Spatio-Temporal Analysis for Monitoring Water Quality of Skudai River, Malaysia

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Key words: water quality monitoring, Water Quality Index, water pollution, spatio-temporal analysis

SUMMARY

Spatio-temporal analysis for monitoring water quality is a study conducted to spatially and temporally assess the trend of water quality at Skudai River, Malaysia. For this study, the data of Water Quality Index (WQI) which involves a total of several monitoring stations from 2012 to 2016 are used. The six components of WQI are Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Suspended Sediment (SS), pH value, and Ammonia Nitrogen (AN). This study aims to analyse the spatio-temporal trend of water quality by spatially and temporally examining specific locations along the river. Initially, the procedure of spatial autocorrelation through Moran's I technique is employed to determine the specific number of monitoring stations to be used for the spatio-temporal analysis. At the end of this procedure, the specific dataset which consists of a total of 11 monitoring stations are accepted. Later on, using this dataset, the temporal trend of water pollution is studied to identify the annual and seasonal pattern of water quality using spatial autocorrelation method. The seasonal pattern represents the entire East coast monsoon, Transition months and West coast monsoon. The finding shows that water pollution consistently occurs at the river downstream for each year and the WQI found higher during the Weast coast monsoon which is from May to September. Finally, the cross-match between the objectives and the findings of this study are able to identify the spatio-temporal trend of water quality as one of the indicators to evaluate water pollution status at Skudai River.

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1. INTRODUCTION

Skudai River, along with Segget River and Tebrau River, was recognized as among the most polluted rivers in Johor Bahru, Malaysia and hence was included in the river rehabilitation program (Iskandar Regional Development Authority, 2014). Figure 1 highlights the location on Johor Bahru within Malaysia. Skudai River is one of the main urban rivers in Johor Bahru and flows from Sedenak to the Straits of Johor through the tributary of Danga River. Millions of ringgits are spent in the past decade to rehabilitate Skudai River and its tributaries. However, the condition of river has remained similar to a certain extent, and the colour is cloudy (Jamin, 2014).

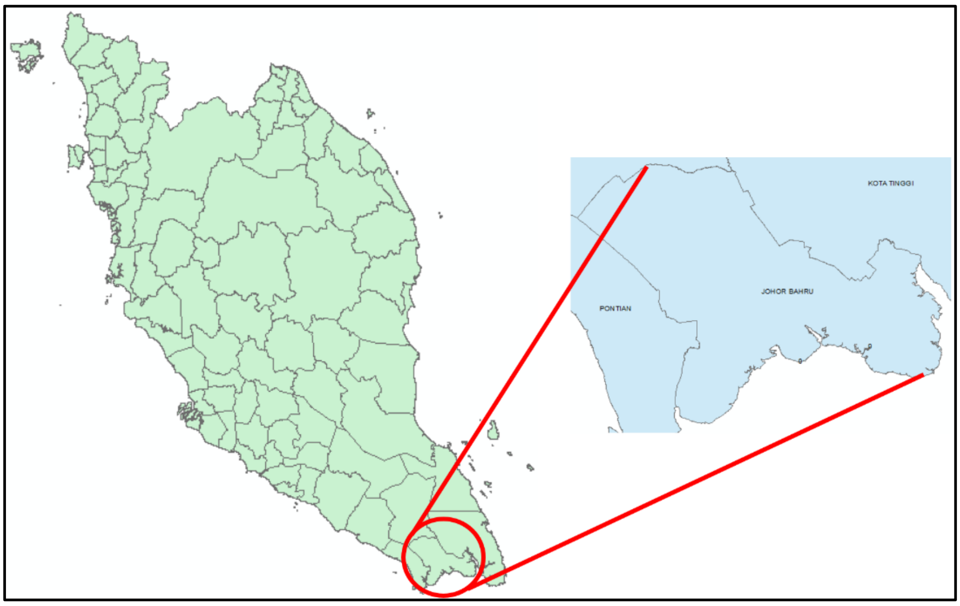

Figure 1. The exact location Johor Bahru within Malaysia

Development in Johor Bahru has grown rapidly since 2006 when the government setup an economic development corridor which is located in the southern part of Johor, known as Iskandar Malaysia (Rizzo and Glasson, 2012). The rise of Iskandar Malaysia as a major economic zone in the southern part of Johor is experiencing meteoric growth in many aspects. The total population in Iskandar Malaysia is recorded at 1.61 million in 2010 and the estimated population is projected to be around 3.0 million in 2025 (Iskandar Regional Development

Authority, 2014). Despite this, massive development in Iskandar Malaysia region comes at a greater price where the major issue is river pollution (Hangzo and Cook, 2014).

