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Assessment of the Current Spatial-Temporal Variations of Salinity on the Surface Waters of Kuala Perlis, Perlis

Aimie Rifhan Hashim[1], Sharir Aizat Kamaruddin[1*], Khairul Naim Abd.Aziz[1], Jamil Tajam[1], Faeiza Buyong[2], Che-Zulkifli Che Ismail[3], Anisah Lee Abdullah[4], Tun Mohd Firdaus Azis[1] and Anastacia Anscelly[5]

[1]*Fakulti Sains Gunaan, Universiti Teknologi MARA, Cawangan Perlis, Kampus Arau, 02600, Arau, Perlis, Malaysia*

[2]*Fakulti Sains Gunaan, Universiti Teknologi MARA, Cawangan Selangor, 40450, Shah Alam, Selangor Darul Ehsan, Malaysia*

[3]*Crustacean Aquaculture Research Division, Fisheries Research Institute (FRI) Pulau Sayak, 08500, Kota Kuala Muda, Kedah*

[4]*Pusat Pengajian Ilmu Kemanusiaan, Universiti Sains Malaysia, 11800 Pulau Pinang, Malaysia*

[5]*World Wildlife Federation Malaysia, 6th Floor, CPS Tower, Centre Point Complex, No 1, Jalan Centre Point, 88800, Kota Kinabalu, Sabah, Malaysia*

Corresponding author: *shariraizat@uitm.edu.my*

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ABSTRACT

Tropical estuaries are known for their diverse hydrological features and rich biodiversity, significantly impacting various species. However, changes in salinity exposure gradients can cause continuous modifications in estuaries' physicochemical properties and habitats. This study aimed to assess the spatiotemporal variations in salinity levels in the surface water of Kuala Perlis, Perlis. In December 2021, five sampling stations were established for each morning, afternoon, and evening session, and salinity values were measured using a refractometer. Analysis of Variance was conducted at a significance level of 0.05 to determine the differences in the spatiotemporal distribution of salinity values using Statistical Package for Social Sciences (SPSS) version 26. The results showed three different salinity ranges along the Sungai Kuala Perlis, ranging from 0.41 to 5.00 ppt, 0.79 to 24.74 ppt, and 0.33 to 14.00 ppt for the morning, afternoon, and evening periods. The salinity ranges varied between the different sampling times. Still, no statistically significant difference was found in the salinity values concerning spatial and temporal variations (> .05). These findings provide preliminary data for river monitoring by authorities, non-governmental organizations, and researchers, as salinity significantly affects water quality conditions in estuaries, particularly the amount of dissolved oxygen.

Keywords: *Estuary, Kuala Perlis, salinity, spatiotemporal study, water quality monitoring*

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INTRODUCTION

Tropical estuary areas have a more comprehensive hydrological structure, enriched biodiversity, and a more significant impact on all species. An estuary is a body of water where saltwater from the sea meets fresh water from rivers. Nothing is more critical to an estuary's operation than the quantity and time of freshwater delivery to the mixing zone [1]. Estuaries have a vital role in economic activities, and they are also regions where fresh and saltwater interact, resulting in various physical, chemical, and biological variables [2]. A mangrove estuary's hydrodynamics and hypsometry are complicated. The water is restricted to the main channel at low tide. However, as the tide rises, unvegetated tidal flats are swamped, and the estuary exceeds its banks, gradually flooding the mangrove vegetation [3]. The biodiversity of the estuaries is highly enriched. Estuaries are very productive environments that serve as breeding, feeding, and rearing grounds for various aquatic organisms, such as fish and shrimps [4]. Macrofauna abundance, biomass, and diversity rose in response to inflow events but were reduced under hypersaline conditions [5]. The abundance of meiofauna grew in tandem with the increase in input and responded primarily to the salinity exposure gradient [6, 7]. Nevertheless, alterations in the estuaries' habitat and physicochemical properties keep changing due to seawater intrusions.

