Status Of Water Quality In Watersheds Due To Mining Industry Activities

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Abstract: Indonesia is one of the gifted countries with abundant natural resources in many sectors such as plantation, fishery, agriculture, and mining. To support the rapid population development, the natural resources exploited massively to fulfill the needs of humans. As a result of this massive exploitation, environmental degradation could not avoid such as air, soil and water pollution. Virtue Dragon Nickel Industry, located in Konaweha watershed, indicates polluted the water in the Konaweha river. Therefore, this study aims to identify the pollution index water of Konaweha River through physical and chemical parameters as well as to recommend river management system. Sampling has taken in two places in river, which were first around the settlement and second around mining industry. Sampling analysis underwent in laboratory and Index of Pollution (IP) used to identify the level of pollution. The result shows that the highest pollution index is in location 1 located near the mining industry which is 7.20 IP and has moderate pollution level. This happens because in first location, the industrial disposal going to the river and the human activities such as agriculture, plantation and illegal sand mining. Meanwhile, in second location has lower index pollution at 5.40 IP. This is because, in second location, the primary source of pollution comes from human activities such as agriculture, plantation and illegal sand mining.

Index Terms: Sustainable Environment, Index of Pollution, Industrial Waste, Water Quality.

1 INTRODUCTION

The increasing the use of natural resources through mining business activities will have the consequence of increasing potential and the occurrence of pollution and environmental damage around the mining location [1]. Thus, it needs to anticipate real and effective efforts in the framework of its control by implementing mining business management patterns based on excellent and right mining principles so that mining development activities can directed to pay attention to and maintain the balance and carrying capacity of environmental functions [2]. The correct mining procedures will have a massive impact on mining business activities. It hoped that mining business activities would be more economical and efficient, and the safety of workers and environmental sustainability will be more guaranteed [3]. The water polluted by waste and then consumed by the community impacts people's health [4]. Waste pollution has an impact on increasing levels of bacteria and heavy metals. Water containing the E Coli bacterium affects diarrheal disease if consumed by the community. Lead heavy metals (Pb) contained in water can cause disorders of the neurological system (nervous system), impaired kidney function, reproductive disorders, and anemia. The clinical implications of Chromium (Cr) pollution in the form of respiratory system disorders. Sources of heavy metal pollutants can come from nature, transportation, and industry, especially mining. The mining industry is one of the industries that the Indonesian government has relied on to bring in foreign exchange. In addition to bringing in foreign exchange, the mining industry also absorbs jobs, and the Regency and City are a source of income for the region.

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In addition to generating foreign exchange and absorbing employment, the mining industry is also prone to environmental destruction. Many mining activities invite the attention of the surrounding community because of environmental destruction, especially mining without permission, which in addition to damaging the environment also endangers the lives of miners because of the limited knowledge of miners and because there is no supervision from the relevant agencies [5]. The presence of a mining company in an area is undoubtedly an added value for the region and the surrounding community. The existence of a mining company operating in an area will undoubtedly open employment opportunities for communities around the mining area [6]. Thus, the number or amount of unemployment will decrease so that it will have an impact on increasing the quality of human resources. Nickel mining activities carried out certainly have positive and negative impacts that will affect the socio-economic conditions of the community. The positive impact in question is to accommodate the workforce, improve the economy of the community around the mine, and increase the microenterprise community around the mine. Besides, the negative impact is the occurrence of environmental destruction and the declining quality of life of local people. The positive and negative impacts of mining activities will bring changes to the socio-economic conditions of communities around the mining area [7]. For human and industrial growth, water considered a significant need. Increasing population and industrialization, the demand for freshwater has increased in the last decade [8]. This demand fulfilled by rivers that provide water for human life and agriculture. Due to the waste discharged from human and industrial activities, river water quality has deteriorated which affects human life and water. According to the World Health Organization (WHO), Central Pollution Control Board (CPCB), Bureau of Indian Standards (BIS), Indian Council for Medical Research (ICMR), the water quality of about 70% of river water contaminated due to pollutants in India and some river water is too poor for human consumption [9]–[11]. This condition will disrupt the survival of the surrounding biota, such as fisheries resources and coastal and marine ecosystems (mangroves, seagrass beds, and coral reefs) and will ultimately have a broad

