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Research Article

Analysis of Saline Intrusion Dynamics and Patterns in the Parit Botak Channel

Muhammad Hazim Ahmad Uma[1*], Sabariah Musa[2], Nur Farahanim Mohd Zulkifli[1]

[1] Department of Civil Engineering, Faculty of Civil Engineering and Built Environment. Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia

[2]Eco-Hytech Research Centre, Faculty of Civil and Environmental Engineering. Universiti Tun Hussein Onn Malaysia, 86400, Parit Raja, Johor, Malaysia

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ABSTRACT

Saline water is measured by its salinity, the amount or concentration of dissolved salts. Daily, a tidal phenomenon occurs in the Parit Botak channel, regardless of whether it is low or high. There is no tidal gate that separates the Parit Botak channel from seawater. Hence, the primary objectives of this study are identifying saline water characteristics and investigating the saline water intrusion patterns during high tide along the Parit Botak channel. In this study, in-situ testing methodology was employed using a multifunctional water quality tester. Three stations were selected to conduct in-situ tests to identify the characteristics of saline water flow in the open channel. The investigation of saline water intrusion was carried out with daily data collection during high tide from November 1st to December 31st, 2023. Weather conditions and moon phases were not considered in this case study. Thus, the investigation along the Parit Botak channel revealed that the water characteristics classify it as brackish to saline, with moderate salinity levels. In addition, the saltwater intrusion was stretched to a distance of 18.03 km, accompanied by a tidal height of 2.96 m. The tide heights impacted the degree and variations of saltwater infiltration, although this relationship was not consistently linear. The irregularity of the fluctuation patterns was caused by severe precipitation or the moon phase.

Keywords: Saline water intrusion, electrical conductivity, agriculture, open channel.

INTRODUCTION

Saline water is characterised by a significant concentration of dissolved salts. Salinity refers to the precise measurement of the concentration of salts present in soil or water. Saline water represents the largest water resource available on our planet. The salinity of freshwater varies between 5 parts per million (ppm) and 1000 ppm. Water with a salt concentration under 150 ppm is deemed safe for consumption, whereas water with a salinity exceeding 1000 ppm is used for household applications [1]. Each day, a tidal phenomenon takes place in the Parit Botak channel, independent of the tidal state, whether it be low or high. The Parit Botak channel is not separated from seawater by any tidal gate. Saline water intrusion or encroachment refers to the phenomenon where saltwater infiltrates freshwater aquifers due to groundwater development [2]. Tidal fluctuations significantly influence saline intrusion. During high tides, especially during spring tides, seawater advances inland through river channels, particularly in low-lying areas like Parit Botak [3]. The process enables saline water to permeate freshwater sources, potentially fulfilling the agricultural requirements of the local population. In dry seasons, the intensity of intrusion escalates as freshwater flow decreases, allowing saline water to penetrate further inland [4]. Consequently, a study is underway to examine the saline water intrusion along the Parit Botak channel. Saline water intrusion is a hydrological phenomenon where saltwater enters freshwater systems. This phenomenon is mainly influenced by natural processes, including tidal activity and sea level rise, alongside human activities such as excessive groundwater extraction and changes in land use [5]. The establishment of agricultural drainage systems and land reclamation practices in the Parit Botak area has altered natural flow patterns, enabling the inland intrusion of seawater during high tide events. The existence of ineffective water gates and unregulated outlets intensifies the problem of saline water persisting in the channel [6].

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This study aims to identify the characteristics of saline water in the Parit Botak channel and to examine the patterns of saline water intrusion into the channel during high tide. The study identifies the characteristics of salt water by testing parameters such as salinity, pH, and electrical conductivity (EC). The parameters were evaluated through an in-situ approach employing a multifunctional water quality tester. The study focused on monitoring saline water intrusion along the Parit Botak channel. The designated area was established from the shoreline, extending to the terminus of the Parit Botak channel. Saline water intrusion frequently occurs in coastal aquifers as a result of density differences between saltwater and freshwater [7]. This study aims to identify the characteristics of water along the Parit Botak channel.

Table 1 *Classification salinity levels of water by using EC method [8]*

Classes of water	EC (µS/cm)	Purpose of use
Non-saline	< 700	Drinking and irrigation
Slightly saline	700 – 2,000	Irrigation
Moderately saline	2,000 – 10,000	Irrigation with caution
Highly saline	10,000 – 25,000	Livestock
Very highly saline	25,000 – 45,000	Limited use for livestock
Brine	>45,000	Mining and industrial uses

Table 1 presents the classification of salinity measurements utilising the EC method (µS/cm), along with its intended application. Grasping the properties of saline water is crucial for the efficient management of aquaculture and agriculture in Parit Botak. Electrical conductivity is an important measure for tracking how much saline water is mixing in, since saline water usually has high conductivity levels, often over 1,500 µS/cm, due to ionic salts. Consequently, examining the degree of saline intrusion will help secure freshwater sources for the local community in Kampung Parit Botak, ensuring safe consumption for aquaculture, agriculture, and the daily needs of the residents.

