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Water Physicochemical Impacts of Sidoarjo Mud Reservoir on Metal Degradation and Environmental Risks

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Keywords

Anoxia; Lapindo mudflow; Metal degradation; Porong River; Water quality

Abstract

Environmental monitoring in the Lapindo mudflow area has primarily focused on pollution assessment, with limited attention to the relationship between extreme water quality conditions and the corrosive environment affecting metallic infrastructure. This study evaluated physicochemical water quality in the Porong River mud reservoir to assess its potential influence on metal degradation. Water samples were collected in triplicate from eight strategically selected sites using stratified random sampling and analyzed using standard physicochemical methods. Severe spatial variations were observed, with Total Suspended Solids reaching 98,910 mg/L, dissolved oxygen depleted to 0.0 mg/L, and Chemical Oxygen Demand peaking at 4,182 mg/L, indicating highly polluted and anoxic conditions. The combination of elevated suspended solids, organic pollutants, and oxygen depletion creates an aggressive electrolytic environment that may accelerate corrosion processes. These findings provide new insights into corrosion-related environmental conditions in mud-volcanic aquatic systems and support environmental monitoring and infrastructure management in long-term mudflow-affected areas.

INTRODUCTION

Water quality deterioration in mud-volcanic environments has become a major environmental concern because it threatens aquatic ecosystems, infrastructure durability, and environmental sustainability. Extreme physicochemical conditions, including elevated suspended solids, organic pollutants, oxygen depletion, and aggressive ions, enhance the electrolyte characteristics of water and accelerate the electrochemical corrosion of metallic materials (Li et al., 2024). Corrosion further releases dissolved metals such as Fe^{2+}, Zn^{2+}, Cu^{2+}, and Pb^{2+} into aquatic environments, contributing to secondary pollution and increasing ecological risks through repeated contamination cycles (Adiyaksa et al., 2023; Sunardi et al., 2020). Consequently, understanding the interactions between water quality and corrosion processes is essential for protecting the environment and ensuring the long-term resilience of infrastructure.

The Lapindo mud eruption in Sidoarjo Regency, East Java Province, Indonesia, has continued since May 2006 and remains one of the world's longest-lasting active mud-volcanic events. To protect surrounding communities and infrastructure, large volumes of mud have been diverted into the Porong and Aloo Rivers. Previous studies reported that the mud containment ponds contain hazardous compounds, particularly phenol (Sufyan et al., 2025),

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while mitigation strategies have emphasized controlling pollutant transport from the eruption source to receiving waters (Islam et al., 2025). Phenol is recognized as a toxic, persistent, and poorly biodegradable organic pollutant, making it a critical parameter in environmental risk assessment (Bibi et al., 2023). Previous studies in Indonesia have also reported phenol concentrations ranging from 0.004 to 0.05 mg/L in groundwater surrounding industrial areas. (Widodo, 2022), indicating its potential persistence in aquatic environments.

A growing body of research has documented the environmental impacts of the Lapindo mudflow on groundwater and surface water quality. Groundwater investigations revealed elevated concentrations of COD, BOD, phenol, H_2S, and heavy metals, particularly in locations adjacent to the mud containment ponds and densely populated residential areas, resulting in water quality unsuitable for drinking purposes (Adiyaksa & Savichev, 2023; Shofiyah et al., 2025; Yanti et al., 2025). Similarly, groundwater quality assessment using the Pollution Index (IP) and National Sanitation Foundation Water Quality Index (NSF-WQI) classified the affected groundwater as lightly to moderately polluted (Islam et al., 2025). Surface water quality in the Porong River also deteriorated near mud disposal areas, although several downstream locations remained suitable for aquaculture (Oulyscya & Harianto, 2019). Collectively, these studies demonstrate that the Lapindo mudflow has profoundly altered the physicochemical properties of the surrounding aquatic environment.

Previous studies have primarily emphasized pollution assessment, groundwater contamination, ecological impacts, and environmental health risks. However, little attention has been given to how extreme hydrochemical conditions collectively create corrosive aquatic environments capable of accelerating metallic infrastructure degradation. This knowledge gap is scientifically important because corrosion is a critical process linking water quality deterioration to infrastructure degradation and the release of secondary metal contaminants. However, this relationship remains insufficiently understood under the unique hydro-chemical conditions of the Lapindo mud-volcanic system. Integrating water quality assessment with corrosion-related environmental interpretation therefore enables a more comprehensive evaluation of the long-term environmental impacts associated with continuous mudflow discharge.

Accordingly, this study aims to characterize the physicochemical properties of water in the Porong River mud reservoir through the analysis of seven physical and chemical parameters measured at eight strategically selected sampling sites. Unlike previous studies that focused primarily on pollution assessment, this research integrates hydrochemical characterization with corrosion-related environmental interpretation to evaluate the potential degradation of metallic materials under extreme mud-volcanic conditions. The findings are expected to provide scientific evidence for environmental monitoring, infrastructure management, and risk assessment in aquatic environments affected by long-term mud volcanism.

