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ASSESSMENT OF FLOOD RISK REDUCTION IN BENGAWAN SOLO RIVER: A CASE STUDY OF SRAGEN REGENCY

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ABSTRACT: Bengawan Solo experiences flooding almost every year and it has been a big problem since it causes damage and losses affecting many people in the area. Sragen is the Regency with the greatest loss due to flooding of the Bengawan Solo River which is the longest river in Java Island with 16,100 km^2 basin area. Dykes are the structural intervention usually proposed to deal with flood water. The objective of this study is to conduct an assessment of dyke height requirement in order to reduce flood risk in Sragen Regency along Bengawan Solo River. The assessment is based on risk level according to regulations of the Head of National Disaster Management Agency Number 2 in 2012, regarding the general guidelines for the assessment of disaster risk. Hazard levels are obtained from the relationship between hazard index parameters and exposed population index. Loss levels are obtained from the relationship between the hazard level parameter and the loss index. Flood risk level is determined from the level of losses and capacity. For mitigation purposes, flood risk reduction analysis has been conducted through a structural approach by simulating dyke construction around the Bengawan Solo River. Several scenarios of dyke height (2m, 4m, and 6m) have been simulated to assess flood inundation.

Keywords: Bengawan Solo River, Flood problem, Risk level, Dyke structure

1. INTRODUCTION

Bengawan Solo is the longest river in Java Island, Indonesia with a length of about ±600 km and catchment area approximately ±16,100 km^2, starting from the Sewu Mountains in the south west of Surakarta, to the Java sea in northern Surabaya. The Bengawan Solo River has a risk of flooding every year [1]. The extreme flood in the upper part of Bengawan Solo River occurred in 1996 and in the downstream of Bengawan Solo River occurred in 2007. Flood peaks that occurred in 1996 is estimated to have discharge around 4,000 m^3/s in Wonogiri, 2,000 m^3/s in Surakarta, and 1,850 m^3/s in Ngawi. Total area of flood in Upper Surakarta City is approximately around 18,000 ha and in Sragen is approximately around 10,000 ha. Height of inundation that occurred reaches 1 m to 2 m and victim died 90 people [2].

Flood is a disastrous event because of its damages when it happens in residential area, especially in urban areas. Flood hazards area increasing due to climate change, subsidence and socio-economic development. Implication of population growth and economic development to be main cause of the increased flood hazard in the world during the last few decades [3] [4]. One of the cities in Central Java with the greatest loss due to Bengawan Solo River flood is Sragen Regency which its loss reached Rp. 232.7 billion in 2009, occurred in 37 villages of 10 districts in Sragen Regency. Considering this condition, it is feared that there will be a flood that is very dangerous to the community in Sragen Regency. One alternative to solve this problem is to conduct risk analysis.

Basically, the purpose of flood management which consists of important information about flood such as exposure area and necessary action [5] is like other disaster management, i.e. to reduce the losses caused by the disaster. Based on the regulation from the Head of National Disaster Management Agency No. 2 of 2012 on the General Guidelines for the Assessment of Disaster Risk [6], risk is defined as the potential losses caused by a disaster in an area and a certain period of time that can be death, injuries, illness, live threat, loss of security, evacuation, damage or loss of property and disruption of community activities. In other words, the goal of disaster management is to reduce risk, with structural or non-structural approaches. Flood risk analysis assists stakeholder to determining the steps and priorities of flood disaster management.

The qualitative flood index map can be arranged by flood hazard index map, vulnerability index map and capacity index map [7]. Flood risk map also is the most relevant for take a decision on reduce risk that caused by past decisions on land-use planning. Flood risk map can prevent the increase of flood hazard risk as an implication of land-use development awareness of the hazard and it becomes very important [8] [9].The flood risk assessment is based on the hazard level and vulnerability to flood of certain areas in Sragen Regency. Flood hazard analysis use inundation flood map where can be simulated by using two-dimensional modelling program HEC-RAS 5.03 [10][11]. Analysis of hazard, vulnerability and capacity is referred to document of BNPB Number 4-year 2008 [12].

2. METHODOLOGY

This research was conducted in Bengawan Solo River, section of Wonogiri-Ngawi with risk map analysis in Sragen Regency. Flood risk is defined as a combination of probability of flood and its potential impact on human health, the environment, cultural heritage and economic activity which associated with a flood event [13].

Flood hazard is characterized by flood probability, flood depth, flow velocity, water staging time, etc. [8]. Referring to Government Regulation Number 26 Year 2008 on National Spatial Plan, it is stipulated that flood prone areas are areas that are often or have high potential to experience flood event.

