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Contents

Preliminary Assessment of Groundwater Contamination Hazard in Open Pit Coal Mine, Barito Timur, Central Kalimantan, Indonesia

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ABSTRACT

Coal mining industry is an important sector in the regional economic of Indonesia. Many mining companies are widespread in Indonesia, especially in Kalimantan Island. It is recognized that environmental impacts of open pit mines are not only natural landscape changing, but also human health hazards. The most significant of them is the probability of groundwater contamination. According to environmental regulations in Indonesia, each mining company is obliged to have Environmental Impact Assessment (EIA) document, before starting production. The purpose of this study is to assess groundwater contamination hazard caused by mining activities, as a part of EIA. Groundwater contamination hazard is evaluated by combining the intrinsic groundwater vulnerability and the contaminants loading in the mine area. DRASTIC method is applied to obtain the groundwater vulnerability, while contaminant loading potential is evaluated based on stepwise procedure application. The results of this study are groundwater contamination hazard maps. Based on the hazard of contaminants, it can be concluded that the highest groundwater hazard area will be occurred at the North of study area. Therefore, the mitigation for the document of EIA will be concerned there. Further research may need to complete this preliminary study.

Keywords: EIA, Loading Contaminant, Groundwater Vulnerability, Open Pit Coal Mine, DRASTIC.

INTRODUCTION

Coal mining industry is important sector to Indonesia. It is a substantial provider of export earnings, economic activity and employment, and supports regional development. Many mining companies are widespread in Indonesia. One area in Indonesian where there are many coal mining activities is Kalimantan Island. Study area is one of the coal mining concessions located in Barito Timur, Central Kalimantan (see Figure 1). The company has a concession covering an area of 2000 Ha. The coal target of its company is about 500,000 ton per month with open pit system. Open pit coal mining is recognized as an activity that causes the environmental degradation. The environmental impacts of open pit mines are not only the changing of the natural landscape but also human health hazards. The most significant of them is the groundwater contamination.

Based on environmental law in Indonesia number 32, 2009 about protection and management of the environment and also several environmental regulations of Indonesia, each mining company in Indonesia is obliged to have the EIA document. The EIA document must be assessed by committee first, before the company is allowed to start the coal production. The purpose of this study is to assess groundwater contamination hazard, caused by mining activity, as a part of EIA.

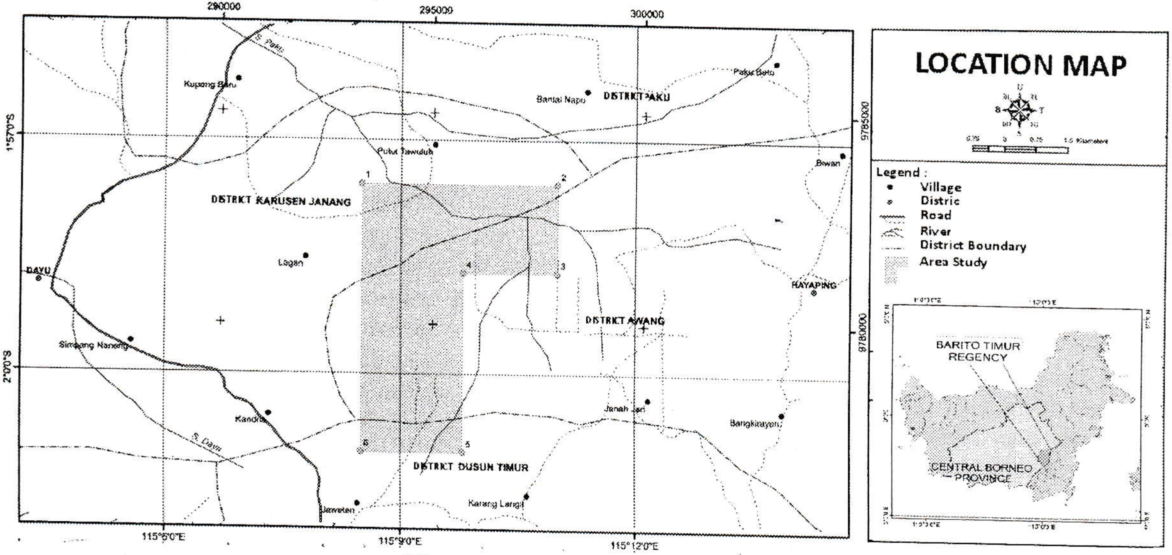


Figure 1. Location of Area Study

According to Putra (2007), the groundwater contamination hazard is defined as the probability that groundwater in the aquifer will experience negative impacts from a given anthropogenic activity to such level that its groundwater would become unacceptable for human consumption. The most logical approach to assess the groundwater contamination hazard based on Foster & Hirata (1988), Foster et al, (2002), Morris et al. (2003) is to regard it as interaction between the contaminant loading (that is, will be, or, might be, applied on subsurface environment as a result of human activity) and intrinsic groundwater vulnerability at the location concerned (See Figure 2).

