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THE EFFECTIVENESS OF IMPLEMENTING A REAL-TIME WATER QUALITY MONITORING METHOD FOR UNHAS LAKE

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ABSTRACT
This study aims to evaluate the effectiveness of a real-time water quality monitoring system compared to conventional laboratory analysis at Lake UNHAS, through two stages: the implementation of a real-time multi-parameter monitoring system and a comparative analysis of the two methods. Monitoring results indicate that the TDS, DO, and pH parameters from both methods predominantly meet applicable quality standards, while the temperature and turbidity parameters do not meet quality standards based on Government Regulation No. 22 of 2021 and Ministry of Health Regulation No. 2 of 2023. The results of the MAPE statistical test showed values of 19.69% for temperature, 16.09% for pH, 47.36% for TDS, 41.66% for DO, and 37.78% for turbidity, indicating that temperature and pH fall into the "good performance" category, while TDS, DO, and turbidity fall into the acceptable category, with the order of accuracy from highest to lowest being pH, temperature, turbidity, DO, and TDS. Overall, all parameters are within acceptable ranges, so this study can serve as a quantitative reference for researchers and environmental practitioners in assessing the reliability of real-time monitoring devices to support data-driven decision-making in the sustainable management of lake ecosystems.
KEYWORDS: Water Quality, Hasanuddin University Lake, Real-Time Monitoring, Laboratory Testing

Introduction

Water plays an important role in human health and well-being, particularly through recreational activities in oceans, rivers, lakes, pools, and spas(WHO, n.d.). However, water quality is increasingly threatened by domestic, agricultural, and industrial waste, which can damage aquatic ecosystems and negatively affect human health (Yani et al., 2019). Urban lakes are important because they function in rainwater harvesting, groundwater recharge, recreation, and ecological balance (Rahman et al., 2021). Nevertheless, rapid urbanization and human activities often cause untreated sewage, wastewater discharge, and pollutant accumulation that degrade lake water quality (Prasad et al., 2024; Wu et al., 2025). Continuous water quality monitoring is therefore essential to identify pollutants and support environmental management (Silva et al., 2022). Common monitoring parameters include pH, turbidity, Dissolved Oxygen (DO), Total Dissolved Solids (TDS), and temperature, which reflect both natural and anthropogenic influences on aquatic ecosystems (Lal et al., 2024). Changes in temperature can reduce oxygen solubility and affect aquatic organisms (Prana Nala Shekina et al., 2024), while high TDS levels may decrease water quality and cause corrosion or scaling problems (Adjovu et al., 2023). Continuous monitoring is important to ensure efficient and sustainable water use (Jan et al., 2021).Recent developments in the Internet of Things (IoT) have improved water quality monitoring by enabling real-time and remote observation (Addow & Jimale, 2023). IoT-based systems integrated with electrochemical sensors and wireless communication technologies can provide continuous and accurate data (Demetillo & Taboada, 2019). Compared to conventional laboratory-based monitoring, IoT systems offer faster responses, lower costs, and reduced data gaps (Cloete et al., 2016; El-Shafeiy et al., 2023; Ooko et al., 2025). One urban lake that requires effective monitoring is Unhas Lake, located near Gate 1 of Hasanuddin University in Makassar. The lake has ecological, educational, economic, and recreational functions (Lestari et al., 2020). However, campus infrastructure development, including hotels and lecture buildings, increases the risk of solid and liquid waste pollution entering the lake (Musdalifah et al., 2022). Therefore, an effective monitoring system is needed to support the sustainability of the Unhas Lake ecosystem.Although many studies have discussed lake water quality monitoring (Caballero & Navarro, 2021; Deng et al., 2024; Elsayed et al., 2021; Flores-Anderson et al., 2020; Li et al., 2020; Strigaro et al., 2022; Yunus et al., 2020), research on the effectiveness of real-time monitoring systems in Unhas Lake remains limited. This study aims to evaluate the effectiveness of a real-time IoT-based water quality monitoring system compared with conventional laboratory methods in Unhas Lake. The novelty of this study lies in integrating a real-time IoT monitoring framework with multi-parameter water quality assessment and comparing it with laboratory analysis to evaluate its reliability and suitability for sustainable environmental management in tropical developing regions. The findings are expected to contribute to scientific knowledge, support environmental management and pollution control in Makassar, and serve as a reference for developing sustainable and cost-effective monitoring systems in Indonesia and other developing countries, while supporting SDG 6 on clean water and sanitation.

