Evaluation of flood volume and inundation depth by GIS midstream of Chao Phraya River Basin, Thailand

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Abstract

Chao Phraya River has small flow capacity downstream. When excessive water flows upstream into it the water level downstream increases with the possibility of flood risk. The purpose of this research is to clarify the flood condition midstream and recommend proper flood management measures. In this research, flood inundation depth is calculated with a Geographic Information System (GIS) in order to understand the temporal, spatial scale and transition. Furthermore, flood volume is calculated to understand the total flood volume needed to be stored midstream before reaching downstream. Results clearly demonstrated excessive streamflow at gauging station located at the beginning of Chao Phraya River, which is midstream of the Chao Phraya River Basin. Flooding of the Yom River and Nan River also has significant impact midstream. Results show that if flood volume of 0.7 billion m^3 flow from upper and middle reaches the lower reach could decrease, it will decrease flood volume at gauging station C.2 simultaneously. By controlling the flood storage volume midstream, there are possibilities of preventing the excessive streamflow capacity and the flooding damage downstream.
Keywords: flood, inundation depth, mitigation measures.

1 Introduction

Floods in Thailand occur almost every year. The flood in 2011 was of the largest scale ever. The Ministry of Finance [1] reported the total damage and losses from the 2011 floods in Thailand amounted to USD 46.5 billion. The total rainfall during 2011 rainy season was 1439mm, which is 143% of the average rainy season

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rainfall during 1982–2001. Moreover, 5 typhoons made landfall in Thailand in 2011. The prevalence of typhoons strongly influenced the rainfall in 2011 sources Komori *et al.* [2].

The Chao Phraya River Basin is often divided into upstream (Northern Thailand), midstream (Nakhon Sawan) and downstream (Chao Phraya Delta) according to hydrological features (fig. 1). There has been much investigation and research about the flood condition downstream of the Chao Phraya River, but investigations and research about midstream have rarely been conducted and the flooding condition has not been clarified. Land use at midstream is mainly agriculture, particularly paddy field. This research would like to understand if land use type at midstream affects the seriousness of flood condition downstream of Chao Phraya River Basin. Cham *et al.* [3] compared land use changes between 2010 and 1996. Results show most of the affected area midstream are paddy fields. There has been nearly no changes on land use type during these 14 years. Nakhon Sawan area is mainly dry field, grassland and paddy fields. These 3 types of land use help in flood mitigation as they have the capacity to store water during the flood period. However, paddy field drains out the inundating water in October through drainage canals, streams tributaries for harvesting purpose in November although paddy field mitigated 2,000 million m^3 during August to September sources (Higuchi *et al.* [4]).

The flood condition in downstream of Chao Phraya River is studied sources (Oki [5]). Prajamwong and Somkiat [6] recommended some flood mitigation methods for the 2011 Thai flood such as lowland as large retention storage. However, estimated flood storage volume for countermeasures has not been clearly indicated in both pieces of research. Kwak *et al.* [7] mentioned the estimation of water extent boundary and flood volume is important to determine a fundamental hazard in flood risk assessment. It detected surface water in a severe flood event for the 2011 Thai flood by applying modified remote sensing indices to near-real-time Moderate Resolution Imaging Spectroradiometer (MODIS) images. Flood volumes were also calculated for detected flood areas by using a proposed flood inundation level (FIL) model with the Digital Elevation Model (DEM). This research also focused on downstream area only. The Thai government announced the action plan of comprehensive continuous flood damage reduction in the Chao Phraya River area in 2012 after flood occurred in 2011. This included the planning of reservoirs and discharge channels in the upper and middle reaches sources Strategic Committee for Water Resource Management (SCWRM) [8]. However, financial issues and predictable strong opposition by local residents in the execution process has posed the possibility of delays in the plan sources (Oki and Komori [9]). Therefore, efficient flood countermeasures in the upstream and midstream, which is important in flood control of the downstream, have not been proposed.

