FLOOD RISK ASSESSMENT WITH HIGH SPATIAL RESOLUTION FOR FLOOD DISASTER MITIGATION WITH CONSIDERING CLIMATE CHANGE SCENARIO

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ABSTRACT

One of the important components in flood disaster risk reduction is the availability of spatial information on flood risk that include: flood discharge \((q)\), flood depth \((h)\), flood extent \((A)\), flood duration \((t)\), and the loss value due to flood which could be quantified in the form of damage costs \((\theta)\). Change in the value of risk \(f(h, A, t, \theta)\) was hypothesized to be sensitive to climate change and other environmental factors that exist at a river basin area. Therefore, it is quite important to control the flood disaster risk as a part of adaptation programs to the climate change impacts and to deal with the increasing pressure due to anthropogenic activities. Additionally, to support the action plan and to increase the understanding and awareness related to the flood disaster mitigation, spatial information on flood risk which having high resolution and precision is required. This study aimed to quantify the spatial information of flood risk with high spatial resolution. 2-D flood-modelling system (e.g., rainfall-runoff-inundation), climate change projection and risk assessment have been used as the main method. Furthermore, this study has been focused in the Batanghari River basin, Sumatera and 13 river catchments flowing through Jakarta Capital City, Indonesia. Obtained risk information forms the basis for long term management decisions on improving operational flood risk management, especially in order to cope with impacts of the future climate change.

Keywords: climate change, flood risk, flood disaster mitigation, Batanghari River, Jakarta

INTRODUCTION

Indonesia, geographically and hydro-topography, is very susceptible to the occurrence of various types of natural disasters especially those related to water related problems such as floods, droughts, and landslides. Indonesia, which has abundant water resources, has approximately 5,590 rivers and 600 of them are potentially at high risk of flooding. In total, the extent of flood prone areas within the main river reaches 1.4 million hectares. National Disaster Management Agency (BNPB) quantify the number of location, frequency and intensity of occurrence, as well as the value of losses from the flood disaster are continue to increase within the last 50 years.

Based on the BNPB information (http://www.satuharapan.com/read-detail/read/tren-bencana-banjir-meningkat-514-korban-setiap-tahun), floods and landslides in Indonesia tend to increase. BNPB mentioned that in 2003 there were
266 incidents of floods and landslides and increased to 822 incidents in 2013. In that period, there are 6,288 events or 572 events per year, cumulatively. The highest number of flood and landslide incidents occurred in 2010, which was 1433 events.

Many studies have demonstrated that there is two factors cause the floods occurrence. First, natural events such as very high rainfall (extreme weather) and sea level rise. This condition is exacerbated by the fact that many people live in locations with topographic conditions are lower than river water levels or below sea level. For example, flood event that occurred in some areas of DKI Jakarta Province due to excessive groundwater extraction process and land movement. Second, human activities that cause excessive pressure on land use demands and later it effects the changes in ecosystem function and environmental degradation.

If there is no more integrated and mitigation effort based on society participation then the changes in climate and land use, which are become more intensive in the future, hypothesized will to continue to contribute the increase of flood hazard and its risk, especially in river basins that have national strategic value. Therefore, the implementation of adaptation program including disaster mitigation in response to climate change at the river basin scale is urgent to be carried out. In this regard, quantification of risks with a strong scientific basis and a higher level of spatial resolution and accuracy are necessary. Another fact, although climate change-related research is already underway, studies of climate change impact projection on flood risk are still limited in Indonesia. Therefore this paper presents the concept of spatial quantification of flood risk in river basin scale with high precision by considering the function of climate change and anthropogenic factors.

**STUDY AREA AND METHOD**

Batanghari River basin (47,479.54 km2) that situated in Sumatera Island, and 13 river basin (6,070.00 km2) flowing through DKI Jakarta Province, the capital city of Indonesia, are selected as study sites. According to the climate projection analyses which focused on the change of average monthly rainfall depth especially in December (peak of rainy season), these two study sites are hotspot
locations that will experience with an increase in the number and intensity of rainfall during the future climate period.

