



Comparison among different ASEAN water quality indices for the assessment of the spatial variation of surface water quality in the Selangor river basin, Malaysia

Yong Jie Wong  · Yoshihisa Shimizu · Kai He · Nik Meriam Nik Sulaiman

Received: 22 December 2019 / Accepted: 9 August 2020 / Published online: 16 September 2020
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Abstract The assessment of surface water quality is often laborious, expensive and tedious, as well as impractical, especially for the developing and middle-income countries in the ASEAN region. The application of the water quality index (WQI), which depends on several independent key parameters, has great potential and is a useful tool in this region. Therefore, this study aims to find out the spatial variability of various water quality parameters in geographical information system (GIS) environment and perform a comparative study among the ASEAN WQI systems. At present, there are four ASEAN countries which have implemented the WQI system to evaluate their surface water quality, which are (i) Own WQI system—Malaysia, Thailand and Vietnam—and (ii) Adopted WQI system: Indonesia. A spatial distribution of 12 water quality parameters in the Selangor river basin, Malaysia, was plotted and then applied into the different ASEAN WQI systems. The WQI values obtained from the different WQI systems have an appreciable difference, even for the same water samples due to the disparity in the parameter selection and the standards among them. WQI systems which consider all biophysicochemical parameters

provide a consistent evaluation (Very Poor), but the system which either considers physicochemical or biochemical parameters gives a relatively lenient evaluation (Fair–Poor). The Selangor river basin is stressed and impacted by all physical, biological and chemical parameters caused by both the aridity of the climate and anthropogenic activities. Therefore, it is crucial to include all these aspects into the evaluation and corresponding actions should be taken.

Keywords ASEAN · Water quality index · Spatial analysis · Selangor river basin

Introduction

Since the inception of the Association of Southeast Asian Nations (ASEAN) in 1967, the oldest functioning regional intergovernmental organization in Southeast Asia, the region has experienced urban sprawl, intensive industrialization and booming population growth, especially in recent decades (Xu et al. 2019; Khuong et al. 2019). ASEAN is comprised of 10 Southeast Asian countries, situated in two geographical sub-regions: (i) Indochina Region (Cambodia, Laos, Myanmar, Thailand and Vietnam) and (ii) Maritime Region (Brunei, Indonesia, Malaysia, Philippines and Singapore). Anthropogenic activities in the region have posed significant pressure on the socioeconomic system, viz. inequality in access to clean water and sanitation in the region (ASEAN Secretariat 2017). It is estimated that up to 90% of the wastewater in this region is discharged

Y. J. Wong (✉) · Y. Shimizu · K. He
Research Center for Environmental Quality Management,
Graduate School of Engineering, Kyoto University, 1-2
Yumihama, Otsu, Shiga 520-0811, Japan
e-mail: wong.jie.88c@st.kyoto-u.ac.jp

N. Nik Sulaiman
Department of Chemical Engineering, Faculty of Engineering,
University of Malaya, 50603 Kuala Lumpur, Malaysia

directly into surface water resources such as lakes, rivers, reservoirs, estuaries and coastal water, thus heavily contaminating water resources (Corcoran et al. 2010; WWAP (United Nations World Water Assessment Programme) 2015). In order to solve this water crisis, the ASEAN countries have established a water quality assessment to regularize wastewater treatment as well as water management (Gholizadeh et al. 2016).

However, assessment of the surface water quality is often labour-intensive, costly and time-consuming. It is a complex process that requires a large number of samples to characterize a waterbody over multiple parameters, including but not limited to physicochemical and bacteriological aspects (Bharti and Katyal 2011). Conventionally, to evaluate surface water quality, the individually measured parameters will be compared with their existing standards/guidelines set by local authorities. Nevertheless, since there is a large number of parameters included, it is difficult to provide a comprehensive evaluation of water quality status with its scientific basis (Noori et al. 2019; Lumb et al. 2011). To address this issue, different approaches are introduced; for instance, multivariate statistical analysis of individual parameters (Magyar et al. 2013; Mohamed et al. 2014; Ogwueleka 2015; Koklu et al. 2010), grey relation analysis (Zhu and Hao 2009; Jing et al. 2007) and water quality indices (WQI) (Lumb et al. 2011; Abbasi and Abbasi 2012; Noori et al. 2019). Among these approaches, the WQI is regarded as one of the most effective tools (Tyagi et al. 2013; Khanna et al. 2013). It is a single indicative value/score or term (e.g. excellent, good, fair, poor, etc.) which expresses the overall quality of water by aggregating normalized values of multiple parameters to its subjective rating curves (Gorde and Jadhav 2013; Sutadian et al. 2016). Thus, the application of the WQI can help provide a simple, stable and reproducible water quality status to the public community and policymakers to make a less subjective decision related to policies (Abbasi and Abbasi 2012; Bassi and Kumar 2017). Also, the WQI is used to compare water quality from different sources and identify water quality trends over a certain period (Khan et al. 2003; Bassi and Kumar 2017). The WQI was first introduced in Germany by Horton (1965) in 1965 and since then, numerous WQIs have been formulated (Bharti and Katyal 2011; Abbasi and Abbasi 2012). The National Sanitation Foundation WQI (NSFWQI) (Brown et al. 1970), Oregon WQI (OWQI) (Dunnette 1979) and Canadian Council of Ministers of the Environment WQI (CCME

WQI) (CCME 2001) are among the most prevalent water quality indices which have had widespread application in many regions of the world and extensive studies have been carried out (Dezfooli et al. 2018; Noori et al. 2019). However, although there are many WQIs available worldwide, there is not one that is universally accepted due to the difference in climate and land use.

In general, there are four steps in the formulation of the WQI (Abbasi and Abbasi 2012), including (1) parameter selection, (2) sub-index formulation, (3) weight establishment and (4) aggregation of weighted sub-indices. Premised on the search for a better WQI, various studies and efforts have been done. For instance, multivariate statistical approaches like principal component analysis (Mohd Ali et al. 2013; Ali et al. 2014; Tripathi and Singal 2019) and cluster analysis (Fathi et al. 2018) are applied in parameter selection to determine the most influential parameters which represent overall water quality status. Also, previous studies have driven further development of aggregation function selection for WQIs which is sensitive, unbiased and easy by evaluating and comparing the sensitivity of each function (Singh et al. 2008), while a few studies focus on the comparison of the WQIs. Lumb et al. (2011) reviewed the commonly used WQIs which were developed from the 1960s till 2010 and their respective pros and cons. Meanwhile, Tyagi et al. (2013) reviewed and presented the merits and demerits of the NSFWQI, OWQI, CCME WQI and weight arithmetic WQI. The application of WQI in ASEAN has gained strong temporal increase (Alves et al. 2014). However, most of the WQI methods are reported in their native language. Besides that, to the best of the authors' knowledge, no study has been reported on the WQI system which is currently being practised in the ASEAN region.

The ASEAN region is located near the equator, which influences it to experience a tropical-hot and humid climate with plentiful of annual rainfall, as well as a large and relatively constant annual net solar radiation. In addition, the similar geological, geographical as well as climate conditions shared in this region have also led to a myriad of environmental problems (Letchumanan 2010; Koh 2009). Therefore, this study is designed to find out the spatial variability of various water quality parameters in a geographical information system (GIS) environment and perform a comparative study among the ASEAN WQI systems in the Selangor river basin, Malaysia.

