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Assessing Water Quality in the Kelantan River Basin Using WQI: Suspended Solids and Ecosystem Health

Azhar Mohd Zain[1]*, Mohd Shukri Abdul Hamid[1]

[1] *School of Quantitative Sciences, UUM College of Arts & Sciences, Universiti Utara Malaysia, 06010 Sintok, KEDAH*

*Corresponding Author: azharireach@gmail.com
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Abstract

Water quality in the Kelantan River Basin was assessed in this study using the Water Quality Index (WQI). The Department of Environment Malaysia provided secondary data for this study with seven sampling locations along the Kelantan River Basin. WQI consists of parameters Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxidant Demand (COD), Ammonia Nitrogen (NH_3-N), Suspended Solids (SS) and pH. For each sampling station, other WQI parameters did not exceed the threshold value except SS with a medium value of 235.50 mg/L. Krukal Walis test showed that these parameters were found to be significantly different ($\rho < 0.05$) between sampling station locations. Based on calculation, the SS sub-index value show 16.7% were classified as clean, 2.4% as slightly polluted and 81.0% as polluted for the entire study period. WQI SS sub-index recorded 46 which are in the Polluted category. Suspended solids are the result of several processes, including river runoff and dredging. Clay is among the inorganic and organic materials that make up it. Excessive levels can bind nutrients and heavy metals, increase water temperature, and degrade water quality. The health of the river basin ecosystem was in Class II water quality determined by the average WQI of 84 at all stations. This study concluded that extensive land development activities in the surrounding areas are affecting water quality, thereby affecting the health of the Kelantan River Basin ecosystem in relation to suspended solids.

1. Introduction

Rivers are a source of fresh water which is an invaluable resource. It is widely used for human consumption for domestic, recreational, agricultural, fishing, industrial and drainage purposes. The general public is generally aware of river pollution. As everyone knows, rivers in Malaysia are the main source of fresh water for drinking. Therefore, there is a strong demand for human consumption, necessitating regular monitoring of river water quality [1-6] and encouraged by a number of additional government agencies, like the Department of Health, require developing nations, like Malaysia, to supply techniques for tracking the water quality in Malaysia in order to guarantee its sustainability.

One of Peninsular Malaysia's biggest rivers is the Kelantan River. The Kelantan River plays a significant role in the local economy and that of the government because of its numerous uses for residential use, agriculture, harvesting, industry, and other purposes [7-8]. Rivers are becoming more susceptible to pollution as a result of expanding development and growing local consumption demands. The state of Kelantan experienced a rise in land use changes between 2012 and 2018, as per the findings of the geographic analysis [7].

The forest area decreased somewhat from 1,067,930 Ha to 912,045 Ha (about 14% reduction), the agricultural land area increased from 404,760 Ha to 496,385 Ha (about 22% growth), and the number of construction operations increased, according to Abdul Maulud et al., (2021) [7]. Roughly 1,729 percent) from 3,031.4 Ha to 55,463.0 Ha. Camara et al., (2019) [8] in their study have investigated how deforestation and agricultural expansion affect river water quality. Land use change and population growth are placing increasing strain on the Kelantan River Basin, which could result in more pollution and water stress in the ensuing decades. Thus, it's critical to keep an eye on the water quality to guarantee that this precious river stays pure. Furthermore, in order to give water managers crucial information regarding the management of water resources, water quality monitoring is required [9-10].

The direct effects of this widespread land use will cause suspended solids (SS) to increase in water bodies. Suspended solids (SS) are categorized into two types: organic particles and inorganic particles with sizes ranging from 10 mm to 0.001 mm [11]. Organic particles include algae, protozoa, bacteria, while inorganic particles include materials such as clay, silt and other suspended solids. These organic suspended solids have the potential to emit unpleasant, toxic and harmful odors [12-13]. Chapman & Kimstach (1996) [14] stated that SS usually originate from sources such as domestic and industrial waste, soil erosion, and river dredging and sand extraction activities. High levels of SS in aquatic environments can block sunlight penetration into rivers, thereby interfering with photosynthesis ([15-18]). The Interim National Water Quality Standard (INWQS) sets the SS value for Class III at 150 mg/L.

