



SPASIAL ANALYSIS OF PHYSICO-CHEMICAL PARAMETERS OF WATER AND SOIL IN THE KUALA LANGSA MANGROVE ECOSYSTEM, ACEH

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Abstract

Mangrove ecosystems play a vital role in maintaining coastal ecological balance through their biological, hydrological, and economic functions. However, increasing anthropogenic activities such as aquaculture, settlement expansion, and infrastructure development have led to environmental degradation in the mangrove areas of Kuala Langsa, Aceh. This study aims to analyze the physicochemical characteristics of water and soil in three mangrove zones—ecotourism, residential, and airport areas—by measuring parameters such as temperature, oxidation-reduction potential (Eh), water and soil pH, salinity, and moisture content. Field sampling was conducted in situ in February 2024 using a purposive sampling method, while data analysis was performed descriptively and quantitatively. The results show that Station 1 (Mangrove Ecotourism Area) exhibited the best environmental conditions, with an average temperature of 30 °C, Eh of 141.67 mV, water pH of 7.14, soil pH of 6.34, salinity of 33‰, and soil moisture of 67.6%. Station 2 (Residential Area) experienced higher anthropogenic pressure, indicated by higher temperature (33.33 °C), negative Eh (-159.33 mV), and lower salinity (2‰). Meanwhile, Station 3 (Airport Area) showed stable environmental conditions with a positive Eh (115.33 mV), neutral pH, salinity of 2.5‰, and moisture of 32.33%. Overall, the Kuala Langsa mangrove ecosystem still demonstrates a good degree of ecological resilience, although some areas have experienced degradation due to human activities. This study highlights the importance of ecosystem-based adaptive management through domestic waste control, tourism activity regulation, and mangrove vegetation conservation as ecological buffer zones to sustain the environmental functions of coastal ecosystems.

Keywords: Mangrove Ecosystem, Water Quality, Soil Quality, Kuala Langsa, Aceh

A. Introduction

Mangrove ecosystems are coastal systems with crucial ecological and economic functions, particularly in supporting fisheries productivity, coastal protection, and controlling seawater intrusion. Mangroves also act as buffer zones and natural filters for pollutants from land-based activities entering the sea. However, the balance of this ecosystem is highly dependent on the quality of the surrounding waters and soil. Environmental parameters such as temperature, pH, salinity, humidity, and redox potential are key indicators for assessing the condition and health of mangrove habitats.

Several recent studies have shown that mangrove degradation generally begins with gradual but consistent changes in the physical and chemical quality of water and soil (Alongi 2020). Decreases in redox potential and soil pH, for example, have been shown to inhibit root respiration and reduce the regeneration capacity of mangrove vegetation (Lovelock et al. 2022). Furthermore, imbalances in water salinity and temperature disrupt the metabolism of benthic organisms and influence the distribution patterns of aquatic species that are part of the primary food chain in mangrove ecosystems (Walcker et al. 2021). Against this backdrop, research examining detailed physicochemical parameters is crucial for identifying potential ecological pressures before further damage occurs.

Anthropogenic pressures on coastal areas have also intensified over the past decade, reinforcing the urgency of data-driven environmental mangrove management. A study by Kodikara et al. (2022) confirmed that port activities and coastal land conversion in Southeast Asia have increased heavy metal levels and deteriorated mangrove soil quality, which in turn has implications for the ecosystem's declining function as a carbon sink. Similarly, findings by Kuenzer and Tuan (2023) suggest that without systematic monitoring of water and soil quality, mangrove areas are at risk of community structure degradation and rapid ecosystem loss. In Kuala Langsa, where port and fishery activities continue to increase, research on temperature, pH, redox potential, salinity, and humidity parameters is crucial as a basis for developing targeted conservation strategies.

