Journal of Natural Sciences and Mathematics Research
J. Nat. Scien. & Math. Res. Vol. 11 No. 2 (2025) 174-182
ISSN: 2460-4453 (Online); 2614-6487 (Printed)
Available online at http://journal.walisongo.ac.id/index.php/jnsmr

Evaluating surface water and groundwater quality parameters in the Karst Mining Zone, Gunungkidul for environmental risk mitigation

Yudistira Zein Sanadha[1], Haerul Anwar[1*], Faisal M. Jasin[1], Bayu Achil Sadjab[2]
[1] Department of Environmental Engineering, Institut Kesehatan dan Teknologi PKP DKI Jakarta, Indonesia
[2] Department of Physics, Halmahera University, Indonesia

Corresponding author's e-mail: anwar.haerul90@gmail.com

ABSTRACT
This study aims to characterize the physical, chemical, and microbiological water parameters of the Oya River (Bleberan Playen) and groundwater in the CV Kusuma Arga monitoring well, located in the white stone mining zone, Ponjong District, Gunungkidul Regency, Special Region of Yogyakarta, Indonesia. The importance of this research is driven by the lack of comprehensive water quality data in active karst mining areas and the potential environmental and health risks associated with contamination. Parameters tested included temperature, electrical conductivity (EC), total dissolved solids (TDS), turbidity, pH, nitrite, ammonia, chloride, sulfate, detergents, dissolved iron, dissolved lead, dissolved copper, dissolved cadmium, dissolved manganese, dissolved nickel, total coliform, and fecal coliform. Testing methods referred to the Indonesian National Standard (SNI) and Standard Methods, including the use of atomic absorption spectrophotometry (AAS) for heavy metal analysis and the membrane filter method for microbiology. The test results showed that most physical and chemical water parameters from both sources met the relevant quality standards. For example, the well water temperature of 27°C and well water pH of 6.9 were both declared to be by standards. However, analysis showed lead concentrations (0.1 mg/l in the river) and cadmium (0.010 mg/l in the river) exceeding World Health Organization (WHO) recommendations for drinking water, although initially categorized as "appropriate". Furthermore, total coliform (3000-5000 MPN/100ml) and fecal coliform (4000-4500 MPN/100ml) concentrations in both samples were very high, clearly indicating a health-risking fecal contamination, despite also being declared "appropriate" in the report. The role of Environmental Engineering science is crucial in sample collection, laboratory analysis, and interpretation of this data. This study contributes to the understanding of water quality in areas affected by mining activities and emphasizes the need for further evaluation for sustainable environmental management.

Keywords:
Water Quality; Groundwater; Mining; Microbiological Contamination; Oya River Gunungkidul

Introduction

Water is an essential compound (H_2O) that is irreplaceable in the life of living beings on earth, playing a vital role as a universal solvent and supporting all biological activities. The availability of clean water is the foundation for public health and sustainable development (UNESCO, 2023; Biswas & Islam, 2021). However, in many regions, water resources face significant pressure due to anthropogenic activities. Increased population and urbanization have increased the water demand, while at the same time, industrial and domestic activities often contribute to water quality degradation through the release of various wastes. Water contamination can originate from organic waste (household, agriculture), inorganic waste (heavy metals, minerals from mining), and pathogenic microorganisms (Rahman et al., 2023; Duru et al., 2022).

Gunungkidul Regency, Special Region of Yogyakarta, is a region with unique geographical characteristics dominated by karst rocks and mining activities, especially white stone (limestone). The extraction of mineral resources, although contributing to the local economy, has the potential to significantly impact the environment, including the quality of water resources

(Chen et al., 2022). Mining operations in karst areas, in particular, can affect surface and groundwater through mine runoff, erosion, and hydrogeological alteration, which can increase suspended solids, heavy metal concentrations, and alter water pH. The complex underground drainage system in karst topography allows pollutants to spread rapidly and widely, making water quality assessment in this area crucial and challenging (Malard & Gibert, 2022). The Oya River, as one of the main rivers in this region, and groundwater wells around the mining area, are important water sources for local communities for domestic and agricultural purposes.

