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Analysis Of Vulnerability Of Groundwater In Mining Area

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Abstract

Mining activities have a considerable influence on groundwater availability. One of the efforts to manage the quantity and quality of groundwater is by analyzing the vulnerability of groundwater. Various methods have been applied to analyze groundwater vulnerability, one of which is the SINTACS method. This method consists of seven parameters groundwater level depth, aquifer type, infiltration rate, unsaturated zone material, soil type, hydraulic conductivity, and topography. These parameters are classified based on the rating and weight of the level of groundwater vulnerability. The results of the classification will be processed using ArcGIS software to determine areas that are potentially vulnerable to groundwater vulnerability. The results of the level of groundwater vulnerability in the study area showed 9% low vulnerability, 63% moderate vulnerability, 23% high vulnerability, 5% high vulnerability

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Keywords: Vulnerability, Groundwater, Mining, Sintacs

I. INTRODUCTION

The term groundwater vulnerability was initially published by J. Margat in the 1960s (Vrba and Zoporozec, 1994). The basic concept is to classify the level of vulnerability of groundwater to the physical environment, which aims to avoid contaminating groundwater due to impacts caused by humans or nature. Earth's materials can act as a natural filter for groundwater contamination (Vrba and Zoporozec, 1994). Water that is infiltrated below the surface can potentially be polluted, however, it can also undergo natural purification processes as it passes through soil and other fine materials in the water-unsaturated zone.

The vulnerability of groundwater has two characteristics, namely natural (intrinsic) and due to human activity (specific). Intrinsic susceptibility refers to aquifers susceptible to contamination and is closely related to geological and hydrogeological components. Meanwhile, specific vulnerability is the vulnerability of aquifers to a group of pollutants or only one particular group of contaminants.

According to Maria (2017), intrinsic susceptibility depends on three main factors, namely:
• The absorption process and travel time of fluid contaminants;
• Flow dynamics of fluid contaminants in the saturated zone;
• The concentration of contaminants remaining when they reach the saturation zone.

Mining activities will change the landscape, including changes in hydrogeological morphology and land use. This can affect subsurface rock layers, topography, and aquifers. The catchment area will affect the availability of groundwater both in quality and quantity due to changes in land use (Vias et al., 2005). It is possible to lower the groundwater level in the mining area because the floor height is far below the ground level, especially the deep groundwater level. A decrease in groundwater potential impacts on a decrease in the groundwater level, groundwater discharge, *land subsidence*, and groundwater quality (Haq et al., 2013). Mining activities have an impact on pollution, such as *overburden dumping*, *workshops*, construction of haul road facilities and infrastructure, hoarding activities, coal processing, and disposal of domestic waste from employees. A model for measuring the level of vulnerability of groundwater to pollution is important by protecting groundwater from contamination due to mining activities. This study aims to determine the groundwater level vulnerability zone to pollution. What is new from this research is to determine the level of groundwater vulnerability that can be applied in mining areas and can be a reference for the government or mining companies to manage groundwater.

II. RESEARCH AREA

The research area is located in Tanah Laut, South Kalimantan. This area is dominated by a tropical climate and is located between latitude 3˚18'25 "S and longitude 114˚33'53" E. It is located about 4 hours from Syamsoedin Noor Airport, Banjarbaru. This location is one of the coal mining concessions with an area of approximately 100 km^2.

III. RESEARCH METHODOLOGY.

Several researchers have developed methods of soil water vulnerability to various kinds. Some of these methods can be used following the designation of the area to be tested for vulnerability and due to the rock type of the area. Methods in analyzing groundwater vulnerability include the DRASTIC, SINTACS, MEDALUS, SI, KHERICI, COP, GOD, EPIK methods, etc. (Table 1). Each of these methods has factors that are near related to hydrological aspects. In areas that are dominated by karst, there are several methods of groundwater vulnerability, including EPIK, GOD, COP, PI, RISKE, REKS, VURAS. MEDALUS can be used in endorheic areas or the highlands (Bouhata & Kalla, 2014). SI can be used in cities, plantations, or agriculture. Then, KHERICI is used in reservoirs in groundwater (Attoui et al., 2012). Meanwhile, SINTACS and DRASTIC have similarities, but this study only uses the SINTACS method because SINTACS has more parameters than others and can be applied in coal mining areas.

