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Original Research

Effectiveness of Water Quality Index for Monitoring Malaysian River Water Quality

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Abstract

The Skudai River has experienced a general decline in water quality over the last several years due to agricultural practices, economic development, and other human activities in the river catchment. The spatial trend of water quality index (WQI) and its sub-indexes are important for determining the locations of major pollutant sources that contribute to water quality depletion in the Skudai and its tributaries. In this study, we have developed WQI for eight sections of the Skudai watershed. Ammonia-nitrogen (NH_3-N) was identified as a major pollutant downstream from the Skudai, with the lowest WQI index (i.e. 38). WQI for the Skudai (natural) was 94, i.e., Class I (very clean) category of river water quality. The Senai River has WQI value of 85 and Class II category (slightly polluted). However, the Kempas River, which was in suburban parts of the Skudai watershed, had WQI of 53 (Class III, polluted). The Melana and Danga rivers were also polluted rivers with WQI of 69 and 57, respectively, in Class III (polluted). Overall water quality in the Skudai and its tributaries was downstream of the river. The study also assessed water quality of the Skudai and its tributaries from other water quality parameters such as conductivity, turbidity, temperature, total dissolved solids, total phosphorous, and nitrogen, which were not part of the WQI formula developed by the Department of the Environment (DOE), Malaysia. The study found that Department of Education (DOE) formula for WQI was not effective in water quality assessment as many important parameters such as nutrients, heavy metals, and fecal coliform (or *E. Coli*) were missing in the WQI formula.

Keywords: Skudai River watershed, water quality index (WQI), water quality parameters, geographic information system (GIS), Malaysia

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Introduction

Water quality index (WQI) is useful in assessing the suitability of river waters for a variety of uses such as agriculture, aquaculture, and domestic use. WQI is used to relate a group of parameters to a common scale and combining them into a single number [1, 2]. WQI is one of the most effective tools to provide feedback on the quality of water to the policy makers and environmentalists [3]. It determines overall water quality status of a certain time and location [4]. There are several water quality indexes developed to evaluate river water quality all over the world. These indexes use various numbers of water quality parameters. For example, Meher et al. [5] used a total of 14 parameters such as pH, total dissolved solids (TDS), alkalinity, dissolved oxygen (DO), conductivity, turbidity, and other parameters for developing a water quality index for different sections of the Ganges River. Al-Shujairi [6] proposed a WQI formula that used seven water quality parameters (TDS, total hardness, pH, DO, biochemical oxygen demand (BOD), nitrate (NO3), and phosphate) to evaluate water quality in the Tigris and Euphrates rivers in Iraq. Terrado et al. [7] presented a detailed review and classification of WQI methods. More literature on other WQI methods can be found in [8-15].

In 1985, a study entitled "Development of Water Quality Criteria and Standards for Malaysia" was carried out by the Malaysian government. A team of multidisciplinary experts from universities throughout the country carried out the study, which aimed to develop standards for monitoring river water quality for domestic water use, fisheries and aquatic breeding, livestock drinking, recreation, and agricultural use [16]. The National Water Quality Standards (NWQS) defined six classes (I, IIA, IIB, III, IV, and V) for river water classification based on the descending order of water quality, i.e., Class I being the "best" and Class V being the "worst" water quality [17]. Table 1 shows range values of different water quality parameters for different classes of river waters. The WQI has been practiced in Malaysia for about 30 years. It is a set of water quality guidelines that categorize the water quality class according to water quality for public use, such as recreational purposes, irrigation, and aquaculture. The WQI formula uses six parameters to determine river water quality: biochemical oxygen demand (BOD), dissolved oxygen (DO), chemical oxygen demand (COD), suspended solids (SS), ammonia-nitrogen (AN), and pH. The WQI formula developed by the Department of Environment Malaysia (DOE) is used by [18-22] for determining water quality in various rivers for different water uses.

