Erosion Risk Modelling Using Geographic Information System in Beringin Watershed, Semarang City

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***Abstract*— One of the main environmental problems that can have an impact on natural, agricultural and environmental resources is soil erosion. During the last years there has been a growing awareness of the importance of problems directly related to erosion in almost Indonesian watershed region. Beringin Watershed is a watershed that became the center of the hydrological cycle in Ngaliyan and Mijen districts. Approach in watershed management is related to erosion threat that can be done by doing in handling and management of watershed. Management of soil conservation, erosion control and management of water catchment areas can be presented in geospatial information that contains spatial information and quantitative data from information on soil erosion. In this study, the risk map model of erosion in Beringin watershed mainly based in expert's knowledge (AHP) and the RUSLE model which is considered to be a contemporary simple and widely used approach of soil erosion assessment. The risk mapping resulted in high class threatening 1.309%, medium grade 48.183%, and 50.508% of the total area of Beringin Watershed. The high-risk areas are located in Subdistrict of Beringin, Kedungpane, Pesantren, and Ngaliyan.**

Keywords—Beringin Watershed, Erosion Risk, RUSLE, GIS, AHP, Semarang city

I. INTRODUCTION

One of the main environmental problems that can have an impact on natural, agricultural and environmental resources is soil erosion [1]. During the last years there has been a growing awareness of the importance of problems directly related to erosion in almost Indonesian watershed region. In some parts of the watershed region, erosion has reached a stage of irreversibility while in some places there is no more soil left [2]. Soil erosion is one of the most common natural phenomena, but agricultural activities as one of human activities can accelerate erosion [3]. River ecosystem is a complex ecosystem that covers the entire catchment area based on the physical boundaries of the earth's surface known as the watershed (DAS). Erosion plays an important role in watershed management. By calculating the forecast of the erosion in the watershed, a solution can be found to realize the sustainable development of water resources and land so as to increase the prosperity of the existing population within the watershed.

Approach in watershed management is related to erosion threat that can be done by doing in handling and management of watershed. Good watershed management can be done by mapping erosion risk. Understanding of disaster risk mapping can be described as a map making activity that represents the negative impacts that can result in material and non-material losses in a region in the event of a disaster [4]. Risk mapping for each region is required in the Law of the Republic of Indonesia No.24 Year 2007 on Disaster Management in Articles 35-36 and Government Regulation No.21 Year 2008 on Disaster Management Implementation in Article 6, then also supported by the Regulation of Head of Disaster Management Agency National (PERKA BNPB) No.2 Year 2012 on Disaster Risk Assessment. It is increasingly showing that the importance of mapping the risk of soil erosion. By mapping these erosion risks can minimize the impacts and losses caused by erosion so that good watershed management can be realized.

Management of soil conservation, erosion control and management of water catchment areas can be presented in geospatial information that contains spatial information and quantitative data from information on soil erosion [5]. The main factors that influence the level of soil erosion are vegetation cover, topographic feature, climatic variables and soil characteristics. The changes of land cover or vegetation cover, as a form of increased human activity will be able to increase the level of soil erosion in an area [6]. The dynamic factors of climate that can affect erosion is rainfall intensity. The topographic features, slope, slope length and shape affect mostly rill and erosion [7]. The remote sensing technology can be used as a method to map land cover/land use or erosion modeling development effectively and efficiently. The latest advances in remote sensing technology have proadvanced image processing techniques, that has given the oportunity for quantitative assessment of farming practices as an indicator in soil erosion risk assessment [8].

