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A GIS MODELLING APPROACH FOR FLOOD HAZARD ASSESSMENT IN PART OF SURAKARTA CITY, INDONESIA

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ABSTRACT

This research is aimed to assess the flood hazard in part of Surakarta using hydrodynamic modelling. Flo2D software is used to simulate the flood for 10, 25 and 100 year return period. The modeling results include two flood parameters, i.e water depth and flow velocity. A comparison was made in flood hazard mapping between single parameter and multi parameters. The multi parameters hazard maps improve the reliability of the hazard class delineation. The impact assessment is done in two point of view, human safety and property damage. The further impact assessment is done by calculating the number of buildings affected by flood.

Keywords: hydrodynamic modelling, flo2D, flood hazard mapping, impact assessment

INTRODUCTION

Surakarta city is one of the area in Indonesia that frequently struck by floods events in recent years. Some of the Surakarta's district are located near the Bengawan Solo River and are prone to flooding. Historically, there are two big floods struck this city, they are a flood in 1966 and a flood in 2007. According to Unit Disaster Mitigation and Evacuation of Surakarta City the later flood cause total economic losses for about Rp. 21,938,500,000 (EUR 1,534,161). It also inundated 12 villages in 5 districts [*Hidayat,* 2008].

The recent damages that occurred due to peak discharge of Bengawan Solo River in December 2007 and the increasing occurrence of flood in recent years have grabbed the attention of community, researcher and local authorities to increase their awareness to flooding. The local authority has implemented both of structural and non structural mitigation measure to reduce the flood risk. However, flooding remains to handle in Surakarta. So it is important to study the holistic approach in the hazard assessment of flood in Surakarta.

There are several methods to assess flood hazard, among them are first using community based approach and second by flood modelling approach. Study to assess flood hazard in Surakarta using community approach was done by Zein in 2010.

The main objective of this research is to carry out a flood hazard assessment using hydrodynamic modelling in part of Surakarta City.

Surakarta, mostly well known as "Solo City" is one of the big cities in Central Java. It is located about 100 km Southeast of Semarang (The capital city of Central Java) and 65 km Northeast of Yogyakarta (Fig.1). Located between hills and mountains with flat topography and passed by river make Surakarta prone to flooding. The Bengawan Solo River which lies in eastern part of the city overflows its banks many times.

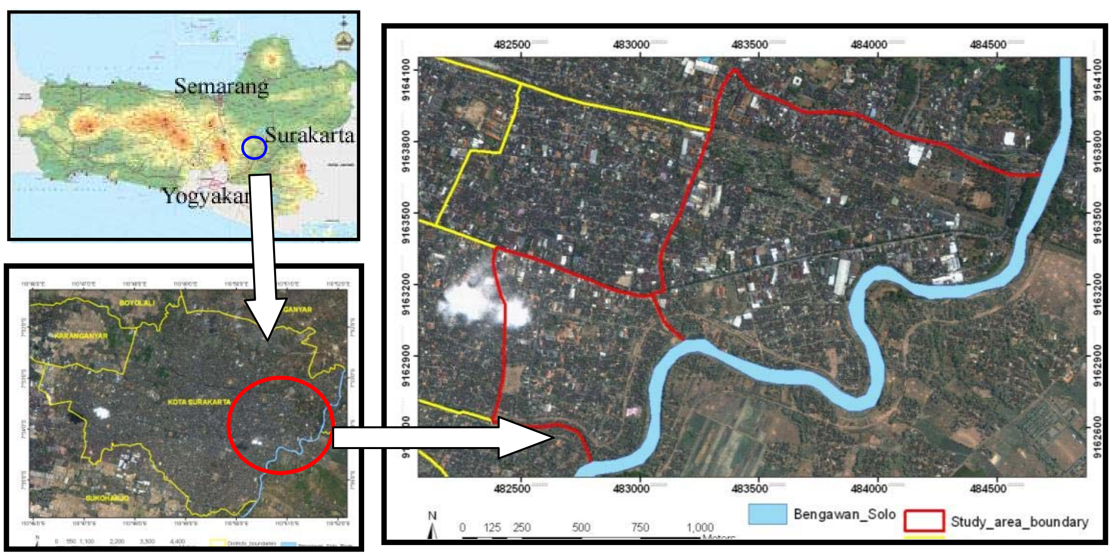


Figure 1. Study area

THE METHODS

In this research, the author tried to assess the flood hazard and impact of the flood by using a hydrodynamic modelling. The Flo2D model will be selected which allows the computation two dimensional overland flow modelling. This study is divided into three main phases, namely 1) Data preparation, 2) Flood modelling, and 3) Hazard and impact assessment.

Data Preparation

The first phase is concern on data preparation and analysis. The main data are divided into spatial data includes the terrain data and land use information and the non spatial data include the discharge information.

Flood Modelling

The second phase focuses on the building and simulating the flood. This phase is consisting of the following technical work: DTM construction and simulating floods using Flo2D software. The DTMs are produced using IDW interpolation method.

The first step to create a flood simulation in Flo2D is building the model. In this step, the user determined the project area, defined the grid size and added the modelling component such as channel, dyke, street, hydraulic structure and etc. Among them only two components were applied in this study. They were channel and dyke. The flow chart that outlines how various components interface with each other is Flo2D use in this study is shown in Fig. 2.

Hazard and Impact Assessment

Flo2D software is used to simulate three recurrence intervals flood events.

Frequency Analysis

Statistical methods should be applied to conclude for flood probability analysis analysis. A Gumbel plot is one of the most widely used statistical measures for evaluate the distribution of the available data and the probability of the occurence of flood events [*Calver et, al.,* 2009]. In this research, a Gumbel method is used to calculated the different return periods for flood modelling.