The importance of this research is grounded in several critical factors. First, current comprehensive data on water quality in the Oya River and wells in the Gunungkidul mining zone is still limited, especially when comparing both types of water sources comprehensively. The complex karst hydrogeological conditions in Gunungkidul, characterized by an intricate subsurface drainage system, make assessing mining impacts on water quality challenging and necessitate targeted investigation (Setiabudi et al., 2021). Second, identifying and monitoring water quality parameters affected by mining activities is essential for environmental and health risk mitigation. For example, exposure to heavy metals from mining waste, even in low concentrations, can cause chronic health problems in the long term such as kidney damage and neurological problems. Research on the impact of heavy metals from mining in tropical areas, such as that conducted by Prusty et al., 2025 in India and by Abaasa et al., 2024 in Africa, shows similar contamination patterns and health risks that need to be monitored. Third, microbiological contamination issues are often overlooked in the context of mining and rural areas, even though the presence of fecal coliform indicates acute health risks due to fecal contamination from poor sanitation or surface runoff. WHO explicitly recommends the absence of *Escherichia coli* and fecal coliform in drinking water due to the potential spread of infectious disease (WHO, 2022).

Water quality characterization generally involves measuring physical, chemical, and microbiological parameters. Global studies consistently highlight temperature as an important indicator affecting the physical-chemical properties of water, including gas solubility and biochemical reaction rates. Water pH, which reflects its acidity or alkalinity, is a fundamental parameter influencing pollutant toxicity and the survival of aquatic organisms. Strict drinking water quality standards in various countries, such as those set by the World Health Organization (WHO) or the Environmental Protection Agency (EPA) in the United States, often require a neutral pH range (6.5-8.5) to minimize the risk of pipe corrosion and health irritation. Electrical conductivity (EC) is widely used as a rapid indicator of total dissolved ions (TDS) and water purity. Increased electrical conductivity often correlates with contamination from agricultural and urban activities, as well as runoff from mining areas that release dissolved minerals and salts. Similarly, turbidity—an indicator of water clarity—is important because suspended particles can reduce visual quality and protect pathogenic microorganisms from disinfection, as noted in the latest WHO water quality guidelines (WHO, 2022).

The presence of heavy metals such as Iron (Fe), Lead (Pb), and Cadmium (Cd) is a significant global concern, especially in mining areas. Pb and Cd are highly toxic and bioaccumulative non-essential contaminants that can cause neurological, kidney, and carcinogenic disorders in humans. Various studies have shown that heavy metal concentrations in waters near mining sites often exceed safe limits set by international regulatory bodies. Analysis of dissolved metals is usually performed using atomic absorption spectrophotometry (AAS), which is a gold standard technique in laboratories worldwide due to its accuracy and sensitivity in detecting low concentrations.

The microbiological aspect of water quality is very important for public health. Bacterial indicators such as Total Coliform and Fecal Coliform (including *Escherichia coli*) are universally used to detect fecal contamination, which indicates the probable presence of pathogens causing gastrointestinal diseases. The presence of *E. coli* and Fecal Coliform in drinking water, even in very small amounts, is a strong indicator of fecal contamination and signifies a serious health risk to consumers; therefore, water that is fit for consumption must not contain either of these pathogenic bacteria at all (WHO, 2022). Research in Indonesia and China also highlights the dangers of fecal coliform contamination in water used for consumption and its impact on public health (Syafruddin et al., 2022; Ma et al., 2023). Testing methods such as membrane filtration or Most Probable Number (MPN) are global standards for detecting these bacteria. In summary, water quality characterization requires a holistic approach involving various parameters. Although testing methods have been internationally standardized, the interpretation of results must always refer to relevant quality standards and consider potential public health risks, especially in areas with high environmental pressure such as mining areas. This study contributes to the current understanding of water quality in a geologically and anthropogenically unique region, and underlines the need for further studies for sustainable water quality monitoring in mining areas.