Methodology

Data collection : Field research was conducted through observation and water sampling in the Hasanuddin University (UNHAS) Lake area using real-time monitoring. Laboratory research involved measuring the levels of contaminants contained in the water samples. The primary data in this study consists of water quality parameters, including Total Dissolved Solids (TDS), Dissolved Oxygen (DO), Turbidity, Temperature, and pH, which were obtained using real-time monitoring and laboratory analysis. The secondary data in this study consists of lake water quality standards found in Government Regulation of the Republic of Indonesia No. 22 of 2021 and Minister of Health Regulation of the Republic of Indonesia No. 2 of 2023. Other secondary data includes Indonesian National Standards for laboratory water analysis for the parameters of Temperature (SNI 06-6989.23-2005),Turbidity (SNI 06-6989.25-2005),TDS (SNI 6989.27:2019), pH (SNI 6989.11:2019), and DO (SNI 06-6989.14-2004).

Materials and Tools : The equipment used in this study for real-time monitoring included a pH sensor, a TDS sensor, a DO sensor, a turbidity sensor, a temperature sensor, an LCD display, and a GPS (Global Positioning System).The equipment used in this study for laboratory analysis included a cool box, a camera, a water sampler, sample containers, an analytical balance, a pH meter, an analytical balance, Erlenmeyer flasks, measuring cups, a burette, an aerator, a measuring pipette, a graduated pipette, porcelain dishes, an oven, tweezers, a desiccator, and a spectrophotometer.Materials used in the laboratory analysis methods included water samples from Lake Unhas, distilled water, and chemicals used for water quality testing, such as $MgSO_4$, NaOH-KI, thiosulfate, H_2SO_4, kanji indicator, $K_2Cr_2O_7$, ferroin indicator, FAS, and filter paper. A sketch of the sensor device for real-time monitoring can be seen in Figure 1.

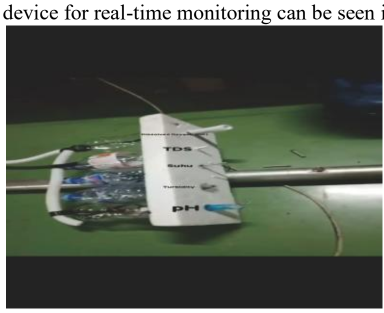

Figure 1.Sensor Device for Real Time Monitoring

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Research Location and Time

The study was conducted at Hasanuddin University Lake, located at Jl. Perintis Kemerdekaan Km. 10, Tamalanrea Indah Village, Tamalanrea Subdistrict, Makassar City, South Sulawesi. The sampling site was selected based on Google Earth maps, taking into account areas that are potential sources of wastewater discharge into the lake. Water quality measurements were conducted using a real-time monitoring system with parameters including Temperature, TDS, pH, DO, and Turbidity, while laboratory analysis was performed by a third party at the BBSPJIHPMM Testing and Calibration Laboratory, Jl. Prof. Dr. H. Abdurrahman Basalamah No. 28, Makassar, using methods compliant with Indonesian National Standards (SNI). The study lasted one month, encompassing the preparation, implementation, and reporting phases. Real-time monitoring data collection was conducted during three time periods: morning (contact times 2 and 3, 07:00–08:00 WITA), noon (contact times 4 and 5, 12:00–13:00 WITA), and evening (contact times 6 and 7, 5:00–6:00 PM WITA), with each measurement lasting 15 minutes per contact time, while contact time 1 was used as an initial performance test for the instrument.

Figure 2. Sampling Points at Hasanuddin University Lake

Quality Standards : The water quality standards used to analyze the water quality of Lake Unhas are those for rivers and similar water bodies, as stipulated in Government Regulation of the Republic of Indonesia No. 22 of 2021 on the Implementation of Environmental Protection and Management and Indonesian Minister of Health Regulation No. 2 of 2023, which can be seen in Table 1 and Table 2

Tabel 1. Lake Water Quality Standards

No	Parameter	Unit	Class 1	Class 2	Class 3	Class 4	Desc.
1	Temperature	°C	Dev 3	Dev 3	Dev 3	Dev 3	Difference from the air temperature above the water surface
2	Total dissolved solids (TDS)	mg/L	1.000	1.000	1.000	1.000	
3	Dissolved oxygen (DO)	mg/L	6	4	3	1	Minimum limit
4	pH		6-9	6-9	6-9	6-9	Does not apply to peat water (Natural conditions)

