Flood Risk Analysis of Godo River Basin, Pati Regency, Central Java, Indonesia, using HEC-Geo RAS

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Dominated by lowland area, most of Pati Regency was identified as inundation area. Flood risk assessment, which is resulted from two factors hazard and vulnerability, are adopted to forecast physical effect of flood on the study area. Hazard depends only on the flow regime of the river and is independent of the land use of the flood plains. Another factor, vulnerability is assumed as the sensitivity of land use to the flood phenomenon, which depends only on land use types. Based on the modeling result, from the largest area that affected by flood are settlement, irrigated paddy field and dryland agriculture, respectively. These results can be useful for government to prepare and determine reasonable mitigation for flood management system.

Key Words : *flood, hazard, vulnerability, risk, modeling, land use, HEC-Geo RAS*

1. INTRODUCTION

Flooding as a natural disaster would be a problem if it occurs on residential areas or agricultural land. The characteristic of flood in each area is different in its duration, intensity, and frequency. Flood effects can be local, affecting a neighborhood or community.

Pati is regency, which has high-risk level of flooding in Central Java Province. From the last news that was released by BNBP (January, 13th 2012), 154 houses in Pati Regency (Jakenan, Gabus and Sukolilo sub district) was sunk by flood. The morphology of flood prone area was formed by alluvial coastal processes and located in catchment area. This area is also indicated as a poor drainage system. With high rainfall intensity, the potential for flooding is very possible to happen.

Located in the northern coastal areas, Pati is dominated by lowland area from zero – 100 meter covered by 100, 769 ha area, it meant agriculture is potentially in this region. However, the lowest altitude (0 - 7 meter) was indicated in Gabus sub district. Based on BPS (2011), Rainfall average in Pati Regency is 2,239 mm and rainy days is 100 day. The highest rainfall is in the Gabus sub district up to 12.601 mm with 74 rainy days, while the lowest rainfall in the Pucakwangi sub district is 953 mm for 74 days with rainy days. Unfortunately, in the dry season the rivers are empty, while in the rainy season several rivers overflow that are tend to flood. Local flood occurs due to high rainfall intensity, which combined with insufficient capacity of urban drainage system (river network). In addition, the information related to flood hazard in Pati regency is limited.

When speaking of the risk situation, some complex concepts appear. Analyzing this intuitive risk comprehension, one assumes that the risk can be analyzed by breaking it up into two independent components; one based on the socioeconomic perception and the other depending on the hydrologic and hydraulic knowledge of the hydrological regime. Although most risk studies have been limited to a hydraulic analysis of the river in order to design structural flood protection works, the modeling of flood is one of the solution to forecast the uncertainty storm events (Gillard, 2006).

In conclusion, flooding is the main disaster problem that need handled accurately in Pati, so it is important to study the holistic approach in the risk assessment to determined flood risk management accurately.

2. RESEARCH OBJECTIVE

The research purposes of this study are comprised into some objectives, there are:

1. To construct flood modeling in Godo river

basin (a part of Juwana watershed) using GIS and others relevant software

2. To assess flood risk surrounded in Godo river basin based on land use characteristics; which types of land use are affected
3. To present consideration of flood management strategies for planning purposes at the study area.

3. RESEARCH METHODOLOGY

3.1 Research Study Area

The location of this research is setting surrounded on the Godo river basin that located in Gabus sub district, a part of Pati Regency. The survey of cross sections data only available for that river (yellow line; see figure 1) that obtained from the Public Work Board of Pati Regency. The following figure describes the location of study area.