impact on reducing the income of coastal communities that depend their lives on biological productivity in coastal areas and sea. Pollution caused by metals can change the structure of aquatic communities, food networks, behavior, physiological, genetic and resistance effects. According to Martin [12], metals can accumulate in the body so that threatening human life can also result in death and even death if the metal enters the food chain. The pollution can be carried away by the body's organs and accumulates, and if it enters the body excessively, it can be sure that it will immediately suffer poisoning [13], [14]. The potential environmental damage that occurs due to mining activities generally carried out in forest areas so that it can cause pollution in the watershed [15]. A watershed is a land area that is topographically bounded by ridges that hold and store rainwater and then drain it into the sea through the main river. The existence of watersheds plays a vital role for the benefit of the lives of many people, especially for the surrounding community. Water pollution has many adverse impacts on the environment, human health, and various living things on earth. The impact of water pollution requires ways that can overcome or overcome starting from knowing the cause of water contamination. Water contamination is the entry of pollutants into the water environment. Pollutants can come from industrial, household and agricultural waste. Liquid waste or wastewater is wastewater produced from human activities, such as household, industrial, agricultural, livestock, aquaculture, and other activities that discharged into water and can reduce water quality. Konoweha River is one of the rivers that have high potential to polluted by nickel mining activities. Indicators of water that have polluted are changes or signs that can observe, such as temperature, pH, color, smell, and taste, the emergence of deposits, colloids and solvents, the presence of microorganisms, and increasing environmental radioactivity for water. Chemical water quality indicators that often used are usually: BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), DO (Dissolved Oxygen), pH, dissolved CO2, suspended solids and organic suspended substances, total solids, Nitrogen and Phosphorus, heavy metals and inorganic solids [16]. Much research has done on water quality studies in mining areas. This study of water quality considered necessary because mining activities can hurt the environment, including water quality, which is one of the crucial elements in human life. Therefore, this study aims to analyze the water quality of the Konaweha River by using a pollution index. The value of water quality standards used in research refers to: (1) Government Regulation of the Republic of Indonesia Number 82 of 2001 concerning Water Quality Management and Water Pollution Control; (2) The United States Environmental Protection Agency (USEPA) Current standards include maximum contaminant levels (MCL), also known as primary standards, for organic and inorganic chemicals that are known to have toxic or carcinogenic effects, for turbidity, and for bacterial populations. Besides, contaminant levels recommended; (3) The European Economic Community (EEC), which established by a European Community Council agreement, issued council directives relating to water quality intended for human consumption. Specifically, the EEC standard provides a standard-setting to apply to toxic chemicals and bacteria that pose health hazards and to the definition of physical, chemical and biological parameters for different water uses. Water quality index calculation methods needed to simplify the value of various types of parameters into a number that can describe water quality so that it easily understood by the public. Water quality index methods that often used in Indonesia are the IP (Pollution Index) Method and the Storet Method, which refers to the Minister of Environment Decree No. 115 of 2003 concerning Guidelines for Determination of Water Quality Status.

2 Research Method

2.1 Research Approach

Sumitomo and Nemerow [17], [18], propose an index related to pollutants that are meaningful for a description. This index stated as a Pollution Index, which is used to control the level of contamination relative to permitted water attribute parameters [19]. This index has a different concept to the Water Quality Index. Pollution Index (IP) determined for an allotment, and then it can develop for several allotments for all parts of a body of water or a portion of a river. Water condition management based on this Pollution Index (IP) can provide input to decision-makers to assess the quality of water bodies for an allotment and act to improve quality if there is a decrease in quality due to the presence of pollutants. IP includes various independent and meaningful characteristic parameter groups.

2.2 Research Location

The research location located in Morosi, Konawe Regency, Southeast Sulawesi Province. The sampling points carried out at two locations, namely the river body around the drainage location of Industrial Nickel Virtue Dragon Company (S 03˚58'59.45"E 122˚23'40.82") and the second location located around the residential area (S 03˚56'27.23 "E 122˚25'40.35").