Methods

This study used a quantitative descriptive design, focusing on the measurement and analysis of physical, chemical, and microbiological parameters in water samples. The research was conducted at the Environmental Laboratory Technical Implementation Unit (UPT) of the Gunungkidul District Environmental Agency. Water samples were collected from two primary locations: the Oya River in Bleberan Playen, and a monitoring well owned by CV Kusuma Arga, situated within a limestone mining area in Ponjong District, Gunungkidul Regency (Figure 1).

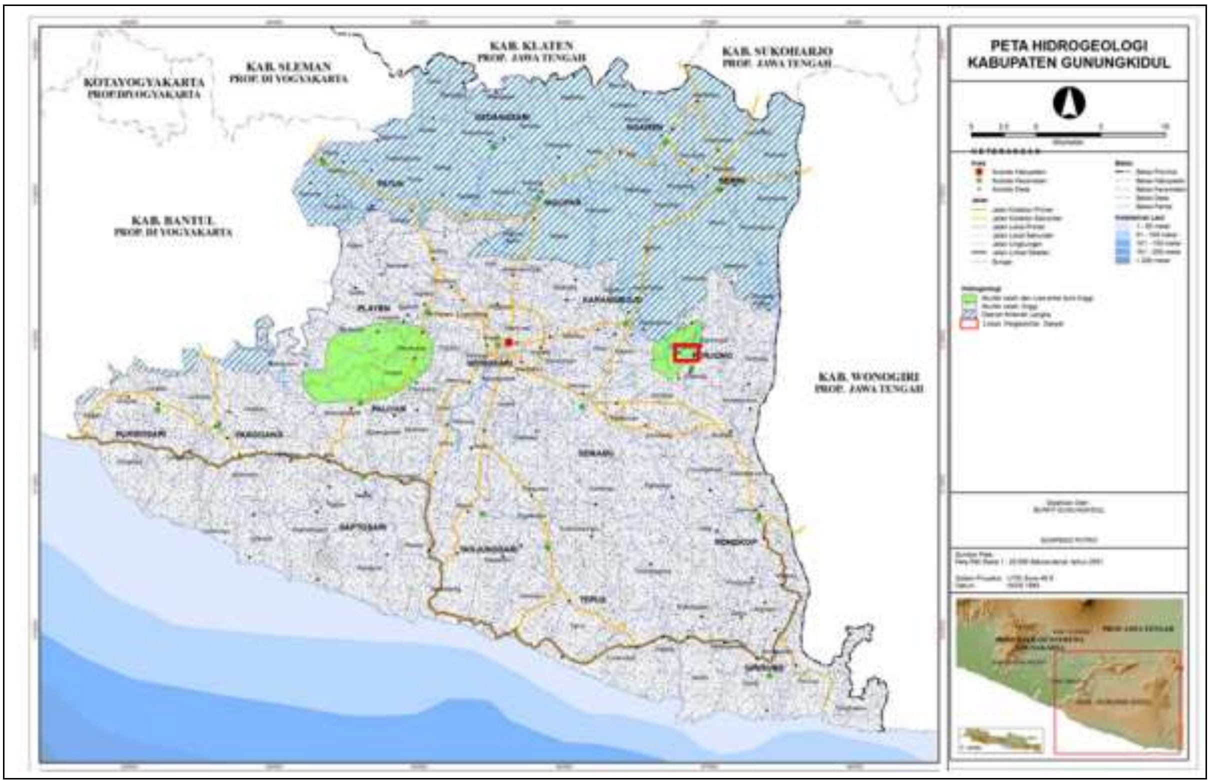

Figure 1. Research site map modified of the hydrological map of Gunungkidul Regency, Yogyakarta [BAPPEDA Gunungkidul, 2010].