Beringin Watershed Semarang is a watershed that became the center of the hydrological cycle in Ngaliyan and Mijen districts. With current exciting conditions, such as land use change and climate change that result in high rainfall rates, allow for erosion threats in the Beringin watershed. The threat of erosion will be a high risk if the region's vulnerability is high and its capacity is low. On the basis of this, then mapping the risk of erosion in Beringin River Watershed is very necessary. In this study, the risk map model of erosion mainly based in a quantitative empirical multi-parametric model which is expert's

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knowledge (AHP) and the RUSLE model which is considered to be a contemporary simple and widely used approach of soil erosion assessment [9]. In both methodologies the research is based on the integration of remote sensing, GIS and precipitation data in order either to evaluate soil loss or to map erosion risk. The results in this study can build a risk map model of erosion in Beringin watershed, Semarang City, which will contribute to policy makers related to land conservation in Beringin watershed, and as disaster information for Semarang city community, especially for people in Ngaliyan and Mijen sub-districts.

II. EROSION MODELLING

Determination of prediction of erosion level in a watershed can be done in various empirical methods.The classified of Cisokan watershed with the USLE method [10]. The same is done by [11] predicted erosion in South Korea's IMHA watershed using RUSLE method. The use of RUSLE and USLE methods is essentially the same but there are differences in the detail of the classification of erosion causing factors i.e rainfall, slope, and land use. However, the most important difference of the empirical method between USLE and RUSLE is on the surface flow factor which in this case is derived from the long factor and the slope of the slope. In this study, the prediction of erosion level using RUSLE in Beringin Watershed has never been done by previous research, but also weighted RUSLE parameter from result of AHP. The selection of RUSLE in this study is supported by the availability of topographic data scale 1: 5,000 in 2000 from the Public Works Department to get a better surface flow factor value compared to the availability of topographic data available today. AHP allows interdependences between soil erosion decision factors to be taken into account and uses expert opinions as inputs for evaluating decision factors. According to [12], some of the main advantages of AHP method over other multi criteria methods, such as point allocation and multi-attribute utility theory, are its flexibility, its ability to check inconsistencies and its appeal to decision makers. Finally, the AHP method gives the chance to assess and map soil erosion risk rather than RUSLE method that calculates absolute values of soil erosion loss.

III. REVISED UNIVERSAL SOIL LOST EQUATION (RUSLE)

Topography, geology, climate, soil, vegetation, land use, and man-made developments can affect the level of erosion, specific degradation, and sediment yield from a watershed. The method most widely used around the world to predict long-term rates of interill and rill erosion from field or farm size units subject to different management practices is USLE. RUSLE was developed to incorporate new research since the earlier USLE publication in 1978 [13]. Agriculture Handbook 703 [14] is a guide to conservation planning with the RUSLE. The underlying assumption in the RUSLE is that detachment and deposition are controlled by the sediment content of the flow. The erosion material is not source limited, but the erosion is limited by the carrying capacity of the flow Both USLE and RUSLE compute the average annual erosion expected on field slopes and are shown in the Equation (1) :

$$A = R\ K\ L\ S\ C\ P \qquad (1)$$

Where:

A = Computed spatial average soil loss and temporal average soil loss per unit of area, expressed in the units selected for K and for the period selected for R.
R = Rainfall-runoff erosivity factor
K = Soil erodibility factor
L = Slope length factor
S = Slope steepness factor
C = Cover management factor
P = Support practice factor

IV. METHODS

Generally, the course of this research is carried out as shown in Fig.1, with the following explanation is the beginning of the study conducted discussion of the discourse on the theme of research through literature studies related to erosion hazard in Beringin watershed and then compiled the formulation of the problem for further research. Then, to complete this research conducted data collection and questionnaire. Data collection was done by obtaining secondary data from various agencies related to this research, and for primary data was conducted interview process and questionnaires from correspondents that result used for validation process and research analysis.The next process is to conduct the research process. The erosion model in this study uses RUSLE Equation, but in weighting each parameter using Analytical Hierarchy Process (AHP) technique. The first step is to process the weighting of erosion parameters by using Analytical Hierarchy Process (AHP) technique.