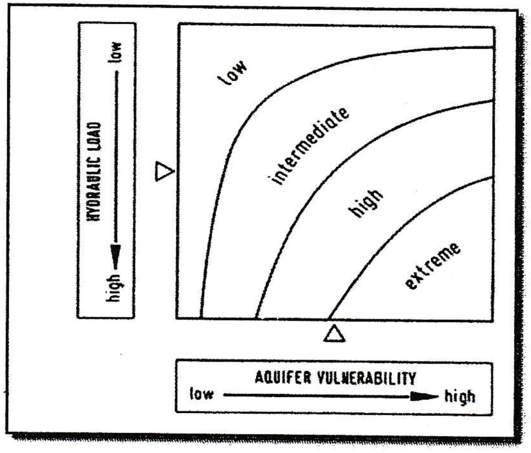


Figure 2. Groundwater contamination hazard as interaction between groundwater vulnerability and contaminant load (Morris et al., 2003)

The relationship between contaminant loading potential (caused by mining activities), intrinsic groundwater vulnerability and probability of groundwater contamination in the area study is needed to assess the environmental impact to groundwater as a part of document.

METHODOLOGY OF ASSESMENT

Intrinsic Groundwater Vulnerability

According to Foster et al. (2002), the term "vulnerability" began to be used intuitively in hydrogeology from the 1970s in France (Albiner and Margat, 1970) and more widely in the 1980s (Haertle, 1983; Aller and other, 1978; Foster and Hirata, 1988). The concept is based on the assumption that the soil-rock-groundwater system may provide a degree of protection against contamination of groundwater by "self purification" or "natural attenuation" (Romijn, 2002). The overall aim of the vulnerability assessment process is to provide relevant information for land-use planning decisions, so that potentially polluting developments can be located and controlled in an environmentally acceptable way (Daly and Warren, 1998).

Groundwater vulnerability is usually estimated in difference methods. In most case, these methods are analytical tools that try to relate groundwater contamination to land use activities (Javadi, 2011). Depend on Foster (1998), the best known, and probably the most widely applied, scheme of vulnerability assessment was developed in USA and is known as the DRASTIC methodology (Aller et al., 1987). It uses seven parameters in its calculation of "Vulnerability Index" with each parameter being assigned a specific weight and rating values as shown in Table 1. The following seven parameters are depth to groundwater, net recharge, aquifer media, soil media, topography, impact of vadose zone, and hydraulic conductivity. Vulnerability to contamination is a dimensionless index function of hydrogeological factor, anthropogenic influences and source of contamination in any given area (Plymale and Angle, 2002). The vulnerability index consists of seven parameters with difference weighting factors. It is calculated based on Equation 1 below.

$$V = \sum_{i=1}^{7} (W_i \times R_i) \qquad [1]$$

Where V is the index value, W_i is the weighting coefficient for parameter i with an associated rating value of R_i. The DRASTIC parameters are weighted from 1 to 5 according to their relative importance in contributing to the contamination potential. The original DRASTIC method published by Aller et al. (1987) does not provide vulnerability classification ranges. It allows the user to interpret the vulnerability index using their own field knowledge and hydrogeological experience (private communication with Putra, 2013) Therefore, in this study, the vulnerability index is using the classification system from Civita and De Regibus 1995, Corniello et al. 1997. This classification system defines five classes of vulnerability of DRASTIC:

- Very high vulnerability (vulnerability index >199),
- High vulnerability (160–199),
- Moderate vulnerability (120–159),
- Low vulnerability (80–119), and
- Very low vulnerability (<79).

Contaminant Loading Potential

Foster (1987) and Foster and Hirata (1988) developed a rating method for a common evaluation of various anthropogenic contamination sources. The rating system is based on the evaluation of four key characteristics of the groundwater contamination sources (Johansson and Hirata, 2002):

1. Class of contaminants; type of contaminants, mobility and persistence properties of a contaminant in respect of its potential to contaminate groundwater.
2. Intensity of contaminants: concentrations and extend of contaminant, which load to the subsurface.
3. Mode of disposition; refer to the vertical location of contaminant sources and the associated hydraulic loading.

