained in section 4.6.1 (part 3). Both maps used clip tools at the village level in GIS software. It was observed that flood risk consists of low, moderate, and high levels, likewise did flood risk perception consists of moderate, high, and very high levels.

Flood risk at high levels was found in six sub-districts namely, Matong, Nong Khaem, and Phrom Phiram of Phrom Phiram district, Ban Mai Suk Kasem (Kong Krailat district), and Chum Saeng Songkhram and Bang Rakam of Bang Rakam district. Low levels were found in four sub-districts namely, Thap Yai Chiang (Phrom Phiram district), Wat Bot (Wat Bot district), and Krai Klang and Krai Nok of Kong Krailat district. The other ten sub-districts were at a moderate risk level.

Most of the flood risk perceptions were at high levels. There were two sub-districts that farmers had flood risk perception at a very high level. This consists of Matong and Wang Won in Phrom Phiram district. Moderate levels were noticed in Ho Klong (Phrom Phiram district), Krai Nai and Krai Nok of Kong Krailat district, Phai Kho Don (Mueang Phitsanulok district), and Chum Saeng Songkhram (Bang Rakam district).

Analyzing the farmers' perception of flood risk with the flood risk map obtained, it was revealed that farmers in high-risk level areas mostly have high-level flood risk perceptions. Wang Won sub-district was at a moderate risk level and farmers there had flood risk perceptions at a very high level. Similarly, Matong sub-district was at the high-risk level and farmers there had flood risk perceptions at a very high level. On the other hand, Thap Yai Chiang and Wat Bot sub-districts were at a low-risk level but farmers there had high-level flood risk perceptions.