The main objective of this research is to calculate flood inundation depth and estimate the flood volume needed to be stored in midstream of Chao Phraya River Basin in order to minimize the flood risk at downstream. Furthermore, it is important to study the time series changes of flood storage volume in midstream for disaster mitigation. In this research, it also includes a field survey to measure

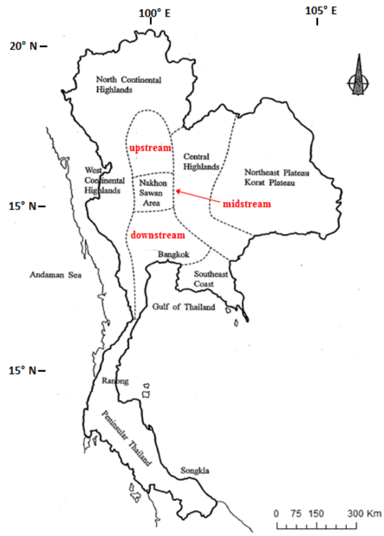


Figure 1: Chao Phraya River Basin in Thailand (source CTI [10]).

the flood marks, calculation of flood inundation depth using GIS, estimation of flood storage volume in time series changes and proposed suitable flood countermeasures.

2 Field survey at Nakhon Sawan

At the end of September, 2012, a field survey to measure the flood level of flood marks has been conducted at Nakhon Sawan, which is midstream of Chao Phraya River Basin. The flood marks investigation was conducted in surrounding area of Nakhon Sawan and each river of upper reach as scope of study is focused on agriculture area. Measurements of flood marks were conducted using a measuring rod. Digital Elevation Meter (DEM) with x, y and z are obtained from the United States Geological Survey (USGS) website, thus difference of z value for flood marks are measured at field for analysis use. Riverbanks, natural banks, back marshes and narrow segments and others are targeted areas as these are the areas might have an impact on the seriousness of flood condition. Location of flood marks used for analysis and validation are shown in fig. 6.

In addition, interviews were carried out with residents living near the field survey location. Interview items were the starting date of floods, the flow direction of floods, living conditions during floods and awareness of floods. Flood mark investigations and interviews were conducted from September 27 to September 29, 2012. Results of investigation will be explained in sections 3.4 and 4.1.

3 Estimation of flood inundation depth

3.1 Data preparation

The inundated area is too wide and it is impossible to obtain all the inundation depth data. When referring to data of Royal Irrigation Department (RID) with flood extent, it is unable to obtain the flooding time, but coverage of area could be used to calculate flood volume. Fig. 2 shows the basic concept to create water surface and calculate flood inundation depth by using flood extent area data from RID and elevation data from DEM. Shuttle Radar Topography Mission (SRTM) is used as DEM data. Data of SRTM-3 (3 seconds about 90m meshes), SRTM-30 (30 seconds about 900 meshes) and SRTM-1 (1 second about 30m meshes, within United States) are free to download. This research uses SRTM-3 as elevation data. Data (N14E099hgt, N14E100hgt, N15E099hgt, N15E100hgt, N16E099hgt and N16E100hgt) are downloaded from USGS website. Streamflow data for gauging station located at upstream and midstream of Chao Phraya River Basin are obtained from RID. Locations of gauging stations are shown in fig. 11.

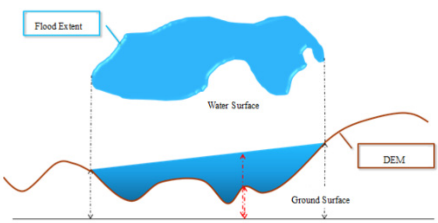


Figure 2: Concept of the calculation for flood inundation depth.

3.2 Calculation of flood inundation depth using GIS

ArcGIS provides a scalable framework for implementing GIS for a single user or many users on desktops, in servers, over the Web, and in the field. ArcGIS is an integrated family of GIS software products for building a complete GIS. It consists of several primary frameworks for deploying GIS such as ArcGIS Desktop, ArcGIS Server, ArcGIS Mobile, ArcGIS Online and ArcGIS Engine sources ArcGIS [11]. ArcGIS Desktop provides a variety of spatial analyst tools to analyse spatial relationship and perform complex raster operations, which is useful for flood volume calculation. This research uses ArcGIS Desktop to calculate the flood inundation depth and flood volume. The process flow of calculating flood inundation depth is described in fig 3. As an example, the processes to calculate inundation depth for September 21, 2011 are described. Firstly, polygon of RID flood coverage is converted into polyline to get the boundary of flood coverage. The content of flood extent is neglected and this study only focus on boundary of it. Next, boundary of flood extent is converted from polyline into raster with cell size must be same with DEM used. Although the boundary of flood extent in raster has obtained the elevation value, it could not create water surface directly.

