USE OF REMOTE SENSING AND GIS FOR FLOOD HAZARD MAPPING IN CHIANG MAI PROVINCE, NORTHERN THAILAND

Minyan DUAN [a, *], Jixian ZHANG [a], Zhengjun LIU [a], Aekkapol Aekakkararungroj [b]

[a] Chinese Academy of Surveying and Mapping, Beijing 100039, China
[b] Bureau of Research Development and Hydrology, Department of Water Resources, BKK 10400, Thailand

KEY WORDS: flood disaster, hydrologic model, HEC-RAS

ABSTRACT:

Throughout the human history floods have been an integral part of the civilization. Still men have not quite coped well to live with floods. Flood hazards result from a combination of physical exposure and human vulnerability to a geophysical process. Physical exposure reflects the type of flood events that can occur and their statistical pattern at a particular site while human vulnerability reflects key socioeconomic factors such as the number of people at risk, the extent of any flood protection works and the ability of the population to anticipate and cope with the hazard. Recently, the advancement in computer-aided technology has been extensively used in formulating models used for flood calculation and hazard analysis. This study focuses on using a hydraulic model HEC-RAS in a GIS and Remote Sensing environment for the area of Ping River basin, northern Thailand, generates the inundation area and the flood depth for the year 2005 flood event in Chiang Mai province by using the 1D HEC-RAS flood model, verifies the model by comparing the model results with the remote sensing image, and prepares hazard maps using the model output and other socio-economic data.

1. INTRODUCTION

Flood disasters are among the world’s most frequent and damaging types of disaster (Parker, 2002). They have been the most common type of geophysical disasters in the late half of the twentieth century, generating an estimated more than 30 percent of all disasters between 1945 and 1986 (Glickman *et al*, 1992; Shah, 1983; Dworkin, 1976; Sheehan and Hewitt, 1973). The data produced by Glickman *et al*. (1992) indicate that globally, flood disasters are about the third most harmful form of geophysical disaster when the number of deaths concern. The majority of floods are harmful to human settlements and yearly flooding, on average, may victimize 20,000 lives and affect 75 million people (Coburn 1994). Throughout the human history floods have been an integral part of the civilization. Still men have not quite coped well to live with floods. This can be attributed to the complex nature of the flood as well as the diverse response to it. It is always hard to tell which one is the better policy and strategy, to fight floods or to learn to live with the floods. Flood hazards result from a combination of physical exposure and human vulnerability to a geophysical process. Physical exposure reflects the type of flood events that can occur and their statistical pattern at a particular site while human vulnerability reflects key socioeconomic factors such as the number of people at risk, the extent of any flood protection works and the ability of the population to anticipate and cope with the hazard (Smith and Ward, 1998).

Recently, the advancement in computer-aided technology has been extensively used in formulating models used for flood calculation and hazard analysis. This requires mainly two parts. A hydrologic model to calculate the runoff from the rainfall and a hydraulic model to determine the water surface profiles at specific locations along the stream. GIS is used to visualize the results of the flood phenomenon and do vulnerability or risk analysis and hazard assessment in a 1D, 2D, or 3D approach. Remote sensing can be used to validate the model results by comparing the flood inundation area. Remote sensing images are used as base maps for flooded areas since they can be acquired in all weather condition and at any time. This study focuses on using a hydraulic model HEC-RAS in a GIS and Remote Sensing environment for the area of Ping River basin, northern Thailand.

Seasonal flooding is a regular feature of the Monsoon climate and flood plain landscapes of Thailand. Most of the major cities in Thailand, including historical and current capitals of Kingdoms, such as Chiang Mai, Ayutthaya and Bangkok, have been built on the foundations of rice-growing civilizations in major flood plains. Communities where lives depend on a seasonal cycles of flood have learnt to live with floods and embrace its arrival with songs and dances. Institutions and cultural practices relating to the management of floods are persistent and have survived for centuries up to now.

2. HYDRAULIC MODEL

Hydraulic models are concerned with the dynamics of flow in channels and in overbank areas. They predict water levels and velocities in time and space. They use boundary conditions such as the results of hydrologic models and recorded flood data (CRC, 2006).

