ORIGINAL ARTICLE

Using Water Quality Index, Principal Component Analysis and IDW Interpolation Water to Determine the Water Quality Assessments of Selected Rivers in Northern Region of Kelantan, Malaysia

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ABSTRACT

Introduction: Poor management of water and non-point sources of anthropogenic activities affects the water quality in Pengkalan Chepa river (PCR), Kemasin river (KR) and Semerak river (SR) located in the northern region of Kelantan. The objective of this study is to determine the water quality assessments using the water quality index (WQI), Principal Component Analysis (PCA) and the inverse distance weighted (IDW) method. **Methods:** Data sets of 14 physico-chemical parameters and 84 observations (14 X 84) were obtained from the Department of Environment (DOE) Malaysia for one year from January to December 2016. WQI was adopted by the DOE whereas PCA was conducted to evaluate the water quality across the three selected rivers and analysed the sources of water pollution in this study. The results of IDW helped us to identify key areas requiring control in the selected rivers. **Results:** Comparison between the 3 rivers showed that SR has the highest WQI reading as it shows low BOD and NH3-N values and high value of DO followed by PCR and KR. PCA identified electrical conductivity (EC), dissolved solids (DS) and total solids (TS) as sources of pollution in PCR. Meanwhile for KR, DS and TS were the sources whereas EC, suspended solids and turbidity influences the water quality in SR. IDW showed spatial BOD and SS distribution in PCR as well as BOD and COD in KR. **Conclusion:** Integrating WQI, PCA and IDW approach aids in water management by focusing on key parameters and areas for water quality assessment.

Keywords: Water quality index, Principal component analysis, Water management, Inverse distance weight

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INTRODUCTION

Rivers carry multiple ecosystem services such as provisioning of water sources and supply, water regulation and purification, cultural services such as recreation and aesthetic values, and supporting services of water and nutrient cycle (1). Nevertheless, rapid urbanization, wastewater effluent from the industries, expansion of mining industries, and excessive use of fertilizers and pesticides in agriculture production caused the deterioration of water quality (2-5). Regular monitoring of water resources is vital for assessing water quality of multiple uses and benefits (6,7).

Water Quality Index (WQI) combine multiple water quality parameters into a single number to assist in decision making and simple data monitoring interpretation (7). Multivariate statistical analysis such as principal component analysis (PCA) is commonly used as a powerful method of interpretation in numerous data sets of water quality analysis to assess the temporal and spatial variations of the water quality in rivers, ascertain the possible pollutants in water bodies and reduce the large dimensionality without losing important information (8, 6). Inverse Distance Weighted (IDW) interpolation method is used to estimate the water quality status using the geospatial techniques for an estimation of spatial information (10).

Continuous water quality monitoring was carried out by Department of Environment (DOE) Malaysia which serves as the basis for the assessment of environment water quality, while NWQS classifies the beneficial uses of the watercourse based on WQI (10). Monitoring conducted annually by DOE are useful in obtaining the baseline status of the quality of river water throughout Malaysia. Hence, this WQ data can be strengthened by classifying the rivers using WQI and using multivariate statistical approach (PCA). Additionally, water quality parameters were collected within certain sampling locations and spatial interpolation through IDW assist in estimating the water quality status of the none sampled points along the river. By knowing this, specific recommendation for effective WQ management of each rivers can be tailor-made suited to the WQ issues of the investigated river. In Kelantan, river water classification is still inadequate, thus, this study aimed to provide a more concise information on which parameters to focus upon by the government and/or private authorities for better water catchment management planning. For this reason, it is critical to investigate the water quality which serves as baseline data for future appraisal.

In this context, this study was conducted as a preliminary monitoring on water quality assessment through 14 basic water quality parameters of the water samples from the PCR, KR and SR, with the following objectives: (1) to determine water quality index (WQI) of selected rivers in Kelantan based on the classification set by National Water Quality Standard (NWQS); (2) to identify the possible pollutants that influenced the water quality classification by using principal component analysis (PCA) and (3) to employ IDW interpolation to produce water quality distribution maps for the year 2016. The results could be used to support water quality management, control pollution sources, and protect water resources in the selected rivers in Kelantan.

