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## Karst Groundwater Vulnerability and Risk to Pollution Hazard in the Eastern Part of Gunungsewu Karst Area

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## Karst Groundwater Vulnerability and Risk to Pollution Hazard in the Eastern Part of Gunungsewu Karst Area

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**Abstract.** Karst landscape generally has a high vulnerability to pollution. Karst landscape is a landscape that forms from soluble rock. The solution processes results many holes which connecting the surface to underground river networks. Soil and vegetation are generally thin and sparse. The increasing of the population and they various activities can add pressures to the landscapes such as in the eastern part of Gunungsewu. The karst groundwater management and protection effort need its intrinsic vulnerability and risks to the groundwater pollution hazard characteristics information. The aim of the study are to assess the level of vulnerability and risk of groundwater in the eastern part of Gunungsewu karst area against pollution hazards, as well as making maps of land use directives in the area. Vulnerability and risk to pollution was based on budiyanto's model. The model was based on remote sensing data of Landsat 8 OLI and GDEM ASTER. The result of this study indicate that most of the study area has a high level of vulnerability to pollution hazard. However, this area mostly has a low level risk to pollution hazard. It is in line to the lack of sources of groundwater pollutants hazard, the presence of soils on karst rocks, and the presence of vegetation cover. Land use direction maps produced based on the level of vulnerability and risk to pollution. It shows that most of these areas are designated as protected areas. However, there are areas for the maintenance of land functions that vulnerable and high risk to pollution.

### 1. Introduction

Karst is a landform composed of a combination of soluble rocks and well-developed secondary porosity [1]. The process is often called as karstification that produce a unique topography. Karst landform is characterized by the presence of closed basin formations in various size called dolin, residual formations or remnants of the dissolution process in the form of hills, and the presence of an underground flow system formed by intensive dissolution processes.

Karst landscape is very susceptible to various natural or human disturbances [2-6] Assessment of karst ecosystem vulnerability are largely associated with karst aquifer conditions [7, 8] and bedrock disclosure [9-13]. Karst aquifer is considered as objects that very susceptible to pollution because of the large porosity of carbonate rocks and low cover filtration ability. Meanwhile, the disclosure of bedrock is a form of karst land degradation that will trigger a decrease in the quality and quantity of water, a decrease in land productivity, and changes in the landscape to be like a desert [14,15]. The condition of karst land that has been exposed to karst rock is difficult to return.

Gunungsewu is a mature karst area which is characterized by the exocarstification and endocarstification processes [16]. In line with this, this area has developed into a residential area with all forms of activities. Increasing population continues due to the process of birth and migration. Population growth in the Gunungsewu karst region has led to increased anthropogenic pressure on this landscape. Gunungsewu karst has the potential for anthropogenic disruption from the activities of the population that have been carried out, such as the disposal of pollutants into allogenic rivers and karst ponds, limestone mining, agricultural activities and urbanization [14, 17-19]. References [20] conclude that population growth in Gunungsewu trigger expansion of agricultural land, as well as having an impact on forest clearance and increased karst rock outcrops. References [1] state that prolonged soil loss in the tropical karst region of Gunungsewu has resulted in severe environmental degradation. These facts imply that the Gunungsewu karst area is vulnerable to environmental problems, especially related to groundwater pollution.

Based on the description above, it is found the importance of managing the Gunungsewu karst landscape. This is due to the fact that the karst area of Gunungsewu has become a residential



environment and also a protected area (geopark). The high social and scientific value in this area needs to be protected from environmental damage. However, many difficulties to reach Gunungsewu karst area require an appropriate technology to assist this research. The advantages of remote sensing in providing spatial and spectral information and geographic information systems in their capacity as a spatial analysis tool, are expected to be used as a basis for assess the karst groundwater vulnerability and risk against pollution. The purpose of this study are to understand the conditions of intrinsic vulnerability and risk to groundwater pollution in the eastern part of the Gunungsewu karst region and provide direction for land management in this area. In this regard, several research problems arise, namely (1) how the intrinsic vulnerability and risk in the eastern part of Gunungsewu karst area against groundwater pollution hazard, (2) how the land use direction in the eastern part of Gunungsewu karst area based on the vulnerability and risk to groundwater pollution hazard.