![Figure 1](image)

**Figure 1.** Projected changes in average monthly rainfall (%) for December in the period of 2075-2099 compared to the average rainfall of December in the period 1979-2004; (a) Batanghari River basin and (b) 13 river basins flowing through Prov. DKI Jakarta, the capital city of Indonesia.

The Batanghari River basin represents a large river basin area dominated by forests, plantations, and agriculture land uses. An intensive conversion of land use from forest to agriculture encountered in this basin. Meanwhile, 13 river basins in Prov. DKI Jakarta classified as small to moderate basin area. Type of land cover in this area is dominated by settlements, paddy fields, and moor. Along with the increase in population and economic activity, in these study areas, there has been a significant intensification of land use conversion, especially from agricultural land use to settlements. As a result, the two selected sites have the same relative problem of increasing the intensity and frequency of flood disasters although they have different flood types and characteristics.

The amount of flood risk determines the magnitude of the disaster level and the level of losses. The formulation of flood risk in this study is based on the equation as below (Tariq et al, 2013):

\[
Flood\ Risk = \frac{Flood\ Hazard \times Exposure \times Susceptibility}{Control\ Measures}
\]  

(1)
Flood risk value is affected by the magnitude of the flood hazard; biophysical condition of river basin which is represented by the vulnerability factor, and; existing flood control measures. Dynamics changes of the flood hazard values are quantified based on the changes of flood dimension that consists of: flood discharge ($q$), flood depth ($h$), flood extent ($A$), and flood duration ($t$). Flood hazard dimension is strongly influenced by the duration and intensity of extreme rainfall with probabilities of occurrence $P$. The vulnerability factor of river basin biophysical component can be explicitly determined by the exposure and susceptibility. Nevertheless, in this study both factors were implicitly quantified in the form of damage costs ($\theta$). If flood risk unit given in the form of loss value with nominal of rupiah ($Rp$) then equation 1 can be simplified as follow:

$$Flood \ Risk \ (Rp) = f(P(t,q,h,A),\theta)$$

(2)

RESULT AND DISCUSSION
Spatial information of flood risk in Batanghari River basin and DKI Jakarta Province in the form of maps had been made by BNPB in cooperation with several related agencies (Figure 2). Based on Figure 2, it can be concluded that the shortage of the flood risk maps created and used at the present time: (1) the information provided is qualitative, i.e. in the form of hazard or strength levels categorized in low, medium and high; (2) the spatial resolution is still low, administrative units such as districts or sub-districts generally serve as the smallest unit of risk identification, and (3) climate change factors have not been included as important variables in the flood risk map creation process. In order to detail the existing map, the concept of flood risk quantification conducted in this study will create flood hazard maps with high spatial resolution. The map created in quantitative way based on hydrological process mechanism-flood propagation including climate change aspect.
Figure 2. Map of flood disaster risk index for DKI Jakarta (left) and Batanghari watershed in Jambi Province (right).

Figure 3 shows the concept for quantifying spatial flood risk for selected river basin. Modeling the process mechanism of runoff and flood distribution spatially inside the river basin is the main method for quantifying flood hazard dimensions such as $q$, $h$, $A$, and $t$. The rainfall-runoff-inundation model is one type of hydrological model suitable for use in the calculation of the flood hazard dimension (Sayama et al., 2012). The smallest unit of area within a model able basin depends on the spatial resolution required, known as grid. For large basin cases like Batanghari River basin, 500 m - 1 km resolution is used, while for 13 DAS in Jakarta use smaller resolution (10 m - 90 m). Furthermore, the temporal dynamics of the flood hazard dimension for each location (grid) are converted into the unit of damage values based on the flood dimension relationship curve and the value of losses made based on the data of the inventory of losses generated from the historical flood disaster that ever happened.