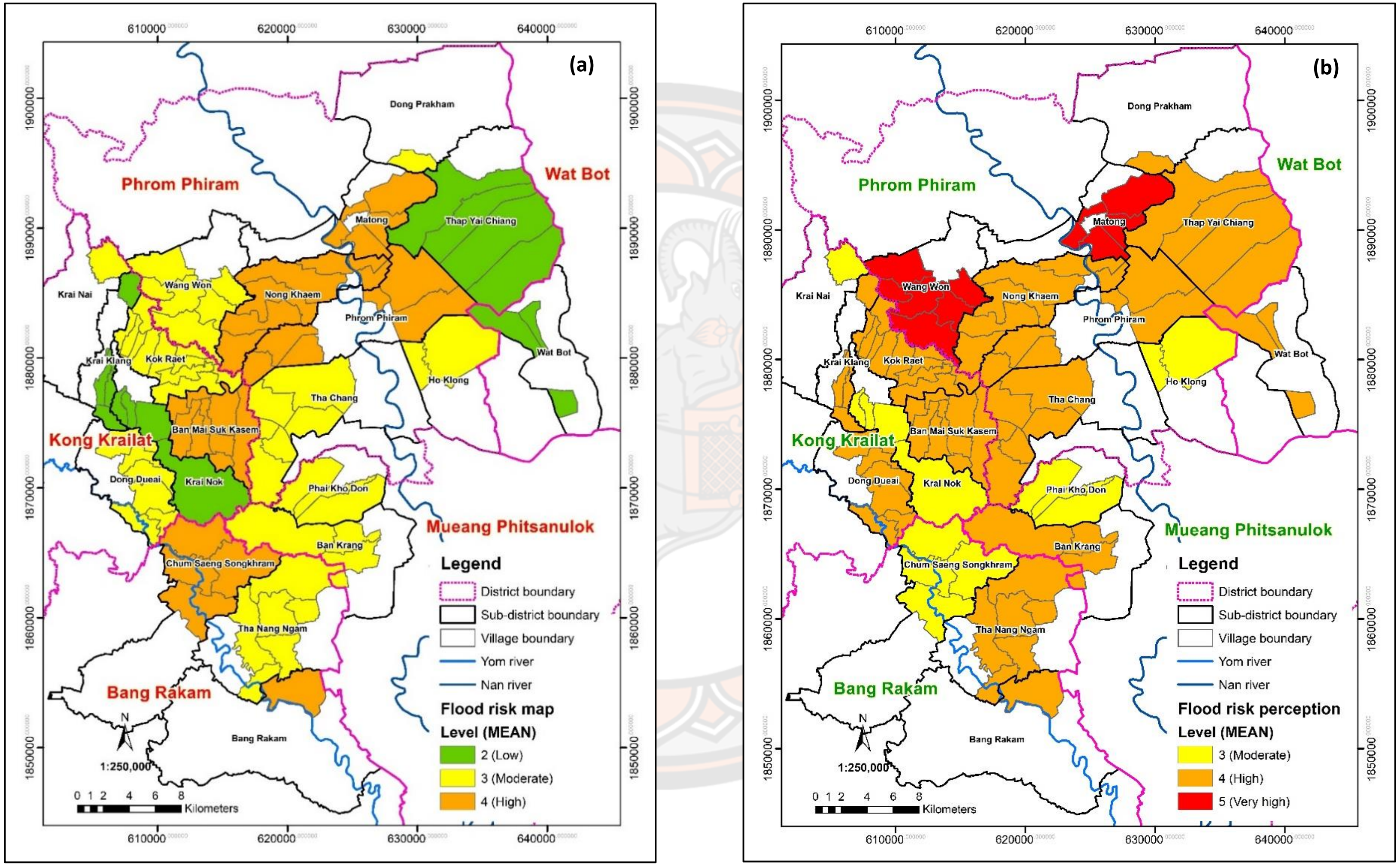


Figure 24 Levels map: (a) flood risk and (b) flood risk perception of farmers

CHAPTER V DISCUSSION AND CONCLUSION

This chapter is given under three topics; discussion, conclusion, and recommendations.

5.1 Discussion

In the conduct of spatial modeling and analysis on flood risk assessment using fuzzy analytic hierarchy process: a case study of Bang Rakam Model in Thailand. Eight factors were considered for the flood hazard map whereas five factors were considered for the flood vulnerability map. The fuzzy AHP approach was used to prioritize factors influencing flood hazard and flood vulnerability with the reference to the weights obtained. The potential flood hazard, flood vulnerability, and flood risk (combination of flood hazard and flood vulnerability), as well as farmers' perception of flood risk, are the outcomes.

One of the most widely used multi-criteria decision analysis (MCDM) is the AHP that is the best way to decide the structure of complicated criteria at various levels (Kabir & Hasin, 2011). However, several researchers have criticized the conventional AHP approach for failing to deal with the uncertain nature of the problems precisely (Vahidnia, Alesheikh, & Alimohammadi, 2009; Yang, Ding, & Hou, 2013). The fuzzy AHP is be considered as a more advanced method of analysis derived from the traditional AHP. It is capable to reflect human thinking by using uncertainty and approximate information to make decisions (Kahraman, Cebeci, & Ruan, 2004) and these features qualify a fuzzy AHP as a proper and effective method for assisting with complicated environmental management decisions (Vahidnia et al., 2009). The criterion or factor weights largely influence and determine the outcome of the final maps. As a result, the combination of fuzzy AHP with GIS gave the analysis ability to determine factor weights and played a crucial part in the prioritization of the factors influencing flood hazard and flood vulnerability. In the study, the eight factors selected for the flood hazard consisted of distance from drainage network, drainage density, elevation, flow accumulation, land use, slope, soil water infiltration, and average annual rainfall (Kazakis et al., 2015; Liu et al., 2015; Lyu et al., 2016; Mahmoud & Gan, 2018a, 2018b). Based on earlier studies (Behanzin et al., 2016; Müller et al., 2011), five flood vulnerability factors namely, age group, dependency ratio, gender ratio, population density, and road density were considered. The fuzzy AHP was used to obtain the preference weights for each factor based on the expert’s opinion. It is noted that, based on the expert’s evaluation of flood hazard, they considered and gave different ratings of drainage density factor. Therefore, the experts were categorized into two groups depending on pair-wise comparison answers of drainage density factor from questionnaires, the first expert group (No. 1, 2, 7, and 8) and the second expert group (No. 3, 4, 5, and 6). The result showed that the average annual rainfall factor was the most important factor influencing flood hazards. Likewise, rainfall is identified as the most influential hazard factor in the analysis of flooding (Lyu et al., 2016; Mohamed & El-Raey, 2019). Factors influencing flood vulnerability revealed that population density and road density were the most important factors. It can be concluded that factor weights and ratings obtained in fuzzy AHP analysis are determined at the discretion of experts, hence the methodology has strongly relied on expert discretion (Ekmekcioğlu et al., 2020).

