Flood Hazard Assessment in Citarum Watershed, Indonesia: Socio-Hydrological Modeling Approach

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1. INTRODUCTION

Citarum River, the longest river in West Java, is one of the most strategic rivers yet one of the most flood-prone rivers throughout history. Based on National Agency for Disaster Countermeasure of Indonesia (BNPB), Karawang regency is the most flooding-prone area in Citarum watershed with the highest number of flood events compared to the upper areas. Recent research have explored the impact of human interventions to floods including urbanization, land-use change, and flood control measures [Di Baldassarre et al., 2009; Heine and Pinter, 2012; Remo et al., 2012]. However, all these works have been looking only at one side of the interaction between floods and societies [Di Baldassarre et al., 2013]. Therefore, mutual linkages between floods and societies are not represented [Di Baldassarre et al., 2013]. Consequently, there is still a need to understand how societies influence the frequency of flooding, while the frequency of flooding (simultaneously) shapes the development of societies, which (in turn) change potential floodplain dynamics and feedbacks [Di Baldassarre et al., 2013]. This study aims to develop a socio-hydrology model to quantitatively explain the coevolution of human-flood systems. We proposed a dynamic analysis using socio-hydrological (SH) model to Indonesia, However, the applicability of the SH model was examined only in the Karawang Regency of Citarum Watershed, and there is no previous study applying the SH model in Indonesia, specifically Karawang Regency as the part of the largest watershed in West Java, Indonesia. Therefore, in this study, the SH model is applied in Karawang Regency.

2. STUDY AREA

Fig.1. Watershed of rivers in Citarum

Citarum Watershed is one of the world's most threatened watersheds and the most degraded in Java Island, Indonesia (Rahmad et al., 2021). The first focus target area presented on this abstract is Karawang Regency, Karawang Regency is considered as a frequent area of flooding in West Java, Indonesia. Floods in Karawang area are mostly because of river overflow sent from upstream (Azis Kemal Fauzie 2016; Bambang Riadi 2017)..

3. METHODOLOGY

The SH model, developed by Di Baldassarre in 2015, uses a set of differential equations to understand the interactions between human activity, technology, and flooding. The model uses the variable F to represent the severity of a flood event, and in the context of this particular study, it is referred to as F1 to indicate that it specifically pertains to river floods which is the case used in this study. The variables and parameters used in Equation (1) are W: high water level, H_: flood protection level before the flooding event, ξH: proportion of flood level enhancement due to the presence of levees and αH: parameter related to the slope of the floodplain and the resilience of the human settlement.

$$F_1 = 1 - \exp\left(-\frac{W+\xi_H H_-}{\alpha_H}\right) if\ W + \xi_H H_- > H_- \quad (1)$$

The Equations (3)–(5) shows the dynamics of the human-floodplain system. The D, H and M represent the population density, flood protection level and flood memory of the community respectively. The parameters in the set of equations are ρD: mean relative growth rate, αD: ratio preparedness/awareness, κT : protection level decay rate and μS : memory loss rate, Δ(Ψ(t)): a function which is always 0 and becomes 1 in flood occasions.

$$\frac{dD}{dt} = \rho_d\left(1 - D(1 + \alpha_D M)\right) - \Delta\big(\Psi(t)\big)FD_{-}(2) \quad (2)$$

$$\frac{dH}{dt} = -\Delta\big(\Psi(t)\big)R - K_T H \quad (3)$$

$$\frac{dM}{dt} = \Delta\big(\Psi(t)\big)FD_{-} - \mu_S M \quad (4)$$

(a) Time-invariant parameters

	Units	Description
αH	(m)	Parameter related to relationship between
ξH	(-)	Proportion of flood level enhancement due to presence of levees
ρD	(year^{-1})	Maximum relative growth rate
αD	(-)	Ratio awareness
εT	(-)	Safety factor for levee heightening
κT	(year^{-1})	Protection level decay rate
μS	(year^{-1})	Memory loss rate

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(b)

Time-varying variables		
	Units	Description
F	(-)	Relative flood damage
D	(-)	Population density
H	(m)	Food protection level
Mpop	(-)	Societal memory of floods
R	(m)	The amount of levee heightening

Fig.2. Time Invariant parameters (a) Time-varying variables (b)

