Flood Hazard and Risk Assessment Due to Land Use Changes in Purbalingga, Indonesia

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Abstract: ***Purbalingga Regency is one of the regencies in Central Java Province that has rapid growing in economic and tourism in accordance with comprehensive urban planning. Land use changes is an important aspect of urban planning. Therefore, spatial analysis is needed to highlight the problem of flooding in Purbalingga Regency. Spatial analysis performed for flood risk is a spatial analysis based on flood hazard zoning and flood vulnerability. Flood hazard zoning and flood vulnerability analysis were conducted using Analytical Hierarchy Process (AHP) and Geographic Information System (GIS) for existing condition, regarding current data and projection condition presented in Purbalingga Urban Planning 2011-2031. Result of flood hazard zoning analysis showed that for existing condition, Purbalingga Regency is mostly considered into the medium category of hazard category with an area of 62,652.077 ha. On the other hand, referring urban planning projection data 2031, there is a decrease in categories of low, medium, and high, but increase in very high and extreme category. Risk assessment shows that Purbalingga Regency currently has an extreme category with an area of 11,080.047 ha, including the proposed location of Wirasaba Airport.***

Keywords: AHP, flood hazard, Purbalingga Regency, risk assessment, urban planning.

I. INTRODUCTION

Flood and inundation are two things that can hinder the development of a region. When a flood occurs, the traffic and trade activities will be hampered, causing huge losses to the economic activities of the area. Flood disaster is affecting economic growth, both in developed and developing countries [1–3]. In terms of loss of Gross National Product (GNP), the most devastating floods occur in developing countries [1]. Based on [3], there is a significantly positive effect on Gross Domestic Product (GDP) growth rates due to climatic disasters.

In general, flood is caused by high of rainfall intensity, land use that cannot absorb water into the ground, especially over large area. One of the parameters to be considered in regional planning is the flood hazard map.

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Traditional methods of flood risk mapping are based on ground surveys and aerial observations, but when the phenomenon is widespread, such methods are time consuming and expensive [4]. Rahmati et al [5] stated that Analytical Hierarchy Process (AHP) technique is promising of making accurate and reliable prediction for flood extent, therefore, the AHP and Geographic Information System (GIS) techniques are suggested for assessment of the flood hazard potential, specifically in no-data regions.

Purbalingga Regency is one of the regencies in Central Java Province that has a fairly rapid development, with reliability in tourism and industry. The appearance of tourism and industrial activities gives a big role in increasing regional GDP in Purbalingga Regency as revenue of those mentioned activities [6]. Moreover, the Purbalingga local government with support of central government and State-Owned Enterprises (BUMN) is attempting to provide better transportation infrastructure i.e. reviving the railway lines of Banyumas, Purbalingga, Banjarnegara, and Wonosobo, along establishing Wirasaba Airport in Sub-district Bukateja [7]. The development of these modes of transportations are expected to support the sustainable development of Purbalingga. The development of Purbalingga Regency cannot be separated from the land use pattern changes of the concerned area. Considering urban development, Purbalingga Urban Planning 2011 – 2031 forecast several land use changes from forests and rice fields to river border, spring border, railway border, settlements and industrial area in Purbalingga Regency. The land use changes, however, will influenced to the hydrological conditions of the catchment area. On the other hand, geographically, Purbalingga Regency is located on the slopes of Mount Slamet, which has height of 3,428 m. The geographical location of Purbalingga Regency is resulted in high rainfall caused by orographic rain. The number of rainy days, high rainfall, and changes of land use patterns in Purbalingga Regency area caused high flood potential in the region. Large-scale flood acutely impacted on public infrastructures, the worst hit sector was transportation, and this imply the importance of mainstreaming disaster risk management in the development sectors [8]. Therefore, it is necessary to assess the flood hazard and flood risk in Purbalingga Regency area. This paper will analyse and compare both rainfall and land use changes projection as part elements of hazard analysis to create the intended model of drainage facility. This viewpoint is expected to provide convenience of the local government in making the right decision, in accordance with the projection of flood disaster in Purbalingga Regency.