In general, there are some standard ways to measure water quality in Malaysia based on Water Quality Index (WQI) and Interim National Water Quality Standards (Hossain et al., 2013). Water quality measurement is a method used to determine the status of water, ranging from polluted, slightly polluted to clean. Polluted water causes change in the physical, chemical and biological aspects of environment that affects the entire biosphere living in water bodies such as plants and organisms (Chen, 2014). Some standards are used to measure water quality in Malaysia, which is either based on WQI or Interim National Water Quality Standards for Malaysia (INWQS). WQI in Malaysia is computed based on six parameters, which are pH, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Ammonia Nitrogen (AN), Suspended Solid (SS), and Dissolved Oxygen (DO) (Naubi et al., 2016). These parameters are then entered into the standard formula to obtain the WQI and then used to classify the river status.

Hence, the aim of this study was to analyse the spatio-temporal trend of water quality as one of the indicators to evaluate water pollution status at Skudai River from Department of Environment (DoE) Malaysia manual and automatic stations data (Department of Environment Malaysia, 2012b) . Later on, the spatio-temporal trend of water pollution using WQI based on annual (2012-2016) and seasonal was analysed.

2. METHODOLOGY

2.1 Study area and data collection

Skudai River is located in Johor as shown in Figure 2. The length of this urban river is 46 kilometres and the catchment area are 325 km^2. Skudai River which flows from Sedenak and flowing into Straits of Johor consists of urban, semi-urban and natural areas (Hashim et al., 2015). The inflow in the Skudai River comes from Melana River, Senai River, Kempas River and Danga River (Shamsudin et al., 2011). Melana River and Senai River are main tributaries upstream under the category of semi-urban river because their catchment includes forest, residential and commercial areas. In contrast, the main tributaries in the downstream area of Kempas River and Danga River are mostly covered by commercial, communication and residential areas located in the urban area.

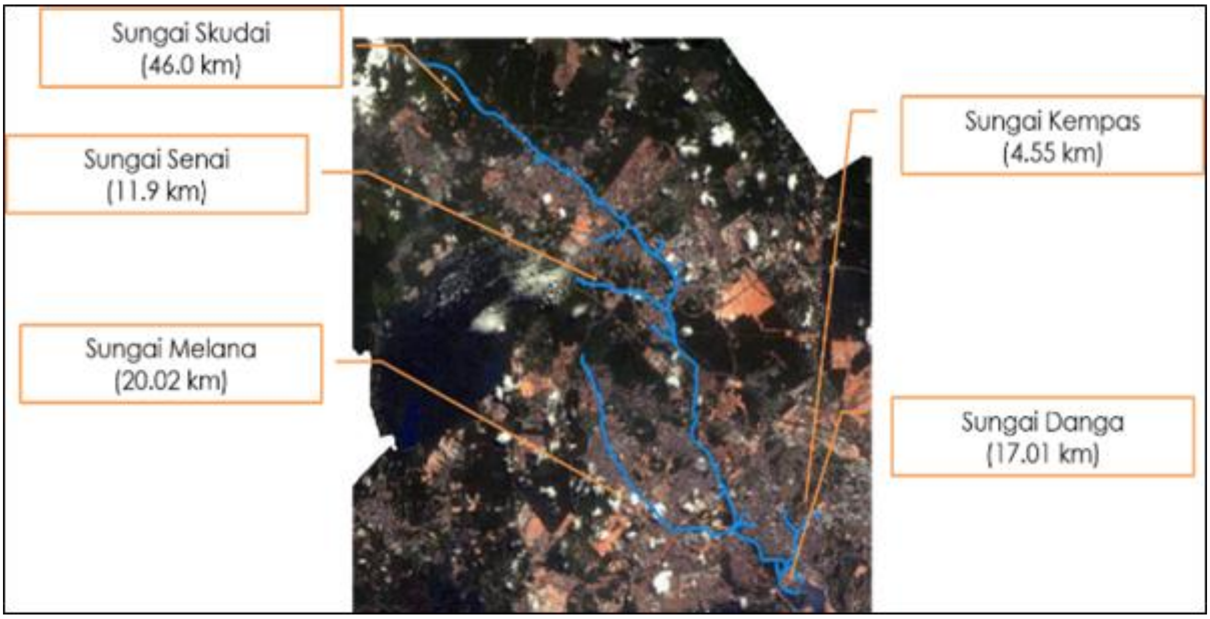

Figure 2. Study area at Skudai River

Skudai River is one of the rivers under the National River Water Monitoring Program and categorized as moderately polluted in 2002 (Ismail et al., 2014). Due to intense development and increase in population, the quality of water in Skudai River is considered as polluted when it was classified as a Class III river in 2012 (Department of Environment Malaysia, 2012a).