Water quality status for different river systems in Peninsular Malaysia is shown in Fig. 1. It shows that a number of rivers had slightly polluted and polluted water. This number may increase in the future if no remedial measures are taken to control effluent coming from local industries and residential areas. The Skudai River falls in the 'slightly polluted' category and immediate actions are required for preventing water quality from further degradation and improving it. The WQI formula developed by DOE serves as the basis for water quality assessment in relation to pollution load and river water classification under the National Water Quality Standards for Malaysia (NWQS). The objective of the study was to assess the WQI as an indicator to evaluate the water pollution status in the Skudai River and its tributaries for agriculture,

Table 1. National Water Quality Standards (NWQS) for Malaysia [18].

	Class						
Parameter	Unit	I	IIA	IIB	III	IV	V
pH		6.5-8.5	6-9	6-9	5-9	5-9	-
DO	mg/L	7	5-7	5-7	3-5	<3	<1
BOD	mg/L	1	3	3	6	12	>12
COD	mg/L	10	25	25	50	100	>100
SS	mg/L	25	50	50	150	300	300
AN	mg/L	0.1	0.3	0.3	0.9	2.7	>2.7

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

Table 2. Sampling stations in the Skudai River watershed.

Sampling Station	Station Code	Catchment Area (km^2)	Latitude	Longitude
Skudai River-Natural	SKN	325	1°40'41" N	103°34'58" E
Skudai River-Head	SKH	-	1°39'38" N	103°36'23" E
Senai River	SEN	33	1°36'19" N	103°38'33" E
Skudai River-Middle	SKM	-	1°32'54" N	103°39'40" E
Melana River	MEL	47	1°30'11" N	103°39'21" E
Skudai River-Tail	SKT	-	1°29'58" N	103°40'57" E
Kempas River	KEM	8	1°29'32" N	103°42'35" E
Danga River	DAN	27	1°28'40" N	103°40'53" E

domestic, and aquacultural use based on the analysis of physico-chemical parameters (DO, BOD, COD, SS, AN, and pH). Some of the salient features of the Skudai and its tributaries are shown in Table 2.

Materials and Methods

Study Area and Sampling Stations

The length and the catchment area of the Skudai are 40 km and 325 km^2, respectively. The Skudai watershed consists of urban, semi-urban, and natural areas depending on the percent of land use for forest, commercial, communication, residential, and other purposes. The inflow in the Skudai watershed comes from the Skudai, Senai, Melana, Dana, and Kempas rivers. The Danga and Kempas are located in the urban area as most of their catchments were covered by commercial, communication, and residential blocks. On the other hand, the Senai and Melana are under the category of semi-urban as about half of their catchments were under forest and the rest under commercial and residential blocks. The natural part of the Skudai was dominated by natural forest as a very limited area was found under use of commercial and residential purposes. The land use in the Skudai watershed was determined by applying a Geographic Information System (GIS) through ArcGIS Version 10. The sampling stations were decided from the land use maps of the Skudai watershed. The entry points of the tributaries to the Skudai were selected for collecting samples for water quality tests.

The water samples were collected from eight sampling stations for *in-situ* and laboratory water quality tests for 12

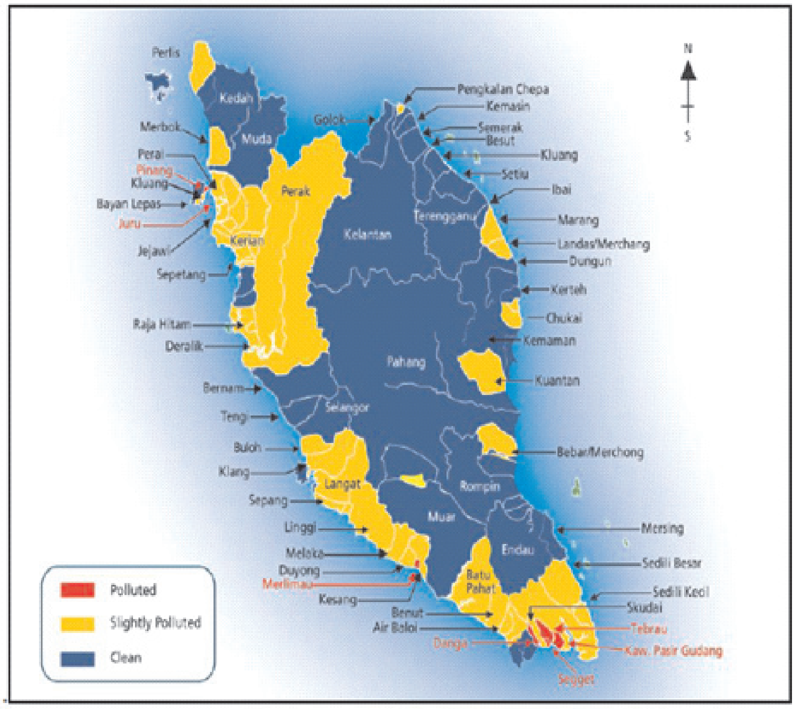

Fig. 1. Water quality status for river systems of Peninsular Malaysia [20].