Despite the studies, further research at the local level is still required to fully understand the connection between changes in WQI and human activities including industry, agriculture, and urbanisation. Thorough examination of river situations where these factors have resulted in notable variations in WQI. Using data from seven sample stations located around the Kelantan River basin between 2019 and 2022. This study aims to show the trend of the water quality status in the basin. By calculating the Water Quality Index (WQI), the National Water Quality Standard (NWQS) for rivers in Malaysia is used to estimate the water quality status of the Kelantan River. This research can contribute to efforts to preserve freshwater ecosystems and biodiversity.

2. Methodology

2.1 Data on River Water

The data used in this study was collected through an online application at Official Portal Department of Environment Ministry of Natural Resources and Environmental Sustainability [19]. The Kelantan River Basin was chosen for research because it provides water to the surrounding communities. The recognized coordinates of the Kelantan River Basin on the east coast of Peninsular Malaysia are latitude 4.6667°N to 6.2000°N and longitude 101.3333°E to 102.3333°E. With a catchment area of 12,925 km2 and a length of over 248 km, the Kelantan River Basin encompasses more than 85% of the state of Kelantan [20]. The location, latitude, longitude, and sample station number are shown in Table 1

Table 1 *Point of water sampling monitoring*

Station	Location	Latitude	Longitude
1.	Jambatan Kusia, Tanah Merah	102.151374	5.775413
2.	Jambatan Sultan Yahya Petra, Kota Bahru	102.227101	6.116425
3.	Tangga Kerai, Bandar Kuala Kerai	102.195505	5.534445
4.	Loji Air Lemal, Pasir Mas	102.154787	6.022443
5.	Sg Relai (Bukan Muka Sauk), Gua Musang	102.309035	4.952144
6.	Loji Ayer Lanas, Jeli	101.890891	5.778035
7.	Skim Bekalan Air Merbau Chondong	102.194703	5.905037

2.2 Data Collection Method

Malaysia's Environmental Quality Monitoring Program (EQMP) by Department of Environment (DoE) gathers information on the quality of the country's rivers, air, and sea water in order to stop and manage pollution. Every year, sampling operations are carried out six times at 1,353 stations spread across 672 rivers, yielding 8,118 samples. In Malaysia, manual river water quality monitoring stations use the Water Quality Index (WQI) to measure and track river water quality, providing long-term trend data for evaluation. The manual approach uses 34 factors (7 in-situ, 27 laboratory) and six frequencies to evaluate the quality of river water through in-situ and laboratory examination. Data information provided by DOE consists of latitude, longitude, Station ID, Location, Sampling frequency, sampling date, Sampling time and parameters [19].

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2.3 Index of Water Quality (WQI)

WQI is determined in Malaysia using six parameters: pH, total suspended solids (TSS), ammonia nitrogen (NH), chemical oxygen demand (COD), biological oxygen demand (BOD), and dissolved oxygen (DO). The primary data used in this investigation is WQI. Information regarding a location's water quality is provided by WQI. WQI is a single value that is produced mathematically by analyzing data on six aspects related to water quality. [21]. Bordalo et al., (2001) [22] states that WQI provides decision-makers with an easy-to-use tool for evaluating a water body's quality and possible uses. Assessing variations in water quality and identifying trends in water quality is made possible by WQI [23]. Must be aware the significance of each parameter in assessing the quality of the water determines its weight: 22% DO, 19% BOD, 16% COD, 16% TSS, 12% pH, and 15% NH_3-N. One can detect these values in equation 1 formula. To determine the WQI value, run calculations and replace all parameter values according to the table. The empirical table must be consulted in order to determine the COD, BOD, and TSS values. Before COD is included to the formula, it needs to be converted to percent saturated. The WQI calculation method is based on the formula below:

$$WQI = (0.22 * SIDO) + (0.19 * SIBOD) + (0.16 * SICOD) + (0.15 * SIAN) + (0.16 * SITSS) + (0.12 * SIpH) \quad \text{(Equation 1)}$$

