Flood Hazard Assessment Based on Hydrological and Spatial Modelling in Middle Chao Phraya River Basin, Thailand

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ABSTRACT

Several areas in Middle Chao Phraya River Basin (M-CPRB), Thailand are regularly prone to flood hazard problem and urban development had spread built areas with a lower capacity of water carrying capacity. The changing climate system also tends to increase adverse impacts of extreme events including extreme weather and precipitation. The main objective of this study is to assess hydrological hazards subject to land use change in the M-CPRB. The study area is focused on three scales incl. the Greater Chao Phraya River Basin (G-CPRB), M-CPRB and Nakhon Sawan Municipality (and vicinity). Hydrological and spatial models were used for simulating flow hydrograph and inundation areas and evaluating land use change with urbanization, respectively. The results show that flood hazards are subject to different land use types and flow discharges, while changing trends have been in both spatial and temporal aspects. Natural and green surface areas play a major role in the hazard results. These findings can be used as key inputs for risk assessment and adaptive policy recommendations in further studies.

1. INTRODUCTION

In the present day, natural disasters become a serious problem globally, particularly floods due to the higher temperatures and changing weather conditions. These catastrophes severely affect economic, social and environmental sustainability [28]. Chao Phraya River Basin (CPRB) in Thailand has been affected by the great flood in 2011 that damaged more than 10 million people were affected, and over 500 individuals were died. The flood occurrences took place approximately 4 months and resulted with an economic loss of $46 billion [22].

Flood is an overflow of water from the river which submerges the floodplain area and surrounding. Climate change causes by negative human activities and it also has an impact on changing weather conditions [19,20]. The effects of climate change are widespread globally in social, economic and environmental aspects. Especially water cycle is one of the main effects of climate change due to changes in rainfall volume and pattern. It becomes a great flood problem in both urban and rural areas. However, the land use change in watershed areas can influence the quality of water and quantity as well as increased excess runoff, reduced surface infiltration performance and water purification [25]. The trend of urbanization and deforestation rapidly increased that directly affect natural forest resources and the green surface areas thus influenced water availability and supply. With an understanding of spatial and temporal aspects regarding land use patterns and changing hydrological components of each basin, water management can be more enhanced on water conservative policies and natural disaster solutions [2].

As a consequence of disasters, mitigation and adaptation plan reducing the effects of disasters are important to handle the problems. In the present, mitigation and adaptation strategies are included in Thailand's national plan moderating disasters focusing only on water resources for agriculture [5]. In spite of the watershed area, water management agencies have many complex dimensions and levels as well as having a variety of development and stakeholders. Besides, CPRB located in the upper and middle parts of Thailand covering an area of 160,000 sq. km and including 23 provinces of Thailand. There are around 25.6 million people living along the river [8]. Flood phenomena are normally problems in this basin causing damages in agriculture and local communities due to lack of adequate reservoirs and proper water management to support water demand and water flow. Recommendation from different public and private agencies is to build dams or reservoirs, but it is still issuing in river basin management and lack of participation from residents and

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communities [9].

Hydrological modeling is an instrument to evaluate and predict of flood hazard and risk areas in different adaptive scenarios. Hydrological modeling was combined from the Hydrologic model, hydraulic model and filed survey data that established natural disasters hazard, vulnerability and risk parameters [1]. A flood hazard map is a visualization tool of water characteristics (water depths, flood duration, river velocity, etc.) with different probability or return periods [23]. The flood hazard map can help authorities identify critical and high damage areas where flood mitigation and evacuation plans have powerful to reduce risk on humans and property [16]. However, flood hazard maps cannot protect the community from floods occurring, they are a knowledge-based tool for flood forecasting and warning to activate human awareness.

The main objective of this paper is to assess flood hazards with land use projection (2020, 2050 and 2100) using hydrological and hydrodynamic models (HEC-HMS and HEC-RAS, respectively). It covers historical analysis from both daily rainfall and monthly runoff data for M-CPRB with a focus on Nakorn Sawan (NSW) municipality and vicinity.

2. LITERATURE REVIEW

Hydrologcal Process including Urbanization and Extreme Events

The water cycle covered over 80% of Earth's surface, including oceans, lakes, rivers, even ice and glaciers, is the hydrological process, which plays a key role in ecosystem function by combining the diverse physical, chemical and biological processes supporting life [17]. The productivity of ecosystems, the mix of species and the biodiversity of water are a major element. For human well-being it is also extremely important: Agriculture, fishing, industrial and hydropower human activities depend on the supply of water. The climate change is predicted to affect critical hydrological processes in South-East Asia, including water supplies, infrastructure, aquatic habitats and access. Higher climate change temperatures also affect hydrologic systems and their extreme occurrences such as flooding, flash flooding, and droughts suggested that extreme hydrological events might become more often if the temperature continues to increase and potentially accentuated by rising precipitation intensity [6]. Furthermore, the nature and timing of floods will vary. Komori et al. also argued, in their 2016 research, that while there is no direct association between increasing frequency of extreme events and climate change, a positive trend shows that urban flooding and flash flooding are more likely [11]. In addition, changes in land use, such as development, a decline in natural retention and poor management of water, can greatly affect extreme occurrences (flood and drought).