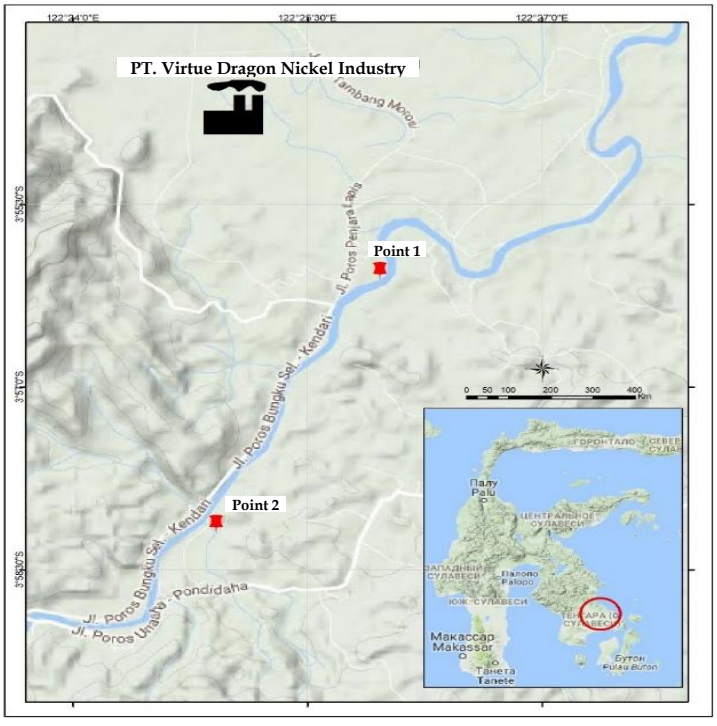

***Fig. 1**. Research Location and Sample Point*

2.3 Measurement Procedure

Water samples were taken with 500 ml polyethylene sample bottles from 30-50 cm depth because, at this depth, it is considered enough to represent the vertical homogeneity of pollutant dispersions and avoid surface effects [16]. Samples taken, then given a few drops of HNO_3 to pH < 2. This treatment prevents the metal from oxidizing, settling, or sticking to the wall or bottom of the container. The water sample then put in an icebox and stored in the refrigerator.

2.4 Data Analysis

Water quality analysis was done by comparing the measurement of water quality with water quality standards according to Government Regulation No. 82 of 2001 concerning Management of Water Quality and Water Pollution Control. Determination of water quality status using the pollution index method following the Decree of the Minister of Environment No. 115 of 2003. Calculation of the pollution index carried out using the following formula:

$$Pij = \sqrt{\frac{\left(\frac{Ci}{Lij}\right)^2 M + \left(\frac{Ci}{Lij}\right)^2 R}{2}} \quad \text{.....} \quad (1)$$

Information:

Lij : *The concentration of water quality parameters stated in the water allotment quality standard (J)*
Ci : *The concentration of water quality parameters in the field*
Pij : *Pollution index for allotment*
(Ci/Lij) M : *Value, maximum Ci/Lij*
(Ci/Lij) R : *Value, Ci/Lij average*

In the Pollution Index method, various water quality parameters used, so the average value of the overall Ci/Lij value used as a measure of pollution, but this value will not be significant if one of the Ci/Lij values is > 1. Therefore, this index must include a highest Ci/Lij value. The river increasingly polluted for an allotment (J) if the value (Ci/Lij) R and (Ci/Lij) M is more significant than 1.0 if the value (Ci/Lij) R and the value (Ci/Lij) M is higher, then the level of pollution of a body of water will be even higher. This method connects the level of pollution of water used for a specific designation with the value of certain parameters, as shown in Table 1 as follows:

***Table 1**. Evaluation of pollution index values*

Index Value	*Status*
0.0 ≤ (Index of Pollution) ≤ 1.0	*Good Condition*
1.0 < (Index of Pollution) ≤ 5.0	*Lightly Polluted*
5.0 < (Index of Pollution) ≤ 10.0	*Medium Polluted*
(Index of Pollution) > 10.0	*Heavily Polluted*

At present there are many methods used to determine the status of water quality such as the Storet and IP methods developed in the USA, in addition there are also the OIP/Overall Index Pollution methods of India developed in India, the INWQS-DOE method in the State Malaysia, and the CCME WQ (Canadian Council of Ministers of the Environment) Method developed in Canada [20]. With the advancement of pollution, technology in an area and waters can not only be tested directly but also through remote sensing via a satellite that analyzes the color and shape of pollution that occurs [21]–[23].

