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SALTWATER INTRUSION EFFECT ON WATER SUPPLY PROJECT IN SUNGAI SEMERAK, PASIR PUTEH, KELANTAN, MALAYSIA

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Abstract

Introduction: *In Kelantan, saltwater intrusion was a problem that worsened the water supply, especially groundwater, which was the main source of water supply. This study was conducted to study the suitability of Sungai Semerak as a site for constructing a water intake station in the Pasir Puteh District to provide an alternative water supply source that previously depended on groundwater.* ***Methods:*** *In this study, three approaches were taken to identify the suitable location. The approaches are the Water Quality Index (WQI) by Malaysia Environmental Department includes six water quality parameters of dissolved oxygen (DO), pH, chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS) and ammoniacal nitrogen (AN) with additional approach of Stratification of saltwater and Groundwater Quality.* ***Result and Discussion:*** *From the data gathered, the freshwater zone shows WQI was in Class III at 52.31, which is higher than 51.9, the lower limit of Class III , which is suitable for water supply with treatment and suitable for irrigation compared to the saline zone, WQI was 47.08, which is in Class IV. Groundwater quality of pH (5.95), Total Dissolve Solids (251.77 mg/L), Conductivity (416.2µS/cm), Turbidity (88.19 NTU), Calcium (14.54mg/L), Magnesium (6.25mg/L), Sodium (36.41mg/L), Bicarbonate (67.11mg/L), Chloride (26.03mg/L), Sulphate (4.67mg/L), Total Hardness (67.12mg/L) also shows acceptable readings for suitability for drinking water.* ***Conclusion:*** *Therefore, Sungai Semerak was suitable for building a water intake station as it was important in a developing state and country.*

INTRODUCTION

Water is vital to any living form on this Earth and influences us as the nation starts developing close to water bodies, whether in Asia or eastern countries. (1-2). Aside from civilisation, our body comprises 60% of water, which is critically important for cellular metabolism, substance exchange between tissues and support of the circulatory system. To maintain good health of the human body, we need access to good quality water at all times, and nowadays, the main water source in most locations in this world is from the water supply system provided by the local government (3-5). Until today, the challenge faced by most people in this world is water scarcity and a lack of good quality water, which affects almost 40% of the global population, and nearly 800 million people face a lack of water supply in their living places (6-7). This situation also happens in Malaysia, and one affected location was in Kelantan. The water supply issue was always highlighted in terms of governance and management in Kelantan due to the high rate of complaints.

The lack of clean water and uneven distribution emphasise the complexity of the problem and the need for policy intervention to overcome this situation and seek a practical solution (8-9). Previously, the water supply in Kelantan largely depended on groundwater sources, especially in the lower areas such as Machang,

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Pasir Puteh, Bachok, Kota Bharu and Tumpat Districts. Still, the groundwater quality was in those district provide low quality of water in term of odour and turbidity, but sometimes also questionable that it may be influence by pollution that has potential health risks associated with nitrate contamination or other pollutants (10-11). As an alternative to resolve this matter, in 2020, the government was planned to find a solution and river water was identified as the water supply source that solely depended on groundwater for a few decade that recently became brackish in few places. However, this project may face problems of the influence of saltwater passing through the tidal gate and saltwater intrusion. Instead of attributing the water issue to the surrounding development, seal level rise that catalyst the tidal level may attribute to the higher salinity in the river. This tudy was aimed to understand the suitability of Sungai Semerak as a location for a water intake station to gather further information about water quality and saltwater stratification in Sungai Semerak. The comparison of groundwater and surface water is still lacking in Malaysia and other regions, along with a detailed salinity stratification study to better understand saltwater intrusion, which will support future development plans.

METHODS

Study Area

This study was conducted in Sungai Semerak, a river that located across three districts of Pasir Puteh, Bachok and Machang, which can be considered enchanting river basin ecosystem Kelantan state compared to Sungai Kelantan, Sungai Kemasin, Sungai Golok and others river in Kelantan (12-15). Rapid development and increased aquaculture activities may influence water quality and marine life (14,16). Along with the planning by the government for the water supply project in this area, it is important to understand the influence of saltwater on the freshwater zone because saltwater may interrupt the water supply and may need much cost for the desalination process may hike consumer water supply as not preferred method by the government (17-18). In Sungai Semerak, 19 points were selected, comprising both saline and freshwater zones. Points 1 to 13 were saline zones, and points 14 to 19 were freshwater zones. The interval was 500m between each point. From these points, six points were selected based on their characteristic to WQI data.