2.1 Types of Hydraulic Models

Hydraulic models can be divided into 1D, 2D quasi 2D or 3D based on their ability to model in 1D, 2D, or 3D space. 1D

* Corresponding author. duanmy@casm.ac.cn

model takes cross sections to describe the geometry of the channel and streamlines of flow are considered into intersect the cross sections at right angles. In reality this is not correct, as there is velocity both in parallel as well as perpendicular to the direction of the stream. 1D model can be used to represent 2D behavior by splitting up the 1D cross-section into multiple 1D cross-section. This is often described as quasi 2D modeling. 2D models are those that consider both x and y components of the velocity of flow. This is a closer approximation of the reality as compared to a1D model. 2D models are well suited where there are a broad estuaries or wide floodplains. Generally more data and more computational power is required to carry out a 2D model simulation. 3D models are those where all the three components of velocity in x, y and z directions of flow are considered. But for flood modeling, 3D modeling is not necessarily considered (USACE. 2002).

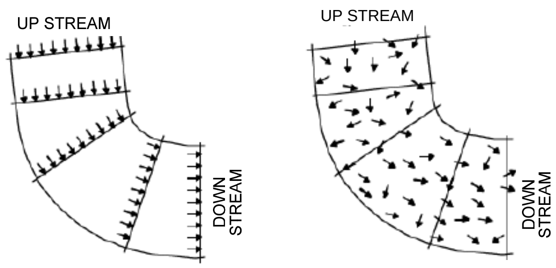


Figure 1. 1D (left) and 2D (right) representations of open channel flow

Another two different types of models are the finite difference model and finite element model. The finite difference model uses a network consisting of a regular grid of nodes to represent the catchment information and the finite element model uses a network that consists of an irregular mesh of nodes where the elements consists of triangles and quadrilaterals.

The major advantage of the finite difference method is that it is relatively simple to set up and operate. The finite element method is better able to handle complex geometries and boundaries while the finite difference method is restricted to handle rectangular shapes and simple modifications of such shapes (USACE. 2002).

2.2 Overview of HEC-RAS

The Hydrologic Engineering Centre's River Analysis System, (HEC-RAS) was developed by the U.S. Army Corps of Engineers (USACE) led by Gary W. Brunner. It was released in 1995 and it was a replacement for HEC-2 which was an earlier version and widely used since 1970. From 1995 to 2000, HEC-RAS could only be used for steady, gradually varied flow modeling. The capability of unsteady flow modeling was added in 2001. After several modifications the current version of HEC-RAS is 3.1.3 and it is available for free download from the HEC-RAS website (Review and Assessment of Hydrologic/Hydraulic Flood Models, 2006).

HEC-RAS model can perform water surface calculations for gradually varied steady flow for a river reach, a dendritic system, or a full network of channels. This steady flow component is capable of modeling subcritical, supercritical and mixed flow regime water surface profiles. The steady flow component is based on the solution of the 1D energy equations. A peak discharge is applied at each cross section to determine the maximum water surface elevation. The unsteady flow component of HEC-RAS simulates one-dimensional unsteady flow through a full network of open channels and is primarily used for subcritical flow regime calculations but may also be applied for supercritical and rapidly varied flows. The unsteady flow module has some additional capabilities like it can model storage area and hydraulic connections between storage areas. The unsteady flow analysis is performed by applying the full equations of motion (St. Venant equations) at a cross-section with upstream and downstream boundary conditions and various other parameters. Data may be directly fed to HEC-RAS or can be imported from excel spreadsheet. It has a GUI to facilitate the input and manipulation of data. This includes a steady flow editor, an unsteady flow editor and a geometric data editor including a junction editor, a cross-section editor and various structures and hydraulic features editors. ArcView GIS also has an extension called HEC-Geo RAS which is actually an interface between ArcView GIS and HEC-RAS. It is specifically designed to process geospatial data for the use with HEC-RAS. No other hydrologic or hydraulic modeling software results can be automatically input to HEC-RAS. The geometric data required to define in HEC-RAS includes:

- Cross-section data
- Reach lengths (measured between cross sections)
- Stream junction information (Reach lengths across junctions and tributary angles)

For an unsteady flow, hydraulic structures are modeled by taking into consideration the physical parameters of the structure in the appropriate standard structure format in the HEC-RAS data editor. The types of structures that can be modeled in HEC-RAS include bridges, culverts, inline and lateral weirs and gates, spillways and levees. Moreover the unsteady component can model storage areas, hydraulic connections between storage areas, hydraulic connections between stream reaches, pumping stations, flap-gated culverts. Other features include calculation of ineffective areas, floodplain encroachment analysis, channel modification analysis, scour analysis at bridges, dam breaching and levee breaking algorithm, groundwater interflow and contraction and expansion losses. Post processing capabilities include:

- Longitudinal profiles: The user can view the water surface profiles along the length of the channel for each flow profile.
- Profile Plots: The user can view the profiles of various parameters such as velocity, flow and depth against longitudinal chainage.
- Rating curves: The user may view the computed rating curves at each cross-section.
- Perspective Plot: The user may view a 3D perspective view of the river system and the water surface profiles.
- Flow and stage hydrographs: The user may visualize flow and stage hydrographs at each cross section for unsteady flow simulation.
- Output tables: Detailed and summarized output tables of various parameters may be viewed and exported.

With the help of HEC-GeoRAS, the user can export the HEC-RAS data to Arc-View for performing more calculations such as flood inundation and hazard mapping (Review and Assessment of Hydrologic/Hydraulic Flood Models, 2006).

2.3 Analytic Hierarchy Process (AHP)

The Analytical Hierarchical Process (AHP) is a multi-criteria decision making technique, which provides a systematic approach for assessing and integrating the impacts of various factors, involving several levels of dependent or independent, qualitative as well as quantitative information.

It is a methodology to systematically evaluate, often conflicting, qualitative criteria (Saaty, 1980). Like other multi-attribute decision models, AHP also attempts to resolve conflicts and analyze judgments through a process of determining the relative importance of a set of activities or criteria by pairwise comparison of these criteria on a 9-point scale. In order to do this, a complex problem is first divided into a number of simpler problems in the form of a decision hierarchy (Erkut and Moran, 1991). AHP is often used to compare the relative preferences of a small number of alternatives concerning an overall goal. AHP is becoming popular in decision-making studies where conflicting objectives are involved. Recently, Siddiqui et al., (1996) introduced a new method known as Spatial – AHP to identify and rank areas that are suitable for a landfill, using knowledge based user preferences and data contained in GIS maps.

3. STUDY AREA

3.1 Background

The Ping River Basin is one of the eight sub-basins in Chao Phraya Basin. It stretches from latitude 19.75° N to 15.75° N and from longitude 98.10° E to 100.20° E, with a catchment area of 34,453 km^2 (Figure 2). It covers about 22% of the Chao Phraya River Basin and contributes about 24% (9044×106 m^3) of the total average annual runoff. Terraced mountains mainly characterize the topography of Ping River Basin. About 55.5% of total basin area is in the elevation range of 500–1500 m.

Chiang Mai is located in the north of Thailand, about 720 kilometers from Bangkok at an elevation of 1,027 feet (310 m.) above sea level. To the North it borders Myanmar's Shan State while to the South it connects with Sam Ngao district of Tak province. Chiang Mai's geography comprises mainly groves and mountains with a broad plain in the middle of the region on both sides of Ping River. The province covers an area of 20,107.057 square kilometers (12,566,910 rai), made up of 8,787,656 rai (69.92%) of forest, 1,611,283 rai (12.82%) of agricultural land and 2,167,971 rai (17.25%) of residential and other land.