RESULT AND DISCUSSION

The Pollution Index (IP) is related to pollutant compounds. This index is used to determine the level of contamination relative to permitted water quality parameters [24]. This index has a different concept to the Water Quality Index. IP determined for an allotment, and then it can develop for several allotments for all parts of a body of water or a part of a body of water. The pollution index uses to determine the level of pollution of the permitted water quality parameters. In this study, the calculation of the pollution index based on the sampling point of sampling and predetermined parameters, namely physical parameters (TSS) and chemical parameters (DO, BOD_5, COD, Fe, pH, and Cr). Water quality standards use based on Government Regulation Number 82 of 2001 concerning Management of Water Quality and Water Pollution Control. The results of water characteristic testing and calculation of pollution indices at each research station presented in tables 2 and 3 as follows:

***Table 2**. Water quality test results of research samples*

Parameter	*Unit*	*Test Results*		*Threshold Value*
		Point 1	*Point 2*	
Biochemical Oxygen Demand $(BOD)_5$	*mg/L*	*2.24*	*1.6*	*2*
Chemical Oxygen Demand (COD)	*mg/L*	*110*	*65*	*10*
Power of Hydrogen (pH)	*mg/L*	*7.82*	*7.87*	*6-9*
Dissolved Oxygen (DO)	*mg/L*	*2.7*	*4.5*	*6*
Iron (Fe)	*mg/L*	*2.76*	*0.27*	*0.3*
Chromium (Cr)	*mg/L*	*0.06*	*0.02*	*0.001*
Total suspended solid (TSS)	*mg/L*	*67.9*	*51.2*	*50*

***Table 3**. The result of the calculation of the pollution index*

Point	*Index of Pollution (IP)*	*Index Value*				*Status*
		0.0 ≤ (IP) ≤ 1.0	*1.0 ≤ (IP) ≤ 5.0*	*5.0 ≤ (IP) ≤ 10.0*	*IP > 10.0*	
1	*7.20*	-	-	*v*	-	*Medium Polluted*
2	*5.40*	-	-	*v*	-	*Medium Polluted*