Materials and methods

Study area

The state of Selangor, situated in the centre and on the west coast of Peninsular Malaysia, is the most developed state in Malaysia with approximately 6.4 million citizens or 19.9% of the total national population (Department of Statistic 2016). Due to its strategic location, Selangor has been undergoing rapid development and urbanization which causes significant adverse effects to its river basins (Basheer et al. 2017). There are four major basins in Selangor, viz. Langat, Klang, Bernam and Selangor (Othman et al. 2014), and the Selangor river basin is the most important in the country. Similar to the major river basins in the ASEAN, the Selangor river basin is the largest source of public water supply, providing approximately 60% of the total water required in both Selangor and Kuala Lumpur (Subramaniam 2004). Besides being rich in natural resources and biodiversity (Zhila et al. 2014), it is also well known for firefly ecotourism (Nada and Kirton 2004; Zhila et al. 2014). It has a catchment area of approximately 2200 km², rising from the foothills of Fraser's Hill, and stretches as far as 110 km to the coast of Kuala Selangor. Currently, there are nine monitoring stations located in the Selangor river basin (Fig. 1), managed by the DOE under the Ministry of Energy, Science, Technology, Environment and Climate Change to conduct bi-/trimonthly sampling to closely monitor the river water quality status. The monitoring stations are located from upstream to downstream of the basin, providing a comprehensive spatial coverage of the river topologies. In light of this, in the present study, the water quality status of the Selangor river basin is selected as the study area to study the spatial distribution of different water quality parameters and compare the application of the different ASEAN WQI systems.

Geospatial analysis

The statistical and spatial distributions of 12 water quality parameters across 9 monitoring stations were investigated by using the Box-and-Whiskers and spatial analysis modules in the ArcGIS 10.5 software, respectively. The Box-and-Whiskers plot presenting the median, range and shape of data distribution (Li et al. 2007) was used to study the statistical variation of all parameters among different monitoring stations. To evaluate

the significant differences of water quality parameters among the monitoring stations, one-way analysis of variance (ANOVA) at 0.05% level of significance on the Statistical Package and Service Solutions (IBM SPSS version 22) was used. Prior to the ANOVA analysis, to satisfy the normality and homogeneity of variance, the data were log-transformed when necessary. At present, there are many options for spatial interpolation functions; the most commonly used methods are inverse distance weighted (IDW), kriging and spline. In this study, the IDW method, a deterministic interpolation technique, was used to generate spatial interpolated thematic maps within the area of interest (Selvam et al. 2014) due to its high accuracy and irreplaceable advantages for data estimation in rivers (Madhloom et al. 2018). Besides that, both kriging and spline methods are stochastic interpolation techniques, where it requires more than 10 sampling points to formulate the curves; therefore, they could not be applied in this study (Mantzafleri et al. 2009).

WQI system in ASEAN countries

According to the Fifth ASEAN State of the Environment, the number of rivers classified as having good water quality in the ASEAN region is decreasing annually, while the rivers classified as having fair and deteriorated water quality are increasing, and this condition has captured the serious attention of policymakers (ASEAN Secretariat 2017). The ASEAN Strategic Plan of Action on Water Resources Management, initiated by the ASEAN working group on Water Resource Management, designed a regional river monitoring program to report the river quality as well as its WQI on a regular basis (ASEAN Working Group on Water Resources Management 2012). In general, the methods for evaluating water quality in the ASEAN region can be divided into three groups: (a) Own WQI system (Malaysia, Thailand and Vietnam), (b) Adopted WQI system (Indonesia) and (c) Without WQI system (Brunei, Cambodia, Laos, Myanmar, Philippines and Singapore). The following section will provide a detailed explanation for each WQI system in the ASEAN region.

Own WQI system

WQI system in Malaysia For the WQI in Malaysia (also known as DOE-WQI), six physicochemical parameters, viz. ammoniacal nitrogen (AN), biochemical oxygen

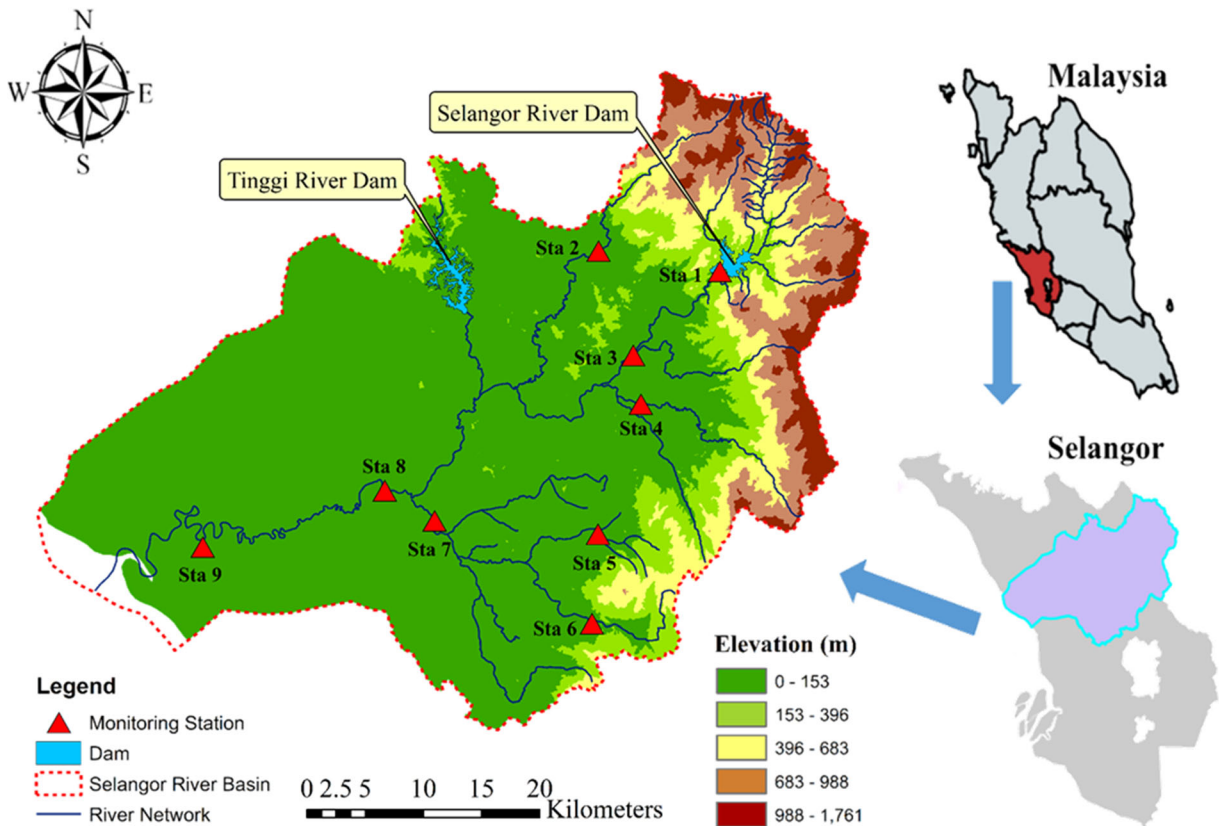


Fig. 1 Map of Selangor river basin and the location of sampling stations

demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), pH and suspended solids (SS), are included to provide the overall river water quality, as shown in Eq. 1. Prior to calculating the DOE-WQI, it is necessary to determine the sub-index value for each parameter from the best fit equations as shown in Table 1.

$$\begin{aligned}
 \text{DOE-WQI} = & (0.15 * SI_{AN}) + (0.19 * SI_{BOD}) \\
 & + (0.16 * SI_{COD}) + (0.22 * SI_{DO}) \\
 & + (0.12 * SI_{pH}) + (0.16 * SI_{SS}) \quad (1)
 \end{aligned}$$

where SI_{AN} , SI_{BOD} , SI_{COD} , SI_{DO} , SI_{pH} and SI_{SS} represent the sub-index values for ammoniacal nitrogen, biochemical oxygen demand, chemical oxygen demand, dissolved oxygen, pH and suspended solids, respectively.