RESEARCH METHODS

This study employed a spatial descriptive analytical approach to evaluate the physicochemical characteristics of water in the Porong River Mud Reservoir, Sidoarjo, and their potential implications for metallic material degradation and environmental risk. Water samples were collected from eight strategically selected locations representing upstream, discharge outlets, downstream mixing zones, and seepage areas using a stratified random sampling approach with triplicate replication (n = 3). The sampling locations comprised the upstream section of the Porong River (1), discharge channels (2, 3, and 5), downstream mixing zones (4), discharge inlets (6), and seepage sites

(7 and 8). Water sampling was conducted by the KAN-accredited Environmental Laboratory of the Mojokerto Environmental Agency in collaboration with the Sidoarjo Mudflow Control Center (PPLS). Water samples were collected using the grab sampling method following SNI 8995:2021. Samples were obtained at a depth of approximately 30 cm below the water surface using polyethylene and sterile glass containers, immediately preserved at 4 ± 2°C, and transported to the laboratory for analysis.

Physicochemical parameters, including pH, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), total dissolved solids (TDS), and temperature, were analyzed in triplicate using calibrated instruments and standardized analytical procedures in accordance with the relevant Indonesian National Standards (SNI). Detailed analytical methods for each parameter are presented in Table 1.

Data analysis consisted of descriptive statistics to evaluate the spatial variation of water quality among sampling sites. Electrolyte corrosivity was assessed using the Langelier Saturation Index (LSI), calculated as LSI = pH -pHs, where pHs represents the calcium carbonate saturation pH determined by temperature and total dissolved solids. Multivariate relationships among physicochemical parameters were further explored using Principal Component Analysis (PCA) to identify the dominant factors influencing water quality variation and potential corrosive conditions. Environmental quality was evaluated using the Pollution Index (PI) based on the Decree of the Minister of Environment No. 115 of 2003 and interpreted according to the surface water quality standards specified in Government Regulation No. 22 of 2021 (Annex VI, Class III). All statistical analyses were performed using appropriate statistical software, and the results were interpreted to evaluate environmental quality and the potential implications for metallic infrastructure degradation.

RESULT AND DISCUSSION

Water Quality Analysis

Based on the water quality test results of the Porong River mud reservoir using 7 chemical and physical parameters, namely pH, temperature, TSS, TDS, BOD, COD, and DO. The data are presented in Table 2 below.

Table 1
Codes and Locations for the 8 Porong River Water Samples

Code Example	Sampling Location
1	Porong River upstream of Outlet 3
2	Discharge Channel 3
3	Discharge Channel 1
4	Porong River downstream of Outlet 1
5	Discharge Channel 3 Inlet
6	Discharge Channels 1 and 2 Inlet
7	Seepage Site P79
8	Seepage Site P74

Source: Processed Primary Data, 2024

Table 2
Chemical and Physical Parameter Test Results of the Porong River Mud Reservoir Water Quality, Sidoarjo

No.	Parameter	Unit	1	2	3	4	5	6	7	8
1	Ph	-	7.25	6.86	7.05	6.94	7.66	6.8	7.36	6.94
2	Temperature	°C	28	29	30	29	28	29	32	31
3	TSS	Mg/L	536	714	1102	269.2	6700	98910	59.2	11262
4	TDS	Mg/L	165	146	201	174	5230	6500	2680	1430
5	BOD	Mg/L	5.91	6.96	7.66	6.58	188.4	1593	462.4	1673
6	COD	Mg/L	19.6	23.2	25.5	21.8	468.5	3946	1156	4182
7	DO	Mg/L	4.83	4.07	3.32	4.19	-	-	-	-

Source: Processed Primary Data, 2025

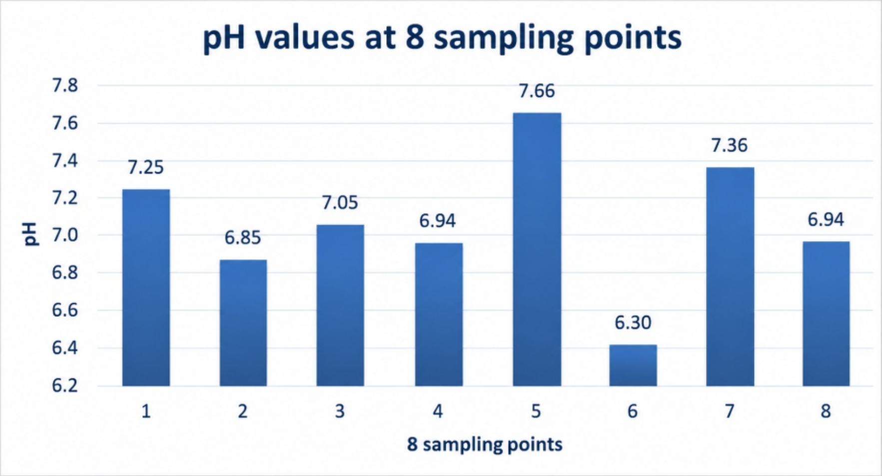
The water quality test results from the 8 sampling points indicate that the aquatic environment of the Porong River around the Sidoarjo mud disposal system has experienced a decline in quality, characterized by high suspended solids loads, high organic matter concentrations, and a decrease in dissolved oxygen levels at several observation points. Generally, pH and temperature remain within the allowable quality standard ranges; however, TSS, BOD, COD, and DO show signs of significant pollution.