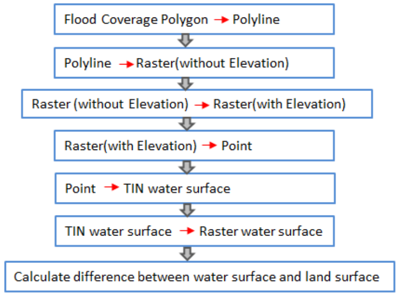


Figure 3: Process flow of calculating flood inundation depth.

Then, the boundary of flood extent needs to change into point format using “Raster to Point” under Conversion Tool. Next, “Create Triangulated Irregular Network (TIN)” under 3D Analyst Tool is used to create water surface in TIN from boundary of flood coverage in point format, which currently consist of elevation value. After this, 3D Analyst Tool is used to calculate difference of elevation value between water surface and land surface. After water surface in raster is created, projection from WGS 1984 into UTM Zone North 47 is transformed.

In order to obtain inundation depth from water surface in raster and DEM, MINUS function in 3D Analyst Tool is used. It calculates difference of elevation in multiple cell values with 2 files of cell values, which are cell value of water surface in raster and cell value of DEM. Then, cell value of water surface in raster will be subtracted from cell value of DEM. Fig. 4 shows the result of calculated inundated depth, dark blue represents area with higher depth value.

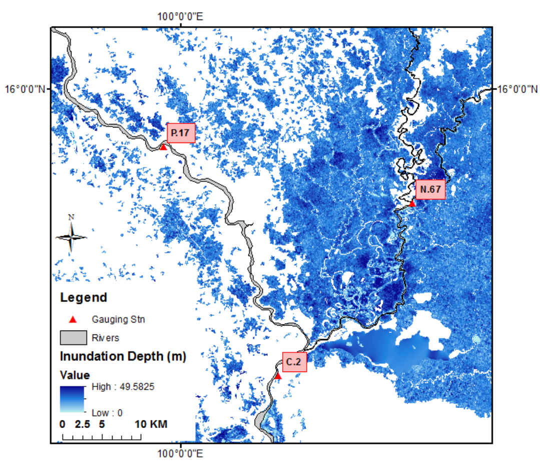
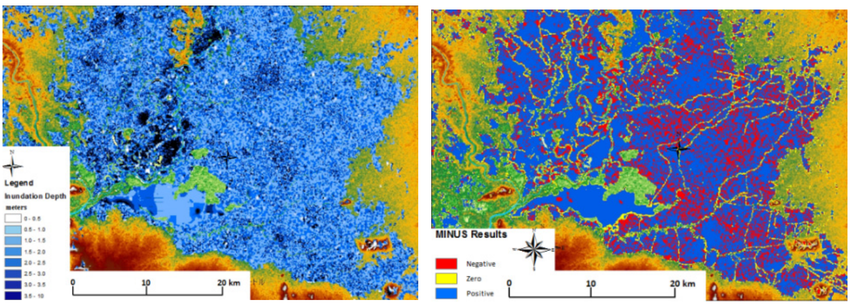


Figure 4: Result of calculated inundation depth after being processed by MINUS Function.

3.3 Error correction

Although inundation depth from water surface in raster is calculated from SRTM, there are some errors occurred in the result (as shown in fig. 5(a)). Those errors happened because of some cells in SRTM are vegetation and natural levee along rivers, which have higher elevation and those values could be higher than values in water surface. When those values are subtracted using MINUS function, it resulted in errors such as negative value (shown in red) or zero value (shown in yellow). In other words, those error values should be flooded area as shown in coverage of polygon data provided by RID but those areas are not flooded in calculated result. Therefore, negative value and zero value are set as “No Data”, the errors are fixed by interpolating cell value from surrounding area.