Flood risk analysis is an analysis of risks of flooding that potentially can damage the society/infrastructures. While flood risk reduction analysis is an analysis of several alternatives of flood mitigation measures, actions, or approaches to reduce the flood risks.

2.1 Flood Hazard Level

Referring to BNPB Number 2 Year 2012 on General Guidelines for Assessment of Disaster Risk, flood hazard levels are grouped into three categories, i.e. flood depth <0.76m categorized as low risk, flood depth 0.76m - 1.5m categorized as medium risk, and flood depth >1.5m categorized as high risk.

The general basic formula for risk analysis compiled in the Disaster Risk Mitigation Planning Manual [14], prepared by the Indonesian National Agency for Disaster Management is in Eq. (1):

$$R = H \times \frac{V}{C} \tag{1}$$

where R is disaster risk, H is hazard/frequency (probability) that the disaster tends to occur with certain intensity and location, and V is vulnerability which is the expected loss (impact) in a area from a disaster case that occurs with a certain intensity.

2.2 Hazard Index Analysis

The classification of flood hazard level is based on inundation depth and flood velocity. Flood hazard index is classified by low, medium, and high.

2.3 Vulnerability Analysis

There are 3 indexes for vulnerability analysis, i.e.: social, economic, and physical. Social vulnerability index is derived from the average weight of the population density (60%), the vulnerable group (40%) consisting of gender ratio (10%), poverty ratio (10%), disability ratio (10%) and age group ratio (10%). Economic vulnerability index is the area of productive land and GRDP (Gross Regional Domestic Product). The productive land area has a greater influence than GRDP with the weight in the calculation of 60%, considering that productive land is more sensitive to the flood. When flood occurs, productive land can not run the production process, while GRDP can still run on sectors that are not sensitive to the flood. In vulnerability analysis, social vulnerability is separated from the other three vulnerabilities because basically the human soul can not be valued with money. Therefore, the social vulnerability parameter is calculated as a separated index, i.e. the exposed population index, while the physical vulnerability and economic vulnerability are classified into the losses index. Physical vulnerability in this study is the density of the houses (permanent and semi/nonpermanent), buildings/public facilities and critical facilities. The physical vulnerability is calculated based on the costs incurred to repair the houses/building/facilities in order to restore its function.

2.4 Capacity Analysis

As in vulnerability analysis, capacity analysis also uses several parameters. These parameters are weighted individually according to their importance level.

2.5 Flood Risk Analysis

In flood risk analysis, there are several stages of parameter calculation, i.e.: hazard level, losses level, and capacity level. Hazard level is obtained from the relationship between hazard index parameters and exposed population index. Classification of hazard level is divided to low (+), medium (*), and high (#) as can be seen in Table 1. Losses level is obtained from the relationship between the hazard level parameter and the losses index. There are 3 classification of losses level as shown in Table 2 which are low (+), medium (*), and high (#). Table 3 shows capacity level obtained from the relationship between hazard level parameter and capacity index. It is classified into low (#), medium (*), and high (+). Disaster risk level is determined from the level of losses and capacity as in Table 4. There are 3 level of disaster risk i.e. low (#), medium (*), and high (+).

Table 1 Hazard level classification

Hazard Level		Exposed Population Index		
		Low	Medium	High
Hazard Index	Low	+	+	*
	Medium	+	*	#
	High	*	#	#

Table 2 Losses level classification

Losses Level		Losses Index		
		Low	Medium	High
Hazard Level	Low	+	+	*
	Medium	+	*	#
	High	*	#	#

Table 3 Capacity level classification

Capacity Level		Capacity Index		
		Low	Medium	High
Hazard Level	Low	*	+	+
	Medium	#	*	+
	High	#	#	*

Table 4 Risk level classification

Disaster Risk Level		Capacity Level		
		Low	Medium	High
Losses Level	Low	*	+	+
	Medium	#	*	+
	High	#	#	*

