FLOOD FREQUENCY ANALYSIS FOR EXTREME EVENTS UNDER CLIMATE CHANGE IN YOM RIVER BASIN OF THAILAND

Aksara Putthividhya and Apiwit Jomvoravong

ABSTRACT

Changes in the flood frequency are expected under global climate change. We seek to utilize the hydrological model HEC-HMS for estimating extreme flood characteristics in Yom river basin. Historical rainfall and flood data in combination with rainfall products from MRI-AGCM3.2S (the latest version of GCM developed by MRI, Japan) were employed for HEC-HMS model calibration. For some parts of the basins with limited streamflow and rainfall data, HEC-HMS with Snyder's hydrograph synthesized and transposed methods were applied using calibrated hydrological parameters from the upstream sub-basins with adequate continuous daily records during 1978-2006. The simulations were accomplished at 10 stream gauges in Yom basin for extreme events occurred in 2000, 2002, and 2004. Execution of the watershed hydrologic model HEC-HMS yielded the annual maximum flood characteristics of interest. The flood-frequency relationships generated by the flood model were used to estimate the Annual Exceedance Probability (AEP) of selected flood characteristics in Yom river basin of Thailand.

Keywords: Extreme Flood, Frequency Analysis, Climate Change, Chao Phraya River Basin, MRI.

1. INTRODUCTION

In 2011, Thailand experienced the worst flood disaster in five decades. The Chao Phraya river basin was severely hit by the flood. The socio-economic damages from this flood were estimated at 45.7 billion USD, especially to the industrial sector, which was 10 times higher than the loss due to the previous major flooding. The Chao Phraya river basin is located in the heart of Thailand, covers roughly 30% of the country’s land surface (i.e., 160,000 km²), and is the largest river basin in the country. The hydrodynamics of rainfall and flow characteristics as well as quantities and intensities of the rainfall and flow in the upper Chao Phraya river basin are in fact controlling the total inflow discharging directly to the lower Chao Phraya and draining into the Gulf of Thailand, respectively. Studies on flood control of the Greater Chao Phraya basin, therefore, have always been focusing on flow characteristics in the upper basin (i.e., Ping, Wang, Yom, and Nan river basins) upstream of C2 gauging station located in Nakorn Sawan province of Thailand.

Yom river basin, located in the upper part of the Greater Chao Phraya river basin, has been facing flood risk management problems as it is considered the only unregulated basin in Thailand. Therefore, the basin is usually experiencing flood and drought cycle throughout the year causing socio-economic damages to water users and the communities. In the present-day hydrologic practice, one approach to estimation of extreme flood characteristics is based on frequency analysis of measured flood peak discharges by fitting a chosen statistical distribution to these values and extrapolating this distribution for determination of peak discharges of low Exceedance probabilities.

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For reliable flood risk assessment in Yom river basin and the development of effective flood protection measures, a good knowledge of flood frequencies at different points (i.e., upstream, midstream, and downstream) in a catchment is required.

The classical approach to obtain design flows is to carry out local or regional flood frequency analysis using long records of observed peak discharge data (Hosking and Wallis 1997). The methods using this approach are well-developed and widely used; however, as it has been shown in many research papers (e.g., Swain et al. 1998) that this approach yields reliable estimates of flood peak discharge if the recurrence intervals of these discharges do not significantly exceed the lengths of measured peak discharge series. It is worth noting that this aforementioned approach generally does not fully utilize the available meteorological observations that contain important information on possible variations of runoff generation processes. Another common shortcomings of this approach is implicit assumptions that the physical mechanisms of runoff generation do not depend on the magnitudes of the water inputs and the drainage basin characteristics are not changed in time in spite of possible human activities and climate change. However, many hydrological processes are essentially non-linear, and the physical mechanisms of extreme flood generation are often quite different from such mechanisms for usual floods. In many cases, the extreme floods can be a result of such unusual combinations of hydro meteorological factors and runoff generation mechanisms that may be unobserved in the historical data.

In this paper, we use the hydrological model HEC-HMS for estimating extreme flood characteristics in Yom river basin. Historical rainfall and flood data in combination with rainfall products from MRI-AGCM3.2S (the latest version of GCM developed by MRI, Japan Meteorology Agency) were employed to calibrate HEC-HMS model. The simulations were accomplished at 10 stream gauges in Yom river basin for extreme events occurred in 2000, 2002, and 2004. Execution of the model HEC-HMS yielded the annual maximal flood characteristics of interest. The flood frequency approach was used to assess peak flows extracted from the simulated flow series linked with climate data in Yom river basin. The model analyses were performed using graphs and statistical criteria such as relative peak discharge error, mean absolute error, and root mean square error.