water quality parameters such as DO, BOD, COD, pH, SS, AN, conductivity, temperature, turbidity, TDS, nitrates, and total phosphorous (TP). A sunny day with no rainfall for the previous 24 hours was chosen for the collection of water samples. The sunny day with no rainfall for the last 24 hours provides a better opportunity to get water quality tests in normal river flow conditions. The water samples during rainfall, on the other hand, may not truly represent river water quality as these are not normal conditions for river flow. The location of water sampling stations in the Skudai River watershed is shown in Fig. 2. We used Horiba water quality testing equipment for the *in-situ* tests of pH, temperature, and dissolved oxygen (DO) parameters. The water samples were then sent to the laboratory for tests of the rest of water quality parameters using American Public Health Association methods [23].

Water Quality Parameters

Good water quality is important for a healthy river and ecosystem. There are several basic conditions that must be met for aquatic life to thrive in river waters. If these conditions are not met, aquatic species become stressed and can even die. The health of a river is generally measured from WQI, which varies from country to country even from one study to another and mostly depends on the number and type of parameter used to develop WQI. In developing WQI for a river, several parameters are needed to be assessed and monitored. The DOE formula for determining WQI uses six parameters (DO, BOD, COD, AN, SS, pH).

Dissolved oxygen (DO) is a measure of the amount of oxygen freely available in water and it is commonly expressed as a concentration in terms of milligrams per litre. DO is temperature dependent. The colder the water, the more oxygen it can hold [10]. Low DO in any river water makes aquatic species move away, weaken, or even die. BOD determines the strength of pollutants in terms of oxygen required to stabilize the wastes. It also measures the amount of food for bacteria found in water. The BOD test provides a rough idea of how much biodegradable waste is present in the water [24]. High BOD in water causes aquatic species to suffocate or die. The COD test is commonly used to measure the amount of organic and inorganic oxydizable compounds in water [25]. High COD will stress aquatic organisms and can lead to their death.

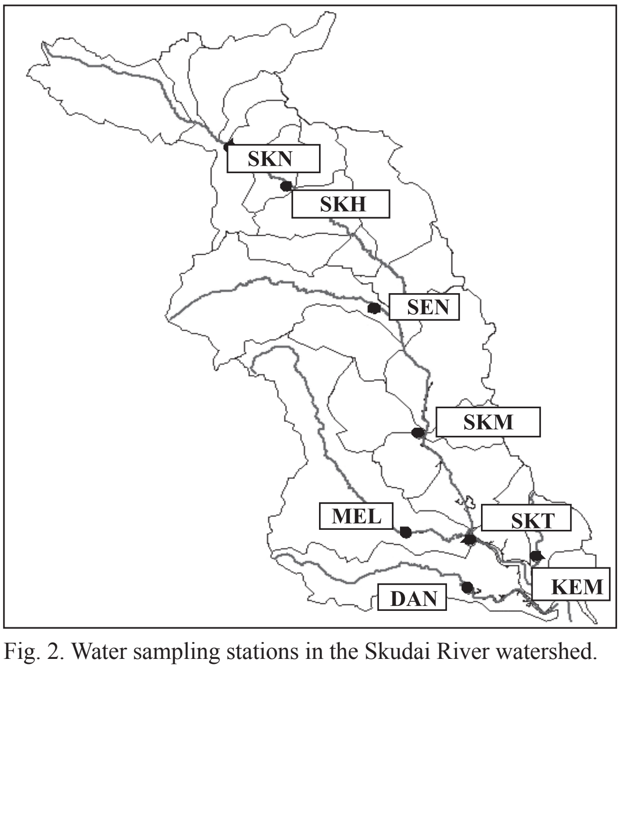

Fig. 2. Water sampling stations in the Skudai River watershed.