Data collection was needed based on the method and analysis conducted. In this study, two types of data were used, which is spatial data and non-spatial data as shown in Table 1. Spatial data were provided by Iskandar Regional Development Authority (IRDA) in shapefile format (*.shp) using Rectified Skew Orthomorphic (RSO) coordinate. These data were obtained from various agencies such as Department of Irrigation and Drainage (DID), DOE, Johor Water Corporation (SAJ) and Johor Economic Planning Unit (UPEN).

Table 1. List of data

Spatial Data		Non-Spatial Data
Data	**Uses**	
• Mukim (suburb) • Dewan Undangan Negeri (state assembly) • Parliament • Local Authority	Administration data	Water Quality Index (WQI)
• Sewerage Treatment Plant (STP) • Squatters • Ground Pollution Trap (GPT) • Industrial area • Wet market • Active Development Area • Housing Estate	Land use activities	
• Water Monitoring Station (WMS) • River • Reserve Area • Water Catchment	Water quality monitoring	

Non-spatial data provided by DOE from 2012 to 2016 consists of WQI data, which includes the value of six parameters of water quality at Skudai River for each month. Data also consists of the river status for each station of the river. The longitude and latitude of the station was stated at this data represents the location of 13 stations. However, some data only recorded 11 stations. Station 3SI15 and 3SI18 were two stations which are not recorded in some months. The river status pollution shows that these two stations were classified as the cleanest stations almost every month.

2.2 Spatial Autocorrelation (Moran's I)

Spatial autocorrelation functionality using Moran's I method was applied to analyze the spatial pattern of vector data. There are two types of data either from 13 stations or 11 stations. Table 2 summarizes the average of WQI (2012 – 2016) for 11 stations and 13 stations. Average of WQI was obtained from the total sum of five years data and divided into five. Hence, this analysis was conducted to identify which types of data should be used in the analysis.

Table 2. Average of WQI for spatial autocorrelation

Stn No	River	11 stn	13 stn
3SI01	Kempas	47.88	47.88
3SI02	Kempas	54.47	54.47
3SI05	Skudai	55.61	55.61
3SI06	Skudai	60.13	60.13
3SI07	Skudai	62.50	62.50
3SI09	Skudai	84.80	84.80
3SI10	Skudai	69.32	69.32
3SI13	Skudai	66.75	66.75
3SI14	Skudai	63.52	63.52
3SI17	Skudai	55.53	55.53
3SI18	Skudai	90.30	-
3SI15	Melana	81.88	-
3SI16	Melana	51.50	51.50

The spatial autocorrelation was used to measure the autocorrelation based on the feature locations of WMS and WQI value. The distribution of the water pollution was measured using the WQI value, either disperse, random or cluster. The degree of dependency was measured among the observations in a geographic area. If autocorrelation exists, the observations are independent of one another. Moran's I is classified as positive, negative and no spatial auto-correlation. The value of Moran's I varies between –1.0 and + 1.0 as shown in Figure 3.