Source: Government Regulation of the Republic of Indonesia No. 22 of 2021

Tabel 2 Water Parameters for Hygiene and Sanitation Purposes

No.	Parameter Type	Maximum permitted level	Unit	Testing Methods
1	Turbidity	< 3	NTU	SNI or equivalent

Source: Regulation of the Minister of Health of the Republic of Indonesia No. 2 of 2023

Data analysis

The first data analysis involved compiling the results of water quality parameter measurements obtained using real-time monitoring devices and laboratory test results from UNHAS lake water samples. The second data analysis involved comparing the water quality measurement results from real-time monitoring and laboratory tests with the Lake Water Quality Standards established by the Government in Regulation of the Minister of Health of the Republic of Indonesia No. 2 of 2023 and Government Regulation of the Republic of Indonesia No. 22 of 2021. The third data analysis involves comparing the results of UNHAS lake water quality measurements using real-time monitoring devices and laboratory tests using the MAPE statistical test to determine the percentage of device performance.

MAPE Test

Data from the designed monitoring system were compared with data from standard measuring instruments. Data analysis was conducted to evaluate the system's accuracy using the Mean Absolute Percentage Error (MAPE) method. MAPE is used to measure error by calculating the percentage deviation between actual data and forecast data(Hairiyah et al., 2025).Evaluation results using the MAPE method show that if the MAPE value is below 10%, the device's performance is excellent; between 10%–20% indicates good performance; between 20%–50% indicates acceptable performance; and above 50% indicates poor performance (Hairiyah et al., 2025). The MAPE calculation is performed using formula (1) as follows:

$$\text{MAPE} = \frac{\sum_{t=1}^{n} \left| \frac{Y't - Yt}{Y't} \right| \times 100\%}{n} \quad (1)$$

Notes:
$Y't$ = Data from the reference instrument (Laboratory Analysis)
Yt = Data from the instrument in use (Real-Time Monitoring)
n = Number of data points

Results and Discussion

Lake water quality based on laboratory tests

Tabel 3 Concentrations of Water Quality Parameters in UNHAS Lake Based on Laboratory Testing

Parameters	Results	Quality standards
Temperature	26,8°C	Deviation ≤ 3°C
TDS	93 mg/L	≤ 1000 mg/L
pH	6.1	6–9
DO	5,5531 mg/L	Min. 4 mg/L
Turbidity	16,0 NTU	< 3 NTU

Source: Water Quality Testing, 2025

Table 3 presents the results of laboratory analysis of water samples from Lake UNHAS. The results of water quality measurements for Lake UNHAS indicate that the parameters of temperature, TDS, pH, and DO meet the established quality standards, as stipulated in Government Regulation No. 22 of 2021, where the measured water temperature was 26.8°C with a deviation of 0.2°C from the air temperature, TDS was 93 mg/L—well below the maximum limit of 1000 mg/L—pH was 6.1, falling within the range of 6–9, and DO at 5.5531 mg/L, exceeding the minimum limit of 4 mg/L, indicating that dissolved oxygen levels are still sufficient to support aquatic life. Meanwhile, the turbidity parameter shows a value of 16.0 NTU, which is relatively high and exceeds the quality standard of < 3 NTU as stipulated in Indonesian Ministry of Health Regulation No. 2 of 2023. Turbidity and suspended sediment concentration are crucial parameters indicative of water quality, playing pivotal roles in evaluating the well-being of aquatic ecosystems and the effectiveness of water treatment processes. The review from Matos (2024), emphasizes the key accomplishments and challenges of the state-of-the-art technologies, providing a comprehensive overview of the current stage of the field and its prospects. and aims to provide valuable insights for researchers, practitioners, and decision-makers involved in environmental monitoring and water facility management, enabling a deeper comprehension of the significance of turbidity and suspended sediment concentration in safeguarding water quality and ecosystem health.