Suspended solids (SS) are natural pollutants and cause turbidity in the river water [26]. The excess amount of SS in water can also be an indicator of land erosion in the river catchment. Water quality degradation due to ammonia-nitrogen (NH_3-N) remains a crucial environmental and public concern worldwide because it can cause eutrophication [27]. pH is a measure of the acid strength in the water. The lower the pH, the more acidic the water [25]. Low pH causes toxic elements and compounds to become available for uptake by aquatic plants and animals [28].

Water Quality Index

WQI for the Skudai and its tributaries was determined by using the WQI formula developed by DOE (Eq.1). The WQI equation consists of different sub-indexes (SIs), which are calculated according to the best-fit relationship (Eqs 2-7). The water quality parameters are attached with different weights. The assigned weight reflects the significance of a water quality parameter for a particular use and it has considerable impact on overall water quality index (WQI) for a particular river [29]. These weights are generally assigned by water quality experts in an opinion survey. The higher the weight, the more important the parameter. For example, DO was the most important water quality parameter in the DOE-WQI formula where this parameter was assigned 22% of total weights. Similarly, pH was given the lowest weight (i.e. 12%) in an opinion survey conducted from water quality experts, which deemed it to be the least important parameter in calculating WQI for the Malaysian rivers.

$$WQI = 0.22 \times SI_{DO} + 0.19 \times SI_{BOD} + 0.16 \times SI_{COD} + + 0.15 \times SI_{AN} + 0.16 \times SI_{SS} + 0.12 \times SI_{pH} \quad (1)$$

…where:

WQI = water quality index,
SI_{DO} = sub-index of DO,
SI_{BOD} = sub-index of BOD,
SI_{COD} = sub-index of COD,
SI_{AN} = sub-index of AN,
SI_{SS} = sub-index of TSS,
SI_{pH} = sub-index of pH.

In this study, sub-indexes of water quality parameters were calculated for each water sample from the use of the following best-fit equations (Eqs 2-7) [30]:

Best-fit equations for DO sub-index:

$$SI_{DO} = \begin{cases} 0 & \text{for } DO < 8 \\ 100 & \text{for } DO > 92 \\ -0.395 + 0.030DO^2 - 0.00020DO^3 & \text{for } 8 < DO < 92 \end{cases} \quad (2)$$

Best-fit equations for BOD sub-index:

$$SI_{BOD} = \begin{cases} 100.4 - 4.23BOD & \text{for } BOD < 5 \\ 108e^{-0.055BOD} - 0.1BOD & \text{for } BOD > 5 \end{cases} \quad (3)$$

Best-fit equations for COD sub-index:

$$SI_{COD} = \begin{cases} -1.33COD + 99.1 & \text{for } COD < 20 \\ 103e^{-0.0157COD} - 0.04COD & \text{for } COD > 20 \end{cases} \quad (4)$$

Best-fit equations for AN sub-index:

$$SI_{AN} = \begin{cases} 100.5 - 105AN & \text{for } AN < 0.3 \\ 94e^{-0.573AN} - 5|AN - 2| & \text{for } 0.3 < AN < 4 \\ 0 & \text{for } AN > 4 \end{cases} \quad (5)$$

Best-fit equations for SS sub-index:

$$SI_{SS} = \begin{cases} 97.5e^{-0.00676SS} + 0.05SS & \text{for } SS < 100 \\ 71e^{-0.0016SS} - 0.015SS & \text{for } 100 < SS < 1000 \\ 0 & \text{for } SS > 1000 \end{cases} \quad (6)$$

Best-fit equations for pH sub-index:

$$SI_{pH} = \begin{cases} 17.2 - 17.2pH + 5.02pH^2 & \text{for } pH < 5.5 \\ -242 + 95.5pH - 6.67pH^2 & \text{for } 5.5 < pH < 7 \\ -181 + 82.4pH - 6.05pH^2 & \text{for } 7 < pH < 8.75 \\ 536 - 77.0pH + 2.76pH^2 & \text{for } pH > 8.75 \end{cases} \quad (7)$$

Results and Discussion

Physico-Chemcial Water Quality Data Analysis

Water samples were collected from eight sampling stations in different locations along the Skudai and its tributaries in September 2014. *In situ* data measurement such as dissolved oxygen (DO), pH, temperature, conductivity, total phosphorus, nitrogen, and turbidity were taken twice from each of the sampling stations and average value was used in WQI. Analysis for parameter such as BOD, COD, SS, and NH_3-N were conducted in laboratory. The results of water quality data analysis are shown in Table 3.