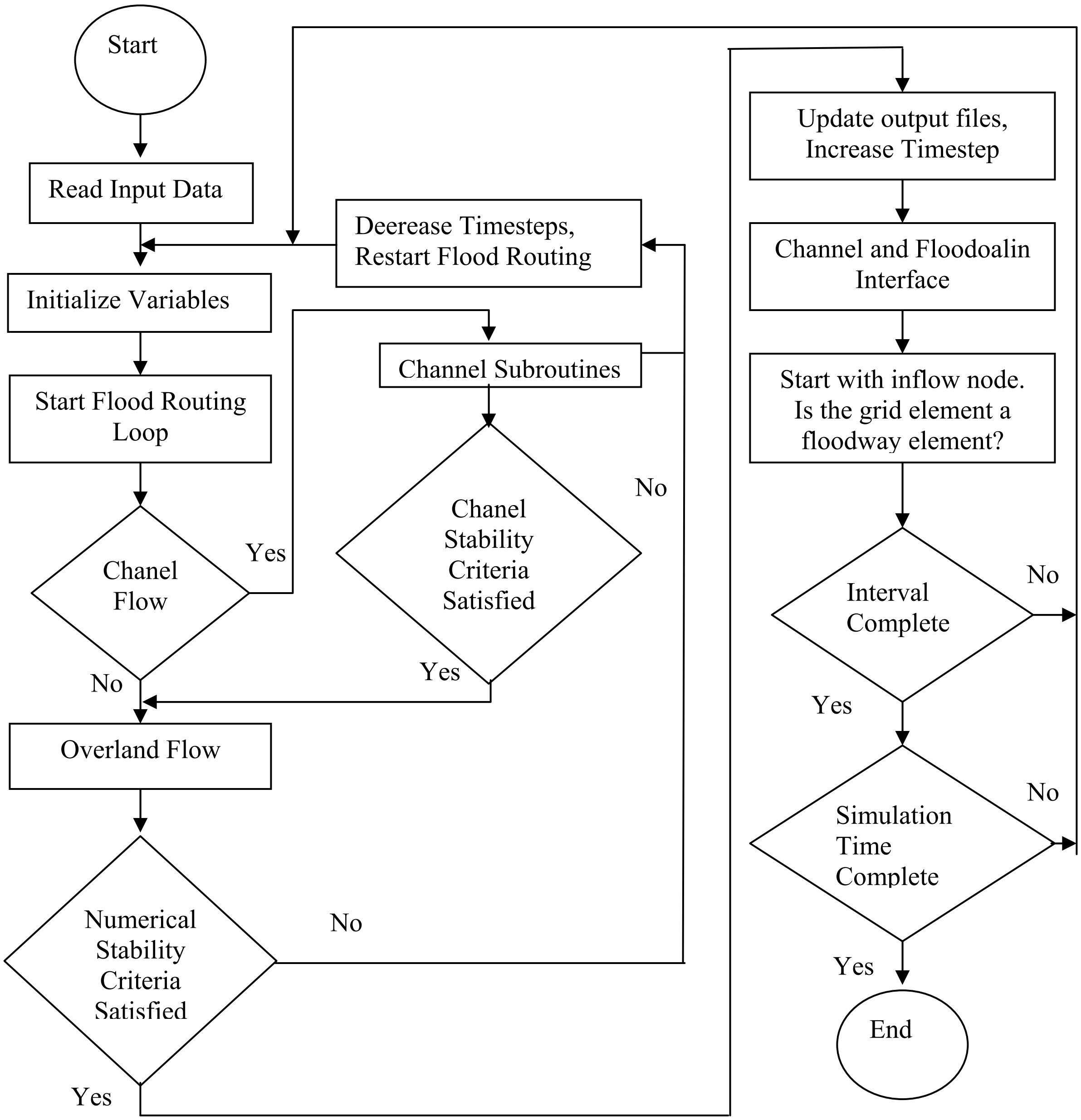


Figure 2. Flo2D flow chart

Validation

Calculation of accuracy and reliability have been used to validate the models. A simple validation method has been applied in this study. This method was based on comparison between the modelling result with the reliable source map [*Marfai,* 2003]. The source map is the inundation extent map of 2007 flood event obtained from Surakarta Public Work Office. This map was generated by manual delineation from the field survey by some personels of those office. Accuracy and reliability value is obtained from confusion matrix method at table operation in ArcGIS software.

Hazard Assessment

The results from the modelling phase, which are in the form of floods characteristic maps (flood extent, flood depth and flood velocity) are used in the hazard assessment. Hazard map was performed by integrating two factors obtained from modelling, that are maximum water depth and maximum flow velocity. The classification of hazard was based on hazard level used by [*Ramsbottom et al.,* 2003] (Fig. 3).

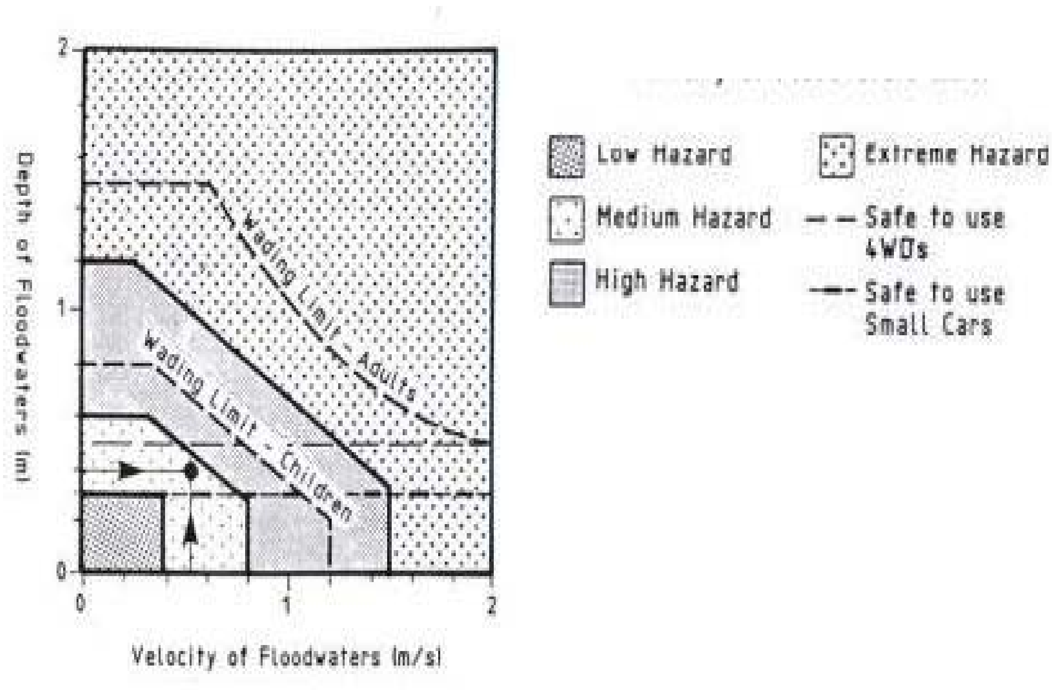


Figure 3. Hazard classification [*Ramsbottom et. al,* 2003]

Impact Assessment

The impact assessment consist of the following work: developed a criteria through user based impact, identification of physical element at risk in the study area derived from Ikonos image and Land use map and then determines the impact of the flood in buildings and land use.