The Kuala Langsa mangrove area faces environmental pressures due to intensive anthropogenic activities such as cultivation, port activities, and land use change (Kusuma et al. 2020; Purba et al. 2023). This pressure can affect water and soil quality, directly impacting the structure and function of the mangrove ecosystem (Zurba et al. 2017; Tarunamulia et al. 2024). If not monitored regularly, environmental degradation can lead to irreversible ecosystem damage (Gland 2024; Zhou et al. 2024).

A common solution is to monitor environmental quality using a scientific approach based on measurable parameters. Observations of temperature, redox potential, water and soil pH, salinity, and humidity can provide a comprehensive picture of the physicochemical conditions of the waters and mangrove substrate (Dumaguit et al. 2024).

By integrating this data, areas experiencing high stress and requiring management priority can be identified. Although there has been considerable research on air and soil quality in various mangrove ecosystems in Indonesia, such as the study of physicochemical parameters (temperature, pH, salinity, DO, BOD, and turbidity) in mangroves on the Suppa Coast, South Sulawesi, conducted by Toriman et al. (2013), and the study by Febriansyah et al. (2022) which assessed air quality based on physical, chemical, and phytoplankton parameters in the Pancer Cengkong and Sine mangrove ecosystems, East Java. Most studies still focus on vegetation and biodiversity, without directly linking them to abiotic environmental conditions. This study aims to spatially analyze water and soil quality in the Kuala Langsa mangrove area by measuring temperature (°C), redox potential (mV), water pH, soil pH, salinity (‰), and humidity (%). This study is designed to reveal current environmental conditions and provide a scientific basis for mangrove ecosystem protection and management efforts.

B. Methodology

1. Research Design

This research was conducted in February 2024 in the Kuala Langsa mangrove ecosystem, located in Langsa City, Aceh Province. This area is a coastal region with high biodiversity and plays a crucial role in maintaining the balance of the coastal ecosystem.

The research locations were selected using purposive sampling, taking into account differences in anthropogenic activity levels and environmental conditions at each location. Three observation stations represented different mangrove ecosystem characteristics: Station 1: A mangrove area within the Kuala Langsa mangrove ecotourism zone, which is relatively well-managed and offers high tourist access. Station 2: A mangrove area adjacent to residential areas,

potentially subject to environmental pressures from the domestic activities of the surrounding community. Station 3: A mangrove area located around the Langsa City airport, with potential ecological disturbances due to transportation activities and infrastructure development. The selection of these three stations is expected to provide a comprehensive picture of the varying conditions of the mangrove ecosystem in the Kuala Langsa area, both in terms of the level of anthropogenic disturbance and its biological and physical-environmental characteristics.

2. Instruments

The instruments used in this study included a digital thermometer for measuring water temperature, a pH meter for assessing the pH of water and soil, a salinometer for determining salinity, a soil moisture meter for measuring soil moisture content, and an ORP meter for evaluating oxidation–reduction potential (Eh). Water temperature was measured by immersing the thermometer sensor into the water until a stable reading was obtained. The pH of water and soil was measured using a calibrated pH meter, with the electrode inserted into the respective samples. Salinity was determined using a salinometer by applying a drop of the water sample onto the instrument's prism surface. Soil moisture was measured by inserting the probe of the soil moisture meter into the sediment at a consistent depth. Meanwhile, redox potential (Eh) was measured using a calibrated ORP meter, with the electrode placed directly into the sample to obtain the oxidation–reduction conditions of the water or sediment. Additionally, a Global Positioning System (GPS) was used to determine the coordinates of the sampling locations, a digital camera for field documentation, and stationery and data recording forms for field data collection. Additional materials, including standard pH buffers and calibration solutions, were used for instrument calibration prior to measurements. All equipment was calibrated according to the manufacturer's Standard Operating Procedure (SOP) to ensure the accuracy and precision of field measurements.