The higher dissolved oxygen (DO) values represent good water quality and best for a healthy ecosystem [31]. The average value of DO in the study area was recorded as 8.5 mg/L, which indicated that the river water was plausibly good for aquatic life. Based on the observed DO values, DAN (3.4 mg/L), KEM (5.7 mg/L), and MEL (7.5 mg/L) can be categorized as class III according to NWQS threshold level for the Malaysian river waters. The lower values of DO may be due to the discharge of organic matter and nutrient-rich industrial effluents [1]. BOD was not detected in water samples of three sections of the Skudai (SKN, SKH, and SKM) and the Senai (SEN), which indicated that water quality in these locations was good for BOD parameters. COD is always greater than BOD for any given sample and is typically less than 20 mg/L in unpolluted waters. A higher level of COD concentration was found in water samples collected from KEM, DAN, MEL, SKM, and SEN with values 78 mg/L, 47 mg/L, 42 mg/L, 28 mg/L, and 26 mg/L, respectively. The higher COD concentration in the majority of water samples indicates that river water was not suitable for aquatic life to thrive. Ammonia-nitrogen (NH_3-N) in water samples ranges between 0 mg/L and 7.2 mg/L, and these values were within the maximum permissible limit of <12 mg/L set by the World Health Organization for river waters [32]. However, the NWQS recommended maximum threshold level of 0.90 mg/L of NH_3-N in river waters to support aquatic life. The water quality of all sampling stations was inferior for aquaculture to thrive except for SKN and SEN, where NH_3-N concentration was 0.0 mg/L and 0.1 mg/L, respectively. High levels of ammonia-nitrogen (NH_3-N) were found at KEM (7.2 mg/L) and DAN (7.2 mg/L) stations, which could be due to the presence of fertilizers and industrial emissions in river water at these sampling stations. Suspended solids (SS) are natural pollutants and cause turbidity in the river water [26]. The excess amount of suspended solids in a river water sample can also be an indicator of land erosion in the river catchment. The highest SS concentration was recorded for the Senai (SEN) and Skudai River-Tail (SKT) stations. The high concentrations of SS at stations SEN (144 mg/L) and SKT (114 mg/L) were probably due to higher rates of soil erosion in the catchments of these two rivers. pH was not a problem for the collected water samples as it ranged between 5.8 and 7.0, which was under the permissible NWQS limits (i.e. 5.5-8.5) for the river waters.

Together with six WQI parameters, water quality at all stations was also assessed from conductivity, TDS, temperature, turbidity, total phosphorous, and nitrogen. Conductivity is a very useful water quality parameter to determine the extent of influence of runoff and effluent discharges in the aquatic system [33]. Conductivity levels of the rivers in the Skudai River watershed ranged between 74 μS/cm and 444 μS/cm. The water samples collected from the Kempas River (KEM) recorded the highest conductivity level (444 μS/cm) among all other sampling stations. However, this conductivity level in the Kempas was still within the permissible limit for river water set by NWQS, where river water with conductivity less than 1000 μS/cm is still suitable for aquatic life and other water inhabitants. TDS concentrations in water samples ranged between 48 and 289 mg/L. With this range, river water can be classified as Class I according to the NWQS benchmark for TDS. River water temperature ranged between 26.5

Table 3. Water quality status and WQI at sampling stations in Skudai River watershed.