Table 1. DRASTIC Weight and Rating System

Depth to Water (Meter)		Recharge (Milimeter)		Topography (Slope %)		Conductivity (Meter/Day)		Aquifer Media		Impact of Vadose Zone		Soil Media	
Range	Rating	Range	Rating	Range	Rating	Range	Rating	Range	Rating	Range	Rating	Range	Rating
(0-1.5)	10	(0-50.8)	1	(0-2)	10	(0.04-4.1)	1	Massive Shale	2	Confining Layer	1	Thin or Absent	10
(1.5-4.6)	9	(50.8-101.6)	3	(2-6)	9	(4.1-12.3)	2	Metamorphic Weathered	3	Silt/Clay	3	Gravel	10
(4.6-9.1)	7	(101.6-177.8)	6	(6-12)	5	(12.3-28.7)	4	Metamorphic/Igneous	4	Shale	3	Sand	9
(9.1-15.2)	5	(177.8-254)	8	(12-18)	3	(28.7-41)	6	Glacial Till	5	Limestone	3	Peat	8
(15.2-22.8)	3	(>254)	9	(>18)	1	(41-82)	8	Bedded Sandstone,Limestone	6	Sandstone	6	Shrinking Clay	7
(22.8-30.4)	2					(>82)	10	Massive Sandstone	6	Bedded Limestone,Sandstone	6	Sandy Loam	6
(>30.4)	1							Massive Limestone	8	Sand and Gravel	6	Loam	5
								Sand and Gravel	8	W. Silt, Sand and Gravel	8	Silty Loam	4
								Basalt	9	Basalt	9	Clay Loam	3
								Karst Limestone	10	Karst, Limestone	10	Muck	2
												No Shrinking Clay	1
DRASTIC Weight:5		DRASTIC Weight:4		DRASTIC Weight:1		DRASTIC Weight:3		DRASTIC Weight:3		DRASTIC Weight:5		DRASTIC Weight:2	

4. Duration of application; probability that contaminant will be discharged and period or intervals for which contaminant load is applied.

In the view of complexity of factors affecting pollutant migration and uniqueness of each field situation, it would be logical to treat each activity or source of individual merit and undertake independent field investigations to assess contaminant loading potential (Foster & Hirata, 1988). However, such investigation will be of a high cost and therefore simpler but consistent low cost procedures are needed. A further complicating factor is that contaminant loading potential will itself change with time, as human activities at the ground surface change (Putra, 2007). There are only few comprehensive methods specifically directed to quantify the contaminant loading potential. Modified method version according to Johansson & Hirata (2002) is applied in this study (See Figure 3). A relative rating of the contaminant loading potential of a source is differentiated in five classes: high, moderate high, moderate, moderate low, and low. The final rating is obtained by applying stepwise procedure of three evaluation steps, the stepwise procedure promotes better understanding of the evaluation process and evaluates the result of the combination of parameter at time . (Johansson and Hirata, 2002).

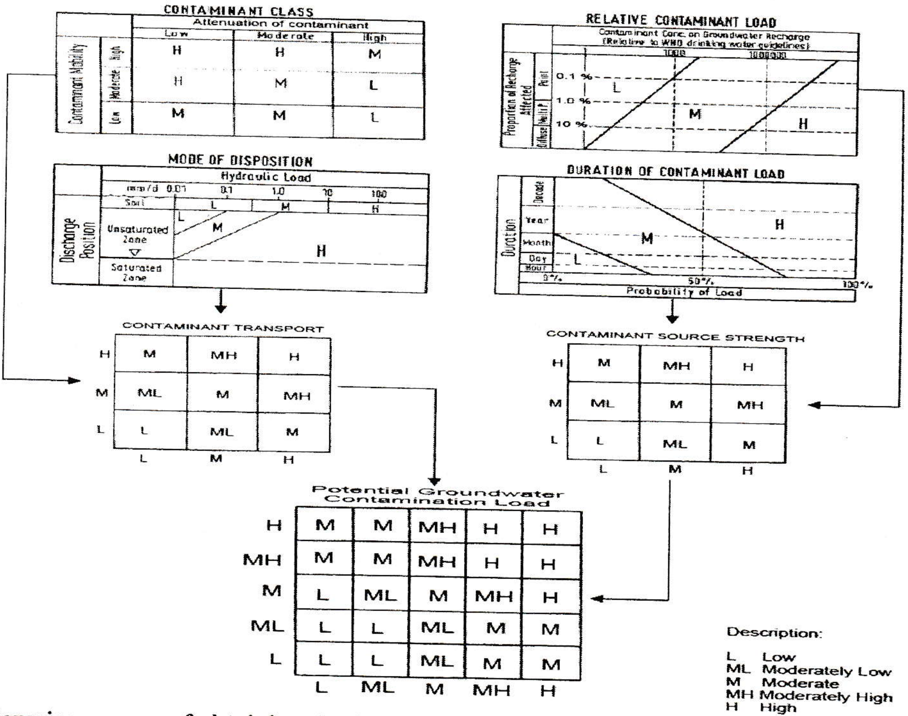
The first step is determination of contaminant transport characteristic. At the first diagram, the contaminant class is evaluated based on the mobility and persistence of each contaminant in the subsurface. At the second diagram, the mode of disposition of the contaminant is evaluated according to relation between depth of contaminant discharge to the groundwater surface and the hydraulic load of source. Contaminant transport is a matrix combination of the contaminant class and the mode of disposition.