The shape factor was used to validate hazard maps in this study and the result showed that the flood hazard map of the first expert group can use for generating the flood risk map. The study revealed that the average annual rainfall factor is the key factor to flooding of Bang Rakam Model 60 areas. It showed that areas with higher rainfall are more likely to be flooded. The areas located close to the high cumulative flow of concentrated flow and drainage density have the potential to generate more surface runoff and post higher flood threat. The study found that Phrom Phiram, Mueang Phitsanulok, and Bang Rakam districts in the Phitsanulok province had very high flood hazards. Causes of flood include many factors such as hydrological events e.g. south-west monsoons, intertropical convergence zones, tropical storms, and depressions, etc. (WMO, 2017). However, the causes of floods in both areas are different. The cause of flood over Phrom Phiram district is overflow from the riverbank whereas, for Bang Rakam district flood occurrence depends on low drainage flow to downstream. Vulnerability is a condition or factor that makes society or communities unable to protect themselves, incapable of handling disaster situations or recovering from hazard effects in performance and timely manner (DDPM, 2015). From the results, it is shown that locations with higher population density have the highest vulnerability. The road is a man-made barrier to prevent flooding, hence the higher the density of roads in a given area, the lower the vulnerability of flooding. The very high levels of flood vulnerability from the obtained vulnerability map include the Kong Krailat district (Sukhothai province), and Phrom Phiram, Mueang Phitsanulok, and Bang Rakam districts in Phitsanulok province. Among these very high vulnerability level areas, the Kong Krailat district was the most vulnerable.

Flood risk assessment is a function that deals with a variety of hazard and vulnerability factors (Ali et al., 2016; Ekmekcioğlu et al., 2020; Nasiri et al., 2016). Over the last two decades, advances in the field of GIS have significantly aided flood mapping and flood risk (Rani et al., 2018). A flood risk assessment method based on GIS is developed (Khan et al., 2015). Moreover, several researchers have also endeavored to combine the fuzzy AHP methods with GIS to generate flood risk maps (Ekmekcioğlu et al., 2020; Meshram, Alvandi, Singh, & Meshram, 2019; Papaioannou et al., 2014; Wang et al., 2011). The flood risk map was created from a flood hazard map and the flood vulnerability map by multiplying in the GIS software. The very high-risk level was mostly at areas along the river and the border between Kong Krailat and Phrom Phiram districts. Four districts had all the levels of flood risk. This included Kong Krailat, Phrom Phiram, Mueang Phitsanulok, and Bang Rakam. The results also revealed that the high-risk areas should be of utmost priority to flood management. This is necessary to increase the retarding water capacity during the flood crisis at the Yom River and to relieve the impact of floods that would have occurred in the community and official place (RID, 2018).

Assessment of farmers' perceptions of flood risk is very important because of its significance in paying attention to the farmers' decision-making process when confronted with uncertain situations (Flaten et al., 2005). In the study, analyzing the farmers' perception of flood risk with the flood risk map obtained revealed that farmers in high-risk level areas mostly have high-level flood risk perceptions. On the other hand, though some sub-districts were at a low-risk level, farmers there had a high level of flood risk perceptions. The farmer probably had learned and increased their awareness through the community participation process of Bang Rakam Model 60. Farmers' risk perceptions show many important findings along with frequent discrepancies between genuine and perceived risk (Botterill & Mazur, 2004). Flood risk perception of farmers depends on the awareness of their surroundings that requires intellect, observing, attention and intention, and quality of mind at that time, as well as previous knowledge or previous experience.

5.2 Conclusion

This thesis aimed to prioritize factors influencing flood hazard and flood vulnerability as well as to assess flood risk with flood hazard and flood vulnerability. An analysis of farmer's perception of flood risk was also done. The study covered areas of the Bang Rakam Model 60 project (2 provinces, 5 districts, 20 sub-districts, 93 villages). The fuzzy AHP based on Chang's extent analysis was utilized to form the pair-wise comparisons used to obtain the preference weights of the decisive answers from the experts through questionnaires. GIS was used to create a flood hazard map, flood vulnerability map, and to generate a flood risk map, and were classified into five categories ranging from very low, low, moderate, high, and very high. Base on the study objectives, the following conclusions are drawn:

5.1.1 To prioritize factors influencing flood hazard and flood vulnerability using fuzzy AHP

Prioritization of the eight factors influencing flood hazard found that average annual rainfall (0.1879) was the most important factor, and was followed by flow accumulation (0.1667), drainage density (0.1611), elevation (0.1423), slope (0.1206), soil water infiltration (0.0988), distance from drainage network (0.0632), and land use (0.0594). Five factors of age group, dependency ratio, gender ratio, population density, and road density were used to prioritize factors influencing flood vulnerability, the results revealed that population density and road density were the most important as they obtained the same fuzzy weights of 0.3107. They were followed by age group (0.1322), dependency ratio (0.1252), and gender ratio (0.1212), respectively.