Flooding is a natural process; however human activity has an impact on flooding. Flooding happens irregularly and varies in magnitude, area, scope and time [10]. River floods are one of the most frequent types of inland floods; occurring when the capacity of a body of water is greater. If a river usually bursts its ribs because to heavy rainfalls over a lengthy time, the floods can cause substantial damage to the surrounding land and a major safety danger. Rivers, especially in flat or urban locations, need excellent defenses to prevent floods.

Hazard Assessment based on Hydrological and Spatial Analyses

The Hydrologic Modeling System (HEC-HMS), which simulates the whole dendritic watershed processes [7]. The software includes numerous conventional processes for hydrological analysis, such as event infiltration, unit hydrographs and hydrological routing. HEC-HMS also provides the essential techniques to perpetually simulate evapotranspiration, melting, and accounting for soil moisture.

The software has a fully integrated working environment with a database, data entry tools, computer engine and tool for the reporting of findings. A graphical user interface enables the user to move seamlessly between the many elements of the program. The HEC-DSS simulation results can be used with other software for water available studies, urban stream, flow forecasting, future urbanization impact, storage spillway design, flood damage reduction, floodplain regulation, and system operations. Simulation results can be stored in conjunction with other software.

HEC-RAS is a hydraulic two-dimensional model created for the help of hydraulic engineers in the investigation and determination of channel flow [21]. For floodplain management and flood insurance research, the model results can be employed. Steady flow describes conditions when depth and speed do not change with time at a given channel position. Lower variations in water depth and velocity from transversal to transversal are characterized by gradually variable flow. HEC RAS' fundamental approach to calculate water surface profiles assumes steady flow and unstable flow, which in natural and manmade channels is fairly prevalent, direct phase calculations start at the downstream end of the reach and advance upstream between neighboring cross sections. The calculations would start at the upstream end of the reach for supercritical flow and continue downstream.

In terms of spatial modeling, Future Land Use Simulation model (FLUS) is generally applied for land use projection to simulate several scenarios of land use considering impact of human activities and environment [12,13,15]. Approach of FLUS model mainly consists of two elements; (1) multiple cellular automata (CA) allocation model and (2) artificial neural network (ANN) algorithm. The multiple cellular automata (CA) allocation model is a simulation model for the study of possible spatial land use patterns under the different circumstances. ANN algorithm is analyzed complicated relation of parameters that influence future land use types [15]; moreover, the land use change projection also concerns 5 main types of land use; agriculture, forest, miscellaneous, built up and water body areas with estimated conservative scenarios on preservation, regeneration, and ecological diversity to analyze increasing of green areas to be highly effective against hazard assessment [20].

Previous Hydrological Studies in Middle Chao Phraya River Basin with Urbanization and Climate Change Impact

CPRB's natural occurrence is flooding because four upper sub-basins and two large dams are important for the Chao Phraya River discharge Flood (CPR). The study indicated that an early-flute warning system with unstable upstream and downstream border conditions was used with the HEC-RAS model to simulate the flow in the CPR river. [3].

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In order to examine the influence of climate change on the hydrology and water resources in CPRB, a watershed hydrological model was used by the Japan Meteorological Research Institution (MRI), to evaluate climate change for this basin. A watershed hydrological model is used. The results reveal that in the late future (2075-2099), the average annual discharge will increase significantly as precipitation increases. In addition, a review of the flood frequency showed an annual increase to the end of the 21th century in maximum daily flows.

The magnitudes of high daily flows were often higher during the historical period (1980–2004) in late future time than their equivalents. These results indicate that catastrophic floods and huge flow releases, such as those in summer 2011, are likely, because of the high predicted precipitation, to increase in the future. The danger of overflooding in conurbations may rise as the magnitude of flood occurrences caused by climate change increases.

The current and long-term discharge dynamics of the CPRB were simulated utilizing a distributed Hydrological Model (DHM), geomorphological hydrological models (GBHM) and three general circulation models (GCM) [18]. The characteristics of this model were based physically on a hydrological model. They employed this model in the next 30 years to predict streamflow. Forcing the DHM model with three modified GCMs is projected for future fluvial discharge patterns. The results show that in the next three decades the average peak discharge could increase. Moreover, in September, the highest flood peaks in the simulated basin appear to be more concentrated. However, it has become more prevalent before or after the major rainy season according to MIROC and CCSM.

Evaluation in multiple scenarios of climate sensitivity and greenhouse gasses of the hydrological responses of the CPRB. The SWAT model (the Tool for soil and water assessment) [14] was applied to simulate the streamflow using meteorological and observed data over nine years from 2003 to 2011. The results indicated that a percentage increase in the flow that reveals the need to create safety measures during floods: the average daily flow (72.3%) during the rainy season in early May (22.7%) and after May (70.1%). More uncertainty about climate change leads the forecasts of extreme floods and drought to correlate. Moreover, changes in the land use of the CPRB may lead to a varied distribution depending on climatic changes such as climate sensitivity scenarios and three emission scenarios.