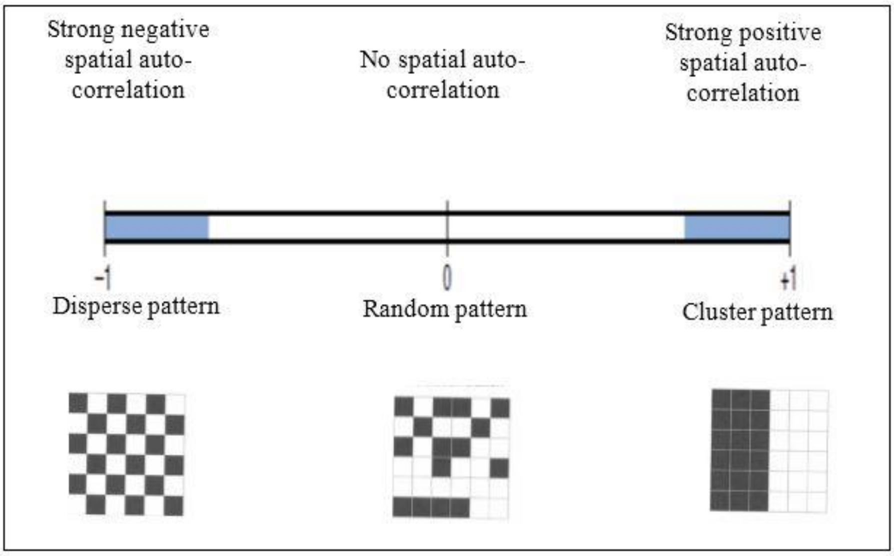

Figure 3. Spatial autocorrelation for point pattern

Spatial autocorrelation (Moran's I) measures spatial autocorrelation based on both feature locations and feature values simultaneously (Murayama and Thapa, 2011). The algorithm below calculates the Moran's I Index value, z-score and p-value to evaluate the significance of that Index. The computation of spatial autocorrelation (Moran's I) is as follows:

$$I = \frac{N\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{(\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij})\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad (1)$$

where
N : the number of cases
X : the mean of the variable
X_i : the variable value at a particular location
X_j : the variable value at another location
W_{ij} : a weight indexing location of *i* relative to *j*

Statistical significance test used for Moran's I is:

$$Z = \frac{I - E(I)}{S_{error(I)}} \quad (2)$$

where
I : the calculated value for Moran's I from the sample
E(I) : the expected value (mean)
S : the standard error

This analysis returns five results which is Moran I Index, Expected Index, Variance, z-score, and p-value. A positive Moran I index value shows tendency toward clustering while a negative Moran I index value shows tendency toward dispersion (Zhou and Lin, 2008). The Expected and Observed Index values were compared. However, index values cannot be interpreted directly. Hence, the statistical significance was measured in z-score and p-value to tell whether or not to reject the null hypothesis.

2.3 Spatio-temporal analysis

In order to analyze the spatio-temporal trend of WQI change with the temporal scale analysis, two methods were used. The first method is to identify the annual spatio-temporal trend of water pollution using WQI annually from 2012 to 2016. As shown in Table 3, the average of WQI for each station from 2012 to 2016 was summarized. The average of WQI was obtained from the WQI data, where the total sum of WQI was divided into 12 and the result is shown in the table below. Later on, any changes that occur in each year were identified using the hotspot analysis method to analyze the movement of WQI at Skudai River.

Table 3. Average of WQI at Skudai River

STN NO	2012	2013	2014	2015	2016
3SI01	49.20	49.25	46.54	56.01	38.39
3SI02	58.31	48.18	49.56	60.4	55.91
3SI05	56.55	58.54	57.57	58.66	46.7
3SI06	61.75	65.95	62.56	61.87	48.52
3SI07	68.59	66.67	59.01	58.75	59.48
3SI09	82.28	86.64	85.58	85.02	84.49
3SI10	71.57	74.48	69.91	67.35	63.28
3SI13	70.13	72.20	66.75	65.65	59.04
3SI14	70.55	74.54	67.13	50.75	54.64
3SI17	58.55	56.55	52.34	59.46	50.73
3SI16	53.91	54.93	52.13	53.65	42.88

The second method is to identify the spatio-temporal trend of WQI based on the seasonal variation which is a common practice worldwide (Qadir et al., 2008). Monsoon in Malaysia is divided into three, the East coast monsoon (EC), West coast monsoon (WC) and transition months (T) (Wong, 1998). The average of WQI were distributed into three parts of monsoon as shown in Table 4. For the East coast monsoon, data were gathered from January, February, March, November and December. Data from May, June, July, August and September were gathered to obtain the West coast data. Finally, the transition months represent data for April and October. Table 4 summarizes the average of WQI during five years in each monsoon. The average of WQI was obtained from the WQI data, where the total sum of WQI was divided into five years and the result is shown in Table 4.

Table 4. Average of WQI based on seasonal data

Station	**EC WQI**	**WC WQI**	**T WQI**
3SI01	44.76	40.5	46.6
3SI02	58.42	52.2	54.2
3SI05	61.05	53.4	53.7
3SI06	61.95	58.2	54.3
3SI07	67.70	60.8	61.7
3SI09	89.66	83.3	85.7
3SI10	76.65	66.3	66.8
3SI13	72.67	64.5	65.1
3SI14	67.42	61.9	65.5
3SI17	56.78	48.3	53.1
3SI16	57.33	46.3	52.1

3. RESULTS AND DISCUSSION

3.1 Spatial Autocorrelation (Moran's I)

The distribution of average WQI was identified using spatial autocorrelation analysis. Results from spatial autocorrelation analysis that make use of the average WQI for 11 stations and 13 stations is summarized as shown in Table 5.