5.1.2 To create a flood hazard map and flood vulnerability map by applying fuzzy AHP and GIS

Flood maps were created using rating and fuzzy weights. The flood hazard map showed very high levels at Phrom Phiram, Mueang Phitsanulok, and Bang Rakam districts in Phitsanulok province. However, most areas on the map (211.94 km^2 or

30.47% of the total area) were at a moderate level, while very fewer areas of 57.81 km^2 or 8.31% of the total area were at a very high level. The flood vulnerability map indicated that most flood vulnerable levels were at moderate and high levels. Very high levels were found at Kong Krailat district in Sukhothai province, and Phrom Phiram, Mueang Phitsanulok, and Bang Rakam districts in Phitsanulok province. The most vulnerable district was Kong Krailat. The results showed that most of the flood vulnerable areas (314.56 km^2 or 45.13% of the entire area) were at a high level and the least area of 38.52 km^2 (5.53%) was at a very high level of vulnerability.

5.1.3 To generate a flood risk map from the flood hazard map and flood vulnerability map for flood risk assessment

Kong Krailat district in Sukhothai province, and Phrom Phiram, Mueang Phitsanulok, and Bang Rakam districts in Phitsanulok province had all the levels of flood risk. Out of the 695.55 km^2 total flood risk area, the results revealed that most parts of the area of 225.67 km^2 or 32.44% were at the moderate level. The smallest portion of the area of 100.11 km^2 (14.39%) was at a low level. The very high-risk levels were mostly at areas along the river and the border between Kong Krailat district in Sukhothai province and Phrom Phiram district in Phitsanulok province. At the sub-district level, the map identified very high flood risk areas at Kok Raet, Dong Dueai, and Ban Mai Suk Kasem sub-districts in Kong Krailat district. In the Phitsanulok province, very high flood risk areas were identified at Phrom Phiram, Mueang Phitsanulok, and Bang Rakam districts. The Phrom Phiram district consists of Tha Chang, Wang Won, Nong Khaem, Phrom Phiram, Matong, Thap Yai Chiang, and Ho Klong sub-districts. The Mueang Phitsanulok district consists of Ban Krang and Phai Kho Don sub-districts. Also, the Bang Rakam district consists of Chum Saeng Songkhram, Tha Nang Ngam, and Bang Rakam sub-districts.

5.1.4 To analyze the farmer’s perception of flood risk with the obtained flood risk map

Data were collected by questionnaire survey with 102 sampled people in the Phitsanulok and Sukhothai provinces at the Bang Rakam Model 60 project. The respondents were composed of 77 heads of households and 25 household members. Most of the respondents were males, at age 51 years and older with senior high school education. The number of members per household was 3 - 4 persons, and the average gross monthly income was 5,001 - 10,000 baht. The average number of respondents have lived at the project site for 42 years. During the flood, most of the respondents were with their spouse or partner. A majority of the respondents had experienced a flood at the farm with a flood depth over 50 cm but experienced no significant flood at their primary residence. The flood mostly impacted the respondents' livelihood through loss of income and crops but in 2019, no cumulative loss due to flooding was experienced. The commonest source of flood information to the respondents was through radio/television. The overall level of the respondent's perception of flood risk was at a high level, and none of the respondent's perceptions was at the very low level. Generally, the Bang Rakam Model 60 project effect was at a moderate level, which indicated that the project had both advantages and disadvantages according to the farmer's perception. Analyzing the farmers' perception of flood risk with the flood risk map obtained, it was revealed that districts that had moderate and high flood risk levels corresponding had farmers whose perceptions of flood risk were at a very high level. Conversely, districts at low flood risk levels had farmers with high-level flood risk perceptions.

Therefore, it is concluded that the GIS-MCDM model created using fuzzy AHP can serve as the basis for government and relevant agencies to assess the best approach to solve flood problems. Mapping of flood hazard, flood vulnerability, and flood risk are important in the planning of water and budget allocation at the Bang Rakam Model 60 project. The maps are easy to read and make it easier to define risk areas and to prioritize prevention or response efforts. Thus, flood maps can be used to assess the danger floods pose to people. This will contribute to decision-making on strategies, operations, and investments for managing risk. The study also revealed the farmer's perceptions of flood risk, this will help RID to supply a sufficient amount of water to support farming. It will also save the government budget used to support agricultural disaster victims and prevent floods that will damage agricultural areas.