The data collection and analysis period was conducted from October 1 to December 31, 2024. The initial procedure involved registering the samples at the laboratory's administrative division, followed by the documentation of sample identities and verification of testing requirements to ensure sample viability prior to analysis. The research methodology utilized a quantitative descriptive approach, employing a conductimeter for physical parameter analysis, flame atomic absorption spectrophotometry (SSA) for the measurement of heavy metal concentrations, a TDS meter for chemical parameter testing, and microbiological assays to quantify microbiological indicator content. Water quality parameter testing was carried out by referring to national and international standard methods to ensure data validity and comparability. Temperature was measured using a water thermometer, in accordance with Indonesian National Standard (SNI) 06-6989.23, 2005 . pH measurements were carried out using a pH meter, the working principle of which is to measure the potential difference between a glass electrode and a reference electrode, which is then converted into a pH value (SNI 06-6989.11, 2004). Electrical Conductivity (EC) was measured using a conductimeter, with the principle of EC measurement using a conductimeter electrode and potassium chloride (KCl) solution as a standard solution at 25°C (SNI 06-6989.1, 2004). Turbidity was determined using a nephelometer, according to SNI 06-6989.25, 2005. The maximum turbidity that can be tested is 40 NTU; if it exceeds this value, the sample must be diluted first. The procedure includes optimizing the nephelometer, inserting a standard turbidity suspension (e.g., 40 NTU) into the tube, and adjusting the instrument to show the turbidity reading of the standard solution. For Total Dissolved Solids (TDS), measurements were carried out using a TDS meter, where water is placed in a clean container, the TDS meter is then immersed, and the results are displayed in ppm (Parts Per Million).

Analysis of dissolved metal levels (Fe, Pb, Cd) was performed using flame atomic absorption spectrophotometry (AAS), a widely recognized technique for detecting metals at low concentrations. For Iron (Fe), the method refers to SNI 6989.4, 2009 ; for Lead (Pb) to SNI 6989.8, 2009 ; and Cadmium (Cd) to SNI 6989.16, 2009. The basic principle of AAS is that metal analytes in an air-acetylene flame are converted into their atomic form and absorb electromagnetic radiation energy from a cathode lamp, with the amount of absorption directly proportional to the analyte concentration. General procedures for metal testing include sample homogenization, addition of concentrated HNO_3 for destruction, heating, filtration (if necessary), and absorption measurement.

Microbiological testing for Total Coliform was performed using selective and differential microbiological media with a membrane filter (m-Endo LES or m-Endo MF), according to Standard Methods, 9222B. This procedure includes selecting an ideal sample size to produce 20 to 80 total coliform colonies and a maximum of 200 total colonies. If the filtered sample volume is less than 10 mL, sterile rinse water needs to be added to the funnel before filtration. Sterile filtration units were used at the beginning of each filtration series, with UV light sanitation not considered full sterilization. Quality control (QC) for sterility and contamination was performed at the beginning and end of the filtration series by filtering diluent water or sterile rinse water. Sample filtration was performed by shaking the sample and rinsing the funnel before carefully transferring the membrane to the media to avoid air bubbles. Incubation was carried out with the petri dish inverted for 22-24 hours after incubation. Confirmation of typical and atypical coliforms requires swabbing the entire membrane surface or inoculating each colony on confirmation media such as Lauryl Tryptose single strength and BGLB.

Results and Discussions

Water quality testing of samples from the Oya River and the CV Kusuma Arga monitoring well in Gunungkidul showed that most physical and chemical parameters were within the ranges initially classified as appropriate. These parameters include temperature, electrical conductivity (EC), total dissolved solids (TDS), turbidity, pH, as well as various concentrations of dissolved metals such as Iron, Copper, Manganese, and Nickel, and also chemical parameters such as Nitrite, Ammonia, Chloride, Sulfate, and Detergents. However, microbiological test results for Total Coliform and Fecal Coliform showed high values in both water sources. The detailed test results for physical, chemical, and microbiological parameters in the Oya River and CV Kusuma Arga monitoring well water samples are presented in Table 1.