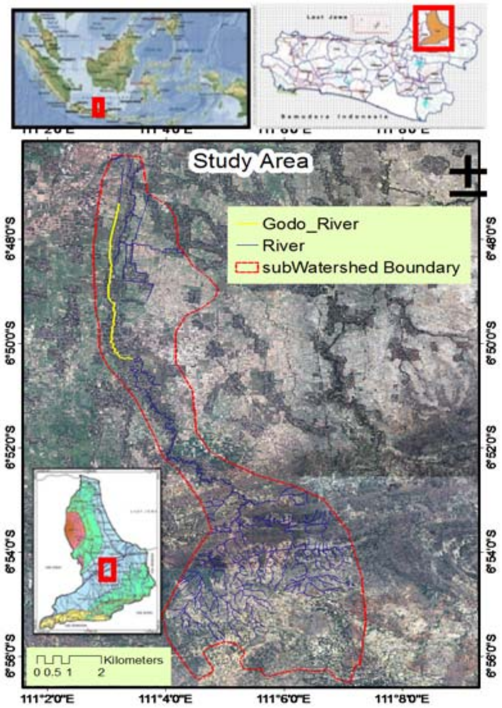

Figure 1 Study Area.

3.2 Data Collection

The data used in this research are comprised into three parts data, there are;

Spatial data ; topographic (contour interval 12.5 m with adding contour line in plain area per 6 m) from National Land Agency (BPN); landuse, administration, slope, soil, Quickbird from City's Development Planning Board of Pati Regency (Bappeda); watershed boundary (Pemali Jratun Watershed Management Agency (BPDAS Pemali Jratun).

Hydrological data; daily rainfall data (3 rain gauge stations) recorded from 2003 – 2012, river geometry data (Godo river cross-section) from Public Work Board of Pati Regency (DPU).

Additional data; profile of study area from Statistic of Pati Regency (BPS), others related information of study area (unstructured interview and information) from society, officer of some agencies, newspaper, internet.

3.3 Data Analysis Method

This study comprised in three phases of analysis.

a) Hydrological Analysis

In this study, hydrological analysis is used to calculate flood recurrence interval, and then the result of its analysis will be applied into hydraulic analysis in HEC RAS running system. Hydrology analysis is meant to obtain the flood frequency estimates, which is presented as flood hydrographs with return periods, for example 5, 10, 25, and 100 years (Kusumastuti, 2009). Hydrology analysis consists of rainfall data collection, rainfall data analysis, and Synthetic Unit Hydrograph (SUH).

The first step are create thiessen polygon and determine the distribution rainfall for each station per area. In this study, three rain gauge stations (Tambakromo, Winong and Gabus) were used to generate Thiessen polygon. From this calculation, we can get the average of rainfall intensity per weight of area. The next step is used the rainfall data defined frequency analysis by annual partial series. The investigation is used to determine which is the appropriate of distribution that can be applied. Some statistic parameters can be used :

$$Yr = \frac{\sum Y_i}{N}$$

$$S = \sqrt{\frac{\sum_{i=1}^{N} (X_i - X)^2}{N-1}}$$

$$Cv = \frac{S}{Y_r}$$

$$Cs = \frac{N}{(N-1)(N-2)S^3} \sum (Y_i - Y_r)^3$$

$$Ck = \frac{N^2}{(N-1)(N-2)(N-3)S^4} \sum (Y_i - Y_r)^4$$

Where:

Yi = maximum rainfall at year - i
Yr = average of rainfall data series
N = total rainfall data
S = standard deviation
Cv = variation coefficient
Cs = skewness coefficient
Ck = kurtosis coefficient

Furthermore, Alternating Block Method (ABM) is used to obtain rainfall distribution with equation:

$$I_t = \frac{R_{24}}{tc} \times \left(\frac{tc}{t}\right)^{2/3}$$

Where:

It = rainfall intensity with duration t (mm/hour)
R24 = maximum rainfall in 24 hours (hour)
tc = concentration time (hour)
t = rainfall duration (hour)

for tc, it can be gathered from equation:

tc = 0,76 × A0,38

where: A = catchment area (km2)

The next step is using Synthetic Unit Hydrograph (SUH) GAMA I, which is developed by Sri Harto (1985) based on the hydrological behavior of 30 watersheds in Java Island. Several main variables of this synthetic unit hydrograph are time to peak (TR), peak discharge (Qp), base time (TB), and recession curve determined by storage coefficient (K). In details, the concept of SUH GAMA I illustrated by figure 2.

where :

Qt : discharge at time t (m3/s)
Q p : peak discharge (m3/s
T : time from peak discharge (hour)
K : storage coefficient (hour)

Some parameters are needed to build SUH Gama I, the following equations are described below.