In order to lessen flood depth in predominantly paddy fields and certain residential areas in the province of Sukhothai, hydrodynamic HEC-RAS model was used in the Lower Yom River Basins, for planning a retention pond and a diversion channel [4]. The results show that when the river flow from the river upstream in Yom into Sukhothai was approximately 400 cu.m/s, it was determined that a 32 million cu.m of storage pool and a 50-100 cu.m/s capacity diversion canal were built. The decrease of 0.21, 24 and 0.40 m water levels below previous flood levels in 1975, 1995 and 2001 may save nearly no flooding in the communities of Sukhothai.

However, all of studies were only analyzed past and future flood hazard under future climate change impact without future land use change impact due to urbanization in many flat areas in CPRB. This is a major gap that this study will be fulfilled. Therefore, this study needs to evaluate future flood situation including land use change aspects using specific land use parameter to investigate impact on river discharge and flood levels.

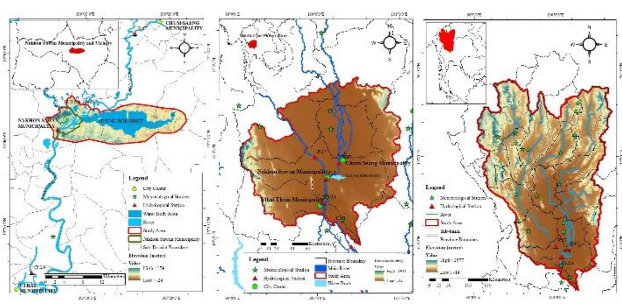
3. METHODOLOGY

Study area's characteristics

The G-CPRB is in the north and middle regions of Thailand. The origin of CPR is a confluence of Ping, Wang, Yom, Nan Rivers which originated in Daen Lao, Phi Pan Nam and Luang Phra Bang ranges between Thailand-Myanmar-Laos boundary where the location is in the northern part of Thailand. CPR is the main trunk stream that releases water to the Gulf of Thailand and significant socio-economic impact in the Mekong Sub-region [4].

The study area of applying HEC-HMS covers upper and middle CPRB with a drainage area of about 102,987 sq.km, as shown in Figure 1(a). The river system can be classified into five sub-basins including Ping, Wang, Yom, Nan and Bueng Boraphet that have a position in a north-south direction, as schematic diagram in Figure 2.

The study for historical analysis considers M-CPRB (Nakorn Sawan, Phichit, Kamphaeng Phet, Phitsanulok, Uthai Thani, Chai Nat, and Sing Buri) as upper central plain ecosystem boundary which can be separate into five sub-basins, i.e., Lower Ping, Wang, Yom, Nan, and Sakae Krang Rivers [8]. About 75% of the area is dominantly agriculture, 16% is forest and water body, and only 9% is a built-up area. For topography conditions, the right side of the river is agricultural and household areas and the lower part of the river is the largest freshwater swamp and Lake of Thailand, namely Bueng Boraphet. The average ground level was around -15 to +1938 above mean sea level (msl). Annual precipitation is 1,337.5 mm and the average temperature is approximate 28.5 degrees Celsius [8]. The M-CPRB is about 26,913 square kilometers. The river flow was drained out 165 kilometers from north to south directions as Figure 1(b).



(a) Study Area for Hydrologic Model, HEC-HMS
(b) Study Area for Historical Analysis
(c) Study Area for Hydrodynamic Model, HEC-RAS

Fig. 1. Study Areas and Identification Name of Sub-Basin for G-CPRB and M-CPRB, respectively.

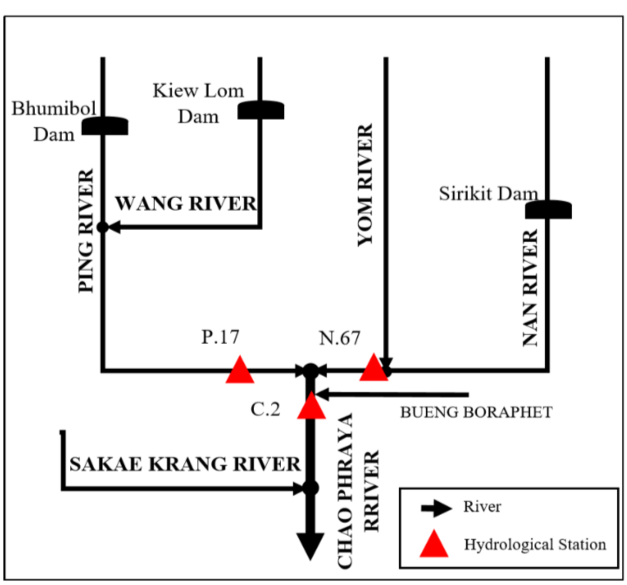


Fig.2. Schematic Diagram of U-CPRB and M-CPRB.

In Figure 1(c), Nakorn Sawan municipality and vicinity covering three districts (namely Mueang Nakorn Sawan, Chum Saeng and Tha Tago) is used for administrative boundary of the study area for applying HEC-RAS. There are about 163.54 sq.km covering 8 sub-districts. This area has Nakorn Sawan Municipality positioning in the right side of CPR, Bueng Boraphet in the left side, Bueng Senat between Ping and Nan rivers.

Data Collection and Analysis Methods

The main data sources such as daily flow discharge, daily precipitation and cover/soil maps per year are from Royal Irrigation Department (RID), Thai Meteorological Department (TMD) and Land Development Department (LDD), respectively. In field survey, six locations where refer 2011 flood situation collected by interview and old pictures. Table 1 shows input data including their sources.