The second step is determination of contamination source strength. The relative contaminant load is evaluated based on the proportion of local recharge affected and the contaminant concentration, which relative to WHO guidelines value. On the other hand, the duration of contaminant load diagram is evaluated by the probability and the duration of a contaminant load. Each contaminant concentration load is predicted by analogical data from effluent groundwater in existing coal mine area.

The last step is a matrix evaluation of the contaminant transport obtained first step and contamination source strength obtained in the second step. The final result of these steps is the final classification of the potential groundwater contamination load of the contamination source.

Groundwater Contamination Hazard

After the groundwater vulnerability and the contaminant loading potential in mining concession plan are assessed, then continued by determining the groundwater contamination hazard. According to Putra (2007), the combination between groundwater vulnerability (natural factor of hazard) and contaminant loading potential (anthropogenic factor of hazard) are proved scientifically as significant parameters on estimating the probability of contamination hazard. Therefore, matrix evaluation (private communication with Putra, 2013) for groundwater contamination hazard assessment is applied in this study. Conceptual stages to assess groundwater contamination hazard in this study are presented in Figure 4.



CONTAMINANT CLASS

	Low	Moderate	High
High	H	H	M
Moderate	H	M	L
Low	M	M	L

CONTAMINANT TRANSPORT

H	M	MH	H
M	ML	M	MH
L	L	ML	M
	L	M	H

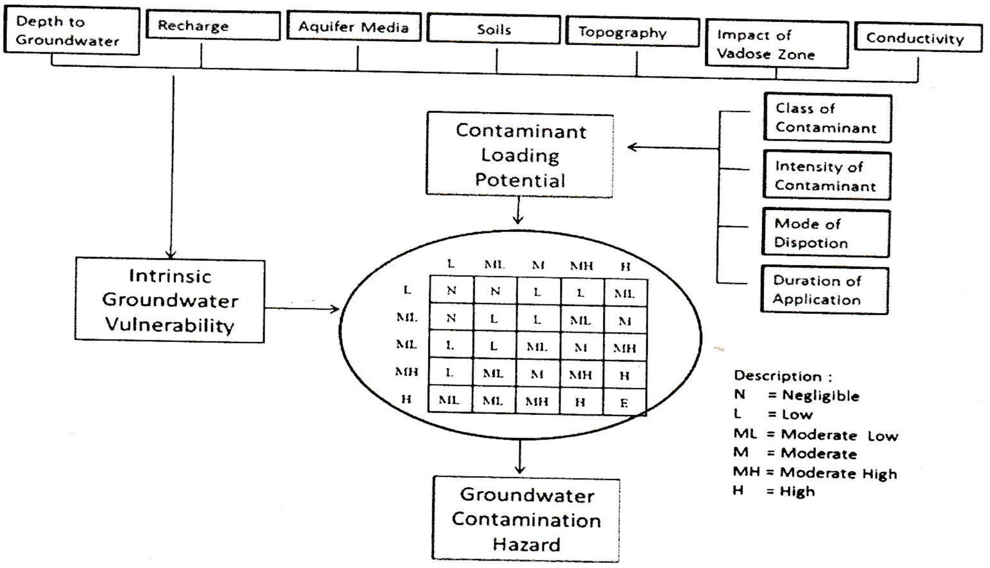
CONTAMINANT SOURCE STRENGTH

H	M	MH	H
M	ML	M	MH
L	L	ML	M
	L	M	H

Potential Groundwater Contamination Load

H	M	M	MH	H	H
MH	M	M	MH	H	H
M	L	ML	M	MH	H
ML	L	L	ML	M	M
L	L	L	ML	M	M
	L	ML	M	MH	H

Figure 3. Stepwise process of obtaining the final rating of contaminant loading potential (Johansson and Hirata, 2002, modified by Putra, 2007)