RESULT AND DISCUSSION

Flood Modelling

A 20 meter grid was chosen in the simulation. The flood hazard assessment was performed using hydrodinamic model in Flo2D. Flood scenarios were generated for hazard mapping. Three scenarios were generated for flood simulation.

Frequency analysis

In order to know the return period of flooding of the Bengawan Solo River, the Gumbel method was used with discharge data from 1976 to 2009. The method obtains a simple statistical approach to calculate the probabilities of occurrence for different records. Based on the data measurement, discharge for different return period were identified (Table 1)

Table 1. Discharge of different return periods obtained by gumbel method

Return Period	Right Probability	Left Probability	Plotting Y Position	Discharge
5	0.200	0.800	1.50	1104.4
10	0.100	0.900	2.25	1332.7
25	0.040	0.960	3.20	1621.2
85	0.012	0.988	4.44	1997.9
100	0.010	0.990	4.60	2047.6
225	0.004	0.996	5.41	2295.1

Flood Scenarios

The second step for flood modelling is generating of input hydrograph a certain return period. Due to the availability of data it was not possible to generate hydrographs at an hourly basis. The available data is annual maximum discharge. However, the probable peak discharge for different return periods were identified using probability analysis (refer to Table 1). In order to maintain parity between the actual data and the model input, the hydrographs were completely based on the estimation of the average data during the particular period of time. In this study the hydrographs were chosen as model inputs for return periods of 10, 25 and 100 years. A 10 year return period is equal to the discharge of 1967 flood event. Three scenarios of flood events in the study area were generated based on these hydrograph (see Fig. 4).

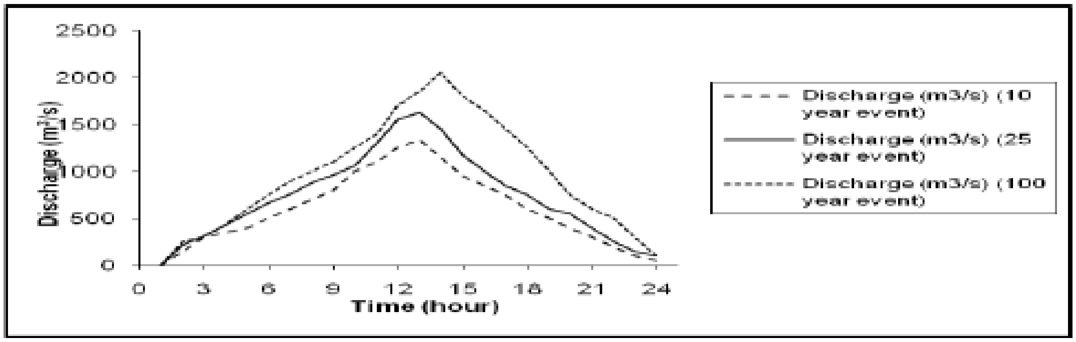
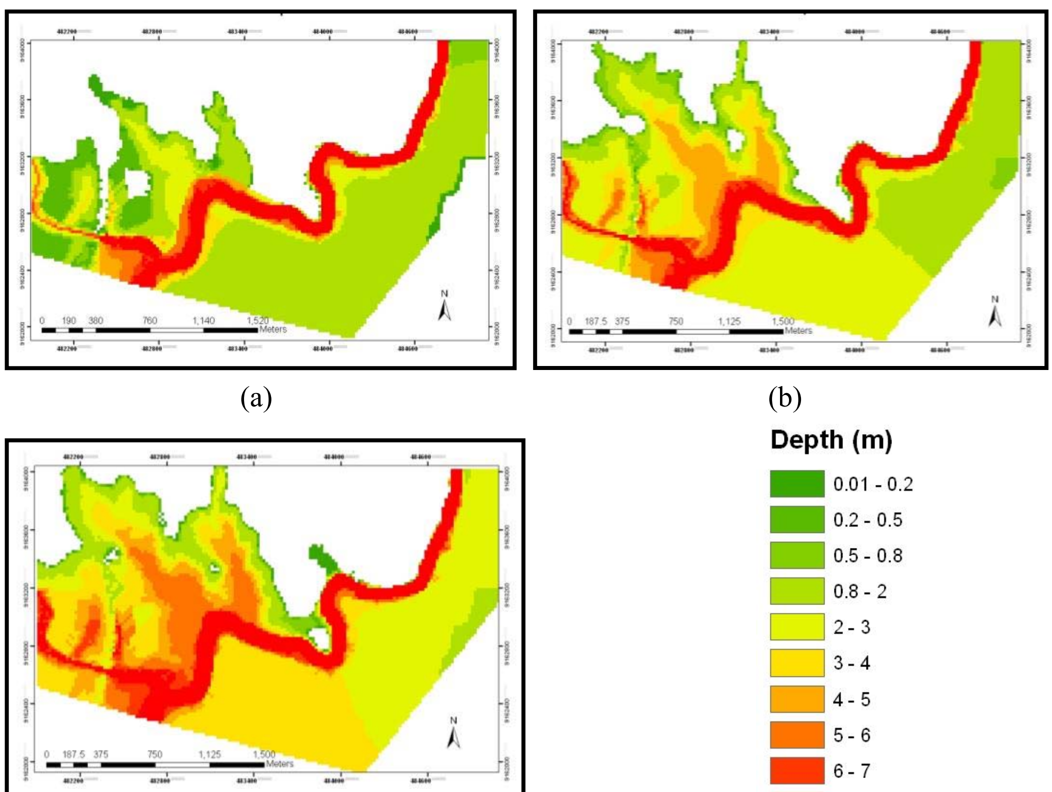


Figure 4. Hydrographs chosen as model input for three different return periods

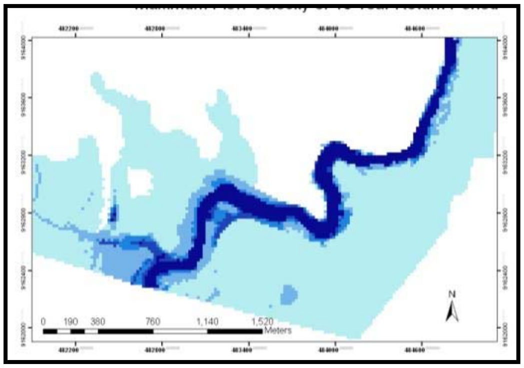
Results of Flood Scenario

The flood characteristics obtained from the Flo2D model results were in the form of water inundation extent (flood extent), water depth (flood depth) and also water velocity (flood velocity). All the maps were obtained for different chosen return periods (Fig. 5 and Fig. 6).