From the results of the research carried out the pollution index has a moderate quality of water quality with an Index of Pollution (IP) value obtained for the first point of 7.20 and the second point of 5.40 from the results it can concluded that the watershed in the nickel mining industrial estate is not suitable for use. The status can also indicate the condition of the watershed threatened in terms of availability and water quality conditions, which means that the existing water cannot use for the community. The availability and quality of water, whether surface or land, has deteriorated due to several important factors such as increasing population, industrialization, urbanization and agriculture [25]. In India itself, precisely on the Damodar River in the South Bengal region water quality monitoring carried out water sampling at 8 points along the riverbank before the rainy season, rainy season, and rainy post-season period of 2012. The number of parameters tested was sixteen. Based on the results of the analysis, it obtained that the water in the Damodar River is suitable for household and irrigation purposes but must treat first if it uses as drinking water. Climatic conditions significantly affect river water quality. It is because the water quality after the rainy season is better than before and during the rainy season. However other locations on the Damodar River have highly polluted water quality due to disposal of domestic waste, disposal of industrial waste, garbage, and pollution due to other human activities [26]. Preventive and regulatory actions needed by monitoring to prevent pollutants that exceed the permitted threshold. Then other research conducted precisely on the Three Gorges Reservoir, China. The number of locations for monitoring water samples is 24, and the number of parameters used is 12 parameters with the sampling period in 2011-2013. The method used is the water quality index method with grade 3 (three) water quality standards according to China's Environmental Quality Standards for Surface Water (GB3838-2002). The results of this study indicate that 3 (three) main parameters that cause the reduction of water quality in TGR are TN, TP, and E-Coli. Water quality did not experience a significant decrease in water level conditions at TGR 175 m. In some monitoring stations that are on a small river, the water quality is not as good as the quality of the water in the main river. The water quality index method is a flexible method for evaluating water quality. Combined with China's Environmental Quality Standards for Surface Water (GB3838-2002), the water quality index can simplify the amount of complex water quality monitoring data so that it easily understood by policymakers and the public [27]. The Pasig River System in Metro Manila tests the status of pollution for aquatic and recreational ecosystems. This research conducted at 14 points along the Pasig River in Metro Manila, with four parameters namely DO, TC, pH, BOD. They are using laboratory test data every three months from the first quarter of 2011 to the second quarter of 2014. Results of the analysis show that the waters in the Pasig river are in the wrong category, both for aquatic ecosystems and for recreation. Inadequate sewage disposal systems and untreated wastewater from domestic, agricultural, commercial and industrial sources are the main factors that cause contamination of the Pasig River system [28]. River water quality testing is carried out in the Ogun and Ona watersheds in Nigeria. A sampling at 27 water monitoring locations in 8 (eight) main rivers in the Ogun and Ona watersheds. The number of parameters used were 12 parameters. The sampling period is 12 months. The method used is a method with water quality standards for household needs, according to WHO. The results of this study indicate that water quality in these watersheds reduced, so it is not recommended for household needs [29]. The next study was carried out in Mahrut River, Diyala, Iraq. Water quality monitoring was carried out for irrigation needs using the water quality index method with 15 parameters. By using data with two different seasons, namely the period 2010-2011. From the results of the analysis of water quality between 43.17 - 45.11. The water quality at the first monitoring point is in the poor category, while in the other 5 (five) stations, it is in poor condition, so it can conclude that the water conditions in the river are in poor condition [30]. In the Seybouse River (northeast Algeria) test water quality using the water quality index method using data at 13 locations based on physical, chemical and biological parameters. Water samples from the middle and two series of the Seybouse River from May 2012 to April 2013. The number of parameters used was 11 parameters: pH, Temperature, DO, Nitrite, Nitrate, Nitrogen Chloride, Copper Cadmium, Aluminum, Turbidity. The water quality index method is a useful tool for evaluating water quality for drinking water needs [31]. The water quality index model used to assess the quality of drinking water in the Seybouse River shows that water quality is poor, with index values ranging from 18.3 to 30.4. Wastewater that is discharged directly or indirectly into water bodies is the primary source of contaminants. The water quality index has collected complex water quality data so that it is easy to understand and this data can be valuable for water users, water suppliers, and researchers. The water quality index is a mathematical mechanism for calculating water quality data into simple terms such as Excellent, good, and bad. This reflects the level of water quality in rivers, rivers, and lakes [32]. Water quality classes are defined depending on the physical, biological, and chemical parameters measured in addition to the water requirements used, such as; drinking water, water used in agriculture, or water used in industry [33]. Also, metal quality indexes have been applied to assess drinking water sources regarding metals [34], [35]. Biochemical Oxygen Demand (BOD) is a characteristic that shows the amount of dissolved oxygen needed by microorganisms to break down or decompose organic matter under aerobic conditions. BOD_5 is an index number for measuring gauges of waste that is somewhere. The higher the concentration of BOD_5 in a place, it shows the concentration of organic matter in the air is also high. BOD_5 measurement results obtained at the first observation point 2.24 mg/l and the second observation point obtained 1.60 mg/l. BOD_5 values obtained ranged from 1.5 - 2.5 mg/l, which means that water conditions are quite vulnerable to pollution and above the maximum BOD_5 threshold recommended in Government Regulation Number 82 of 2001 concerning Management of Water Quality and Water Pollution Control. Then the BOD_5 value obtained is still below the recommended maximum BOD_5 standard for marine biota in the Decree of the Minister of Environment Number 51 of 2004 for the life of marine biota with a maximum value of 20 mg/l. BOD_5 parameter is a general parameter that can use to determine the level of water