Furthermore, this paper can be the first step in making the model of drainage facility in the future.

II. MATERIAL AND METHODS

A. Study Area

Purbalingga Regency which has 18 sub-districts spans on 101 ° 11'-109 ° 35' East Longitude and 7 ° 10'-7 ° 29' South Latitude, located in the Southern of Pekalongan and Pemalang Regency, the West of Banjarnegara Regency, the Northern of Banjarnegara and Banyumas Regency, and the eastern of Banyumas Regency. The location of Purbalingga Regency can be seen in Figure 1.

Purbalingga Regency has a land area of 77,764 ha, as well as topographic conditions of the plateau with a slope of more than 40% in the northern, and lowlands with a slope of 0-25% in the south. Hydrologically, Purbalingga Regency is located in the Serayu River Basin. Based on 11 rain stations in Purbalingga Regency, this area has an average rainfall day of 130 days, with an average rain depth of 4,158 mm in the last 5 years [6].

B. Modelling and Design Experiments

There are varied ways to assess flood risk area. One of those is a spatial analysis using GIS to obtain then the flood risk maps. A flood risk map is created by overlaying some maps and adding weight ratings for each map. In doing a disaster risk analysis, two important elements are generally required, i.e. hazard and vulnerability [9–11]. Hazard can be defined as potentially catastrophic elements, where such elements can be threats from nature and technology [12,13]. Whilst vulnerability is elements (can be physical or social conditions of the area) affected by disaster [14,15].

The assessment weight for each element is performed using Analytical Hierarchy Process (AHP). The AHP method was introduced by Saaty in 1977 and has been widely used by researchers and policymakers to analyse problems involving many complex elements [16,17]. With AHP method, we will get the weight criteria for each element based on the relation of importance to the problem.

III. ANALYSIS AND DISSCUSSION

A. Analytical Hierarchy Process (AHP)

AHP is a theory of measurement through pairwise comparisons. It relies on the judgements of an expert to derive priority scales [18]. The comparisons may be taken from either actual measurement or from a fundamental scale which reflects the relative strength or preferences and feeling. The general rule is that the hierarchy should be complex enough to capture the situation, but small and nimble enough to be sensitive to change [19].

Pairwise comparisons are the basic of the AHP. AHP starts with define a problem and make a hierarchy structure contains the goal of the decision (as parent element) and the derivatives (as child elements). Thereafter, build a pairwise comparison matrices of child elements and judge each element using scale in numbers (1 – 9). The greater number of scale indicates the importance of a child element against other child elements to the parent element. The results obtained from AHP are weighted factor of each child elements to the parent element.

When a decision maker judges the scale of child elements, there can be inconsistency of decision making. Therefore, it is necessary to do a consistent analysis through pairwise comparisons in order to know the consistency ratio (*CR*). The permitted consistency ratio (*CR*) in the AHP analysis is less than 0.1. To get the *CR* value, firstly it needs to know the value of consistency index (*CI*) and random index (*RI*). The value of *CI* is calculated using Equation 1, with λ_{max} is the maximum eigenvalue of the comparative matrix based on n number of criteria calculated by Equation 2. The value of *RI* is represented by average *CI* values gathered from random simulation of Saaty pairwise comparison matrices *CI*s, as shown in Table 1.

Table – I: Random Index (RI) [16]

N	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
RI	*0*	*0*	*0.58*	*0.90*	*1.12*	*1.24*	*1.32*	*1.41*	*1.45*

After the *CI* and *RI* values are obtained, the calculated *CR* is calculated using Equation 3 [16,20].

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (1)$$

$$\lambda_{max} = \sum_{j=1}^{m} \frac{(S.v)_j}{m.v_j} \quad (2)$$

$$CR = \frac{CI}{RI} \quad (3)$$

where: *m* represents a number of independent rows of the matrix, *S* represents pairwise comparison matrix and *v* means the matrix eigenvector.

B. Flood Hazard Zoning

Naturally, there are many elements that affect flood hazard. [16,21] provides several alternative elements that cause flood hazard, such as rainfall, slope, soil texture, geology, land use, drainage, and vegetation. In the analysis of flood hazard zoning in Purbalingga Regency, the used elements are rainfall, main-river and tributary maps, slope, land use, and road, which then are made into the thematic maps.