This condition demonstrates that although the basic chemical characteristics of the water remain relatively stable, the pollutant load entering the water body remains high and has the potential to gradually reduce the carrying capacity of the Porong River. These findings suggest that the Porong River aquatic system is still under environmental pressure due to the accumulation of mud materials, organic runoff, and anthropogenic activities around the disposal area (Agung et al., 2021).

pH

The pH values measured at the eight sampling locations ranged from 6.80 to 7.66 (Figure 1), indicating neutral to slightly acidic conditions that comply with the Class III river water quality standard (pH 6–9) established in Government Regulation No. 22 of 2021. Although all sampling sites met the regulatory threshold, compliance with the water quality standard does not necessarily indicate a low corrosion risk. The corrosivity of aquatic environments is governed not only by pH but also by its interaction with dissolved oxygen, total dissolved solids (TDS), and other aggressive dissolved ions that collectively determine the electrochemical characteristics of the water (Haromain et al., 2024).

As illustrated in Figure 1, pH values were relatively stable at the upstream and river channel stations (1, 2, 3, and 4), whereas slightly lower values were observed at the seepage sites (S9 and S10). This spatial pattern is likely associated with localized hydrochemical processes occurring within the mud reservoir rather than natural river variability. The seepage sites also exhibited complete dissolved oxygen depletion (DO = 0.0 mg/L) together with elevated organic pollution loads, particularly COD reaching 4,182 mg/L. Under such anoxic conditions, microbial degradation of organic matter produces dissolved carbon dioxide (CO_2), hydrogen sulfide (H_2S), and other metabolites



Source: Processed Primary Data, 2024

Figure 1

pH parameter test results at 8 sampling locations

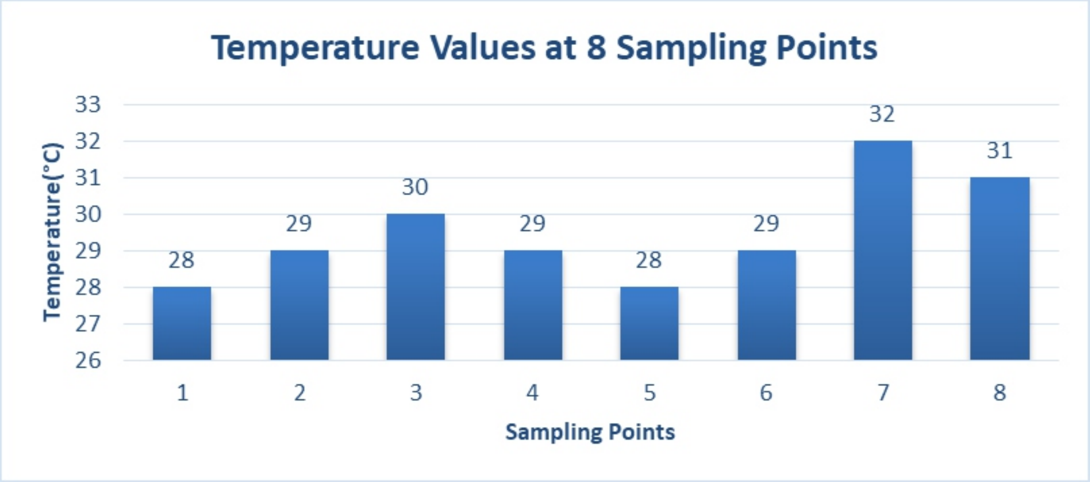
that contribute to lowering pH. The simultaneous occurrence of low pH, oxygen depletion, and high organic loading therefore reflects an anaerobic aquatic environment with enhanced chemical reactivity.

From a corrosion perspective, the observed pH values should be interpreted together with other physicochemical parameters rather than as an isolated indicator. Previous studies have demonstrated that waters with near-neutral pH may still exhibit high corrosivity when accompanied by elevated electrolyte concentrations and aggressive dissolved ions (Haromain et al., 2024). In the present study, the seepage areas were characterized by substantially higher TDS concentrations, reaching 6,500 mg/L, indicating increased ionic strength and electrical conductivity. These conditions facilitate electron transfer between anodic and cathodic sites on metal surfaces, thereby accelerating electrochemical corrosion and increasing the susceptibility of submerged metallic infrastructure to localized deterioration such as pitting corrosion. Consequently, although the measured pH values satisfied the national water quality standard, the combined hydrochemical characteristics indicate that the seepage zones represent the most aggressive environments for metallic material degradation within the Porong River mud reservoir.

Temperature

Water temperature across the eight sampling locations ranged from 28.6°C to 30.0°C (Table 2 and Figure 2), remaining within the permissible deviation (±3°C) specified in Government Regulation No. 22 of 2021 for Class III surface waters. These results indicate that the Porong River mud reservoir maintains relatively stable thermal conditions despite continuous mud discharge. As shown in Figure 2, only minor spatial variations were observed, with the highest temperature recorded at 2 (30.0°C) and the lowest at 4 (28.6°C). The slightly lower temperature at S5 is likely associated with mixing and dilution processes following its confluence with the Porong River, whereas temperatures at the remaining sampling sites remained relatively uniform.