	L	ML	M	MH	H
L	N	N	L	L	ML
ML	N	L	L	ML	M
ML	L	L	ML	M	MH
MH	L	ML	M	MH	H
H	ML	ML	MH	H	E

Figure 4. Conceptual stages to assess groundwater contamination hazard (modified from Putra, 2007)

RESULT AND DISCUSSION

Intrinsic Groundwater Vulnerability of Coal Mine Area in Barito Timur

The attribute layers for DRASTIC parameters are assembled within a Geographic Information System (GIS) format. Depths to groundwater are about 9.4 to 33.3 meter, measured from exploration and geotechnical boreholes. Using the measurements at these points, the two dimensional variation of depths to groundwater are constructed. Recharge is calculated from rainfall in coal mine area. Rainfall in study area is included in high category. It is approximately 3000 mm. High rainfall may influence significantly to groundwater contamination. High rainfall makes contaminant able to reach the groundwater easily. Based on drilling logs for each borehole, soil types in area study are categorized by sandy loam and peat, while aquifer media and vadose zone are classified by massive sandstone and clay. Hydraulic conductivity distribution in area study is 0.088-1.334 m/day. It is developed using slug test and pumping test at geotechnical boreholes. Using the topographic map of the study area prepared by USGS, a digital elevation model (DEM) is created. According to slope map obtained from DEM model, the slopes values are varied between 8-15 %. After determining all the necessary maps, each map is classified and rated, then multiplied by its weighting factor to calculate DRASTIC index.

The index result was divided into 5 equal groups (Aller et al., 1987). Large numbers indicate high vulnerability potential and small numbers indicate low vulnerability, based on the classification system from Civita and De Regibus 1995, Corniello et al. 1997 (see Figure 5).

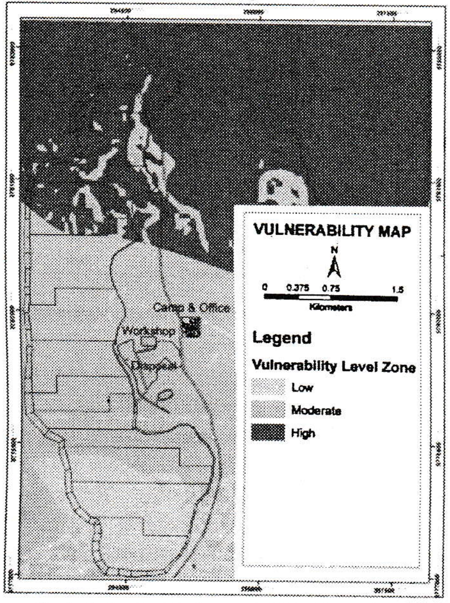


Figure 5. Intrinsic Vulnerability Level

Loading Contamination Hazard of Coal Mine Area in Barito Timur

Natural groundwater quality in Barito Timur is analyzed to know the probability of existing loading contaminant in study area (Table 2). Based on guideline value for drinking water (WHO, 2004), natural groundwater in Barito Timur is acceptable. None of water component concentration is higher than the guideline value. Mining operation does not only need the heavy equipment, but also a lot of employee as operators, officers, mechanics, helpers, chefs, and others The effect of this condition is commonly adverse on the quality of recharge source. The most important recharge source would be the infiltration of waste water from large numbers of septic tanks, latrines, and soakways (Lerner, 2002). In addition, amount of nitrates are also generated by blasting activity which using TNT (trinitrotoluene).

The most commonly problem associated with coal mining is acid mine drainage. The acid forms when precipitation brings water in contact with pyrite (FeS_2) (Zaporozec, 2002). The acid mine drainage does not have a typical composition, but generally it contains relatively high concentrations of sulfate, iron, and other metal; low pH; high acidity (U.S. EPA, 1977 in Zaporozec, 2002). Poly-Aromatic Hydrocarbons (PAHs) are formed as a complex mixture of compounds during incomplete combustion of organic matter (fuel, tar, oil and grease) in workshop area. These contaminants tend to be absorbed to the organic matter in the soil, instead of being dissolved in the infiltrating water and through this be transported downwards to the groundwater.

Effluent groundwater of coal mines in developed country (Table 3) and developing country (Table 4) are presented to be used to analogy the probability of contaminant loading in study area. In addition, the result assessments of the loading contaminant in coal mine area are summarized in Table 5. According to Table 3, sulfate, nitrate and PAHs (oil and grease) concentrations in effluent groundwater of coal mine in developed country are about 33-14,565.2 mg/l, <0.2-125.3 mg/l and <0.5, respectively. While, the concentrations in developing country are smaller, they are about 220-8477 mg/l of nitrate, 0.9-58 mg/l of nitrate and 0.05-4.78 of PAHs. However, the concentration of contaminant, which used to assess loading contamination hazard in this study, are analogized by the highest value of effluent groundwater quality of coal mines in Indonesia

The contaminant transport in first step and contamination source strength in the second step, are evaluated by matrix evaluation to obtain the final classification. The final classification of stepwise process step is the potential groundwater contamination load of the contamination source. Sulfate loading contaminant, PAHs loading contaminant and Nitrate loading contaminant are presented in Figure 6, Figure 7 and Figure 8, respectively.