(a) (b) (c)

Figure 5. Distribution of maximum water depth for three different return periods. (a) 10 year return period. (b) 25 year return period. (c) 100 year return period



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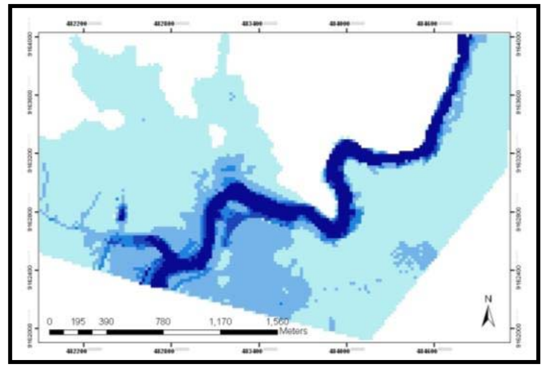

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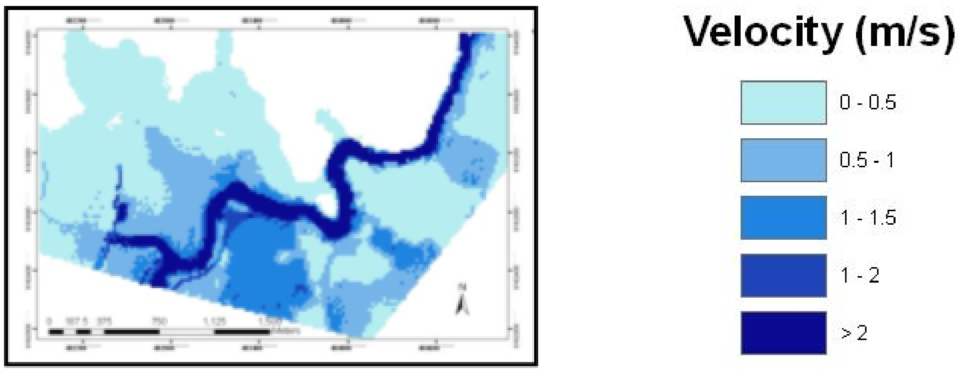


(c)

Figure 6. Maximum flow velocity of three different return periods. (a) 10 year return period. (b) 25 year return period. (c) 100 year return period.

In general, the high flow velocity was observed in the narrow part of the river. The highest value of flow velocity on the river is 17.3 m/s in the 100 year return period. For the floodplain, maximum water velocity is smaller than the flow in the river. The value of flow velocity in the floodplain mainly under 0.5 m/s, some extreme value (more than 2 m/s) is reach in the places where next to the river.
Validation

Due to only a partial area of modelling result map and source map overlie each other, only the pixels within this area have been compared. A comparison between the numbers of pixel in every class ("flooded" and "non flooded") from modelling result map of 2007 flood event and source map (2007 inundation flood map obtained from Surakarta Public Work) has been made in the form of confusion matrix. The result is shown in Table 2.

Table 2. Confusion matrix of modelling result map and source map

		Source Map		Reliability
		Flooded	Non-flooded	
Modelling	Flooded	4043	1944	0.6753
Result Map	Non-flooded	596	2543	0.8101
Accuracy		0.8715	0.5667	

Average accuracy = 74%
Average reliability = 72%

The overlaid betwen the modelling result map and the source map is shown in Fig. 7.

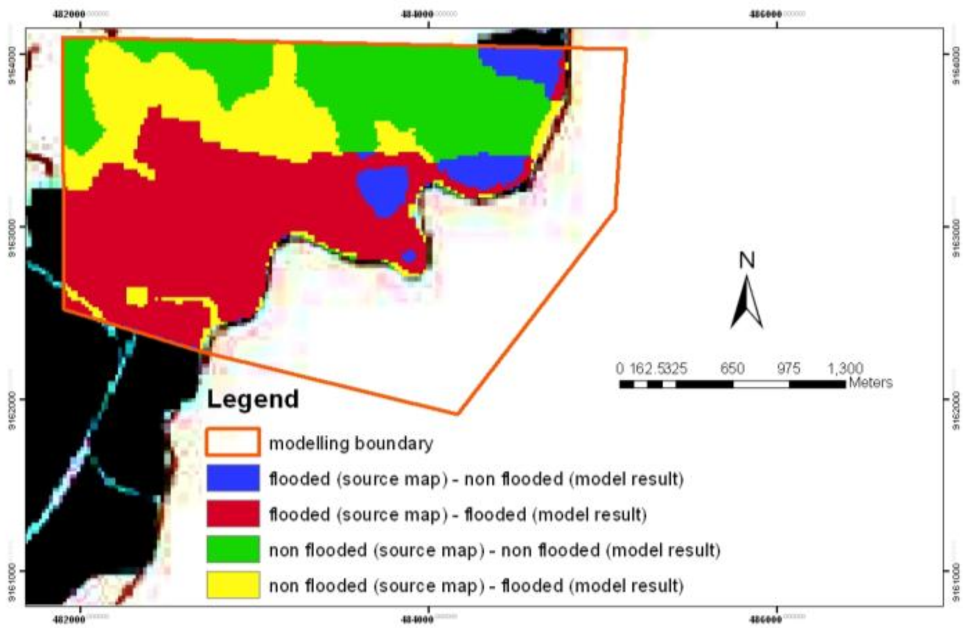


Figure 7. Overlaid between modelling result map and reliable source map flood hazard mapping

In the past, maximum water depth is the most common way of representing the level of flood hazard. With the development of 2D hydrodynamic models, it was possible to create flood hazard maps incorporating the other parameters such as depth, velocity and kinematic energy for better representation of the hazard.

This study was attempted to combine above parameters and derive a multi parameter for flood hazard map representing depth and flow velocity. In the final hazard map both parameters were integrated based on multi criteria based on Table 3. An equal weighting criterion was given to maximum water depth and maximum velocity. The resulting integration hazard map was classified in four categories as “Low”, “Medium”, “High” and “Extreme”.