<table>
<thead>
<tr>
<th>Gauging Station</th>
<th>Location</th>
<th>Area (km²)</th>
<th>Mean elevation (m a.s.l)</th>
<th>Range of Mean annual Precipitation (mm) (1954-2005)</th>
<th>Available Period for Streamflow data</th>
</tr>
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<tbody>
<tr>
<td>Y20</td>
<td>Song, Prat</td>
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<td>237</td>
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<td>since 1977</td>
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<td>Y1C</td>
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<td>133</td>
<td>1101-1150</td>
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<tr>
<td>Y14</td>
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<td>78</td>
<td>1301-1350</td>
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<tr>
<td>Y8</td>
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<tr>
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<td>14,856</td>
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<td>Y16</td>
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<td>1251-1300</td>
<td>since 1995</td>
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<td>Y17</td>
<td>Samneang, Pijit</td>
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<td>29</td>
<td>1151-1200</td>
<td>1977-1980, since 1990</td>
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<tr>
<td>Y5</td>
<td>Photee, Pijit</td>
<td>22,344</td>
<td>26</td>
<td>1051-1100</td>
<td>1967-1997</td>
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</table>
2. METHODS

2.1 Study Area

The upper Chao Phraya plain of Thailand depicted in Figure 1 covers about 160,000 km² in 8 provinces with the total population of 4 million. The main land use is 63% agriculture, out of which 21% is irrigated, and 24% is devoted for forestry. The average elevation of the basin is 40-60 m above mean sea level. Yom river basin is one of the eight sub-basins, stretching from latitude 15°50’N to 19°25’N and from longitude 99°16’ to 100°40’E with a watershed area of 23,616 km² as illustrated in Fig.1, covering about 16.56% of the Chao Phraya river basin. The climate of the study area belongs to the tropical monsoon type. Mean annual rainfall is approximately 1,143 mm and rainfall distribution is almost uniform in the entire basin, contributing to 26,990 MCM of the total average annual runoff. Terraced mountains mainly characterize the topography of upper Yom basin from Phayao province to Phrae province, and then followed by floodplain area at Sukhothai, Pichit, and parts of Phitsanulok province. The main land use of the basin is predominantly rice cultivation and cattle grazing.
### 2.2 HEC-HMS Hydrologic Model

HEC-HMS (Hydrologic Engineering Centre – Hydrologic Modelling System) model was developed by the US Army Corps of Engineers (Feldman 2000) that could be applied for many hydrological simulations. It is a reliable model that has been applied to analyze urban flooding, flood frequency, flood warning system planning, reservoir spillway capacity, stream restoration, etc. (U.S. Army Corps of Engineers 2010). HEC-HMS contains four main components: 1) an analytical model to calculate overland flow runoff as well as channel routing; 2) an advanced graphical user interface illustrating hydrologic system components with interactive features; 3) a system for storing and managing data, specifically large, time variable data sets; and 4) a means for displaying and reporting model outputs (Bajwa and Tim 2002). In HEC-HMS model, interception, evaporation and infiltration processes in the basin are determined from loss components while runoff processes are computed as the pure surface routing using transform component (Yusop et al. 2007). Calibration of rainfall-runoff HEC-HMS model with respect to local observational data help improve model predictability in the basin of interest, providing users with greater confidence in the more reliable model (Muthukrishnan et al. 2006).

### 2.3 Data Collection

Daily rainfall was collected from 23 stations scattered around the basin for the past 28 years (1979-2006). Monthly evaporation data of the same periods for the agro-meteorological stations was used in this study as well. The rainfall, evaporation, and daily river discharge (for the past 28 years (1979-2006) at 10 gauging stations) data were kindly provided by Royal Irrigation Department (RID) and Thai Meteorological Department (TMD). Monthly minimum flows from each gauging station are considered as the base flow.

**Meteorological Data**

Three different climate experiments, i.e., present climate (1979-2006), near future climate experiment (2015-2039), and the far future climate experiment (2075-2099) were employed from MRI-AGCM3.2S variables. Gridded daily precipitation, 2-m high air temperature, 10-m high wind speed, vapor pressure and incoming short wave radiation, calculated on a 1×1 km grid for the period 1979 to 2006, were used in this study for flood frequency relationship development. Wind speed, vapor pressure and incoming short wave radiation were obtained from the MRI model at approximately 8 km resolution and interpolated down to the 1×1 km spatial grid.

