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Research Article

Assessment of Saltwater Intrusion and Its Effects on Water Quality at Pantai Punggur, Johor

Nur Farahanim Mohd Zulkifli [1], Sabariah Musa [2]*, Muhammad Hazim Ahmad Uma [3]
[1, 3] *Department of Civil Engineering, Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, 86400, Johor, Malaysia*
[2] *Eco-Hytech Research Centre, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, 86400, Johor, Malaysia*
**Corresponding Author Email: nurfarahanimzulkifli@gmail.com*

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ABSTRACT

Coastal regions in Malaysia face significant risks from saltwater intrusion, influenced by multiple factors such as climate change, increasing sea levels, and human activities like agriculture, industry, and urban development. A study was carried out to investigate saltwater intrusion at Pantai Punggur, Batu Pahat. A series of tests are conducted to determine the characteristics of water using the Horiba Water Quality Monitor test. The parameters under consideration include salinity (ppt), dissolved oxygen (DO) (mg/L), turbidity (NTU), total dissolved solids (TDS) (g/L), and pH. Ten distinct sections were examined along the Pantai Punggur to assess the various parameters. The findings reveal that the highest salinity levels in Pantai Punggur are found at point sections 1 to 4, where saltwater intrusion is evident, exhibiting salinity values between 17.8 and 26.2 ppt. Consequently, saline water is observed at section points 5 to 10, where the measurement approaches 0 ppt. In terms of dissolved oxygen, the results indicate that the locations with the highest DO levels are points 8 and 9, with measurements ranging from 6.5 to 7.5 mg/L. The pH values at sampling points 1 to 6 are expected to be alkaline, falling within the range of 7.3 to 7.84. The red zone in turbidity indicates the peak turbidity values, which range from 60 to 80 NTU at point sections 8, 9, and 10. The maximum value for Total Dissolved Solids (TDS) ranges from 18 to 25 between sampling point 1 and point 2. These findings enhance our comprehension of the dynamics within coastal ecosystems. The study offers important findings for upcoming agricultural methods in salt-affected regions, with the goal of enhancing crop yield and informing stakeholders about the effects of saltwater intrusion on farming.

Keywords: Water Quality, Salinity, Turbidity, Dissolved Oxygen, Total Dissolved Solids.

INTRODUCTION

Saltwater intrusion has emerged as a significant challenge that coastal communities around the globe are facing [1]. As sea levels rise along the coast, saltwater may seep into the land. This causes sea level rise to submerge low-lying areas, resulting in the loss of some activities near the coast. These pose a major threat to the sustainable development of coastal areas as they directly impact the physical property, important coastal infrastructure including transport network and utility infrastructure, production process, natural and cultural resources, and indirectly, impact the ecosystem, economic activities, income, wealth, public health, safety, and overall social well-being of the coastal community [2].

Saline water intrusion represents a significant challenge impacting surface water bodies in coastal regions worldwide [3]. Coastal regions in Malaysia face significant challenges from saline water intrusion, influenced by various factors such as climate change, rising sea levels, and human activities including agriculture, industrialisation, and urbanisation [4]. Several studies have been carried out in Malaysia to evaluate the effects of saline water intrusion on surface water bodies. Climate change influences the salinity levels of surface water bodies within the Klang River Basin, Malaysia [5]. The investigation revealed a notable increase in the salinity of surface water bodies because of

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climate change, resulting in a deterioration of water quality and aquatic ecosystems. Saline water intrusion has the potential to impact agricultural production in coastal areas [6].

Conversely, the harmful effects of high soil salinity on the soil ecosystem go beyond the chemical and physical properties of the soil, adversely affecting plants, microbes, and various soil organisms [7]. This study focuses on the impact on agricultural activities. This phenomenon arises from the intrusion of saline water, resulting in the decline of various coastal plant species. Many crops face significant challenges when attempting to grow in environments characterised by elevated salinisation levels in both soil and water. Saltwater intrusion into groundwater from coastal areas or excessive irrigation leads to a gradual process of soil salinisation, making it unsuitable for agricultural purposes [8]. Coastal low-lying areas present significant challenges in water resource management due to their dense populations, intricate human activities, and heightened vulnerability to various threats, including saltwater intrusion. A significant portion of agricultural land globally is in low-lying coastal regions that have undergone reclamation [9]. As a result, soil salinisation in low-lying coastal areas is anticipated to emerge as a critical global challenge in safeguarding food security and advancing sustainable development [10].