pollution from a source of pollution. Based on the pollution level criteria of the BOD_5 value, the Konaweha watershed classified as moderate to high. The higher concentration of BOD_5 indicates that the waters have polluted, while the BOD_5 concentrations which classified as moderate and can categorize as poor waters. The Konaweha River management effort from the environmental aspect is at the first location of the management effort recommendations, namely the need to emphasize and supervise the law enforcement of industries or business actors, especially the nickel industry which proven to pollute river water and dispose of waste without going through waste management procedures that are well. Then for the second location, which is a recommendation in the management effort, it starts with the awareness of the community and industry, not to over-mining sand and to dispose of garbage into the river. When viewed from the land use at this second location is a residential and plantation area. So that the pollution index does not exceed quality standards, the community and industry players (sand mines) need to reduce excessive river dredging activities and especially to the public to maintain environmental cleanliness and not to litter into river bodies. High levels of total suspended solid (TSS) sourced from all solids (sand, mud, and clay) or particles that suspended in water and can be living components (biotic) such as phytoplankton, zooplankton, bacteria, fungi, or dead components. (abiotic) Such as detritus and inorganic particles [36]. Suspended solids are the place where heterogeneous chemical reactions take place, and function as the earliest precipitating material and can inhibit the ability to produce organic matter in water. The penetration of sunlight to the surface and deeper parts does not take place effectively due to being blocked by suspended solids, so photosynthesis does not take place ideally [37], [38]. The high total suspended solid (TSS) can also directly disturb aquatic biota such as fish because it filtered by gills. Total suspended solid (TSS) value can be one of the biophysical parameters of water that dynamically reflects changes that occur on land or in water. Total suspended solids (TSS) are beneficial in the analysis of polluted domestic waters and discharges and can use to evaluate water quality, as well as determine the efficiency of treatment units. Then the value of the Power of Hydrogen (pH) obtained in the study was 7.8 mg/L which means it was still below the recommended threshold of 6 - 9 mg/L. The pH value probably influenced by the alkalinity conditions in the form of sedimentary carbonate solution (CO32-) to bicarbonate (HCO3-) sourced from rainwater runoff in November from land around the mining environment. Furthermore, coral limestone contains a lot of calcium carbonate ($CaCO_3$). Mackereth [39] argues that pH is also closely related to carbon dioxide and alkalinity. At pH < 5, alkalinity can reach zero. The higher the pH value, the higher the alkalinity value and the less free carbon dioxide content. Most aquatic biotas are sensitive to changes in pH and like pH values around 7 - 8.5. Aquatic biochemical processes such as nitrification strongly influenced by pH values. The nitrification process will end if the pH is acidic. Metal toxicity shows an increase in low pH [40]. The toxicity of a chemical compound also influenced by pH. Ammonium compounds that can ionize found in waters with low pH. Ammonium is non-toxic (innocuous). In an alkaline atmosphere (high pH) more ammonia found, which not ionized (unionized) and is toxic. This non-ionized ammonia more easily absorbed into the body of aquatic organisms than ammonium [41]. Ammonia measured in water is total ammonia (NH_3 and NH+). Ammonia rarely found in waters that have enough oxygen supply. Conversely, in anoxic regions which usually found at the bottom of water, ammonia levels are relatively higher. Likewise, with nitrate, nitrate (NO_2) usually found in minimal amounts. Nitrite levels in natural waters range around 0.001 mg/L and should not exceed 0.06 mg/L.

CONCLUSION

Economically, mining activities can bring enormous benefits, but the economic benefits obtained are not comparable with environmental damage due to mining activities, which are conditional on exploration and exploitation of natural resources. Nevertheless, the result of these activities is environmental damage which if not carried out rehabilitation and conservation of the environment will be detrimental to the people who live around it. The role of government and industry to conserve the environment, which uses as a material mining location. In the future, it expected that a sustainable environmental order would create that can raise the economic conditions of the community without causing environmental damage.

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REFERENCES

[1] M. Tost, M. Hitch, V. Chandurkar, P. Moser, and S. Feiel, “The state of environmental sustainability considerations in mining,” J. Clean. Prod., vol. 182, pp. 969–977, 2018.

[2] G. Hilson, “The environmental impact of small-scale gold mining in Ghana: identifying problems and possible solutions,” Geogr. J., vol. 168, no. 1, pp. 57–72, 2002.

[3] M. Ichsan Ali, G. Darma Dirawan, H. Syam, and M. Mulyadi, “Effect of Knowledge toward the Behaviour of Gold Miners Environmentally Sound: A Case Study in Bombana Regency,” Int. J. Appl. Environ. Sci., vol. 9, no. 4, pp. 1275–1289, 2014.