**Hydrological Model Application**

This study employed HEC-HMS modeling tool to simulate flow characteristics in Yom river basin using 28-yr long rainfall data records from 23 rain gauging stations located within the basin as well as monthly evaporation data from the same period from agro meteorological station. Watershed and meteorology information were combined to simulate the hydrologic responses. Required data for hydrological modeling includes: catchment/sub-catchment area; landuse patterns; daily rainfall data (generated from GCM with biased correction for current period, near future, and far future); daily river flow data; monthly evaporation data; base flow; peaking coefficient; imperviousness; standard lag; initial deficit; constant rate; time of concentration; storage coefficient and curve number. These values were taken considering the prominent soil type in the basin. HEC-HMS is applied with the deficit and constant loss method by keeping the monthly based flow constant. MODCLARK transformation is used with Standard Hydrological Grid (SHG) size of 2×2 km² for incorporating the distributed precipitation for the model.
Model Calibration

Daily rainfall data, monthly base flows of the rivers, monthly evaporation data of Yom river basin for the year 2002 were employed for model calibration. The calibrated model was verified with real daily runoff discharge at gauging station Y14 located in Sri Satchanalai, Sukhothai province. Long term flow characteristics of Yom river and its tributaries were generated. The calibrated model was later used to simulate river runoff response due to future rainfall projection in 2015-2039 and 2075-2099 periods.

3. RESULTS AND DISCUSSION

3.1 Precipitation Products

Figs. 2A-C show bias-corrected daily extreme precipitation (mm) generated from MRI-AGCM3.2S from 1998-2006 (Figure 2A), 2015-2039 (Figure 2B, near future climate experiment period), and 2075-2099 (Figure 2C, far future climate experiment period) as spatial inputs for the hydrological model HEC-HMS. The present extreme rainfall pattern suggests that more extreme precipitation is expecting in the lower part of the basin from Sukhothai province down to Kampangpetch and Nakornsawan, ranging from 100 to 140 mm. The future rainfall projection both in the near and far future climate periods under the extreme rainfall conditions reveals the decline in extreme rainfall in the lower basin. The percentage changes in daily maximum precipitation in the near future and far future periods relative to 1998-2006 are also shown in Figs. 2D and 2E, respectively. In these figures, the significant increase in future precipitation is found over the central part of the basin, sometimes increasing by as much as 50%, although the absolute increase is less than 225 mm/d. Some weak increases can be observed over the southern part of the basin, as much as 15%. A decrease is evident over the northern part of the basin from 10-15% in the near and far future period of simulation. These different responses to global warming reflect the large uncertainty in future precipitation change over the basin.

![Figure 2. Extreme Rainfall Patterns in Yom River Basin: (A) Present; (B) Near Future (2015-2039); (C) Far Future (2075-2099); (D) Rainfall Difference between Near Future and Present; and (E) Rainfall Difference between Far Future and Present.](image-url)
Frequency analysis of extreme rainfall patterns was carried out on spatial present, near future, and far future climate experiments as shown in Figure 3. Figs. 3A-C illustrate the present observed rainfall vs. MRI-simulated rainfall at several return periods for controlled stations 59032 (in Sawankalok, Sukhothai province), 39022 (in Bangragum, Pisanulok province), and 40043 (in Song, Phrae province), respectively. The previous work by Hanittinan and Koontanakulvong (2012) reported that the bias-corrected MRI simulated rainfall patterns fit with the observed data from representative RID rain gauge stations better compared to the products from other GCMs (e.g., ECHAM5 and CSIRO). Projections of future extreme rainfall for near future (2015-2039) and far future (2075-2099) are also presenting in Figs. 3D-F in comparison to present extreme rainfall and real observations at various return periods. Reduction in maximum rainfall magnitude in both near and far future periods further plays an important role in rainfall-runoff simulation in HEC-HMS hydrological model and flood estimation in the basin of interest.

Figure 3. Frequency Analysis for Present Observed and MRI Rainfall Products at Various Location in Yom River Basin.

3.2 Runoff Simulations

The simulated stream flow from HEC-HMS is checked to confirm that they are reasonable and consistent with the observations. The calibration of HEC-HMS was done automatically in semi-distributed mode for the catchment under investigation. The model parameters are calibrated until the results are favorable with close proximity of the observed and the simulated hydrographs. Validation of the hydrological model was performed on the additional precipitation and discharge data set from Year 2002. Results for the hydrologic model showed a reasonable fit between model simulation and observations; hydrograph shape and timing of peaks matched well as shown in Figure 5, although the model tended to overestimate runoff. In the majority of sub-basins of Yom river basin, the hydrograph shape was
accurately reproduced in model output. However, the model tended to overestimate volume of runoff and frequently did not accurately define peak sharpness as observed through stream measurements. Calibration of the model improved results by greatly decreasing the volume of runoff and improving peak sharpness at most locations. The results in Figure 5 demonstrated the simulated hydrographs using observed precipitation for the validation periods at the selected gauging stations. The visual assessment confirmed the fairly good fit between observed and simulated data with a little higher peak flows for extreme events. Based on the above validation all parameters were considered generally suitable for hydrologic modelling. The results were discussed more in detail in terms of flood frequency analysis of annual maxima peak flow of the extreme events in the basin.