According to the previous study, the rich biological ecosystem of Pantai Punggur relies on brackish water for various purposes, including agriculture, aquaculture, and household needs [11]. Nonetheless, the area is susceptible to the encroachment of saltwater due to both natural occurrences and anthropogenic influences. According to a prior investigation by Rahman, the effects of saltwater intrusion reach beyond environmental issues to include socio-economic ramifications, influencing the livelihoods of communities reliant on brackish water resources [12]. Saline water encroaches upon freshwater sources, jeopardising agricultural output, the quality of drinking water, and the health of aquatic ecosystems, thereby presenting a significant threat to human health and ecological balance. This investigation focused on examining the physical and chemical characteristics of saltwater intrusion in brackish water at Pantai Punggur, with the goal of proposing a mitigation strategy.

MATERIALS AND METHODS

The preliminary work involved on gathering data at the location by examining the salinity levels within the study area. The parameters examined in this study included salinity, Dissolved Oxygen (DO), pH of the water sample, turbidity, Total Dissolved Solids (TDS), and conductivity (EC).

Study Area

A location study was conducted at Pantai Punggur, Batu Pahat, situated at 1°41'18.5172' North and 103°5'56.9544' East in Johor, to assess the distribution of saltwater intrusion in the region. Collecting water samples near the sea is advisable to identify the source of saltwater intrusion. According to earlier investigations, the study area is identified as a zone of saline water intrusion, distinguished by clay soil that impacts the groundwater in Batu Pahat, Johor [13]. Ten distinct sections have been established to assess the extent of saltwater intrusion in the region. The sample collection took place in November 2023 during the Northeast Monsoon Season, spanning a distance of 0.45 km. The point section was gathered in a specific location to determine the parts per thousand (ppt) of saltwater intrusion units. The identification of saltwater intrusion sites involves the assessment of flooded areas through salinity testing outcomes. Each point section collected will serve as a reference to determine the extent of saltwater intrusion within the study area. Figure 1 illustrates the study area's location: (a) at Pantai Punggur and (b) the 10-point sections where the water analysis was conducted.

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Fig. 1 Location of the study area (a) Pantai Punggur; (b) 10-point sections

Data Collection

This study involves the analysis of 10-point sections at Pantai Punggur to determine the extent of saltwater intrusion. The point section underwent analysis using the Horiba monitor for water quality, as illustrated in Figure 2. The Horiba water quality monitor is engineered to provide precise measurements of various water quality parameters, allowing users to gather essential data for pollution control, ecosystem oversight, and environmental studies. This instrument offers a comprehensive analysis of water's physical and chemical properties by measuring various parameters, including temperature, dissolved oxygen, pH, and conductivity. Prior to commencing the water quality monitoring process, the Horiba water quality monitor was carefully set up. The instrument was subjected to a comprehensive examination to verify its cleanliness and overall condition. In order to avoid any potential cross-contamination during measurements, the sensor probes underwent a meticulous rinsing process with clean water. This step was crucial for ensuring the precision and dependability of the following readings. Devices equipped with data logging features enabled seamless transfer of information to a computer or storage medium. This additional phase facilitated an in-depth examination of the gathered data.

Fig. 2 Water quality meter for physical and chemical testing

Salinity of Water

The classification of salinity levels will be determined based on the values presented in Table 1. Salinity is defined as the concentration of soluble salts in soils, with sodium chloride (NaCl) being the primary component. An essential measure associated with soil salinity is electrical conductivity (EC), with elevated values indicating increased salinity levels. The examination of saltwater intrusion into brackish water flow at Pantai Punggur indicates that salinity plays a crucial role. The process of data collection facilitates the identification of salinity levels at each section by examining the salinity values expressed in parts per thousand (ppt). The salinity measurements for this study have been categorised according to the location of each point, beginning with the nearest point in the coastal area of Pantai Punggur and continuing until the salinity reading reaches 0 ppt.