SINTACS is an acronym for the parameters in the hydrological component consisting of groundwater depth (S), infiltration rate (I), unsaturated zone material (N), soil texture (T), aquifer type (A), hydraulic conductivity (C), topography (S). The SINTACS model has two outcomes: a numerical index of the weights and ratings applied to the seven parameters. Each parameter has a weight: the value is 1-5 based on essential things: the greater the weight means, the greater the level of vulnerability. The ranking of each parameter is around 1 to 10 depending on the relative effect of vulnerability if rating 1 means the least pollutant potential, and ten means the highest pollutant (Piscopo, 2001). The SINTACS index is shown in the equation below.

SINTACS Index (Di) = $DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw$ (1)

where,

S: Depth of water table (m);

I: Infiltration (mm / year);

N: Non Vadose Zone;

T: Texture of soil;

A: Aquifer;

C: Conductivity Hydraulic;

S: Slope of topography (mm / day);

r: Rating;

w: Weight.

Table 1.
Comparison of groundwater vulnerability methods (Linggasari et al., 2019)

No	Metode	Dikembangkan Oleh	Tahun	Parameter																						
				Depth	Recharge	Aquifer	Soils	Topography	Vadose Zone	Conductivity of Hydraulic	protective cover	Concentration of flow	Precipitation	Infiltration	GW Occurance	Materials of vadose zone	Saturated aquifer	Epikarst	Karst network dev	Atttenuation potencial	Land Use	Exfiltration	Rock type	Evaprotranspiration	Irigation	Temperature
1	DRASTIC	Aller, dkk	1985	√	√	√	√	√	√	√																
2	COP	Vias, dkk	2006								√	√	√													
3	GOD	Foster	1987	√		√									√											
4	SVV	Putra, dkk	2007		√				√							√										
5	PI	Goldscheider, dkk	2000								√			√												
6	AVI	Van Stempvoort, dkk	1993							√							√									
7	EPIK	Doerfliger dkk	1999								√			√				√	√							
8	SINTAC	Civita	2000	√	√	√	√	√	√	√																
9	SI	Ribeiro	2000	√	√	√		√													√					
10	SEEPAGE	Navulur dan Engel	1999	√		√	√		√											√						
11	PRAST	Civita	1994		√	√	√	√			√															
12	APLIS	Andreo, dkk	2008	√		√	√	√						√							`					
13	LOS	Aschonitis, dkk	2012				√	√		√														√	√	√
14	EPPNA	Inag	1998	√	√	√		√													√					
15	GLA	Holting, dkk	1995																√	√						
16	RISKE	Petelet-Giraud,	2000				√							√				√	√				√			
17	REKS	Witkowski dkk	1997				√											√	√							
18	VURAS	Vrana	1999		√									√								√		√		
19	LEA	Otnar, dkk	1996								√	√														
20	VULK	Jeannin, dkk	2001								√								√							

Increasing the SINTACS index will result in a higher possibility of groundwater pollution. SINTACS classification and rating can be seen in Figure 1 to Figure 7, while the weight rating of each parameter is depicted in Table 2, and the vulnerability class is in Table 3.