Seawater intrusion has been worsening throughout the years, and this occurrence heavily impacts the estuaries and alters the aquatic ecosystem of the estuaries. Sea-level rise is a significant factor that causes saltwater intrusion in low-lying coastal areas worldwide. Furthermore, fluctuating evaporation and precipitation patterns will likely alter the duration of saltwater incursion in estuaries [8]. Seawater intrusion is a natural phenomenon that degrades fresh groundwater and expands the aquifer. Shallow and deep aquifers are essential for maintaining freshwater quality in coastal aquifers [9, 10]. Previous studies reported seawater intrusion effects on the environment, including freshwater resource losses, shifted groundwater physicochemical qualities, and deterioration of the coastal forest and its biota, particularly in tidal areas [11]. It can also degrade urban infrastructure due to growing humidity and salt corrosion. In light of the environmental issues caused by seawater intrusion and the need to maintain freshwater quality in freshwater sources and protect urban infrastructure, monitoring the river body until it reaches the estuary is crucial. This comprehensive monitoring approach can help researchers and authorities understand the present physicochemical parameters of the water bodies, including rivers and estuaries, and provide essential data for developing alternative solutions to curb seawater intrusion through effective water quality monitoring.

Furthermore, water quality monitoring is an excellent method for tracking the physicochemical qualities of the estuary over time. Water quality monitoring or quality assessment of the marine environment is commonly conducted by evaluating causes (pollutants) and consequences (ecosystem impact) [5]. They can also be used for long-term trend monitoring to discover environmental changes [12]. Malaysia's Department of Environment (DOE) has issued the National Water Quality Standard (NWQS) as a significant reference to categorize the river state to the public. Class E (Interim) is the benchmark for estuarine waters subject to seasonal and diurnal fluctuation. Class E1 represents the coastal plain, Class E2 represents the lagoon-type estuary, and Class E3 is used when assessing estuaries with a broad and complicated distributary network. [13]. Thus, conducting water quality monitoring at Kuala Perlis, Perlis is compulsory.

Previous studies showed collective findings on water quality monitoring conducted in Kuala Perlis. Perlis River is located at latitude 6.40° and longitude 100.13° on Malaysia's northern peninsula. The Perlis River is a 350-square-kilometer river basin with over ten tributaries. From Kangar City to Kuala Perlis, the

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river stretches 9.6 kilometers [14]. Water quality index investigations were performed along three stations set up along the Kuala Perlis River, and the water quality index was determined to be 58.30, 61.87, and 41.64, respectively [14]. This discovery reveals declining trends in WQI values, indicating increased water pollution in the Sungai Kuala Perlis. Dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), ammoniacal nitrogen, and pH were chosen as the six parameters. Class II is the water quality index at high tide upstream and downstream of Sungai Perlis. However, it is Class III during low tide. However, there are no variations in the water quality index during high and low tides in the middle stream of Sungai Perlis, classified as Class III. The pollutant profiles also revealed that the river was less contaminated at high tide than at low tide conditions [15]. Despite prior water quality monitoring efforts along Sungai Kuala Perlis, there remains a research gap regarding the current spatiotemporal variation of salinity in the river, which serves as crucial baseline information for conducting comprehensive monitoring to understand better the present condition of seawater intrusion in the estuaries. Therefore, this research study aims to fill this gap by assessing the spatiotemporal variation of salinity levels along Sungai Kuala Perlis, providing valuable insights for water quality monitoring and management in the region.

The critical point of assessing the water quality within estuaries is monitoring the salinity changes. Surface salinity is lower than bottom salinity at most sites in the Sungai Merbok estuary, showing the presence of density stratification within the estuary [16, 17]. Another research showed that the salinity in the surface water ranged from 13.31 to 24.22 ppt and from 14.17 to 25.09 ppt in the bottom water [18]. The salinity profile of Sungai Baru estuary, Kuala Perlis, was studied during tides and neap tides in 2003. During spring tides, the salinity varied from 2.44 to 24.48 ppt, 21.00 to 24.76 ppt, and 9.80 to 15.54 ppt, respectively, in the morning, afternoon, and evening. However, during the neap tide, salinity varied between 5.06- 25.27 ppt, 5.60-25.02 ppt, and 12.71-25.62 ppt, respectively, in the morning, evening, and afternoon [18]. Salinity is a critical parameter in the water monitoring study. The researcher conducted much effort to understand, map, and visualize the salinity to obtain proper knowledge of the salinity of the river bodies, such as mapping salinity using the spline interpolation technique in several places in Malaysia [5, 17, 19]. Regular assessment of spatial-temporal variation in salinity is necessary to gain insight into the seawater intrusion problem, understand changes in the river, and recognize the current condition of estuary bodies.