Although temperature complied with the national water quality standard, its influence on water quality should be interpreted together with other physicochemical parameters. Elevated water temperature decreases oxygen solubility while simultaneously increasing microbial metabolic activity and the rates of biochemical and chemical reactions (Ritonga et al., 2026). These processes increase oxygen consumption during organic matter decomposition, thereby intensifying dissolved oxygen depletion in



Source: Processed Primary Data, 2024

Figure 2

Temperature Parameter Test Results at 8 Sampling Point Locations

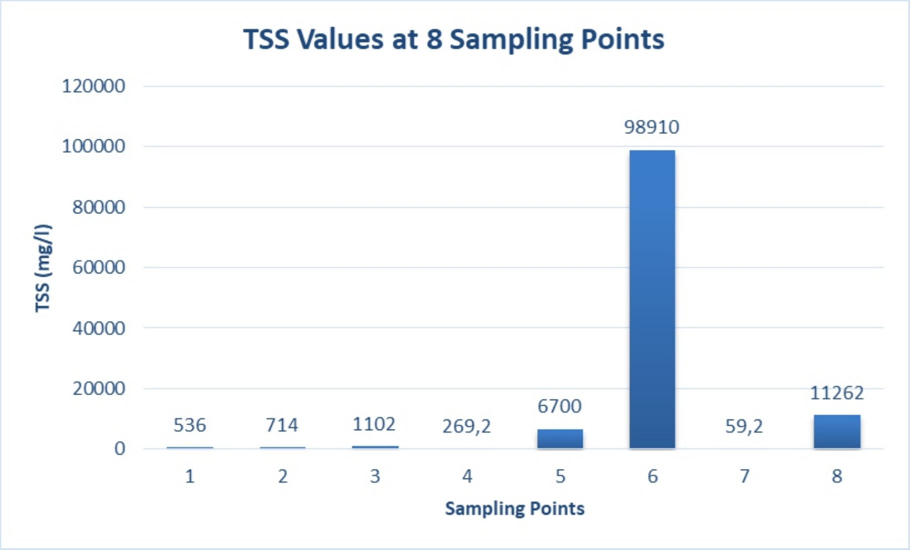
waters receiving high organic loads. In the present study, complete oxygen depletion (DO = 0.0 mg/L) occurred at the seepage sites, where high concentrations of organic pollutants were also recorded, suggesting that temperature may have acted as a facilitating factor rather than the primary driver of anoxic conditions.

Higher temperatures accelerate corrosion by enhancing the kinetics of electrochemical reactions at the metal–water interface, thereby increasing the corrosion rate. Higher temperatures increase ionic mobility and diffusion rates within the electrolyte, facilitating electron transfer between anodic and cathodic regions and thereby enhancing corrosion reactions, particularly when combined with elevated concentrations of dissolved solids and other aggressive ions. As discussed by Ritonga et al. (2026), the effect of temperature on corrosion becomes substantially greater when accompanied by high electrolyte conductivity and deteriorating water quality. Therefore, although temperature was not the dominant parameter controlling water quality in the Porong River mud reservoir, its interaction with TDS, DO, and organic pollutants likely intensified both the corrosive characteristics of the aquatic environment and the degradation potential of submerged metallic infrastructure.

Total Suspended Solids (TSS)

Among all measured parameters, Total Suspended Solids (TSS) showed the greatest spatial variability, with concentrations ranging from 536 to 98,910 mg/L across the eight sampling locations (Figure 3). All sampling sites substantially exceeded the Class III water quality standard of 50 mg/L established under Government Regulation No. 22 of 2021, indicating an exceptionally high suspended sediment load throughout the Porong River mud reservoir. As illustrated in Figure 3, the highest TSS concentration was recorded at the main discharge inlet, reflecting the direct influence of continuous volcanic mud discharge, whereas concentrations at downstream locations remained elevated despite partial dilution and sediment settling.

The exceptionally high TSS concentration observed at 6 was several orders of magnitude higher than those reported for anthropogenically impacted coastal waters, such as Lampung Bay (64–118 mg/L) (Wati et al., 2016). This marked difference suggests that suspended sediment dynamics within the Porong River are primarily controlled by continuous mud-volcanic discharge rather than conventional watershed runoff or urban activities. Similar to estuarine systems, the redistribution of suspended particles is further influenced by



Source: Processed Primary Data, 2024

Figure 3

TSS Parameter Test Results at 8 Sampling Point Locations

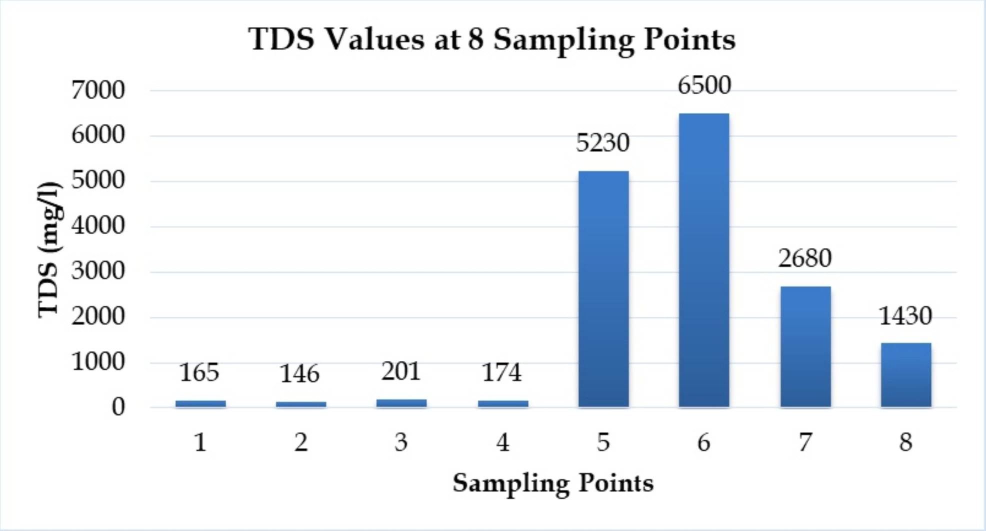
hydrodynamic processes, including tidal fluctuations that regulate sediment transport and deposition (Purba et al., 2018). Consequently, suspended solids remain mobile over considerable distances, extending their influence beyond the immediate discharge area.