In addition, considering the diversity values of soil and topographic properties within the catchment, the quantification of each flood dimension variables is based on the: (1) input of probability data of extreme rainfall events (Hosking & Wallis, 1997) with $t$-day duration and return period $N$-year, and (2) land use type which indirectly represents the influence of anthropogenic factors. To find the impact of climate change and anthropogenic factors, at least two climatic periods (Apip, 2014) and different types of land use includes the current conditions and future projection, should be used in the analysis.
Figure 3. Concepts (frameworks) for spatial quantification of flood risk of watershed scales in scenarios of global climate change impacts and increased anthropogenic factor stresses.

One of the outputs of this research is spatial-temporal information of flood risk. Mathematically, it is formulated as a function of several components, namely: flood flow discharge ($q$), flood depth ($h$), flood inundation extent ($A$), flood duration ($t$), and economic losses value, which are quantified in the form of damage costs ($\theta$). The $q$, $h$, $A$, and $t$ variables are the three variables that naturally (due to extreme rainfall) affect the flood hazard. Furthermore, the magnitude $\theta$ is very influenced by high flood hazard and conditions of vulnerability and resilience of existing biophysical conditions within the watershed, in particular the condition of the community and infrastructure facilities of flood control (exposure & vulnerability components).

For example, the manufacture of spatial flood hazard distributions under climatic conditions has now been established for both selected sites. The criteria for extreme rain are based on rainfall data that causes major flooding. The flood incident of February 2002 in Jakarta and the flood incident of December 2003 in Batanghari watershed was chosen as the basis for the selection of extreme rainfall category. The spatial and temporal information of extreme rainfall in both locations can be seen in Figures 4 & 5.
Figure 4. (a) Spatial distribution of cumulative rainfall (mm) during November-December 2003 in Batanghari river basin (above) and (b) The average extreme rainfall design of Batanghari river basin area made based on rainfall during the flood event of December 2003 (below).
Figure 5. (a) Spatial distribution of cumulative rainfall from January to February 2002 in Jakarta and surrounding areas (above) and (b) The average extreme rainfall design of the area in 13 river basins through Prov. DKI Jakarta made based on rainfall during the flood event in January 2002 (below).
Subsequently, by using the calibrated rainfall-runoff-inundation distribution model, the spatial information of the flood hazard components in unit $h$ is shown in Figure 6 & 7. The initial flood hazard simulation results in both locations show good spatial information. For Batanghari watershed, flood propagation through all areas had been categorized into flood-prone areas with medium-high category. Those areas spread from the middle to downstream of the watershed. Likewise for Jakarta, the propagation of flood hazard dimensions through the usual locations affected by floods, namely the downstream of the watershed, especially North Jakarta, West Jakarta, and Central Jakarta.

The flood dimension relationship curve especially $h$ with the value of losses that may occur for various types of land use is then used to generate spatial flood risk information with unit of loss value, for example in rupiah nominal. More detailed and quantitative information is expected to help the user, especially BNPB, adding detail information flood risk map that has been made previously.

Figure 6. Flood hazard spatial information in Batanghari River basin delineated from the simulated flood inundation depth (m) which occurred in December 2003.
Figure 7. Flood hazard spatial information for the Jakarta Capital City of Indonesia, it was delineated from the simulated flood inundation depth (m) which occurred in February 2002. The spatial information of the inundation pattern can be compared with the observed inundation pattern (observed; bottom left picture).
Conclusion

The concept of spatial risk formulation by incorporating aspects of climate change and anthropogenic factors, had been made and applied in the Batanghari River basin and 13 River basins that flow through the Jakarta city. physically-based distributed hydrological modeling system, called as rainfall-runoff-inundation model, was used as the main method in quantifying flood hazard dimensions ($q$, $h$, $A$, $t$). The relationship curve between flood hazard dimensions and its economic loss values were made based on the damage inventory data, collected from the historical flood disaster events. Furthermore, the curve was used for the conversion of flood hazard dimension units in each location (square grid) and land use type into damage costs.

In order to investigate the impacts of climate change and anthropogenic factors, at least two different climatic periods and types of land use, the current conditions and forward-looking results, was used in the analysis.

REFERENCES