Table 5. Result of spatial autocorrelation

Properties	**13 Station**	**11 Station**
Moran's Index	0.42	0.16
z-score	2.18	1.00
p-value	0.03	0.32
Variance	0.053	0.068
Expected Index	-0.083	-0.100
Distribution	Clustered	Random

Both results show the positive value of Moran's Index which indicates tendency towards clustering. However, the z-score value and p-value were analyzed to show the statistical significance. The z-score of 13 stations is 2.18, and the uncorrected p-value associated with a 95% confidence level, where this indicates the clustered pattern could be the result of random chance. To conclude, the p-value is 0.03 and the null hypothesis is possible to reject. Figure 4 represents the result of 13 stations in normal distribution graph.

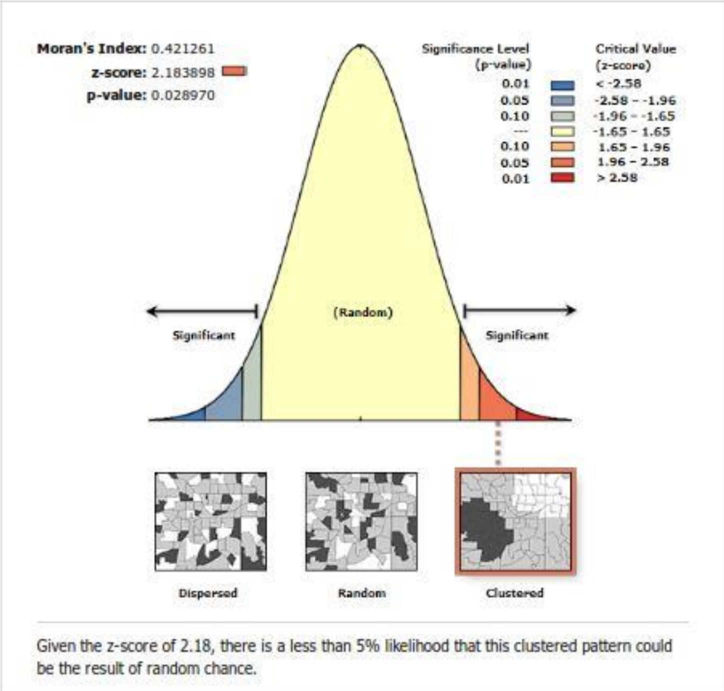

Figure 4. Spatial Autocorrelation report for 13 stations

The z-score value of 11 stations is in the middle of normal distribution, which 1.00 represents the expected outcome, as the pattern does not appear to be significantly different than random. Since the p-value is 0.32 and not statistically significant, the null hypothesis cannot be rejected. Figure 5 shows the normal distribution graph for 11 stations. Thus, data from 11 stations were acceptable for subsequent analysis. This is due to the random nature of the spatial process.