Table 1. Observation Results of Oya River and CV Kusuma Arga Monitoring Well Water Sample Testing

Sample Origin		Test Result			
Parameter	Unit	S. River (Oya, Bleberan	S. Monitoring Well CV Kusuma Arga	WHO Standart and SNI	Appropriate and Not Appropriate
Physical					
Temperature	°C	30°	27°	No specific limit (depends on climate)	Appropriate
DHL	μs/cm	539	532	20–1500	Appropriate
TDS	mg/l	242,5	250	50–150	Appropriate
Turbidity	NTU	1	1	< 5 NTU	Appropriate
Chemical					
pH		6,4	6,9	6.5 – 8.5	Appropriate
Nitrite	mg/l	0.0002	0,006	3	Appropriate
Ammonia	mg/l	0,3	0,1	1. 5	Appropriate
Chloride	mg/l	8,48	7	< 250	Appropriate
Sulfate	mg/l	8.50	8,46	< 500	Appropriate
Detergent	mg/l	0,17	0,15	< 0.5	Appropriate
Dissolved Iron	mg/l	0,2	0,3	< 2	Appropriate
Dissolved Lead	mg/l	0,1	0,0012	0.01	S. River Oya Not Appropriate
Dissolved Copper	mg/l	0,006	0,004	2	Appropriate
Dissolved Cadmium	mg/l	0,010	0,008	0.003	Not Appropriate
Dissolved Manganese	mg/l	0,009	0,003	< 0.08	Appropriate
Dissolved Nickel	mg/l	0,003	0,002	0.07	Appropriate
Microbiological					
Total coliform	MPN/ 100ml	5.000	3.000	0	Not Appropriate
Fecal coliform	MPN/ 100ml	4.500	4.000	0	Not Appropriate

Based on the results presented in Table 1, the well water temperature was 27°C, while the river water temperature was 30°C. A temperature of 27°C for well water is in accordance with SNI 06-6989.23:2005, which sets the normal water temperature at around 8°C from room temperature (27°C). Stable temperature conditions are important because they influence oxygen solubility and biochemical reaction rates in aquatic systems. Research by Appels et al. (2020) emphasizes that high temperatures can reduce dissolved oxygen solubility, which negatively impacts aquatic ecosystems and self-purification processes. The relatively stable temperature in well water indicates protection from atmospheric fluctuations, while a slight increase in the river may be influenced by ambient temperature or flow characteristics.

Electrical Conductivity (EC) measurements showed 539 μS/cm for river water and 532 μS/cm for well water. These values indicate moderate levels of dissolved ions and were initially classified as appropriate based on the preliminary evaluation. EC measures the ability of water to conduct electricity, which is directly related to the concentration of dissolved ions. Comparison with research in other mining areas shows a wide variation. For example, a study by Li et al. (2021) in a coal mining area in China showed much higher EC in waters contaminated by mine runoff (reaching thousands of μS/cm), indicating the release of metal ions and dissolved salts. The EC found in Gunungkidul is relatively lower, indicating a more moderate level of mineralization, although monitoring is still needed to prevent undesirable increases that could indicate pollution.

The Total Dissolved Solids (TDS) concentration of river water was 242.5 mg/l and well water was 250 mg/l. The TDS value of 250 mg/l for well water is declared in accordance with the standard concentration of particles in solution (<300 mg/l) based on IK 6.4/A-012. TDS includes various types of dissolved solids such as minerals, salts, and organic compounds. Research by Sari and Huljana (2019) on well water at a landfill showed highly variable TDS values, some exceeding 1000 mg/l, which are much higher than the results of this study. This indicates that although there are mining activities, the contribution of dissolved solids from natural sources or other anthropogenic contamination may still be dominant or well controlled in this study area compared to heavily polluted locations.

Both water samples showed a turbidity value of 1 NTU, which means the water is quite clear and in accordance with SNI. Turbidity is a parameter that indicates how clear the water is by measuring the amount of light that can pass through it. This value is substantially lower than turbidity levels commonly reported in urban rivers or erosion-prone areas, which can reach tens to hundreds of NTU, as documented in the Citarum watershed, Indonesia (Susanti et al., 2021). The low turbidity in the Oya River and wells in Gunungkidul indicates relatively good land management around the water source or low activity that causes particle suspension, which can also increase disinfection effectiveness.

The pH value of river water is 6.4 and well water is 6.9. The pH of well water (6.9) is within the safe range recommended for safe water use (6.5-8.5) according to SNI 6989.11-2019, and is declared "appropriate". The pH of river water (6.4) is slightly below the lower limit of the safe range (6.5-6.7). A study by Putri et al. (2020) on river water contaminated with acid mine drainage often showed very low pH (below 4), which did not occur in the Oya River. The pH difference between well water and river water may indicate the influence of local geology or interaction with different surface water, but both are still within an acceptable range for freshwater ecosystems.