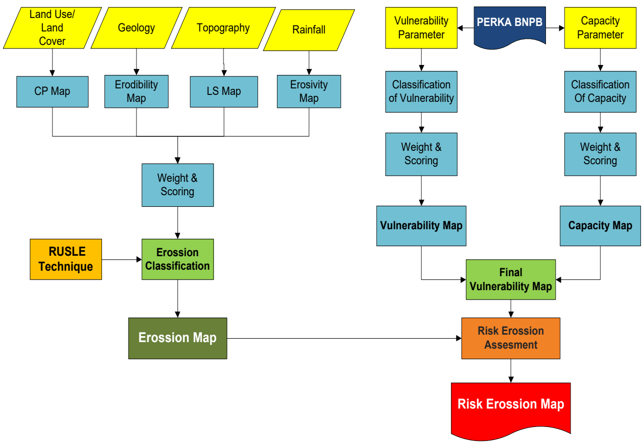

Fig.1. Flowchart of methodology

The result of AHP will get the weight and priority value of each erosion parameter. After performing the AHP process, a mapping of erosion threats using Geographic Information System (GIS) is performed by overlaying each of the erosion parameters by using the weight of the results of the AHP process. The next step is to mapping the vulnerability and capacity of the secondary data related to the territorial conditions in the Beringin Watershed. Vulnerability and capacity mapping process using GIS with reference to BNPB Regulation no. 2 of 2012.

The process of mapping the threat, vulnerability, and erosion capacity in Beringin Watershed, using GIS technique through risk matrix multiplication is obtained by the result of map of risk of erosion of Beringin Watershed, which in turn ends the conservation analysis of erosion hazard in Beringin watershed based on risk map result . In this study used descriptive analysis method, which in this study supported by the study of literature and the use of secondary data. To improve the accuracy of the study, the results of the analysis will be validated by field checks. In each subdistrict/village the high erosion rate will be measured by handheld GPS position.

In this study used several assumptions to limit the results of research, while the assumptions used are:

1) The parameters used in calculating the erosion rate are the erosivity, the sensitivity of the soil to erosion, the length factor of the slope, the slope of the slope, the cover and the land processing, by empirical calculation using RUSLE
2) In determining land use, variations of plant species are ignored.
3) In the RUSLE modeling all parameter maps are changed in raster form with a 10 x 10 m^2 grid
4) Contour data was obtained from the 2000 map, with a fairly relevant scale for topographic conditions in the watershed area and no significant topographic changes.
5) The absence of erosion prevention efforts such as the construction of terraces and others.
6) Rainfall data and the latest image retrieval year is 2014-2016, validation of results conducted in 2017.
7) The use of the weight of each parameter of erosion level is done by AHP method where the informant conducted by the quesioner is an expert who has knowledge and experience knowing the condition of the Beringin watershed, thus giving the right AHP result in generating the priority and weight of the erosion rate parameter.
8) The existence of limitations of secondary data obtained so as to reduce the accuracy of research conducted with the reality in the field, but anticipated with the field validation.
9) Field validation by conducting a survey on each subdistrict / village in the Beringin Watershed area and conducting interviews / questionnaires to village / village officials who are considered to know the condition of their territory against the threat of erosion.

V. Result and Analysis

A. Result R Erosion Parameter Mapping

The Beringin River Basin has four rainfall observer stations. In this study were taken four stations covering the research area, namely Climatology Station, Ngaliyan, Beringin and Mijen. The calculation of this data uses monthly rainfall data for two years. Monthly rainfall data for 2 years from 2015-2016 are processed and multiplied by the Lenvain equation to obtain an erosivity factor. Spatial interpolation assumes that data attributes are continuous in space and these attributes are spatially dependent. Interpolation is done by using IDW (inverse distance weighted) method on spatial analyst tools. The interpolation method according to the inverse distance method, that is good enough in estimating the sample value at a location.