“Spline” under 3D Analyst Tool is used to fix the error by interpolating raster surface. There are several options of raster interpolation but Spline is chosen because it has a two-dimensional minimum curvature. The spline interpolated results in smooth surface passes exactly through the input points and it reflects the original data. After corrected using Spline method, the result of inundation depth from water surface in raster, which is GIS calculated result, is presented in fig. 5(b).



(a) (b)

Figure 5: (a) Error of inundation depth in raster and (b) final GIS calculated result for inundation depth after Spline interpolation.

3.4 Data validation and discussion

The results of inundated depth calculated in GIS method needs to be validated. In order to validate those results, field survey data of flood marks measurement is used. The maximum inundation depth value from the GIS calculated result is used to compare with field data. Some locations of flood marks are noticed as flood location when field survey is conducted at Nakhon Sawan in the end of September, 2012. However, those locations are not included in coverage of polygon data provided by RID. Thus, measured flood marks in those areas are out of scope, and could not be used to validate GIS calculated result. 16 flood marks are measured but only 8 flood marks are within the area covered by RID data.

Therefore, these 8 flood marks are used to validate raster of inundated depth calculated in GIS. Fig. 6 shows location of 8 flood marks measured in Nakhon Sawan and Fig. 8 shows the results of comparison between field survey and GIS calculated result, the inundation depth values are mostly consistent except No.5, which is Bung Boraphet. It is a natural freshwater lake located at the south of Nan River, and beginning of Chao Phraya River. The difference of inundation depth is affected by the water level of Bung Boraphet during measurement.

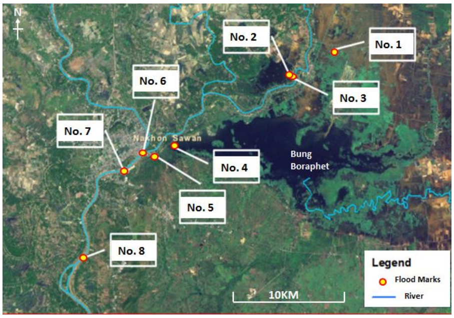


Figure 6: Location of flood marks.

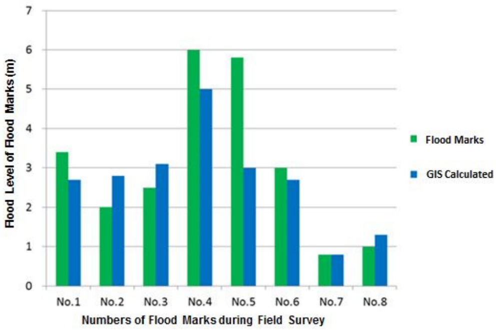


Figure 7: Comparison of inundation depth between field survey and GIS calculated.

4 Estimation of flood storage volume

4.1 Analysis data of field survey

Based on findings obtained from interviews during field survey, it is understood flooding in Nakhon Sawan started from the middle of August, peaked on September 20 and continued until late October, 2011, which is in good agreement with streamflow condition at gauging station C.2. Flood volume from the Nan River flowed into Bung Boraphet, which is the largest natural domestic lake in Nakhon Sawan. Some of it flowed out into the Chao Phraya River when Ping River converged. There are high-floored houses around Bung Boraphet and residents in this area live with floods. Reports were recorded that this flood did not cause many damages to people living with this kind of lifestyle. Fig. 8 shows area of 110 km from gauging stations of Y.7 and N.7 to gauging station C.2. It is targeted as subject area to calculate flood storage volume. Fig. 10 shows a comparison between the streamflow at gauging station C.2, located at Nakhon Sawan and the flow amount at gauging station C.13, about 100 km south of the gauging station C.2. These data are obtained from RID. CTI [10] mentioned harmless streamflow limit for gauging station C.2 is 4000 m^3/s. While the flood in Nakhon Sawan reached its peak from September 21 to October 25, the harmless streamflow limit of 4000 m^3/s was exceeded at gauging station C.2 and the streamflow at gauging station C.13 reached its peak from September 12 to November 8. Streamflow exceeding the harmless streamflow limit at gauging station C.2 from September 21 to October 25 are integrated and total streamflow volume over the harmless streamflow limit is about 1.3 billion m^3 (shown in shaded area in fig. 9).