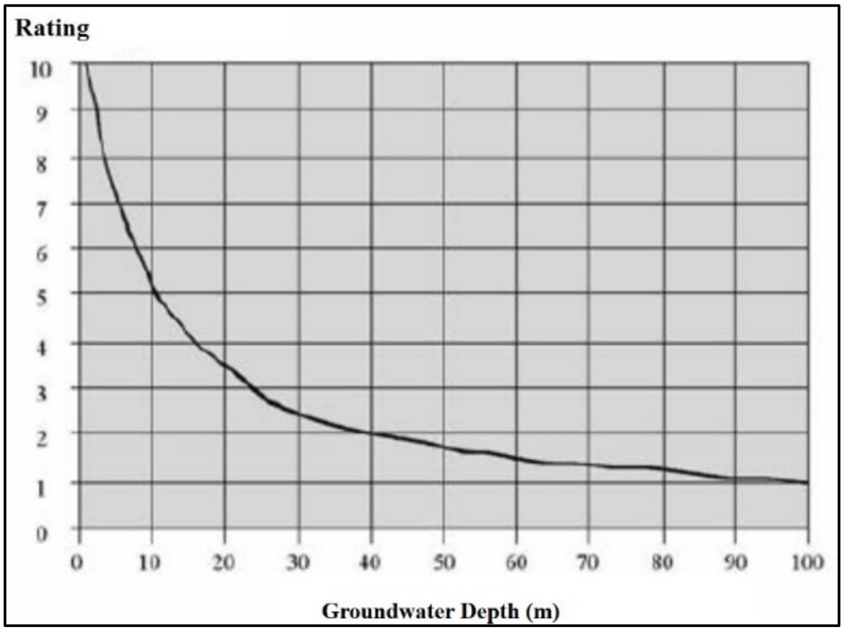

Figure 1. Classification and Rating of Watertable depth (Civita, 2000)

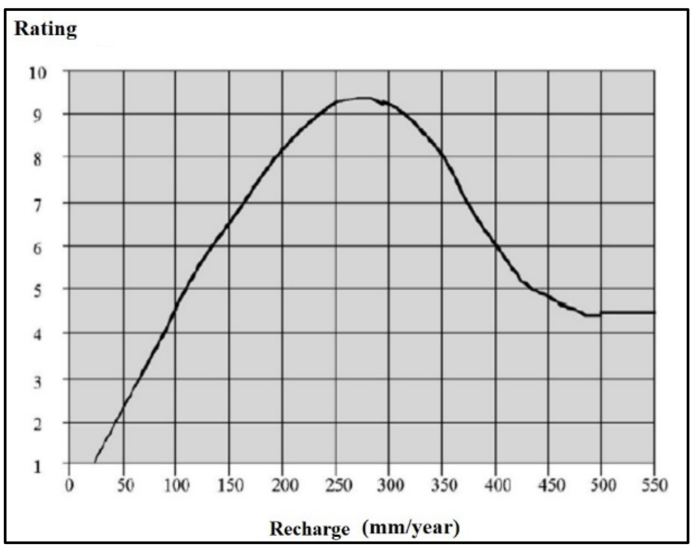

Figure 2. Classification and Rating of Recharge (Civita, 2000)

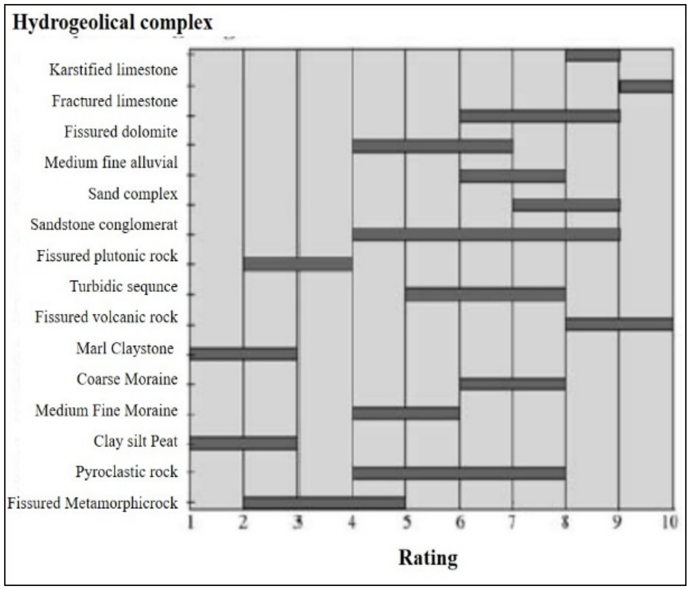

Figure 3. Classification and Rating of Aquifer Media (Civita, 2000)