METHOD

Salinity testing was conducted across the study area to evaluate the influx of saline water. This investigation primarily focusses on conducting a salinity assessment. Two salinity tests were conducted to analyse the characteristics of saline water and evaluate the extent of saltwater intrusion. The investigation employs in-situ testing, utilising a multifunctional water quality tester to assess salinity across three stations. This testing method is crucial for accurately classifying water in designated regions as fresh, brackish, or saline. This type of test is essential for assessing the effects of saltwater intrusion, a common challenge faced in low-lying coastal areas [9]. This procedure is consistent with the methodologies outlined regarding salinity measurement techniques [10]. The height of tides influences the intrusion of saltwater, and an increase in tidal range can facilitate the movement of saltwater further upstream [11]. The investigation reveals that tidal heights have a considerable influence on the extent and variability of saltwater intrusion, although this relationship is not consistently linear.

1.1 Site Observation

The saline water from Pantai Parit Botak permeates the Parit Botak waterway. A daily tidal phenomenon takes place near Pantai Parit Botak, characterised by the regular alternation of high and low tides. Consequently, saline water is also released from the beach into the channel. During a high tide event, there is a likelihood of heightened saline water intrusion into the Parit Botak channel. As a result, this event led to the salinisation of freshwater in the Parit Botak waterway. Figure 1 illustrates the geographical context of the study area at Parit Botak channel, along with the specific locations of the collected samples at stations P1, P2, and P3.

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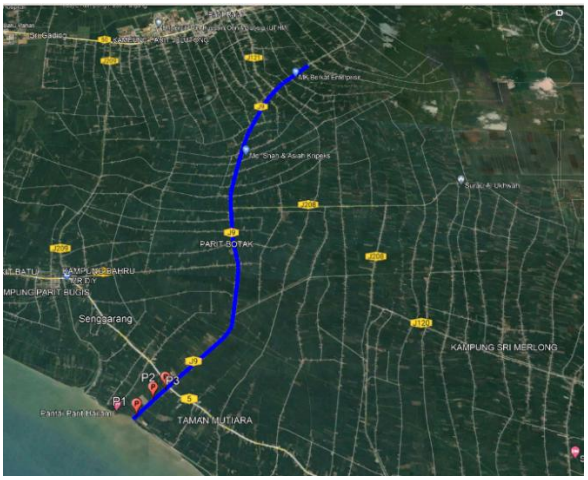

Fig. 1 *Study area of Parit Botak channel and the location points for identifying saline water characteristics*

1.2 Salinity testing

Water samples were gathered from locations P1, P2, and P3. A suitable volume of water sample was collected to enable the insertion of the water quality tester. Following this, in-situ testing was performed on the collected water sample utilising a multifunctional water quality tester, as illustrated in Fig. 2. These devices are widely employed in environmental monitoring due to their portability, accuracy, and ease of use in field conditions [9].

Fig. 2 *Data reading by using multifunctional water quality tester*

A study on saline water intrusion was conducted at Pantai Parit Botak from November 1, 2023, to December 31, 2023, coinciding with high tide events. The tidal data for Kuala Batu Pahat, Johor, was sourced from the official site of Pusat Hidrografi Nasional to ascertain the precise timings and elevations of high tides. The tidal prediction for Kuala Batu Pahat has been selected because it is the closest observation station to Pantai Parit Botak. The degree of saline water intrusion along the Parit Botak channel was assessed through an analysis of the salinity percentage in the water. The projected upper limit for salinity percentage was determined to be 0.01%. Subsequently, the distance from Pantai Parit Botak to the designated location was assessed. The detection of saline water intrusion during high tide was established from this channel.

RESULTS AND DISCUSSION

The data collection took place from November 1, 2023, to December 31, 2023, aimed at capturing daily variations in saline water intrusion and its chemical characteristics along the Parit Botak channel. The parameters employed to assess the properties of saline water include salinity, total dissolved solids (TDS), pH, and electrical conductivity (EC).