The rainfall data used to create a rainfall map are the monthly average rainfall data from 2009 to 2014, and the selected data are the largest of the monthly rainfall data. The main river and tributary maps are further processed into river buffer maps. Multiple ring buffer are used to create river maps by using border criteria of 10 m, 15 m, and 30 m, based on Regulation of Minister of Public Works and Public Housing (PERMEN PUPR) [22]. Regarding to land use, the spatial analysis of GIS in this paper is made to analyse of two land use conditions, i.e. the analysis of existing condition and in accordance with the Urban Planning 2031. The pavement road element is included as element of hazard zoning analysis, since pavement roads can inhibit infiltration, so that increase the potential of flood hazard.

Overlay was made for flood hazard zoning map from all thematic maps by incorporating the weight factor of the AHP analysis. Based on AHP analysis, it was found that the weight factor for each element is 0.424 for rainfall, 0.253 for main river buffer, 0.149 for tributary buffer, 0.092 for slope, 0.051 for land use and 0.031 for road. The consistency ratio of AHP for flood hazard zoning is 0.08.

In this paper, the score for assess hazard, vulnerability, and risk using numerical score of low to high as the simplified matrix to rank hazard, vulnerability, and risk assessment [23].

The scores for low, medium, high, and very high category are 0 – 1, 1 – 2, 2 – 3, and > 3, respectively. The hazard with the highest total score is the one that deserves priority attention [24].

The results of spatial analysis are shown in Figure 2. Figure 2 (a) shows the flood hazard zoning of existing conditions (2016 land use data), while in Figure 2 (b) shows flood hazard zoning on Purbalingga Urban Planning 2011-2031. Based on the spatial analysis, changes of land use area can be seen in Table 2, and changes of hazard category area are shown in Table 3.

Table – II: Land Use Area in Purbalingga Regency

Land Use	Existing 2016 (ha)	Urban Planning 2031 (ha)	Land Use Change (%)
Forest	15,226.58	14,955.18	-1.78
Wetland rice fields	22,361.37	16,660.70	-25.49
Dry rice fields	24,014.82	5,812.36	-75.80
Settlement	17,007.58	17,264.64	1.51
Industry	105.47	534.26	406.54
River	1,432.56	1,127.23	-21.31
Springs border		358.68	
Railroad border		55.26	
River border		2,551.36	

Table – III: Hazard Area in Purbalingga Regency

Land Use	Existing 2016 (ha)	Urban Planning 2031 (ha)	Hazard Category Change (%)
Low	1,135.42	711.27	-37.36
Medium	62,652.08	62,636.15	-0.03
High	16,847.84	16,829.93	-0.11
Very High	1,781.83	1,817.68	2.01
Extreme	28.63	51.08	78.41

Based on Figure 2, it appears that the flood hazard zoning map did not undergo significant changes. However, if it is analyzed more detail, based on land use changes, there was reduction in the area of low, medium, and high hazard category, along with increasing area of very high hazard category. From Table 2, there has been decline land use of forest, wetland rice fields, and dryland rice fields, into springs borders, railway borders, and river borders. On the other hand, there are significant increase in the area of settlements and especially industries.

The land use changes have a considerable impact on the hazard category, as shown in Table 3. Table 3 showed that there are decreasing areas of low, medium and high category, along with increasing area of very high and extreme category, until it reaches 78.41%.

On the flood hazard zoning map of existing condition, most of the extreme category are in Karang Jambu sub-district which has a big slope of land and river. Whilst the category of very high, and high respectively occur in almost all main rivers through Purbalingga Regency and all of the tributary in Purbalingga Regency. It indicates that hazard-affected sites for extreme, very high, and high categories occur because of their proximity to the river basin. Meanwhile, based on the flood hazard zoning map based on urban planning data of 2031, the extreme, very high, high, and medium category sites are becoming widespread due to land use changes.