Where; SIDO = Sub index DO (% saturation) SIBOD = Sub index BOD SICOD = Sub index COD SIAN = Sub index NH_3 -N SISS = Sub index SS SIpH = Sub index pH $0 \leq WQI \leq 100$

2.4 WQI Interpretation

Table 2, Table 3 and Table 4 are the interpretation of water quality indices by the Department of Environment, Malaysia [2]:

Table 2 *National water quality standards for Malaysia*

Parameter	Unit	Class					
		I	IIA	IIB	III	IV	V
Ammonia Nitrogen	mg/l	0.1	0.3	0.3	0.9	2.7	>2.7
Biochemical Oxygen Demand	mg/l	1	3	3	6	12	>12
Chemical Oxygen Demand	mg/l	10	25	25	50	100	>100
Dissolved Oxygen	mg/l	7	5 – 7	5 – 7	3 – 5	<3	<1
pH	-	6.5 – 8.5	6 – 9	6 – 9	5 – 9	5 – 9	-
Total Suspended Solid	mg/l	25	50	50	150	300	300

Table 3 *Water classes and uses*

Class	Uses
I	Conservation of the natural environment. Water Supply I – Practically no treatment necessary. Fishery I – Very sensitive aquatic species
IIA	Water Supply II – Conventional treatment required. Fishery II – Sensitive aquatic species.
IIB	Recreational use with body contact.
III	Water Supply III – Extensive treatment required. Fishery III – Common, of economic value and tolerant species; livestock drinking.
IV	Irrigation
V	None of the above.

Table 4 *DOE water quality classification based on water quality index*

Parameters	Index		
	Clean	Slightly polluted	Polluted
Biochemical Oxygen Demand (BOD)	91 - 100	80 - 90	0 - 79
Ammonia Nitrogen (NH_3-N)	92 - 100	71 - 91	0 - 70
Total Suspended Solids (SS)	76 - 100	70 - 75	0 - 59
Water Quality Index	81 - 100	60 - 80	0 - 59

2.5 Analytical Statistical

The data of this study were analyzed using IBM SPSS software version 26. With SPSS, the data set was statistically analyzed, including descriptive analysis involving measurements of variability and distribution, as well as minimum, maximum, percentage, median and interquartile range (IQR). It is important to use descriptive analysis to describe the condition of each parameter in relation to the water quality classification based on the water quality index. It was also used for data analysis, at a significance level of $\rho < 0.05$. Given that the data were not normal, a rank-based non-parametric test, the Kruskal-Wallis H test (also known as one-way ANOVA on ranks) was used to determine whether two or more groups of independent variables on a continuous or ordinal dependent variable were statistically significantly different [24]. Comparisons of physicochemical parameters with station locations were performed using the Kruskal Wallis test for comparison between locations. Dunn's paired test, adjusted using the Bonferroni correction to show differences between locations. All results will be reported and discussed transparently and responsibly in the form of tables, graphs, diagrams and other forms.

3. Result and Discussion

3.1 Physical and Chemical Concentration in Space at Each Sampling Point in the Kelantan River Basin

Table 5 shows the descriptive parameters of water quality data that includes the median value, Interquartile Range (IQR), minimum and maximum values of physicochemical parameters from the sampling point stations along the Kelantan River Basin. SS exceeded the threshold limit according to INWQS with a median value of 235.50 mg/L. Other parameters are in the standard for Malaysia River.