Water quality measurement

In this study, a calibrated multiparameter was used to measure the water quality parameters of river water. For the salinity parameter, reading was taken at each one-meter depth of each point at a 500m interval, assisted by a handheld GPS by moving in a boat, as shown in Figure 1. The multiparameter readings stabilised for a few seconds and were repeated three times (19). 19 points were identified along Sungai Semerak, which comprised two zonations. Points 1 to 6 were in the saline zone, and 7 to 9 were in the freshwater zone. The barrier for these two zones was the tidal gate.

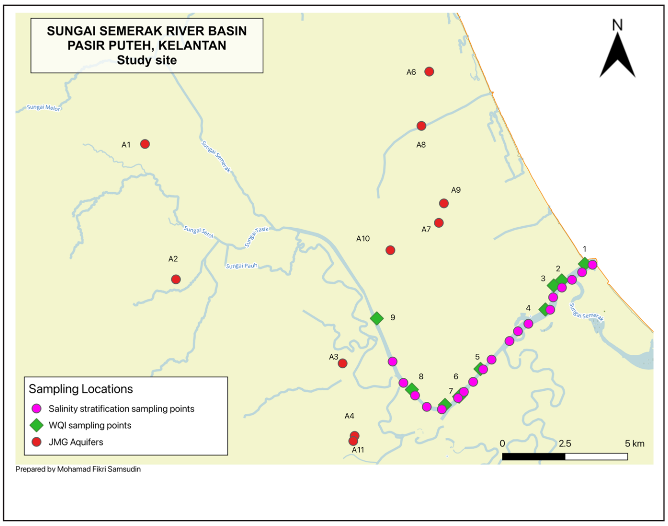

Figure 1: The location of Sungai Semerak, Pasir Puteh, Kelantan and the sampling point.

Table 1. Location of each sampling site.

	Zonations					
	Saline Zone			Freshwater Zone		
Sampling Station	**Wave Breaker**	**Villamas Residence Tok Bali**	**Tidal Gate Kg. Gong Kulim (1)**	**Tidal Gate Kg. Gong Kulim (2)**	**Padang Freefly Kg. Kulim**	**Kg. Kulim Under Bridge**
Coordinate	5°53’50”N	5°52’47”N	5°50’55.36”N	5°50’55.36”N	55°50’43.99”N	5°51’6.03”N
	102°28’60” E	102°28’4” E	102°26’23.36”E	102°26’23.36”E	102°28’60” E	102°25’14.48”E

For the water quality index, parameters involved includes pH, water surface temperature, dissolved oxygen (DO), conductivity and total dissolved solids (TDS). By using the multiparameter of YSI, the sensor was submerged in the river to get the readings. In order to ensure accuracy, we meticulously stabilised and recorded the readings on three separate occasions over a span of several seconds. Six sampling points were identified for data collection within the scenic Sungai Semerak, as illustrated in Figure 1 and elaborated upon in Table 1. For laboratory analysis, the parameters were total suspended solids, Ammoniacal nitrogen, biological oxygen demand (BOD) and chemical oxygen demand (COD), which were following the HACH method adapted from the standard method recommended by USEPA.

Water Quality Index

In this study, the Water Quality Index (WQI) was utilised to evaluate water quality at designated locations and timeframes. The WQI was formulated by the National Water Quality Standards (NWQS) of Malaysia's Department of Environment (DOE). It is calculated according to the formula recommended by the Department of Environment, Malaysia, as outlined below:

WQI= (0.22x Subindex DO) + (0.19x Subindex BOD) + (0.16x Subindex COD) + (0.15x Subindex NH3-N) + (0.16x Subindex SS) + (0.12x Subindex SIpH)

River Vertical Profiling

For river vertical profiling, a Garmin GPSMAP 298 Sounder was used in this study to measure the depth profile of Sungai Semerak. This sonar unit was equipped with a GPS module antenna and a transducer to acquire the location and depth of the river. After setting up from the beginning of the sampling point, the sonar will continuously detect the depth and the coordinate. (20). Figure 2 shows the illustration of data collection in Sungai Semerak.