The classification of DOE-WQI is identical to the Malaysia river classification (Department of Environment 2008), where scores for Class I (Excellent), 92.6–100; for Class II (Good), 76.5–92.7; for

Class III (Fair), 51.9–76.4; for Class IV (Poor), 31.0–51.8; and for Class V (Very Poor), 0–31.

WQI system in Thailand There are two different WQI systems in Thailand, namely, (i) General WQI (known as PCD-WQI) and (ii) Marine WQI, which is used to evaluate surface and coastal water quality, respectively. In this study, the PCD-WQI will be discussed. There are five water quality biochemical parameters included, viz. AN, DO, BOD, total coliform bacteria (TCB), and faecal coliform bacteria (FCB). The formula is shown in Eq. 2:

$$\text{PCD-WQI} = \frac{\sum(SI_{DO}, SI_{BOD}, SI_{TCB}, SI_{FCB} \text{ and } SI_{AN})}{5} - \text{Special score} \quad (2)$$

where SI_{TCB} and SI_{FCB} represent the sub-index values for total coliform bacteria and faecal coliform bacteria, respectively.

The sub-indices of the PCD-WQI were generated based on two criteria, which are Thailand surface water

Table 1 Best Fit Equations for DOE-WQI sub-index values. (Department of Environment 2008)

DOE-WQI sub-index computation	
Sub-index for DO in % saturation (SI_{DO})	
$SI_{DO} = 0$	for $x \leq 8$
$SI_{DO} = 100$	for $x \geq 92$
$SI_{DO} = -0.395 + 0.030x^2 - 0.00020x^3$	for $8 < x < 92$
Sub-index for BOD in mg/L (SI_{BOD})	
$SI_{BOD} = 100.4 - 4.23x$	for $x \leq 5$
$SI_{BOD} = 108e^{-0.055x} - 0.1x$	for $x > 5$
Sub-index for COD in mg/L (SI_{COD})	
$SI_{COD} = -1.33x + 99.1$	for $x \leq 20$
$SI_{COD} = 103e^{-0.0157x} - 0.04x$	for $x > 20$
Sub-index for AN in mg/L (SI_{AN})	
$SI_{AN} = 100.5 - 105x$	for $x \leq 0.3$
$SI_{AN} = 94e^{-0.573x} - 5 x - 2 $	for $0.3 < x < 4$
$SI_{AN} = 0$	for $x \geq 4$
Sub-index for SS in mg/L (SI_{SS})	
$SI_{SS} = 97.5e^{-0.00676x} + 0.05x$	for $x \leq 100$
$SI_{SS} = 71e^{-0.0061x} + 0.015x$	for $100 < x < 1000$
$SI_{SS} = 0$	for $x \geq 1000$
Sub-index for pH (SI_{pH})	
$SI_{pH} = 17.02 - 17.2x + 5.02x^2$	for $x < 5.5$
$SI_{pH} = -242 + 95.5x - 6.67x^2$	for $5.5 \leq x < 7$
$SI_{pH} = -181 + 82.4x - 6.05x^2$	for $7 \leq x < 8.75$
$SI_{pH} = 536 - 77.0x + 2.76x^2$	for $x \geq 8.75$

quality standard (Pollution Control Department 1994) and the historical frequency distribution of parameter concentration from the years 2000 to 2010 for local rivers as shown in Table 2. The PCD-WQI has an unique feature, known as the special score. The PCD team has developed a special criteria grade for each parameter in PCD-WQI, based on the concentration of water quality parameters as shown in Table 3 (Pollution Control Department 2016a). In order to calculate the PCD-WQI, first the sub-index value and the grade of each parameter are determined. Next, the grade for each parameter based on the special score criteria is computed and compared with the sub-index grade. If there is one level difference between the sub-index grade and the special criteria grade, the special score will be 10. For instance, the sub-index grade is “Good”, whereas the special criteria grade is “Fair”, the special score will

be 10. For the case where a two-level difference occurs, special score will be 15 and for three-level difference, the special score will be 20. There are four classes for the PCD-WQI, namely, Good (PCD-WQI = 71–100), Fair (DOE-WQI = 61–70), Poor (PCD-WQI = 31–60) and Very Poor (PCD-WQI = 0–30).

WQI system in Vietnam In order to create a benchmark of surface water quality for the protection and management of water resources, the Ministry of Natural Resources and Environment (MONRE) of Vietnam developed its own WQI (known as MONRE-WQI) and issued in the Decision No. 879/QD-TCMT (Pham et al. 2017). Similar to Thailand and Malaysia, the selection of parameters was carried out by the judgement of professional experts and government agencies.

There are 9 parameters included in the MONRE-WQI, which are divided into four groups: (i) Chemical Group (AN, BOD, COD, DO, $PO_4^{3-}P$), (ii) Physical Group (SS and turbidity), (iii) Biological Group (TCB) and (iv) pH group.

In the MONRE-WQI, the effect of temperature on the solubility of oxygen is considered, and DO saturation (DO_{sat}) values are first calculated using Eq. 3 (Elmore and Hayes 1960):

$$DO_{sat} = 14.652 - 0.41022T + 0.0079910T^2 - 0.000077774T^3 \tag{3}$$

where DO_{sat} is the dissolved oxygen concentration (mg/L) and T is the water temperature (C).

Next, $DO_{\% sat}$ is calculated using Eq. 4:

$$DO_{\% sat} = \frac{DO_x}{DO_{sat}} \times 100\% \tag{4}$$

where DO_x is the monitored value of DO.

The first step in calculating the MONRE-WQI is to determine the individual sub-index value for each parameter by using the linear interpolation rescaling method as shown in Eq. 5a and 5b and its application condition set by the Ministry of Natural Resources and Environment (2011). The permissible threshold concentration and sub-index values for all parameters are presented in Table 4.