Table 5 *The concentrations of physicochemical parameters at all sampling stations*

Parameter	Median (IQR)	Minimum	Maximum	WQI	Threshold
DO	7.49(0.43)	5.63	8.30	I	>6 mg/L
BOD	1.00(4.00)	0.00	7.00	II	<3 mg/L
COD	16.00(10.00)	3.00	89.00	II	<25 mg/L
NH_3-N	0.06(0.09)	0.00	7.00	I	<0.9 mg/L
SS	235.50(339.75)	0.00	3770.00	IV	<150 mg/L
pH	7.33(0.63)	5.29	8.74	I	5.5 - 9.0

Table 6 *Physicochemical parameters at different sampling stations*

Station	Parameters (mg/L) Median (IQR)					
	DO	BOD	COD	NH_3-N	SS	pH
1	7.41(0.39)	1.00(4.75)	19.00(6.75)	0.04(0.08)	300.50(499.50)	7.35(0.57)
2	7.49(0.50)	1.50(4.75)	16.00(9.00)	0.07(0.12)	242.00(213.00)	7.47(0.54)
3	7.48(0.50)	1.00(2.75)	12.50(10.75)	0.04(0.07)	445.00(842.75)	7.20(0.62)
4	7.49(0.42)	1.00(4.00)	17.00(12.00)	0.09(0.62)	339.00(290.25)	7.36(0.72)
5	7.77(0.41)	1.00(4.00)	15.50(10.25)	0.03(0.06)	46.00(122.50)	7.58(0.71)
6	7.49(0.45)	1.00(5.00)	15.00(11.50)	0.15(0.26)	44.00(93.00)	6.87(0.76)
7	7.36(0.40)	1.00(3.75)	19.00(9.75)	0.05(0.10)	340.00(257.00)	7.39(0.60)
Total	7.49(0.43)	1.00(4.00)	16.00(10.00)	0.06(0.09)	235.50(339.75)	7.33(0.63)

Table 6 shows the WQI parameter values for each station. Although only SS violates the standard, other parameters will be discussed descriptively to give a true picture of the condition of this river basin. The highest median DO value recorded was 7.77±0.41 mg/L at Station 5 and the lowest median DO value was 7.36±0.40 mg/L at Station 7. The river maintains a healthy aquatic habitat, as evidenced by the mean DO value of 7.49 ±0.43 mg/L indicating that the results are higher than the minimum threshold therefore falling into class I. Kruskal Wallis test showed that there was a statistically significant difference in DO concentration by station ($p < 0.05$). Since DO represents the total dissolved oxygen in the river flow, the DO parameter is important for water quality assessment. Therefore, maintaining high DO levels is important for the stability of aquatic ecosystems. Low pollution levels are indicated by high DO content, and vice versa. The average value of DO level at 6 mg/L was required in order for aquatic organisms to live [25].

Station 2 recorded the highest median BOD at 1.50±4.75 mg/L, while Station 3 had the lowest at 1.00±2.75 mg/L. The average BOD values (1.00 mg/L) remained below the National Water Quality Standards (NWQS) limit, classifying them as class II, indicating a healthy ecosystem in Sungai Kelantan Basin for biological aquatic life. The Kruskal-Wallis H test showed no statistically significant difference ($p > 0.05$), indicating a uniform distribution of BOD across all location categories. BOD serves as an indicator of pollution stemming from industrial, domestic, and agricultural waste [26]. Elevated BOD values signify water contamination [27], suggesting the presence of non-organic substances that microorganisms can decompose, resulting in heightened oxygen consumption [28].

The highest COD was recorded at 19.00±9.75 at Station 7, while the lowest was 12.50±10.75 mg/L at Station 3. The average COD value was 16.00±10.00 mg/L. Kruskal-Wallis H test showed that there was a statistically significant difference in COD ($p < 0.05$). COD evaluates the quantity of oxygen required to chemically oxidize organic matter, serving as an indicator of water quality [29] [26]. COD value is important in measuring dissolved chemicals in river water, indirectly reflecting the organic content. Usually, exceeding the BOD value, COD value results from complete oxidation of all organics, unlike BOD, where only a portion is decomposed.