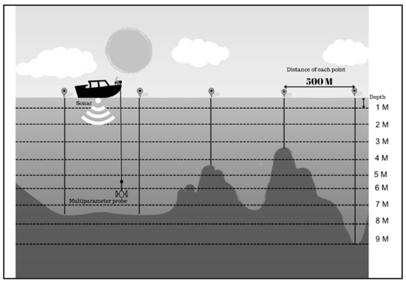

Figure 2. Sampling illustration.

Data Analysis

A river profile was constructed based on the data collected. One-way ANOVA was used to compare the average values; furthermore, the FORECAST.LINEAR function was utilised to assess the potential extent of saltwater intrusion in the event of a malfunction at the tidal gate that allows saltwater to flow through.

Groundwater Quality Analysis

Groundwater data were obtained from the Mineral and Geoscience Department of Kelantan (JMG) for three consecutive years. This data was necessary to understand whether groundwater was influenced by the Sungai Semerak surface water or the surface water influenced the groundwater.

RESULT

DOE Water Quality Classification based on the Water Quality Index

According to the Water Quality Index (WQI) presented in Tables 2 and 3, the overall WQI value falls within Class IV at 49.17, indicating pollution according to the WQI classification. In the freshwater zone, the WQI is categorised as Class III at 52.31, a higher score compared to the saline zone at 47.08 in Class IV, which also signifies pollution. This study finds that during both spring and neap tides, the WQI has been classified as Class IV, as indicated in Tables 2 and 3, which indicates that tidal conditions do not much influence the water quality index.

Table 2. Water Quality Index in Sungai Semerak.

Parameter	Unit	Doe Water Quality Index Classification						Index Range
		Overall	Class	Saline	Class	Freshwater	Class	
Ammoniacal Nitrogen	mg/L	0.13	II	0.13	II	0.13	II	-
Biochemical Oxygen Demand	mg/L	7.07	IV	7.26	IV	6.88	IV	-
Chemical Oxygen Demand	mg/L	32.64	III	50.72	IV	14.56	II	-
Dissolved Oxygen	mg/L	4.26	III	4.21	III	4.35	III	-
pH		7.46	I	7.46	I	7.46	I	-
Total Suspended Solid	mg/L	57.76	III	40.11	II	75.4	III	-
Water Quality index		49.17	IV	47.08	IV	52.31	III	Polluted

Table 3. Water Quality Index during Spring tide and Neap tide.

Water quality index	value	class
Overall	49.17	IV
Spring tide	49.01	IV
Neap tide	50.12	IV

Average Salinity of Sungai Semerak.

The average salinity obtained from Sungai Semerak from sampling point 1 until point 19, as shown in Figure 3. From the data gathered, the highest salinity was recorded in Sampling Point 1 due to being closest to the sea and a part of the sea and obviously influenced during spring tide as seawater enters the river and may go further. From sampling point 14 to sampling point 19, the salinity was below 1 ppt because it was located in a freshwater zone separated by Kampung Kulim Tidal Gate. From this data, it is shown that the tidal gates are currently well-functional in managing flooding caused by tidal and provide flood protection depending on their operational methods and duration, which shows their important role in flood control and mitigation as the gates control water movement by preventing the quick inflow of saline water during high tides and enabling outflow of freshwater during low tides.