METHODS AND MATERIALS

Study area

Pengkalan Chepa river (PCR), Kemasin river (KR) and Semerak river (SR) are located in the northern region of Kelantan. The PCR is one of the seven major river basins in Kelantan (11) which drains the basin area of 17129.24 hectares. It originates from the junction of Kelantan river through Keladi river and flows over about 12 kilometres into the South China Sea. It is located in the industrial, institutional, residential and highly populated areas (4) and near to the closed Sabak dumpsite at Teluk Kitang (12), which used to be the biggest non-engineered landfill in Kelantan. SR and KR integrates into the Semerak river basin where both rivers are important as water sources for agricultural activity. SR is one of the main rivers in Pasir Puteh with the area of 28km^2 and it drains from Pinggiran Bandar Pasir Puteh to Tok Bali area (13). SR is the main water sources for paddy irrigation in the surrounding Limbong, Bukit Awang and Semerak district, aquaculture farming transportation while KR is also used as a water source for paddy irrigation and tobacco cultivation (14). SR used to be adjacent to a non-engineered landfill in Bukit Gedombak (15).

Physical and chemical water quality parameters

In this study, the data sets of 14 physical and chemical parameters and 84 observations (14 Ч 84) were obtained from the DOE for one-year (January to December 2016) whereby the water samples were collected from these rivers with one (1) month interval. PCR and KR consist of two stations which are 4KE42 and 4KE43 and 4KS01 and 4KS04, respectively. While SR consists of three stations namely 4KS02, 4KS05 and 4KS06 as shown in Fig. 1. The selected parameters were dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), pH, ammoniacal nitrogen (NH3-N), conductivity (EC), turbidity, water temperature (T), dissolved solids (DS), total solids (TS), nitrate (NO3-) and phosphate (PO_4^{3-}).

Water quality index (WQI)

These data were analysed to determine the WQI at each river based on the National Water Quality Standards for Malaysia (NWQS). This index use data from six water quality parameters and calculated into a mathematical equation, which rates the water quality into five classes, depending on its quality and usage (16). The six variables in WQI (DO, BOD, COD, SS, NH3-N and pH) as adopted by the DOE was calculated using the following equation (1):

$$WQI = 0.22^* SIDO + 0.19^* SIBOD + 0.16^* SICOD + 0.15^* SIAN + 0.16^* SISS + 0.12^* SIpH \quad (1)$$

where SI stands for sub-index for each parameter involved. In Malaysia, WQI is commonly used to evaluate water quality level that can be classified into five classes from Class I to Class V (17). The scores for each class are; Class I: >92.7, Class II: 76.5 - 92.7, Class III: 51.9 - 76.5, Class IV: 31.0-51.9 and Class V:<31.0.

Multivariate statistical analysis

Data treatment

All descriptive and statistical analyses were carried out using Microsoft® Excel 2019 with the statistical add-in XLSTAT version 2019.1.3. The data were tested for normality using Kurtosis and Skewness statistical tests. The values exceed 0 and were positively skewed. Therefore, log transformation (log10) was applied on the raw data to eliminate the influence of outliers within the data (18). After the transformation, the range of Kurtosis (0.86 to 3.22) and Skewness (-1.25 to 1.15) changed which are fit to be used in PCA.
Principal component analysis

Principal Component Analysis (PCA) is commonly used in data reduction within large data sets of correlated variables into uncorrelated variables without losing much of the information (19). It transformed the data into uncorrelated variables called principal components (PCs) where it was derived from the linear combinations of the original variables and shows how many variates are important to describe the observed variances in the data (20). PCA was performed on the normalized data sets for 14 variables separately for each river, PCR, KR and SR to find out the possible sources or factors that influenced the water quality. In PCA, the largest variability of the original data set represents in the first PC was acquired from the linear combination of the variables with maximum variance. While, the second PC visualize the linear combination with the second largest variability and is uncorrelated to the first component (20). The PC can be calculated by using the following equation (2) below;

$$Z_{ij} = a_{i1}x_{1j} + a_{i2}x_{2j} + a_{i3}x_{3j} + \ldots + a_{im}x_{mj} \quad (2)$$

where z is the component score, a is the component loading, x the measured value of a variable, i is the component number, j the sample number of variables. In this study, the PCA has been carried out on the normalized data sets using Varimax rotation to attain better resolution with Kaiser Normalization.

Spatial Interpolation using IDW with ArcGIS

The spatial analysis of 6 chemical parameters used in WQI was carried out using the ArcGIS version 10.1 software. Interpolation of the data has been done using inverse distance-weighed (IDW) method of spatial analysis tool. IDW method was used to map water quality distribution which estimate unknown values with the assumption that the values of sampled points closer to the unsampled point are more similar to one another than those further away (21).