Spatial-temporal variation of salinity assessment should be regularly carried out to understand the characteristics of salt in the river and estuarine ecosystems. Water bodies can be varied spatially and temporally. Based on water quality monitoring in Chini Lake, the parameters selected fluctuated temporally and geographically, with TSS, turbidity, chlorophyll-*a*, sulfate, DO, ammonia-N, pH, and conductivity being the most impacted [20]. Water quality varied regionally and temporally; the highest spatial variability occurred during the no-flow phase, with flow-driving temporal variations [21]. Spatial salinity variation can also influence the distribution of aquatic animals in estuaries such as copepods. The distribution of the copepod in the Sungai Perai estuary was divided based on the salinity gradient [4]. Previous research has shown that salinity was an important environmental factor influencing the larval fish composition in estuaries [22]. Temporally, the salinity level in the estuaries was influenced by the tides. The findings showed vertical mixing occurred at spring tide, and a salinity gradient remained throughout the neap tide. Although the water column is shallow, statistics on salinity and temperature show that decreased salinity corresponds to greater temperature [18]. Overall, it is vital to monitor the salinity level in the Sungai Kuala Perlis estuary over time. Therefore, this study aims to experimentally investigate and provide preliminary data on the current spatiotemporal salinity variation in Sungai Kuala Perlis.

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EXPERIMENTAL

This section briefly details the sampling procedure, sampling site selection, and location placement (latitude and longitude). The observations made during sample operations were also recorded, and the sampling location was plotted thoroughly using satellite pictures.

Sampling Method

Sampling was conducted in early December 2021, and five locations were determined, starting from the first location (L1), Jetty Tok Kuning, until it reached the river's mouth, the fifth location (L5). Each sampling location was carefully marked and recorded using Global Positioning System (GPS). Sampling was conducted three times in the morning, afternoon, and evening. Water samples were collected around one meter below the surface [19]. A size 1.5-liter plastic bottle was used to manage the water samples, carefully labeled according to sampling sites, and brought to the laboratory for further analysis. The salinity reading was immediately taken after the sample collection using a refractometer. The reading was taken, and the average reading for each sampling time and location was calculated.

Sampling Sites

The sampling sites were visited three times: morning, afternoon, and evening. Each sample station (S1-S5) will be identified during surface water sampling, and the latitude and longitude will be recorded each time using a GPS. Table 1 shows the sampling station's coordinates.

Table 1: Sampling stations with corresponding coordinates during morning, afternoon, and evening sampling sessions in Sungai Kuala Perlis, Perlis.

Sampling	Stations	Latitude	Longitude
Morning	S1	6˚25'04.853"N	100˚09'01.853"E
	S2	6˚25'19.128"N	100˚08'32.333"E
	S3	6˚25'03.461"N	100˚08'22.434"E
	S4	6˚24'37.799"N	100˚08'23.903"E
	S5	6˚24'28.511"N	100˚08'23.364"E
Afternoon	S1	6˚25'04.992"N	100˚09'00.774"E
	S2	6˚25'17.364"N	100˚08'46.409"E
	S3	6˚25'20.808"N	100˚08'31.746"E
	S4	6˚24'57.449"N	100˚08'18.917"E
	S5	6˚24'27.263"N	100˚08'20.742"E

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Evening	S1	6˚25'04.787"N	100˚09'01.290"E
	S2	6˚25'22.188"N	100˚08'44.322"E
	S3	6˚25'00.653"N	100˚08'19.679"E
	S4	6˚24'34.355"N	100˚08'29.033"E
	S5	6˚24'27.479"N	100˚08'23.364"E

Furthermore, water collection sample locations in Kuala Perlis were plotted based on latitude and longitude for each sampling interval. The map may be used to determine the sample point location precisely. Figure 1, Google, 2021b, depicts the morning sampling site; Figure 2, Google, 2021a, the afternoon sampling position; and Figure 3, Google, 2021c, the evening sampling location.