[4] M. I. Ali, “Environmental Pollution Knowledge of Small-Scale Miners in Bombana Regency, Indonesia,” Pollut. Res., vol. 37, no. 1, pp. 56–62, 2018.

[5] M. I. Ali, “The Consequences of Illegal Mining in the Environment: Perspectives Behavioral, Knowledge and Attitude,” Int. J. Environ. Eng. Educ., vol. 1, no. 1, pp. 25–33, 2019.

[6] A. Kumah, “Sustainability and gold mining in the developing world,” J. Clean. Prod., vol. 14, no. 3–4, pp. 315–323, 2006.

[7] C. Vintró, L. Sanmiquel, and M. Freijo, “Environmental sustainability in the mining sector: Evidence from Catalan companies,” J. Clean. Prod., vol. 84, no. 1, pp. 155–163, 2014.

[8] Mithen, O. Sampebua, Sunardi, and G. D. Dirawan, “Model local wisdom to preserve the

environment in South Sulawesi and West Sulawesi Indonesia," Man India, vol. 95, no. 4, pp. 1041–1050, 2015.
[9] F. J. Thakor, D. K. Bhoi, H. R. Dabhi, S. N. Pandya, N. B. Chauhan, and N. B. Chauhan, "Water quality index (WQI) of Pariyej lake Dist. Kheda-Gujarat," Curr. world Environ., vol. 6, no. 2, p. 225, 2011.
[10] C. R. Ramakrishnaiah, C. Sadashivaiah, and G. Ranganna, "Assessment of water quality index for the groundwater in Tumkur Taluk, Karnataka State, India," J. Chem., vol. 6, no. 2, pp. 523–530, 2009.
[11] R. Jindal and C. Sharma, "Studies on water quality of Sutlej River around Ludhiana with reference to physicochemical parameters," Environ. Monit. Assess., vol. 174, no. 1–4, pp. 417–425, 2011.
[12] M. H. Martin, Biological monitoring of heavy metal pollution: land and air. Springer Science & Business Media, 2012.
[13] S. Martin and W. Griswold, "Human health effects of heavy metals," Environ. Sci. Technol. briefs citizens, vol. 15, pp. 1–6, 2009.
[14] M. K. Raikwar, P. Kumar, M. Singh, and A. Singh, "Toxic effect of heavy metals in livestock health," Vet. world, vol. 1, no. 1, p. 28, 2008.
[15] L. D. De Lacerda, "Updating global Hg emissions from small-scale gold mining and assessing its environmental impacts," Environ. Geol., vol. 43, no. 3, pp. 308–314, 2003.
[16] W. W. Eckenfelder, Water quality engineering for practicing engineers. Barnes & Noble, 1873.
[17] N. L. Nemerow and H. Sumitomo, "Benefits of water quality enhancement report no. 16110 DAJ, prepared for the US Environmental Protection Agency," 1970.
[18] H. Sumitomo and N. L. Nemerow, "Pollution Index for Benefit Analysis," Syracuse Univ. Dep. Civ. Eng. Syracuse, NY, 1969.
[19] N. L. Nemerow, Scientific stream pollution analysis. McGraw-Hill, 1974.
[20] A. Lumb, T. C. Sharma, and J.-F. Bibeault, "A review of genesis and evolution of water quality index (WQI) and some future directions," Water Qual. Expo. Heal., vol. 3, no. 1, pp. 11–24, 2011.
[21] M. I. Ali, G. D. Dirawan, A. H. Hasim, and M. R. Abidin, "Detection of Changes in Surface Water Bodies Urban Area with NDWI and MNDWI Methods," Int. J. Adv. Sci. Eng. Inf. Technol., vol. 9, no. 3, pp. 946–951, 2019.
[22] M. I. Ali, A. H. Hasim, and M. R. Abidin, "Monitoring the Built-up Area Transformation Using Urban Index and Normalized Difference Built-up Index Analysis," Int. J. Eng., vol. 32, no. 5, pp. 647–653, 2019.
[23] A. J. Patandean and A. H. Hasim, "Geophysical Exploration in Hot Springs Region Soppeng Regency, Indonesia," J. Ser. J. Phys. Conf. Ser., vol. 1028, 2018.
[24] N. L. Nemerow and A. Dasgupta, "Industrial and hazardous waste treatment," 1991.