Elevated TSS has important ecological and engineering implications. High concentrations of suspended particles increase water turbidity, reduce light penetration, and suppress photosynthetic activity by limiting the availability of solar radiation to primary producers (Agung et al., 2021). Suspended particles also function as adsorption media for heavy metals and other contaminants, facilitating pollutant transport throughout the aquatic system. In the present study, the locations characterized by elevated TSS also exhibited severe oxygen depletion and high organic pollution loads, indicating that excessive suspended solids contributed to the deterioration of overall water quality by reducing oxygen availability and promoting the accumulation of organic-rich sediments.

From a material degradation perspective, elevated TSS increases the likelihood of erosion–corrosion through the continuous impact of suspended particles on exposed metallic surfaces. Mechanical abrasion removes protective passive films, exposing fresh metal to electrochemical attack and accelerating corrosion rates, particularly under conditions of high TDS and low dissolved oxygen. This synergistic interaction between suspended solids and aggressive hydrochemical conditions substantially increases the vulnerability of hydraulic infrastructure, including steel gates, pipelines, and pumping systems. Because turbidity has been shown to exhibit a strong linear relationship with TSS ($R^2 > 0.60$), as demonstrated in the Doce River, Brazil (Oliveira et al., 2018), rapid turbidity monitoring may provide a practical surrogate for real-time assessment of suspended sediment loads and their associated risks to both water quality and metallic infrastructure.

Total Dissolved Solids (TDS)

Total Dissolved Solids concentrations ranged from 146 to 6,500 mg/L across the eight sampling locations (Figure 4). Most upstream, discharge, and downstream river stations exhibited relatively low TDS values (146–201 mg/L), remaining well below the Class III water quality standard of 1,000 mg/L established under Government Regulation No. 22 of 2021. However, a pronounced increase was observed at the seepage sites, where TDS reached 6,500



Source: Processed Primary Data, 2024

Figure 4

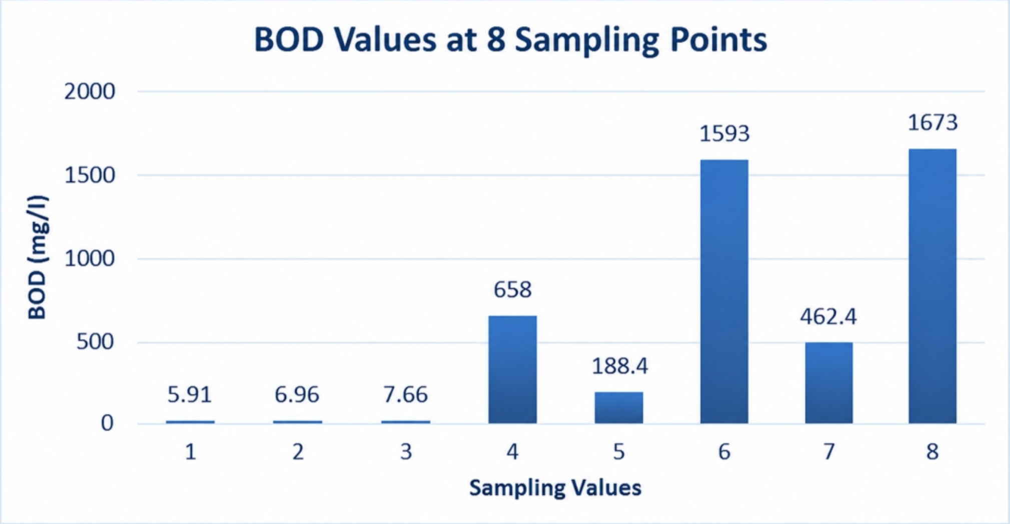
TDS Parameter Test Results at 8 Sampling Point Locations

mg/L, indicating localized enrichment of dissolved inorganic constituents associated with prolonged interaction between seepage water, mud deposits, and surrounding geological materials.

As shown in Figure 4, the spatial distribution of TDS demonstrates that dissolved solids accumulated primarily within the seepage zones rather than along the main river channel. This pattern suggests that dissolved ions were concentrated through prolonged water–sediment interaction and limited hydrological exchange, allowing minerals and soluble salts to diffuse continuously into the surrounding water. Unlike suspended solids, which are transported predominantly by river flow, dissolved solids remain in solution and directly increase the ionic strength and electrical conductivity of the aquatic environment. Similar observations have been reported in waters affected by geological processes, where localized hydrochemical conditions strongly influence dissolved ion concentrations.