3. RESULTS AND DISCUSSIONS

Synthetic unit hydrograph analysis is used to determine the flood discharge. The data used to calculate the synthetic unit hydrograph is the regional rainfall data in Bengawan Solo River basin. Thiessen polygon method is used to calculate the regional rainfall. From the regional rainfall analysis, the highest rainfall occurred in 2007 (194 mm) and the lowest rainfall occurred in 2014 (79 mm). The calculation of discharge is based on each sub-basin with return period of 10 years. The 10 year return period rainfall for Wonogiri sub-basin is 345 mm, for Serenan sub-basin is 133 mm, for Jurug sub-basin is 146 mm, for Sragen 1 sub-basin is 148 mm, for Sragen 2 sub-basin equal to 316 mm, for Sragen 3 sub-basin is 342 mm, for Ngawi sub-basin is 313 mm, for Kajangan sub-basin is 331 mm and for Nepent sub-basin is 347 mm. The distribution of hourly rainfall used in the first hour of rain distribution is 38.7%, for the second hour is 32.3%, for the third hour is 18.7%, and for the fourth hour is 10.3% [15]. Snyder synthetic unit hydrograph method is used to calculate 10-year return period flood discharge. Selection of 10-year return period is based on master plan of urban drainage system (Sragen City is categorized as big city). The flood discharge is calibrated with observational discharge with AWLR (Automatic Water Level Recorder) in Serenan sub-basin and Kajangan sub-basin. Flood discharge for Serenan sub-basin is 2,071 m^3/s and for Kajangan sub-basin is 3,727.6 m^3/s. The simulation result for both sub-basins is close enough with the result from AWLR.

Analysis of water profile and flood inundation in Upper Bengawan Solo River is conducted by using 2-dimensional flow modeling program i.e. HEC-RAS 5.0.3. In this modeling, the required data are as follows: DEM (Digital Elevation Model) data, cross section and long section of the river, Manning’s n coefficients for surface flow based on land use data, and hydrograph data of flood discharge. The simulation result shows that the inundation area is 11,620 ha, while the average flood velocity is less than 0.75 m/s.

Based on the flood risk analysis, there are several villages that are classified as low, medium, and high. Villages included in the low risk index are Bandung, Dari, Gabus, Karanganyar, Karangwaru, Karungan, Kebonromo, Kedung Upit, Klandungan, Pandak, Sidokerjo and Tangkil. Villages included in the category of medium risk index are Jambanan, Karangtengah, Patihan, Purwosuman, Singopadu, and Sribit. Villages included in high risk index are Bedero, Bendo, Bentak, Cemeng, Gawan, Gedongan, Gentan Banaran, Gringging, Jabung, Japoh, Jati, Jatitengah, Karangudi, Kecik, Kliwonan, Krikilan, Newung, Padas, Pengkol, Pilang, Pringanom, Sambungmacan, Sidodadi, Tanggan, Taraman, Tenggak, and Toyogo. Hazard index map, vulnerability index maps, and capacity index are shown from Fig. 1 to Fig. 5. The map of loss index, hazard level, loss level, capacity level, and risk level are shown from Fig. 6 to Fig. 10.