The concentration of dissolved Iron (Fe) in river water is 0.2 mg/l and in well water is 0.3 mg/l. These levels are stated to be "appropriate". Although iron is a natural element, concentrations exceeding standards can cause aesthetic problems (color, taste) and the growth of iron bacteria. Research by Adeyeye et al. (2021) in Africa showed much higher Fe levels (up to several mg/l) in groundwater sources affected by mining activities, indicating that Fe levels in this study area are relatively controlled compared to extreme cases. The dissolved Lead (Pb) obtained had very low concentrations in well water (0.0012 mg/l) and 0.1 mg/l in river water. Although stated as "appropriate," the presence of Pb, even in low concentrations, is a global concern due to its toxicity. WHO recommends a Pb limit for drinking water of 0.01 mg/l. The value of 0.1 mg/l in river water exceeds the WHO recommendation tenfold, indicating a source of lead contamination that needs to be investigated. A study by Pan et al. (2020) on heavy metal pollution in mining-affected rivers in China also highlighted Pb as one of the main pollutants.The dissolved Cadmium (Cd) concentration in river water is 0.010 mg/l and in well water is 0.008 mg/l. Although declared "appropriate" in the report, Cd is a highly toxic heavy metal. The WHO recommended limit for Cd in drinking water is 0.003 mg/l. The concentrations found in both samples exceed this limit, indicating a potential health risk despite being declared "appropriate" in the report. This is similar to findings in several mining locations in developing countries, where Cd contamination is a persistent problem. Other chemical parameters such as Nitrite (0.0002 mg/l river, 0.006 mg/l well) , Ammonia (0.3 mg/l river, 0.1 mg/l well) , Chloride (8.48 mg/l river, 7 mg/l well) , Sulfate (8.50 mg/l river, 8.46 mg/l well) , Detergent (0.17 mg/l river, 0.15 mg/l well) , dissolved Copper (0.006 mg/l river, 0.004 mg/l well) , dissolved Manganese (0.009 mg/l river, 0.003 mg/l well) , and dissolved Nickel (0.003 mg/l river, 0.002 mg/l well) also showed values declared "appropriate".

For microbiological parameters, Total Coliform results showed 5000 MPN/100ml for river water and 3000 MPN/100ml for well water. These values are substantially higher than recommended limits. In comparison, the WHO (https://www.google.com/search?q=2022) standard for drinking water is 0 Total Coliform per 100 mL. Although categorized as "appropriate" in the report, this interpretation may refer to different standards (e.g., for raw water or non-drinking purposes). This high contamination indicates a sanitation failure or surface infiltration into the water source. Furthermore, the concentration of Fecal Coliform was 4500 MPN/100ml for river water and 4000 MPN/100ml for well water. These elevated levels indicate recent fecal contamination, posing a serious health risk if the water is consumed without treatment. International standards for drinking water strictly prohibit the presence of fecal coliform. These findings far exceed globally accepted limits, indicating that the water is not suitable for drinking without adequate treatment (e.g., disinfection). Research by Syafruddin et al. (2022) in urban rivers in Indonesia and Ma et al. Ma et al. (2023) in rural water sources in China also found significant levels of fecal coliform contamination, confirming that this problem is common in many areas and requires serious public health intervention.

Overall, although most physical and chemical parameters were within accepted limits, the high concentrations of total coliform and fecal coliform in both water sources indicate significant microbiological contamination. This suggests the need for water treatment measures (e.g., disinfection, filtration) to ensure water safety for public health, especially if used for domestic purposes. In addition, lead and cadmium concentrations exceeding WHO recommendations in river water need special attention in the context of mining impacts.