From a corrosion perspective, elevated TDS represents one of the principal factors controlling the aggressiveness of an aquatic environment. Increased concentrations of dissolved ions, including chloride and sulfate, enhance electrolyte conductivity and facilitate electron transfer between anodic and cathodic sites on metallic surfaces, thereby accelerating electrochemical corrosion (Haromain et al., 2024). In the present study, the highest TDS concentrations coincided with complete dissolved oxygen depletion and elevated organic pollution loads, indicating that corrosion risk was governed by the combined effects of high ionic strength, oxygen-deficient conditions, and deteriorating water quality rather than by a single parameter alone.

Comparison with previous studies further highlights the unique hydrochemical characteristics of the Porong River mud reservoir. Rani & Afdal (2021) reported that the Sitiung segment of the Batanghari River exhibited alkaline water (average pH 8.73) despite very low TDS concentrations (29.7 mg/L), indicating that elevated pH alone did not correspond to increased dissolved ion content. In contrast, the seepage waters of the Porong River were characterized by extremely high TDS under near-neutral pH conditions, demonstrating that electrolyte concentration rather than pH was the dominant factor influencing the corrosive characteristics of the aquatic environment. These findings emphasize that corrosion susceptibility should be evaluated through the interaction of multiple



Source: Processed Primary Data, 2024

Figure 5

BOD Parameter Test Results at 8 Sampling Point Locations

physicochemical parameters rather than by considering individual water quality indicators in isolation.

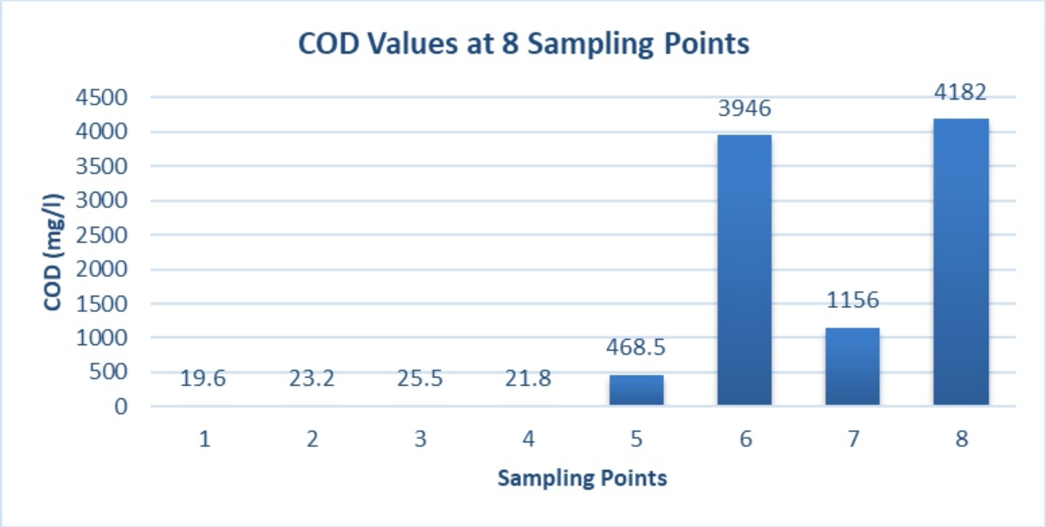
Biochemical Oxygen Demand (BOD)

Biological Oxygen Demand (BOD) concentrations ranged from 5.91 to 1,673 mg/L across the eight sampling locations (Figure 5), substantially exceeding the applicable water quality standard under Government Regulation No. 22 of 2021. The elevated BOD values indicate excessive inputs of biodegradable organic matter into the Porong River mud reservoir and reflect intense microbial decomposition processes occurring throughout the study area. As shown in Figure 5, BOD increased markedly from the upstream stations toward the discharge and seepage zones, where the accumulation of organic-rich mud and limited water exchange created conditions favorable for prolonged organic matter degradation.

The observed spatial distribution of BOD corresponds closely with the dissolved oxygen (DO) profile presented in Table 2. Stations with the highest BOD concentrations also exhibited complete oxygen depletion (DO = 0.0 mg/L), indicating that oxygen consumption by aerobic microorganisms exceeded the rate of oxygen replenishment. During the decomposition of biodegradable organic matter, microorganisms utilize dissolved oxygen as an electron acceptor, leading to progressive oxygen depletion and the subsequent development of hypoxic or anoxic conditions. Once oxygen becomes depleted, anaerobic decomposition dominates, producing reduced compounds such as hydrogen sulfide (H_2S) and methane (Ch_4), which further degrade water quality and alter the aquatic biogeochemical environment.

The spatial distribution of organic pollutants within the Porong River mud reservoir is strongly influenced by hydrodynamic processes. Similar observations in estuarine environments have shown that tidal fluctuations regulate the transport, deposition, and redistribution of organic-rich sediments, thereby affecting the spatial variability of BOD (Purba et al., 2018). In the present study, however, the persistently elevated BOD values indicate that continuous mud discharge remained the dominant source of organic loading despite natural dilution processes.

Elevated BOD indirectly increases corrosion susceptibility by promoting oxygen-deficient environments that favor the proliferation of anaerobic microorganisms, particularly sulfate-reducing bacteria (SRB). These microorganisms generate sulfide species capable of initiating microbiologically influenced corrosion (MIC), accelerating localized



Source: Processed Primary Data, 2024

Figure 6

COD Parameter Test Results at 8 Sampling Point Locations

corrosion and pitting on submerged metallic infrastructure (Suryaningrum & Adriyani, 2023). Therefore, the combined occurrence of high BOD, complete dissolved oxygen depletion, and elevated dissolved solids suggests that the seepage zones represent the most aggressive environments for both ecological degradation and metallic infrastructure deterioration within the Porong River mud reservoir.