Water Quality Parameter	Unit	Water Sampling Station							
		SKN	SKH	SEN	SKM	MEL	SKT	KEM	DAN
DO	mg/L	10.3	8.9	9.1	13.3	7.5	9.7	5.7	3.4
BOD	mg/L	ND*	ND	ND	ND	3.0	ND	24.0	4.0
COD	mg/L	5.0	14.0	26.0	28.0	42.0	19.0	78.0	47.0
AN	mg/L	ND	1.3	0.1	1.0	4.8	1.6	7.2	7.2
SS	mg/L	33.0	34.0	144.0	97.0	76.0	114.0	29.0	40.0
pH	-	6.4	6.5	5.8	6.4	6.8	6.3	7.0	6.8
Conductivity	µS/cm	121.0	157.0	74.0	133.0	202.0	155.0	444.0	416.0
TDS	mg/L	79.0	102.0	48.0	86.0	131.0	100.0	289.0	271.0
Temperature	^oC	27.4	28.1	26.5	27.5	28.4	28.4	30.0	30.7
Turbidity	NTU	61.5	57.2	211.7	197.3	166	227.3	48.4	110.7
Total phosphorous	mg/L	0.6	ND	0.3	ND	0.2	2.5	0.2	2.1
Nitrogen	mg/L	7.1	7.1	7.1	11.1	6.6	6.2	3.5	3.1
Overall WQI		94	84	85	79	69	78	53	57
Class		I	II	II	II	III	II	III	III
Water Quality Status		Very Clean	Clean	Clean	Slightly Polluted	Polluted	Slightly Polluted	Polluted	Polluted

*ND = Not detected

Table 4. Sub-indexes of water quality parameters for different water sampling stations.

Station	Sub-Indexes					
	SI_{DO}	SI_{BOD}	SI_{COD}	SI_{AN}	SI_{SS}	SI_{pH}
SKN	100	96	92	90	80	96
SKH	100	96	80	41	79	97
SEN	100	96	67	90	55	88
SKM	100	96	65	48	55	96
MEL	100	88	52	0	62	99
SKT	100	96	74	36	58	95
KEM	85	26	27	0	82	99
DAN	44	83	47	0	76	99
WQI	91	85	63	38	68	96
Class	I	II	III	IV	III	I
Water Quality Status	Very Clean	Slightly Polluted	Polluted	Severely Polluted	Polluted	Very Clean

and 30.7ºC and was not threatening river health and the inhabitants.

Turbidity values in river water can increase with the increase of concentrations of organic matter, suspended solids, effluents and/or surface run-off. It is highly dependent on time and seasonal variations due to biological activity and surface run-off [1]. The turbidity levels in the study area ranged between 57.2 and 227.3 NTU, which exceeded the permissible level of 25 NTU for domestic use of water [34]. The turbidity value of water sample collected at SKT (Skudai River-Tail) was the highest (227.3 NTU) among all water samples.

The second highest value of turbidity was found at the Senai (211.7 NTU). High turbidity levels raise water temperature, lower dissolved oxygen, prevent light from reaching aquatic plants (which ultimately reduces their ability to photosynthesize), and harm fish. Total phosphorous (TP) values were between 0 mg/L and 2.5 mg/L in Skudai waters, including tributaries. TP was not detected in water samples collected from SKH and SKM stations. Thus river water at these two locations was of good quality for TP parameter only. Total phosphorous concentration greater than 0.1 mg/L will impact a river ecosystem [35]. Nitrogen (N) concentration in water samples ranged between 3.1 mg/L and 11.1 mg/L. The highest N concentration was found in water samples of SKM (Skudai River-Middle) with a value of 11.1 mg/L. Nitrogen concentrations over 10 mg/L will have an effect on the freshwater aquatic environment [36]. Nitrogen concentration of 10 mg/L is also the maximum permissible limit in human drinking water by the U.S. Public Health Service. For a sensitive fish such as salmon the recommended concentration is 0.06 mg/L [36].