Figure 4. Yom River Network Composed of Yom Main River Course with Its Runoff Station and Tributaries Generated in HEC-HMS Model.

By using the bias-corrected precipitation as input to regional hydrological model HEC-HMS applied with Yom river network (i.e., Yom main river course and its tributaries with stream gauge stations shown in Figure 4), a series of daily discharge for 28 years in each climate experiment period was generated as shown in Figure 6. By comparing present and future climate periods in flow duration curve, the response of rainfall-runoff to a changing climate can be assessed. The comparison of the runoff in the present climate and the future climate revealed significant increases about 10-40% of the mean monthly discharge in the present climate. The runoff characteristics of the near future climate, however, significantly rose up in September (i.e., common wet periods in Yom river basin). The mean runoff in the dry period did not change much due to changes in temperature, evapotranspiration, and rainfall intensity with less effect to the mean rainfall-runoff relationship.
3.3 Frequency Analysis of Extreme Events

In flood frequency analysis, a relationship between a flood magnitude $Q$ and its return period $T$ was developed by statistical modelling of a time series of peak flows. For this, annual daily maximum peak series were primarily used. The annual maximum series consisted of one value, the maximum peak flow from each year of simulation. Gumbel distribution function, shown to be generally effective with the common areas in Thailand, was fitted to the observed annual maximum peak flows for the 28 yr records and extrapolated up to a return period of 100 yr. The hydrological model was run for designed 24 and 72 hours’ storms for the return periods of 25, 50, 75, and 100 yr as shown in Figure 7. From the frequency analysis results, the maximum daily flow at Y.14 station tended to increase steadily every recurrence year.
Figure 7. Cumulative Distribution Functions of the Annual Maximum Daily Discharge at Y14 Station for Present, Near Future, and Far Future Climate in Yom River Basin Fitted with Gumbel Distribution Model.

By comparing with real observations, i.e., the fitted Gumbel to observed peak flows, under the simulated range of design flows, a good agreement could be detected and evaluation of change in extreme floods and flood risk from future climate periods could be assessed. Changes in return period of 2 to 100 years design storms for flood in different climate periods are also illustrated in Figure 7 at one representative location in Yom river basin. The magnitude of streamflow in the future period has a general tendency to increase for all period of occurrence time compared to the results of present climate conditions. It is worth noting that at smaller return period, there is no significant change in flow for near future and far future period. Since Yom river basin is considered an unregulated basin with no structural water management tool, the low flow trend for near future experiment might result in increased drought risk in the basin.

CONCLUSIONS

The main contribution of this study is for flood hazard assessment in Yom river basin, which is critical for design flood control and mitigation system. In this paper, we applied derived flood frequency analysis, where design floods were estimated based on simulation results from a hydrological model (HEC-HMS), which was driven by observed or synthetic rainfall data. Flood frequency analysis for 2-, 5-, 10-, 25-, 50-, 75-, and 100-yr return periods were investigated. The model calibration and verification results revealed satisfactory overall agreement between observed and computed data. Although there were definite discrepancies in the results, they were considered acceptable. The flood simulations are believed to be further improved with more data collection with updated landuse changes to mimic the impacts of climate change into the model. Changes in return period of 2 to 100 years design storms for flood in different climate periods at some representative locations in Yom river basin had a general tendency to increase for all period of occurrence time. At smaller return period, there was no significant change in flow for near future and far future period. Since Yom river basin is considered an unregulated basin with no structural water management tool, the low flow trend for near future experiment might result in increased drought risk in the basin. With the historical flood observation exists, derived flood frequency analysis provides several advantages: i) when using
hydrological modelling for design it is possible to consider planned alterations in land use and management, future changes in climate or the introduction of new flood protection measures, whose effect is not contained in observed historical flood records; ii) hydrological modelling allows one to obtain the full hydrograph for design, which is usually not available from peak flow records. This is most important for the design of reservoirs or for flood mapping where the flood volume is essential; and iii) the estimation of design flows can be carried out for completely ungauged or sparsely gauged basins if the parameters of the hydrological model are recognized and the rainfall model can be applied for unobserved regions.

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REFERENCES