Conclution

Based on a comprehensive analysis of water quality from the Oya River and groundwater in the white stone mining zone of Gunungkidul Regency, it can be concluded that most of the physical and chemical parameters tested meet the relevant standards and are declared safe in the report. This includes temperature, electrical conductivity (EC), total dissolved solids (TDS), turbidity, pH, as well as concentrations of nitrite, ammonia, chloride, sulfate, detergents, dissolved iron, dissolved copper, dissolved manganese, and dissolved nickel. However, there are significant concerns regarding some dissolved metals such as Lead and Cadmium in river water, which show concentrations exceeding international drinking water recommendations, although initially categorized as "appropriate" in the preliminary report. The most crucial aspect is the microbiological parameters; Total Coliform (3000-5000 MPN/100ml) and Fecal Coliform (4000-4500 MPN/100ml) showed very high concentrations in both water sources. The presence of significant Fecal Coliform indicates serious fecal contamination and suggests that the water is unsafe for consumption without adequate treatment, although in the preliminary report it was also categorized as "appropriate". Therefore, risk mitigation and further water treatment measures are needed to ensure the safety and sustainability of water resources in this mining area.

Acknowledgments

The authors would like to thank all reviewers who have provided suggestions to improve this article

Conflicts of interest

The authors declare no conflict of interest concerning the publication of this article. The authors also confirm that the data and the article are free of plagiarism.

References

Abaasa CN, Ayesiga S, Lejju JB, Andama M, Tamwesigire IK, Bazira J, et al. (2024). Assessing the quality of drinking water from selected water sources in Mbarara city, Southwestern Uganda. PLoS ONE 19(3): e0297794. https://doi.org/10.1371/journal.pone.0297794

Adeyeye, A. O., Akinyele, A. A., & Olagbaju, S. D. (2021). Physico-chemical and heavy metal assessment of groundwater from selected communities in Oyo State, Nigeria. *Journal of Water and Environmental Sciences*, 3(1), 1-10.

Afandi, I., and Amdani, K. (2018). Design and Construction of a Drinking Water Feasibility Detector for Refill Drinking Water Depots (AMIU) Based on AT89S51 Microcontroller and LCD Using Infrared and Photodiode as Indicators. Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Medan, Indonesia. Medan: Universitas Negeri Medan.

Appels, W. M., Hu, C., & Cai, C. (2020). The role of water temperature in river health assessment: A case study of the Yellow River Basin, China. *Environmental Research Letters*, 15(11), 114022.

Aryani, T. (2017). Analysis of Packaged Drinking Water Quality (AMDK) in Yogyakarta Reviewed from Physical and Chemical Water Parameters. *Media Ilmu Kesehatan*, Vol.6, No.1. Azwar, S. (2016). *Research Methods*. Yogyakarta: Pustaka Pelajar.

BAPPEDA Kabupaten Gunungkidul. (2010). Rencana Tata Ruang Wilayah (RTRW) Kabupaten Gunungkidul tahun 2010–2030. Gunungkidul (ID): Badan Perencanaan Pembangunan Daerah Kabupaten Gunungkidul.

Chen, J., Li, R., Jiang, Y., Hu, K., Xu, J., Liu, H., ... & Zhang, Z. (2022). Comprehensive assessment of water quality in mining areas: a case study in Southwest China. *Environmental Science and Pollution Research*, 29(45), 68131-68142.

Duru, E. C., Nwufo, B. C., & Nzeh, C. A. (2022). Microbiological quality of drinking water sources in selected rural communities of Imo State, Nigeria. *Journal of Applied Sciences and Environmental Management*, 26(3), 447-453.

Li, J., Zeng, X., Zhou, Y., Cao, Z., Yu, G., & Sun, Y. (2021). Hydrochemical characteristics and controlling factors of groundwater in a coal mining area: A case study in China. *Environmental Pollution*, 277, 116812.

Liu, X., Wang, Q., Li, J., & Li, Y. (2021). Impact of Coal Mining on Groundwater Quality and Health Risk Assessment in Northern China. *Journal of Cleaner Production*, 291, 125916.

Ma, J., Wang, Z., Zhang, J., Wu, W., & Li, M. (2023). Microbial contamination in drinking water sources and its implications for public health in rural areas: A review. *Science of The Total Environment*, 858, 160012.

Malard, F., & Gibert, J. (2022). Karst ecosystems: functions and services. *Hydrogeology Journal*, 30(1), 1-18.