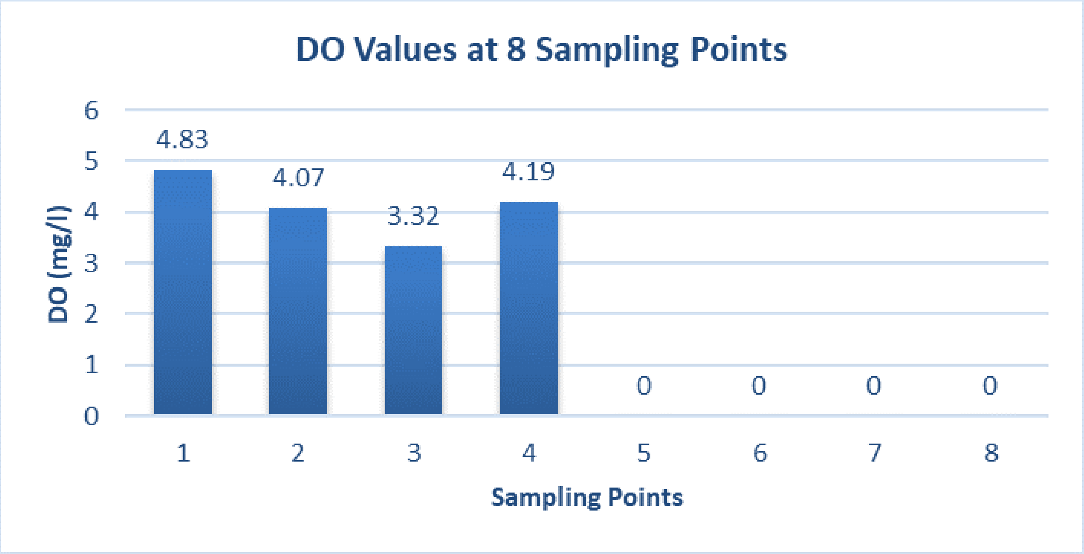
Chemical Oxygen Demand (COD)

Chemical Oxygen Demand (COD) concentrations ranged from 19.6 to 4,182 mg/L across the eight sampling locations (Figure 6), demonstrating pronounced spatial variability in the accumulation of chemically oxidizable substances within the Porong River mud reservoir. Although the upstream stations exhibited relatively lower COD values, concentrations increased markedly toward the discharge and seepage zones, where continuous mud disposal promoted the accumulation of organic-rich materials and other chemically oxidizable constituents. As illustrated in Figure 6, the highest COD values greatly exceeded the Class III water quality standard of 40 mg/L established under Government Regulation No. 22 of 2021, reflecting severe chemical pollution in these localized environments.

The observed COD distribution closely corresponds with the dissolved oxygen profile presented in Table 2. Elevated COD indicates a greater oxygen demand for the oxidation of organic and inorganic compounds, thereby increasing oxygen consumption within the aquatic environment. In the present study, stations characterized by the highest COD concentrations also exhibited complete dissolved oxygen depletion (DO = 0.0 mg/L), demonstrating that excessive chemical oxygen demand contributed to the development of persistent anoxic conditions. Similar to BOD, the accumulation of oxygen-consuming substances limits oxygen availability for aquatic organisms while altering the redox conditions of the water body.

Hydrodynamic processes further influence the spatial distribution of COD. As reported by Purba et al. (2018), tidal fluctuations regulate the transport, retention, and redistribution of dissolved and particulate pollutants in estuarine environments. Consistently elevated COD concentrations in the seepage and discharge areas indicate that continuous mud discharge remained the dominant source of chemical loading, whereas natural dilution and sedimentation were insufficient to substantially reduce pollutant concentrations.

High COD indirectly increases corrosion susceptibility by promoting oxygen-deficient environments that favor



Source: Processed Primary Data, 2024

Figure 7

DO Parameter Test Results at 8 Sampling Point Locations

reductive biogeochemical processes. Under anoxic conditions, sulfate-reducing bacteria and other anaerobic microorganisms become increasingly active, producing corrosive metabolites such as hydrogen sulfide that accelerate microbiologically influenced corrosion (MIC). Furthermore, deteriorating water quality associated with elevated COD may increase the chemical aggressiveness of the aquatic environment toward exposed metallic infrastructure (Yanti et al., 2025). Therefore, the simultaneous occurrence of extremely high COD, complete dissolved oxygen depletion, and elevated dissolved solids indicates that the seepage zones represent the most corrosive environments within the Porong River mud reservoir.

Dissolved Oxygem (DO)

Dissolved oxygen (DO) concentrations ranged from 3.32 to 4.83 mg/L at the upstream and river channel stations, while complete oxygen depletion (DO = 0.0 mg/L) was recorded at the discharge and seepage zones (Figure 7). These observations indicate a pronounced spatial deterioration in oxygen availability throughout the Porong River mud reservoir. As illustrated in Figure 7, DO concentrations progressively declined from the upstream section toward the mud disposal and seepage areas, where oxygen was entirely depleted. The recorded values at these locations fell below the minimum requirement for Class III surface waters established under Government Regulation No. 22 of 2021, demonstrating the development of persistent anoxic conditions within the most heavily polluted sections of the reservoir.