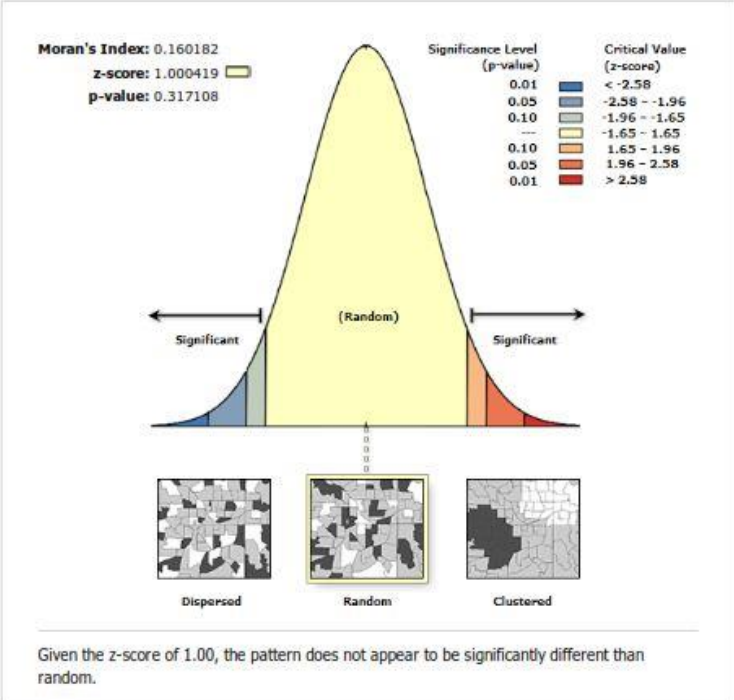

Figure 5. Spatial Autocorrelation report for 11 stations

3.2 Spatio-temporal analysis

Figure 6 shows hotspot analysis was conducted to identify the spatio-temporal of WQI from 2012 to 2016. The lowest WQI in 2012 occurs at Station 3SI05 which indicates the most polluted station. The other three stations with a lower WQI were Stations 3SI06, 3SI01 and 3SI02, which may indicate slightly polluted or tends to be polluted. This shows that Station 3SI05 has the lowest value of WQI and was surrounded by three downstream stations with lower values of WQI.

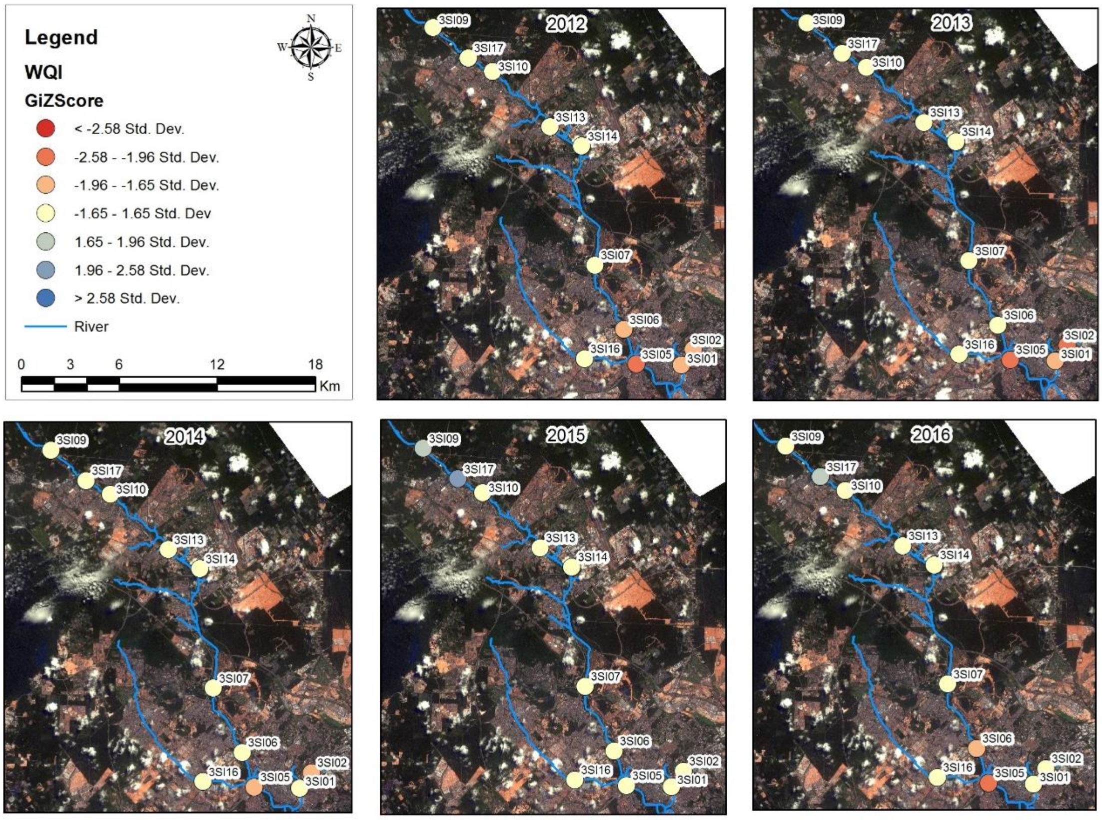

Figure 6. Spatio-temporal hotspot analysis of WQI from the year 2012 – 2016

However, two stations were found polluted in 2013 which are Stations 3SI02 and 3SI05, while the lower WQI at Station 3SI01 indicates slightly polluted or tends to be polluted. In 2014, Stations 3SI02 and 3SI05 have the lowest WQI but the z-score of both stations slightly increases compared to 2013. This shows that the water quality at Skudai River improved slightly in 2014.