5.3 Recommendations

The following are relevant recommendations to be considered in future studies:

1) The successful application of the fuzzy AHP must be based on identifying comprehensive criteria and experts on the subject and correctly prioritize and rank the criteria without subjective bias.

2) Finding relevant experts is difficult due to the limited number of experts and time constraints. Experts lack the willingness to participate in academic research, therefore, new researchers should explore effective methods and alternatives to attract relevant experts.

3) Digital Elevation Model (DEM) with excellent resolution and accuracy should be used in the study as it shows higher accuracy results.

4) This study did not analyze the physical factors that affect the choice of irrigation technologies such as return period, water depth, etc. If these are analyzed it can provide a better understanding of the causes and the amount of flood for each year.

5) A comparison with other advanced multi-criteria decision analyses (MCDM) is needed to find a suitable and reliable method for various modeling.

6) The advantages and capability of the fuzzy AHP combined with GIS, can be explored in other disaster studies such as drought, landslide, wildfire, etc.

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APPENDIXS

APPENDIX A Questionnaires for pair-wise comparison (Hazard)

Date: …..…./…..…./……..   Questionnaire no. ☐☐

Questionnaires for pair-wise comparison

Objective: To prioritize factors influencing flood hazard using fuzzy AHP

This questionnaire was prepared to collect data for my thesis as a requirement for the Master of Science degree in Disaster Management, Naresuan University. The data and results from this questionnaire will be used for educational purposes only.

Explanation This questionnaire is divided into four parts as follows:

Part 1: General information (Expert)
Part 2: Description of the importance of evaluation
Part 3: Pair-wise comparison and evaluation for each factor
Part 4: Consideration of the class and rating for each factor

Please answer all questions by marking check (✓) into the box (☐) or by adding text to the blank that matches your response the most.

Part 1: General information (Expert)

Name Title: ☐ Mr. ☐ Mrs. ☐ Ms. ☐ Dr.
☐ Assistant Professor ☐ Associate Professor ☐ Professor
☐ Other (specify) ……………………………………………..…………...

Name: .... Age: .... (years)

Workplace: ....

Position: ……………………...............Work experience: ……………..... (No. of years)

E-mail: ………………………………………… Phone number: ………..………........

Part 2: Description of the importance of evaluation

Example

Expert evaluates the importance of the factors by comparing with each other in each row of the table as follows:

- If you consider that the **left-hand factor** is more important than the **right-hand factor**, please mark ✓ on the left-hand side according to the level of importance.

- If you consider that the **right-hand factor** is more important than the **left-hand factor**, please mark ✓ on the right-hand according to the level of importance.

Factors (Criteria1)	**Importance level**									**Factors (Criteria2)**
	← Left								Right →	
	Extremely more important =9	Very strongly more important =7	Strongly more important =5	Moderately more important =3	Equally important =1	Moderately more important =3	Strongly more important =5	Very strongly more important =7	Extremely more important =9	
A		✓								B
A							✓			C
B				✓						C

Meaning

1) Expert considers that **A** is very strongly more important than **B**

2) Expert considers that **C** is strongly more important than **A**

3) Expert considers that **B** is moderately more important than **C**

Part 3: Pair-wise comparison and evaluation for each factor

Question What factors do you think influence flood hazard, comparing one factor to another in the rows? Please mark ✓ in the blanks according to the level of importance.

Factors (Criteria 1)	**Importance level** Left ←								→ Right	**Factors (Criteria 2)**
	Extremely more important =9	Very strongly more important =7	Strongly more important =5	Moderately more important =3	Equally important =1	Moderately more important =3	Strongly more important =5	Very strongly more important =7	Extremely more important =9	
Distance from drainage network (m)										Drainage density (km/km^2)
										Elevation (m)
										Flow accumulation (pixels)
										Land use
										Slope (%)
										Soil water infiltration
										Average annual rainfall (mm)
Drainage density (km/km^2)										Elevation (m)
										Flow accumulation (pixels)
										Land use
										Slope (%)
										Soil water infiltration
										Average annual rainfall (mm)
Elevation (m)										Flow accumulation (pixels)
										Land use
										Slope (%)
										Soil water infiltration
										Average annual rainfall (mm)

Factors (Criteria 1)	Importance level Left ←							→ Right		Factors (Criteria 2)
	Extremely more important =9	Very strongly more important =7	Strongly more important =5	Moderately more important =3	Equally important =1	Moderately more important =3	Strongly more important =5	Very strongly more important =7	Extremely more important =9	
Flow accumulation (pixels)										Land use
										Slope (%)
										Soil water infiltration
										Average annual rainfall (mm)
Land use										Slope (%)
										Soil water infiltration
										Average annual rainfall (mm)
Slope (%)										Soil water infiltration
										Average annual rainfall (mm)
Soil water infiltration										Average annual rainfall (mm)

Part 4: Consideration of the class and rating for each factor

Table 1 Sensible level

Number	Sensible level
1	Very low
2	Low
3	Moderate
4	High
5	Very high

Consider the class and give the appropriate rating base on the class for each factor influencing flood hazard by using a number to represent the sensible level as shown in Table 1 (You can use the same number).