Equation 5a is applicable to all parameters, except when $DO < 88\%$ saturation and $pH < 6$:

Table 2 Best Fit Equations for PCD-WQI sub-index values. (Pollution Control Department 2016a)

PCD-WQI sub-index computation	
Sub-index for DO in mg/L (SI_{DO})	
$SI_{DO} = 15.25x + 0.1667$	for $x \leq 4.0$
$SI_{DO} = 5x + 41$	for $4.0 < x \leq 6.0$
$SI_{DO} = 12.083x - 1.5$	for $6.0 < x < 8.4$
$SI_{DO} = -78x + 755.2$	for $8.4 < x \leq 8.9$
$SI_{DO} = -13.043x + 177.09$	for $8.9 < x \leq 11.2$
$SI_{DO} = -7.561x + 115.68$	for $x \geq 11.3$
Sub-index for BOD in mg/L (SI_{BOD})	
$SI_{BOD} = -19.333x + 100$	for $x \leq 1.5$
$SI_{BOD} = -20x + 101$	for $1.5 < x \leq 2.0$
$SI_{BOD} = -15x + 91$	for $2.0 < x < 4.0$
$SI_{BOD} = -6.4583x + 56.833$	for $x \geq 4.1$
Sub-index for TCB in MPN/L (SI_{TCB})	
$SI_{TCB} = -0.0058x + 100$	for $x \leq 500$
$SI_{TCB} = -0.0007x + 74.333$	for $500 < x \leq 2000$
$SI_{TCB} = -0.0002x + 65.286$	for $2,000 < x \leq 16,000$
$SI_{TCB} = -8e^{-6x} + 32.292$	for $x > 16,000$
Sub-index for FCB in MPN/L (SI_{FCB})	
$SI_{FCB} = -0.029x + 100$	for $x \leq 100$
$SI_{FCB} = -0.0033x + 74.333$	for $100 < x \leq 400$
$SI_{FCB} = -0.0003x + 62.395$	for $400 < x \leq 9,000$
$SI_{FCB} = -1e^{-5x} + 32.208$	for $x > 9,000$
Sub-index for AN in mg/L (SI_{AN})	
$SI_{AN} = -131.82x + 100$	for $x \leq 0.22$
$SI_{AN} = -35.714x + 78.857$	for $0.23 \leq x \leq 0.50$
$SI_{AN} = -22.556x + 72.278$	for $0.51 \leq x < 1.83$
$SI_{AN} = -6.1024x + 42.167$	for $x > 1.83$

Table 3 Special score criteria for PCD-WQI (Pollution Control Department 2016b)

Parameter	Special score criteria			
	Good	Fair	Poor	Very Poor
DO (mg/L)	≥ 4.0	≥ 2.5	≥ 2.0	≥ 0.0
BOD (mg/L)	≤ 1.5	≤ 2.0	≤ 4.0	> 4.0
TCB (MPN/L)	≤ 500	≤ 2000	> 2000	
FCB (MPN/L)	≤ 100	≤ 400	> 400	
AN (mg/L)	≤ 0.22	≤ 0.50	≤ 1.83	> 1.83

$$SI_i = \frac{q_i - q_{i+1}}{BP_{i+1} - BP_i} (BP_{i+1} - C_p) + q_{i+1} \tag{5a}$$

Equation 5b is only applicable when DO < 88% saturation and pH < 6:

$$SI_i = \frac{q_{i+1} - q_i}{BP_{i+1} - BP_i} (C_p - BP_i) + q_i \tag{5b}$$

where SI_i is the i th parameter sub-index value; C_p is the concentration of measured parameter; BP_i and BP_{i+1} are the values of permissible lower and upper threshold concentrations of the class, respectively; q_i and q_{i+1} are the sub-index values corresponding to the upper and lower threshold of the class, respectively.

Finally, the sub-index values for individual parameters are aggregated by using Eq. 6. There are five classifications for the MONRE-WQI, viz. Excellent (MONRE-WQI = 91–100), Good (MONRE-WQI = 76–90), Fair (MONRE-WQI = 51–75), Poor (MONRE-WQI = 26–50) and Very Poor (MONRE-WQI = 0–25):

$$MONRE-WQI = \frac{WQI_{pH}}{100} \left[\frac{1}{5} \sum_{a=1}^5 WQI_a \times \frac{1}{2} \sum_{b=1}^2 WQI_b \times WQI_c \right]^{1/3} \tag{6}$$

where WQI_a is the Chemical Group Parameter (AN, BOD, COD, DO, $PO_4^{3-}P$), WQI_b is the Physical Group Parameter (TSS and turbidity), WQI_c is the Biological Group Parameter (TBC) and WQI_{pH} is the pH group.

Adopted WQI system in Indonesia

In Indonesia, the Decree No. 115/2003 by the Ministry of Environment and Forestry (2001) and the Guidelines for Determination of Water Quality Status by the Ministry of Environment and Forestry (2003) suggest adopting the Storage and Retrieval of Water Quality Data System (STORET) and Pollution Index (PI) methods to access the water pollution level in surface waters (Rohmad Barokah et al. 2017). According to these regulations, rivers in Indonesia are classified into four classes (Ministry of Environment and Forestry 2018). The following section describes each method in detail.

Table 4 Vietnam water parameters threshold concentration and sub-index values. Ministry of Natural Resources and Environment (2011)

i	q _i	BOD (mg/L)	COD (mg/L)	AN (mg/L)	PO ₄ ³⁻ P (mg/L)	Turbidity (NTU)	SS (mg/L)	TCB (MPN/L)		
1	100	≤ 4	≤ 10	≤ 0.1	≤ 0.1	≤ 5	≤ 20	≤ 250		
2	75	6	15	0.2	0.2	20	30	500		
3	50	15	30	0.5	0.3	30	50	750		
4	25	25	50	1	0.5	70	100	1000		
5	1	≥ 50	≥ 80	≥ 5	≥ 6	≥ 100	>100	>1000		
i	1	2	3	4	5	6	7	8	9	10
DO (%sat)	≤ 20	20	50	75	88	112	125	150	200	≥200
q _i	1	25	50	75	100	100	75	50	26	1
i	1	2	3	4	5	6				
pH	≤ 5.5	5.5	6	8.5	9	≥ 9				
q _i	1	50	100	100	50	1				

STORET method The STORET method is an electronic data system developed by the United States Environmental Protection Agency (US EPA) in the 1960s to monitor and manage water quality. It evaluates water quality by comparing the measured parameter with its standard, according to the aforementioned river classification. The calculation procedure for the STORET method is as follows:

- (i) Obtain the minimum, maximum and mean values of the measured parameter.
- (ii) Compare the measured value with the water quality standard (Ministry of Environment and Forestry 2001) according to the river classification.
- (iii) Zero score is given if the measured value does not exceed the standard; otherwise a score is given according to the number and properties of parameter (Table 5).
- (iv) Total score is used to describe water status where:

Class A: Score = 0, Good
 Class B: Score between $- 1 \leq X \leq - 10$, Lightly Polluted
 Class C: Score between $- 11 \leq X \leq - 30$, Moderately Polluted
 Class D: Score $- 31 \leq X$, Highly Polluted

Pollution index method Nemerow and Sumitomo (1970) proposed an index which can determine the level

of pollution relative to the permissible threshold standard, known as the pollution index (PI) method. All measured parameters with different ranges of concentrations are normalized to a relative value which lies within a comparable range by using Eq. 7 (Suwandana et al. 2011):

$$PI_j = \sqrt{\frac{\left(\frac{C_i}{L_{ij}}\right)_{max}^2 + \left(\frac{C_i}{L_{ij}}\right)_{ave}^2}{2}} \tag{7}$$

where PI_j is the pollution index for river class (j); C_i is the measured concentration of parameter (i); L_{ij} is the permissible values for parameter (i) for river class (j); $(C_i/L_{ij})_{max}$ is the maximum value of C_i/L_{ij} and $(C_i/L_{ij})_{ave}$ is the average value of C_i/L_{ij} .