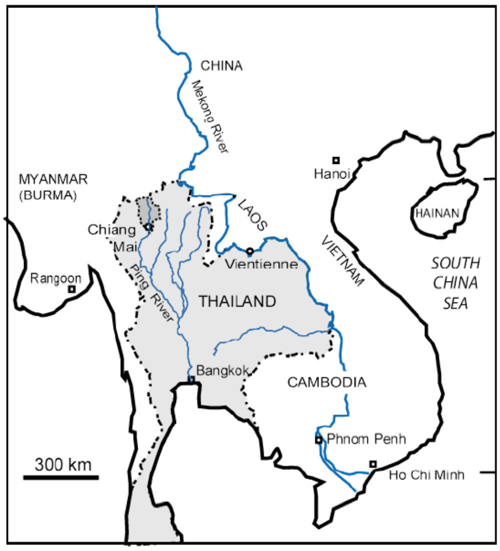


Figure 2. Location map of Ping River Basin

The weather in Chiang Mai is relatively cool all year round, with an average temperature of 25° C. Temperatures typically range between 20° C and 31° C. The relative humidity averages 72%, and annual rainfall is normally 1,000-1,200 mm.

3.2 Floods in Chiang Mai

Infrequent large floods usually occur in northern Thailand late in the May–October rainy season. Although the May–October rainfall is dominated by storms of moist air moving northeast from the Indian Ocean, large floods are typically associated with tropical 25 depressions moving westward from the South China Sea.

Date	Description
13-16 Aug.	A heavy monsoon rainstorm associated with a low-pressure trough moving westward across northern Thailand
20-22 Sept.	Tropical storm Vincente weakened to a tropical depression traveling westward across Indochina from the South China Sea
29 Sept. – 1 Oct.	Typhoon Damrey swept westward across the Indochina Peninsula as a tropical storm

Table 1. Three flood events of Chiang Mai in 2005

4. METHODOLOGY

The extent and severity of damage from flooding are usually defined by water depth. Such an inundation analysis can be carried out effectively and efficiently by using numerical modeling tools on a GIS platform. This also provides a framework for the decision-support system and facilitates evaluation of alternatives for flood management.

For this work, the HEC-RAS version 3.1 was used to calculate water surface profiles; ArcView GIS 3.3 was used for GIS data processing. The HEC-GeoRAS 3.1 for ArcView GIS was used to provide the interface between the systems. HEC-GeoRAS is an ArcView GIS extension specifically designed to process geospatial data for use with HEC-RAS. The extension allows users to create an HEC-RAS import file containing geometric attribute data from an existing geographical data and complementary data sets. GeoRAS automates the extraction of spatial parameters for HEC-RAS input, primarily the three-dimensional (3D) stream network and the 3D cross-section definition. Results exported from HEC-RAS are also processed in Geo-RAS. The ArcView 3D Analyst extension is required to use GeoRAS.

4.1 Hydrological Data Selection

The general procedure adopted for inundation modeling consists basically of four steps:

i) GeoRAS pre-processing to generate a HEC-RAS import file,

ii) Running of HEC-RAS to calculate water surface profiles,

iii) Post-processing of HEC-RAS results, and

iv) Flood hazard mapping.

Figure 3 explains these procedures in flow diagram.