Parameter sampling and measurement were conducted directly in the Kuala Langsa mangrove ecosystem area, Langsa City, Aceh Province. Observation points were determined using a purposive sampling method, taking into account vegetation conditions and the location's proximity to potential pollution sources. Based on these considerations, three observation stations were established: Station 1, a mangrove area located in an ecotourism area; Station 2, a mangrove area adjacent to residential areas; and Station 3, a mangrove area located around the Langsa City airport area. Measurements were repeated four times at each station, and all observation points were mapped using GPS to ensure location consistency at each repetition.

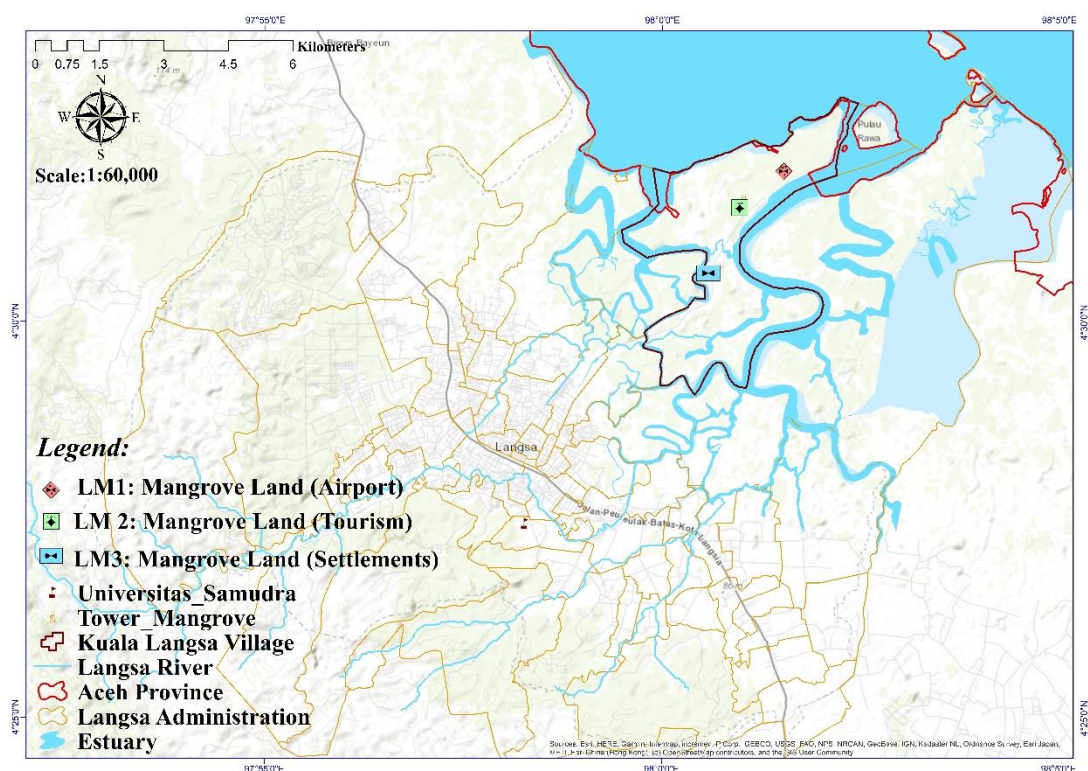


Figure 1. Research location map in Kuala Langsa, Langsa City, Aceh, Indonesia

3. Technique of Data Analysis

Data from physical and chemical parameter measurements, including water temperature, water and soil pH, salinity, soil moisture, and redox potential (Eh), were analyzed quantitatively to describe environmental conditions at each observation station. Mean values, standard deviations, minimum and maximum values were calculated for each parameter to examine spatial variation between stations and between replicates. Comparisons between stations were made by examining differences in parameter value trends as indicators of the influence of environmental activities in the surrounding area, such as tourism, settlements, and proximity to airports.