The assessment of the flood hazards is categorised according to optimal duration of return and damage to property and persons. Several physical characteristics were used for simulated flood maps (water depth elevation, flood wave velocity, and duration of flooding). Moreover, this study used water depth level to classify flood hazard Level (FHL) as the values less than 0.6 m are low hazard level, 0.6-1.0 m are medium level, 1.0 to 3.5 m are high hazard level, and more than 3.5 m are is very high hazard level [24].

Table 1. Data Collection for Hydrological Models

No	Items	Sources
1	Historical Daily Discharge and Water Elevation Data	Royal Irrigation Department
2	River Cross-Sections and Manning Roughness Coefficients	
3	Historical Daily Precipitation, Evaporation and Temperature Data	Thailand Meteorological Department
4	Land Cover, Land Use and Soil type Maps	Land Development Department
5	Digital Elevation Model (DEM)	Aster Global DEM
6	Locations and Inundation Depths	Field Survey

Overall Approach and Methodology

Flood Hazard Assessment is divided into four main parts as shown in Figure 3. Firstly, considering the simulation of flow discharge hydrograph with different periods used hydrological modeling (HEC-HMS). The key inputs are historical daily rainfall and discharge data, digital elevation model (DEM), soil and land use types are essential for model calibration and validation. Secondly, generating flood inundation areas used historical daily flow discharge data by using hydrodynamic modeling (HEC-RAS) that analyzed from observed river elevation data and river cross-section to calibrate and validate the model. Thirdly, the estimation of the flood hazard map is assessed by using a flood depth parameter. Finally, flood hazard maps were analyzed including land use change projection following the trend of historical change by using Future Land Use Simulation model (FLUS).

Model Formulation and Inputs/Outputs

The Hydrological Model, HEC-HMS, simulates runoff volume, peak flow rates, timing and sedimentation [27]. Simulating flow discharge based on historical rainfall data. First, using HEC-GeoHMS, Extending HEC-HMS, the raster layer, the sub basin and river network systems are developed. It can be sent as basic maps to the HEC-HMS model. Secondly, the input into the model of raster, precipitation data, earth cover and soil map, which employed a set of data to generate data for each sub-case from precipitation to ruin. In addition, numerous weather processing formulae such the simple water surface detention canopy method and the SCS curve number for each sub-basin must enter the runoff curve number.

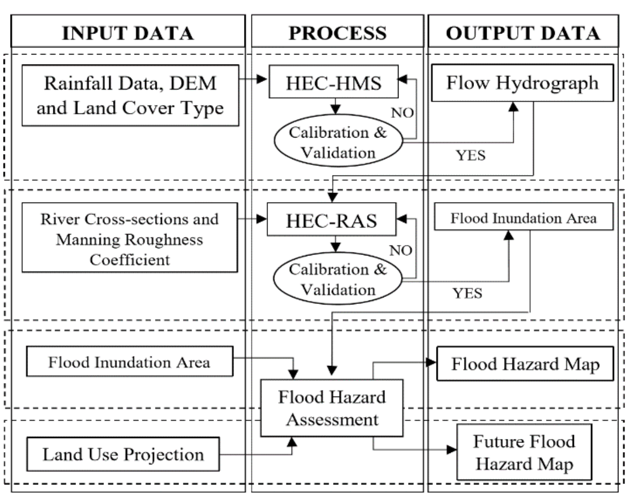


Fig. 3. Overall Methodology

For channel routing Clark units hydrograph. The precipitation weights are utilized for the Thiessen Polygon amendment to provide an indicator of weights that adds latitude and longitude to all sub-basins. The simulation of the overall flow from each basin can thus check the link between observation and simulation of C.2 discharge data (Mueang Nakorn Sawan) discharge gauges. Calibration and validation periods were analyzed only five months from July to November in 2008-2012 and 2013-2017, respectively. Application standard sensitivity indicators can show the performance of modeling and accuracy of observed and simulated flow discharge.

HEC-RAS, the U.S. Army Corps of Engineers' River Analysis System model was used to perform two-dimension flow analysis, which combined the 1D and 2D models [26]. HEC-RAS 2D was utilized to create flood maps with unstable flow data. This study. Daily dumping data, fluvial cross-cutting data, the ruggedness coefficient and DEM are detected as the key input. HEC-GeoRas, the extension model for ArcGIS programmatic application, prepares fluvial geometry information for the production of base maps for HEC-RAS modelling (e.g. flux centerline, stream centerline, xs cut line and base map). This model is capable of generating streams, flow and bank lines.