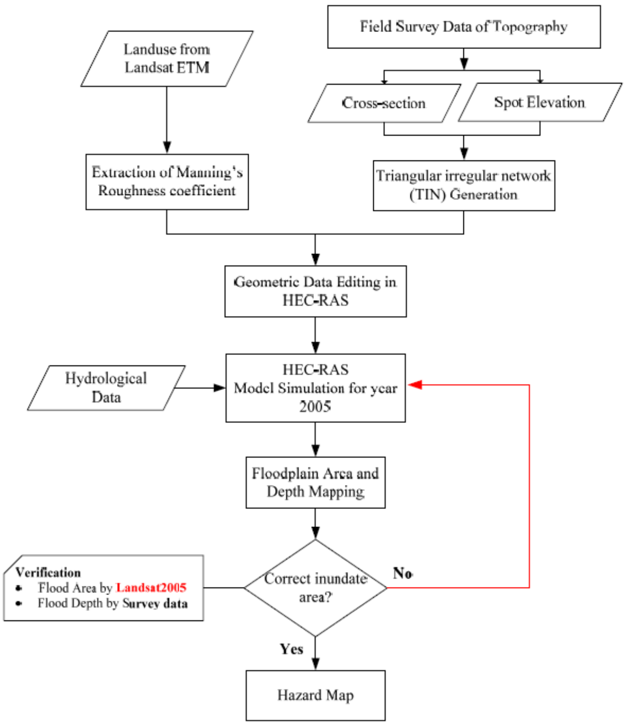


Figure 3. 1D floodplain analysis using HEC-RAS

4.2 GeoRAS Pre-processing and TIN Generation

The main purpose of this step was to generate the geometric data which was the DEM for HEC-RAS input from the existing topographic and bathymetric data. The topographic data consisted of the spot heights of the flood plain taken from the surveyed data, the WGS84 ellipsoidal heights of the flood plain, bathymetric data from Ping River and the GPS surveyed data collected along the river banks.

DEM was created form all these themes in Arc-View GIS software. A land use map of the study area was classified from the Landsat7 (ETM+) image of April 08, 2005. Manning's roughness coefficient values were derived from the land use map for each pixel based on the land use classes. Cross-sections were selected at 45 positions at the river after the river centerline and the river banks delineation were completed as part of the geometric data formulation. These cross sections included the 16 gauge stations along the river. Geometric correction in HEC-RAS incorporated checking the Manning's roughness coefficient values for each cross-section and restraining twenty values per cross section as of the model constraint and bank-line modifications.

The TIN model was generated from the spot heights acquired from different sources in ArcView GIS which included:
1) GPS surveyed data collected along the two river banks, accuracy 5 meters.
2) The spot heights of the flood plains taken from the surveyed data in 2003, accuracy 2.5 meter, (Source: Land development Department)
3) River bed cross section elevation data accuracy 15 centimeter, (Source: Department of Water Resource).

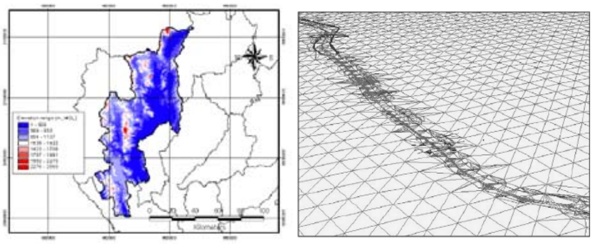


Figure 4. TIN generated from spot heights

4.3 Running GeoRAS

This step was to generate the flood depth maps for the year 2005 September. Since the lack of the instantaneous peak discharge data, the daily average data for the period of 1983 to 2004 were considered for analysis. The highest values of discharge of particular months were taken in as a representation for the month. Boundary conditions for the upstream as well as the downstream were chosen in terms of water levels corresponding input discharges for the sixteen gauge stations. Steady flow analysis was performed for the month of September.

4.4 Post-processing of HEC-RAS

Model result of inundation area was compared with the Landsat (ETM+) taken during the flood event of 2005. Flood depth was compared with the field surveyed data generated by the survey on the floodplain during the field visit at the selected locations as a part of model output verification.

4.5 Hazard Mapping

Hazard mapping was prepared by using the population data, the land use data, and the flood depth in the GIS-base environment. Population data was generated from the number of population in each village. Land use was classified into four classes and internal weight was assigned. Area for hazard mapping was selected in the communes affected by flood. In total, there were 949 villages and 14 districts with an area of 1583.53km^2. Flood depth was reclassified into low, medium, high and very high and internal weight was given to each class. In the same way, weighted population was reclassified into low, medium, high and very high and internal weight was assigned respectively.