In the Kelantan River Basin, NH_3-N concentrations ranged from 0.00 mg/L to 7.0 mg/L, with lower concentrations observed at Station 5 and higher concentrations at Station 6. The median concentration across all stations in this study was 0.06 mg/L, which did not exceed the standard and thus fell into class I. The Kruskal-Wallis H test showed that there was a statistically significant difference in NH3-N concentrations ($p > 0.05$). The NH_3-N parameter is a key indicator of various sources of pollution such as human and animal waste, domestic sewage, urban and industrial effluents, and agricultural fertilizers [6] [27]. Water with high ammonium nitrogen (NH_3-N) content is polluted because it contains a lot of organic matter. According to the Interim National Water Quality Standards (INWQS) for Class III, the acceptable NH_3-N content in rivers for water supply should not exceed 0.9 mg/L.

Findings from table 6 show that Station 5 showed the highest median pH reading at 7.58, while Station 6 showed the lowest pH at 6.87. Despite the variations, the overall median pH of 7.33 remained within the National Water Quality Standard (NWQS) limits, categorizing the Kelantan River Basin as class I, indicating a thriving ecosystem for aquatic life. The Kruskal-Wallis H test showed that there was a statistically significant difference in pH concentrations by station ($p < 0.05$). Water quality is also influenced by the amount and distribution of rainfall; lower pH values are associated with deeper water levels [30]. According to Nur Fahirah et al., (2019) [31], pH increased significantly at lower salinity levels but decreased slowly at higher salinity ranges.

Table 6 shows that Station 3 recorded the highest SS level with a median of 445.00 mg/L, while the lowest median was found at Station 6 with 44.00 mg/L. The mean SS was 235.50 mg/L. The SS recorded values exceeding the threshold value of the Malaysian national water quality standard. The Kruskal-Wallis H test showed that there was a statistically significant difference in the Total concentration ($p < 0.05$). The mean SS value in this study fell within the standard and was therefore classified as class IV. As a result, in terms of SS values, this river was categorized as an unhealthy ecosystem and considered unsafe for aquatic biological life. Typically, soil erosion, caused by human activities, is considered the main source of SS from the surrounding area. Peavy et al., (1985) [27] explained that increased land use activities in an area are closely related to higher SS content in their respective rivers. High levels of SS in the aquatic environment can prevent sunlight from penetrating into the river, thus interfering with the photosynthesis process In terms of the static value of the river itself, it will decline. This is because the photosynthesis process in the water body is no longer productive.

This happens because the rate of sunlight penetration is decreasing due to the SS layer in the water. This also disrupts the operation of the river ecosystem. There are many previous studies that have examined SS. For example, Abdüsselam Altunkaynak & Wang, (2011) [32] stated that wind, tides, and waves can easily wash and suspend fine SS in shallow estuaries, increasing turbidity levels. Clearly, this high SS is harmful to aquatic life and disrupts the health of river ecosystems. This should not be taken lightly as it will ultimately affect human life.

3.2 Water Quality Index (WQI) and Ecosystem Health Status

Table 7 *WQI and river basin status*

Station	WQI	Class	Category/ Status
1	86	II	Clean
2	82	II	Clean
3	83	II	Clean
4	85	II	Clean
5	84	II	Clean
6	84	II	Clean
7	84	II	Clean
Mean	84	II	Clean

The average WQI value for each sampling station is shown in Table 7. This WQI is based on the DOE Water Quality Index categorization. The DOE WQI calculation formula and procedure were used to calculate the WQI (Equation 1). The surface water quality of the Kelantan River Basin was assessed for each station using the index. Station 1 had the largest WQI value, measuring 86, while Station 2 had the lowest WQI value, measuring 82. The average WQI recorded throughout the study period was 84. Each sample site documented a clean class II rating. DOE Water Quality Classification Based on the Water Quality Index classifies the entire Kelantan River Basin as clean. Class II conventional treatment water supply is required. For Fisheries II it is suitable for sensitive aquatic species. Recreational use with body contact is suitable for this class.