National Standardization Agency. (2004). SNI 06-6989.9-2004 Water and wastewater Part 14: Test method for nitrite (NO2-N) by spectrophotometry, (2), 13. https://doi.org/SNI 06-6989.9-2004. Accessed on December 28, 2017.

Pan, X., Li, C., Ma, X., Ma, Y., & Yang, Y. (2020). Heavy metals in river sediments of a typical mining area in Southwest China: Pollution assessment and source apportionment. *Environmental Pollution*, 262, 114309.

Prusty, P., Mohakud, S.K., Mandal, A.R., Parray, K.A. and Farooq, S.H. (2025), Assessment of Heavy Metal Contaminations in Groundwater and Surface Water Resources of Sukinda Valley, Odisha, India. *Geological Journal*. https://doi.org/10.1002/gj.5227.

Putri, A. T., Arisandy, D., & Pratiwi, D. (2020). Analysis of River Water Quality Due to Coal Mining Waste in Jambi Province. *Jurnal Ilmu Lingkungan*, 18(3), 566-574

Rahman, S. M., Hossain, M. A., Islam, M. T., & Ali, M. Y. (2023). Water quality assessment of rural drinking water sources and health risk in Bangladesh. *Environmental Science and Pollution Research*, 30(2), 3345-3356.

Regulation of the Minister of Health of the Republic of Indonesia, Number 32, 2017.

Rukandar, D. (2017). Water Pollution: Definition, Causes, and Impacts. *Mimbar Hukum*, 21(1), pp. 23–34.

Sa'idi, M. M. (2020). Analysis of Drinking Water Quality Parameters (pH, ORP, TDS, DO, and Salinity) in Packaged Drinking Water (AMDK) Products. pp. 1–70.

Sari, M. and Huljana, M. (2019). Analysis of Odor, Color, TDS, pH, and Salinity of Well Water at Landfill. *ALKIMIA : Jurnal Ilmu Kimia dan Terapan*, 3(1), pp. 1–5. doi: 10.19109/alkimia.v3i1.3135.

Setiabudi, D. H., Suryanegara, S. M., & Hasyim, A. W. (2021). Hydrogeological Characterization and Groundwater Quality in the Gunungsewu Karst Area, Gunungkidul, Yogyakarta. *Jurnal Geologi Indonesia*, 16(3), 209-220.

Sharma, S., & Kaur, P. (2021). Water pollution and its impact on human health: A review. *Environmental Science and Pollution Research*, 28(40), 56093-56108.

Sugiyono. (2015). *Educational Research Methods (Quantitative, Qualitative, R&D Approaches)*. Bandung: Alfabeta.

Susanti, F., Pratiwi, N., & Rosidin, C. (2021). Analysis of Downstream Citarum River Water Quality Based on Physical and Chemical Parameters. *Jurnal Ilmu Lingkungan*, 19(2), 221-230. Syafruddin, S., Sari, M., & Fitri, S. (2022). Study of Microbiological Quality of Refill Drinking Water in Banda Aceh City. *Jurnal Kesehatan Lingkungan Aceh*, 1(2), 1-8.

Tika, P. (2006). *Budaya Organisasi dan Peningkatan Kinerja Perusahaan*. Jakarta: Bumi Aksara.

Ullah, A., Faheem, M., Muhammad, A., & Ahmad, N. (2022). Heavy metal contamination in groundwater and associated health risks in mining areas: A systematic review. *Environmental Geochemistry and Health*, 44(8), 2821-2840.

Wang, P., Yang, C., Zhang, Y., & Li, R. (2024). Health risk assessment of heavy metals in drinking water sources impacted by mining activities: A case study in Southwest China. *Environmental Science and Pollution Research*, 31(1), 1-13.

World Health Organization. (2022). *Guidelines for drinking-water quality: fourth edition incorporating the first addendum and second revision*. World Health Organization.

Zhang, J., Li, Y., Wu, X., & Wang, H. (2023). Environmental risk assessment of heavy metals in groundwater from a typical mining area in China. *Ecotoxicology and Environmental Safety*, 255, 114867.