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Table 1 Water salinity [14]

Salinity Status	Salinity (ppm)	Salinity (ppt)	Salinity (%)
Fresh water	<1000	<1	0.1
Slightly saline water	1000 – 3000	1 – 3	0.1 – 0.3
Moderately saline water	3000 – 10000	3 – 10	0.3 – 1
Highly saline water	10000 – 35000	10 – 35	1 – 3.5
Ocean water	>35000	>35	>3.5

pH Level of Water Sample

The pH requirement for seawater ranges from 6.5 to 8.5, with a maximum deviation of 0.2 units from this typical range. Aquatic species necessitate that the pH of their water environment remain within a defined range to ensure optimal growth and survival. Nonetheless, testing the pH of water is crucial, as aquatic organisms can perish if the pH levels are excessively high or low. The classification of the pH data will be based on the water pH level values, as illustrated in Table 2. The optimal pH range for the majority of crops lies between 6 and 7.5. Soil pH refers to the relationship between the availability of plant nutrients and the acidity or alkalinity of the soil [15]. Therefore, assessing the pH of a water sample is crucial for understanding its appropriateness for plant growth and potential agricultural yield.

Table 2 Water pH levels [16]

Type of water	pH level
Tap water	7.5
Distilled reverse osmosis waters	5 – 7
Common bottled waters	6.5 -7.5
Ocean water	8
Acid rain	5 – 5.5

Dissolved Oxygen (DO)

To thoroughly comprehend the chemical and physical properties of the water sample at Pantai Punggur, it is essential to consider Dissolved Oxygen (DO) as a significant parameter. Concentrations of dissolved oxygen below 3 mg/L may lead to plant stress, root suffocation, and an imbalance in microbial communities [17]. Dissolved oxygen is often associated with soil aeration in discussions about soils, influencing various soil properties. Dissolved oxygen is crucial for maintaining aerobic conditions in water samples, as salts can influence soil structure. Salinity influences the permeability and porosity of soil, while dissolved oxygen content impacts the redox potential, subsequently affecting microbial activity and nutrient cycling. Table 3 presents the ranges of dissolved oxygen as interpreted by the water quality data [18]. Maintaining optimal dissolved oxygen levels (5–8 mg/L) in irrigation water is essential for ensuring crop health, enhancing soil fertility, and promoting agricultural sustainability. Insufficient dissolved oxygen (DO) levels lead to poor root development, microbial imbalances, and issues with waterlogging, while properly oxygenated water facilitates nutrient uptake and supports robust plant growth. Efficient oversight of irrigation, aeration, and drainage systems is crucial for sustaining dissolved oxygen levels and fostering sustainable and productive agricultural practices. Consequently, analysing the dissolved oxygen levels in the soil can provide insights into the overall health of the soil and its ability to support microbial activity and plant growth in saline-alkaline conditions.

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Table 3 DO level for water irrigation [18]

DO level (mg/L)	Water Irrigation
<6 mg/L	Ideal for all crops, promotes root respiration
4–6 mg/L	Acceptable for most crops, but aeration may be needed
<3 mg/L	Unsuitable for many crops, risk of root stress and soil degradation

Turbidity and Total Dissolved Solid (TDS)

Increased turbidity levels in aquatic environments can influence the adjacent soil compositions. The presence of turbid water at Pantai Punggur could potentially influence the brackish water in the area, especially if the turbidity is caused by suspended sediment or particulate matter. The suspended particles can influence the permeability, texture, and structure of water, potentially settling at the surface or becoming part of its matrix. It is crucial to keep turbidity levels in irrigation water below 50 NTU to avoid system clogging, promote proper soil infiltration, and enhance crop health. High turbidity levels surpassing 100 NTU could indicate sediment pollution, organic contamination, or possible health hazards. Implementing effective filtration, managing sediment appropriately, and adopting optimal irrigation practices are crucial for the sustainable use of water in agriculture. Therefore, considering the turbidity of the brackish water may provide valuable insights into understanding potential interactions between water quality in the study area, despite it not being a direct soil parameter.

Table 4 TDS level for agriculture water [19]

TDS level (mg/l or ppm)	Water Quality for Agriculture
<450 mg/L	Excellent (Suitable for all crops)
450–2000 mg/L	Acceptable (Tolerable for most crops)
2000–3000 mg/L	Risky (Only salt-tolerant crops can survive)
>3000 mg/L	Unsuitable (Causes soil degradation and salinity stress)