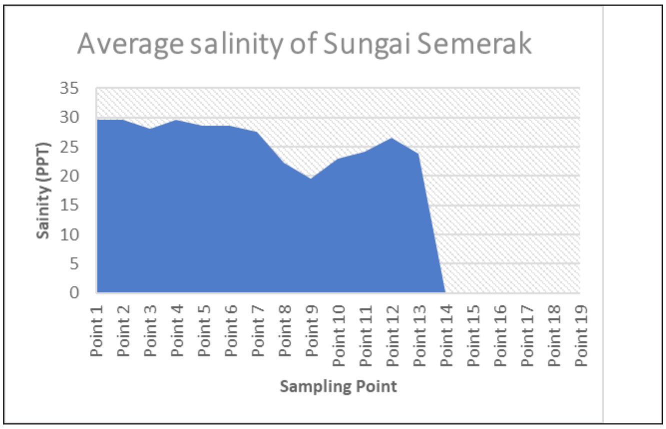

Figure 3. Average Salinity of Sungai Semerak

A heatmap graph was created using data gathered, as illustrated in Figure 4, to show the variation of salinity level in the Sungai Semerak. From the illustrated heatmap, salinity was slightly higher at the bottom of the river compared to water salinity, which was close to the river surface.

During the ebbing spring tide, which is also called low tide, the freshwater zone was higher and discharged freshwater into the saline zone. The IADA Kemasin Semerak released river water to the saline zone and simultaneously reduced the salinity from an average of 26 PPT to as low as 10 PPT. From point 8 to point 13, salinity was lower in surface water due to the river being more comprehensive in point 8.

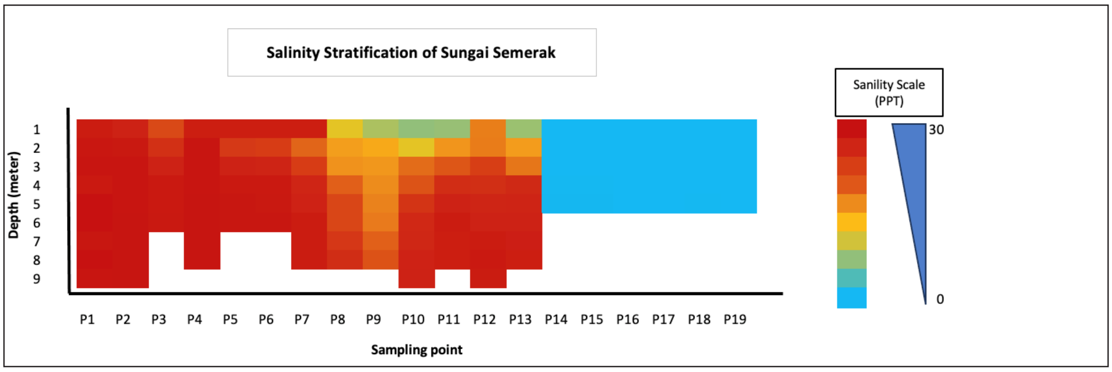

Figure 4. Salinity stratification of Sungai Semerak.

Saltwater Encroachment in Sungai Semerak

In Sungai Semerak, the tidal gate separated the freshwater and saline zones. From the data gathered, salinity was significantly reduced to below 1 PPT in the freshwater zone. The main purpose of constructing the tidal gate was to prevent the saltwater from entering the river further and protect crops. Saltwater should be avoided so that the local government can establish a water intake station for the water supply. According to the Malaysia Water Quality Standard and WQI, the river salinity was below 0.5 PPT in Class 1 are suitable for water supply. Despite that, as the Environmental Protection Agency of the USA (EPA) and the Government of Western Australia ruled, the suitable salinity for drinking water and irrigation must be less than 0.05 PPT. In this study, the data gathered in Figure 5 shows that the average salinity for the freshwater zone was 0.05 PPT, and the average salinity for the saline zone was 26.24 PPT.

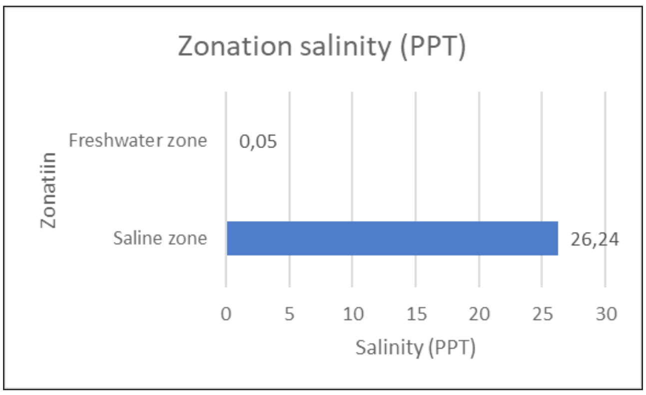

Figure 5. Salinity Zonation

The Effect of the Damaged Tidal Gate in Sungai Semerak.