**2. Methods**

The research was held in the eastern part of Gunungsewu karst landscape. Based on the division of hydrogeological areas in reference [16], it includes in the Sadeng Block area. Administratively, this research area is includes in the Wonogiri and Pacitan Region. The boundaries of the study area are the Giritontro valley in the northern side, Telengria Pacitan Bay in the eastern side, the Indian Ocean in the southern side, and DIY Province in the western side.

The remote sensing imagery used in this study are Landsat 8 OLI and GDEM ASTER. Initialing of the study area in the image was done by visual interpretation. The image was cropped using QGIS software. The cropped image continues with the radiometric correction process to reduce the effect of cloud interference. This processing changes the spectral data of the original image into the Top of Atmosphere (TOA) spectral value. This process is also done by cutting the cloud cover area and its shadows. The karst rock index was formed by comparison of SWIR 1 / Red channels from Landsat 8 OLI imagery. The karst surface roughness index was formed from the GDEM ASTER image data through the menu on SAGA. Vulnerability analysis carried out using the following method [21].

$$z1 = 4,278 - 154,33(B2) + 39,385(B5) - 4,557(IB) + 0,059(IK) \dots\dots\dots(1)$$

$$z2 = -8,256 + 135,341(B2) - 3,968(B5) - 19,870(IB) - 0,102(IK) \dots\dots\dots(2)$$

- Information  
 z1, z2 : the value of the logistic regression model  
 B2, B5 : band 2 and band 5 spectral values  
 IB : spectral value of the rock index  
 IK : spectral value of surface roughness index

Z1 and Z2 values are then processed using the following Log Regression formulations:

$$P(y_i = 1) = \frac{e^{z_i}}{1 + \sum_j e^{z_j}} \dots\dots\dots(3)$$

- Where :  
 P(yi) : logit value in the i-th category  
 zi : logistic regression value for the i-th category  
 e : natural log number = 2,718

The category of pixel vulnerability tested was known from the proximity of the regression logit value to the value of y. The value of the logit regression will be in range of the value of y. After the vulnerability image was obtained, the risk analysis was carried out. The mathematical formulation was processed using the SAGA GIS device. The formulation used as follows.

$$\text{Log}(Y_{\max, b, H}) \dots\dots\dots(4)$$

- Information:  
 Ymax : The largest Y value in pixels  
 b : The weight value for Y  
 H : Hazard value on pixels

This analysis produces an image of the risk of pollution in the eastern part of the Gunungsewu karst area against pollution. Spatial distribution was analyzed spatially by using tabular data and overlaying with administrative data of the study area. Furthermore, the Gunungsewu karst land use direction was built.

The direction of land use is principally based on the value of the vulnerability and risk that exists at the location. According to the model, the land use was directed to four types of zones, namely the land function recovery area, the land function maintenance area, the land function conservation area, and the land use improvement area. Land use protection zones was designed to the areas that have a [27] level of vulnerability or risk to groundwater pollution. Land use recovery areas was designed to areas with low vulnerability, but have a high risk to groundwater pollution. Land use maintenance zones was designed to areas with high levels of vulnerability or risk to groundwater pollution. While [27] the area of land use improvement is determined in areas that have a high level of vulnerability, but the risk of groundwater pollution is low. The logical process is carried out by basing on the following model.

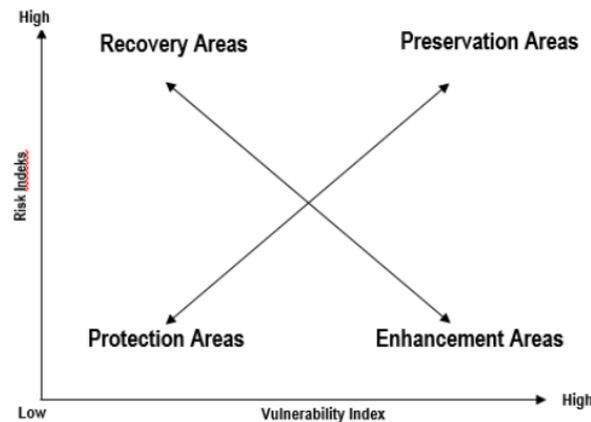


Figure 1. Model of land use direction.