RESULTS

Physical and Chemical Water Quality parameters

Table I shows the 14 water quality parameters, but the focus of this paper is on the 6 parameters associated with WQI. Therefore, the 1st paragraph will discuss on the 6 parameters involved in WQI followed by the remaining 7 parameters. The average DO values for these rivers ranged from 4.94 – 5.63 mg L^{-1} (Table 1), the lowest at PCR compared to KR and SR. As shown in Table 1, KR and PCR also have high BOD (7.67 ± 4.24 mg L^{-1} and 6.08 ± 3.13 mg L^{-1}) and COD (24.28 ± 12.26 mg L^{-1} and 19.21 ± 8.82 mg L^{-1}) levels. In terms of nutrient quality, the highest concentration of NH_3-N was detected at PCR (0.73 ± 0.75 mg L^{-1}) among the three rivers. In this finding, pH values varied from 6.15 to 6.93, which falls within the slightly acidic category (Table 1). In contrast, SS was the highest in SR (43.61 ± 77.78 mg L^{-1}) while the lowest SS was detected at PCR (22.58 ± 18.95 mg L^{-1}).

In this study, T for these three rivers varied from 29.56 to 30.30 °C (Table I). The lowest T value was recorded at SR (29.56 ± 2.16 °C) while the highest at PCR (30.30 ± 2.39 °C). The mean turbidity value in KR is 77.94 ± 161.03 NTU, 113.83% and 4.51% higher than PCR and SR respectively. DS value ranged from 44.89 to 5349.15 mg L^{-1}. The highest DS value was reported at PCR where it exceeded the NWQS limit (500 mg L^{-1}). EC at PCR is the highest (7836.13 ± 9603.30 μS cm^{-1}) among these three rivers where it was also above the NWQS limit (1000 μS cm^{-1}). TS was highest at PCR (5371.74 ± 6654.36 mg L^{-1}) and the lowest at SR (95.04 ± 86.26 mg L^{-1}). The range of PO_4^{3-} values shown in Table 1 are between 0.028 – 0.039 mg L^{-1} which is within the acceptable NWQS limit. Meanwhile, NO^{3-} concentration was highest at PCR (0.19 ± 0.22 mg L^{-1}) and lowest at SR (0.065 ± 0.15 mg L^{-1}).

Table I Mean ± standard deviation values for the physical and chemical parameters and their WQI results of the three rivers from January 2016 to December 2016.

Parameters	Units	Rivers: Pengkalan Chepa (PCR) n = 24	Kemasin (KR) n = 24	Semerak(SR) n = 36
Category		Urban	Semi - urban	Semi - urban
DO	%	66.72 ± 17.97	69.07 ± 22.17	74.06 ± 14.56
DO	mg L^{-1}	4.94 ± 1.37	5.20 ± 1.63	5.63 ± 1.16
BOD	mg L^{-1}	6.08 ± 3.13	7.67 ± 4.24	5.75 ± 3.81
COD	mg L^{-1}	19.21 ± 8.82	24.28 ± 12.26	22.79 ± 9.53
SS	mg L^{-1}	22.58 ± 18.95	24.67 ± 17.86	43.61 ± 77.78
pH	-	6.93 ± 0.63	6.15 ± 1.10	6.62 ± 0.77
NH_3-N	mg L^{-1}	0.73 ± 0.75	0.56 ± 1.62	0.10 ± 0.13
T	℃	30.30 ± 2.39	29.70 ± 2.61	29.56 ± 2.16
EC	μS cm^{-1}	7836.13 ± 9603.30	988.83 ± 2168.21	83.44 ± 54.39
Turbidity	NTU	36.45 ± 21.64	77.94 ± 161.03	74.58 ± 144.65
DS	mg L^{-1}	5349.15 ± 6649.75	605.16 ± 1324.74	44.89 ± 33.96
TS	mg L^{-1}	5371.74 ± 6654.36	630.63 ± 1326.14	95.04 ± 86.26
NO_3^-	mg L^{-1}	0.19 ± 0.22	0.065 ± 0.15	0.092 ± 0.16
PO_4^{3-}	mg L^{-1}	0.028 ± 0.030	0.039 ± 0.060	0.037 ± 0.033
WQI	-	75	70	80
Class	-	III	III	II
Status	-	Slightly polluted	Slightly polluted	Slightly polluted

Fig. 1 Location map of the study area in the Pengkalan Chepa River (4KE42 and 4KE43), Kemasin River (4KS01 and 4KS04) and Semerak River (4KS02, 4KS05 and 4KS06).