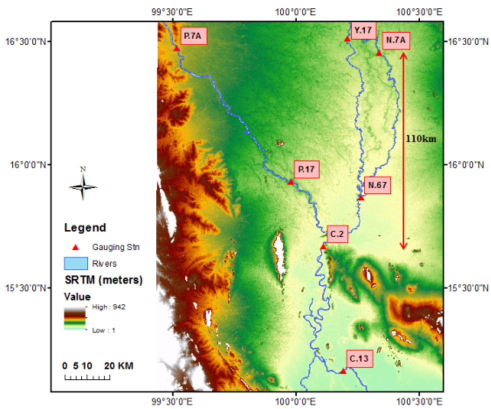


Figure 8: Subjected area for estimating flood storage volume.

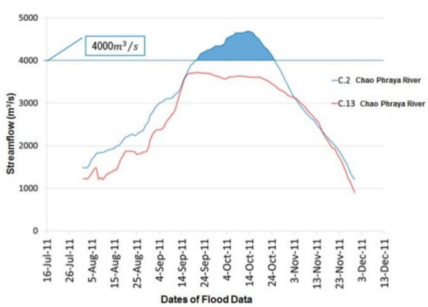


Figure 9: Streamflow data at Chao Phraya River at gauging station C.2 and C.13.

4.2 Time series changes of flood storage volume

In order to understand the scale of flooding in different times, it is necessary to evaluate time series variation of flood storage volume. In this study, flood storage volume is estimated from GIS calculated result with RID data. It is calculated using mean value of inundation depth in raster with area obtained from data provided by RID. The time series variation of flood storage volume for the subject area is shown in fig. 10. As data obtained from RID is limited, a fixed interval between dates of data couldn't be made. Therefore, interval of calculation is chosen from 7 to 10 days. Based on obtained results, it is understood the flood increases slowly in August and reaching its peak on September 21 then decreases, which is same with the responses received by interview during field survey and streamflow condition of gauging station C.13, fig. 9). From September 21 to October 30, decrease of nearly 1 billion m^3 can be seen in fig 13. It is similar to the 1.3 billion m^3 that over harmless streamflow limit at gauging station C.2 in the same period as shown in fig 10. Thus, there is possibility that this amount of volume flow from midstream to downstream and affected streamflow at gauging station C.2 exceeded its capacity. However, these flood volume spreads to surrounding area after went through gauging station C.2, particularly east side of Bangkok city and result in flood volume decrease gradually after September 21 at gauging station C.13.

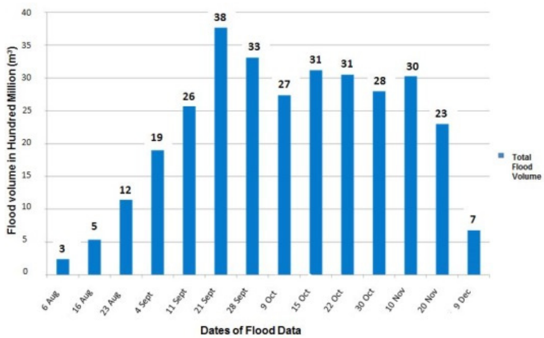


Figure 10: Time series change of flood storage volume.

4.3 Countermeasures and discussion

Time series changes of flood storage volume in midstream show the possibilities of storing flood volume in midstream is able to ease the flood condition downstream area. To study in detail, subjected area had been divided into 3 sections, upper, middle and lower reaches fig. 11.