[25] S. Tyagi, B. Sharma, P. Singh, and R. Dobhal, "Water quality assessment in terms of water quality index," Am. J. Water Resour., vol. 1, no. 3, pp. 34–38, 2013.
[26] D. Haldar, S. Halder, P. Das, and G. Halder, "Assessment of water quality of Damodar River in South Bengal region of India by Canadian Council of Ministers of Environment (CCME) Water Quality Index: a case study," Desalin. Water Treat., vol. 57, no. 8, pp. 3489–3502, 2016.
[27] Y. Zhao, Y. Qin, L. Zhang, B. Zheng, and Y. Ma, "Water quality analysis for the Three Gorges Reservoir, China, from 2010 to 2013," Environ. Earth Sci., vol. 75, no. 17, p. 1225, 2016.
[28] R. K. Regmi and B. K. Mishra, "Use of water quality index in water quality assessment: A case study in the Metro Manila," 2016.
[29] A. O. Oke, A. Y. Sangodoyin, and T. Omodele, "Classification of river water quality in Ogun and Ona River Basins, Nigeria using CCME framework: Implications for sustainable environmental management," Cogent Environ. Sci., vol. 3, no. 1, p. 1295696, 2017.
[30] L. H. Rachedi and H. Amarchi, "Assessment of the water quality of the Seybouse River (north-east Algeria) using the CCME WQI model," Water Sci. Technol. Water Supply, vol. 15, no. 4, pp. 793–801, 2015.
[31] A. Louhi, A. Hammadi, and M. Achouri, "Determination of some heavy metal pollutants in sediments of the Seybouse River in Annaba, Algeria," Air, Soil Water Res., vol. 5, p. ASWR-S10081, 2012.
[32] S. H. Al-Shujairi, "Develop and apply water quality index to evaluate water quality of Tigris and Euphrates Rivers in Iraq," Int. J. Mod. Eng. Res., vol. 3, no. 4, pp. 2119–2126, 2013.
[33] A. Sargaonkar and V. Deshpande, "Development of an overall index of pollution for surface water based on a general classification scheme in Indian context," Environ. Monit. Assess., vol. 89, no. 1, pp. 43–67, 2003.
[34] S. V. Mohan, P. Nithila, and S. J. Reddy, "Estimation of heavy metals in drinking water and development of heavy metal pollution index," J. Environ. Sci. Heal. Part A, vol. 31, no. 2, pp. 283–289, 1996.
[35] B. Backman, D. Bodiš, P. Lahermo, S. Rapant, and T. Tarvainen, "Application of a groundwater contamination index in Finland and Slovakia," Environ. Geol., vol. 36, no. 1–2, pp. 55–64, 1998.
[36] G. S. Bilotta and R. E. Brazier, "Understanding the influence of suspended solids on water quality and aquatic biota," Water Res., vol. 42, no. 12, pp. 2849–2861, 2008.
[37] J. R. Gray, Comparability of suspended-sediment concentration and total suspended solids data, no. 0–4191. US Dept. of the Interior, US Geological Survey, 2000.
[38] D. J. Lewis, K. W. Tate, R. A. Dahlgren, and J. Newell, "Turbidity and total suspended solid concentration dynamics in streamflow from California oak woodland watersheds," in In: Standiford, Richard B., et al, tech. editor. Proceedings of the Fifth Symposium on Oak Woodlands: Oaks in California's Challenging Landscape. Gen. Tech. Rep. PSW-GTR-184,

Albany, CA: Pacific Southwest Research Station, Forest Service, US Department of Agriculture: 107-118, 2002, vol. 184.

[39] F. J. H. Mackereth, “Some methods of water analysis for limnologists,” Sci. Publ. (Freshwater Biol. Assoc. no. 21, 1963.

[40] V. Novotny, H. Olem, and A. Olness, Water quality: Prevention, identification, and management of diffuse pollution. New York, United States: Van Nostrand Reinhold, 1994.

[41] T. H. Y. Tebbutt, Principles of water quality control., no. Ed. 4. Pergamon Press, 1992.