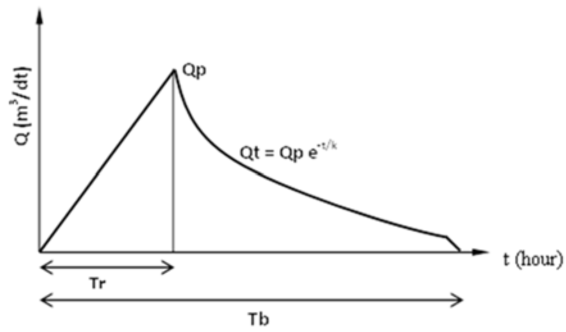

Figure 2 The concept of SUH GAMA I

$$T_r = 0.43\left(\frac{L}{100SF}\right)^3 + 1.0665SIM + 1.2775$$

$$Q_p = 0.1836A^{0.5886}T_r^{-0.4008}JN^{0.2381}$$

$$T_b = 27.41321T_r^{0.1457}S^{0.00986}SN^{0.7344}RUA^{0.2574}$$

$$k = 0.5617A^{0.1798}S^{-0.1446}SF^{-1.0897}D^{0.0452}$$

$$Q_b = 0.4715A^{0.6444}D^{0.9430}$$

where :

A : catchment area (km2)
L : length of main channel (km)
S : slope
SF : source factor, comparison between total length of first order river and total length of all order
SN : source frequency, comparison between the number of first order river and the number of all order
WF : width factor, comparison between catchment width at 0.75 L and 0.25 L from hydrometric station.
JN : number of river junction
SIM : symmetry factor, WF multiply by RUA
RUA : catchment area at the upper part
D : drainage density, number of total length of all order river per unit of catchment area.

Based on the computation using SUH GAMA I, the flood return period can be resulted.

b) Flood Modeling

Arc Map with the extension HEC-GeoRAS are used to build data preparation and post-processing. Hydraulic analysis is performed within HEC-RAS. Arc Map and HEC-GeoRAS are used to calibrate and validate the hydraulic results obtained through HEC-RAS. Triangular Irregular Networks (TIN) is placed as background layer terrain. RAS layers represent cross-sections and other data that depict the river and its surrounding terrain.A land use layer used to estimate Manning's n values along each cut line.

Later stage, the analysis of hydraulic is using HEC-RAS software. Hydraulic analysis contains four steps, there are (Ackerman, 2011); importing and defining the geometric data; completing the geometric and flow data; computing HEC-RAS; and reviewing the results. This study is used steady flow analysis. Steady flow describes condition in which depth and velocity at a given channel location that no change with time.

c) Flood Risk Assessment

The methodology of flood risk assessment was adopted from the approach, which is developed by Gillard (1996). The calculations for hazard, vulnerability and risk based on land use types. Frequently the risk analyze provide an information of the precise interaction of environment and society at the "pressure point", at the point where and when the disaster starts unfold (Wisner et al, 2003) : Risk = Hazard x Vulnerability

The hazard takes into account the probability associated to flood events as well as their main physical characteristics, flow velocity and flood depth. The vulnerability refers mainly to the flood prone area characteristics related to the potential of damage and to the local recovery capacity. Disaster is outcome from combination of hazard and vulnerability (Concado et al, 2008).

4. RESULT AND DISCUSSION

4.1. Flood Frequency Analysis

Firstly, the Thiessen polygon method is constructed to provide a weighting factor for each rain gauge station. The table 1 shows the results calculation of Thiessen polygon. Furthermore, the average of rainfall data from each station was determined by same date among three rain gauge stations. The next step is determining rainfall distribution at Godo River basin area. The result can be seen at the table 2.

According to statistical properties and calculation used Chi square and Smirnov-Kolmogorov, the distribution that agrees is Log-Pearson Type III. Furthermore, Alternating Block Method (ABM) is

Table 1 Thiessen Polygon of Godo Subwatershed.