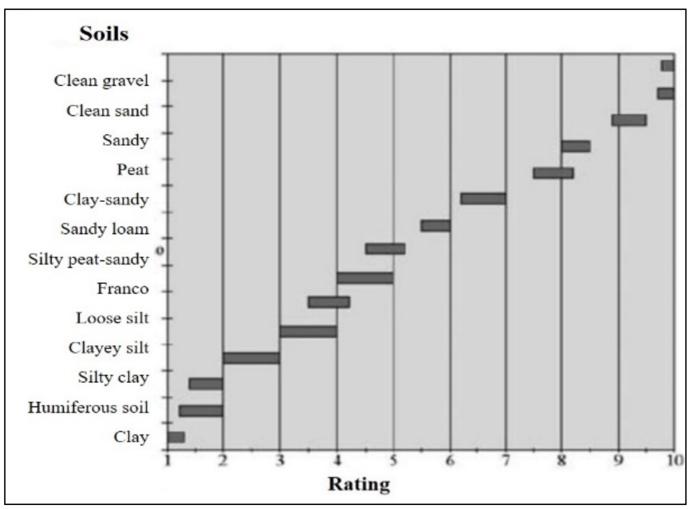

Figure 4. Classification and Rating of Soil Media (Civita, 2000)

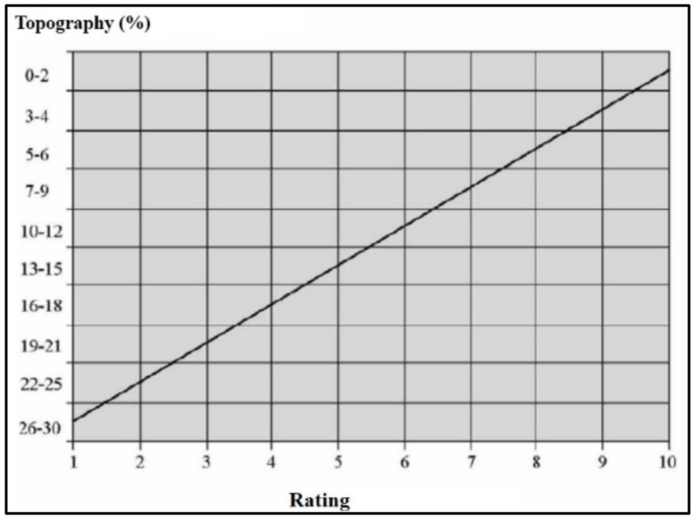

Figure 5. Classification and Rating of Topography (Civita, 2000)

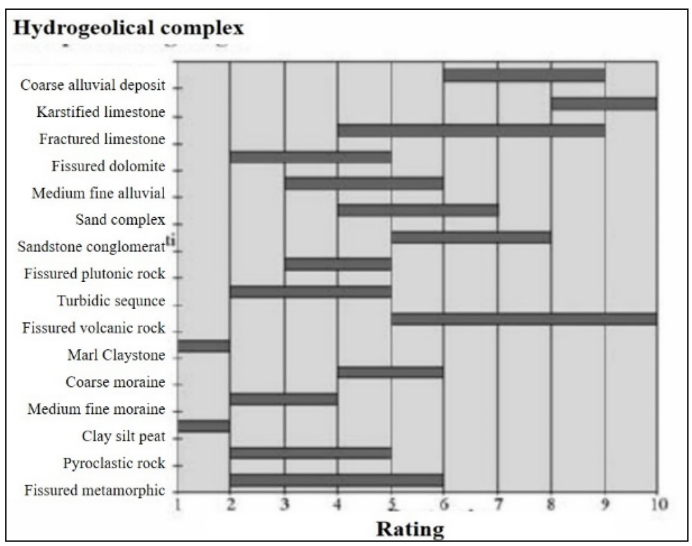

Figure 6. Classification and Rating of Material In Vadose Zone (Civita, 2000)