Water Quality Index (WQI)

Based on WQI, PCR and KR are classified in Class III as slightly polluted within the range of 51.9-76.5 (Table 1). Meanwhile SR is classified in Class II which may be due the highest DO value and low BOD and NH3-N values. This finding implies that the river water in SR is appropriate for sustaining aquatic life as well as it is secure to use the river water for paddy irrigation nearby.

Principal Component Analysis

Five varimax factors rotated to an eigenvalue greater than one (>1) were obtained for each river (Table II). The factor loadings with varimax rotation resulted in four factors that accounted for 85.41% of the cumulative variance in PCR (Table II a). Varimax Factor (VF1) described 26.77% of the total variability with strong positive loadings on EC, TS and DS. While VF2 only shows 21.34% of the total variability with moderate positive loadings on DO and NH3-N. VF3 had 15.15% of the total variability with moderate loading on BOD whereas VF4 had strong positive loading with SS. While in KR, the VF1 explaining 28.98% of total variability with strong positive loading on DS and TS while having moderate positive loading with EC, NH3-N and DO which cover 81.84% of the total variance (Table II b). While VF2 represents 19.55% with a moderate positive loading on BOD, COD and turbidity contributed to anthropogenic activities from the agricultural area and improper sanitation systems by the residential area. VF3-VF5 did not have any strong or moderate positive loadings in KR. In the SR, five PCs explaining 77.31% of the total variance in the data sets where VF1 accounts 26.70% of total variability where it only shows moderate positive loading on SS, EC and turbidity (Table II c). VF2 explains 18.87% of the total variance mainly contributed by COD expected to come from the agricultural runoff and domestic waste discharge nearby the study area. VF3 had moderate positive loadings with DO with no significant loadings in VF4 and VF5.

Table II Factor loadings of 14 variables on significant principal components for Pengkalan Chepa River, Kemasin River and Semerak River.

Parameters	VF1	VF2	VF3	VF4	VF5
a) Pengkalan Chepa River					
DO (mg L^{-1})	0.044	*0.604*	0.212	0.020	0.003
DO (%)	0.085	*0.523*	0.250	0.008	0.017
BOD (mg L^{-1})	0.107	0.070	*0.600*	0.001	0.146
COD (mg L^{-1})	0.151	0.117	0.446	0.002	0.230
SS (mg L^{-1})	0.077	0.011	0.006	*0.837*	0.002
pH	0.005	0.076	0.019	0.001	0.122
NH_3-N (mg L^{-1})	0.238	*0.590*	0.001	0.004	0.057
T (°C)	0.009	0.197	0.123	0.056	*0.500*
EC (µS cm^{-1})	*0.887*	0.002	0.000	0.037	0.048
Turbidity (NTU)	0.445	0.032	0.000	0.435	0.000
DS (mg L^{-1})	*0.873*	0.000	0.011	0.061	0.027
TS (mg L^{-1})	*0.825*	0.000	0.022	0.087	0.030
NO_3^- (mg L^{-1})	0.000	0.279	0.352	0.036	0.224
PO_4^{3-} (mg L^{-1})	0.003	0.487	0.080	0.002	0.109
Eigenvalue	3.748	2.988	2.121	1.586	1.516
Variability (%)	26.771	21.341	15.149	11.328	10.825
Cumulative %	26.77	48.11	63.26	74.59	85.41
b) Kemasin River (KR)					
DO (mg L^{-1})	0.474	0.088	0.167	0.181	0.008
DO (%)	*0.517*	0.120	0.097	0.188	0.010
BOD (mg L^{-1})	0.001	*0.569*	0.134	0.166	0.082
COD (mg L^{-1})	0.002	*0.672*	0.084	0.103	0.084
SS (mg L^{-1})	0.007	0.353	0.077	0.001	0.362
pH	0.184	0.006	0.000	0.450	0.032
NH_3-N (mg L^{-1})	*0.535*	0.003	0.215	0.004	0.036
T (°C)	0.080	0.141	0.204	0.007	0.001
EC (µS cm^{-1})	*0.651*	0.057	0.001	0.256	0.003
Turbidity (NTU)	0.000	*0.582*	0.091	0.002	0.220
DS (mg L^{-1})	*0.795*	0.074	0.000	0.107	0.005
TS (mg L^{-1})	*0.799*	0.033	0.003	0.108	0.037
NO_3^- (mg L^{-1})	0.005	0.015	0.439	0.015	0.090
PO_4^{3-} (mg L^{-1})	0.009	0.024	0.230	0.041	0.322
Eigenvalue	4.057	2.737	1.741	1.630	1.293
Variability (%)	28.979	19.548	12.436	11.641	9.237
Cumulative %	28.98	48.53	60.96	72.60	81.84