3.3 Pattern of the WQI

Figure 1 shows, with a combined score of 37.50%, stations 2 and 5 were slightly polluted, and station 7 had the lowest overall score of 20.83% over the course of the study. It can be concluded that fishing, leisure, and household use in the Kelantan River basin are safe.

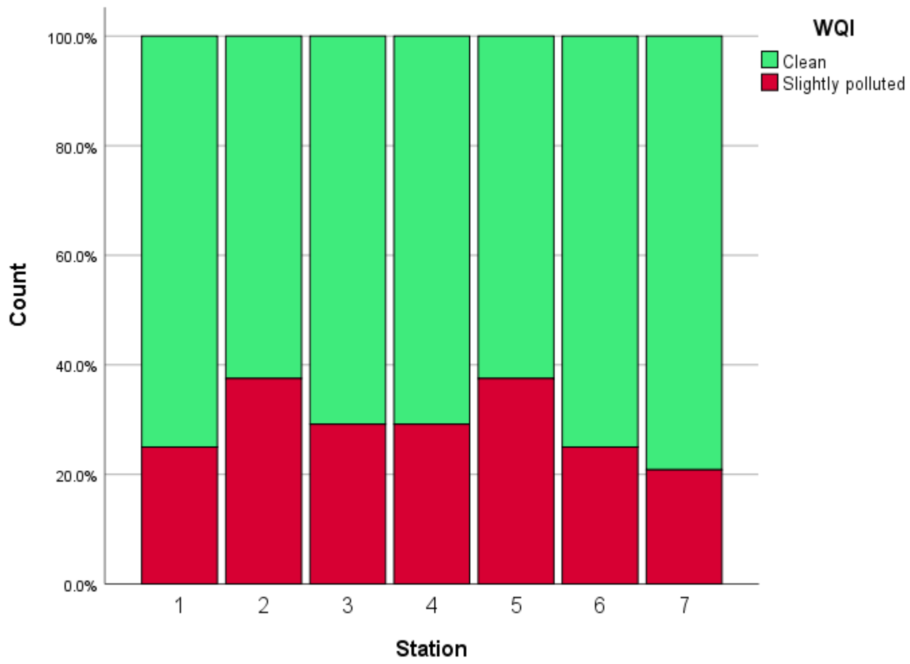

Fig. 1 *WQI status between sampling station*

3.3.1 Biochemical Oxygen Demand (BOD) Sub-Index Status of Kelantan River Basin

Figure 2 illustrates that 33.33% of all observations are contaminated. 13% percent of this total percentage is slightly polluted, and the remaining nineteen percent is polluted. A total of 66.67% of rivers are considered clean. Compared to other stations, Station 5 has the lowest level of river cleanliness based on sub-basin (Polluted = 25.00%, Slightly Polluted = 12.50%). According to BOD parameters, Station 4 has the cleanest river status of all stations (Clean = 70.83%, Slightly Polluted = 12.50%, Polluted = 16.67%). The overall WQI BOD sub-index recorded 96 which are in the clean category.

