Flood Hazard Assessment in Upstream Region of Chao Praya River with GIS

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Abstract:
The paper presents the river flooding condition in Nakhon Sawan, which is located at the midstream region of Chao Phraya River, i.e., area where the Ping and Nan rivers meet. This study focus on the Year 2011 large flood event at upstream of Chao Phraya river, including the situation of reflooding where water from low-lying floodplain areas flow back into river channels. The paper describes in details of field investigation for post flood event, flood volume calculation and hydraulic model to simulate dynamic flow behaviors and flood distributions. The flooding model is validated by comparison of its numerical results with observed flood inundation coverage and calculated flood volume. Consequently, the outcomes of flood modelling constitute suitable inputs for subsequent analysis. Relationship between the land use and flood situation are discussed. Based on Thailand Master Plan, precautionary measures are recommended in order to reduce flood damage condition in the lower reaches of Chao Phraya River.

Keywords: River Flooding Condition, GIS
1 Introduction

Flood in year 2011 affected 66 of the country’s 77 provinces started in June in the northern regions with storm Haima, which brought 128% of the average rainfall for June. Haima was quickly followed by tropical storm Nock-Ten throughout parts of July and August, which resulted in rainfall of more than 150% of the average for both months. Though rainfall slowed slightly, storms continued to hit the country from north to the east and rainfall remained above average throughout September and October (135% and 116% respectively). The accumulated water from months of storms and above average precipitation resulted in the flooding of the central regions. The total damage and losses from the 2011 floods in Thailand amounted to USD 46.5 billion. Rehabilitation and reconstruction needs over the next two years and beyond are estimated at USD 50 billion [1].

Upstream of Chao Phraya River seems to be a large effect to the downstream of the flood coverage. However, a clear view of inundation and flood condition on upstream of Chao Phraya River has not yet been obtained. Therefore, this research studies on the upstream of Chao Phraya River in order to understand its impact to downstream flooding and the proposed non-structural flood countermeasures. This research also studies if Bung Boraphet is suitable to store the flood volume at upstream area to minimize the seriousness of flood at downstream of Chao Phraya River.

The Chao Phraya River has the largest river basin in Thailand, with total drainage areas of approximately 157,924km² covering about 35% of the nation. In the past, the low land areas of the Chao Phraya River delta have been designated as freshwater swamp forests approximately 400 km north to south and 180 km wide. This has almost been removed entirely and changed into a plain for rice paddies, urban areas and industrial estates [9]. These changes accelerated seriousness of the flood in Bangkok. Therefore, land use changes of Nakhon Sawan area will be discussed in this research.

![Figure 1 Background of research area.](image-url)
Nakhon Sawan (located 15° 41′ 26″ N, 100° 6′ 50″ E) is located 250 km from the north of Bangkok. The city is located in the midstream region of the Chao Phraya River. The river flows came from the Ping River, Yom River and Nan River. Based on Figure 1(b), Nakhon Sawan is a basin surrounded by high land and it has tendency accumulate water. Particularly east of Nakhon Sawan, near to STA C2 (Gauging Station), there is a low plain extends and a large wetland called Bung Boraphet exists. Bung Boraphet has various animals and plants and designated as an environmental protection area. It functions as an area of important for both fisheries and agriculture.

2 Post-Flood Investigations

From 27 to 29 September, 2012, investigation of flood marks and interviews were conducted. Investigation was mainly focused on boundary of Nakhon Sawan and each river located at the upstream of Chao Phraya River. Flood marks measurement was conducted on riverbanks, natural banks, back marshes and narrow segments, etc., by using measuring rod. Furthermore, interviews also conducted with residents who stay nearby location of flood marks investigation. Some of the items such as started date of floods, the flow direction of floods, lifestyle during floods and awareness of floods are included in the interview.

Figure 2 shows location of flood marks investigation and measurement results. It shows observations are mostly at 1m to 2.5 m height of flood marks from the ground or water level of swamps. Area around Bung Boraphet have higher height might be affected by its water level. Besides, roads, natural banks in urban areas were observed mostly at 1 m or lesser.

![Figure 2 Investigation points (IP) and measurement results.](image-url)
Some of the observations from interviews are as listed:

- Flooding in Nakhon Sawan started from the middle of August, peaked on 20 September and continued until late October 2011.
- Flood water from the Nan River flowed into Bung Boraphet, which is the largest natural domestic lake located in Nakhon Sawan. Besides, some of it flowed out into the Chao Phraya River at the outlet.
- Residents around Bung Boraphet live with high-floored houses. Report were recorded that this flood event did not bring much damage to them.

3 Data Preparation and methodology

3.1 Volume Calculation in ArcGIS

In order to calculate flood water volume in ArcGIS (ESRI.co.), data from TMS (Thailand Flood Monitoring System) are converted to raster. Those data content boundary of flood coverage in the period from August to December, 2011. DEM from GMTED (Global Multi-Resolution Terrain Data 2010) Year 2010 and SRTM (Shuttle Radar Topography Mission) Year 2005 are used to obtain elevation. Next, TIN is created to generate water surface and then projected into UTM (Universal Transverse Mercator) N47. Last, minus method is used to calculate the flood level and volume.