CONTINUE

Table II Factor loadings of 14 variables on significant principal components for Pengkalan Chepa River, Kemasin River and Semerak River. (CONT.)

Parameters	VF1	VF2	VF3	VF4	VF5
c) Semerak River (SR)					
DO (mg L^{-1})	0.002	0.221	*0.737*	0.014	0.013
DO (%)	0.005	0.199	*0.739*	0.004	0.037
BOD (mg L^{-1})	0.031	0.437	0.133	0.109	0.053
COD (mg L^{-1})	0.005	*0.631*	0.012	0.021	0.030
SS (mg L^{-1})	*0.694*	0.052	0.010	0.024	0.000
pH	0.158	0.002	0.045	0.202	0.207
NH_3-N (mg L^{-1})	0.330	0.001	0.005	0.014	0.439
T (°C)	0.328	0.005	0.035	0.193	0.180
EC (µS cm^{-1})	*0.630*	0.159	0.015	0.010	0.069
Turbidity (NTU)	*0.598*	0.160	0.032	0.063	0.002
DS (mg L^{-1})	0.472	0.275	0.074	0.044	0.027
TS (mg L^{-1})	0.151	0.372	0.097	0.129	0.005
NO_3^- (mg L^{-1})	0.290	0.071	0.047	0.010	0.015
PO_4^{3-} (mg L^{-1})	0.045	0.057	0.043	0.489	0.016
Eigenvalue	3.738	2.642	2.024	1.327	1.093
Variability (%)	26.704	18.871	14.458	9.477	7.805
Cumulative %	26.70	45.57	60.03	69.51	77.31

* Values in Italic are considered strong and moderate loadings

Spatial Distribution Map

Water quality parameters used in WQI were interpolated for all 3 rivers but only selected parameters from PCR and SR were illustrated in Fig. 2-5. Based on IDW, the interpolation showed areas to focus for certain parameters in PCR. For example, low BOD and SS were mapped within the inland areas and increased as it flows toward the sea. Meanwhile, distinctive patterns were mapped for SR: BOD and COD were higher at the upstream and lower as it flows to the sea, potentially related to the activities of dense residential areas in the upstream causing degradation of organic matter of natural origin, run-off or wastewater discharges.

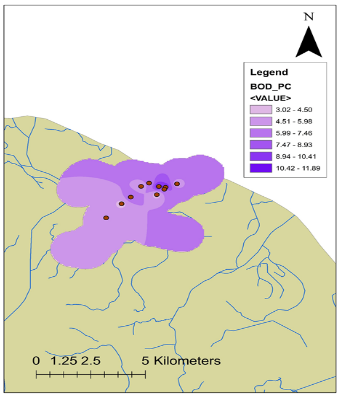

Fig. 2 Spatial distribution of BOD in Pengkalan Chepa River (PCR)

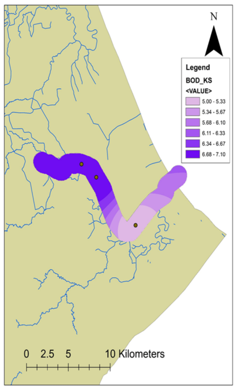

Fig. 3 Spatial distribution of BOD in Semerak River (SR or KS)

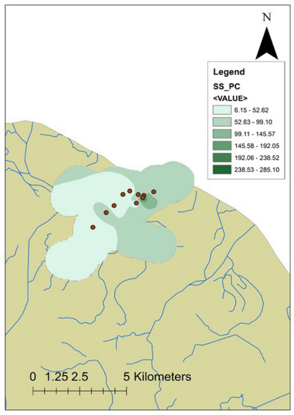

Fig. 4 Spatial distribution of SS in Pengkalan Chepa River (PCR)

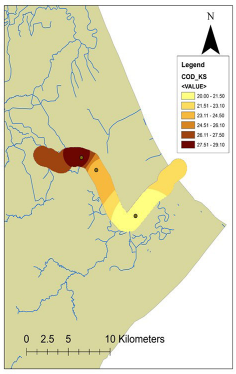

Fig. 5 Spatial distribution of COD in Semerak River (SR or KS)

DISCUSSION

Physical and chemical water quality parameters

The value of DO and BOD in PCR and KR (Table I) fell within Class III of the National Water Quality Standard (NWQS) (22). The DO and BOD values may be due to the high rate of bacterial decomposition of organic waste (23), untreated or partially treated sewage from agricultural-based activities and industries (10).