Table 3. Criteria for flood parameters

Hazard Categories	Max Water Depth (m)	Max Flow Velocity (m/s)
Low	D 0.25	$V \leq 0.2$
Medium	$0.25 < D \leq 0.6$	$0.2 < V \leq 0.8$
High	$0.6 < D \leq 1.2$	$0.8 < V \leq 1.5$
Extreme	> 1.2	> 1.5

The final hazard map generated based on multi parameter weighting classification is shown in Fig. 8.

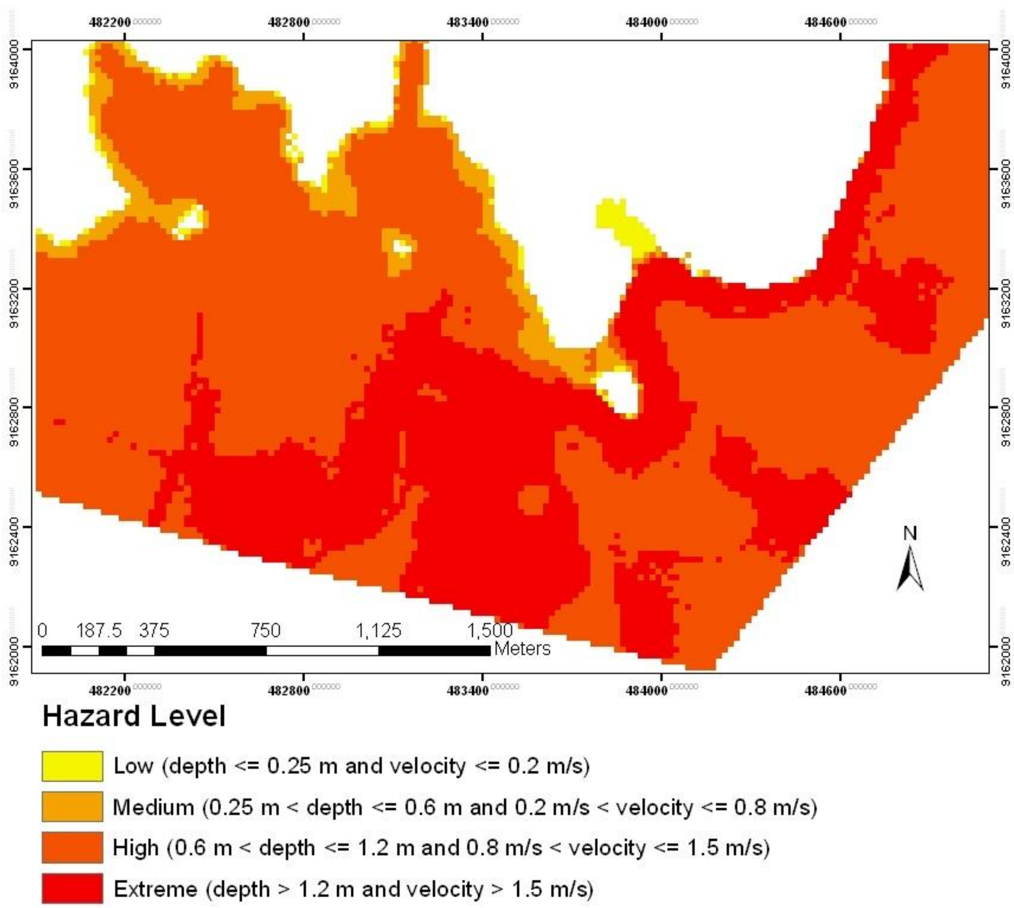
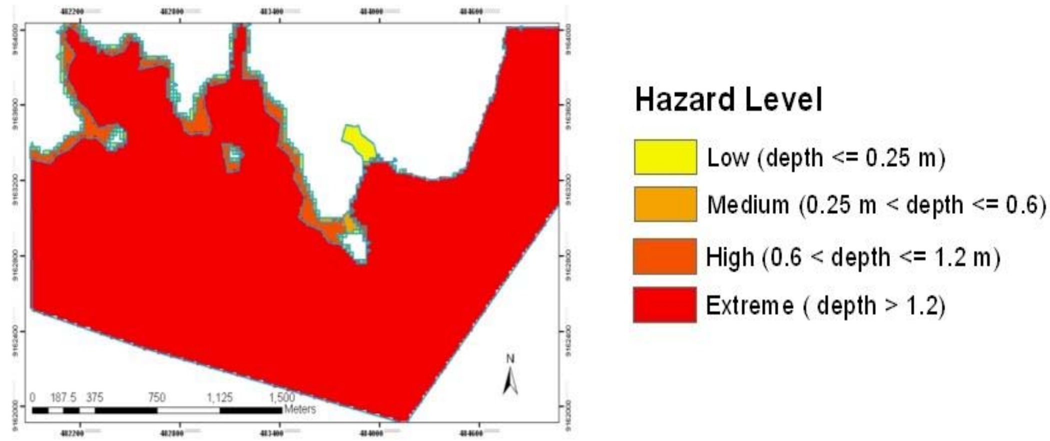


Figure 8. Flood hazard map based on multi parameters



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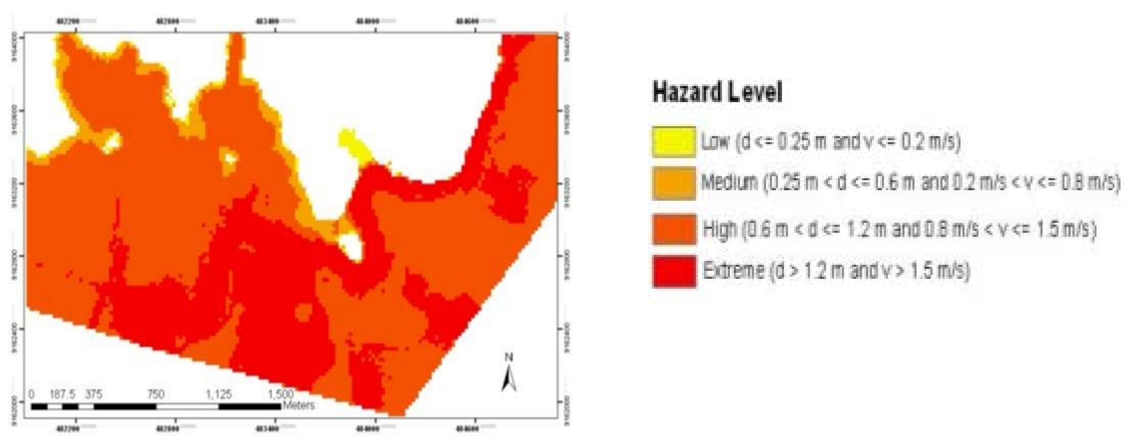


(b)

Figure 9. Comparison between single parameter map and multi parameter hazard map of 100 year return period. (a) Single parameter hazard map. (b) Multi parameter hazard map

A comparison is made on single hazard map that generated based on inundation depth with the multi parameters hazard map that generated by integrating water depth and flow velocity (Fig.10).