Furthermore, the measurement results for each parameter were compared with relevant environmental quality standards, such as seawater quality standards and coastal soil quality standards, to assess the ecological status of the mangrove area. Patterns of relationships between parameters, such as the relationship between salinity and pH or between soil moisture and Eh values, were interpreted to understand the dynamics of biogeochemical processes in mangrove sediments. The analysis was performed using Microsoft Excel or other simple statistical programs to ensure calculation accuracy and facilitate graphical visualization.

C. Findings and Discussion

1. Findings

Station 1 Mangrove Ecotourism

Observation results (Figure 1) at Kuala Langsa Mangrove Ecotourism Station 1 show that environmental quality is in a condition that supports the ecological function of mangroves.

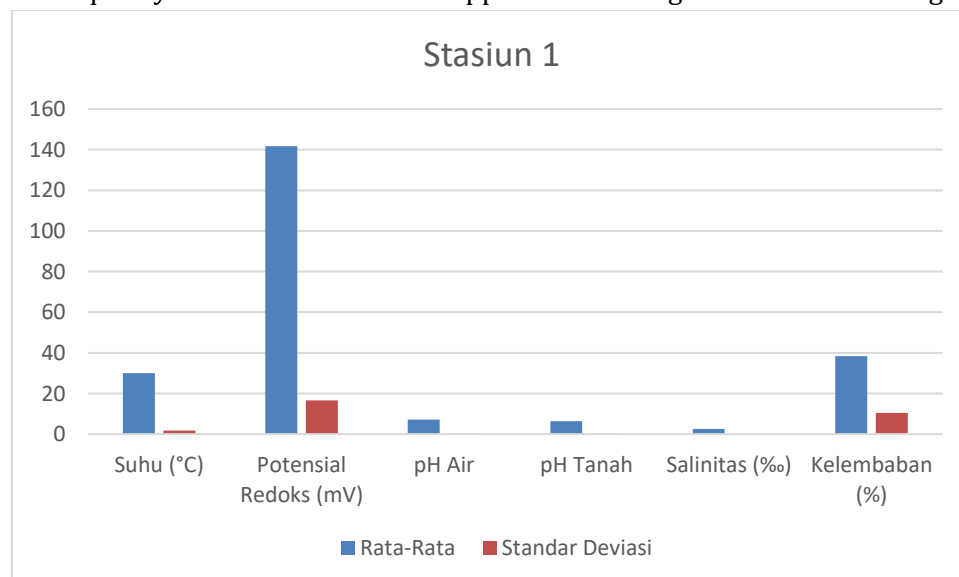


Figure 1. Water and Soil Quality Graph in Mangrove Ecotourism Areas

Physical and chemical parameter measurements in the research area indicate environmental conditions conducive to the sustainability of the mangrove ecosystem. The average water temperature was recorded at 30°C, with relatively little daily variation. This value indicates stable thermal conditions, reflecting the influence of tropical air temperatures and seawater circulation around the research area.

This temperature stability has the potential to maintain the metabolic activity of aquatic organisms at optimal levels. The redox potential (ORP) value was 141.67 mV, indicating relatively oxidative water conditions. This value indicates that oxidation processes are still occurring well in the sediment and water, which generally reflects healthy aerobic microbial activity. The water pH was around 7.14, indicating neutral conditions that are generally ideal for aquatic organisms and water chemical stability.

Meanwhile, the average soil pH was 6.34, indicating slightly acidic conditions common in mangrove ecosystems due to the accumulation of organic matter and microbiological activity in the topsoil. Furthermore, the water salinity was recorded at 33‰, indicating the dominance of seawater in the area. This value indicates that the study site is located in a euhaline zone with high salinity, a characteristic of coastal mangrove habitats. The soil moisture level averaged 67.6%, reflecting moist and saturated soil conditions. This value indicates that the substrate has a high water retention capacity, thus supporting root respiration and mangrove vegetation growth even under partially anaerobic conditions. Overall, the combination of temperature, pH,

ORP, salinity, and soil moisture parameters reflects suitable environmental conditions for mangrove growth and biological activity in the study area.