Factors	**Classes**	**Rating**
1. Distance from drainage network (m)	200	
	500	
	1,000	
	2,000	
	> 2,000	
2. Drainage density (km/km^2)	0 - 6.26	
	6.26 - 17.20	
	17.20 - 29.09	
	29.09 - 45.35	
	45.35 - 79.45	
3. Elevation (m)	22 - 44	
	44 - 55	
	55 - 94	
	94 - 156	
	156 - 240	
4. Flow accumulation (pixels)	0 - 5,874	
	5,874 - 26,014	
	26,014 - 56,224	
	56,224 – 82,238	
	82,238 – 213,987	
5. Land use	Agricultural land	
	Forest land	
	Miscellaneous land	
	Urban and built-up land	
	Water body	
6. Slope (%)	0 - 3	
	3 - 5	
	5 - 12	
	12 - 28	
	28 - 70	
7. Soil water infiltration	High	
	Slightly high	
	Moderate	
	Slightly low	
	Low	
	Other	
8. Average annual rainfall (mm)	997 - 1,054	
	1,054 - 1,100	
	1,100 - 1,157	
	1,157 - 1,215	
	1,215 - 1,275	

APPENDIX B Questionnaires for pair-wise comparison (Vulnerability)

Date: …..…./…..…./……..   Questionnaire no. ☐☐

Questionnaires for pair-wise comparison

Objective: To prioritize factors influencing flood vulnerability using fuzzy AHP

This questionnaire was prepared to collect data for my thesis as a requirement for the Master of Science degree in Disaster Management, Naresuan University. The data and results from this questionnaire will be used for educational purposes only.

Explanation This questionnaire is divided into four parts as follows:

Part 1: General information (Expert)
Part 2: Description of the importance of evaluation
Part 3: Pair-wise comparison and evaluation for each factor
Part 4: Consideration of the class and rating for each factor

Please answer all questions by marking check (✓) into the box (☐) or by adding text to the blank that matches your response the most.

Part 1: General information (Expert)

Name title ☐ Mr. ☐ Mrs. ☐ Ms. ☐ Dr.
☐ Assistant Professor ☐ Associate Professor ☐ Professor
☐ Other (specify) ………………..…………………………………...

Name: ……………………………………………………………… Age: .... (years)

Workplace: …………………………………………………………………………….................

Position: ……………………………….........Work experience: ……………..... (No. of years)

E-mail: ……………………….....…………… Phone number: ……………..…...........

Part 2: Description of the importance of evaluation

<u>Example</u>

Expert evaluates the importance of the factors by comparing them with each other in each row of the table as follows:

- If you consider that the **left-hand factor** is <u>more important than</u> the **right-hand factor**, please mark ✓ on the left-hand side importance level according to the level of importance.

- If you consider that the **right-hand factor** is <u>more important than</u> the **left-hand factor**, please mark ✓ on the right-hand side importance level according to the level of importance.

Factors (Criteria1)	Left				**Importance level**				Right	**Factors (Criteria2)**
	Extremely more important =9	Very strongly more important =7	Strongly more important =5	Moderately more important =3	Equally important =1	Moderately more important =3	Strongly more important =5	Very strongly more important =7	Extremely more important =9	
A		✓								B
A							✓			C
B				✓						C

<u>Meaning</u>

1) Expert considers that **A** is very strongly more important than **B**

2) Expert considers that **C** is strongly more important than **A**

3) Expert considers that **B** is moderately more important than

Part 3: Pair-wise comparison and evaluation for each factor

Question What factors do you think influence flood vulnerability, comparing one factor to another in the rows? Please mark ✓ in the blanks according to the level of importance.