No.	Rain gauge station	Precipitation Area (m^2)	Percentage of area (%)
1	Tambakromo	22170856.80	38
2	Gabus	4047071.39	7
3	Winong	32771125.33	56
Total		**58989053.53**	**100**

Table 2 Rainfall Distribution of Godo Subwatershed.

No.	Year	Date	Tambakromo	Gabus	Winong	Rainfall Average (mm)
			0.38	0.07	0.56	
1	2003	4 December	25	0	125	78.84
2	2004	13 December	0	25	65	37.83
3	2005	4 March	1	3	40	22.80
4	2006	1 May	0	25	52	30.60
5	2007	14 December	0	0	90	50.00
6	2008	19 February	0	25	54	31.71
7	2009	22 April	0	67	65	40.71
8	2010	10 December	20	0	58	39.74
9	2011	4 December	0	40	108	62.74
10	2012	8 March	0	0	66	36.67

chosen to determine rainfall simulation distribution. Before calculating intensity of rainfall with t duration, tc has been determined for 4 hours. There are basic parameters of Godo Subwatershed.

Table 3 Parameters of Godo sub watershed.

No.	Parameter	Symbol	Unit	Value	Results of calculation		
1	Length of 1 order stream		km	17.78	TR	=	2.77
2	Total length of all stream order		km	50.00	QP	=	2.52
3	Catchment area	A	km^2	58.99	TB	=	26.72
4	Length of main channel stream	L	km	26.59	K	=	6.97
5	Source factor	SF	-	0.36	ϕ	=	10.48
6	Symmetry factor	SIM	-	1.23	QB	=	5.63
7	Width factor	WF	-	2.15			
8	Number of junction	JN	-	14.00			
9	Slope of river (average)	S	-	0.01			
10	Source frequency	SN	-	0.52			
11	Upstream catchment area	RUA	-	0.57			

The computation to acquire flood hydrograph with return period of probability is summarized in figure 3.

Based on the figure 3 the maximum discharges for each return periods are 5yr (56.24 m3/s), 10yr (71.04 m3/s), 25yr (93.75 m3/s), 50-yr (112.36 m3/s), 100-yr (134.74 m3/s) and 200-yr (158.80 m3/s).

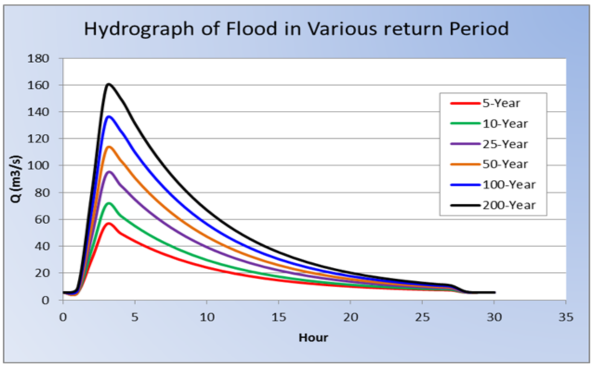

Figure 3 Hydrograph of Flood in various return periods.

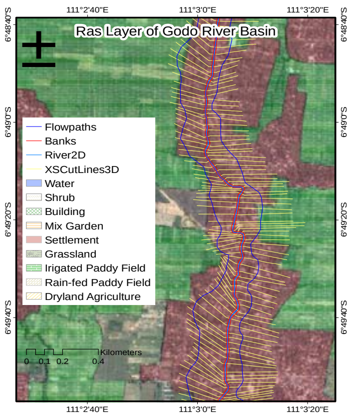

Figure 4 Creating ras layer of Godo river basin.

4.2. Flood Modeling using HEC GeoRAS

Creating RAS layers with land use layer to estimate Manning's n values along each cut line has been done, its also called preprocessing step. The figure 4 illustrated the RAS layer of study area.

4.3. Hydraulic Analysis

In the beginning step is imported the river network. It also determines the naming convention within HEC-RAS that will be used for referencing additional data. The cross-sectional data was added and tests were performed to ensure that the cross-sections captured in ArcMap are sufficient for the hydraulic analysis. Edits and adjustments can be made to inaccurate cross-sections by using the graphical cross-section editor tool in HEC-RAS.