Figure 1: Morning sampling location [23]

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Figure 2: Afternoon sampling location [24]

Figure 3: Evening sampling location [25]

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RESULTS AND DISCUSSION

The findings of this research on the variation of salinity level in Kuala Perlis were analyzed and presented separately for its temporal and spatial aspects along Sungai Kuala Perlis. The data was organized in tables and figures, and the Statistical Package for Social Sciences (SPSS) version 26 was used for analysis. The discussion will focus on the current spatiotemporal variation of salinity level and its potential impact on marine ecosystems. Research finding highlights the significance of monitoring the salinity level in Sungai Kuala Perlis.

Temporal Variation of Salinity at Kuala Perlis River

The finding found three different salinity ranges measurements. The salinity values were within ranges 0.41– 5.00 ppt, 0.79 – 24.74 ppt, and 0.33 – 14.00 ppt for the morning, afternoon, and evening periods throughout five sampling stations. The salinity distribution for five sampling stations for three sampling times was recorded in Table 2.

Table 2: Spatial-temporal variations in salinity levels (ppt) measured at five sampling stations during morning, afternoon, and evening periods along Sungai Kuala Perlis.

Sampling	Station	Salinity Level (ppt)
Morning	S1	0.41
	S2	0.10
	S3	0.20
	S4	1.94
	S5	5.00
Afternoon	S1	0.79
	S2	5.00
	S3	15.00
	S4	23.42
	S5	24.74
Evening	S1	0.33
	S2	1.32
	S3	7.41
	S4	12.52
	S5	14.00

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During the morning sampling, the salinity distribution was recorded at 0.41, 0.10, 0.20, 1.94, and 5.00 ppt, respectively, at S1 to S5. The average salinity range of the morning sampling was 1.53 ppt. While the salinity distribution was at the highest range during afternoon collection was 0.79, 5.00, 15.00, 23.42, and 24.74 ppt throughout S1, S2, S3, S4, and S5. The mean salinity distribution was calculated at 13.79 ppt, the highest among the average obtained from other sampling times. Lastly, during the evening sampling time (PM), the salinity distribution averaged 7.12 ppt. The salinity was recorded at 0.33, 1.32, 7.41, 12.52, and 14.00 ppt at stations one to five along the Sungai Kuala Perlis. Figure 4 illustrates the surface salinity at five different sampling stations.

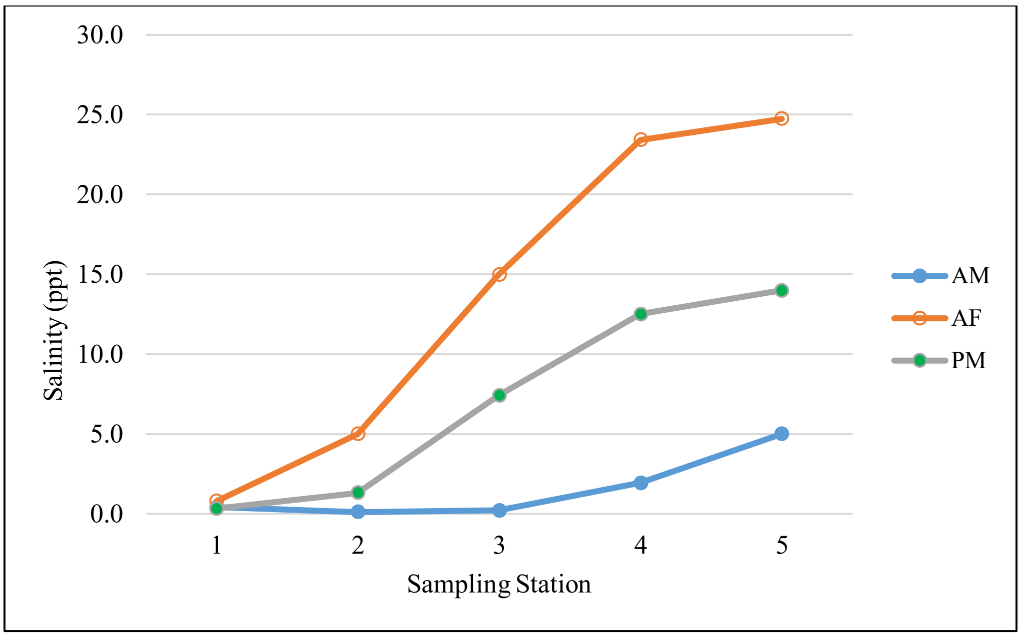

Figure 4: Surface salinity at five different sampling stations

The average salinity distribution shows inclining trends from the morning sampling (AM) until afternoon sampling (AF) and drops again during evening sampling (PM). However, not least than the mean salinity during the morning sampling. The standard deviation also shows slight expansion among the range of salinity values from the mean of salinity obtained on each sampling time throughout locations, which was 1.53 ppt, 13.79 ppt, and 7.12 ppt, respectively, for the morning (AM), afternoon (AF), and evening (PM) sampling time. Even though there is an average difference between the values, there was no significant difference between the surface salinity distribution at three different sampling times. Figure 5 shows the mean surface salinity at different sampling times.