Factors (Criteria 1)	**Importance level** Left ←							→ Right		**Factors (Criteria 2)**
	Extremely more important =9	Very strongly more important =7	Strongly more important =5	Moderately more important =3	Equally important =1	Moderately more important =3	Strongly more important =5	Very strongly more important =7	Extremely more important =9	
Age group (%)										Dependency ratio
										Gender ratio
										Population density (persons/km^2)
										Road density (km/km^2)
Dependency ratio										Gender ratio
										Population density (persons/km^2)
										Road density (km/km^2)
Gender ratio										Population density (persons/km^2)
										Road density (km/km^2)
Population density (persons/km^2)										Road density (km/km^2)

Part 4: Consideration of the class and rating for each factor

Table 1 Sensible level

Number	Sensible level
1	Very low
2	Low
3	Moderate
4	High
5	Very high

Consider the class and give the appropriate rating base on the class for each factor influencing flood vulnerability by using a number to represent a sensible level as shown in Table 1 (Can use the same number).

Factors	Classes	Rating
1. Age group (%) $\frac{\text{Population aged }(0-14\text{ years}) + (60+\text{ years})}{\text{Total population}} \times 100$	29.01 - 30.99	
	30.99 - 34.85	
	34.85 - 37.37	
	37.37 - 41.14	
	41.14 - 51.92	
2. Dependency ratio $\frac{\text{Population aged }(0-14\text{ years}) + (60+\text{ years})}{\text{Population aged }15-59\text{ years}} \times 100$	40.87 - 44.82	
	44.82 - 53.51	
	53.51 - 59.56	
	59.56 - 69.83	
	69.83 - 108.00	
3. Gender ratio $\frac{\text{Male population}}{\text{Female population}} \times 100$	73.68 - 89.17	
	89.17 - 96.05	
	96.05 - 101.71	
	101.71 - 112.28	
	112.28 - 136.36	
4. Population density (persons/km^2)	3 - 46	
	46 - 94	
	94 - 184	
	184 - 318	
	318 - 610	
5. Road density (km/km^2)	0.48 - 4.28	
	4.28 - 6.50	
	6.50 - 8.96	
	8.96 - 12.84	
	12.84 - 20.68	

APPENDIX C Questionnaire survey

Date: …..…./…..…./……..   Questionnaire no. ☐☐☐

Questionnaire survey

Objective: To analyze the farmer's perception of flood risk with the flood risk map obtained.

Address: …………..……………………………………………………........................

Respondents: ☐ 1. Household head
☐ 2. Household member (relationship to household head: ….….…….)

Explanation This questionnaire is divided into five parts as follows:

Part 1: General information
Part 2: Flood experience
Part 3: Flood risk perception
Part 4: Effect of the Bang Rakam Model 60 project
Part 5: Comments and suggestions

Please answer all questions by marking ✓ into ☐ or adding text to the blank that matches your reality the most. Your data and results from the questionnaire will be used for educational purposes only.

Aphittha Yodying
Master of Science degree in Disaster Management
Faculty of Engineering, Naresuan University

Part 1: General information

1. Gender
☐ 1) Male ☐ 2) Female

2. Age
☐ 1) Below 20 years ☐ 2) 20 - 30 years ☐ 3) 31 - 40 years
☐ 4) 41 - 50 years ☐ 5) 51 years and older

3. Education level

☐ 1) Uneducated ☐ 2) Primary School (Grade 1-3)
☐ 3) Primary School (Grade 4-6) ☐ 4) Junior High School
☐ 5) Senior High School ☐ 6) Vocational Certificate
☐ 7) High Vocational Certificate ☐ 8) Bachelor Degrees
☐ 9) Higher than Bachelor Degrees

4. Household member

☐ 1) 1 - 2 persons ☐ 2) 3 - 4 persons
☐ 3) 5 - 6 persons ☐ 4) More than 6 persons

5. Average monthly income (Gross income)

☐ 1) Less than or equal 5,000 baht ☐ 2) 5,001 - 10,000 baht
☐ 3) 10,001 - 20,000 baht ☐ 4) Over 20,000 baht

Part 2: Flood experience

1. How long have you been living here? .... years

2. Who were you living with at the time of the flood? (Select all that apply)

☐ 1) Living alone ☐ 2) Spouse or partner
☐ 3) Children ☐ 4)Parents or father/mother only
☐ 5) Other (specify): ....

3. What type of flooding have you experienced? (Select all that apply)

☐ 1) Flooding on road for a long time (1 week or longer)
☐ 2) Farm was flooded
☐ 3) Primary residence was flooded
☐ 4) Some parts of the primary residence were flooded (e.g., open space, parking lot)
☐ 5) Other (specify): ....