The calculation procedure for the PI method is as follows:

- (i) Obtain the C_i/L_{ij} value of individual measured parameter.
 - a. A higher level of parameter corresponds to a higher level of pollution.

Case 1: If C_i/L_{ij} is ≤ 1
 Direct calculation using Eq. 8:

$$\frac{C_i}{L_{ij}} \tag{8}$$

Case 2: If C_i/L_{ij} is > 1

Table 5 Scoring determination by the STORET method (Canter 1977)

Number of parameters	Measured parameter value	Parameter		
		Physical	Chemical	Biological
< 10	Maximum	- 1	- 2	- 3
	Minimum	- 1	- 2	- 3
	Mean	- 3	- 6	- 9
≥ 10	Maximum	- 2	- 4	- 6
	Minimum	- 2	- 4	- 6
	Mean	- 6	- 12	- 18

Standardization is required by applying Eq. 9:

$$\left(\frac{C_i}{L_{ij}}\right)_{new} = 1.0 + 5\log\frac{C_i}{L_{ij}} \tag{9}$$

b. A lower level of parameter corresponds to a higher level of pollution.

Standardization is required by applying Eq. 10:

$$\left(\frac{C_i}{L_{ij}}\right)_{new} = \frac{C_{im} - C_i}{C_{im} - L_{ij}} \tag{10}$$

where C_{im} is the saturation value of parameter at room temperature.

c. Threshold of parameter is defined by a range.

Case 1: If $C_i \leq$ average L_{ij}

Standardization is required by applying Eq. 11:

$$\left(\frac{C_i}{L_{ij}}\right)_{new} = \frac{C_i - (L_{ij})_{ave}}{(L_{ij})_{min} - (L_{ij})_{ave}} \tag{11}$$

Case 2: If $C_i >$ average L_{ij}

Standardization is required by applying Eq. 12:

$$\left(\frac{C_i}{L_{ij}}\right)_{new} = \frac{C_i - (L_{ij})_{ave}}{(L_{ij})_{max} - (L_{ij})_{ave}} \tag{12}$$

where $(L_{ij})_{min}$ and $(L_{ij})_{max}$ are the minimum and maximum values of L_{ij} , respectively; and $(L_{ij})_{ave}$ is the average value of $(L_{ij})_{min}$ and $(L_{ij})_{max}$.

(ii) Determine the values of $(C_i/L_{ij})_{max}$ and $(C_i/L_{ij})_{ave}$.

(iii) Calculate the PI by using Eq. 7 and the pollution level is then classified as follows:

$0 \leq PI_j \leq 1$: Clean

$1 < PI_j \leq 5$: Slightly Polluted

$5 < PI_j \leq 10$: Moderately Polluted

$PI_j > 10$: Highly Polluted

Results and discussion

Spatial analysis of water quality

In this present study, 6 datasets in 2016 (January, March, May, July, September and November) comprise 12 water quality parameters (AN, BOD, COD, DO, FCB, NO₃, pH, PO₄³⁻-P, TCB, SS, turbidity and water temperature) of the Selangor river basin were obtained from the DOE, Malaysia. The statistical variations of all parameters among the different monitoring stations were plotted as shown in Fig. 2 (a) and (b), whereas the spatial distribution of every parameter was presented in Fig. 3(a) - (l).

The oxygen demand parameters (BOD and COD) were observed to be quite consistent along the whole river and statistically significant differences were not found among stations ($P > 0.05$), with median values of 6.2 and 17 mg/L, respectively. The highest BOD and COD concentration was observed in Sta 7, with concentrations of 13 and 33 mg/L, as presented in Fig. 3 (a) and (b), respectively. The DO and pH values for all monitoring stations along the Selangor river basin were always in ‘‘Class I’’ classification, with more than 6 mg/L and within 6–9, respectively. However, degradation of these two parameters can be observed from upstream to downstream and significant differences were observed among stations ($P < 0.05$), as

shown in Fig. 3 (c) and (h), respectively, mainly due to the land use changes. At the upper stream, the main land use types are forest and water bodies, and as the river extends to the middle stream and downstream, the main land use types are replaced with agriculture and urban area which have posed significant effects to the water quality (Othman et al. 2018). As the climate in Malaysia is equatorial (hot, humid and rainy) throughout the year, therefore, no significant temperature variation was observed among stations ($P > 0.05$), as shown in Fig. 3 (d).

Due to the discharged effluent from the surrounding wastewater treatment plant and agricultural activities especially in the middle stream and downstream, significant differences among stations were observed for the AN and NO_3 ($P < 0.05$) where the concentrations of AN and NO_3 were higher in the middle stream and downstream region (Fig. 3 (e) and (f)). The highest concentrations of AN and NO_3 were observed at Sta 7 and Sta 9, with concentrations of 1.8 and 3.3 mg/L, respectively. All the monitored values for $\text{PO}_4^{3-}\text{-P}$ were found to be below 0.1 mg/L and no significant difference was observed ($P > 0.05$), as shown in Fig. 3 (g).

The rapid urbanization and increased industrial activities at the middle and downstream of the river basin have led to high SS concentrations and turbidity in the river basin due to the direct discharge of drainage from the residential and commercial areas (Mahazar et al. 2013; Chowdhury et al. 2018). Significant differences for SS concentration and turbidity were observed among stations ($P < 0.05$) and the SS concentration and turbidity degraded from upstream to downstream (Fig. 3 (i) and (j)), with the highest concentration at Sta 9, with concentrations of 480 mg/L and 250 NTU, respectively.

The Selangor river basin is also facing microbial contamination as the median values of FCB and TCB were more than 50 and 500 MPN/L, exceeding the standard set by the government (Fig. 3 (k) and (l)). Significant differences among stations were observed in FCB and TCB concentrations ($P < 0.05$), where the highest FCB and TCB concentrations occurred at the middle stream station (Sta 5), with concentrations of more than 200 and 10,000 MPN/L, respectively.