Station 2 settlements

The results of environmental parameter measurements in the mangrove ecosystem adjacent to residential areas (Station 2) show variations in physical and chemical conditions reflecting the influence of anthropogenic activities. The average value and standard deviation of each environmental parameter are presented in Figure 2.

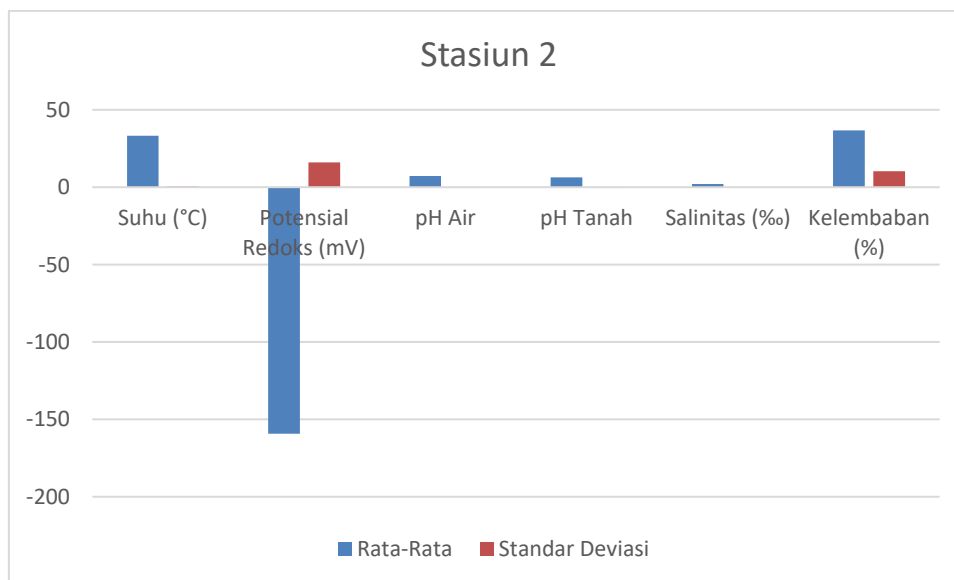


Figure 2. Graph of Water and Soil Quality in Residential Areas

Measurements at Station 2 showed that the water temperature ranged between 33–34°C, with an average of 33.33°C and a standard deviation of 0.58°C. This value was slightly higher than the temperature at the Mangrove Ecotourism Station (30°C).

The redox potential (Eh) at this location reached -159.33 mV, indicating reductive (anaerobic) conditions in the mangrove sediment. The water pH was recorded at 7.27 and the soil pH at 6.28, indicating neutral to slightly acidic conditions. A salinity value of 2‰ indicates a strong influence of freshwater from surface runoff and residential drainage. The average soil moisture content was 36.67% with considerable variation (SD = 10.41%).

Station 3 Airport

Environmental conditions at Station 3, adjacent to Langsa City Airport, demonstrate a relatively stable mangrove ecosystem with minimal anthropogenic disturbance compared to the other two stations. Temperature, redox potential, and pH values are within the optimal range for the continued functioning of the tropical mangrove ecosystem.