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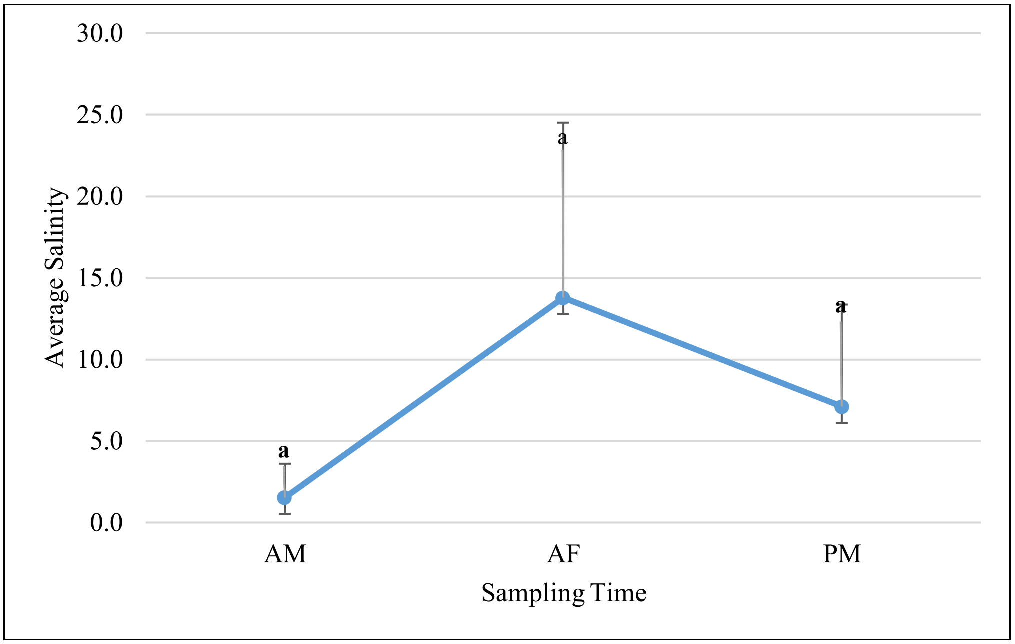

Figure 5: Mean surface salinity at different sampling times. *Same letters indicate values with non-significant differences (P > .05).

The impact of sampling time on surface water salinity levels during the morning, afternoon, and evening sampling periods was studied using a one-way between-subject ANOVA. The results of the analysis indicated that there was no significant influence of sampling time on surface salinity value at the $p < .05$ level for the three conditions [$F(2,12) = 3.566$, $p = 0.061$]. These findings imply that the time of day when water samples are collected does not significantly impact surface salinity levels. Therefore, the evaluation conducted in the Kuala Perlis study area found no temporal variations in salinity levels. The one-way ANOVA for temporal variation of salinity is presented in Table 3.

Table 3: One-Way ANOVA for temporal variation of salinity

Temporal Variation of Salinity	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	376.755	2	188.378	3.566	0.061
Within Groups	633.967	12	52.831		
Total	1010.723	14			

There was not a significant effect of the sampling time on surface water salinity value at the $p< .05$ level for the three conditions [$F(2,12) = 3.566$, $p = 0.061$].

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Spatial Variation of Salinity at Kuala Perlis River

Moreover, from the data collection in this study, the distribution of salinity on the surface water of Kuala Perlis at the different sampling locations can also be found. An increasing pattern was recorded, and the salinity level increased as the sea approached. Station 1 shows the lowest value in mean salinity of the surface water at 0.51 ± 0.25 ppt. However, the lowest salinity value found on the surface water of Kuala Perlis was at Station 2 during the morning sampling, which was 0.10 ppt. The highest salinity value was recorded during the afternoon sampling at station 5, 24.74 ppt. Location 1 is the furthest from the sea opening than location 5, nearest the sea. There is a mean difference in the salinity distribution between locations, as shown in Figure 6. However, the data obtained were proceeded and computed using one-way ANOVA to determine the significant difference at level, $p < .05$ value.