Comparison between ASEAN WQI systems

WQI values for the Selangor river basin DOE-WQI, PCD-WQI and MONRE-WQI systems are presented in Fig. 4(a), while values for STORET and PI methods are presented in Fig. 4(b) and Fig. 4(c), respectively. A substantial

difference among them is observed. Due to the disparity in the parameter selection and the standards among the WQI systems, there is a difference in the WQI values (Akkoyunlu and Akiner 2012). At present, the Selangor river basin is highly contaminated by the bacteriological parameters, mainly due to the lack of disinfection processes for the discharge of effluents from septic tanks (Faridah Othman et al. 2014). However, for the DOE-WQI in Malaysia, only physicochemical parameters are taken into consideration, while the biological aspect is excluded. Besides that, unequal weighting is applied in the DOE-WQI, which may lead to insensitivity to the low weighted parameter and subjectivity to the index (Cude 2001). Thus, the WQI values obtained by the DOE-WQI are relatively higher compared with the PCD-WQI and MONRE-WQI. Surface water in the ASEAN region has high turbidity and TSS (Fukushi et al. 2010) due to high erosion and sediment transfer caused by very high annual rainfall, the mountainous interior of the islands and peninsular, steep local reliefs, etc. This is currently experienced in the Selangor river basin, too (Gupta 1996; Mohamad and Goh 2015). Yet, the physical parameter is excluded in the PCD-WQI. There is a unique feature in the PCD-WQI, which is the special score. Howbeit, the formulation of the special score is case dependent as the development was performed according to river conditions as well as the water quality standard in Thailand (Pollution Control Department 2016b), which may have led to a biased final index for the Selangor river basin. The MONRE-WQI included all biophysicochemical parameters and applied equal weighting in the indices, which makes it seem to be the most well-developed WQI compared with the DOE-WQI and PCD-WQI. Notwithstanding, there is a relatively strict standard observed for the physical as well as biological properties and driving the values of the MONRE-WQI is the lowest compared with the DOE-WQI and PCD-WQI.

The STORET and PI methods are developed by the US EPA and the standard of parameters is generated according to the water quality conditions in the United States. There is a huge difference in climate, topography and even policy between the ASEAN region and the United States, and thus the water quality standard may not fit one another. Therefore, more studies should be carried out to revise the standards, taking water quality conditions into consideration. As shown in Fig. 4(b) and Fig. 4(c), due to the strict standards set in the United States, the values for both systems are poor. Besides that, as the number of necessary parameters is not clear, incorporating all parameters provided in the standard can present a very thorough

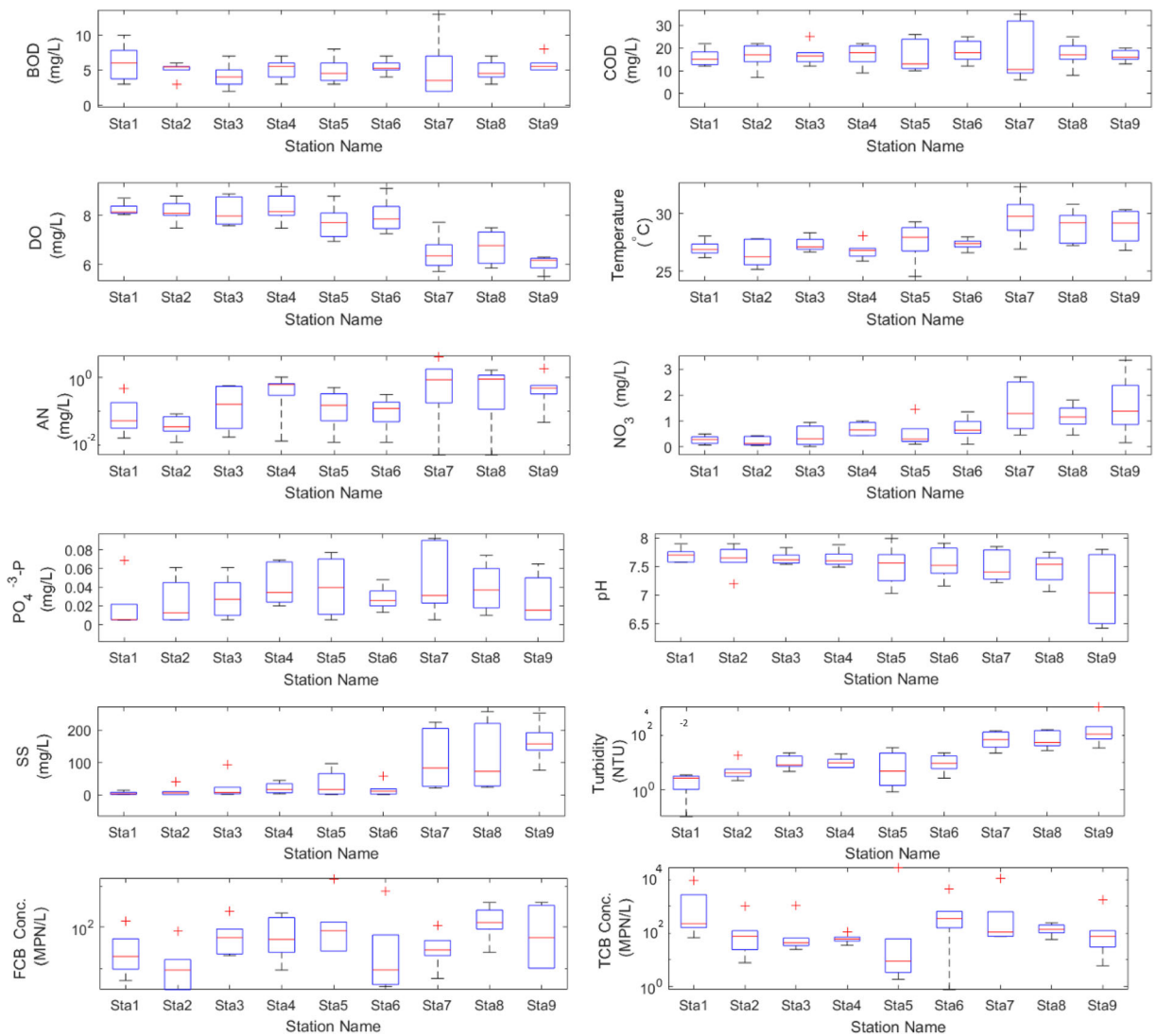


Fig. 2 Box-and-Whisker plot of water quality parameters for the Selangor river basin in year 2016

information on the water quality status. However, the cost of monitoring will be exorbitant too and vice versa. The PI method is less sensitive towards the difference in parameter values, as the evaluation is influenced by one of the parameters with the highest ratio to the water quality standard, $(C_i/L_{ij})_{max}$, and the average of parameters which exceed the quality standard, $(C_i/L_{ij})_{ave}$ (Kannel et al. 2007). On the other hand, the STORET method is more sensitive and capable of detecting the dynamic changes of all parameters while having the capability to provide a more comprehensive evaluation of the water quality status of the river (Saraswati et al. 2014). Therefore, the STORET method is more suitable in assessing the water quality

status of the watershed (Rohmad Barokah et al. 2017). Based on the analysis of the STORET and PI methods, the pollution status of all stations in the Selangor river basin was evaluated as “Highly Polluted”. This is because the $(C_i/L_{ij})_{max}$ of biological parameters towers in the whole Selangor river basin; therefore even though there is only one parameter exceeding the water quality standard, the value of PI can be very high.