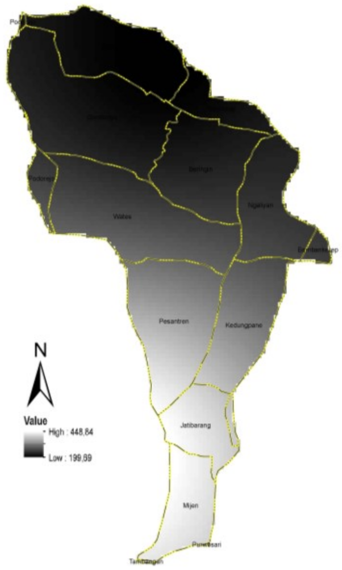

Fig.2 R Erosion Parameter Map

B. Result K Erosion Parameter Mapping

Soil Erodibility Factor (K) represents both the soil susceptibility to erosion and the amount and rate of runoff. Soil texture, organic matter, structure and permeability determine the erodibility of a particular soil. The K factor reflects the ease with which the soil is released by splashing during rain and / or surface flow. K erosion parameter mapping is done by scoring the value of K that refers to the Center for Land Research and Development (2004).

Fig.3 K Erosion Parameter Map

The value is included in the attribute table contained on the map of ground type of Semarang City that has been cliped along the previous Beringin Watershed. Map scores results in a vector format which is then called the map K (soil erodibility factor). The score erodibility of soil type in study area are : Grey Alluvial Soils (0.47), Dark Brown Mediterranean Soils (0.46), Association of Reddish Brown Latosols (0.12) and Association of Brown Latosols (0.31).

C. Result LS Erosion Parameter Mapping

Long Slope Factors and Damping Factor (LS) are the result of a combination of slope length and steepness relative to the standard plot unit. This reveals topographic effects, particularly the length of the slopes and the steepness of soil erosion. Increased hillside length and steepness in increasing LS factor. The length of the factor slope (L) is defined as the distance from the runoff source to the point where either the deposition is initiated or the runoff entering the clear channel that may be part of the drainage network. On the other hand, the steepness factor (S) reflects the effect of steep slope erosion. The assumption used is that the LS factor values will differ between the upper and lower slopes. The LS value will be greater in place of accumulated flow from the upper slope although it has the same slope length and slope. The Beringin Watershed area has a morphology of hills with varying slopes. Starting from a region with medium to high slopes. The number of areas in the Beringin watershed which has a steep slope of course is feared will cause erosion hazard. Based on the calculation of LS factor, the area with the highest LS factor is in the middle and north of the Beringin River Basin. This area is located in District Ngaliyan. The most visible LS factor is in Ngaliyan and Beringin urban villages. In these two regions, there are many areas that have steep slopes. The Gondoriyo Subdistrict area also has a region with a high LS factor. Most of the villages of Banbankerep and Wonosari also have high LS factor. Although only a part of this region has a high value, did not rule out this area is an area prone to erosion. Some areas with high LS factor values exist in areas with land cover in the form of settlements. It is feared this will trigger the dangers of erosion. In Ngaliyan Dictrict with some subdistrict have high LS factor value also have high rainfall. This condition will certainly increase the rate of erosion.

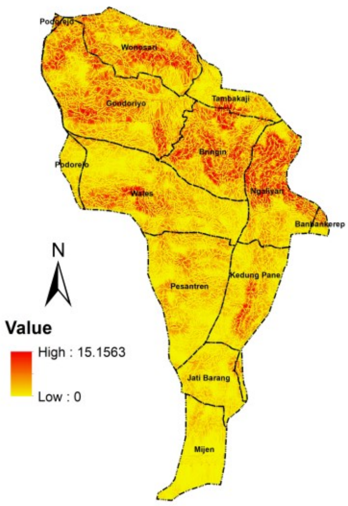

Fig.4 LS Erosion Parameter Map

D. Result C Erosion Parameter Mapping

Map C (Land cover management factor) is a mapping of the previously used land-use digits that are then weighted for each classification attribute. The weighting refers to Table I. Scoring on map C is done by entering the scores into the attributes of each land use classification. After all classes of land use are filled by each score, then converted to vector map into raster map so that the map C is formed.