Sub-Indexes of Water Quality Parameters

Sub-index (SI) values were determined for each water quality parameter to observe the influence of individual parameters on river water quality. The best-fit equations shown in methodology (Eqs 2-7) were used for that purpose. SI values of six water quality parameters were obtained in every station to show the spatial variation. Classification of river waters under each water quality parameter were developed based on the SI values (Table 4). Sub-index values of DO were obtained for all

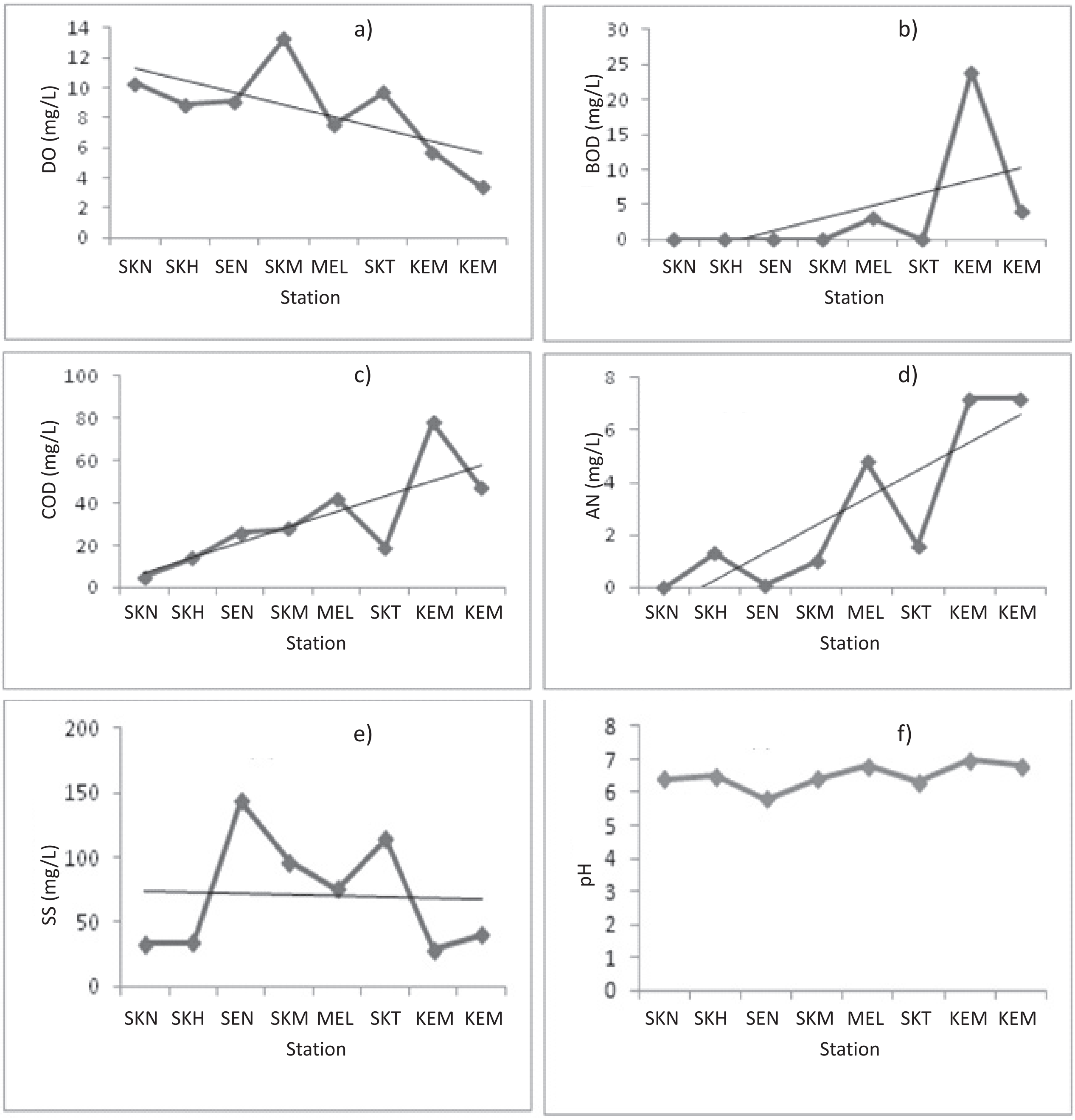

Fig. 3. Concentrations of water quality parameters at sampling stations (a) DO, (b) BOD, (c) COD, (d) AN, (e) SS, (f) pH.