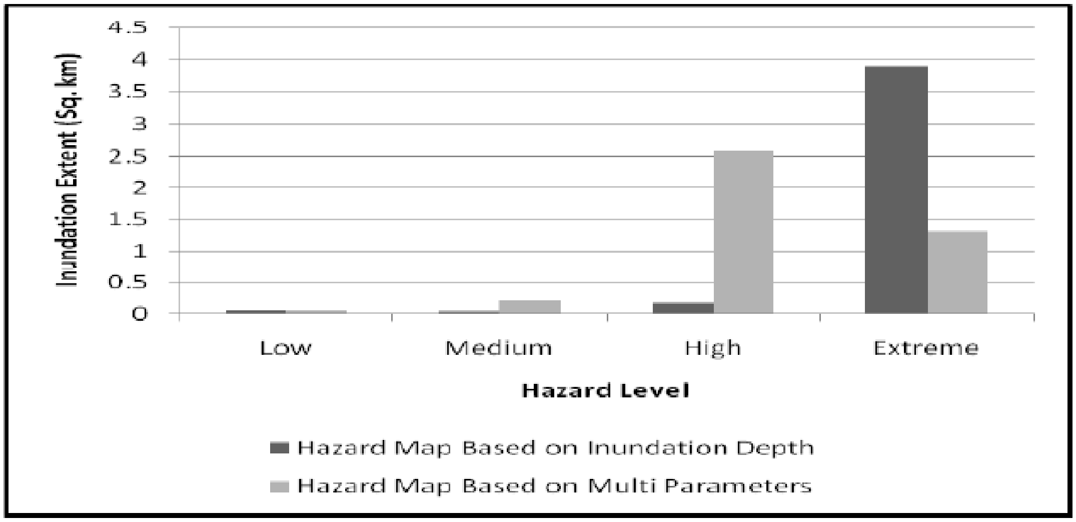


Figure 10. Inundation extent of each hazard class in single and multi parameter approach

A 62% decrease in extreme zone was observed in the multi parameters hazard map compared to that of single parameter hazard map (Fig.11). In the single parameter, areas where inundation depths are more than 1.2 meters were classified as extreme hazard. However in multi parameters, it will further check for water flow velocity. If it is less than 1.5 meters it will classify as high hazard. Therefore reliability of the hazard class delineation can be improved by integrating some flood hazard parameters.

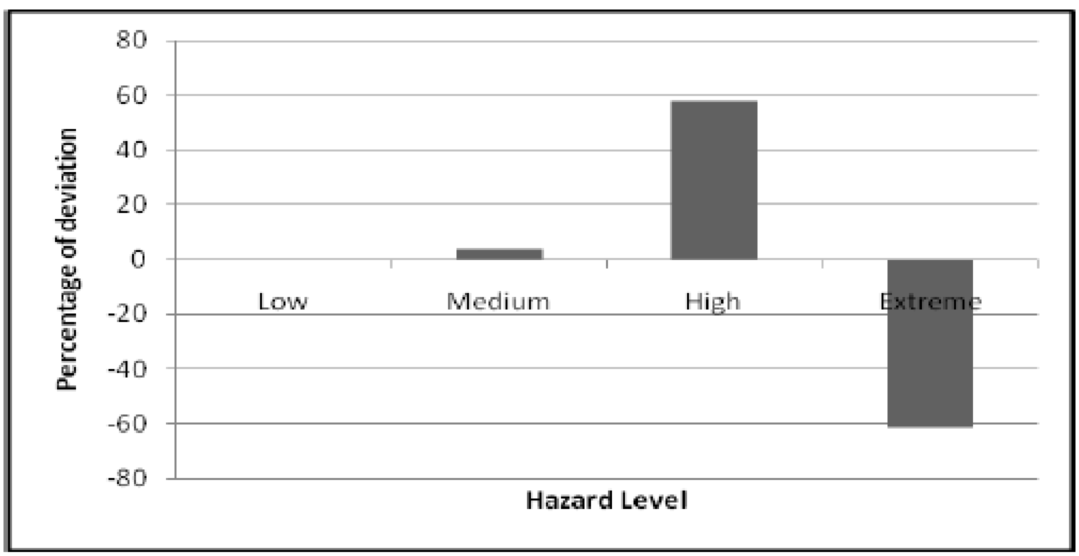


Figure 11. Percentage of deviation in single and multi parameter approach

All the result scenarios were integrated to obtain classic hazard map. Fig.12 shows the flood hazard map of the study area considering return periods 10, 25 and 100 years with their corresponding probability of occurrence.

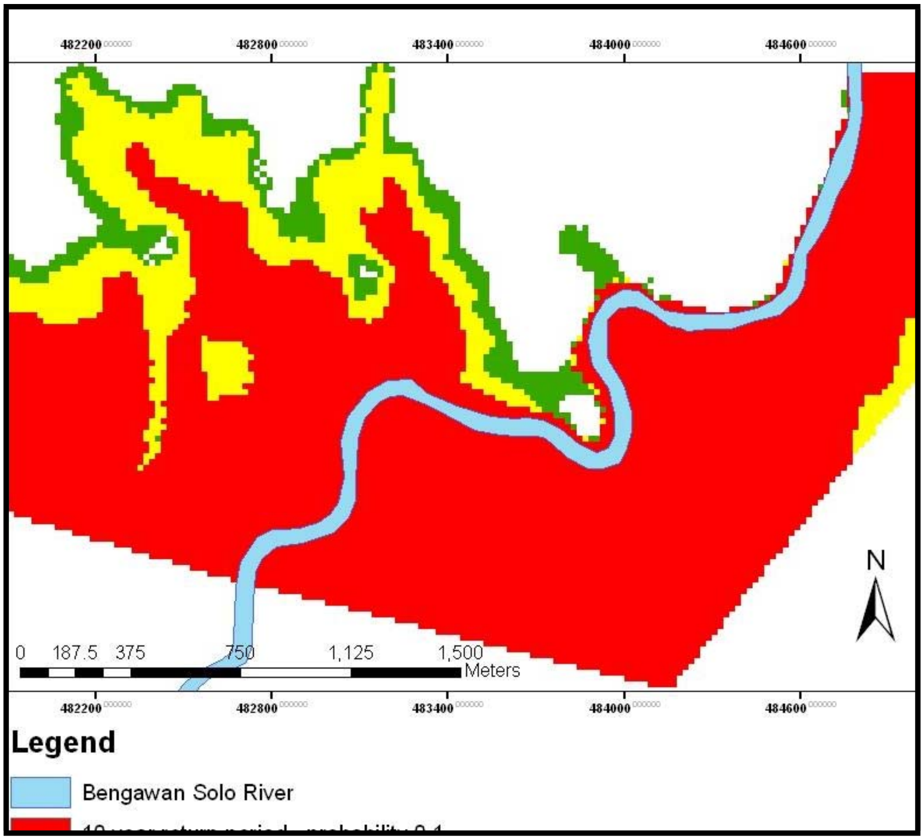


Figure 12. Flood hazard map for different return periods (10, 25 and 100 years)