The presence of dissolved ions in saltwater significantly influences the Total Dissolved Solid (TDS) levels in brackish water systems. The optimal TDS range for agricultural water is presented in Table 4. The relationship between the salinity of the soil solution and the total dissolved solids in the soil is significant. Assessing TDS provides valuable information regarding the levels of dissolved ions present in the soil water. Previous studies have indicated that farmers can adjust their irrigation practices to prevent soil salinisation by effectively managing TDS levels [20]. Maintaining TDS levels below 1000 mg/L in irrigation water is crucial for promoting sustainable agricultural practices. Elevated levels of total dissolved solids (TDS) lead to salt stress, degradation of soil quality, and reduced efficiency in irrigation practices, ultimately resulting in negative effects on crop yields. Implementing efficient water management, using soil amendments, and adopting appropriate irrigation strategies are essential for mitigating salinity buildup and preventing soil degradation. Increased TDS levels can significantly influence overall soil fertility, nutrient availability, and the structure of the soil. TDS analysis offers a comprehensive assessment of the soil's chemical composition and its appropriateness for various land applications, such as vegetation or agriculture.

RESULTS AND DISCUSSION

Table 5 presents a summary of the data collection conducted at Pantai Punggur, Johor. This data collection aimed to assess the water quality affected by saltwater inundation at Pantai Punggur.

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Table 5 Summary of salinity and pH data at Pantai Punggur

Point Section	Coordinate	Distance Interval (m)	Salinity (ppt)	pH	Dissolved oxygen (mg/L)	Turbidity (NTU)	Total dissolved solid (g/L)
1	1°41'7.58"N 103° 5'51.00"E	0	25.30	7.53	4.85	17.5	24.2
2	1°41'7.19"N 103° 5'52.08"E	23.0	26.22	7.84	3.31	19.5	25.0
3	1°41'9.79"N 103° 5'51.72"E	65.0	22.40	7.61	4.81	28.2	4.80
4	1°41'10.30"N 103° 5'52.08"E	85.0	22.30	7.43	4.90	29.1	4.80
5	1°41'10.80"N 103° 5'53.16"E	116.0	3.60	7.27	5.74	30.1	4.10
6	1°41'11.47"N 103° 5'53.88"E	150.0	3.60	7.29	5.60	31.3	4.10
7	1°41'13.42"N 103° 5'53.88"E	190.0	3.40	6.78	6.72	23.4	3.91
8	1°41'13.88"N 103° 5'54.24"E	210.0	3.40	6.60	6.78	68.4	3.90
9	1°41'14.68"N 103° 5'56.04"E	264.0	1.20	6.2	7.21	75.2	3.82
10	1°41'17.42"N 103° 5'57.48"E	360.0	0.60	6.35	7.23	75.2	3.82

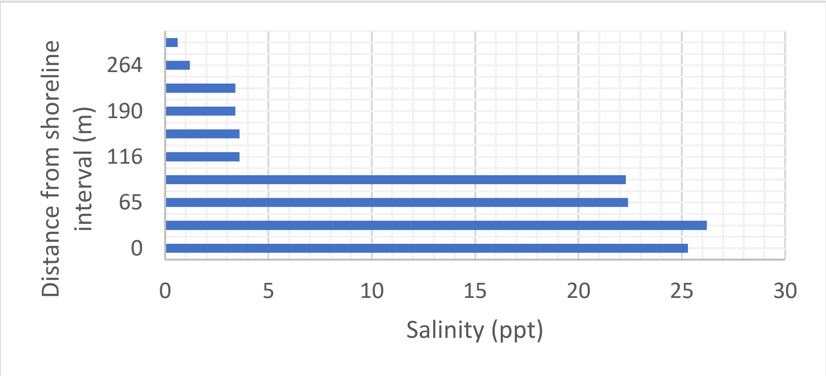

Fig. 3 Salinity-Distance from shoreline

The salinity test was conducted on December 4, 2023. Figure 3 illustrates the findings of the salinity evaluation. The data gathered at station 1 along the beach reveal a salinity level of 25.3 ppt. The observed value aligns with the established characteristics of standard seawater, given that this location is recognised as a significant source of saltwater. Measurements of salinity at stations 1 and 2, situated near the beaches, show an increase due to coastal winds carrying saltier ocean water inland. The observed rise in tides during sample collection is noteworthy, as the retreating tide facilitates the influx of saltwater from advancing coastal areas, resulting in elevated salinity levels. At station 10, the recorded salinity measurement is 0.6, which closely approximates a value of 0. The water sample has been identified as brackish water. Observations during sample intake reveal that the brackish water region displays

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unique characteristics, such as a subtle brownish hue resulting from dissolved organic matter and algae. The observed salinity values exhibit a decreasing trend from stations 5 to 10, attributed to the interplay between seawater and freshwater contributions from rivers and estuaries, shaped by coastal currents and tidal dynamics. This elucidates the occurrence where salinity diminishes as one moves further away from sources of saltwater.