Theme	Reclass	Class Indicators	Internal Weight
Population	Low	0-3,000	1
	Medium	3,000-6,000	2
	High	6,000-10,000	3
	Very High	10,000-25,000	4
Land Use	Class 1	Forest cover + Water body	0
	Class 2	Grasslands	2
	Class 3	Agricultural area	3
	Class 4	Built-up area	5
Flood Depth	Low	(0-0.2) meters	1
	Medium	(0.2-0.5) meters	2
	High	(0.5-1.0) meters	3
	Very High	>1.0 meters	4

Table 2. Reclassification and internal weight

AHP (Analytic Hierarchy Process) was used for assigning the final weight into each factor. The final flood hazard map after calculation was reclassified into low, medium, high and very high. The criteria for the use of AHP are:

- Flood depth is 2 times as important as Population
- Population is 3 times as important as Land use
- Flood depth is 4 times as important as Land use

	Population	Flood depth	Land use
Population	1	1/2=0.5	3
Flood depth	2	1	4
Land use	1/3=0.33	1/4=0.25	1

Table 3. Criteria for AHP analysis

5. RESULTS

5.1 Flood Extent and Depth (HEC-RAS)

As for the Figure 5 it is noticed that the depth varies from 0~1.68 m in the flood plain and on the river. The total flooded area is 1,579 km^2. Maximum area was inundated from a flood depth of 1.09 – 1.68 m. That indicates how large the year 2005 flood was. Flood at 1 meter depth or more is probably sufficient to cause damage to any built-up area if it stays for some time.

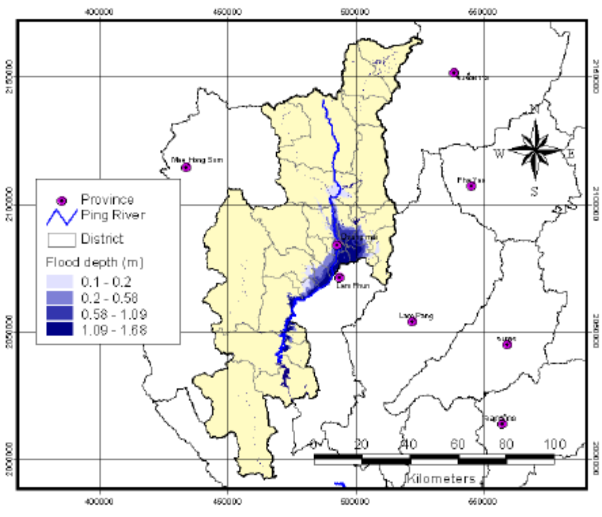


Figure 5. Flood depth of the study area from HEC-RAS

5.2 Comparison with the Base Data

The model result was verified with the Landsat (ETM+) image (Source: Land Development Department). It is seen that the model result reasonably matches with the Lamdsat. Verification of depth was carried out with the survey at 30 points in the flood plains during the field visit by interviewing people. The result matched quite closely in Mae Rim, Sansay and Muang districts but a little differed in Jom Thong district. Another area of uncertainty was the high values of depth at the boundaries of the flood plain which should be verified since HEC-RAS may act as a wall to the water flowing across the boundary and thus computing a high value particularly in the southern of Salaphi and Sankamphang districts. This can be overcome by extending the area of modeling and that needs more survey and elevation data.

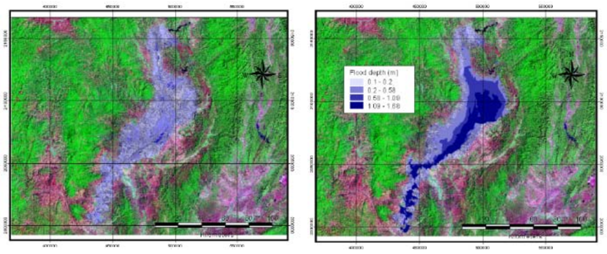


Figure 6. Landsat image (left) compared with flood extent from HEC-RAS (right)