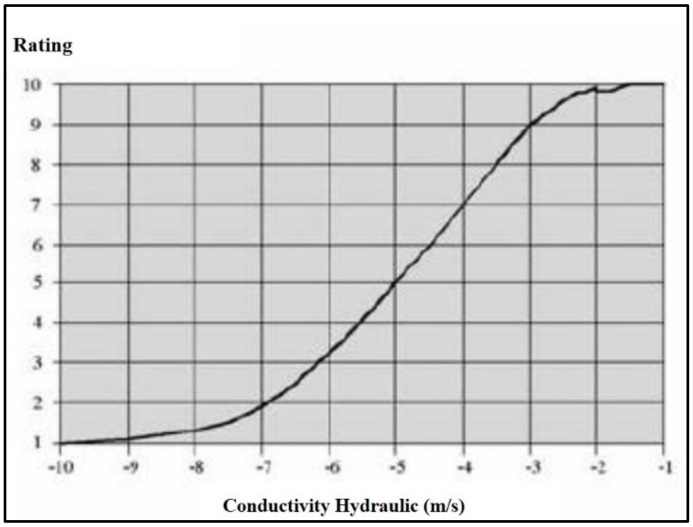

Figure 7. Classification and Rating of Conductivity Hydraulic (Civita, 2000)

Table 2. Weight of SINTACS (Civita, 2000)

Parameter	**Normal**	**Severe**	**Seepage**	**Karst**	**Nitrates**	**Featured**
Depth of water table	5	5	4	2	5	5
Recharge	4	5	4	5	4	5
Aquifer Media	3	3	5	5	3	2
Soil Media	3	5	2	3	2	5
Topography	3	2	2	5	1	3
Impact of vadose zone	5	4	4	1	5	4
Conductivity Hydraulic	3	2	5	5	3	2

Table 3. Criteria of the vulnerability ty assessment by using the SINTACS method

Class Of Vulnerability	Index SINTACS
Very Low	<81
Low	81-105
Moderate	106-140
High	141-186
Very High	187-210