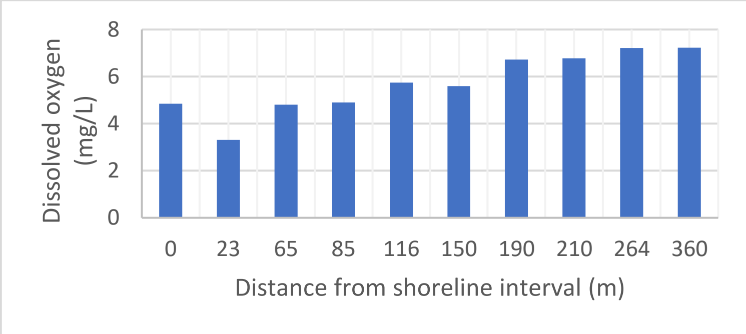

Fig. 4 DO-Distance from shoreline

The data presented in figure 4 illustrates the concentrations of dissolved oxygen within aquatic systems alongside the occurrence of saltwater intrusion. The concentration of dissolved oxygen at station 1 was the lowest compared to all other stations. This occurrence transpired due to station 1 recording the highest salinity measurement. The water in that area exhibited a higher concentration of salt relative to oxygen, a finding also addressed in research conducted by the Environmental Protection Agency (EPA). Estuaries undergo a decline in dissolved oxygen concentrations with rising salinity levels. This occurs due to the limited solubility of oxygen, resulting in the formation of distinct layers of water [21]. Dissolved oxygen levels falling below 1 mg/L are inadequate for sustaining aquatic life, while concentrations exceeding 3 mg/L pose a risk to prevalent aquatic species. As dissolved oxygen levels decrease due to increasing salinity, the aquatic environment can rapidly become perilous for the organisms inhabiting it. Tracking dissolved oxygen levels in aquatic environments is essential for the health and sustainability of marine ecosystems. The maximum dissolved oxygen level recorded was at station 10, with a measurement of 7.23 mg/L. Nonetheless, the salinity at this station is relatively low, recorded at only 0.6 ppt. This study has shown that as salinity increases, the level of dissolved oxygen decreases.

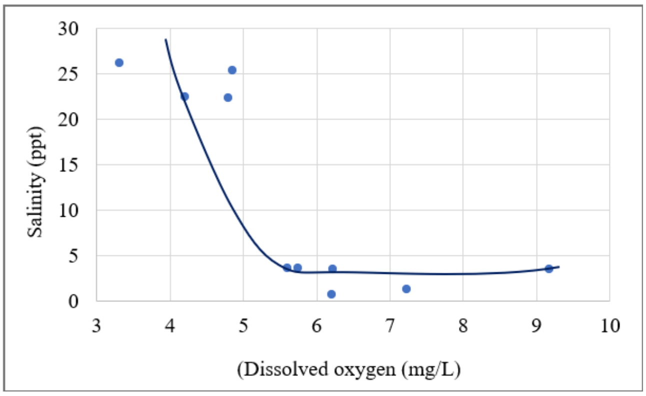

Fig. 5 The relationship between salinity and DO values

Figure 5 displays the relationship between salinity levels and dissolved oxygen concentrations in Pantai Punggur. The blue line of best fit illustrates a positive correlation between the two variables, showing that dissolved oxygen levels tend to decrease as salinity increases. The graph illustrates several blue dots, each representing unique data points that highlight the relationship between salinity and dissolved oxygen levels. An observed positive correlation suggests that increased levels of dissolved oxygen correspond with elevated salinity concentrations. In estuaries, increased salinity correlates with lower dissolved oxygen levels, affecting aquatic organisms and the overall quality of water [21]. The concentrations of dissolved oxygen and salinity levels significantly influence water quality assessment, indicating that increasing salinity results in a substantial exponential decrease in dissolved oxygen levels

[22]. This phenomenon arises from the 20% reduced concentration of dissolved oxygen in saltwater in comparison to freshwater. Dissolved oxygen levels decline at the equator due to increased salinity and temperature conditions [23]. Evaluating dissolved oxygen levels is crucial for understanding water quality, which plays a vital role in the survival of fish and other aquatic organisms.