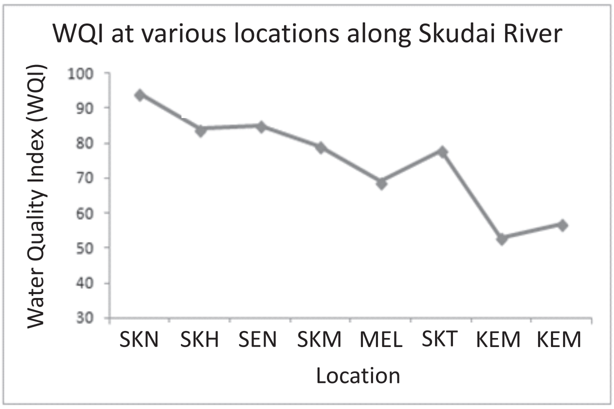

Fig. 4. WQI of designated locations along the Skudai River.

sampling stations except the Kempas and Danga rivers, where DO sub-index values were 85 and 44, respectively. Low ammonia-nitrogen (NH_3-N) index was obtained for most of the sampling stations, which indicated the presence of higher amounts of NH_3-N in river water samples. The result showed that the lowest (worst) AN sub-index was found at the Kempas with 53, followed by the Danga (57) and Melana (69). The sub-indexes of DO, BOD, and pH values were mostly within the NWQS permissible limits for quality of river waters in Malaysia. On the other hand, AN, COD and SS were the parameters that greatly affected water quality in the Skudai and its tributaries. Local sources causing higher concentrations of AN, COD, and SS parameters in river water may be identified and remedial measures may be taken on a priority basis.

Trend Analysis of Water Quality Parameters

Fig. 3(a-f) shows the trend of different water quality parameters for water samples collected from different sampling stations in the Skudai watershed from upstream to downstream of the watershed. DO values have a declining trend downstream of the Skudai (Fig. 3a). This indicates that the depletion of oxygen in water from upstream of the river to the downstream, which could be problematic for aquatic life in the Skudai and its tributaries. BOD values were almost unchanged in the river system except for the Kempas (24 mg/L) (Fig. 3b). All other parameters (COD, AN, SS, pH) have an increasing trend downstream of the Skudai. The increasing trend in COD, AN, SS, and pH could be because of local pollutants (e.g. untreated industrial, domestic, and agricultural wastewater) entering the river system at different locations. We emphasize that the identification of pollution sources was beyond the scope of the current study.

Trend of WQI

The trend of WQI values along the Skudai is shown in Fig. 4. WQI values were decreasing in flow direction of the river (upstream to downstream). Based on the values of individual water quality parameters stated as above, the trend in decreasing WQI values along the river was not unexpected. For the calculated WQI values, Skudai River-Natural (SKN), Senai River (SEN), and Skudai River-Head (SKH) were found to be clean rivers. WQI for SKN was 94, making it a Class I river. SEN had WQI value of 85, making it Class II (slightly polluted). The Kempas, Dana, and Melana rivers had WQI values of 53, 57, and 69, respectively, and were falling in Class III (polluted). Average WQI score for the Skudai River and its tributaries was found to be 75, which is higher (better) than the WQI score (i.e. 66) determined by [20]. It shows that the current water quality in the Skudai watershed has been getting better since 2011. This might be because of strict implementation of pollution control rules and regulations on water quality for industries and other commercial sectors and/or the introduction of some remedial measures taken by the Skudai River management team and the Department of Environment (DOE) in recent past.

Conclusions

The result shows WQI of the Skudai River ranging from 94 to 53, which denotes degradation of water quality downstream of the river. Water quality in the upstream sections of the Skudai and its tributaries was better than the downstream river sections and tributaries. There was significant increase in values of the most important water quality parameters (BOD, COD, NH3-N, and others) downstream of the river, which indicates that the local pollutants may be contributing incrementally in degrading of river water quality. The calculation of sub-indexes for individual water quality parameters was helpful in identifying the more problematic parameters and the river sections where remedial measures can be initiated on a priority basis. Ammonia-nitrogen (NH_3-N) and chemical oxygen demand (COD) were two main issues with almost all water samples.

We must emphasize that decisions regarding water quality for any river should be based on site characteristics, as the WQI formula developed by the DOE does not take into account some very important parameters such as nutrients (phosphorous, nitrogen), heavy metals (iron, zinc), and E. Coli. We also propose modifications in the existing WQI formula by including more water quality parameters, which can be helpful in assessing river water quality more accurately.

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