Table 2. Natural Groundwater Quality of Coal Mine Area in Barito Timur

Component	Unit	Guide line Value[1]	Sample Number				
			H-1	H-2	H-3	H-4	H-5
pH		6.5-8	7.2	7.3	7.04	6.89	7.04
TDS[2]	mg/l	1000	124	204	108	68	57
BOD[3]	mg/l	-	0.2	0.1	0.2	0.2	0.2
COD[4]	mg/l	-	5.1	3.9	4.4	4.5	5.2
Iron	mg/l	0.3	0.01	0.02	0.08	0.07	0.07
Manganese	mg/l	0.1	0.01	0.01	0.02	0.08	0.01
Chloride	mg/l	250	8.3	12.4	6.23	10.3	6.23
Nitrate	mg/l	50	n/a	n/a	n/a	n/a	n/a
Sulphate	mg/l	250	3.5	3.4	2.9	3.4	3.1
Magnesium	mg/l	-	0.2	0.1	0.1	0.12	2.4
Calcium	mg/l	-	4.03	10.1	6.04	16.1	6.04

[1] WHO, 2004
[2] TDS Total Dissolve Solid
[3] COD Chemical Oxigen Demand
[4] BOD Biological Oxigen Demand

Groundwater Contamination Hazard of Coal Mine Area in Barito Timur

The results of the vulnerability index and each contaminant loading are combined in a matrix evaluation to obtain three maps. They are groundwater sulfate hazard map (Figure 9), groundwater poly-aromatic hydrocarbon hazard map (Figure 10), and groundwater nitrate hazard map (Figure 11).

Based on the degree of hazard contamination, sulfate contamination hazard map is divided into five classes (low, moderate low, moderate, moderate high and high) poly-aromatic hydrocarbons (PAHs) contamination hazard is divided into five classes (negligible, low, moderate low, moderate, moderate high), then nitrate contamination hazard is divided into seven classes (negligible, low, moderate low, moderate, moderate high, high, extreme).

Almost all concession of coal mine has probability of sulfate contamination, as a result of acid mine drainage. However, the nitrate contamination hazard has the higher degree of hazard contamination.

Table 3. Average Effluent Groundwater Quality of Coal Mines in Industrial Country

Constituent	Unit	Pennsylvania[1]		Norway[2]		UK[2]		Wales[2]		Australia[3]
		Amstrong	Clarion	Kongens Gruve	Lokken	Magpie Sough	Dunston	Ynsarwed	Morlais	Queensland
pH		2	2.2	2.7	2.11	7.2	6.3	4.2	6.9	6.69
Alkalinity	meq/l	0	0	0	0	4.28	3.74	2.76	6.07	2100
Oil and grease	mg/l	-	-	-	-	-	-	-	-	<0.5
TDS	mg/l	-	-	-	-	-	-	-	-	15
Iron	mg/l	2200	3200	134	4720	<0.00 05	10.6	180	26.6	0.94
Manganese	mg/l	3.3	260	n/a	n/a	<0.0002	1.26	6.1	0.93	0.28
Zinc	mg/l	-	-	36.3	87.4	0.074	<0.007	0.061	<0.002	0.016
Chloride	mg/l	-	-	n/a	-	19	26	32	25	6600
Nitrate	mg/l	-	-	-	-	-	-	-	-	<0.1
Sulphate	mg/l	14565	14000	901	17036	33	210	1554	455	2100
Magnesium	mg/l	-	-	-	-	-	-	-	-	590
Calcium	mg/l	-	-	47.8	330	98	64.5	222	64.5	270
Natrium	mg/l	-	-	n/a	n/a	8	51.4	109	155	-
Aluminium	mg/l	-	-	33.1	580	0.005	<0.045	<0.5	<0.01	0.004

Source Data : [1] Prediction of Water Quality at Surface Coal Mines (Kleinmann, 2000) [2]Geochemical Processes Controlling Minewater Pollution (Banks et al, 2003), [3]Underground Water Impact Report (Oakley Creek Coal Pty Ltd, 2012)

Table 4. Average Effluent Groundwater Quality of Coal Mines in Developing Country