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1.3 Characteristic of saline water

The parameters employed to assess the properties of saline water include salinity, total dissolved solids (TDS), pH, and electrical conductivity (EC). The samples were gathered from three distinct sites along the Parit Botak channel, labelled P1, P2, and P3. The coordinates for these locations are 1°42'16"N 103°04'37"E, 1°42'34"N 103°04'54"E, and 1°42'45"N 103°05'07"E, respectively, as illustrated in Fig. 3. Every point was documented with three measurements.

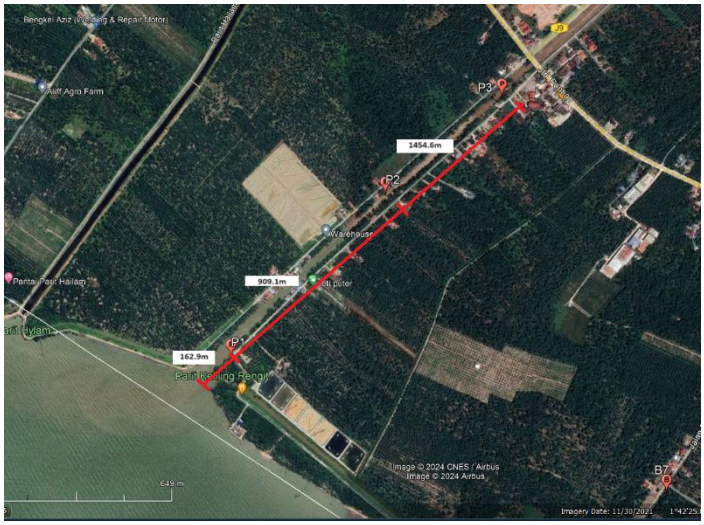

Fig. 3 *The location of station point and point distance from shoreline Parit Botak*

Table 2 *Saline water with EC value at Parit Botak channel*

Sampling point	Distance from shoreline (m)	Seawater level rise (m)	EC (µS/cm)		EC average (µS/cm)
1	162.9	2.80	19,698	19,781	12,663
			19,848		
			19,798		
2	909.1		13,245	10,780	
			9,748		
			9,346		
3	1454.6		7,788	7,428	
			8,743		
			5,754		

The data regarding the EC level of saline water along the Parit Botak channel is presented in Table 2. The increase in sea levels results in saline water advancing up to 1400 meters from the shoreline, particularly noted during a recorded rise of 2.8 meters. The data presented indicates that the classification of water in the Parit Botak channel is highly saline at a distance of 909 m from the shoreline. Nonetheless, within the range of 909 m to 1454 m, the salinity levels are moderate. In the Parit Botak channel, EC values generally increase during high tide and during times of heightened sea levels, particularly under spring tide conditions. Early observations in similar coastal areas of Malaysia show that EC values can go over 50,000 µS/cm near the estuary, and then slowly drop as you move upstream, affected by tidal changes, freshwater flow, and the shape of the channel [6,4].

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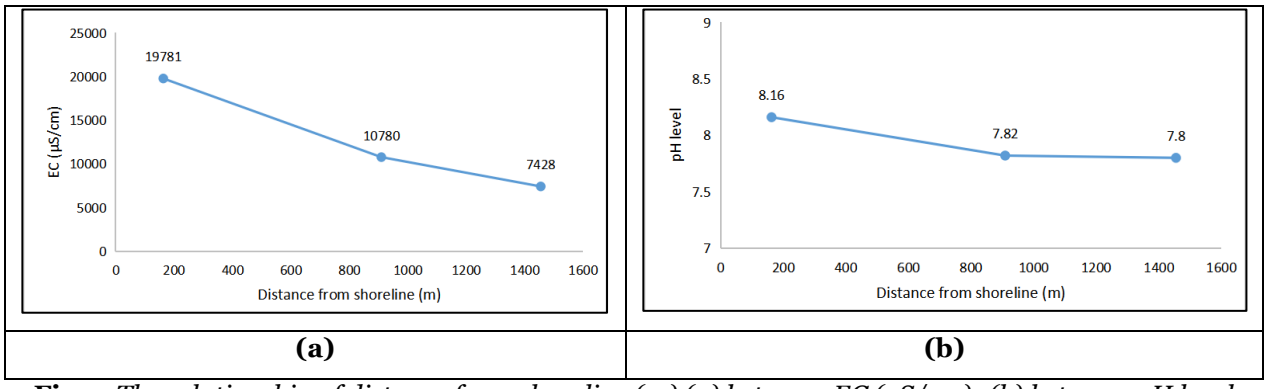

Fig. 4 *The relationship of distance from shoreline (m) (a) between EC (µS/cm); (b) between pH level*

According to Figure 4, the EC value in the Parit Botak channel decreased as the distance from the shoreline. This is because the saltwater intrusion occurred when the sea level rose to 2.80 meters. As seawater from the shoreline entered the Parit Botak channel, a significant quantity of freshwater became diluted with saline water. Consequently, the salt concentration in the water at the furthest distance diminished, resulting in a fall in the EC value. Based on the previous study, at the mouth of the estuary, where seawater has the biggest effect, EC readings can range from 35,000 to 50,000 µS/cm, which is typical for coastal salty water [5]. As one moves further upstream from the shoreline, there is a gradual decline in EC values, which indicates dilution from freshwater inputs and a decrease in tidal mixing [4].