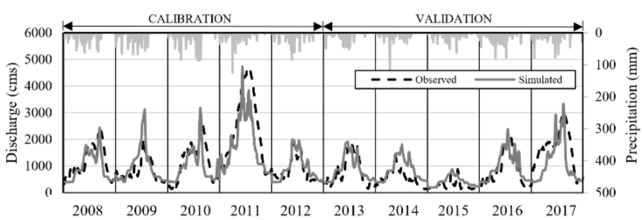
The HEC-GeoRAS outputs are the major HEC-RAS input for simulating flood maps. Furthermore, river cross sections from both field surveys and geographical information systems to boost the accuracy of a topographical map are another input data. Following entry of the data, all outputs were validated by means of statistical indicators by comparison of the observed and simulated water levels at C.2 (Mueang Nakorn Sawan). Unsteady flows will be selected for analysis in 2011, the biggest flood in Thailand, for a flood occurrence. The period of calibration was 2008-2012. For the validation period 2013-2017, this study analyzes five months annually (July-November). All inputs have been utilized to simulate flood maps, divided into a depth of water per grid.The performance of HEC-HMS and HEC-RAS modeling was carried out using statistical measures by using observed and simulated data. The standard statistical performance indicators include coefficient of determination (R^2), Nash-Sutcliffe Efficiency (*NSE*), Percent Bias (*PBIAS*), Volume Ratio (*Vr*) and Root Mean Square Value (RMSE).

4. RESULTS AND DISCUSSIONS

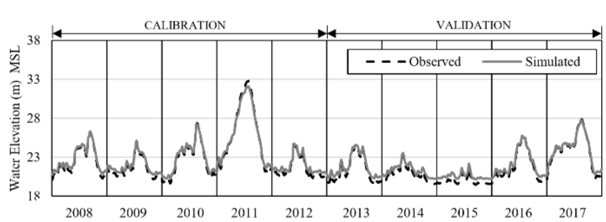
4.1 Calibration and Verification of Hydrological and Hydrodynamic Modelling

Hydrologic model, HEC-HMS was generated flow hydrograph/ daily water discharge from daily precipitation and land use data. The calibration was analyzed using comparative computed and simulated daily flow discharge data (July-Nov) in 2008-2012 and then validated from 2013-2017 at a hydrological station, namely Mueang Nakorn Sawan station that gathers from Royal Irrigation Department, Thailand. In calibration and validation processes, the hydrologic parameters were adjusted using a trial-error approach until both observed and simulated discharge similarly. The result of the comparison of observed and simulated was shown a good agreement in Figure 4(a). However, the study found that the lowest discharge is 94.50 cms. The computed coefficient of determination values of stations was found around 70-80% to be almost the same as the observed values. The values of Nash-Sutcliffe Efficiency and Root Mean Square Value were found as the range of 0.78 to 0.81 and 60 to 70, respectively, while these values should be 1 and 0 for perfect agreement. Additionally, 0.88-1.04 is a reasonable ratio of the observed to the calculated flow discharges.

HEC-RAS model was simulated flood inundation map from flow hydrograph that is output from HEC-HMS. The model was calibrated and validated using a comparative simulated and observed water surface elevation data (Jul-Nov) between 2008-2012 and 2013-2017, respectively, which gathers by station C.2 (Mueang Nakorn Sawan). With the calibration approach, surface roughness coefficient of channel and floodplain were corrected by trial and error that showed within range 0.030 to 0.033 for along river. However, the result of calibration and validation at station C.2 were shown in Figure 4(b), where ground elevation based on mean sea level. In conclusion, the coefficient of determination values of a station was found around 99-100% to be almost the same as the observed values. The values of Nash-Sutcliffe Efficiency and Root Mean Square Value were found to vary from 0.96 to 0.98 and 0.04 to 0.08, respectively. The Volume Ratio between the observed and computed water levels is 1.00-1.02, which is very satisfactory.



(a) Model Calibration and Validation for HEC-HMS



(b) Model Calibration and Validation, HEC-HMS

Fig. 4. Calibration for 2008-2012 and Verification for 2013-2017 at Station C.2 (Mueang Nakhon Sawan).

Moreover, about five flood-surveyed points were submerged and damage from 2011 flooding, were selected to validate between the computed and observed flood depths in 2011. The study found that have only four points such as Boromarajonani College of Nursing, Sawanpracharak Hospital, Park Wat and Nakorn Sawan were to have the volume as simulated water depths.

As a result of the flood hazard assessment, the study used a water depth parameter from the computed inundation map to delineate the flood hazard map. Flood hazard level (FHL) presented on four hazard levels including very low, low, medium, high and very high. However, the 2019 flood hazard area per each level represented in Figure 5.

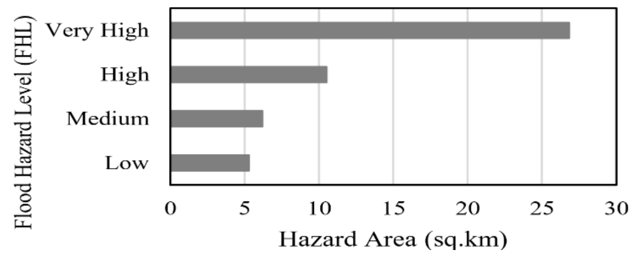


Fig. 5. Flood Hazard Areas with Levels in 2011.

As shown in Figure 6, flood hazard map in 2011 covering Nakorn Sawan municipality and surrounding was found that Bang Muang and Bueng Sanet Municipalities have hazard levels from high to very high. Also, the Soult-west of the capital city was medium and high damage due to nearby Bang Pramong cannel where diversion from the west side of Nakorn Sawan city. With the left side of CPR, there is a large inundation area including Bueng Boraphet, irrigation area and surrounding. The flood areas between Ping and Nan River have high damage such as Bueng Sanet, Bueang Sanun and Old River.