Constituent	Unit	Indonesia				India[5]		Bolivia[6]
		Berau[1]	Kutai Kartanegara[2]	Kutai Kartanegara[3]	Kutai Barat[4]	Jharia Coalfield	Ranigan Coalfield	San Jose
pH		3.12	6.5	2.1	6.23	7.3	7.4	1.47
Alkalinity	meq/l	-	-	-	-	188.7	448	0
Oil and grease	mg/l	-	-	-	0.17	0.05	4.78	-
TDS	mg/l	-	1671.3	1220	54	2001	1622	-
Iron	mg/l	13.19	3.65	2.4	0.13	24	28	2460
Manganese	mg/l	4.05	0.67	4.4	<0.02	-	-	27.4
Zinc	mg/l	-	0.64		-	-	-	79.4
Chloride	mg/l	-	6.95		-	85.51		32670
Nitrate	mg/l	4.58	1.26	0,9	-	58	4.6	-
Sulphate	mg/l	220	34.94	349	-	84.49	789	8477
Magnesium	mg/l	46.82	-	-	-	43.38	180	-
Calcium	mg/l	43.12	-	-	-	59.08	216	1780
Natrium	mg/l	10.05	-	-	-	-	-	17256
Aluminium	mg/l	-	-	-	-	-	-	559

Source Data : [1]Marganingrum & Noviardy, 2010, [2]Research and Development Ministry of Home Affair Republic of Indonesia, 2010 , [3]Environmental Management and Monitoring Report of PT. Tunas Sinar Abadi, 2012, [4]Environmental Management and Monitoring Report of PT. Singlurus Pratama Coal, 2012[5] Impact of Coal Mining in Mine Water Quality (Singh, 1988), [6] Prediction of Water Quality at Surface Coal Mines (Kleinmann, 2000)

Table 5. Assessment of loading contamination hazard of coal mine area in Barito Timur

No.	Type of Contaminant		Nitrate	PAHs	Sulphate
1	**Class of Contaminant**	**Contaminant Mobility**	Very High	Low	High
		Attenuation of Contaminant	Very Low	Moderate	Low
2	**Intensity of Contaminant**	**Concentration of Contaminant**	Low (4.58 mg/l)	Low (0.17 mg/l)	Low (349 mg/l)
		Proportion of recharge	Diffuse (>10%)	Multipoint (1 - 10 %)	Diffuse (>10%)
3	**Mode of Dispotion**	**Hydraulic Load**	Moderate (1-10 mm/d)	Moderate (0.1 - 10 mm/d)	High (10-100 mm/d)
		Discharge Position	Moderate (Unsaturated zone)	Deep (saturated zone)	Moderate (Unsaturated zone)
4	**Duration of Application**	**Duration**	Long (Decade)	Short (Hour to Day)	Short (Day to Month)
		Probability of Load	High (60-100%)	Low (0-25%)	Moderate (30-70%)