TABLE I. CLASSIFICATION OF LAND USE AND SCORE VALUE

Land Cover	Score
Rice Field	0.04
Bush	0.1
Forest	0.01
Settlement	0.5
Plantation	0.01
Field	0.28
Talun Garden	0.02

Source : Kironoto, 2003

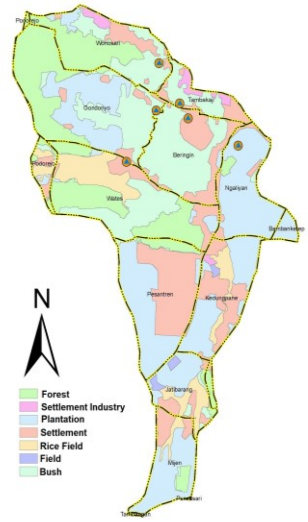

Fig.5 C Erosion Parameter Map

E. Result P Erosion Parameter Mapping

Soil conservation practice factor (P) describes the effects that support practices such as contouring, planting paths, and terracing. Most often this variable is assigned a value of 1 indicating that there is no on-site support practice within the study area. Since this study focuses on the evaluation of the risk of soil erosion, rather than the actual estimated soil erosion loss, it uses a value of 1 on the P factor.

F. Result and Analysis of Erosion Hazard Mapping

In a disaster risk assessment, disaster reference is a potentially disaster-stricken area. In this study, the potential for erosion can be assumed to be a hazard, then the risk assessment parameter representing hazard is the threat of erosion of the Beringin Watershed. In Perka BNPB Number 2 Year 2012, stated that the risk level assessment is divided into 3 (three) classes that is low, medium, and high. Therefore, to determine the distribution of erosion threat, the classification of erosion level in Table II needs to be modified as in table II. The result of classification and its value can be seen in Table II.

TABLE II. MODIFICATION OF SOIL EROSION CRITERION LEVEL CRITERIA

Erosion Value (Ton/Ha/Year)	Level of Erosion
0 – 15	Low
15 - 180	Moderate
> 480	High

Erosiveness is the first factor causing erosion, where erosion starts from the start of the rainwater to the ground. The soil has different characteristics ranging from size, element, shape. The morphological conditions of the area certainly affect the run-off of water, so that the morphological differences are very influential on soil erosion. Morphological factor is a combination of the length of the slope and the slope of the slope. The next influential faculty is crop management and land use for various activities such as settlement, plantation, agriculture and so on. The RUSLE (Revised Universal Soil Loss Equation) calculates the amount of erosion or lost soil in an area in tons / ha / year, or the amount of soil lost within one year. The following equation multiplies the causes of soil erosion. Raster calculator performs mathematical calculations effectively and efficiently compared to manual methods.

The distribution of erosion hazard in each subdistrict can be seen in Fig.6. The high erosion hazard is spread over Bringin village, Aji Ngaliyan Farm, Wonosari, Gondoriyo and Kedung Pane. This is because the four parameters affecting the erosion rate have a high value. High rainfall causes the soil to easily erode. Type of soil that is sensitive to erosion also adds to the high rate of erosion because the mediteran and alluvial soils are easily eroded. Slope length and high slope also exacerbate the condition where the soil will be easily brought to the lower region.