Lake Water Quality Based on Real-time Monitoring

Table 4 Concentrations of Water Quality Parameters in Lake UNHAS Using Real-Time Monitoring Equipment

Time (In 15 minutes)	1	2	3	4	5	6	7	Average	Quality Standard
Temperature (Air 27 °C)	33.5	33.5	33.5	33.25	33.25	33.25	33.25	33.36	Deviasi ≤ 3°C
TDS	205.2	184.5	176.2	172.2	168.7	164.6	171.3	177.51	≤ 1000 mg/L
pH	8.14	7.91	7.17	7.17	6.86	6.91	6.94	7.30	6–9
DO	10.69	10.12	9.76	9.55	9.09	8.84	8.87	9.56	Min. 4 mg/L
Turbidity	16.88	22.41	28.47	32.5	28.665	35.41	28.64	27.57	< 3 NTU

Source: Water Quality Testing, 2025

Table 4 presents the results of water quality monitoring at Lake UNHAS using a real-time monitoring device. With this real-time monitoring device, data is recorded every 15 minutes, represented by numbers 1–7, which indicate the time the device was in contact with the lake water. Contact time 1 was a device test. Contact times 2 and 3 were recorded at 7:00 and 8:00 a.m. Contact times 4 and 5 were taken at 12:00 and 1:00 p.m. Contact times 6 and 7 were taken at 5:00 and 6:00 p.m. The results of real-time water quality monitoring of Lake UNHAS over seven time intervals show that the TDS (average 177.51 mg/L), pH (average 7.30), and DO (average 9.56 mg/L) parameters met the established quality standards. Conversely, the temperature parameter showed a deviation of 6.36°C from the air temperature of 27°C, exceeding the tolerance limit of ≤3°C, while the turbidity parameter showed an average value of 27.57 NTU, which exceeds the established quality standard of < 3 NTU. Additionally, Bessell-Browne, (2017) explained that turbidity measurement is an essential diagnostic tool, revealing the degree to which suspended particles interfere with light transmission through water. Beyond its aesthetic implications, it is pivotal in shaping aquatic ecosystems and in water treatment assessment. Turbidity levels profoundly affect light penetration, a critical factor for photosynthetic organisms. Excessive turbidity hinders the photosynthetic processes of aquatic plants and algae, disrupting the delicate balance of the ecosystem.

Comparison of Laboratory Tests and Real-Time Monitoring

Temperature

Figure 3 shows a comparison of temperature levels between real-time monitoring and laboratory analysis. Temperature measurements taken using the real-time monitoring device showed values ranging from 33.25°C to 33.5°C, with an average of 33.36°C, while laboratory analysis yielded a value of 26.8°C, with an average difference of 6.56°C. The advantage of the real-time monitoring system lies in its ability to continuously record temperature fluctuations, as seen in the temperature drop from the morning period (contact times 2–3) to the afternoon (contact times 4–5) from 33.5°C to 33.25°C, which then stabilized until contact time 7. An evaluation of Government Regulation No. 22 of 2021, which sets a maximum temperature deviation of ≤3°C from the ambient air temperature (27°C), indicates that the real-time monitoring device's results, with a deviation of 6.36°C, do not meet the quality standards, while the laboratory results, with a deviation of 0.2°C, are deemed to meet the established standards. The high measured temperature values are suspected to be influenced by shallow water conditions, allowing sunlight to penetrate more easily and raise water temperatures (Kulla et al., 2020)

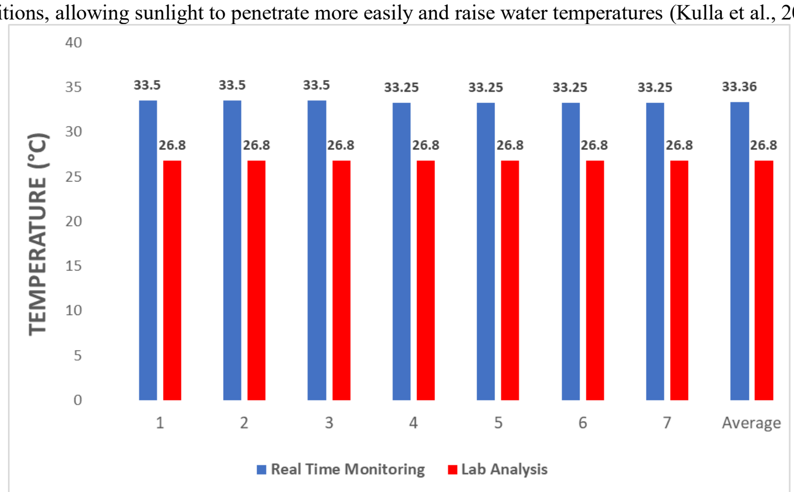


Figure 3. Temperature diagram

TDS (Total Dissolved Solid)