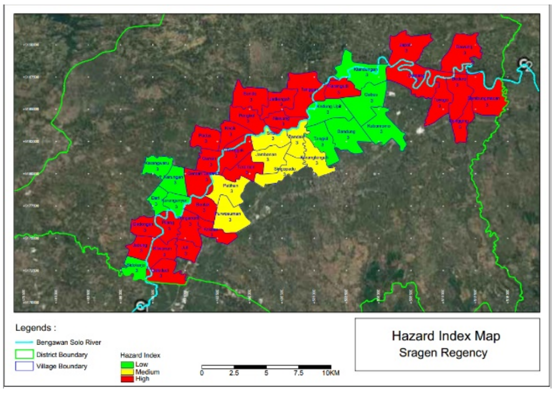

Fig.1 Hazard index map

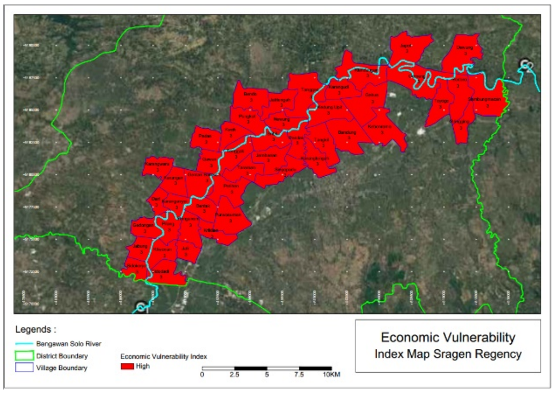

Fig.2 Economic vulnerability index map

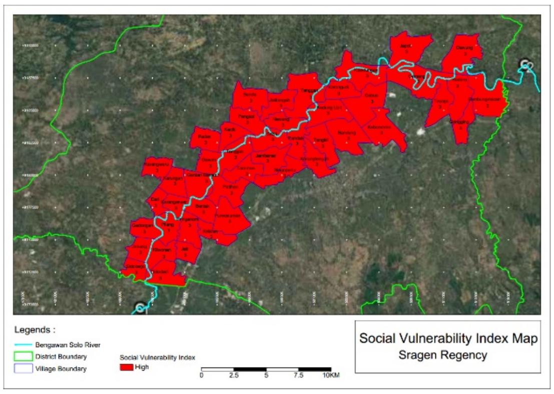

Fig.3 Social vulnerability index map

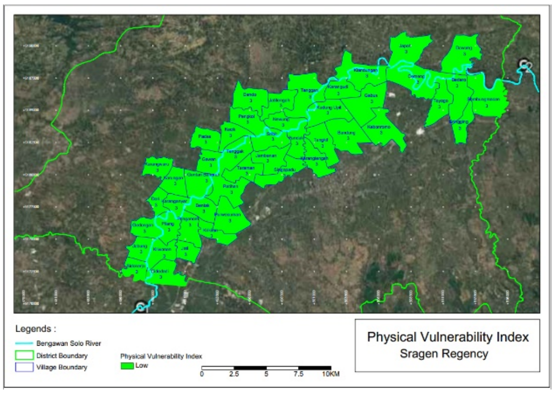

Fig.4 Physical vulnerability index

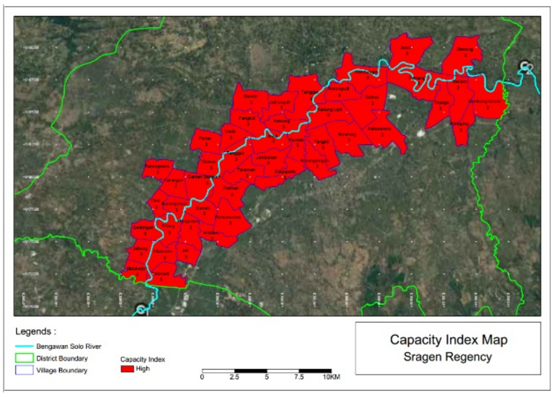

Fig.5 Capacity index map

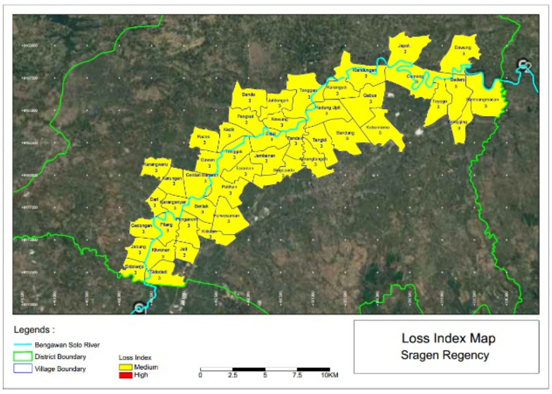

Fig.6 Loss index map

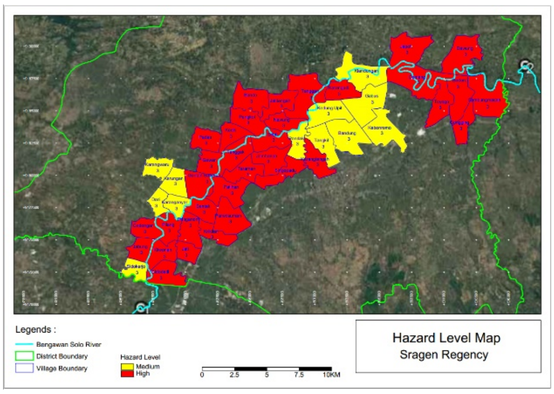

Fig.7 Hazard level map

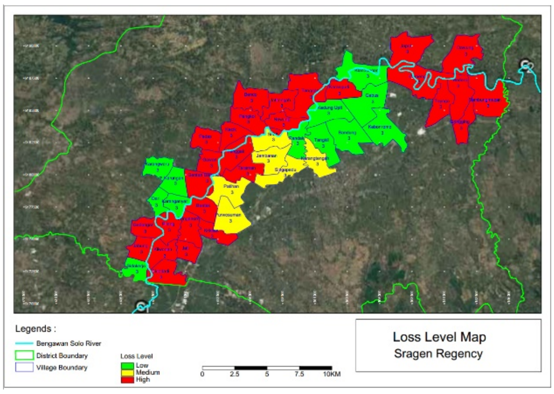

Fig.8 Loss level map

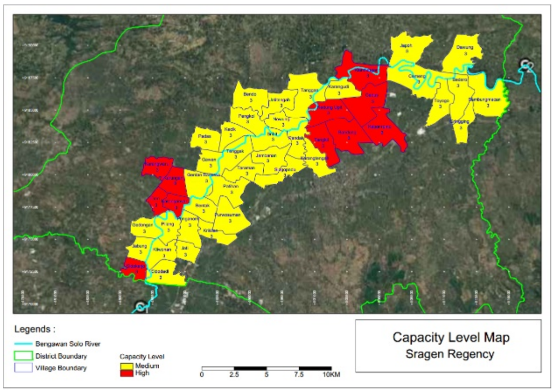

Fig.9 Capacity level index

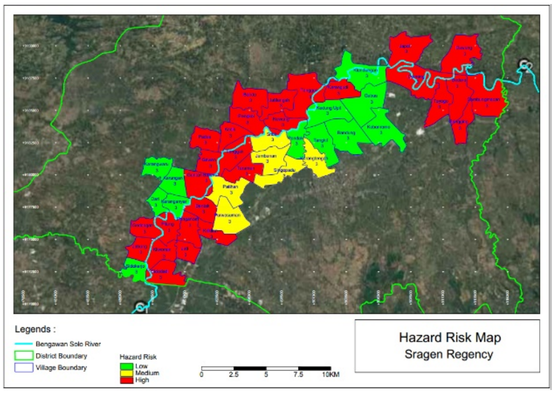

Fig.10 Risk level map

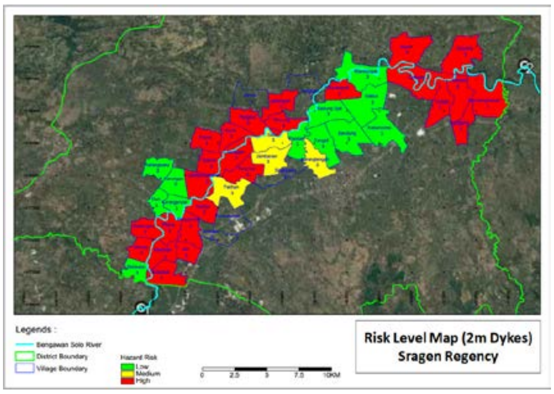

Fig.11 Risk level map with 2m dyke's scenario

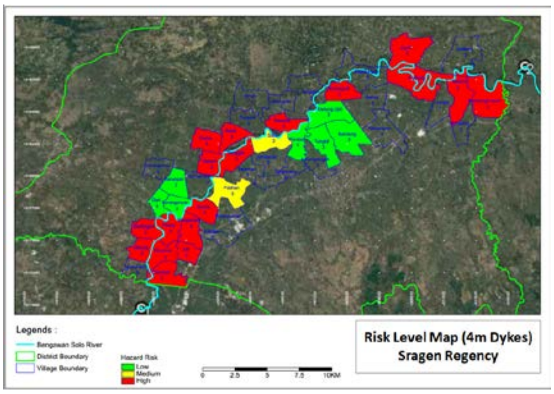

Fig.12 Risk level map with 4m dyke's scenario

Fig.13 Risk level map with 6m dyke's scenario

Risk reduction analysis is conducted regarding flood mitigation. For this purpose, dyke's construction is planned with several height scenarios to deal with flood. From the analysis results as shown from Fig. 11 to Fig. 13, the construction of dykes with a height of 2 meters can reduces inundation area by 11% (6 villages) and the four-meter-high dyke reduces the inundation area by 49% (19 villages). Meanwhile, the inundation area for all 46 villages can be cleared up with 6-meter-high dyke. However, these simulations only focus on reducing the flood inundation. Therefore, for further development of this study, several improvements shall be proposed such as feasibility of construction and also economic analysis of each alternatives.

4. CONCLUSIONS

Based on the above study, it can be concluded that the inundation simulation for 10-year return period flood with discharge of 3,784.7 m^3/s on existing condition caused 42 villages inundated by flood. The risk level index in the villages of Bandung, Dari, Gabus, Karanganyar, Karangwaru, Karungan, Kebonromo, Kedung Upit, Klandungan, Pandak, Sidokerjo, Tangkil are categorized as low category, while the villages of Jambanan, Karangtengah, Patihan, Purwosuman, Singopadu, Sribit are in medium category, and 13 other villages are in high category. The risk index in Sragen Regency is greatly influenced by the hazard index from the Bengawan Solo river discharge.

For mitigation purpose, flood risk reduction analysis flood has been conducted through structural approach by simulating dyke construction around the Bengawan Solo River. Several scenarios of dyke's height (2m, 4m, and 6m) have been simulated to deal with flood inundation. Further development of this study, several improvements shall be proposed such as feasibility of construction and economic analysis of each alternatives.

5. ACKNOWLEDGEMENT

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