In order to compare all WQI systems, the WQI values are converted into the river grade classification, as shown in Fig. 5. Besides that, the river grade classifications for the DOE-WQI and MONRE-WQI are modified as follows: “Good” (DOE-WQI = 76.5–100.0 and MONRE-WQI =

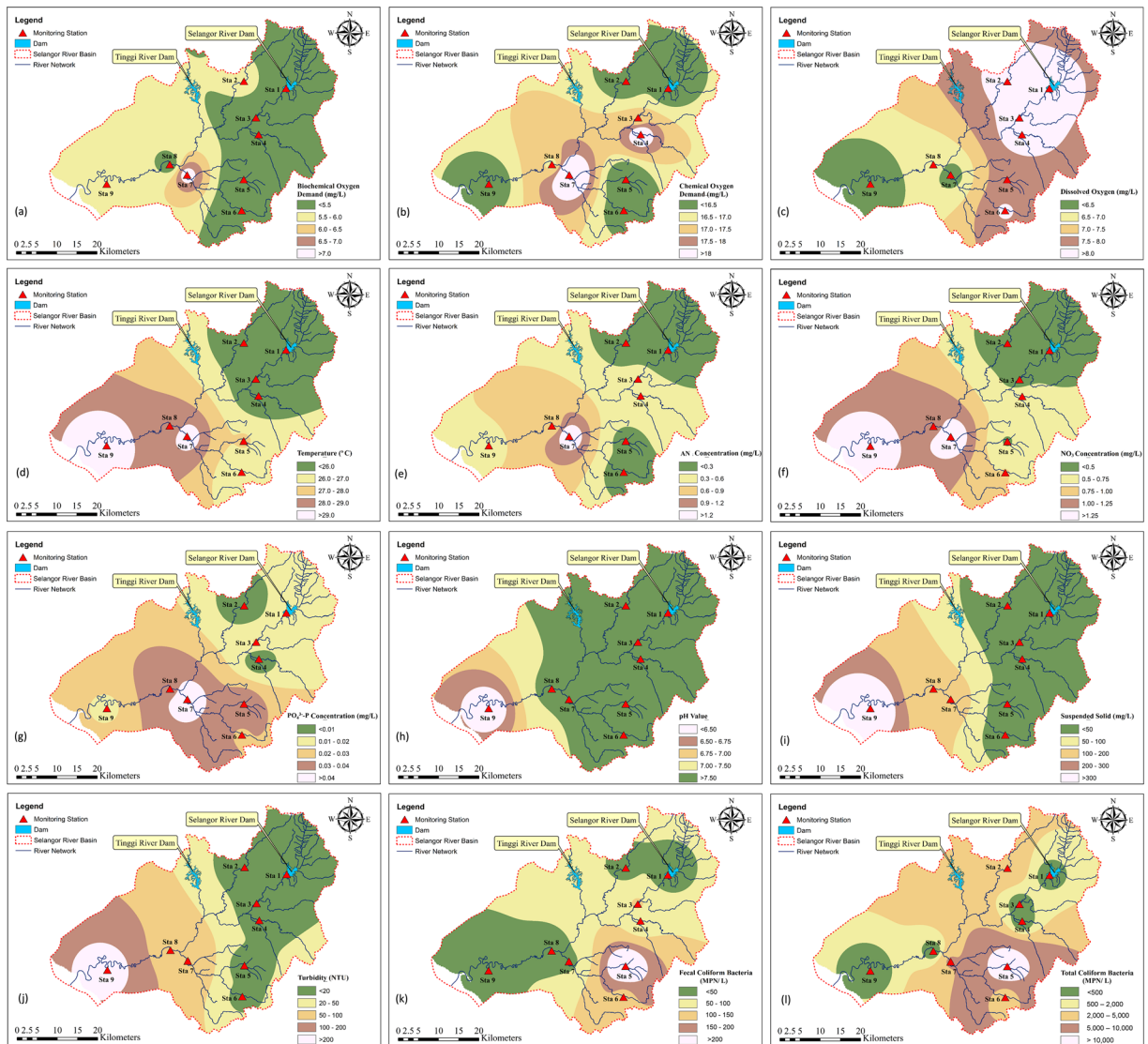


Fig. 3 Spatial distribution for water quality parameters in the Selangor river basin

76.0–100.0); “Fair” (DOE-WQI = 51.9–76.4 and MONRE-WQI = 51–75); “Poor” (DOE-WQI = 31.0–51.8 and MONRE-WQI = 26–50) and “Very Poor” (DOE-WQI = 0–3.0 and MONRE-WQI = 0–25.0). It can be observed that the evaluation of water quality status for all stations in the Selangor river basin by the MONRE-WQI, STORET and PI methods is similar, where the river quality is “Very Poor”. The DOE-WQI evaluated sampling stations 7 and 9 which are located at the downstream with high anthropogenic activities, as “Poor”, mainly due to the very high SS concentration in these two stations. The remaining stations were rated as “Fair” mainly due to the relatively high BOD and COD concentrations along the river. The PCD-WQI rated sampling station 1 as “Fair”

due to the relatively low AN and FCB concentration as compared with other stations, whereas sampling station 7 was rated “Very Poor” due to the very high AN, FCB and TCB concentrations. The remaining stations were rated as “Poor” mainly caused by the high BOD, FCB and TCB concentrations. It can be observed that the WQI systems which include all biophysicochemical parameters into consideration provide a consistent evaluation, but the system which considers either physicochemical or biochemical parameters gives a relatively lenient evaluation. For the Selangor river basin, as aforementioned, the basin is stressed and impacted by all physical, biological and chemical parameters caused by both the aridity of the climate and anthropogenic activities. Therefore, the current DOE-