Moreover, a gradual change takes place in 2015 when no station has a low WQI. The result shows most of the stations in normal distribution which tend to be polluted or clean. Importantly, two upper stations have high WQI, which are Station 3SI17 and Station 3SI09. It shows that WQI at Skudai River was slightly increased, thereby showing improvement in water quality.

In 2016, Station 3SI17 had the highest WQI but the z-score shows that it slightly decreased compared to 2015. The lowest value of WQI occurs at Station 3SI05, indicating the station is polluted. While, the lower WQI occurs at Station 3SI06. This shows that Station 3SI05 might be affected by Station 3SI06 as Station 3SI06 is located before Station 3SI05. Since Station 3SI06 was slightly polluted, the nearest stations might also be influenced.

The analysis shows different results compared to the results as shown in Figure 7. The graph shows only the highest and lowest WQI based on the value of WQI instead of considering the surrounding spatial distance. The spatial factors are important elements that need to be considered because it shows the effects of surrounding area. For instance, Station 3SI05 was the most polluted station because it is surrounded by other polluted stations.

Figure 7. Spatio-temporal graph of WQI from 2012 to 2016

Figure 8 summarised the seasonal spatio-temporal results of average WQI in Malaysia. The figure shows that most of the WQI was lower during the West Coast Monsoon except Station 3SI06, which has lower WQI during the Transition months. However, during the East Coast Monsoon, the WQI was higher than other monsoons in all stations except Station 3SI01.

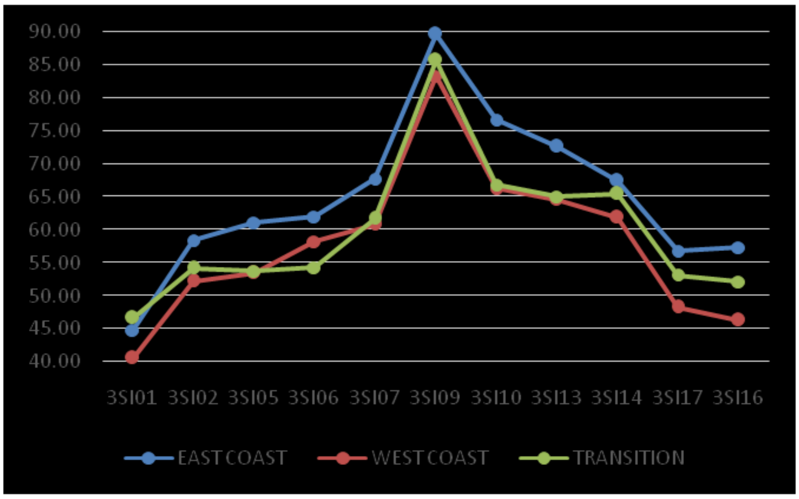

Figure 8. Spatio-temporal graph of WQI based on seasonal

Spatio-temporal of WQI based on seasonal is shown in Figure 9. The result shows that during the East Coast Monsoon, Station 3SI05 was the most polluted station due to having the lowest WQI. The z-score during the East Coast Monsoon is -2.094, which tends to be polluted. Station 3SI05 was surrounded by two slightly polluted stations, Stations 3SI01 and 3SI02, which are located around 4 kilometres approximately from Station 3SI05.