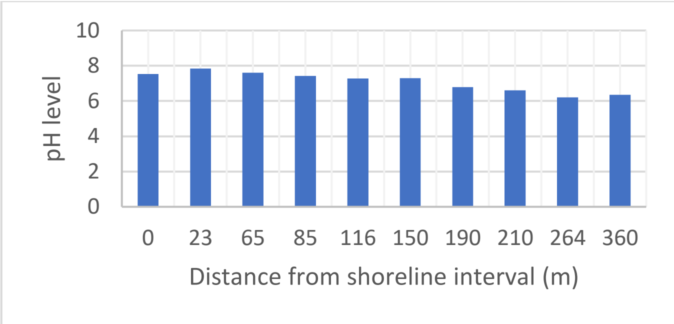

Fig. 6 pH-Distance from shoreline

The pH values presented in figure 6 for all samples were obtained through measurements taken with the water quality monitor in the laboratory setting. Saltwater intrusion can alter soil pH, leading to conditions that may become too acidic or too alkaline, depending on the particular composition of salts [24]. The findings show that pH values vary between 6 and 8 across stations 1 through 10. The data suggests that the aquatic organisms at the study site are able to flourish without encountering any obstacles. A study conducted in the Mekong Delta, Vietnam, revealed that an increase in soil salinity from 0 to 25% was associated with a decrease in soil pH, ranging from 5.14 to 5.72 and 4.08 to 5.14 [25]. The pH values observed at stations 7–10 are under 7, signifying an acidic classification. It is anticipated that the station will include organic materials, such as leaves and plants, capable of decomposing in brackish water. The procedure led to the liberation of acidic compounds, including humic and carbonic acids. The pH measurements collected from stations 1 to 6 indicate an alkaline pH level. In certain areas, elevated salinity does not consistently correlate with increased pH levels. This phenomenon occurs as ocean acidification resulting from CO_2 absorption can decrease pH levels, even in conditions of elevated salinity [26]. In estuaries, variations in pH arise from the interaction between freshwater and seawater, the introduction of organic matter, and the exchange of CO_2. This investigation attributes the improved mixing and circulation in coastal waters to the effects of waves and tides. This procedure facilitates the upkeep of a consistent pH level through exchange and water dilution processes.

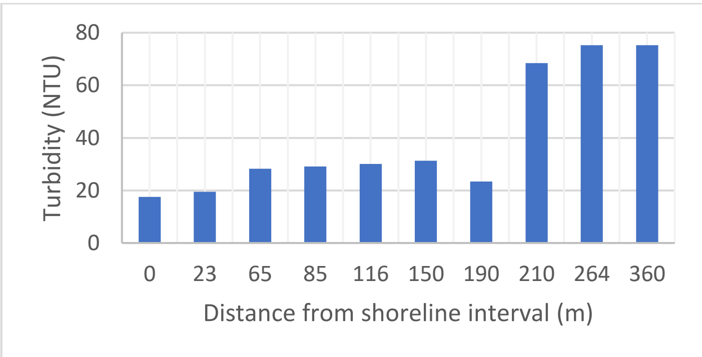

Fig. 7 Turbidity-Distance from shoreline

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Fig. 8 Water condition at station 10

Figure 7 illustrates the turbidity values. The location of the sample station impacted the data collected. Station 10 exhibited the highest turbidity, which can be linked to the water's interaction with the clay soil found in that area. Figure 8 illustrates the state of the area at station 10. The rise in turbidity correlates with a decline in salinity, as the river inputs freshwater and suspended sediments, resulting in reduced salinity levels. Elevated river discharges, marked by reduced salinity, lead to heightened turbidity because of suspended sediments. During dry seasons marked by heightened salinity, there may be a decrease in turbidity resulting from a reduction in sediment input [27]. The robust wind conditions observed during the sampling period had a significant impact on turbidity. Intense winds can generate turbulence in shallow waters, resulting in the mixing of sediments from the riverbed and their subsequent resuspension into the water column.