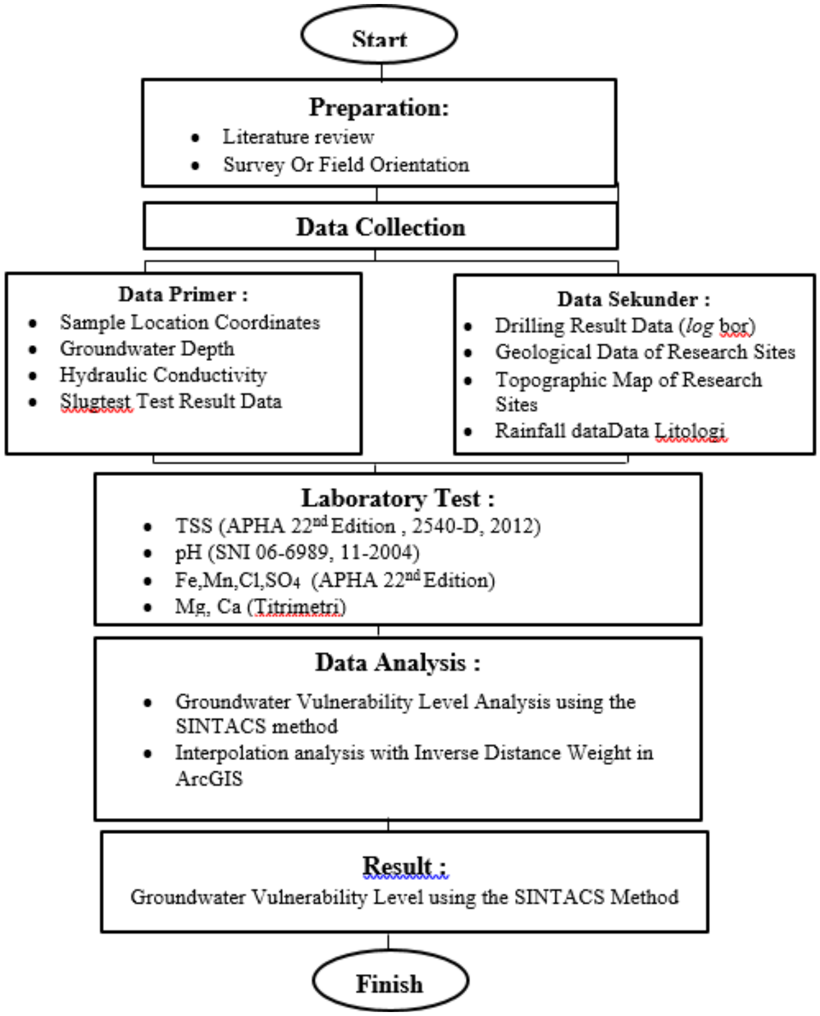

Figure 8. Research methodology diagram

IV. RESULTS AND DISCUSSION

Parameters used in weighting groundwater vulnerability include groundwater level depth, recharge, aquifer media, soil media, topography, unsaturated zone material, hydraulic conductivity. The level of groundwater vulnerability was made by overlapping the seven SINTACS parameters in the study area.

IV.1. Depth of Water

The groundwater level depth measurement was carried out on 40 drill points, where the test was carried out *slug test* on ten well points, and the other 30 drill points used interpolation. The depth of the groundwater level in the mining plan is about 3 - 50 meters. The deeper the groundwater level, the smaller the potential for groundwater pollution, and vice versa. If the groundwater level is getting shallower, the potential for groundwater pollution will be even more significant. This is evidenced by the deeper the groundwater level, the longer the contaminants reach the groundwater level, the longer the potential for pollution will also be smaller.

IV.2. Infiltration The

Characteristics and conditions of the soil surface of the study area are dominated by sandstone; this causes the value of the infiltration rate to be higher because sandstone quickly passes or absorbs water. The infiltration rate in the study area is 200 mm / year, which occupies a rating of 9.5 in the SINTACS method, which indicates that the research area has the potential for groundwater pollution, because the higher the infiltration rate, the contaminants will quickly and easily enter the groundwater table. Recharge calculated by rainfall data.

IV.3. Aquifer Type Aquifer

The media is determined based on the existing rock formations in the study area. Formation characteristics refer to the density or compactness of the rocks that make up the formation. The larger the grain size of the constituent rocks, the value *rating* larger the aquifer media. The results of the interpretation of drill log data in the study area indicate that the aquifer media in the area is *sandstone* with a value of 6. The size of the sandstone grains can affect the vulnerability of groundwater in the mining plan because the sandstone aquifer media allows it to store and release groundwater in large quantities, which is quite large.

IV.4. Soil Texture

The soil has a significant effect on the water, including dissolved contaminants that infiltrate the soil surface into the soil. In general, the more adequate the grain size, the less potential for dissolved contaminants to enter the soil. Based on drill hole and field observations, the soil texture in the study area is dominated by sandy loam in the western part of the mining plan area. Meanwhile, the eastern part is dominated by silt and clay. Sludge and clay have large grain sizes, which reduce soil permeability and limit the movement of contaminants.

IV.5. Slope (Topography)

The topographic slope of the study area determines the surface water flow velocity. Based on the contour of the topographic map, the study area has a topographic slope or slope varying from 6% to 74%. Areas with low or small slope levels tend to hold water for a long time. This condition allows water to infiltrate the soil and increase the mobility of rainwater. Areas with a high degree of slope tend to cause water to flow directly. The topographical slope affects the situation at the time of mining activities, namely indicating whether rainwater will *run off* or be retained on the ground.

IV.6. Impact of Vadose Zone (Unsaturated Zone)

The impact parameter of *the unsaturated zone material* is the effect of the zone above the groundwater level. These parameters indicate whether water is moving towards the aquifer layer or not. The better the material's ability to drain water, the greater the class value is given in this parameter. The identification of unsaturated materials using lithology data/rock layers from the *log is* determined based on the layer above the aquifer media in the study area. The identification of unsaturated zone materials in the study area obtained silt/clay and gravel sand with silt/clay.