The tidal gate was vital to Sungai Semerak to prevent saltwater encroachment to the freshwater zone. Statistically, using the equations for FORECAST. LINEAR is a+bx, and the effect of damaged tidal gate was calculated, where:

$$a = \bar{y} - b\bar{x} \quad \text{and:} \quad b = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sum (x-\bar{x})^2}$$

Where x and y are the samples, which means AVERAGE (known_x's) and AVERAGE (known y's). From the data calculated, if the tidal gate has malfunctioned, the saline water may reach up to 25 km into the freshwater zone since the interval of each point was 500 m; therefore, the 0 PPT was reached at point 50, as shown in Figure 6. The river's furthest point and highest salinity may be reached during flooding spring tide as the saline zone water level increases higher than freshwater and worsens during the dry season.

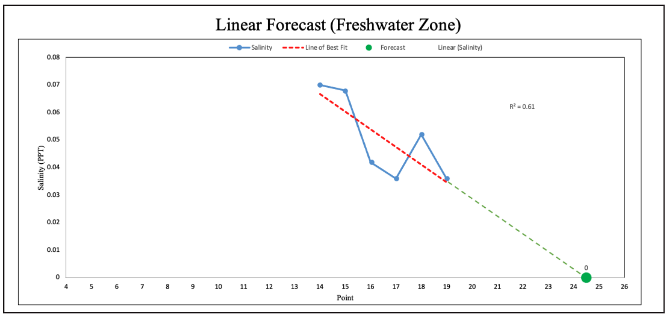

Figure 6. Linear Forecast of Saline Zone.

Figure 7 shows the forecast point where the salinity may reach 0 PPT. From the calculated data, 0 PPT may be reached between points 24 and 25. Since the distance of each point was 500 m intervals, the water will be 0 PPT at 12.25 km distance from the shore. As a result of forecasting, point 16 onwards was suitable for the water intake project. Still, to avoid any complications from any tidal gate problem, the station must be built as far as 25 KM from the shore. From both predictions of points which saltwater can reach, it shows how important it is for a preliminary study to identify a suitable site for building a water intake station by considering what will happen if the tidal gate is damaged or malfunctions, which will lead to saltwater polluting the freshwater zone.

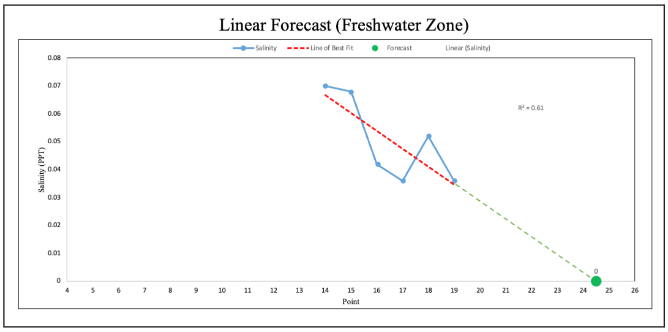

Figure 7 Linear Forecast of the freshwater zone.

Sungai Semerak River Basin

The average groundwater quality is shown in Table 4, which is based on the data gathered. The average salinity for groundwater was highest in Klinik Kesihatan Beris Kubur Besar at 1.86 PPT. The average pH of groundwater was highest at 6.85 at Kg. Beris Lalang. KKBKB recorded the highest reading at 462 mg/L and 1167 µS/cm for the average TDS and conductivity of groundwater. The average turbidity was recorded as the highest in Kg. Selising at 155.8 NTU. The average mineral contained in groundwater, KKBKB, was recorded as having the highest calcium and sodium content at 24.86 mg/L and 112.64 mg/L. In Kg. Beris Lalang, the average mineral contained in groundwater, was recorded highest in magnesium, bicarbonate, chloride and total hardness at 10.39 mg/L, 196.33 mg/L, 56.47 mg/L and 124.85 mg/L. Almost all aquifers provide good quality groundwater, as suggested by the Groundwater Standard by DOE, for human consumption and suitability for irrigation.