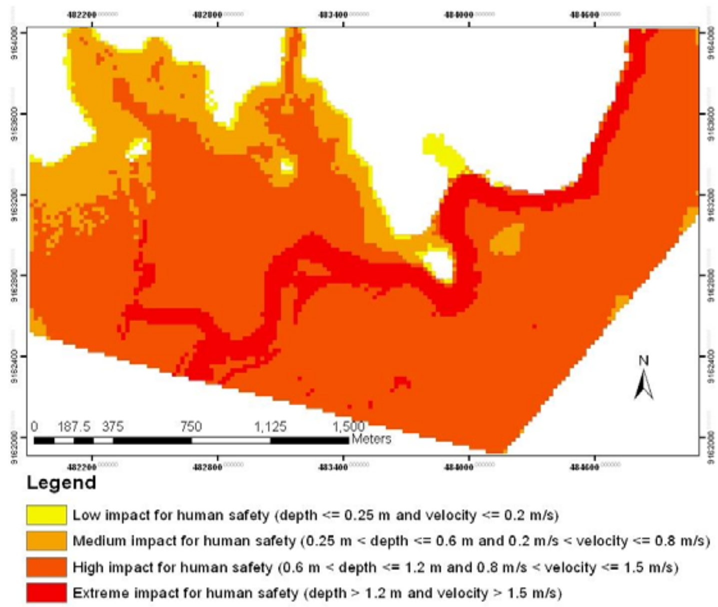
Impact Assessment

Flood impact assessment serves as a tool for estimating the overall adverse effects of floods for a particular area. In this study the impact assessment is developed through user based impact. This methodology raises attention to different concerns of the diverse parties potentially affected by floods (see Table 4).

Table 4.Weightings for different interest groups

Visions	Factors	
	Max Water Depth	Max Flow Velocity
Human safety	35	65
Property/Estate	70	30

The author select 100 year return period scenario to better illustrate the differences among impact results of different visions. First, the two parameters (maximum water depth and maximum flow velocity) were classified to form thematic maps based on the criteria listed in Table 3. Then, these thematic maps were weighted according to Table 4 and integrate to generate flood impact map for different visions (Fig.13).



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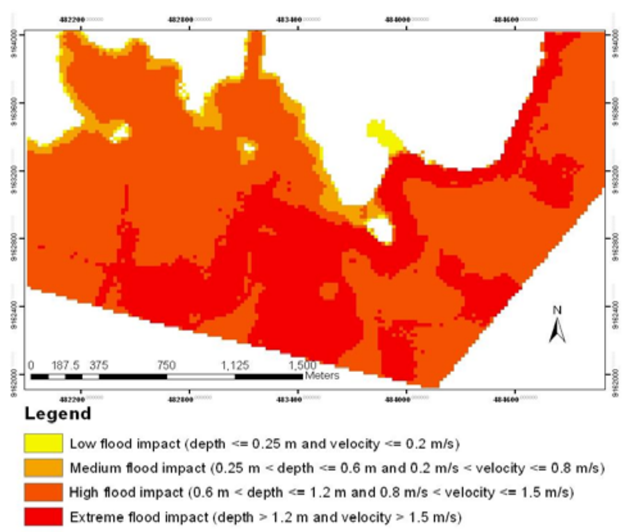

(b)

Figure 13. Flood hazard zone (a). Considering human safety. (b) Considering property damage

The percentage of each impact category comparing to the total inundated area were calculated (Fig. 14). It is easy to see that there are different values among the category percentages for vision. In human safety vision, the high impact category takes account of 70.5%. For potential damage to properties and estates, 62% of flooded area has high level impact category. These different values reflect the different focuses toward floods, which could be further used to help decision making related to the impact of flood.

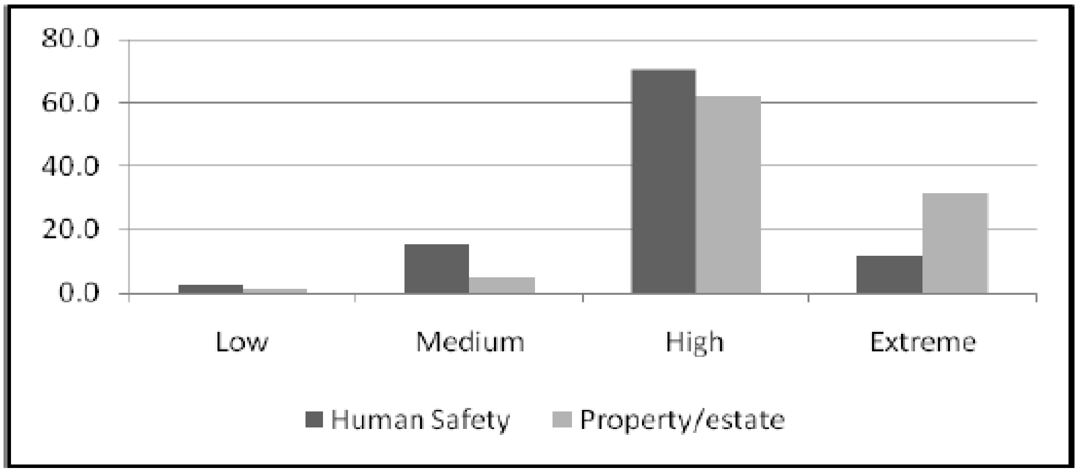

Figure 14. Percentage of flood impact categories for different vision (100 year return period)

The further impact assessment was done to the physical element at risk. The calculations are focus on Kampung Sewu Village and Pucangsawit Village. The inundation areas in Kampung Sewu Village and Pucangsawit Village based on 100 year return periods can be seen in Fig. 15.