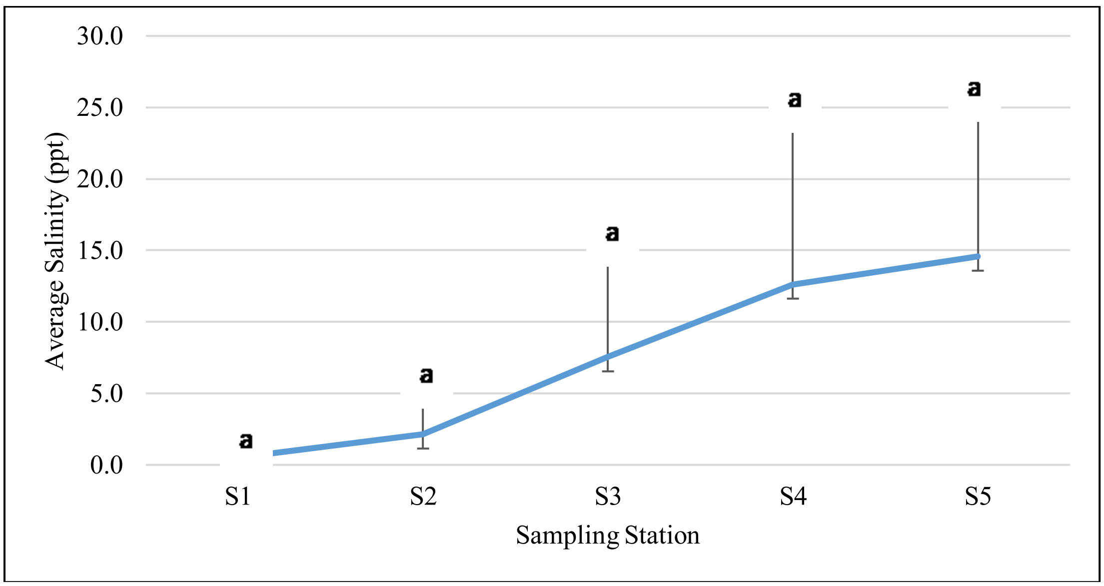

Figure 6: Salinity distribution at different sampling locations. S1-S5: Sampling Station 1 till Sampling Station 5. Similar letters indicate values with non-significant differences ($P > .05$).

To examine the impact of different sampling stations on the water surface salinity values in the five selected locations, a one-way between subject's ANOVA was conducted. The study found that the variation of sampling station location did not have a significant impact on the water surface salinity values in the five locations at the $p < .05$ level, as indicated by the F-value of 2.105 and a corresponding P-value of 0.155 [$F_{(4,10)} = 2.105$, $P = 0.155$]. The outcome suggests no substantial spatial difference in the salinity levels among the stations in the selected locations. To provide further insight, Table 4 illustrates the one-way ANOVA outcomes of the spatial variation in salinity values, which support the conclusion that there is no statistically significant difference among the sampling stations. This finding is crucial as it implies that there may be a consistent salinity level in the selected locations, which could be used as a baseline for further monitoring and management of water quality.

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Table 4: One-Way ANOVA of spatial variation in salinity

Spatial Variation of Salinity	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	461.994	4	115.498	2.105	.155
Within Groups	548.729	10	54.873		
Total	1010.723	14			

There was no significant effect of sampling location on water surface salinity value at the $p < .05$ level for the five locations [$F(4,10) = 2.105$, $P = 0.155$].

Extreme salinity impacts the marine ecosystem, especially for living organisms in estuaries. As mentioned earlier, extreme salinity is caused by seawater intrusion that badly affects the low-lying estuaries. The excessive salinity increase can disrupt the estuarine area's natural landscape. Extreme salinity will impact the marine ecosystem by altering the soil and groundwater salinity, causing stress on plants, fish, and sessile organisms and reducing the dissolved oxygen in the water bodies.