Source: Budiyanto, 2018

The process of forming this land use direction map was carried out using SAGA GIS software. Meanwhile the layout and presentation of the image was done by using QGIS.

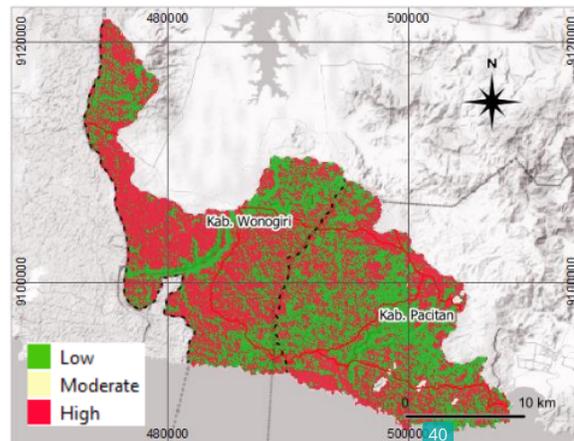
### 3. Result and Discussion

#### 3.1. Calculation of vulnerability levels

Vulnerability calculation done based on the Budiyanto model [21]. The calculation carried out into several stages which apply mathematical formulations to the image data in this study. The first step according to the model is the calculation to get the values of Z1 and Z2. These values indicate the role of land cover and land morphology in the study area on two different axes. These two axes shows different tendencies associated with differences in the spectral values of each of these parameters. Furthermore, to get the vulnerability value, the logit value is calculated on the two axes.

The distribution of vulnerability levels in the study area shows in Figure 2. Each level of vulnerability was symbolized by a color symbol. Based on these figures it appears that most of the research areas of the area were visualized in red. This means that most of the research area has a high level of vulnerability. Areas of high vulnerability are widely available in the western area of the study area, especially in the Wonogiri district. This areas are associate with hilly areas and the Gunungsewu karst valley. Areas with low levels of vulnerability were symbolized in green in the image. Areas of low vulnerability appear to be scattered and follow certain lineaments patterns in the study area. Morphological formations associated with low vulnerability are valley and river channel forms and

lineages of karst valleys and hills. The distribution of low vulnerability areas in the west is mostly at the base of the ancient solo Bengawan river flow in Wonogiri Regency. Meanwhile, the eastern part of Pacitan Regency appears to be more diffuse and forms a more random pattern. This area is also associated with high spectral values in band 5 of Landsat 8 OLI satellites. This means that in that area there is a relatively wide vegetation cover. The yellow color is a symbol of a moderate level of vulnerability. Areas with moderate levels of vulnerability have a small total area. This moderate vulnerability has a random distribution with the least amount of area. Visualization of the image, the vulnerability is currently in several karst basins. This distribution is associated with non-vegetated karst basins but there are soil deposits at these locations.



**Figure 2.** The vulnerability map to pollution in the study area.

Based on pixel analysis of the imagery data, the extent of each vulnerability level can be calculated. Areas with a high level of vulnerability cover an area of 25,562.61 Ha or cover 56% of the entire research area. Areas with low vulnerability are ranked second. This low level of vulnerability has a coverage of 20,288.79 Ha or as much as 44% of the entire study area. Meanwhile the area with the lowest level of vulnerability is the area with the smallest proportion. This area has an area of 16.29 Ha or equal to less than 1% of the entire study area. This finding is in line with references [22] and [21] which state that in most of the research areas in the karst area of Gunungsewu has a high level of vulnerability.