This tool was used to view all the imported cross-sections for this study and was found to be in order. Cross-sections were intersecting with the stream centre line, bank lines and land cover layers. It indicates the 168 cross-sectional cut lines that should be imported into HEC-RAS. The results of imported of geometric data from Arc Map to HEC RAS that can be seen in geometric data window as shown in figure 5.

The hydraulic analysis can commence once the geometric and flow data have been entered into HEC-RAS. A surface profile for steady subcritical flow was modeled for each selected peak discharge value (5-years, 25-year, and 100-year recurrence).

4.4. Flood Risk Assessment

Gilard (1996) presented an approach that divides the flood risk into the factors of vulnerability and hazard. He described the vulnerability as the sensitivity of land use to the flood phenomenon, which depends only on land use type and social perception of the risk. The second factor, hazard, depends only on the flow regime of the river and is independent of the land use of the flood plains. Consequently, the same flow will flood the same area with the same physical parameters; whatever should be the real land use. The result of inundation area modeling from the total bounding polygon (252.88 ha) is illustrated by figure 6.

The percentage of inundation area according to the flood modeling area for each flood period is very high because more than 90 %, even on the high probability of flood return period (5-year).

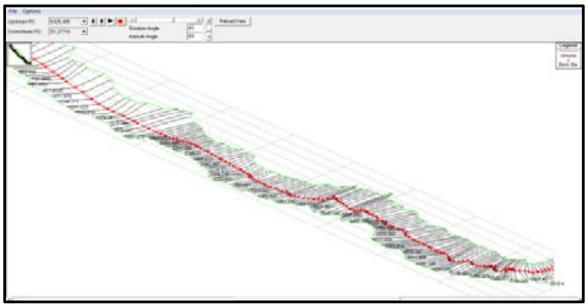

Figure 5. Geometric data (the result of imported geometric data).

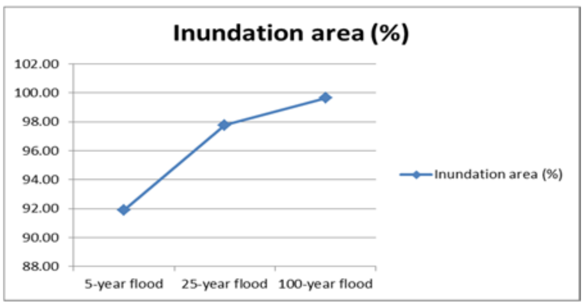

Figure 6. Percentage of inundation area.

Table 4 Flood Hazard of Godo river basin.

Water Depth (m) and Classification of Flood Hazard	Flood Plain Area (ha)					
	5 Years Flood	(%)	25 Years Flood	(%)	100 Years	(%)
0.1 < D < 0.5 (Low)	13.21	5.68	8.87	3.59	2.07	0.82
0.5 < D < 1.5 (Medium)	34.61	14.89	25.31	10.24	17.22	6.84
D > 1.5 (High)	184.58	79.42	213.09	86.18	232.67	92.34
Total	232.40	100.00	247.27	100.00	251.97	100.00

Table 5 Vulnerability based on landuse.

Land use type (ha)	Total Vulnerbility Area (ha)					
	5-year flood		25-year flood		100-year flood	
	Area	%	Area	%	Area	%
Settlement	156.95	67.53	170.17	68.82	174.58	69.29
Irrigated Paddy Field	62.06	26.70	63.45	25.66	63.73	25.29
Dryland Agriculture	13.39	5.76	13.66	5.52	13.66	5.42
Total	232.40	100.00	247.28	100.00	251.97	100.00

Furthermore, the result of hazard classification is shown in table 4. Generally from the result shown in table 4, the high level of hazard is more than 75 %, then the medium level is more than 5 % and the low level of flood hazard is from less than 1 % to 5 % from the total bounding polygon.