The result shows that total flood volume during peak period, 21 September is about 5,010 million m³. Result of flood volume from both GMTED and SRTM shows SRTM provides better result because of its 90m resolution. However, there are still some error data (Flood water level < -1m) as shown in Figure 3(a). Those error data might cause by housing or trees area. In order to remove error data, spline tool under Spatial Analyst is used and corrected data can be seen from Figure 3(b).

Figure 3 Calculated results by ArcGIS.
3.2 Modelling Approach

NAM (Nedbør-Afstrømnings-Model) Rainfall-Runoff model in MIKE 11 (DHI.co) has chosen for simulating 1D hydraulic modelling of rivers condition in upstream of Chao Phraya River. Rainfall data in year 2011 for upstream of Nan, Ping and Yom river are inputted. Water discharge data for STA Y17, STA N7 and STA P7A are used as inflow boundary type for upstream area in model. Projection of the model has defined as UTM N47 and cross sections are defined in each river. Each river has at least 7 cross sections in the model. The simulation period for MIKE 11 is 1 April to 31 December, 2011 as limited water discharge data obtained.

Furthermore, GMTED and SRTM are used as base map for MIKE 21 for 2D modelling. Finally, both 1D and 2D are combined in MIKE FLOOD to simulate the flood condition. Simulation period is focus from 1 August to 30 December, 2011. The results of model are discussed in next section.

4 Results and Discussions

4.1 Modelling Results

Simulated water discharge (MIKE 11) after flood event has been validated with RID data to ensure the accuracy of river flow. The period of 2 August to 29 October, 2011 are focused.

Based on Figure 4(a), STA P17 on Ping River has similar water discharge for both RID and MIKE 11 result. There is only 400 million m$^3$ lesser in simulated result and it is high possibilities that this amount came from some small streams located right before STA P17 in this period.

Figure 4(b) shows the comparison at STA N67. There is a total 1,438 million m$^3$ lesser than RID. This amount might come from small streams along Yom River and Nan River before reaching STA N67 and it caused reflooding. Furthermore, RID has differences on (Y17+N7) – N67 about 6,300 million m$^3$ while MIKE 11 result has difference about 6,600 million m$^3$ with RID data. Referring to (Figure 4(b)), it can be concluded extra 300 million m$^3$ are flow into small streams before STA N67, STA N7 and STA Y17 before reflooding happen in 21 September to 25 October.

On the other hand, simulated result of STA C2 shows a total of 1538 million m$^3$ lesser than RID in the same period (Figure 4(c)). This amount is similar to the difference at STA N67. Therefore, the overflow at STA N67 and STA C2 is mostly affected by reflooding from floodplains and small streams along Nan River and Yom River before STA N67. In the period of 21 September to 25 October, which is the period of STA C2 exceed harmless limit 4000 m$^3$/s, simulated result has a difference of 900 million m$^3$ with RID. It means these 900 million m$^3$ are flowed in from small streams while 400 million m$^3$ are affected by mainstream.

Generally, MIKE 11 results have been considered compatible with RID as differences are acceptable.
Figure 4 Comparison of water discharge at gauging station (STA).

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4.2 Comparison of Evaluated Methodology

Figure 5 shows the comparison of flood event in 3 different timeframe between simulated flood results from MIKE FLOOD, flood coverage from TMS and calculated flood volume by ArcGIS. On 6 August, 2011, there is an amount of 29 million m$^3$ happen after STA N67 and 298 million m$^3$ after STA C2. As model only focuses on mainstream, this amount did not flow into small streams and accumulated at area after STA N67 and STA C2. On the other hand, Breach points’ location at Yom River and Nan River are similar to TMS. The total simulated flood volume is 640 million m$^3$ while calculated flood volume is 270 million m$^3$. The additional 370 million m$^3$ from model is considered equivalent with 330 million m$^3$ that accumulated after STA N67 and STA C2 in model. It means this flood volume flowed into small streams naturally in August when the water level of small streams is less than its capacity. In the other words, small streams mitigated flood in August and early September.

Flood condition on 21 September, 2011 is the starting of flood peak based on interview result. The flood scenario looks similar in between simulated model and TMS. The flood volume started accumulated after STA C2 in TMS. There are some scattered flood coverage at west side of area, which is affected by overflow from small streams around Yom River and Ping River. There are also bigger flood coverage at east of Bung Boraphet area in TMS, those volume are flowed from small streams around Yom River and Nan River. Therefore, reflooding is started on September when water level of small streams is over its capacity. Simulated result has total flood volume of 3,260 million m$^3$ and calculated flood volume is 5,010 million m$^3$. Obviously, the difference of 1,748 million m$^3$ is part of the reflooding flood volume from flood plain and small streams.

15 October, 2011 has the most serious flood coverage in model because model focus on mainstream. In reality, tributaries around Nakhon Sawan ease the flood condition in August and early September. Thus, 15 October has lesser flood coverage than 21 September as shown in TMS. Additionally, overflow from Ping River started in October, which is same as TMS. These flood amount flows toward Bung Boraphet area because of its lower elevation. There is also flood condition after Station P17 in TMS, which is accelerated by reflooding. Simulated model has a total of 3,840 million m$^3$ and calculated result has a total of 4,270 million m$^3$. The difference of 430 million m$^3$ is flows from small streams or floodplain.