For pH level, it was observed that the pH value also declined with increasing distance from the shoreline. The water at the Parit Botak channel was characterized as having a neutral to slightly alkaline pH. The percent salinity at the Parit Botak channel was found 2.80 m seawater level, which affected the pH level. The pH level at the Parit Botak channel shows a positive correlation with salinity. Consequently, as the saltwater level increased, the pH level at the closest shoreline was elevated. At Parit Botak, close to the shoreline, the pH levels are typically alkaline, influenced by the prevalence of seawater. The movement of water inland and its interaction with freshwater can result in a slight decrease in pH, typically reflecting values ranging from 7.0 to 7.6. Nonetheless, pH is affected by photosynthetic activity, nutrient load, and the decomposition of organic matter, resulting in local variations that are not solely reliant on distance [2].

1.4 Pattern of saline water intrusion

Data regarding saline water intrusion has been gathered along the channel to examine the patterns of saline water intrusion into the Parit Botak channel during high tide. Previous studies, field observations, and maps made at Parit Botak show that salinity levels increase significantly upstream during high tide, especially when there isn't enough freshwater flowing out [12]. This investigation was carried out on a daily basis from November 1, 2023, to December 31, 2023. The salinity percentage has been evaluated across various geographical locations, with a focus on the months of November 2023 and December 2023. Figures 5 and 6 illustrate the selected locations for examining the infiltration of saline water during the months of November and December, respectively. The investigation into saline water intrusion was conducted exclusively during high tide in November 2023 and December 2023. The height and timing of the high tide were derived from the tidal data available on the official website of Pusat Hidrografi Nasional.

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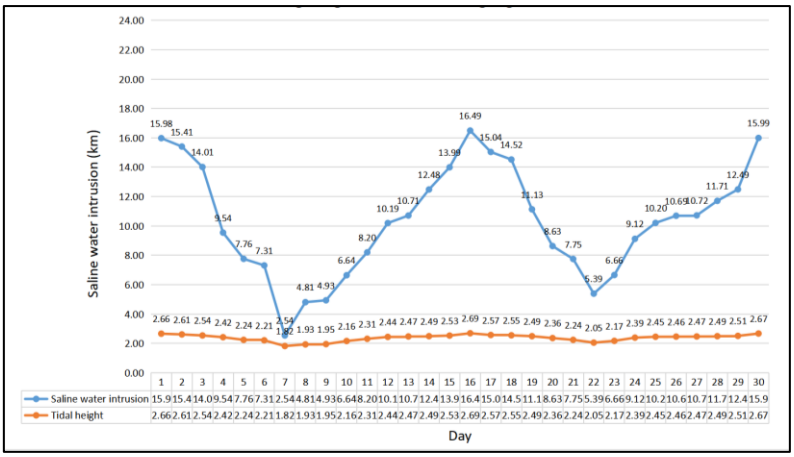

Fig. 5 *Saline water intrusion along Parit Botak channel during November 2023.*

Figure 5 shows how the amount of salty water coming into the Parit Botak channel changes each day during high tide in November 2023, measuring how far the salty water reaches from the shore in kilometres along with the current tidal height. The data indicates that the peak tidal level in November was recorded on the 16th, reaching a height of 2.69 meters. The distance from the shoreline was measured at 16.49 km. It was generally expected that tidal heights would correspond with the extent of saline water infiltration. As the tide height increased, there was a notable rise in the intrusion of saline water. The findings indicate that the pattern of saline water infiltration during high tide can exhibit variability.