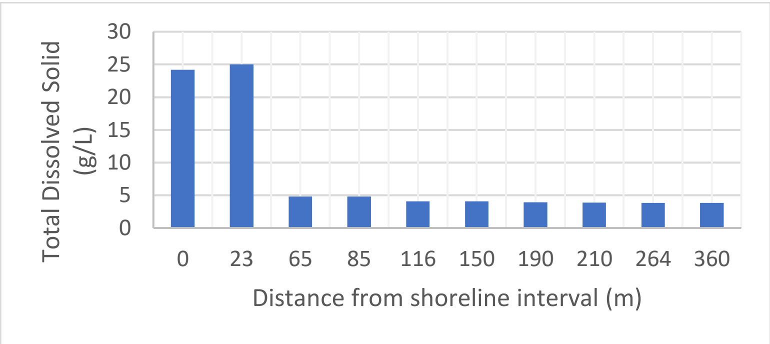

Fig. 9 TDS-Distance from shoreline

Figure 9 illustrates the total dissolved solids measurement at Pantai Punggur. Stations 1 and 2 demonstrated the highest TDS values, recorded at 24.2 and 25 g/L, respectively, due to their proximity to the nearest beach. The phenomenon occurs due to elevated concentrations of salt particles in coastal water, resulting in an increased TDS value at the shoreline. TDS consists of inorganic salts along with a minor quantity of organic matter. At the station's water source, one can observe the presence of common inorganic salts, featuring cations such as calcium, magnesium, potassium, and sodium, alongside anions including carbonates, nitrates, bicarbonates, chlorides, and sulphates. Elevated total dissolved solids, often linked to increased salinity, affect water taste, corrosion potential, and the well-being of aquatic organisms [28]. Salinity and TDS are crucial factors in assessing water quality, influencing potability, corrosion, and the well-being of aquatic ecosystems. Elevated TDS levels can impede the survival of aquatic organisms by obstructing light penetration in the water column. This subsequently influences photosynthesis and the overall productivity of these organisms.

This outcome could support farmers in their efforts to enhance agricultural practices. Gathering water quality data provides crucial understanding for sustainable agriculture, protecting crops, soil, and water resources. Regular monitoring enables the prompt detection of problems, improves water utilisation efficiency, and supports ongoing agricultural productivity. Making informed decisions leads to better outcomes for both farmers and policymakers, ultimately resulting in enhanced economic returns and the preservation of the environment.

CONCLUSION

In summary, the findings reveal that the maximum salinity was observed at point section 1, located nearest to the beach, whereas point section 10 showed the minimum salinity value, being positioned further away from the saltwater intrusion. The measurement at point Section 10, recorded as 0.6 ppt, is classified as brackish water. Brackish water is characterized by a salinity level that exceeds that of freshwater but remains lower than that of seawater. This particular water is frequently observed in estuaries, where the confluence of rivers and the sea occurs. Estuaries serve as the dynamic interfaces where freshwater from rivers converges with saltwater. The pH value has a direct correlation with the salinity level. With an increase in salinity, there will be a corresponding rise in the pH value. The higher presence of salt compared to oxygen in the water reduces the concentration of dissolved oxygen in regions with elevated salinity. Point section 1 exhibits a DO value of 4.85 mg/L, which is notably lower than the values observed in point sections 5 to 10, where the measurements range from 5 to 7 mg/L. The main factor contributing to the rise in pH with increasing salinity is the alkalinity associated with dissolved salts. The turbidity exhibits an increase from section 8 to section 10, with values ranging from 68 to 83 NTU. The result suggests that the sample introduced a suspended particle during the influx of freshwater in estuaries. An increase in salinity typically correlates with a rise in total dissolved solids (TDS). These findings deepen our understanding of the interactions within coastal ecosystems. This study provides valuable insights for future agricultural practices in saltwater regions, aiming to improve crop productivity and educate stakeholders on the impacts of saltwater intrusion on agriculture.

RECOMMENDATION FOR FUTURE WORK

This study presents several recommendations for further exploration of saltwater intrusion in relation to brackish water flow. A robust monitoring and early warning system is crucial for prompt interventions related to saltwater intrusion. Previous studies have suggested using IoT-based sensors that operate in real time to monitor pH, dissolved oxygen (DO), total dissolved solids (TDS), and salinity levels in irrigation systems [29]. The ongoing observation of salinity levels, alongside weather data, offers essential insights for predicting and alleviating the effects of saltwater intrusion. Through the assessment of agricultural methods that withstand climate change, we can address the persistent impacts of rising sea levels and saltwater intrusion [30]. Effectively managing brackish water necessitates the utilisation of geographic data to identify vulnerable regions, assess infiltration rates, and develop targeted solutions. Implement and utilise comprehensive soil management strategies to mitigate the impacts of saltwater intrusion on soil vitality. This process entails selecting suitable crops, incorporating soil nutrients, and implementing irrigation techniques that are efficient under brackish water conditions.

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