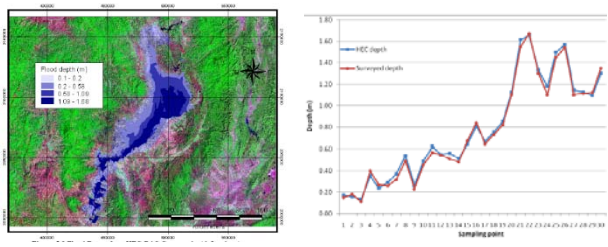
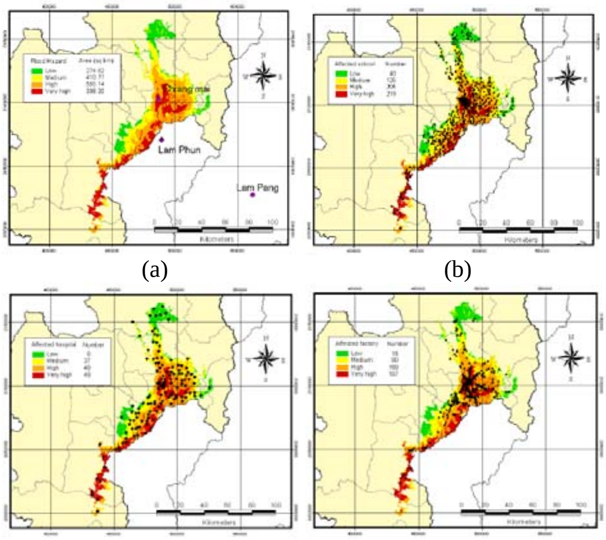


Figure 7. Flood depth verification points (left)
Comparison of HEC depth with surveyed depth (right)

5.3 Flood Hazard Mapping

The final hazard map was calculated using equation from AHP equations. It is seen from the Figure 8 that the total area under hazard was 1,579 km^2. Out of this area, 274 km^2 was low hazard, 410 km^2 was medium hazard while 555 km^2 was high hazard and 338 km^2 was under very high hazard category.



(a) (b) (c) (d)

Figure 8. Food hazard maps
(a) Flood hazard map;
(b) Affected school under each flood hazard category;
(c) Affected hospital under each flood hazard category;
(d) Affected factory under each flood hazard category

From the above results, we can get the conclusions that schools, hospitals, factories affected by the flood of 2005 were calculated by overlaying them with the final hazard map (Figure 8(a)). And there are 590 schools, 142 hospitals and 451 factories were affected by the flood of 2005.

6. CONCLUSION AND RECOMMENDATIONS

Flood hazard mapping is an important component for appropriate land use planning in flood plain areas. It creates easily-read, rapidly-accessible charts and maps which facilitates the administrators and planners to identify areas of risk and prioritize their mitigation or response efforts. This paper presents an efficient methodology to accurately delineate the flood-hazard areas in the Chiang Mai province; Northern Thailand in a GIS based analysis. The study has used one of the multi-criteria decision-making techniques, Analytical Hierarchical Process (AHP) which provides a systematic approach for assessing and integrating the impact of various factors, involving the levels of dependent and independent, qualitative and quantitative information. Furthermore, valuable advantage of HEC-RAS software is that it is readily available for free download at HEC-RAS website.

The method presented proves very applicable to adopt for further study as can be seen from the verification step that the model outputs either the inundation area or depth were reasonably close to the satellite image and surveyed data respectively. The summarized results can be concluded as follows:

1) Inundation area from HEC-RAS shows that the flood depth varies from 0~1.68 m in the flood plains and on the river. The total flooded area is 1,579 km^2.
2) Flood inundation area by and large closely agrees with the Landsat image of the study area.
3) Flood depth from HEC-RAS is quite close to the surveyed points.
4) Flood hazard analysis shows that maximum area under high hazard category.
5) Most of the areas affected by the flood were agricultural areas.
6) Most number of affected schools, hospitals, and factories are under very high flood hazard.
7) This approach can be extended to the other parts of the basin.

The results described in this study should provide helpful information about flood hazard management and should be useful in assigning priority for the development of very high risk areas for flood control planning, and the construction and development of flood countermeasures.

In addition, it is evident that flood hazard mapping at pre-feasibility level could be carried out using secondary information from maps, satellite images, and published and unpublished documents.

Finally, this type of flood hazard map in digital form can be used as a database to be shared among the various government and non-government agencies responsible for the construction and development of flood defense.

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ACKNOWLEDGEMENTS

The author would like to acknowledge the Chinese Academy of Surveying and Mapping and Asian Institute of Technology for providing a small project that enabled us to undertake this study.