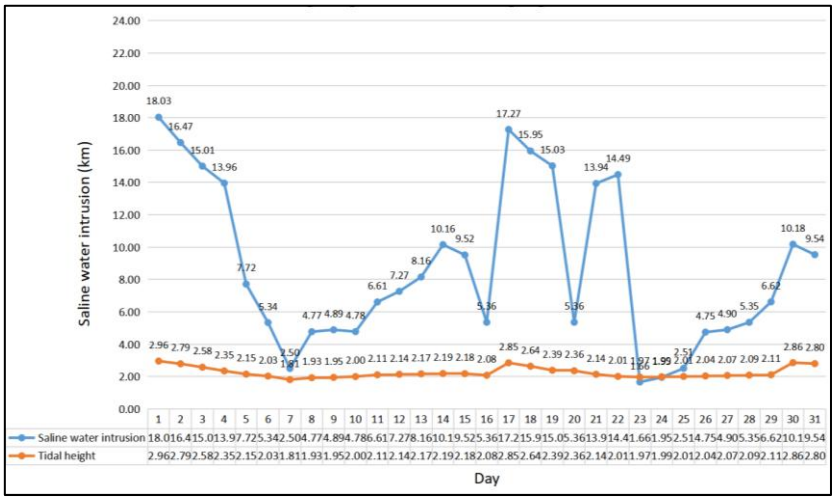

Fig. 6 *Saline water intrusion along Parit Botak channel during December 2023.*

Figure 6 indicates that the peak tidal level in December was recorded on December 1st, 2023, reaching 2.96 meters, accompanied by a saline water intrusion of 18.03 kilometres. On December 7th, 2023, the lowest tidal level was documented at 1.81 meters. On December 23, 2023, the minimum recorded value of saltwater intrusion was 1.66 kilometres, coinciding with a tidal height of 1.97 meters. The findings reveal that the patterns of saltwater intrusion during high tide in December 2023 exhibited considerable diversity. The relationship between tidal height and saline water intrusion in December 2023 exhibited a non-linear pattern. The fluctuations in salinity exhibited an irregular pattern rather than a straightforward linear relationship, significantly influenced by river discharge and tidal interactions [13]. This situation happened because of water-related factors, especially the impact of heavy rainfall and certain shapes of the land that increase the connection between saltwater movement, salinity at the river mouth, and tidal changes [14]. In December 2023, an unusual and significant volume of rainfall occurred, leading to an increase in the freshwater level at the shoreline. During the wet season, increased rainfall can lead to higher river discharge, potentially mitigating salt intrusion [15]. During periods of high tides, saline water intrudes, leading to a dilution of the freshwater resources. This, in turn, affected the linear relationship observed between tidal height and saltwater intrusion. The results showed that the average salt content was 1.64%, the pH was 6, and the electrical

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conductivity was 12,663 µS/cm in the Parit Botak channel. Consequently, the Parit Botak channel was classified as brackish to saline water, exhibiting moderate salinity levels. Furthermore, the extent of saltwater intrusion reached 18.03 km, correlated with a tidal height of 2.96 m.

This aligns with the findings of Zhou and Li [16], who investigated tidal impacts on saltwater intrusion in estuarine channels. The investigation revealed that saltwater intrusion reached a distance of 18.03 km, correlated with a tidal height of 2.96 m. This aligns with the study conducted by Hughes and Kelvin [17], which investigated the seasonal and tidal effects on salinity intrusion in river mouths. It was observed that salinity patterns exhibited irregularities influenced by severe precipitation or lunar phases, though these elements were not the main emphasis of the study. This aspect is examined regarding the impact of precipitation on variations in salinity [18]. The findings of this study enhance our comprehension of the impact of tidal dynamics on salinity intrusion, echoing the broader implications in their research on coastal estuaries [19, 20].

CONCLUSION

The absence of a water gate at Parit Botak Beach has resulted in the intrusion of saline water into the Parit Botak channel. Significant salt levels throughout the river served as evidence of this. The in-situ method assessed the salinity levels at three distinct locations within the case study area. The use of a multifunctional water quality tester revealed that the average salinity percentage, pH level, and electrical conductivity at the Parit Botak channel were 1.64 %, a pH value of 7.93, and 12,663 µS/cm, respectively. The findings indicate that the Parit Botak channel has been classified as containing brackish to saline water, characterised by a moderately high salt concentration. The fluctuations in tide heights influenced the extent and variations of saltwater infiltration, though this correlation was not uniformly linear. Salinity levels show significant variations in accordance with the tidal cycle, increasing during spring tides and decreasing during neap tides. This observation reinforces previous findings that highlight the significant influence of tidal dynamics in estuarine environments [21]. The irregularity of the fluctuation patterns was attributed to significant precipitation or the lunar phase. Nevertheless, the study overlooked the weather conditions and moon phases. Understanding these characteristics is crucial for efficient management of local water resources, particularly in protecting agricultural practices and ensuring the quality of groundwater. Implementing effective monitoring and mitigation strategies, such as improved hydrological modelling and upstream freshwater regulation, is essential for addressing the challenges posed by ongoing saline intrusions in Parit Botak and similar coastal channels in Malaysia.

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