Observation results show that areas with a high level of vulnerability are mostly in karst hills with lots of rock outcrops, thin soil conditions and not much vegetation cover. The type of vegetation that is often found is grass with a small amount. There are a few stands of trees with a small amount. The size of the existing woody tree has a small trunk diameter with a dense canopy. The slopes are generally steep. Some are emerge with clear rock outcrops. This condition is consistent with the characteristics of karst regions elsewhere as stated in references [1, 4, 13].

In areas of low vulnerability, land is dominated by vegetation cover of various sizes. Vegetation cover is relatively broad compared to areas of higher vulnerability. There is a lot of vegetation with large logs and forms a mixed garden pattern. Hilly slopes are relatively sloping with utilization as terraced agricultural land. The valley of karst hills is covered by agricultural crops such as crops and other woody plants. Land in general is relatively thick. At the bottom of the valley, this land is widely used as rainfed agricultural land. The soil and vegetation in this place have a very important role in karst underground water. The presence of vegetation cover and soil provide a role as a filtration agent for the entry of pollutants into the underground water network [23-25].

Areas with moderate levels of vulnerability have characteristics similar to areas with low levels of vulnerability, but less extensive of vegetation cover. Vegetation types tend to be grass. There are woody tree stands with small and rare size. Some places have karst rock outcrops with thin soil cover. Grass with size and density is rarely found in some areas such as hillsides. The total areas with

a moderate level of vulnerability have the least coverage compared to other levels of vulnerability. Spatially this area with a moderate level of vulnerability is scattered randomly throughout the study area.

### 3.2. Calculation of the level of risk

The calculation of risk level is based on the existing land use conditions in the study area. Land use analysis is based on land use classification analysis from Landsat 8 OLI image data. Land use in the study area are in the form of mixed forests and gardens, settlements and built up areas, agricultural land with medium and rare density plants, and open land. Forest areas and mixed gardens generally have a high density vegetation cover. Vegetation in the form of woody plants with various types. At the bottom there are many small vegetations in the form of shrubs and grasses. Settlement areas and built up areas are spread along the road network in a clustered pattern. Settlement near highways generally has a high density. Meanwhile settlements far from highways are low density. Settlement areas often occupy dry karst basin areas. This place is next to agricultural land. Agricultural land is spread on the foundations of karst valleys and partly on hillsides in the form of terraces. Vegetation density is at a sparse to moderate level. The types of agricultural vegetation at the bottom of the karst basin are partially palawija, while on the hillsides there are also woody plants. Open land in the form of soil outcrops and karst rocks.

This form of land use and cover then weighted according to its potential as a source of groundwater pollutants hazard. Land uses that can potentially produce pollutants are given a high weight. Land uses that have no potential to produce pollutants are given a low weight. Land uses that are considered to have the potential to produce pollutants are settlements, mining and industry. Land uses which are considered to have low potential to produce pollutants are forests and mixed gardens. The assessment model was carried out using the basic Log formulation ( $Y_{max} \cdot b \cdot H$ ) [21]. This model has been applied in the western part of Gunungsewu karst region and gave a good results. The model is used to form the image of the risk level of underground karst water pollution in the study area. The results of these calculations obtained the risk level image as shown below.

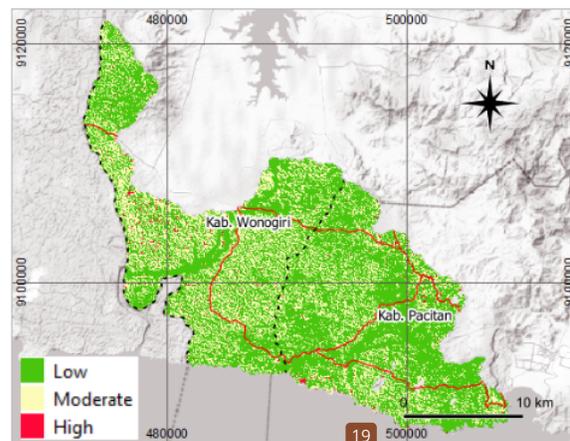


Figure 3. Risk of pollution in the study area

Based on the calculation results show that most of the research areas have a low level of pollution risk. This is due to the lack of pollutants in the area. High levels of intrinsic vulnerability are not accompanied by the presence of dangerous sources of pollutants. Some hillsides still have vegetation and soil cover which relatively helps the filtration process of pollutants. Wastes can't enter to the hole or pit in the rock cause of filtration process by the vegetation and soil.