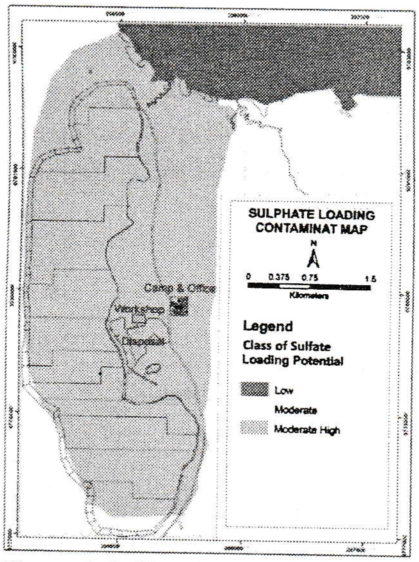


Figure 6. Sulfate Loading Contaminant Map

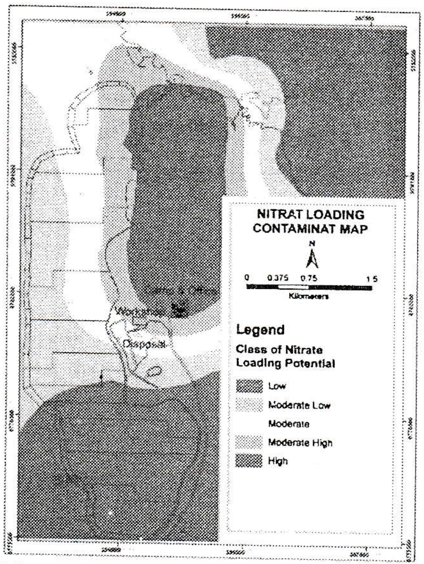


Figure 8. Nitrate Loading Contaminant Map

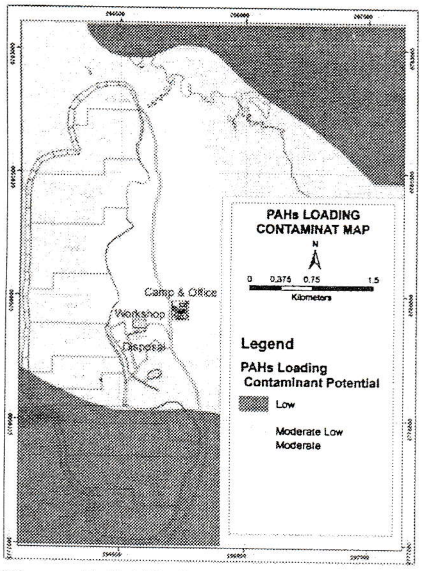


Figure 7. PAHs Loading Contaminant Map

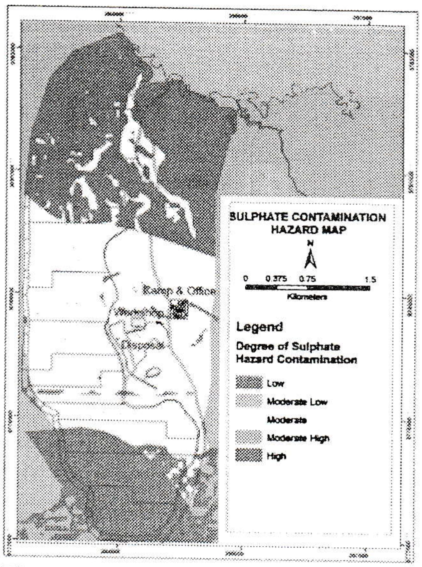


Figure 9. Sulfate Contamination Hazard Map

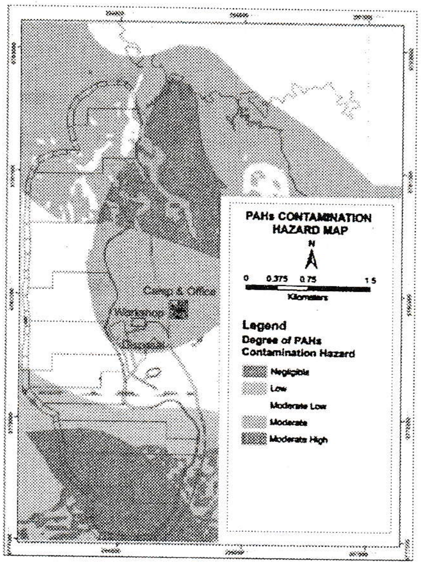


Figure 10. PAH Contamination Hazard Map

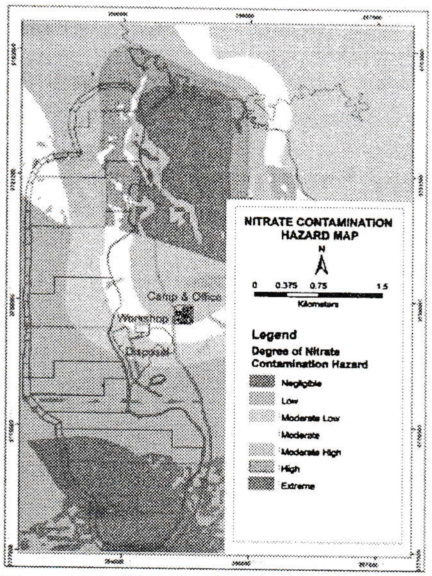


Figure 11. Nitrate Contamination Hazard Map

CONCLUSIONS

Open pit coal mine has many impacts on groundwater quality. Hence, an Environmental Impact Assessment is required as part of the authorization process. Groundwater contamination hazard assessment ensures better consideration of environmental impacts on groundwater quality, caused by open pit coal mine. By groundwater contamination hazard in study area, a groundwater protection management can be developed. Based on the hazard of contaminant (sulfate, poly-aromatic hydrocarbon and nitrate), it can be conclude that the largest probability of contamination hazard in study area is sulfate, which is generated as acid mine drainage reaction in environment. While, the highest level of contamination hazard is nitrate. In addition, the highest hazard of groundwater contamination area will be occurred at North of coal mine concession, which may reach to groundwater. Therefore, the mitigation and protection management in Environmental Impact Assessment document will be concerned there. This is a preliminary assessment of groundwater contamination hazard, which is applied in coal mine area as a part of Environmental Impact Assessment, thus further comprehensive research is needed to complete this study.

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