There are some existing swamps and large flood plain in the Lower Ping River, Lower Yom River and Lower Nan River, these swamps and flood plain and played its role for flood mitigation in August to September [8]. Result of simulation shows small streams did have capacity to store more than about 300 million m$^3$ volume in August to Early September. However, the inundating water in swamps, flood plain and small streams was naturally released to the mainstream and reflooding happened from 21 September, 2011.
4.3 Verification of Simulated Result with Investigated Flood Marks

The measurement of flood marks are used to be compared in between field investigation result and simulated result (Figure 6). Location of IP (Investigation Points) can refer to Figure 2. Among 8 IP, IP 1, IP 2 and IP 6 are matched with different of ± 0.5m. However, the 225m resolution of DEM has limited the accuracy of the simulated result. IP 3 falls into dry area in model because the location is near to dike so it might be dike area in DEM. IP 7, which is location of a huge warehouse has different ± 1m, it is near to Chao Phraya River so the location
in model might be another side of warehouse. Besides, IP 4 and IP 5, which are at Bung Boraphet area has different ± 2m, it might be affected by water level of Bung Boraphet in DEM.

5 Relationships of Land Use and Flood Condition

Year 2010 and Year 1996 land use data is obtained from CTI Engineering Co, resolution for both are in 500m. Flood coverage with inundation level 1m-6m from simulated result are used to research on types of land use affected and the weekly capacity of flood volume on land use type also drawn Figure 7(a) and 7(b).
Without considering water area (Figure 7(a)), most of the affected area is paddy field. Based on total percentage of affected land use type with total land use type area, about 21.5% of paddy field was inundated during flood peak with mostly by 1m high of flood level. The next will be 17% of total urban area. However, interview result shows damage to resident was low because of existing high-floored houses. Total affected grass field and dry field are similar with 9.1% and 9.4% respectively. Both of them are mainly affected with 1m of flood level. Forest is least affected with 5.5% of total forest area. Remaining percentage is considered water area.

Based on the result of Figure 7(b), paddy field can considered as alternative to store flood volume before harvesting as it could store nearly 2,000 million m$^3$. Although paddy field mitigated 2,000 million m$^3$ during August to September, the field drains out the inundating water in October through drainage canals, streams tributaries for harvesting purpose in November. As a result, this volume amount accelerates flood condition in October at STA C2.

Referring to land use changes from Year 1996 to Year 2010, there is not many changes on land use type within these 14 years. Nakhon Sawan area is mainly dry field, grassland and paddy field. These 3 types help in flood mitigation as they have the capacity to store water during flood season. The growth of urban area will definitely continue in coming years, if these 3 types of land use are reduced, the flood risk will increase simultaneously.

6 Flood Mitigation Measures

Based on 2012 Chao Phraya River basin flood control master plan, there are some non-structure measures are discussed. Listed are those major components for upstream area. [5]

- Forest and Land Rehabilitation/Conservation
- More Reservoirs
- Land Use/Development Regulation
- Protection for Provincial Urban Areas
- Absorbing Flood Peak and Increasing Income in Irrigated Floodplain
Based on the result of flood volume calculation and risk analysis, it is understand that 900 million m$^3$ of flood volume over harmless limit is flows in from small streams along Yom river and Nan River, whereas 400 million m$^3$ is flows from mainstream. In order to store amount of 900 million m$^3$, the most effective measures will be absorbing flood peak and increasing income in irrigated floodplain. Irrigation system for agricultural can be improved by utilizing water volume from small streams along Yom River and Nan Rivers. To store 400 million m$^3$ in mainstream, height of existing dike along mainstream can be increase to enhance its capacity.

Bung Boraphet only has the capacity of 30 million m$^3$ with area of 5km$^2$ and water depth of 6m [8]. Even if it expanded 7km$^2$ and water depth of 8m after dike installation, it still has capacity of 56 million m$^3$ only. The extra 26 million m$^3$ is only 2% of total 1,200 million m$^3$ that needs to be stored. It is needed to research on other available swamps to store the extra amount of flood volume and use for irrigation areas in the dry season.

7 Summary

This research aim to understand the phenomena and principle of flooding scenario in upstream of Chao Phraya River, although the simulated flood scenario has flood started at location after STA C2, the flood result at upstream area is acceptable. Moreover, it is clearly those small streams at upstream area able to store 1,200 – 1,500 million m$^3$ during August to September 2011 and ease the flood condition. It is vital to store this flood amount in October to minimize the seriousness at flood condition at the downstream.

ArcGIS used data from satellite imagery to produce quantitative results of past flood event. On the other hand, MIKE FLOOD uses hydraulic data such as cross section of river and river discharge to simulate the past event and it able to estimate the future flood for risk reduction. This simulation only focuses on mainstream because data for small streams are limited. In order to improve the simulation model, it is recommended to use a smaller resolution DEM and include small streams with hydraulic data into the model.

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