Figure 4 shows a comparison of TDS concentrations between real-time monitoring and laboratory analysis. TDS measurement results using the real-time monitoring device showed values ranging from 164.6 mg/L to 205.2 mg/L with an average of 177.51 mg/L, while laboratory analysis yielded a value of 93 mg/L, with an average difference of 84.51 mg/L. The advantage of the real-time monitoring system lies in its ability to continuously record TDS fluctuations, as evidenced by the decrease in TDS values from contact time 2 to 6 within the range of 4.1–8.3 mg/L, which then increased again from contact time 6 to 7 by 6.7 mg/L. An evaluation of Indonesian Government Regulation No. 22 of 2021, which sets the Class 2 TDS water quality standard for lakes at 1,000 mg/L, indicates that both measurement methods meet the established standards. TDS levels in water bodies are influenced by rock weathering, surface runoff, and anthropogenic activities, where excessive accumulation of dissolved substances can increase turbidity and inhibit sunlight penetration, thereby affecting photosynthetic processes in the water (Lopa et al., 2014)

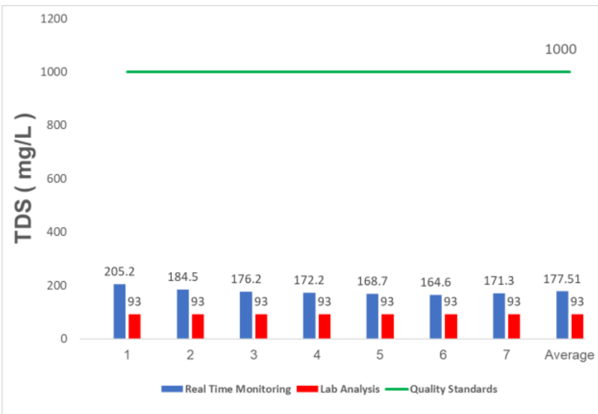


Figure 4: Total Dissolved Solids (TDS) Diagram

pH (Derajat Keasaman)

Figure 5 shows a comparison of pH values from real-time monitoring and laboratory analysis. The pH measurements obtained using the real-time monitoring device ranged from 6.86 to 7.3, with an average of 7.3, while laboratory analysis yielded a value of 6.1, with an average difference of 1.2. The advantage of the real-time monitoring system lies in its ability to continuously record pH fluctuations, as seen in the decrease in pH values from contact time 1 to 5 within a range of 0.23–0.31, which then increased again from contact time 5 to 7 within a range of 0.03–0.05. An evaluation of Indonesian Government Regulation No. 22 of 2021, which sets the Class 2 lake water pH quality standard within the range of 6–9, indicates that both measurement methods still meet the established standards. However, the laboratory pH value of 6.1, which is close to the minimum limit, indicates a trend toward water acidification that warrants attention, given that pH variations can affect the stability of aquatic ecosystems, phytoplankton dominance, and primary productivity (Melinda et al., 2022) while the presence of basic compounds such as detergents has the potential to significantly affect pH values (Lopa et al., 2014). According to Setiawan, (2025) its adoption improved aquaculture productivity by 15–20%, highlighting the effectiveness of IoT integration in supporting sustainable fish farming practices. Overall, this research confirms that IoT-enabled real-time monitoring can provide accurate, efficient, and scalable solutions for water quality management in aquaculture, and offers a foundation for future enhancements incorporating dissolved oxygen and ammonia sensors, artificial intelligence-based prediction models, and fully automated control mechanisms.

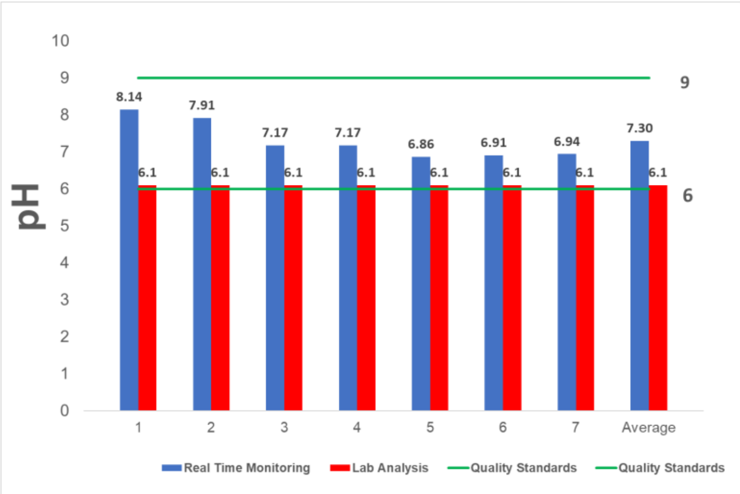


Figure 5: pH Diagram

Dissolved Oxygen (DO)