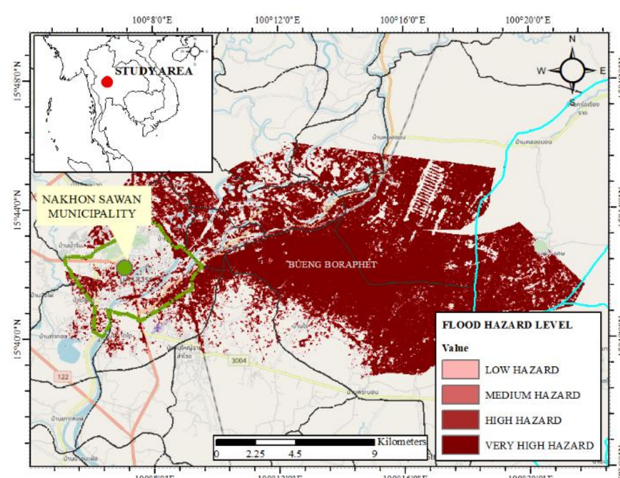


Fig. 6. Flood Hazard Map in 2011 for NSW Municipality and Vicinity.

4.2 Results of Model Applications for Historical Analysis

Historical Analysis was analyzed the spatial and temporal aspects of runoff volume and precipitation data of M-CPRB where includes Nakorn Sawan and some parts of the Uthai Thani provinces. Historical runoff volume analysis is used four stations N.67 (Chum Seang, Nakorn Sawan Province), P.17 (Banphot Phisai, Nakorn Sawan Province), C.2 (Mueang Nakorn Sawan, Nakorn Sawan Province) and C.35 (Sappraya, Chainat Province). It can refer to upper, medium and lower of M-CPRB, respectively. The upper was covered lower Ping, Yom, and Nan Basin. The second area includes Nakorn Sawan Province where U-CPRB. Lastly, the lower part is to start from Uthai Thani until Chai Nat Provinces.

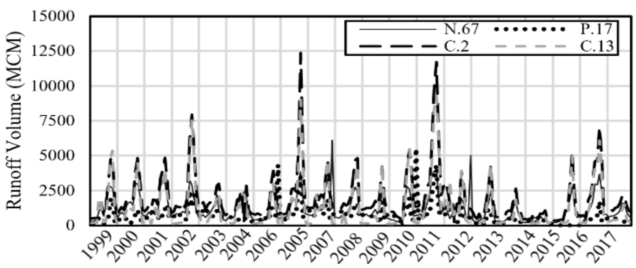


Fig. 7. Historical Monthly Runoff in 1999-2017 at Stations P.67, P.17, C.2 and C.13.

From Figure 7, the relationship between monthly flow volume data at stations P.17, N.67, C.2 and C.13 from 1999 to 2017. Historical monthly flow volume data at station C.2 have volume more than station C.13, P.17 and N.67 because Nakhon Sawan Province is a collection point of Ping, Wang, Yom and Nan Rivers. However, Sappraya Station at Chatnat has river volume data lower than the middle part because of the bypass project at both sides of Chao Phraya River that used Tha Chin and Chai Nat and Pa Sak Rivers to drain excess water when the flood occurs.

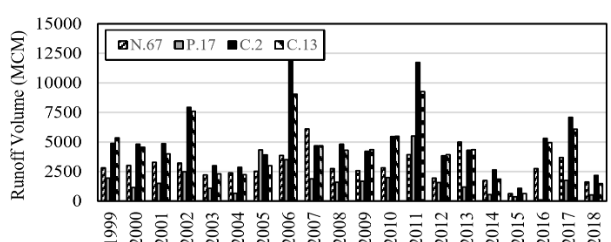


Fig. 8. Historical Monthly High Runoff Flow in 1999-2017 at Stations N.67, P.17, C.2 and C.13.

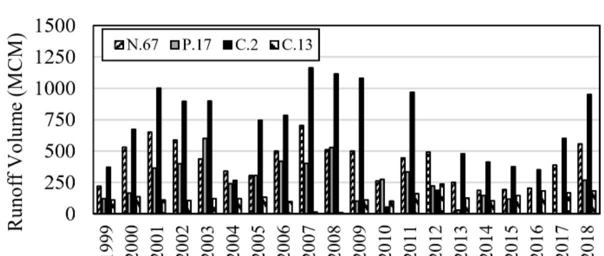


Fig. 9. Historical Monthly Low Peak Runoff in 1999-2017 at Stations N.67, P.17, C.2 and C.13.

Figure 8 represents the maximum monthly flow volume from 1999-2015 that it tends to reduce to start in 2011 until 2016 which has lowest than 500 MCM in the whole areas of M-CPRB in 2012-2016. With historical analysis, the monthly flow discharge at Chainat Province is lower than Nakorn Sawan because Chainat Province has many floods management projects such as Chao Phraya dam, Tha Chin bypass projects. This is the main cause to reduce water flow in CPRB when passes at C.13.

With a monthly low peak volume graph (See in Figure 9), a histogram indicates the flow volume trend in four upper, middle and lower discharge stations. The graph is significantly lower for all stations from 2007-2015 near to zero. Due to abnormally high moonsoonal rainfall, the curve is quite different for 2011 from the historic minimum volume. The basic flow of CPR can be increased by over 900 MCM.