Table 4. The average groundwater quality of Sungai Semerak river basin aquifer.

Site / Parameters	Klinik Kesihatan Beris Kubur Besar (KKBKB)	Sek. Keb. Kolam	Kg Selising	Kg. Beris Lalang	Kg Kelubi	Average	Groundwater Standard of Malaysia
Salinity (PPT)	**1.86**	0.26	0.31	0.77	0.23	0.69	-
pH	4.49	6.06	6.11	**6.85**	6.23	5.95	5.0-9.0
Total Dissolve Solids (mg/L)	**462**	333.67	103.33	284.67	75.2	251.77	1500
Conductivity (µS/cm)	**1167**	144.33	175.33	469.33	125	416.2	1000
Turbidity (NTU)	140.17	86.5	**155.8**	19.53	38.93	88.19	1000
Calcium (mg/L)	**24.86**	2.43	10.58	22.28	12.57	14.54	-
Magnesium (mg/L)	16.6	1.21	2.48	**10.39**	0.59	6.25	150
Sodium (Na) (mg/L)	**112.64**	15.59	9.56	37.83	6.41	36.41	200
Bicarbonate (HCO3 (mg/L)	49	20.94	53.05	**196.33**	16.25	67.11	-
Chloride (Cl-) (mg/L)	51.79	6.68	7.71	**56.47**	7.52	26.03	250
Sulphate (SO42-) (mg/L)	3	7	3	3	7.33	4.67	250
Total Hardness (mg/L)	115.19	27.13	35.02	**124.85**	33.43	67.12	500
Distance From sea (m)	3270	13500	**14440**	3090	10300	-	-

From the data gathered, distance from the sea influences the salinity of groundwater, as the aquifer near the sea was intruded by saltwater, as in KKBKB, the salinity was higher due to the distance being close to the sea. Table 5 shows the Spearman Correlation Between Groundwater and River Parameters. In this study, groundwater salinity, sodium, and chloride show strong positive correlations with river BOD and COD, and strong negative correlations with DO and WQI. These suggest that groundwater becomes more saline or ion-rich, and river water quality will degrade with higher BOD and COD levels, lower DO, and lower WQI. Besides that, pH shows no correlation, likely due to uniform river pH (7.46 across sites).

Table 5. Spearman Correlation Between Groundwater and River Parameters

Groundwater \ River	BOD	COD	DO	pH	WQI
Salinity	0.87	0.87	-0.87	NaN	-0.87
TDS	0.58	0.58	-0.58	NaN	-0.58
Sodium	0.87	0.87	-0.87	NaN	-0.87
Chloride	0.87	0.87	-0.87	NaN	-0.87
pH	0.00	0.00	0.00	NaN	0.00

DISCUSSION

DOE Water Quality Classification based on the Water Quality Index

The observed variations in Water Quality Index (WQI) values during spring and neap tides can be attributed to the influx of seawater into the rivers and the freshwater runoff occurring during the rainy season. This dynamism in the area, characterised by continuous interactions between seawater and river discharge, significantly impacts the WQI (21). During high tide, especially during a flooding spring tide, seawater will enter further into the river and reach the farthest point. Besides that, when the rainy season happens during the ebbing spring tide, which has the lowest tidal level, the river will reduce the salinity due to dilution from rainwater and heavy river discharge from the upstream. Saltwater may influence and alter key water quality parameters, especially salinity, temperature, dissolved oxygen and nutrient levels in the river.

During the rainy season, freshwater runoff increases and dilutes saltwater, which affects the water quality of rivers and estuaries. This runoff carries sediments, organic matter, and nutrients, further influencing the WQI by altering turbidity, biochemical oxygen demand, and other parameters. As a result, the combined effects of tidal fluctuations and seasonal freshwater discharge play a crucial role in shaping the variations in WQI values over time. In Sungai Semerak, the primary sources of pollutants are fisheries industrial, dockyard activities, construction, and agricultural practices along the river, which will elevate levels of COD, BOD, and various nutrients in the river. The situation will likely worsen if there is no intervention for a long time (22-23).