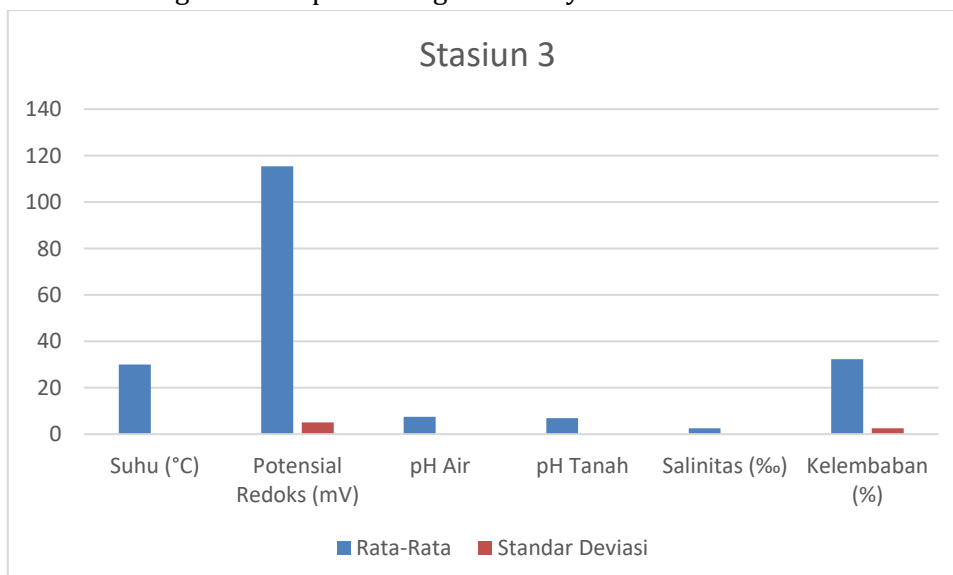


Figure 3. Graph of Water and Soil Quality in the Airport Area

Observations at Station 3 showed a constant water temperature of 30°C, indicating good thermal stability with minimal fluctuations in heat energy. A redox potential (Eh) of 115.33 mV indicates favorable oxidative conditions, indicating the availability of dissolved oxygen in the sediment layer and allowing for aerobic decomposition of organic matter.

The water pH of 7.47 and the soil pH of 6.96 indicate neutral to slightly alkaline conditions, reflecting the stability of the aquatic system. A salinity value of 2.5‰ indicates that the ecosystem around Station 3 is located in an estuary zone influenced by freshwater. A soil moisture content of 32.33% indicates a water-saturated substrate that supports the activity of soil microorganisms. A low standard deviation of moisture (2.52) indicates physical environmental stability without significant fluctuations.

In general, comparisons between stations indicate a gradient in environmental quality from Station 1 (ecotourism) to Station 2 (residential), with conditions improving at Station 3 (airport). The highest temperature and lowest Eh values were found at Station 2, indicating a strong influence of human activities on oxidation-reduction conditions and water stability. Conversely, Stations 1 and 3 showed positive Eh values, indicating good oxidative conditions and adequate sediment aeration. The relatively stable pH values at all stations indicate the mangrove system's ability to maintain chemical balance. Low salinity values at all stations (2–2.5‰) indicate the dominance of freshwater influences in the Kuala Langsa coastal area.

2. Discussion

The average water temperature of 30°C is within the optimal range reported by Kusmana et al. (2019), which is between 28–32°C, which is considered ideal for the growth of plankton and aquatic microorganisms and accelerates the decomposition of organic matter. The ORP value of 141.67 mV indicates relatively oxidative conditions. This supports the findings of Syahrial et al. (2022), who stated that an ORP in the range of 100–300 mV reflects healthy aerobic microbial activity and facilitates the mineralization of organic matter without producing toxic compounds such as sulfides.

Therefore, the ORP conditions in this study area can be categorized as safe for mangrove roots and soil biota. The water pH parameter, which is in the neutral range (average 7.14), is consistent with the research results of Lestari et al. (2019), which showed that a pH between 6.5–8.5 is the optimal range for water chemical stability and nutrient availability for organisms. Meanwhile, the slightly acidic soil pH (6.34) aligns with the natural acidic conditions of mangrove soil due to the accumulation of organic matter and microbiological activity.

This value supports ideal conditions for dominant mangrove species such as *Rhizophora* and *Avicennia*. A salinity of 33‰ indicates a strong influence of seawater and aligns with the euhaline zone (>30‰) as classified by Alongi (2002), who explained that many mangrove species have physiologically adapted to hypersaline conditions. Furthermore, the soil moisture content of 67.6% also supports a study by Rahman et al. (2020), which states that humidity above 60% allows mangrove roots to maintain respiration under partially anaerobic conditions.