Some areas as settlements or rock outcrop areas have a high risk of pollution. Based on observations, it shows that residential areas often have contact between a household waste disposal site and a place where water enters into groundwater channel. Settlement produce household wastes in

various kind and type. The wastes will enter to water body and pollute it. Outcrop area has no filtration agent to stop waste entering to the groundwater channel.

The results of the calculation of the area of risk level for groundwater pollution can be seen in the following table.

**Table 1.** Area of risk of groundwater pollution in the study area

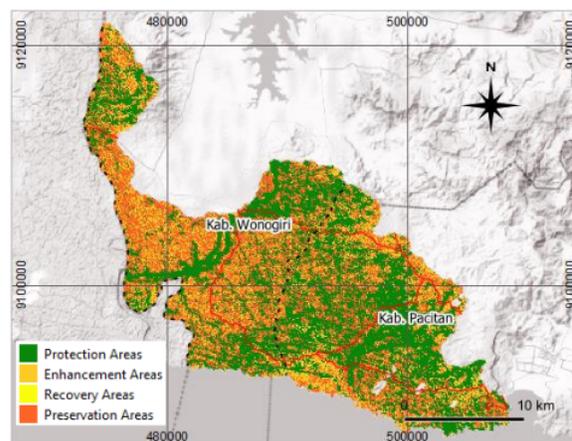
No	Risk Level	Widht (Ha)	Percent (%)
1	High	543,87	1,19
2	Moderate	15.120,36	32,97
3	Low	30.203,46	65,85

Source: Calculation results

Table 1 shows that the area with a high level of risk is only 1.19% or an area of 543.87 hectares in the form of residential land areas, other built up areas and karst rock outcrop areas. The level of risk is having a fairly large area that reaches 32.97% of the entire study area which is 15,120.36 hectares. While the area with a low level of risk reaches 64.85% or an area of 30,203.46 hectares. This condition is in line with the opinion of reference [24] that a high level of vulnerability does not always has a high risk of pollution hazards, when at that location there are no sources of pollutants.

**3.3. Directions for land use in the study area**

Land use guidance is based on the level of vulnerability and risk that exists at that location. The analysis was done mathematically on the image of the level of vulnerability and the image of the level of risk generated in this study. The direction map of the processing results shows the following conditions.



**Figure 4.** The landuse direction map of the research area

Figure 4 shows a map of land use direction in the study area. Protected areas are intended to preserve and sustain land conditions in a sustainable manner. The area of land use improvement is an area intended to improve the ability of degraded land or degraded land. Land recovery area is an area to restore the ability and function of the damaged land. While the maintenance area is intended to maintain critical and damaged lands.

Based on Figure 4, it is known that there are many areas that need to be designed as enhancement areas for land functions in the western part, namely in the area of Wonogiri Regency. In this area, exploitation of the land should not be carried out which results in further damage to this area. This area must be maintained and can be used as an area for scientific purposes. Protected areas of land use are widely distributed in the eastern region, especially in the Pacitan Regency. In this area land can be used as an area of agriculture, settlement, and services. There are many recovery areas in the southern part of the study area extending from west to east.

#### 4. Conclusions

Based on the calculation in the research it was concluded that most of the research area has a high vulnerability to groundwater pollution hazard. Rock outcrop and karst surface roughness, vegetation sparsely, and soil thickness which are identified from remote sensing data, are the triggers factors of the vulnerability in the research area. However, the high level of vulnerability to groundwater hazard is not necessarily in line to the risk level. Most of the research area has low risk level to groundwater pollution. There are no many sources of dangerous pollution hazard. The highest level of pollution hazard comes from settlement, industries, and minning activities in a bit amount. Based on vulnerability and risk condition against pollution, the research area designed as enhancement area, protection area, recovery area, and preservation area.

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