Overall, WQI values classified as Class IV are deemed appropriate for irrigation purposes as suggested by the DOE (24). However, these values may fluctuate with seasonal changes, especially during the rainy season, which will dilute the river and estuary water. Typically, Class I WQI values are observed in the upper sections of the river or the catchment area, which are pristine and clear water and benefit the sensitive wildlife (25). Notably, during neap tides, water quality concentrations tend to show the lowest readings among the various tides at 50.12 compared to Spring tides at 49.01 (26). However, both values during Spring and the neap tide were in the same classes in class IV.

Salinity of Sungai Semerak and the Encroachment of Saltwater in Sungai Semerak

The data shows the gates are currently well-functional in managing flooding caused by tidal and provide flood protection depending on their operational methods and duration, which shows their important role in flood control and mitigation as the gates control water movement by preventing the quick inflow of saline water during high tides and enabling outflow of freshwater during low tides. Moreover, other factors such as seasonal precipitation, river flow, and sedimentation can influence the operational efficiency of the tidal gates over more extended periods of time. It is necessary to implement regular maintenance and different forms of manipulation of these structures to enable them to provide maximum mitigation of flooding while guaranteeing the healthy functioning of natural systems in the waters affected (27-29). Tidal gate can also manage reducing marine species starting colonisation in the freshwater zone when the freshwater zone is exposed to saline water for too long, and correlate with sea level rise, which may change this zone from a freshwater zone to a saline zone permanently.

From the illustrated heatmap, salinity was slightly higher at the bottom of the river compared to water salinity, which was close to the river surface because saltwater is denser than freshwater in a riverine system, which leads to saltwater settling at the bottom of the river. However, saltwater may intrude on the freshwater zonation if there is no barrier or tidal gate, especially during a spring tide, when water may reach further.

Besides that, during ebbing low tide, the freshwater flow may reduce salinity in saline zones and estuaries (30). This situation is supported by a previous study in which salinity may vary during tidal fluctuation and during rainy seasons (12, 31-33).

During the ebbing spring tide, which is also called low tide, the freshwater zone was higher and discharged freshwater into the saline zone. The IADA Kemasin Semerak released river water to the saline zone and simultaneously reduced the salinity from an average of 26 PPT to as low as 10 PPT. From point 8 to point 13, salinity was lower in surface water due to the river being more comprehensive in point 8, and the distance reduced the top layer salinity in Sungai Semerak, as supported by previous studies by others (34-36). The salinity varies in shallow and deep areas and is reduced in wide rivers.

In Sungai Semerak, the tidal gate separated the freshwater and saline zones. From the data gathered, salinity was significantly reduced to below 1 PPT in the freshwater zone. The main purpose of constructing the tidal gate was to prevent the saltwater from entering the river further and protect crops. Saltwater should be avoided so that the local government can establish a water intake station for water supply. According to the Malaysia Water Quality Standard and WQI, the river salinity was below 0.5 PPT in Class 1 are suitable for water supply. Despite that, as the Environment Protection Agency of the USA (EPA) and the Government of Western Australia ruled, the suitable salinity for drinking water and irrigation must be less than 0.05 PPT. In this study, the data gathered in Figure 5 shows the average salinity for the freshwater zone was at 0.05 PPT, and the average salinity for the saline zone was 26.24 PPT.

In Sungai Semerak, the water salinity in the freshwater zone was good for water supply and irrigation based on EPA suggestions and suitable for water intake projects for water supply. Saltwater intrusion is increasingly influenced by several factors, including elevated salinity levels, extended periods during which salinity exceeds national standards, prolonged saltwater encroachment, and significant stratification of salinity. These changes result from uneven sand dredging, rising tides, and shifts in wind direction. The combination of rising tides and wind patterns can intensify tidal dynamics, allowing saltwater to penetrate further upstream (37-39).