In this study the elements at risk were identified based on topographic map of 1:25,000 and Ikonos imagery. The 1:25,000 was used to derive the land use information while the Ikonos imagery was used to update information about buildings and houses. A building footprint map was made by digitizing on screen the buildings from Ikonos imagery in ArcGIS software. Field verification then was performed by comparing the building footprint map to the real condition. The type of element at risk in term of building point of view can be identified as below:

- Physical elements : houses, factory, hotel
- Public facilities: schools, market, store, mosque, church

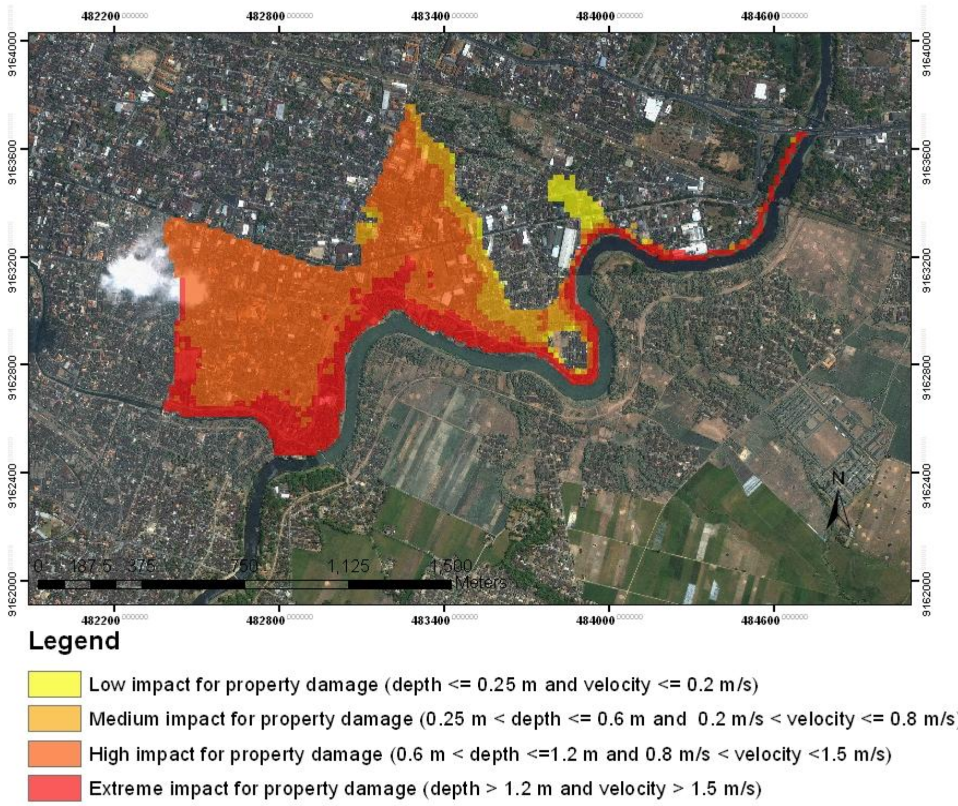

Figure 15. Flood Impact map of 100 year return period in kampung sewu village and pucangsawit village

Actual element at risk was calculated using modelling result which simulated inundated area based on 100 years return period. The Fig.16 shows the element at risk affected by flood in terms of buildings in Kampung Sewu Village and Pucangsawit Village for the return period 100 years. The modeling results include two flood parameters, i.e water depth and flow velocity. A comparison was made in flood hazard mapping between single parameter and multi parameters. The multi parameters hazard maps improve the reliability of the hazard class delineation. The impact assessment is done in two point of view, human safety and property damage. The further impact assessment is done by calculating the number of buildings affected by flood.

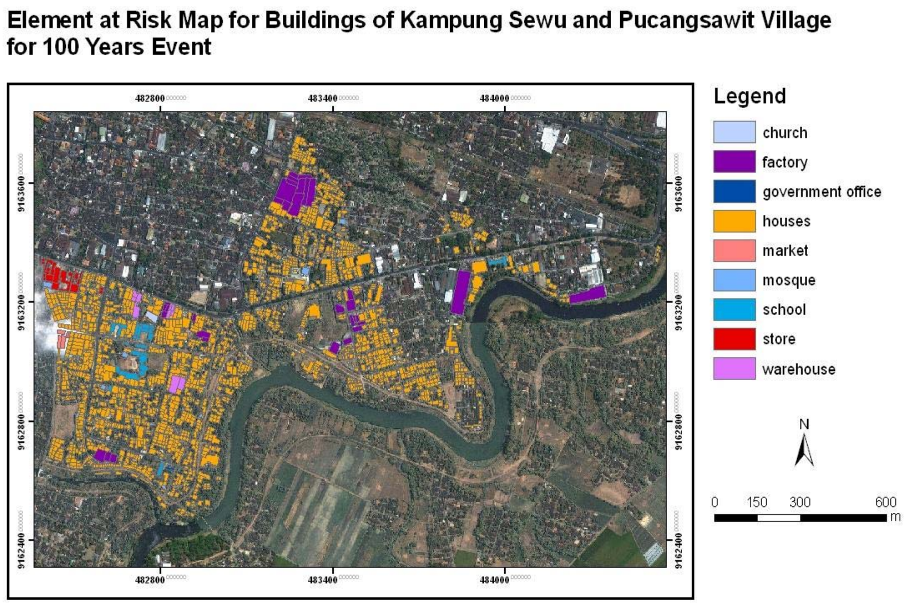

Figure 16. Element at risk for buildings

CONCLUSION

a. The results of the three scenarios of flows modelling using Flo2D can used to analyze the hazard in certain area.
b. The flood hazard can be generated through a single parameter of the flood hazard or by combining multi parameters of flood hazard. The reliability of the hazard class delineation can be improved by integrating some flood hazard parameters (water depth and velocity).
c. Integrating with another data such as land use map and Ikonos imagery, the flood hazard map obtained from modelling can be used to calculate the physical element at risk in the study area.

RECOMMENDATION

a. In modelling flood for larger return periods, e.g 225 and 500 years, it is recomended to conduct it in the bigger areas as the difference can be seen clearly.
b. The computation time is major constraint in flood modelling. It is recommended to use a fast computer with memory minimum requirement is 2 GB.
c. The further research such as risk assessment can be conducted in the study area.

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