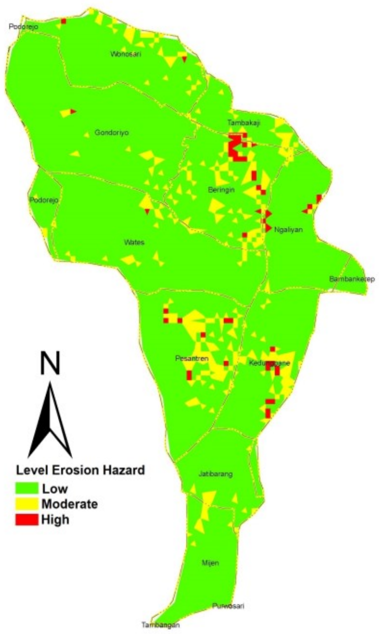

Fig.6 Erosion Hazard Map

Land cover in the form of settlements also make the water can not be well restrained in the soil. Most of the high levels of erosion hazard are spread over residential areas. Podorejo Urban Village, Wates, Pesantren has a distribution of moderate and low erosion hazards. Subdistrict of Jatibarang and Mijen belong to low and moderate erosion hazard. A small part of the area has moderate erosion rates. This is certainly a positive impact because of the still preserved watershed conditions in the upstream area. The main parameter that causes erosion is the high rainfall. The maintenance of land cover in the form of forest and plantation is one of the factors that reduce the rate of erosion. Overall, most of the Beringin watershed area is dominated by low erosion hazard, with the percentage of 91.175%, moderate erosion level 7.688% and high erosion hazard 1.137% from whole of Beringin Watershed.

G. Result and Analysis of Erosion Vulnerability Mapping and Risk Mapping

Vulnerability is a condition of a community or society that leads or causes an inability to deal with the threat of disaster (BNPB, 2012). Basically, vulnerability is an unsafe condition that exists in society, where these conditions will affect the magnitude of the impacts of a disaster. Vulnerability maps can be divided into social, economic, physical and ecological or environmental vulnerabilities. Vulnerability can be defined as Exposure times Sensitivity. Finally, all vulnerabilities are the result of a product of social, economic, physical and environmental vulnerability, with different weighting factors for each different type of threat. Mathematically the total vulnerability index parameter for Erosion threat (BNPB, 2012) can be seen in equation (2). Based on the mapping of each indicator in this vulnerability mapping, the distribution of erosion vulnerability area and the level criteria can be seen in Table III.

$$\textit{Erosion Vulnerability} = (0.4 * \textit{skor Social Vulnerability}) + (0.25 * \textit{skor Economic Vulnerability}) + (0.25 * \textit{skor Physical Vulnerability}) + (0.1 * \textit{skor Environment Vulnerability}) \quad (2)$$

TABLE III. DISTRIBUTION OF EROSION VULNERABILITY AREA AND LEVEL CRITERIA

No	Subdistrict	Vulnerability Area (Ha)			Total Area (Ha)
		Low	Moderate	High	
1	Pesantren	170.801	193.995	0.000	364.796
2	Jatibarang	0.000	47.085	109.448	156.533
3	Mijen	0.000	33.511	139.640	173.151
4	Kedungpane	7.710	271.364	0.000	279.074
5	Wonosari	0.000	151.313	134.944	286.257
6	Podorejo	4.297	43.398	0.000	47.695
7	Tambak Aji	0.000	104.370	0.000	104.370
8	Gondoriyo	0.000	163.819	350.174	513.993
9	Ngaliyan	0.000	25.152	212.009	237.161
10	Beringin	0.000	294.180	4.983	299.163
11	Bamban Kerep	0.000	0.113	22.631	22.744
12	Wates	0.000	175,401	289.000	464.401
Total		182.808	1503.701	1262.830	2949.338
Percentage		6.198	50.984	42.818	100

The notion of risk is the potential loss due to a hazard event based on probability, frequency, pressure and consequence, while disaster risk is the potential loss caused by a disaster in a region and a certain period of time that may be death, injury, illness, life threatened, loss security, displacement, damage or loss of property, and disruption of community activities (BNPB, 2008). Risk analysis can be done by several methods. One of the methods used is using **VCA** (Vulnerability Capacity Analysis) method. Formulations that measure risk with threat, vulnerability, and capacity parameters can be formulated as R = H x V / C ; where R (Risk), H (Threat or Hazard), V (Vulnerability) and C (Capacity). The risk analysis is then performed final risk assessment by using the risk matrix. The value of risk is determined by how vulnerable and how strong the capacity of society is in an area when danger comes. In this risk matrix, danger is the most dominant factor in determining the value of risk. The risk map as a result of disaster risk mapping is made by visualizing the results of risk matrix assessment into thematic maps.