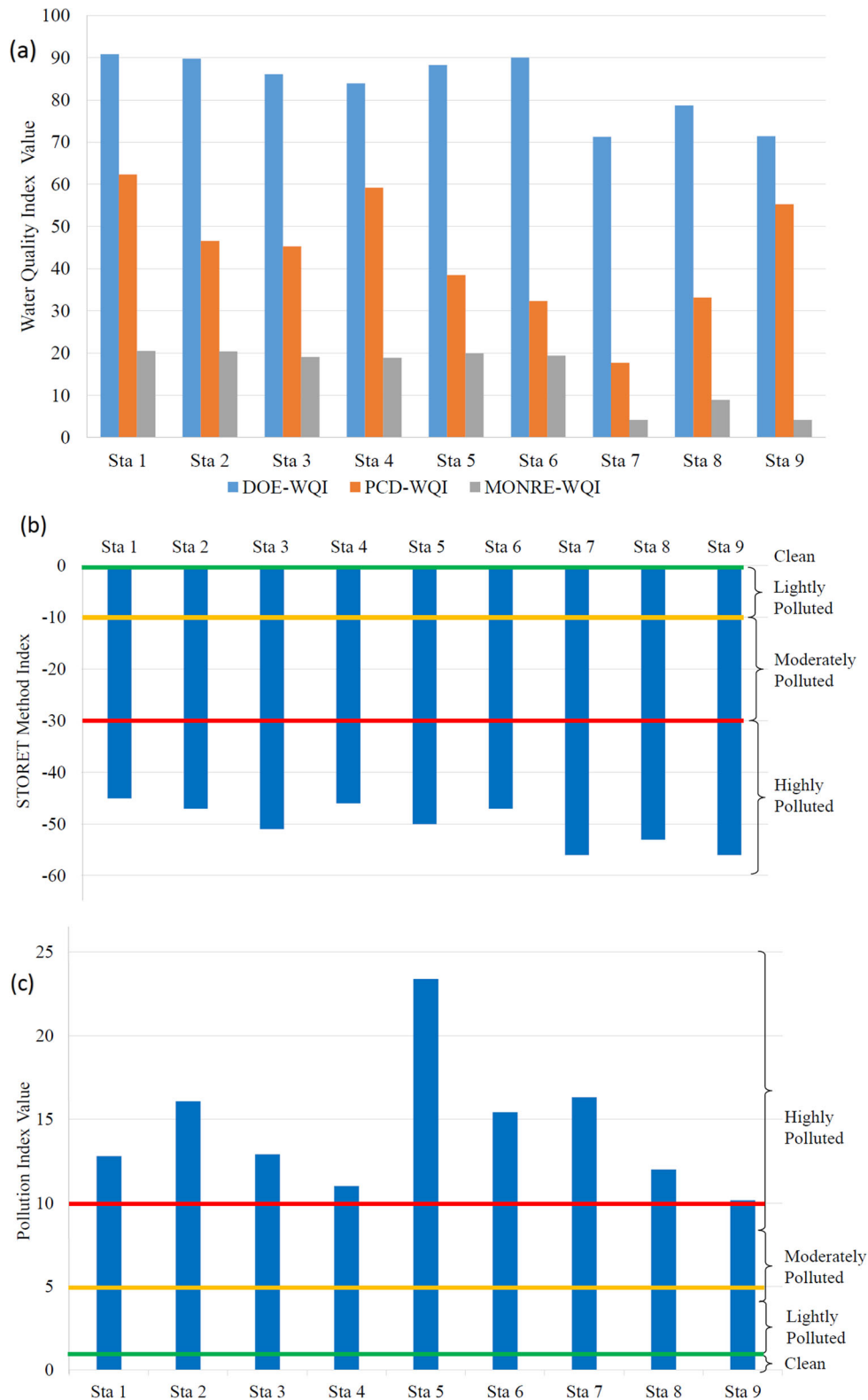


Fig. 4 Water quality index value for the Selangor river basin by using (a) DOE-WQI, PCD-WQI and MONRE-WQI, (b) STORET method and (c) PI method

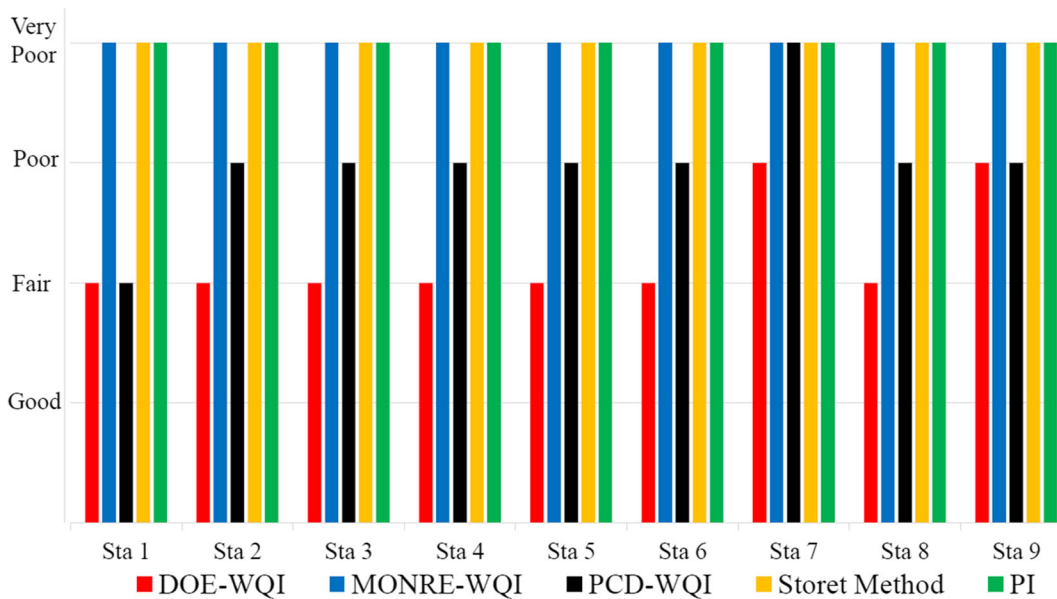


Fig. 5 Comparison of river quality classifications using different ASEAN WQI systems

WQI adopted in Malaysia may not be able to effectively provide a comprehensive evaluation for the river quality in Malaysia, it is crucial to include all these aspects into the evaluation and corresponding actions can be taken to improve the river condition.

Besides that, as it can be noticed, the application of ASEAN WQI systems is used to evaluate the general water quality status, omitting the specific purpose, i.e. the effect to the aquatic organism, human health, etc. The specific purpose of the index is important as different subjects of assessment will lead to different parameter selection as well as the permissible threshold concentrations. For instance, the presence of coliform bacteria in water tends to cause more harm to human beings than it does to aquatic creatures, although these are not exclusive. At present, there are few developed indices that specified the purpose of application, viz. Almeida’s Index (Almeida et al. 2012) and Contact Recreation Index (Nagels et al. 2001), which are used to assess the suitability for recreation use; CCME WQI (CCME 2001), Bhargava’s Index (Avvannavar and Shrihari 2008) and Boyacioglu’s Index (Boyacioglu 2007) are used to assess the suitability for drinking water supply.

Conclusion

Continuous water quality monitoring and evaluation based on individual water quality which encompasses

different aspects (physical, chemical and biological) is often unviable, especially for the developing and middle-income countries in the ASEAN region. The application of the WQI with several independent key parameters which can reflect the overall water quality status is a useful tool in this region.

Statistical and spatial analysis were performed to analyse the 12 water quality parameters (AN, BOD, COD, DO, FCB, NO₃, pH, PO₄³⁻-P, TCB, SS, turbidity and water temperature) across the Selangor river basin. Monitoring stations located downstream (Sta 7, Sta 8 and Sta 9) were heavily polluted by both chemical and physical parameters, which were caused by sand mining and urban activities (Aqeel Ashraf et al. 2011), whereas Sta 5 and Sta 6 were greatly affected by biological parameters caused by the undisinfectated effluents from septic tanks and industries (Faridah Othman et al. 2014).

A comparative study was performed using five different ASEAN WQI systems over nine monitoring stations in the Selangor river basin, Malaysia, to analyse the river quality status in 2016. Due to the different aspects of parameters and standards included in each system, the grading of the river quality is varied. The MONRE-WQI, STORET and PI methods which consider both biological and physicochemical aspects tend to be the most stringent systems for ranking the quality of surface

waters in the Selangor river basin, whereas the DOE-WQI and PCD-WQI ranked the water quality of Selangor streams as “Fair” and “Poor”, respectively, in almost all cases. Integration between the WQIs and GIS enables more in-depth analysis and provides more valuable information to evaluate the water quality status in river basins for necessary actions to be taken. As a future direction, the subject of assessment/specific purpose and the level of treatment required should be defined to ease policymakers in designing, formulating and implementing pollution abatement strategies.

Acknowledgement The authors would like to express their deepest gratitude to the Department of Environment, Malaysia, for permitting the use of the Selangor river basin water quality data for this study. We thank the two anonymous reviewers and the associate editor Prof. Andrew S. Hursthouse for their constructive comments which helped in improving the article significantly.

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