The Effect of the Damaged Tidal Gate in Sungai Semerak

In this study, he highest salinity and furthest point may occur during the flooding spring tide when the level of saline zone water exceeds that of freshwater. This situation worsens during the dry season, which lasts from January to September (12). In other studies, it was observed that river discharge decreased during the dry season, which led to saltwater intrusion, particularly during spring tides. As river flow increases, the impact of tidal velocity becomes more pronounced, resulting in a reduced response time. Additionally, changes in river discharge affect saltwater intrusion asymmetrically (40). The most important benefit of identifying this point was to find a suitable location for building a water intake station to supply fresh water and reduce the influence of salt water. As a result of forecasting, point 16 onwards was suitable for the water intake project. Still, to avoid any complications from any tidal gate problem, the station must be built as far as 25 KM from the shore. From both predictions of points which saltwater can reach, it shows how important it is for a preliminary study to identify a suitable site for building a water intake station by considering what will happen if the tidal gate is damaged or malfunctions, which will lead to saltwater polluting the freshwater zone.

Average Groundwater Quality of the Aquifer in Sungai Semerak River Basin

In this study, strong positive correlations were observed between groundwater salinity, sodium, and chloride concentrations with river water BOD and COD, while strong negative correlations were found with DO and WQI. These relationships suggest that as groundwater becomes more saline or enriched with ions, may due to saltwater intrusion or other geochemical influences, the river water quality deteriorates, indicated by increased organic pollution (high BOD and COD) and reduced oxygen availability (low DO). The decline in WQI further reinforces this degradation in water quality. These findings imply a potential interaction between groundwater and river water, where the discharge of ion-rich groundwater into the river may contribute to elevated pollution levels. In contrast, pH showed no significant correlation, likely because the river pH remained uniformly buffered around 7.46 across all sites. This uniformity suggests that pH may not be a sensitive indicator of groundwater influence in this context. Overall, the results highlight the importance of monitoring groundwater quality in managing and protecting adjacent river ecosystems, especially in areas vulnerable to saltwater intrusion or anthropogenic impacts (35,36).

Suitability of Sungai Semerak as a Water Intake Station

The tidal gate is crucial for Sungai Semerak, preventing saltwater from intruding into the freshwater zone. If the tidal gate is damaged, saline water could extend up to 25 km into the freshwater area, measured at points 500 meters apart. The highest salinity typically occurs during flooding spring tides, particularly during the dry season from January to September annually, when river discharge decreases, and saltwater may enter.

From the data gathered, the saltwater may reach between points 24 and 25, about 12.25 km from the shore. Identifying these points was critical in locating a suitable site for a water intake station to supply fresh water while minimising saltwater impact. Points 16 onwards are identified as suitable for this project as the planned station location should be at least 12.5 km from the shore to avoid tidal gate complications (27, 41).

The Water Quality Index (WQI) at points 16 to 25 is Class III, indicating it is safe for human use with proper treatment required. While it is suitable for livestock consumption and irrigation, the water requires processes such as coagulation and disinfection, which can raise treatment costs. Long-term exposure to contaminants can indirectly affect human health through animal products. Additionally, water quality is threatened by agricultural runoff and untreated wastewater, necessitating pollution control measures and public awareness campaigns to enhance sustainability (26,42-43).

The nearest aquifer has low salinity and appears to have limited interaction with the river, indicating a separation that reduces the risk of mutual contamination. This distinction is beneficial for maintaining the ecological health of Sungai Semerak and ensuring that the aquifer remains a reliable freshwater source (44-46). Ongoing monitoring is essential to confirm the stability of this relationship, especially in light of potential land-use changes or increased groundwater extraction (47-49). For this study, the analysis of heavy metals was not conducted, as we focused solely on the Water Quality Index (WQI) recommended by the Department of Environment, Malaysia. In future research, it may be beneficial to consider heavy metal content in river water, as the degradation of river water can vary over time due to ongoing development in the area.

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CONCLUSION

The plan to construct the water intake station was a brilliant alternative to relying on groundwater for water supply. Sungai Semerak was deemed suitable for the project, and the tidal gate would play a crucial role in controlling saltwater entry into the river. According to the forecast, the station should be built at least 25 km from the shore to prevent saltwater intrusion. Further action is required to maintain the tidal gate's functionality, and additional study is needed to assess the environmental health in this area.

AUTHORS' CONTRIBUTION

MFS: Study concept, methodology selection, collecting data, data analysis, mapping, and preparation of manuscript draft. ATSH: reviewing the manuscript and validation. MFMA: reviewing the manuscript, editing, and writing validation.

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