The spatial and temporal aspects of precipitation for M-CPRB were analyzed from daily rainfall records measured by TMD on 1999-2017. Three rain gauges including 386301 (Phichit Agro., Phitchit Province, 400201 (Nakorn Sawan) and 400301 (Takfa Agro., Nakorn Sawan Province). This can refer to upper, medium and lower parts of M-CPRB. The upper part covers the lower Ping, Yom, and Nan Basin. The second area includes Nakorn Sawan Province where located U-CPRB. Also, the lower part starts from Uthai Thani until Chai Nat Provinces.

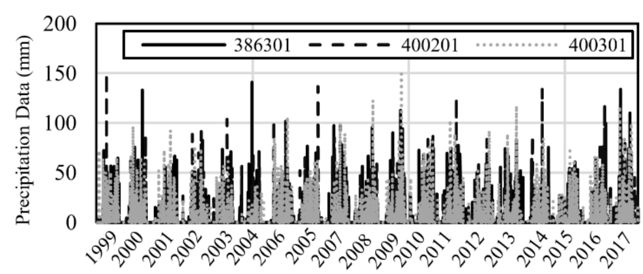


Fig. 10. Historical Daily Precipitation in 1999-2017 at Weather Stations 386301, 400201 and 400301.

The graph shows historical daily precipitation data at stations 386301, 400201 and 400301 on 1999-2017 as Figure 10. Historical data at station 400201 and 400301 have precipitation depth more than station 386301 because of Equatorial Trough across M-CPRB. Moreover, Takfa Station in the lower area of Nakorn Sawan had the highest rainfall.

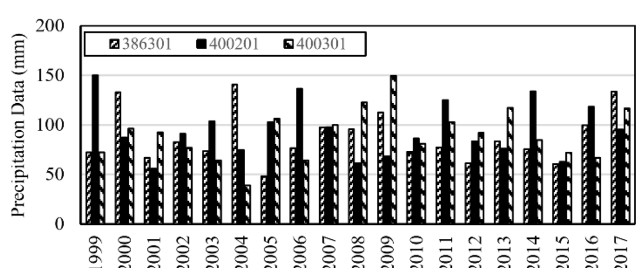


Fig. 11. Historical Maximum Daily Precipitation in 1999-2017 at Weather Stations 386301, 400201 and 400301.

With high peak daily precipitation graphs (See in Figure 11), a histogram shows the maximum of daily rainfall depth at three weather stations in upper, medium and lower (386301, 400201and 400301). The three graphs each station tend to slowly reduce around 7.8 percent per decade, especially, the peak rainfall at Nakorn Sawan Ago station in 1999, 2006, 2011, 2014 and 2016 tend to grow down approximately 20 mm per 15 years. Also, the trend of Phichit rainfall record is slightly reduced from 140.8 to 133.8 mm (2004-2017).

As a result, the trends of historical monthly runoff volume and daily precipitation records changed in temporal and spatial aspects depended on extreme weather phenomena. The historical peak and low runoff volume of each part are slightly reducing and also M-CPRB has the highest flow volume when compared with L-CPRB. The lower and middle parts of CPRB has higher rainfall depth more than upper CPRB. Also, the trend of rainfall pattern is reducing for the whole area.

4.3 Projections of Future Hydrological Hazards with Land Use Change and Urbanization Patterns

The trend of land use change impact is a significant parameter on flow discharge and soil infiltration volumes [25]. The Curve Number (CN) volumes which cover from land use types per each basin depend on the proportion of agriculture, forest, miscellaneous, built up and water body areas. The hydrologic model/HEC-HMS was used to simulated flow discharge hydrograph with land use prediction on 2020, 2050 and 2100. The prediction method was analyzed from historical land use maps in 2013 and 2018 collected by LDD using a linear regression method.

The simulation of the potential land use prediction in M-CPRB was analyzed taking into account patterns in economic trend. The land use map in 2016 and 2019 was used as the last land use trend while the land use map in 2020 was expected comparing it with observed land use based on Kappa statistical analysis (K). The K value is 0.92, which is greatly appropriate and fairly accurate for potential land use predictions. Figure 12 indicates the simulated land use projection in 2020, 2050, and 2100 that was separated to five types, i.e., agricultural, forest, miscellaneous, build-up and water body areas. All of those types tend to increase following past land use change trend. Except, forest area seems to reduce and change to be build-up, agricultural and water body areas.

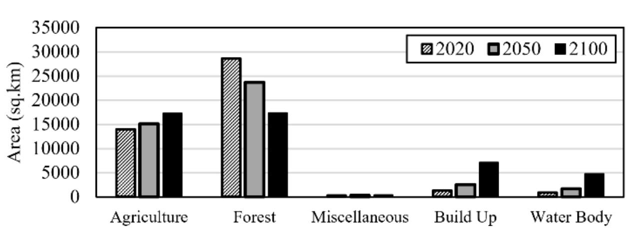


Fig. 12. Land Use Change Projection of M-CPRB for 2020, 2050 and 2100.

As a result, the projection on flow discharge volumes shows on three lines of maximum, average and minimum volumes as Figure 13. With the whole lines, was a similarity increase, especially, the maximum trend is clearly increasing from 3,300 to 3,500 in 2020 and 2100, respectively.