Figure 6 shows a comparison of DO concentrations from real-time monitoring and laboratory analysis. DO measurements using the real-time monitoring device showed values ranging from 8.84 mg/L to 10.69 mg/L with an average of 9.56 mg/L, while laboratory analysis yielded a value of 5.553 mg/L, with an average difference of 4.007 mg/L. The advantage of the real-time monitoring system lies in its ability to continuously record DO fluctuations, as seen in the decrease in DO values from contact time 2 to 6 in the range of 0.25–0.57 mg/L, which then increased from contact time 6 to 7 by 0.03 mg/L. An evaluation of Indonesian Government Regulation No. 22 of 2021, which sets the minimum DO quality standard for Class 2 lakes at 4 mg/L, indicates that both measurement methods meet the established standards. High DO values indicate good water quality, given that dissolved oxygen is significantly influenced by temperature, salinity, water movement, atmospheric pressure, and phytoplankton concentration, where DO fluctuations are also affected by plankton respiration at night and photosynthesis during the day(Ilham Ainalyaqin & Indah Wahyuni Abida, 2024), and plays a crucial role in supporting the metabolism of aquatic organisms and the decomposition of organic matter in water bodies (Roslinda Ibrahim et al., 2024)

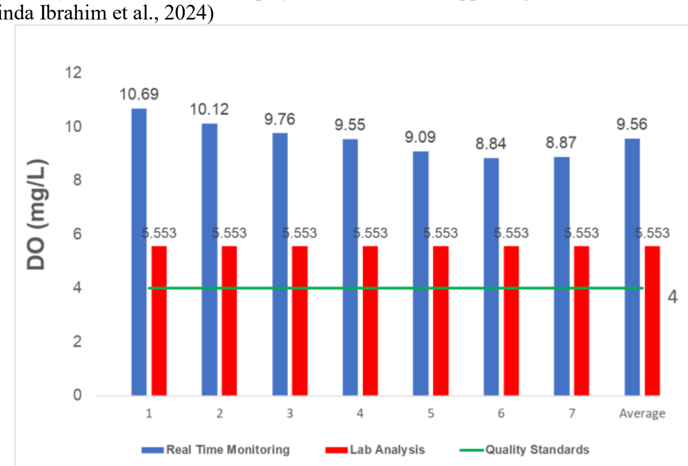
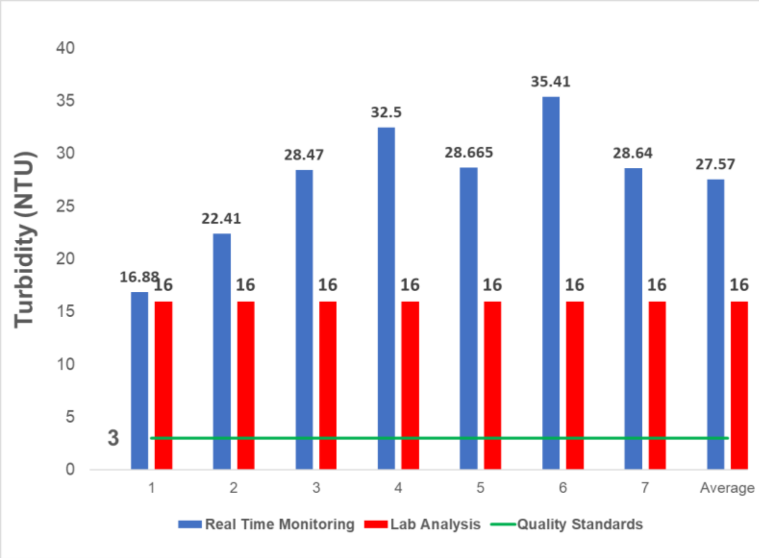