First and foremost, extreme salinities can impact the marine ecosystem, especially the estuarine area, by altering the groundwater and aquifer. Depletion of water resources would occur as the living animals that depend on freshwater will suffer due to the water scarcity caused by seawater intrusion [9]. Furthermore, extreme salinity will cause the salinity in the soil to increase, thus affecting mangrove forest distribution. In disturbed ecosystems, the tide-dominated salinity gradient that drives species zonation changes, accompanied by nutrient shortage, anoxia, and sulfide accumulation, results in the disappearance of salinity-sensitive species [26]. To conclude, extreme salinity will alter the salinity of the soil and groundwater sources.

Next, extreme salinity will cause stress on aquatic living organisms such as plants, fish, and sessile organisms. Some living creatures in the estuary environment, including mangroves and fireflies, are sensitive to changes in salt levels [27]. Estuaries are natural fish hatcheries that raise a variety of fish species. The larval fish assemblage will be restructured when salinity, turbidity, and zooplankton feeding change [22]. The region with a high salinity gradient will lose its enriched biodiversity. Meiofauna populations in the Merbok mangrove system are relatively tiny and appear tied to salinity fluctuations, and they travel following the salinity gradient that best suits their needs [7]. Changes in salinity can have an immediate or indirect impact on freshwater biota. Toxic consequences of increased salinity produce physiological changes that result in species' loss (or gain). Indirect changes can occur when increased salinity alters community structure and function by eliminating (or introducing) species that offer refuge or food or affect predation pressure [28]. Due to extreme salinity, soil salinity will increase, resulting in lower seedling survival, productivity, growth rates, mangrove loss, and conversion to hypersaline mudflats [29]. In short, extreme salinity can induce stress among aquatic organisms directly or indirectly.

Finally, higher salinity also can cause a reduction in the amount of dissolved oxygen in the water bodies. The spatial-temporal surface and bottom dissolved fluctuations were strongly associated with salinity variations. The higher the salinity value, the lower the dissolved oxygen. [30]. Marine hypoxia produced by long-term exposure to low dissolved oxygen levels has happened in coastal and estuarine areas worldwide, with detrimental repercussions for marine life. Hypoxia affects marine zooplankton in many

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ways. Higher trophic level organisms and the structure and function of marine ecosystems may suffer [31]. High salinity can indirectly harm by altering the amount of dissolved oxygen and damage the ecosystem. In summary, monitoring the salinity level is crucial to prevent harm to the ecosystem and habitat caused by extreme shifting in the gradient due to seawater intrusion. However, this study's limitation is that it only provides findings based on a one-day sampling (morning, afternoon, ad evening) from five locations along Sungai Kuala Perlis. Despite this limitation, the research findings are valuable as preliminary baseline data or pilot studies that can be used to develop strategies for extensive river monitoring annually or yearly.

CONCLUSION

The preliminary data on the present spatiotemporal variation in salinity assessment on the Kuala Perlis River surface water was successfully gathered and investigated based on the findings. The results showed three different salinity ranges along the Sungai Kuala Perlis, ranging from 0.41 to 5.00 ppt, 0.79 to 24.74 ppt, and 0.33 to 14.00 ppt for the morning, afternoon, and evening periods. The salinity ranges varied between the different sampling times. Still, no statistically significant difference was found in the salinity values concerning spatial and temporal variations (> .05). The findings or data from this research on salinity variation can be used as a reference or base guideline for researchers, governments, and non-government organizations to monitor the seawater intrusion incident in the Kuala Perlis River estuary and plan for the conservation of the estuary along the Kuala Perlis area. The data also can be used to preserve the Sungai Kuala Perlis ecosystem and promote sustainable river management.

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AUTHOR’S CONTRIBUTION

Aimie Rifhan Hashim carried out the research and wrote and revised the article. Sharir Aizat Kamaruddin, Khairul Naim Abd. Aziz and Jamil Tajam designed the research and supervised research progress; Tun Mohd Firdaus Azis supervised statistical analysis; Faeiza Buyong, Che Zulkifli Che Ismail, and Anisah Lee Abdullah anchored the review, revisions, and approved the article submission. Anastacia Anscelly supervised the spatiotemporal study on localized geographic conditions.

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CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted without any self-benefits or commercial or financial conflicts and declare the absence of conflicting interests with the funders.

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