IV.7. The Conductivity of Aquifer.

Hydraulic conductivity is defined as the ability of the aquifer material to transmit water, which controls the flow rate of groundwater under a specific hydraulic gradient. Aquatic hydraulic conductivity is the ability of an aquifer to escape from the water and affects the velocity of water flow. The greater the hydraulic conductivity value, the greater the potential for groundwater pollution. The hydraulic conductivity in the mining plan area is 0.17-1.99 m / day. This value is obtained based on the slug test that has been carried out.

Based on the identification of the seven parameters above, the field results are shown in Table 4

Table 4. SINTACS Index Results

Level of Vulnerability	Very Low			Low			Moderate			High		
	R	W	Score	*R*	W	Score	*R*	W	Score	*R*	W	Score
Depth of Watertable	1-2.7	5	5-13.5	2.4-7.8	5	12-39	2.4-9.4	5	12-48	10	5	50
Recharge	8	4	32	8	4	32	8	4	32	8	4	32
Aquifer Media	8	3	24	8	3	24	8	3	24	8	3	24
Soil Media	3-4	3	9-12	4-6	3	12-18	4-6	3	12-18	6	3	18
Topography	1	3	3	1-7.5	3	3-22.5	2.3-9.5	3	6.7-28.5	10	3	29
Impact of vadose zone	2	5	10	1-6	5	5-30	2-6	5	10-30	6	5	30
Conductivity Hydraulic	3	3	10	3.2 - 5	3	9.6 - 15	3	3	10	5	3	15
SINTACS Index	78			107-138			143-179			198		

IV.8. Groundwater Vulnerability Map The

The level of groundwater vulnerability is made based on the scores from the *rating* and load of the SINTACS method. The Value *rating* of each SINTACS parameter is multiplied by the load/weighting factor to obtain the SINTACS index value. The SINTACS index is divided into six classes. The larger the SINTACS index, the higher the level of vulnerability, while the small index indicates a low level of vulnerability. The SINTACS index value that has been determined from each *log*, is interpolated using the method *Inverse Distance Weighted* to obtain delineation between points so that the zone in the study area is known. The results of data processing using the SINTACS method in the form of a groundwater vulnerability map can be seen in Figure 9.