Figure 6 DO Diagram

Turbidity

Figure 7 shows a comparison of turbidity values between real-time monitoring and laboratory analysis. Turbidity measurements using the real-time monitoring device showed values ranging from 16.8 NTU to 35.41 NTU with an average of 27.57 NTU, while laboratory analysis yielded a value of 16 NTU, with an average difference of 11.57 NTU. The advantage of the real-time monitoring system lies in its ability to continuously record turbidity fluctuations, as evidenced by the increase in turbidity values from contact time 1 to 4 within the range of 4.03–5.53 NTU, which then fluctuated from contact time 5 to 7. An evaluation of Indonesian Ministry of Health Regulation No. 2 of 2023, which sets the water turbidity quality standard for hygiene and sanitation purposes at <3 NTU, indicates that neither measurement method meets the established standard, with an average instrument value of 27.57 NTU and a laboratory value of 16 NTU. High turbidity values hinder the penetration of sunlight into the water, thereby disrupting the photosynthesis process, reducing chlorophyll levels, and decreasing the water's primary productivity, as turbidity reflects the optical properties of water determined by the ability of particles to reflect and absorb light (Ngantu & Boma, 2023).



Gambar 7 Turbidity Diagram

MAPE Test

Tabel 5 MAPE Test in real-time monitoring compared to laboratory tests

Parameter	Average Real Time Monitoring	Average Laboratory Testing	MAPE Test
Temperature	33,36	26,8	19.69 %
TDS	177.51	93	47.36 %
pH	7.,30	6,1	16.09 %
DO	9,56	5,531	41.66 %
Turbidity	27.57	16	37.78 %

Table 5 presents the results of the MAPE statistical test comparing real-time monitoring and laboratory analysis. Based on the MAPE statistical test conducted on all water quality parameters, the MAPE values obtained were 19.69% for Temperature, 16.09% for pH, 47.36% for TDS, 41.66% for DO, and 37.78% for Turbidity. These results indicate that the real-time monitoring device's measurements for Temperature and pH fall within the "good" performance range, while those for TDS, DO, and Turbidity fall within the "acceptable" performance range. Based on this data, the performance ranking of the real-time monitoring device from lowest to highest is: pH, Temperature, Turbidity, DO, and TDS.Overall, all parameters measured using the real-time monitoring device remain within an acceptable range; therefore, the device can be considered sufficiently effective for use as a method for monitoring the water quality of Lake UNHAS, although further calibration and refinement are still required to improve measurement accuracy.

Conclusion

Water quality monitoring of Lake UNHAS using a real-time monitoring system and laboratory analysis shows that the real-time monitoring device consistently…

Water quality monitoring of UNHAS Lake using a real-time monitoring system and laboratory analysis shows that the real-time monitoring device consistently produces higher values for all parameters, with a difference of 6.56°C for temperature, 84.51 mg/L for TDS, 1.2 for pH, 4.007 mg/L for DO, and 11.57 NTU for turbidity. An evaluation of Government Regulation No. 22 of 2021 and Ministry of Health Regulation No. 2 of 2023 indicates that the temperature readings from the device (a deviation of 6.36°C) and turbidity readings from both methods (27.57 NTU and 16 NTU) do not meet the established standards and require further attention, while the TDS parameters (177.51 mg/L and 93 mg/L), DO (9.56 mg/L and 5.553 mg/L), and pH (7.3 and 6.1) remain within the applicable quality standards, so the water conditions of Lake UNHAS for these three parameters are still classified as good.

The results of the MAPE statistical test showed values of 19.69% for temperature, 16.09% for pH, 47.36% for TDS, 41.66% for DO, and 37.78% for turbidity, with the order of accuracy from highest to lowest being pH, temperature, turbidity, DO, and TDS. Overall, all parameters fell within acceptable ranges, indicating that the real-time monitoring system is sufficiently effective as a method for monitoring water quality in Lake UNHAS. However, significant differences in results compared to laboratory analysis indicate limitations in sensor sensitivity; therefore, efforts to improve accuracy are needed through periodic calibration, routine maintenance, optimization of sensor placement, and the use of higher-specification sensors to produce measurements that are more consistent with laboratory analysis results.

This research provides empirical quantitative evidence through MAPE statistical evaluation, demonstrating the effectiveness of real-time monitoring systems for continuous lake water quality surveillance, thereby enriching the literature on environmental sensor technology and serving as a reliable reference for researchers in assessing the accuracy of multi-parameter monitoring devices in freshwater ecosystems. These findings also offer a scientific basis for the Makassar City Government to prioritize remediation of non-compliant parameters, particularly temperature and turbidity, while adopting real-time monitoring technology as a cost-efficient solution for sustainable urban lake ecosystem management.

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