The result of vulnerability according to landuse characteristics in the Godo river basin area are shown in table 5. The settlement area is the most vulnerable area more than 60 % of total inundation area, then followed by irrigated paddy field (25%) and dry land agriculture (5%). Finally, from the combination of flood hazard and vulnerability the flood risk modeling of Godo river basin can be resulted as shown by figure 7and 8 respectively

From these figures the affected of land use characteristics are settlement, irrigated pady field and dryland agriculture. In detail, the affected area by flood is shown in table 6.

According to the table, the settlement area had the most dangerous area affected by flood. It provides caution to the government that flood risk management in Godo river basin area need handling as soon as possible for reducing more hazardous impact to economic and society in future. Furthermore, the basic cost of assumption derived from the data of economic loss from local government. This record of economic loss data based on flood events in the Gabus sub-district area. This record data gathered from flood events on Januari, 2011 and February 2011. The table 7 describes the assumption of economic loss by flood based on data from local government.

According to those assumptions, the figure 9 shows the estimation of economic loss by each flood.

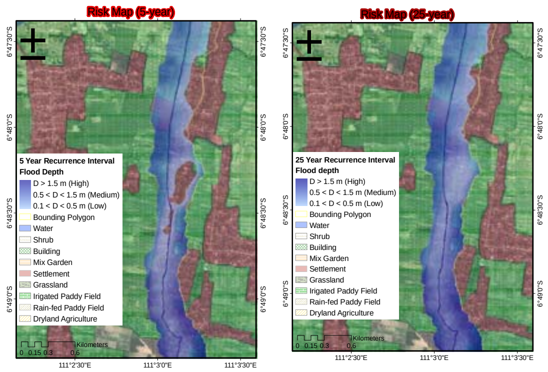

Figure 7 Risk map (Left:5-year and Right:25-year).

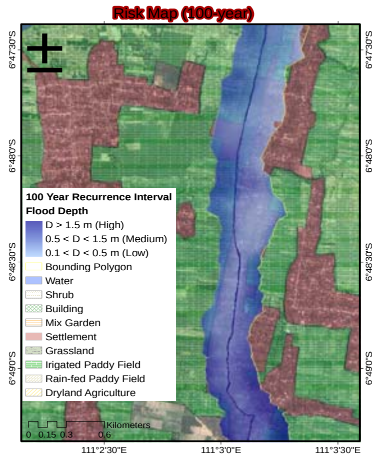

Figure 8 Risk map (100-year).

Table 6 The risk of land use characteristics affected by flood.

Landuse	Flood Depth (m)	Total Flooded Area (ha) based on Flood Return Periods					
		5-year	%	25-year	%	100-year	%
Settlement	0.1 < D < 0.5 (Low)	9.37	4.03	8.2	3.32	1.94	0.77
	0.5 < D < 1.5 (Medium)	22.79	9.81	18.12	7.33	15.5	6.15
	D > 1.5 (High)	124.78	53.69	143.83	58.17	157.13	62.36
Irrigated Paddy Field	0.1 < D < 0.5 (Low)	2.23	0.96	0.66	0.27	0.13	0.05
	0.5 < D < 1.5 (Medium)	7.22	3.11	4.46	1.80	1.52	0.60
	D > 1.5 (High)	52.61	22.64	58.34	23.59	62.08	24.64
Dryland Agriculture	0.1 < D < 0.5 (Low)	1.61	0.69	0	0.00	0	0.00
	0.5 < D < 1.5 (Medium)	4.59	1.98	2.73	1.10	0.2	0.08
	D > 1.5 (High)	7.19	3.09	10.93	4.42	13.48	5.35
Total		232.39	100.00	247.27	100.00	251.98	100.00

Table 7 Assumption of economic loss by flood.