4. What was the water depth at your primary residence?

☐ 1) No significant flood at the primary residence
☐ 2) 1 - 50 cm. ☐ 3) Over 50 cm.

5. What was the water depth at your farm?

☐ 1) No significant flood to farm
☐ 2) 1 - 50 cm. ☐ 3) Over 50 cm.

6. How have you been affected by the flood in this location? (Select all that apply)

☐ 1) Monetary loss due to repair of flood damages
☐ 2) Monetary loss due to lost valuables or equipment
☐ 3) Time took off work to clean up
☐ 4) Partial loss of access to the property (e.g., public health center, hospital)
☐ 5) It affected the physical health of someone in my home
☐ 6) Lost income
☐ 7) Loss of crops

☐ 8) No significant effect

☐ 9) Other (specify): ....

7. Please, estimate your total cumulative loss in baht. If you suffered a monetary loss due to flooding in the last year (2019) such as damage to a primary residence, farm, crops, income, etc.

☐ 1) Zero, I had no monetary loss from flooding over the last year

☐ 2) Less than or equal 5,000 baht

☐ 3) 5,001 - 20,000 baht

☐ 4) 20,001 - 50,000 baht

☐ 5) 50,001 - 100,000 baht

☐ 6) Over 100,000 baht

☐ 7) I don’t know

☐ 8) I prefer not answering

Part 3: Flood risk perception

1. What source of flood news have you received? (Select all that apply)

☐ 1) Radio/Television

☐ 2) Newspaper/Posters

☐ 3) Document/Brochures

☐ 4) Village broadcasting

☐ 5) Village headman/Village committee

☐ 6) Household members/Neighbors

☐ 7) Internet

☐ 8) Other (specify): ....

2. Do you perceive flood risk in the following sentences? Please answer all questions by marking ✓ that matches your reality the most.

No.	Sentences	Yes/Correct	No/Wrong
1	Low-lying areas are at risk of flooding every year.		
2	The area where rivers flow through is at risk of flooding easily.		
3	The watershed without a dam increases its risk of flooding.		
4	Planting trees to increase forest cover can reduce the risk of flooding.		
5	Building/expanding roads in the village is likely not a contributor to flooding.		
6	If it continually rains for several hours in the village, it might cause a flood.		
7	If the amount of water in the river increases rapidly and flows strongly, it is an indication that there could be severe flooding in the village.		
8	Water network systems for water management may not reduce the risk of flooding in villages.		
9	Flooding affects the quality of water used for consumption.		
10	Floods cause a rise in contagious diseases e.g., conjunctivitis, leptospirosis, etc.		

Part 4: Effect of the Bang Rakam Model 60 project

What is the level of effect that Bang Rakam Model 60 project has brought you? Please answer all questions by marking ✓ that matches your reality the most.

No.	Questions	Level effect				
		Very high	High	Moderate	Low	Very low
1	Is the irrigation water enough for cultivation?					
2	Can you harvest the product before the flood season?					
3	Has the quantity of products obtained increased compared to the periods without Bang Rakam Model 60 project?					
4	Is the quality of products obtained better compared to that before the Bang Rakam Model 60 project?					
5	After the commencement of the Bang Rakam Model 60 project, do the previously inundated areas still experience flooding?					
6	Are you encouraged to earn extra income during the flood season (Aug-Nov) through fishing, fish sauce making, etc?					
7	Is your understanding of Public relations, building perception, and the Bang Rakam Model 60 project thorough?					
8	Is the compensation for damages and allowance sufficient for you?					
9	Is there sufficient support for sandbags, water blocking equipment, etc. to you?					
10	Are there are improvements in bridges, roads, and paths that were damaged by the flood?					
11	Are there mobile health units and medical personnel to treat the various diseases caused by the flood?					
12	Do authorities visit, assess the damage, and give encouragement?					

Part 5: Comments and suggestions

…………………………………………………………………………................................

....

...................................…………………......………………………………………………

Thank you very much for taking the time to cooperate in answering the questionnaire

(Aphittha Yodying)

BIOGRAPHY

Name-Surname	Aphittha Yodying
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Publication	Yodying, A., Seejata, K., Chatsudarat, S., Chidburee, P., Mahavik, N., Kongmuang, C., & Tantanee, S. (2019). Flood hazard assessment using Fuzzy Analytic Hierarchy Process: a case study of Bang Rakam Model in Thailand. Paper presented at the 40th Asian Conference on Remote Sensing (ACRS 2019), Daejeon Convention Center(DCC), Daejeon, Korea.