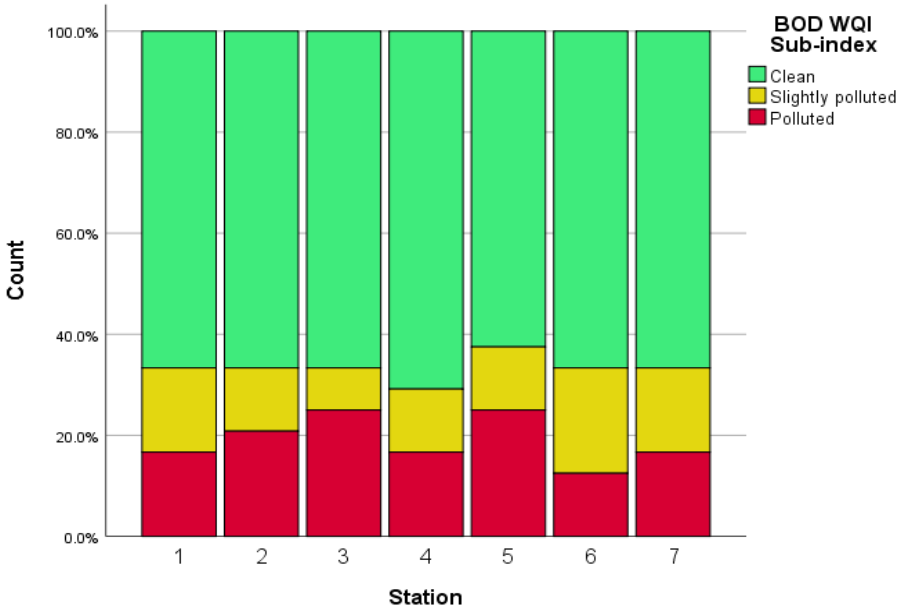

Fig. 2 *BOD sub-index between sampling stations*

3.3.2 Ammonia Nitrogen (NH_3-N) Sub-Index Status of Kelantan River Basin

According to figure 3, station 5 is the most polluted, with a reading of (Clean = 58.33%, slightly polluted = 3.33%, and Polluted = 8.33%), while the cleanest stations are stations 6 with readings (Clean = 79.17%, slightly polluted = 16.67%, and Polluted = 4.17%). The overall WQI NH3-N sub-index recorded 94 which is in the Clean category. NH3-N is a crucial parameter in the analysis of disturbances that impact river basin health. It is the primary indicator of the presence of sewage particularly that from animals like pigs. In general, the Kelantan River Basin has low levels of NH3-N-based pollution sources. When treated and untreated wastewater is released into lakes and rivers from point and nonpoint sources, ammonia nitrogen (AN) is frequently present [33] [34].