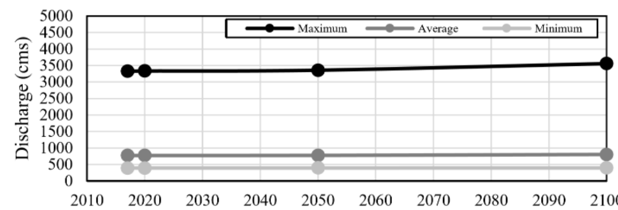


Fig. 13. Maximum, Average and Minimum Discharge Projections at NSW Station in 2020, 2050 and 2100, respectively.

With output from HEC-HMS modeling, predicted flow hydrograph data with different years used to simulate flood inundation area at Nakorn Sawan municipality and surrounding. The water depth per each grid was analyzed to be four flood hazard levels (FHL) that present low, medium, high and very high relied on water depth. Four graphs were shown in Figure 14 to present the trend of hazard area per FHL in the future period. A very high hazard line has a high proportion of more than others. In other words, the study area has many submerged areas that are the water depth level of more than 3.5 meters.

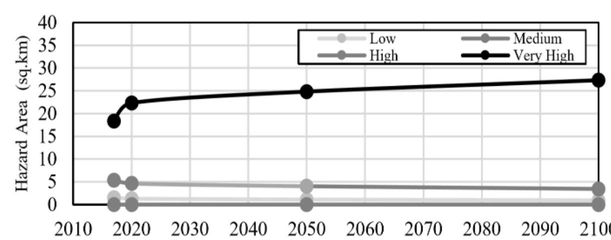


Fig. 14. Flood Hazard Level Projections for NSW Municipality and Vicinity in 2020, 2050 and 2100.

Predicted flood hazard maps on 2020, 2050 and 2100 show as Figure 15. The flood hazard areas tend to increase and spread to the community when compared with three maps. In the next step, flood hazard maps with land use projection will apply with water management/adaptive strategies and climate projection. Besides, the risk assessment will use flood hazards to be the main input data.

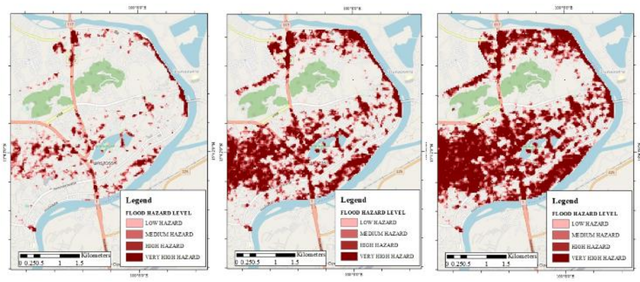


Fig. 15. Flood Hazard Maps for NSW Municipality in 2020, 2050 and 2100, respectively.

4.4 Discussions

Hydrological and hydrodynamic modeling for M-CPRB has high reliability and correction, as with previous study [4]. The study found that the right side of CPR where Bueang Boraphet and surrounding are located was submerged and very high hazard level than Nakorn Sawan municipality, as with previous study [14].

Land use change has an effect on water discharge and inundation areas that tend to increase as future land use and urban growth. Especially, Nakorn Sawan tends to spread from center to surrounding without proper control. Also, Boraphet and Sanet lakes were disturbed to be settlement and irrigation areas. In other words, the reservoir storage capacity which can store water when flooding occurs was significantly reduced. The changing flow runoff under land use tends to increase around 4 cms or 43,000 cu.m per year.

The M-CPRB has highest peak runoff and precipitation volume than U- and L-CPRB (with both the discharge and rainfall data tend to reduce on average of 1 and 0.78 percent per year). Therefore, M-CPRB has higher hazard in the future, in comparison to U-CPRB and L-CPRB.

Previous studies [14] and [18] have analyzed only the change of hydrological factors under climate change in the CPRB. However, it did not consider water management and adaptive strategies. Based on the hazard assessment results, water management and flood protection measures/strategies need to apply different measures such as levees, diversion channels, green infrastructure and water detention under climate and land use changes. Green surface conservation is one non-structural measure to increase soil infiltration and water storage capacity which has high potential in the M-CPRB.

5. CONCLUSIONS AND RECOMMENDATIONS

It was found that flood hazard levels and areas are dependent on flow discharge levels and land use types. Land use change and urbanization tend to increase and spread out from urban to rural areas that can also increase runoff volumes and inundation areas. For the whole CPRB records, historical runoff volume and rainfall show a slight reduction every year for all parts of M-CPRB, while M-CPRB has higher flow discharge and precipitation than U-CPRB and L- CPRB.

The results of this study can be utilized as inputs to flood risk assessment with adaptive policy/strategies related to land use change, especially concerning natural and green surface areas (such as Bueng Boraphet and Senat in the study area) can potentially reduce peak discharge and water level as natural detention storage. There are some limitations on the dataset in the study which is unavailable and missing in historical rainfall, discharges, river cross sections and reservoir capacities, which could potentially affect the modelling analysis results. Further research should be more on hydrological hazard prediction with damage and loss analysis by applying extreme climatic events in the assessment, which can be more comprehensive on including both climate change and urbanization impacts.

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