Meanwhile, the COD in SR and KR were approaching the threshold level of 25 mg L^{-1} in Class IIB of NWQS (22), which could be attributed by domestic waste (4). High NH_3-N in PCR can be associated with organic waste of agricultural activity and the surface runoff at the riverbank (10, 3). The slightly acidic pH values could be associated with NH_3-N from domestic wastewater and fertilizers (3) used in agricultural-based activities in these rivers. SS values of KR was 9.26% higher than PCR, which might be affected by surface runoff near the study area. High SS can increase the turbidity values, affect water clarity and restrict light availability for photosynthesis (24).

DS is determined by the inorganic and small organic matters normally presents in the water body including calcium, iron, phosphorus, and other ions. In this study, DS is related to electrical conductivity (EC) which describe the water capacity to pass an electric current is related to the ionized substance concentration in the water bodies. So, it is related to the EC in water since a high reading of DS and EC at PCR may be due to the domestic waste from the nearby residential area and industrial waste discharge into the river. Similar studies were done by Baitule et al., (26) and Dutta et al., (27) in Nag river which agreed that high TDS and EC values influenced by municipal sewage discharge and land runoff.

The acceptable limit of phosphate concentration in drinking water must be below 0.10 mg L^{-1} (28). The highest PO_4^{3-} concentration is detected at KR with 0.039 ± 0.060 mg L^{-1} may be due to runoff of fertilizers from the paddy cultivation area. The NO^{3-} concentration in both KR and SR are affected by the agricultural runoff since they are near to paddy and tobacco cultivation (29).

WQI

PCR and KR were categorised under class III WQI while SR under class II. This finding is consistent with the status reported for PCR and KR as slightly polluted in Environmental Quality Report (22). A study by Rohasliney (11) also reported WQI of slightly polluted in PCR from the year 2008-2009, indicating that the water quality status has been affected by urbanization, textile and food manufacturing industries and land run-off from construction activities near the river. In our study which was taken in 2016, the specific parameters driving the WQI of PCR were DO and BOD. The average value of DO level should be at 6 mg/L for aquatic organisms to thrive (30). BOD values should be <3 mg L^{-1} to categorize the WQI in class I and II (22).

PCA

High factor loading of DS and EC in PCR may be attributed to the industrial pollution due to high number of ions in the water bodies and domestic waste in the area. PCR is a highly populated urban area with increasing infrastructure development, domestic drainage, agro-based and industrial activities (11). Meanwhile, high factor loading of DS and TS in KR represents the contribution of non-point source pollution by soil erosion from the forest area and the organic waste from the agricultural farm. DS and TS originates from surface runoff in the solid form from unplanned land clearing activities (25). SS, EC and turbidity in SR may be due to agricultural runoff or activity of paddy cultivation. SS indicates land runoff within the river catchment (17) which leads to turbid waters through the presence of silt, clay and organic matter from urban development areas involving clearing of lands and agricultural runoff (25). EC could be related to the ionized substance concentration in the water bodies from various anthropogenic activities (25). IDW allows identification of key areas to target as priority for remediation which is consistent with findings from other studies in water quality (14, 21).

CONCLUSION

In this study, SR has the highest WQI in Class II followed by PCR and KR in Class III. From PCA, we can conclude that EC, DS and TS were the parameters influencing PCR water quality while water quality of KR was affected by DS and TS values. Meanwhile, water quality at SR was primarily influenced by EC, SS and turbidity values. IDW showed some emerging patterns for water quality distribution in PCR; high BOD and SS towards the coastal area. Domestic and agricultural runoff are the factors causing water quality degradation in these rivers. These findings assist in identifying the parameters of concern and the river sections for priority remedial measures. Recommendations are suggested to incorporate temporal variability between monsoon seasons and continuous monitoring for any temporal or spatial changes.

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