C. Flood Vunerability

Flood Vulnerability is the situation where the social, economic, and physical elements that have the potential to be affected due to flooding event [9]. There are 3 elements that are considered to affect flood vulnerability in Purbalingga Regency i.e. population density, infrastructure, and cultural sites located in Purbalingga Regency. The three elements are also made into thematic maps and overlaid by using weight factor of AHP. The weight factor value for people density, infrastructure, and cultural sites is 0.634, 0.192, 0.174 respectively, and the consistency ratio is 0.01. The result of flood vulnerability for Purbalingga Regency can be seen in Figure 3, and shown in Table 4, which the scores for very low, low, medium, and high category are < 1, 1 – 2, 2 – 3, and > 3, respectively.

Table – IV: Vulnerability Area in Purbalingga Regency

Vulnerability Category	Area (ha)
Very Low	21,210.973
Low	43,259.167
Medium	13,297.131
High	3,070.674
Extreme	0

Based on Figure 3 and Table 4, most of the areas in Purbalingga Regency are still relatively safe regarding flood vulnerability. Nevertheless, there are some areas in high vulnerability category. There are all of Purbalingga Sub-district and several points in Padamara and Kalimanah Subdistricts. While the medium categories occur in Padamara and Kalimanah sub-districts, and scattered at some point in the southern Purbalingga Regency. High and medium vulnerability category areas are the area of high population density and important infrastructure.

D. Flood Risk

Flood risk analysis and assessment are integral parts of the flood risk management approach [25]. Flood risk analysis and assessment are used to take a decision dealing with flood hazards and mitigation. Flood risk was analysed using the conventional risk equation shown in Equation 4 [26].

$$Risk = Hazard \times Vulnerability \quad (4)$$

The risk reaches intermediate to high values (upper level of the figure) if (1) the hazard is high, or (2) there are many elements at risk exposed, or (3) the vulnerability is high [14]. The rising both or one of hazard and vulnerability will increasing risk level. The descending both or one of hazard and vulnerability will decreasing risk level.

The spatial analysis of flood risk in Purbalingga Regency was done by overlaying hazard maps and vulnerability maps using Equation 4, for the existing conditions of 2016 and projection data 2031.

The scores for no risk, low risk, medium, high, and extreme risk category are 0 – 1, 1 – 2, 2 – 3, 3 – 4, and > 4, respectively. The overlay results of projection data 2031 is shown in Figure 4 and are labelled in Table 5.

Table – V: Risk Area in Purbalingga Regency

Land Use	Existing 2016 (ha)	Urban Planning 2031 (ha)	Risk Category Change (%)
No Risk	1,541.50	1,149.76	-25.41
Very Low	4,783.69	4,758.56	-0.53
Low	27,053.60	26,990.35	-0.23
Medium	21,816.33	21,846.86	0.14
High	16,226.38	16,167.03	-0.37
Extreme	11,080.05	11,207.31	1.15

Based on Figure 4 and Table 5, extreme categories occur quite a lot in the west and south of Purbalingga Regency, including Kutasari, Bojongsari, Mrebet, Bobotsari, Padamara, Purbalingga, Kalimanah, Kemangkon and Bukateja sub-districts as well as the proposed location of Wirasaba Airport. The comparisons of existing data 2016 and urban planning projection 2031 shows that overall the risk category are decrease but extreme risk category.

IV. CONCLUSION

From the urban planning projection 2031, most of the land use changes are for river border, springs, and railway borders (2,965.293 ha), while for settlements and industrial area are only 685.846 ha. If the urban planning projection 2031 is being obeyed, based on the analysis of flood hazard and risk assessment, Purbalingga Regency did not experience any significant changes for each category.

Regarding the flood risk assessment, currently, Purbalingga Regency has wide area of extreme risk category, it is around 11,080.047 ha, including Purbalingga sub-district as regency capital, and the proposed location of Wirasaba Airport. It indicates that the local government of Purbalingga Regency has to be aware of doing comprehensive drainage system. In order to provide the drainage system of Purbalingga Regency, especially in residential area and airport, it is necessary to analyzed the infiltration because of the land use changes and forecast the soil recharge, so the local government can fulfil an adequate drainage facility system.

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