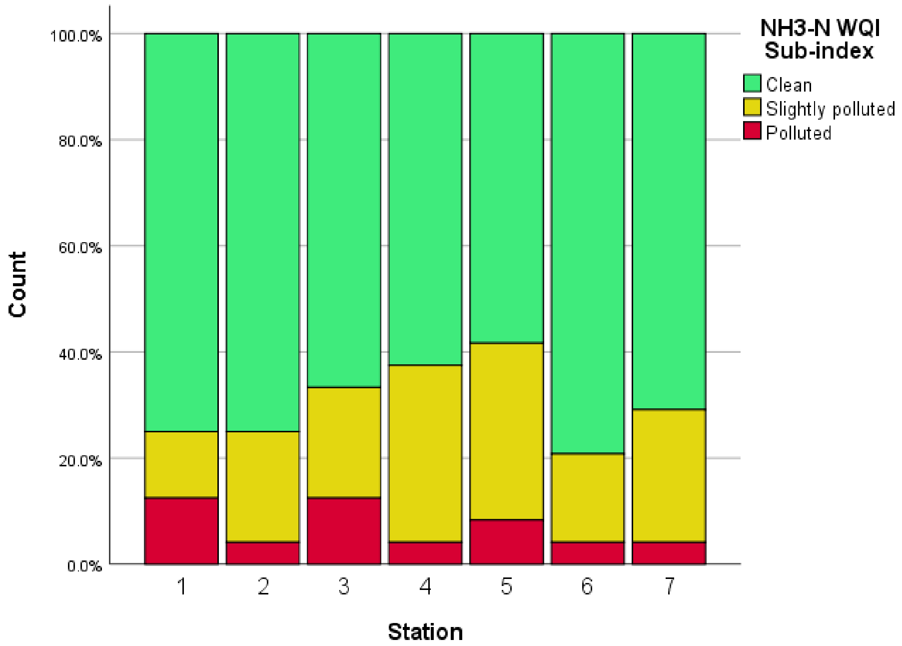

Fig. 3 *NH3-N sub-index between sampling station*

3.3.3 Suspended Solid (SS) Sub-Index Status of Kelantan River Basin

According to figure 4, Stations 2 and 3 have the highest concentration of SS at 12.50% and 87.50%, respectively. These are followed by Station 5 at 12.50% and slightly polluted at 4.17% and 83.33%, Stations 4 and 7 at 20.83% and 79.17%), and Station 1 at 16.67% and slightly polluted at 8.33% and 75.00%, respectively. Additionally, Station 6 had the lowest SS concentration, according to the analysis's findings (Clean = 20.83%, Slightly Polluted = 4.17%, Polluted = 75.00%). The overall WQI SS sub-index recorded 46 which are in the Polluted category. It is currently acknowledged that SS play a significant role in the worsening of water quality, which causes aesthetic problems, increased water treatment costs, a reduction in fishing resources, and significant for the biological degradation of aquatic habitats. Consequently, suggested water quality criteria for SS concentrations in freshwater systems have been established by government-led environmental agencies [35].

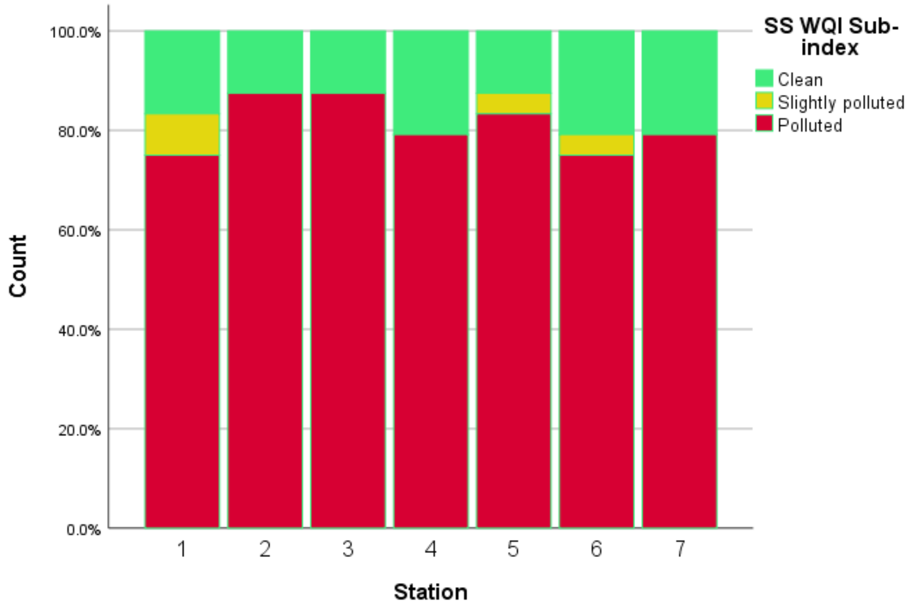

Fig. 4 *SS sub-index between sampling station*

4. Conclusion

Based on the study findings, the Kelantan River Basin is classified as a healthy and safe environment for aquatic biological life, but there are signs of deterioration in water quality for suspended solids. Both human health and ecology are at great risk from the effects of the increase in SS concentrations evenly across most sampling stations representing the Kelantan River Basin. Soil erosion, river dredging, sand extraction, and household and industrial waste discharged into the Kelantan River must all be reduced by taking significant and immediate action. The study recommends monitoring the amount of industrial, land reclamation, and household sewage discharged into the environment, as well as closely monitoring different sources of pollution through artificial intelligence technology. In addition, the study recommends expanding regular, open research and making knowledge easily accessible to all levels of society. Ultimately, this issue will affect human, animal and environmental lives. Neglect will lead to worse disasters in the future.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

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Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Azhar bin Mohd Zain, Mohd Shukri bin Abdul Hamid;* ***data collection:*** *Azhar bin Mohd Zain, Mohd Shukri bin Abdul Hamid;* ***analysis and interpretation of results:*** *Azhar bin Mohd Zain, Mohd Shukri bin Abdul Hamid;* ***draft manuscript preparation:*** *Azhar bin Mohd Zain, Mohd Shukri bin Abdul Hamid. All authors reviewed the results and approved the final version of the manuscript.*

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