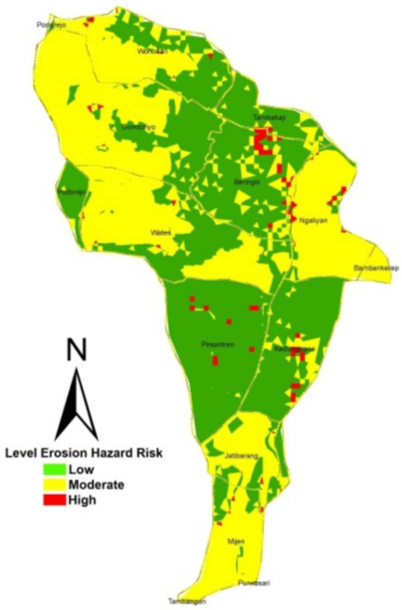

Fig.7 Erosion Hazard Risk Map

TABLE IV. DISTRIBUTION OF EROSION RISK AREA AND LEVEL CRITERIA

No	Subdistrict	Erosion Area (Ha)			Total Area (Ha)
		Low	Moderate	High	
1	Pesantren	357.074	1.806	5.917	364.797
2	Jatibarang	40.217	115.250	1.066	156.533
3	Mijen	27.472	144.901	0.778	173.151
4	Kedungpane	242.725	29.774	6.575	279.074
5	Wonosari	129.762	154.728	1.767	286.257
6	Podorejo	45.602	2.093	0.000	47.695
7	Tambak Aji	89.773	13.213	1.383	104.370
8	Gondoriyo	153.486	359.456	1.049	513.991
9	Ngaliyan	16.456	215.562	5.143	237.160
10	Beringin	228.484	57.020	13.660	299.164
11	Bamban Kerep	0.113	22.631	0.000	22.744
12	Wates	158.493	304.656	1.253	464.402
Total		1489.656	1421.090	38.592	2949.338
Percentage		50.508	48.183	1.309	100

The resulting map of the threat of erosion and erosion vulnerability maps can be done mapping the erosion risk modelling of Beringin Watershed. Assuming the value of capacity has the same value of each class then the calculation of the risk of erosion is only using the formula $\boldsymbol{R = H \times V}$. The result of mapping the erosion risk of Beringin Watershed can be generated as shown in Fig. 7 and Table IV. Based on Fig.7, that can be analyzed that the areas are affected by high risk are in Subdistrict of Beringin, Kedungpane, Pesantren, and Ngaliyan.

VI. CONCLUSION

The results of this research can be concluded as follows:

1. RUSLE calculation and GIS can be used to map erosion hazard levels, where the prosentase of high erosion hazard in this study area 1.137% from whole of Beringin Watershed, which located in Subdistrict of Beringin, Pesantren, Tambakaji, and Kedungpane. While the medium and low class that threatened erosion respectively amounted to 7.688% and 91.175% of the total area in Beringin Watershed.
2. Erosion Vulnerability Mapping of the Beringin Watershed is produced through four vulnerability indicators, are physical vulnerability, economy vulnerability, physical vulnerability, and environmental vulnerability. The results of this erosion vulnerability mapping resulted in high grade of 42.818%, medium grade 50.984%, and low 6.198% of the total area in the Beringin Watershed.
3. Erosion Risk Mapping in study area is derived from the calculation of the criteria matrix between erosion hazard and erosion vulnerability. This risk mapping resulted in high class threatening 1.309%, medium grade 48.183%, and 50.508% of the total area of Beringin Watershed. The high-risk areas are located in Subdistrict of Beringin, Kedungpane, Pesantren, and Ngaliyan.

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