The relatively high temperature at Station 2 indicates the influence of local activities, such as household waste disposal and surface water flow from residential areas, which can increase the temperature of the surrounding waters. The low Eh value (–159.33 mV) indicates anaerobic conditions due to low dissolved oxygen in the substrate, resulting in the decomposition process being dominated by anaerobic microorganisms (Reddy et al. 2008; Zhang et al. 2024).

This condition is common in mangrove ecosystems that experience high loads from human activities, such as waste and land litter (Alongi, 2015). The pH of the water and soil remained within the mangrove tolerance range (6.0–8.5 according to Kathiresan & Bingham, (2001), indicating that the mangrove buffering capacity is still able to maintain environmental stability despite the influence of residential activities. The low salinity value indicates the dominance of freshwater, which can reduce the diversity of aquatic biota and affect the presence of certain mangrove species (Duke et al., 2007).

The stability of the water temperature at Station 3 indicates an environment that does not experience significant thermal fluctuations, despite its proximity to the airport. This indicates that heat emissions from aviation activity and surrounding infrastructure do not significantly impact water temperature. Temperature stability is crucial because it influences the metabolic activity of aquatic organisms and biogeochemical processes in the sediment (Rahman et al., 2020).

The positive Eh value (115.33 mV) aligns with Alongi (2015) criteria, which states that values above +100 mV indicate healthy oxidative conditions. These conditions support the stability of nutrients such as nitrogen and phosphorus in the sediment and reflect sufficient oxygen availability for the aerobic decomposition of organic matter. Compared with Station 2, which had a negative (reductive) Eh value, Station 3 exhibits a much lower level of environmental disturbance. The pH of the water (7.47) and soil (6.96), which are in the neutral-slightly alkaline range, demonstrate the natural ability of the mangrove ecosystem to neutralize acidic or alkaline inputs from rainwater and surface runoff Nurjanah et al., 2021).

These conditions also support the physiological activity of mangroves and other aquatic organisms, in line with the ideal mangrove pH range (6.0–8.5) according to Kathiresan & Bingham (2001). The low salinity value (2.5‰) indicates a significant freshwater influence, likely from rainfall or small river flows around the airport. However, this value is still within the tolerance range of most euryhaline mangrove species. This salinity stability indicates that there have been no major hydrological changes or excessive seawater intrusion at the site. The high and stable soil moisture (32.33%) supports the activity of soil microorganisms and the absorption of nutrients by mangrove root systems (Lestari et al., 2019).

The low standard deviation of moisture (2.52) confirms that the physical conditions of the environment do not fluctuate significantly. Overall, the mangrove ecosystem along the coast of Kuala Langsa demonstrates quite good ecological resilience, although residential areas are beginning to show signs of environmental degradation. Therefore, an integrated management strategy is needed to maintain the sustainability of the ecosystem, including controlling domestic waste, monitoring tourism activities, and preserving mangrove vegetation around the airport as an ecological buffer zone (Pranowo et al., 2022).

D. Conclusion

The results of the study indicate that the three observation stations have varying environmental conditions reflecting differences in the level of anthropogenic pressure. Station 1 (Mangrove Ecotourism) is in good environmental condition with relatively low influence of human activities, while Station 2 (Residential Settlement) shows ecological disturbances due to waste disposal and domestic activities that increase pressure on the mangrove ecosystem. Meanwhile, Station 3 (Airport) shows high stability of physical and chemical environmental conditions despite being close to major transportation infrastructure. These findings emphasize the importance of implementing ecosystem-based adaptive management to maintain the sustainability of the Kuala Langsa mangrove ecosystem as a natural coastal fortress that has ecological, social, and economic functions that are very vital for the balance of the coastal environment.

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