4. RESULTS AND DISCUSSION

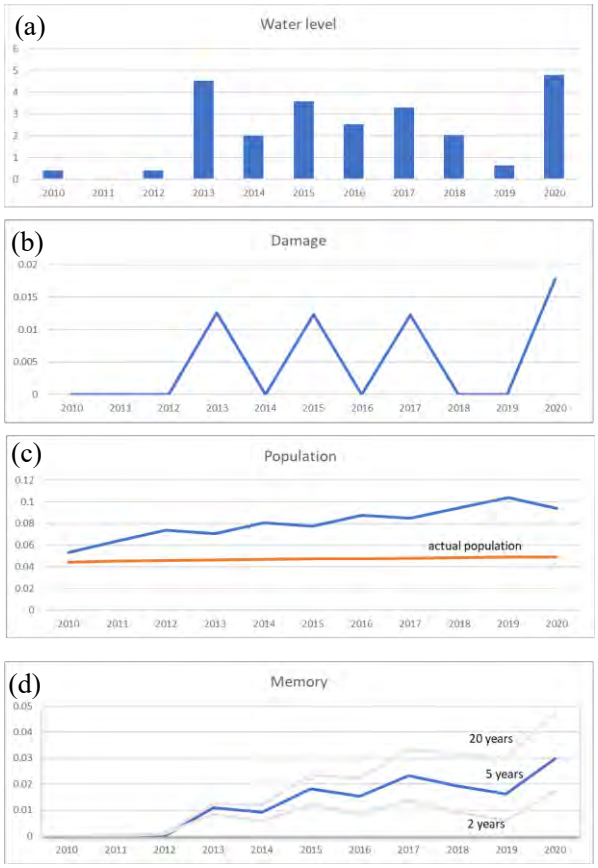

Fig.2. Simulation results of SH Model. (a) High water levels (mm), (b) Flood damages (c) Changes in the population density (d) Variation of the memory of the society under different memory loss rates (the output is blue line, light shaded areas indicate the range of memory loss rate scenarios for 5 and 20 years)

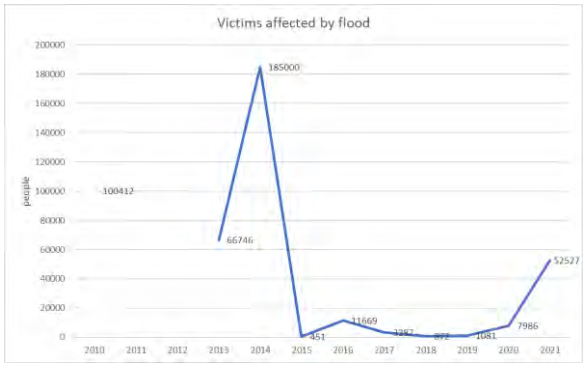

Fig.3. Observed Flood Damage

In the output of flood damage, the model captured the damage values in the study area (Figure 2(b)). Particularly, in 2014, despite the large urban flood condition, damage values were not captured by the original model because the 3 m threshold was not exceeded during this event. The uncaptured damages also happened in 2016, 2018 and 2019 because of the same reason. However, the estimated damages of the SH model matched well with the observed damages in 2013, 2015, 2017 and 2020.

On the other side the flood situations in 2015 and 2018 are overestimated and the Figure 4. Correlation between water level (mm) and model does not correctly capture the actual damages. Although this difference between the estimated and actual values could be due to missing data, it may also be a setting issue of the parameter αH (parameter related to the slope of the floodplain and the resilience of the human settlement). Moreover, for the years 2011 and 2012, damage data were not available in the dataset.

In this study, we estimated the memory dynamics of local residents in response to flooding by applying the SH model. As a result, it was found that the residents' memory was maintained at a high level due to the regular occurrence of flooding. It is important to have a clear understanding of the level of flood memory in order to determine the appropriate times to implement programs focused on raising awareness and educating the public about flood hazards, especially during long, less-flood frequent periods. As shown in Figure 3(d), the graph of the flood memory shows different stages or phases.; the initial low memory period (2010– 2012), improving memory period (2012–2013), declining memory period (2013–2014) and improving memory period (2014–2015) and so on. The flood damage graph can also be used to understand how the various phases of the flood memory affect the community living in the floodplain.

Even though the difference of the population density estimation (figure 2(b)), and the actual population is not so high, the estimation resulted by the model cannot capture the actual population well, it can be caused by the data that is used as comparison to calculate the number of relative population is too higher hence the values resulted tends to be constant.

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