Landuse types	assumption of economic loss (per ha/$)
Setlement (low and medium level of flood hazard)	50
Setlement (high level of flood hazard)	160
Irrigated Paddy Field	2100
Dryland Agriculture	4549.5

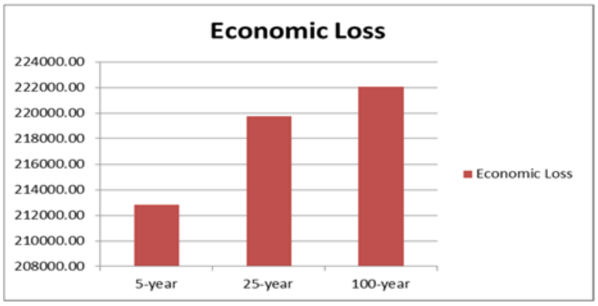

Figure 9 Economic loss estimation (5, 25, 100-year) This estimation gives perspective that flood disaster also caused high economic cost.

4.5. Flood Management Strategies

SWOT analysis could be a useful tool for the strategic planning process and environmental management. SWOT analysis is widely recognized and it constitutes an important basis for learning about the situation and for designing future procedures, which can be seen necessary for thinking in a strategic way (Lozano and Valles, 2007). SWOT analysis is used for analyzing strategies that can be applied in the Godo river basin area for reducing the impact of flood risk. The components of Strengths, Weaknesses, Opportunities and Threats were determined based on the condition of the study area. Some information has been gathered by unstructured interview process from related stakeholder in the study area.

Based on the analysis and information, there are some factors as Strengths;

- The new governmental institution that has authority to take care of disasters was established (Regional Disaster Management Agency of Pati Regency / BPBD).
- According to land use characteristics, open space land which is not used was identified in the surrounded of study area.
- Some infrastructures of flood control were identified like dikes, levees and evacuation places.

Some factors of Weakness in study area:

- Gabus sub district was indicated as the lowest altitude (elevation) area in Pati Regency.
- The growth of population is equal to the developing of residential along the Godo river.
- Interest conflict between economic and conservation policy
- High rainfall intensity in rainy season.
- Limited information about flood hazard and hydrology data.

Some factors as Opportunities:

- Government policy related to riparian conservation.
- Land rehabilitation project every year
- Positive participation of social community

For Threats, there are some factors are identified:

- Climate change global issues
- Deforestation at the upstream area
- Growth of population

According to those, SWOT factors from the study area. Some strategies can be applied in the study area.

S – O Strategies:

- Intensified cooperation between government institution and social community for flood mitigation activities
- Utilize the open space land to increase community participation in the management of flood plains.
- Engage society in rehabilitation project
- Utilize and maintain flood control infrastructure properly
- Engage the social community to protect flood control infrastructures

W-O Strategies:

- Implementing regulations and policies in flood plain area in order to control residential development in the river area
- Training program to create understanding of the inhabitant about correlation between economic losses and conservation
- Build Automatic Water Level Recorder (AWLR) system
- Build Automatic Rain Gauge Station system

- Create flood hazard information and map annually
- Build rain water harvesting system
- Build good relationship community between upstream and downstream to create simple early warning system of flood

S-T Strategies:

- Increase the role of institutions to prepare programs for facing of global climate change.
- Increase the role of institutions to reduce deforestation in upstream area
- Increase the role of institutions to create training programs for society about environmental conservation

W-T Strategies:

- Government should facilitate the program and activities to society for preparedness of climate changes.
- Improve spatial planning control in flood plain area
- Create conservation and training program to restore upstream area for reducing sedimentation and flood effect

5. CONCLUSIONS

1. This study has shown that flood modeling is possible with the use of available limited data, although the implemented model could not be empirically calibrated or validated (due to the unavailability of suitable historic satellite image of flood events.
2. The tools of floodplain modeling and analysis show that these tools provide efficient, effective and standardized results. It means can save time and resources.
3. The adopted flood risk assessment approaches a perspective, visualization and quantification that can help decision-makers to better understand the problem.
4. The flood risk assessment was made by combining the results of vulnerability and hazard assessment. Based on the assessment, settlement, irrigated paddy field and dryland agriculture area sequentially are implying to a significant impact on livelihood and agriculture due to the flooding.
5. According to the result of economic loss estimation, the impact of flooding in the study area is very significant even on the highest probability of flood return period (5-year).
6. SWOT analysis from the data and information based on local condition at the study area can give consideration for applying better flood management to reduce flood impacts.

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