Fig. 12 shows the time series variation of flood storage volume from September 20 to October 30 in 3 sections. Flood volume in upper reach decreases gradually. Besides, decrease rate of flood volume in middle and lower reaches is relatively mild. Flood volume in middle reach has the highest value than flood volume in upper and lower reaches. Flood volume from upper and middle reaches flow out

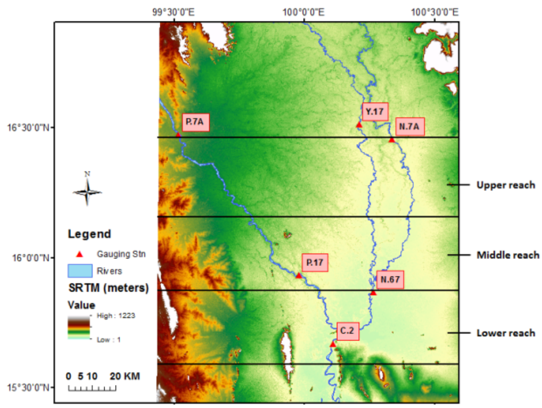


Figure 11: Subjected area for estimating flood storage volume is divided into 3 sections.

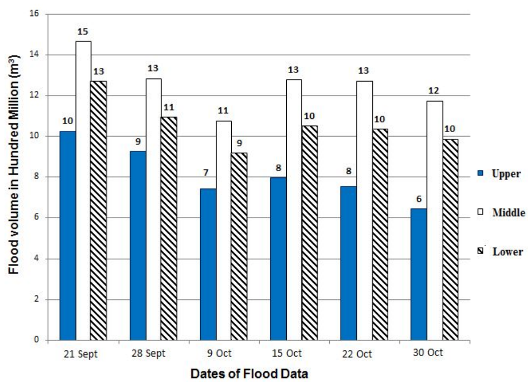


Figure 12: Time series change of flood storage volume at upper, middle and lower reaches.

from river channel to flood plain in close proximity, and then it flows into lower reach. It affects flood volume in middle and lower reaches excess streamflow capacity, causing inundation occurred at surrounding area of gauging station C.2. Therefore, if flood volume decreased gradually in upper reach and it will decrease slowly in middle and lower reaches. Furthermore, it is understood 0.4 billion m^3 flowed from upper reach and 0.3 billion m^3 flowed from middle reach to lower reach from September 21 to October 30. These amounts should be stored before reaching lower reach.

Consequently, if flood volume of 0.7 billion m^3 flow from upper and middle reaches to lower reach could decrease, it will reduce flood volume exceeded its capacity at gauging station C.2 simultaneously.

The amount of volume could be stored in middle reach or upper reach to ease the flood condition in lower reach. This result is compatible with action plan for management of major water reservoirs and assigning water retention as proposed in Thailand Master Plan. The 0.7 billion m^3 could be stored by modifying the operation of large reservoirs in the upper river basin, or constructing potential water storage in the middle or upper river basin area. It is important to improve capacity of existing reservoir located at midstream of Nan River and Yom River as it has possibilities to mitigate flood condition in Thailand.

Results from this research has shown the flood storage volume in middle reach has highest value than upper and lower reaches from the end of September, 2011 to the end of October, 2011, which is the peak of flooding period. GIS tools help to estimate total flood volume to be stored in midstream effectively. Agriculture area in midstream has capacity to store flood volume temporarily and has potential to ease the severity of flood at downstream. The land use planning in Nakhon Sawan to be given attention for future flood mitigation measures use.

5 Conclusions

Based on the streamflow data obtained from RID, it is understood that flooding of the Yom River and Nan River has a significant impact in the midstream flood. After flood storage volume is analysed in time series changes, the reasons of excessive streamflow capacity at the Chao Phraya River gauging station C.2 reached peak period from September 21, 2011 are understood. Furthermore, there is a decrease of nearly 1 billion m^3 in midstream area from September 21 to October 30 based on calculation result using GIS and RID data. This amount is similar to decreased streamflow value at gauging station C.13. By controlling the flood storage volume about 0.7 billion m^3 in midstream (upper and middle reaches), there are possibilities to prevent the excessive streamflow capacity and the flooding damage in downstream. It is recommended to conduct simulation of flood condition at study area in order to have more accurate estimation for flood volume and inundation depth. The simulated results are able to use for validate GIS calculated results in this study. Consequently, different conditions of flood control will be simulated and analysed in future research to understand effectiveness of proposed counter measurements.

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