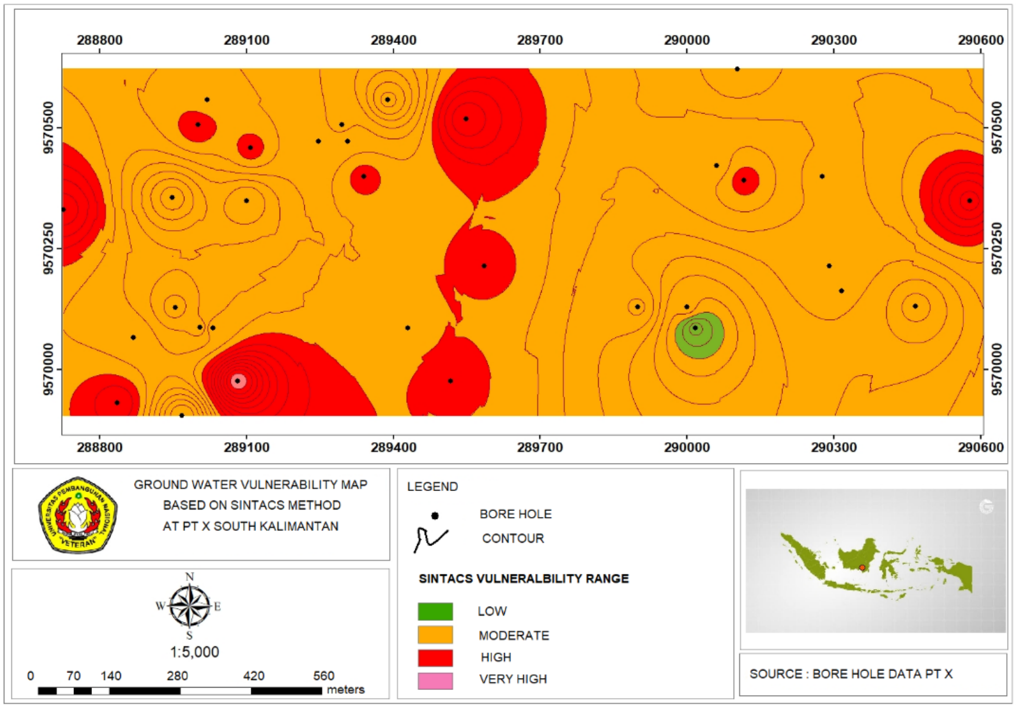

Figure 9. Groundwater Vulnerability Map

IV.9.Verification

Verification of vulnerability level assessments can be done in various ways. The most common approach, especially for the relationship assessments carried out with the methods *overlay* and *index,* compares the vulnerability maps with the actual incidence of contaminants in groundwater.

Parameters of iron (Fe), manganese (Mn), suspended residue (TSS), the content of Chloride (Cl), Sulfate (SO_4), Magnesium (Mg), and Calcium (Ca) and pH were selected as contaminant parameters for the validation of the SINTACS model in the research area. This is according to the Minister of Environment Decree No. 113 of 2003 concerning Wastewater Quality Standards for Coal Mining Businesses and/or Activities because groundwater in the research area will be used as a water source for office activities, such as clean water for washing hands, washing vehicles, ablution, and others.

Based on the correlation coefficient of the seven SINTACS indices, it can be concluded that the Fe parameter has a greater level of correlation than other parameters. This is evident from the fact that the SINTACS index drill hole also has a high Fe content (Figure 10).

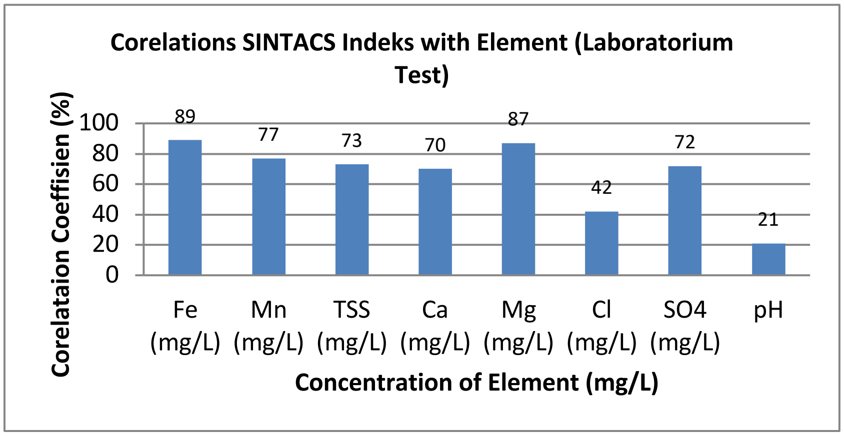

Figure 10. Correlation of the SINTACS Index to Metal Concentrations

V. CONCLUSION

From the results of the research on the level of groundwater vulnerability using the SINTACS method. It was concluded that there were four categories of vulnerability in the study area, namely 9% areas with low levels of vulnerability, 63% areas with moderate levels of vulnerability, 23% areas with a high level of vulnerability, and 5% of areas with a very high level of vulnerability. Based on the zoning, it is necessary to make a priority scale for handling groundwater related to the mining plan, along with determining the location of mining facilities and infrastructure, to minimize the negative impact on mining activities due to groundwater in the study area. In the zoning map, it is estimated that groundwater with a high vulnerability category is located in the Southwest and West to East. Therefore, it is necessary to treat groundwater before carrying out excavation and not to place infrastructure in the area. Another recommendation related to groundwater handling is to carry out regular groundwater monitoring, including the quality and reduction of groundwater levels.

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