The observed depletion of dissolved oxygen closely corresponded with the spatial distribution of BOD and COD presented in Table 2. Elevated concentrations of biodegradable organic matter and chemically oxidizable substances substantially increased oxygen consumption during microbial respiration and chemical oxidation, resulting in oxygen demand that exceeded natural reaeration capacity. Consequently, prolonged anoxic conditions developed in the discharge and seepage zones, fundamentally altering the redox status of the aquatic environment. Similar processes in estuarine ecosystems have been shown to be influenced by tidal circulation, which regulates pollutant transport and oxygen replenishment (Purba et al., 2018). However, the persistence of DO depletion in the Porong River mud reservoir indicates that continuous mud discharge remained the dominant driver of oxygen depletion despite hydrodynamic mixing.

Ecologically, sustained anoxic conditions severely reduce habitat suitability for aerobic aquatic organisms, leading to physiological stress, biodiversity loss, and the dominance of anaerobic microbial communities. Under oxygen-deficient conditions, anaerobic metabolism generates reduced compounds such as hydrogen sulfide (H_2S), which further deteriorate water quality and increase ecological vulnerability. These findings demonstrate that dissolved oxygen is an integrative indicator of ecosystem health, reflecting the combined effects of organic loading, chemical pollution, suspended solids, and hydrological processes within the reservoir.

From a material degradation perspective, dissolved oxygen is also a critical parameter controlling corrosion mechanisms. The coexistence of complete oxygen depletion, elevated BOD and COD, high TDS, and excessive suspended solids creates highly aggressive hydrochemical conditions that promote microbiologically influenced corrosion (MIC) and differential aeration corrosion on submerged metallic infrastructure (Ritonga et al., 2025). In such environments, anaerobic microorganisms become increasingly dominant, while elevated electrolyte conductivity and continuous particle abrasion further accelerate electrochemical deterioration. Therefore, the anoxic seepage zones identified in this study represent the highest-risk environments for both ecological degradation and long-term structural failure of hydraulic infrastructure. These findings emphasize that corrosion risk within the Porong River mud reservoir is governed by the synergistic interaction of multiple physicochemical parameters rather than by dissolved oxygen alone, highlighting the importance of integrated water quality assessment for predicting infrastructure vulnerability in mud-affected aquatic systems.

CONCLUSION

This study demonstrates that water quality deterioration within the Porong River Mud Reservoir is governed by the synergistic interaction of suspended solids, dissolved solids, organic pollution, and dissolved oxygen depletion rather than by individual physicochemical parameters alone. The integration of these parameters identified the discharge and seepage zones as the most aggressive hydrochemical environments, where excessive suspended sediments, elevated dissolved ions, and persistent anoxic conditions collectively accelerate ecological degradation while increasing the corrosion potential of submerged metallic infrastructure. These findings extend previous water quality assessments by establishing a scientific linkage between extreme hydrochemical conditions associated with volcanic mud discharge and material degradation processes, thereby providing a more comprehensive framework for assessing infrastructure vulnerability in geological disaster-affected aquatic systems. Beyond evaluating environmental quality, this study demonstrates that dissolved oxygen depletion, together with elevated TDS, TSS, BOD, and COD, functions as an integrated indicator of corrosive aquatic environments, offering a scientific basis for predicting corrosion-prone zones and supporting the development of risk-based monitoring strategies for hydraulic infrastructure. Consequently, the findings contribute not only to environmental pollution assessment but also to the broader fields of water resource management, environmental engineering, and infrastructure resilience in mud-volcanism environments. Nevertheless, several limitations should be acknowledged. The investigation was conducted during a single monitoring period and therefore did not capture seasonal hydrological variability, tidal fluctuations, or temporal changes in mud discharge intensity. Furthermore, the corrosion potential was inferred from hydrochemical characteristics rather than being validated through direct corrosion experiments on metallic materials. Future research should integrate long-term seasonal monitoring with experimental corrosion assessments, including weight-loss measurements, electrochemical techniques, and microbiologically influenced corrosion (MIC) analyses, to quantify material degradation rates under varying environmental conditions. Further investigations into corrosion-resistant alloys, environmentally friendly corrosion inhibitors, and advanced protective coatings are needed to identify effective mitigation strategies for hydraulic infrastructure exposed to volcanic mud environments.. From a practical perspective, continuous monitoring of key water quality parameters, supported by sediment control measures at major discharge points and the implementation of corrosion protectiobeing validated through direct corrosion experiments on metallic materials. Future research should therefore integrate long-term seasonal monitoring with experimental corrosion assessments, including weight-loss measurements, electrochemical techniques, and microbiologically influenced corrosion (MIC) analyses, to quantify degradation rates under varying environmental conditions. Additional investigations on corrosion-resistant alloys, environmentally friendly corrosion inhibitors, and advanced protective coatings are also recommended to identify effective mitigation strategies for hydraulic infrastructure. From a practical perspective, continuous monitoring of key water quality parameters, supported by sediment control measures at major discharge points and the implementation of corrosion protection systems for criticaln systems for critical infrastructure, will be essential to minimize long-term environmental impacts and strengthen the resilience of infrastructure in areas affected by active mud volcanism.

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