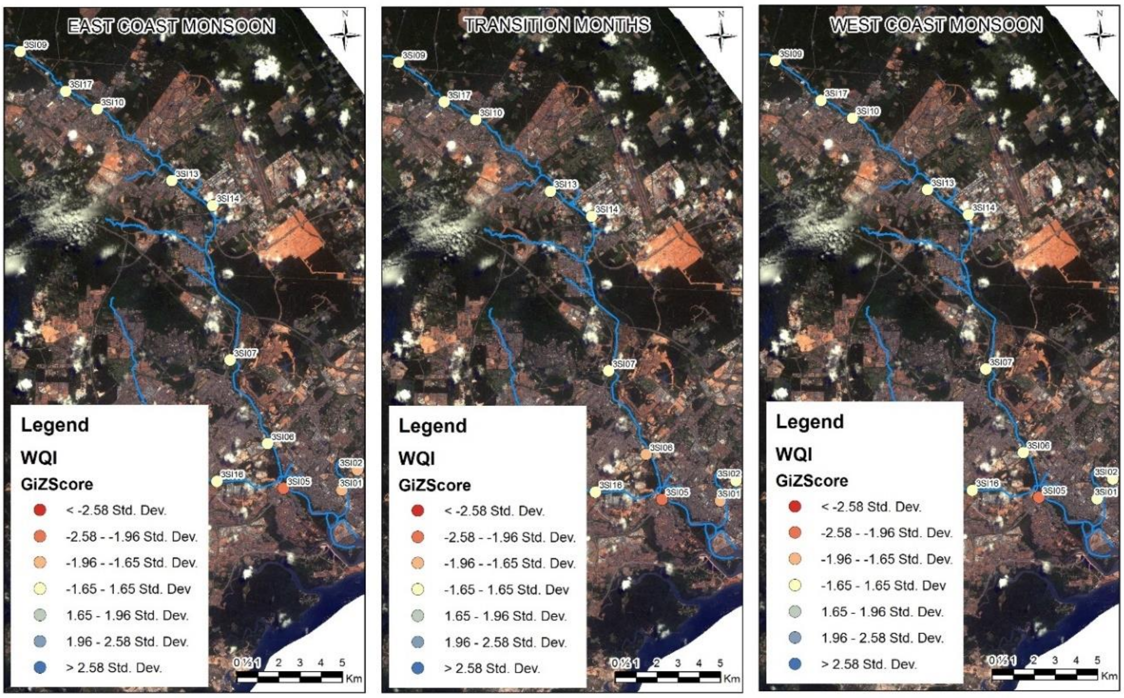

Figure 9. Spatio-temporal trend of WQI based on seasonal

During the Transition months, Station 3SI05 remains as the polluted station due to having the lowest WQI. The z-score is -2.167, which tends to be polluted. Two stations with the lower WQI were Stations 3SI06 and 3SI01, which are located within 3 kilometres from Station 3SI05. This shows that Station 3SI05 was surrounded by polluted stations which then affects its water quality.

Station 3SI05 remains polluted during the West Coast Monsoon due to the lowest WQI. The z-score during the West Coast Monsoon is -1.985. Station 3SI05 was the only polluted station during this monsoon. However, the surrounding stations show the normal distribution tends to be polluted or clean. Hence, Station 3SI05 was surrounded by other stations which have lower WQI.

This analysis shows that many influencing factors may contribute to the level of water quality at Skudai River. During the East Coast Monsoon, the weather is usually rough due to continuous rain for several days (Harun et al., 2014). Several locations may receive maximum rainfall during this period. The rate when the rain falls is heavy, and affects the sources of pollution to

flow from the river upstream to the river downstream. In addition, the river current is also often affected by rainfall. On the other hand, the whole country except Sabah is relatively drier during the West Coast Monsoon as most locations experience minimum monthly amount of rainfall (Harun et al., 2014).
Station 3SI05 was the most polluted station during the five year study period and polluted with SS and has lowest DO concentration. This analysis shows that Station 3SI05 consistently has the lowest WQI every year except 2015, and during all monsoons could be associated with the dumping activities which occur continuously and affect the water quality at Skudai River. In 2015, strict enforcement was probably taken by the authorities or cleaning processes may be conducted at Skudai River, which then increases the level of water quality.

4. CONCLUSION

Based on the water quality analysis, it is concluded that the river status at the downstream area was the most polluted area. However, the center of the river tends to be polluted in a certain period probably due to the intensity of human activities at that area. Further studies are urgently needed to investigate any relationship between human activities and land use development towards the water quality at Skudai River due to unusual water quality conditions occurs in 2015.

Although this study generates the results of the spatio-temporal trend of pollution based on the annual and seasonal analysis, the movement of pollution and its pollutant should be observed and identified (Ambrose et al., 1988). Finally, the analysis to model the spatial relationship is recommended to be used in order to answer questions such as the relationship between the quality of water and any influencing factors. Geographical weighted regression method can be used in this study to model, examine and explore the better understanding factors behind the spatial pattern to predict the spatial outcomes (Tu, 2011). It is the hope that the analysis presented here will support the efforts of policymakers in the future.

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BIOGRAPHICAL NOTES

Norezzayana Rohaizat graduated with a first class honours from Universiti Teknologi Malaysia and now works as a GIS Executive in a planning firm in Johor Bahru, Malaysia. The winner of The ESRI Young Scholars Award 2015 (Malaysia), she represented Malaysia to The ESRI International User Conference in San Diego, USA in the same year. She travels and reads during her pastime.

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