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Assessment of Water Quality Status for the Selangor River in Malaysia

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Abstract Water quality degradation in the Selangor River will still be present in the years to come since pollutant loads from poultry farms, municipal wastewaters, and industrial wastewaters are not envisaged to be handled effectively. This will be facing the problems of water quality status to use for multiple purposes and to provide its aquatic environment continuously. The water quality evaluation system is used to assess the water quality condition in the river. This system distinguishes two categories of water condition i.e., the water quality index and water quality aptitude. The assessment of water quality for the Selangor River from nine stations along the main stream, which concludes that water has been highly polluted (index 5) immediately downstream of station 02 Selangor River before confluence with Kubu River due to high concentration of microorganisms and immediately downstream of station 06 Selangor River before confluence with Batang Kali River due to high concentrations of microorganisms and suspended particles, was verified. Mineral micropollutants were found to gradually pollute the stream water, ranging from the unpolluted water (index 1) in the upstream to the bad quality (index 4) in the downstream area.

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1 Introduction

Water resources management entails the development of appropriate quantities of water with an adequate quality. The tendency of water demands in Malaysia was estimated to increase from 9,543 m^3/day in 1995 to 15,285 m^3/day in 2010, or the increase of 60% during 15 years, to 20,338 m^3/day in 2020, or 113% during 25 years (DOE 2003). There is a need to control and maintain the quality of raw water in the river to ensure the safe quality of available water because the deterioration of water quality reduces the usability of the resources for multistakeholders (Fulazzaky 2005). The quality of surface water has become a critical issue in many countries, especially due to the concern that freshwater will be a scarce resource in the future so a water quality monitoring program is necessary for the protection of freshwater resources (Pesce and Wunderlin 2000).

Since the data of water quality may be interpreted individually to explore the impact of the elements content in water to the environment and human health in accordance with the experiences and knowledge of personal experts, the results of water quality analysis become doubtful and yield uncertain information (Fulazzaky 2005). The assessment of river quality is commonly based on three choices, which are: (1) water choice, referred to as the water quality evaluation system (WQES), to assess the physico-chemical and biological quality of water in terms of the water quality index (WQI) and the suitability of water for supporting natural functions of the aquatic environment and water uses in terms of water quality aptitude (WQA); (2) physical environment choice, referred to as the physical quality evaluation system, to assess the level of manmade change on the main channel, channel margins, and river banks; and (3) biological choice, referred to as the biological quality evaluation system, to assess the state of the biosciences of the aquatic environment (Oudin et al. 1999).

Several approaches have been introduced to assess the status of water quality in the stream (Shastry et al. 1972; Aston et al. 1974; Lizcano et al. 1974; Nunes et al. 2003; Tsegaye et al. 2006; Meeroff et al. 2008). The WQI has been considered as one criterion for surface water classifications, based on the use of standard parameters for water characterization. This index is a numeric expression used to transform large quantities of water characterization data into a single number, which represents the water quality level (Sánchez et al. 2006; Bordalo et al. 2006). An interactive fuzzy multiobjective linear programming model has been introduced in the earlier study to simulate the allocation of waste load efficiencies with satisfactory results which indicate usefulness of the model in managing more complex river basins along with better flexible policies of water management (Singh et al. 2007). While the models give useful insights, questions still remain concerning the limitations inherent in the models (Marsden et al. 1973).

Although the Department of Environment WQI using six parameters, i.e., DO, BOD, COD, SS, NH_4^+, and pH, has been promoted as a tool to define the status of surface water quality in Malaysia (DOE 2003; Shuhaimi-Othman et al. 2007; Sari and Wan Omar 2008), this tool is not responsible to assess all the water quality parameters in checking the water quality status comprehensively. For instance, a major contribution of phosphorus affects the degradation of stream and lake water quality through algal blooming and associated eutrophication (Hoorman et al. 2008). Hence, the application of WQES as part of the water quality monitoring program that aims to convert the data to information is more suitable. This envisages possess the operational procedure standard generating the data to information based on all the parameters monitored. The information produced from the WQES is provided with two categories that are the water quality status and the water suitability for different uses and its ecosystem (see Fig. 1). Besides, to identify the critical parameter(s) affecting the quality of water and to verify the sources of pollution discharged to the stream water are reasonable (Fulazzaky 2005).

The objectives of this study are (1) to assess the status of water quality for the Selangor River and to identify the most polluted parameters and alterations to ascertain the quality of stream water and (2) to define the sources of pollutant discharged in the river in order to recommend the priority of measures that needs to be envisaged by the local authority.

2 The Importance of WQES to Assess the Selangor River Water

Selangor River emerges from the foothills of Fraser's hill and traverses the northeast region of Selangor for some 110 km, or about 200 km from Fraser's summit, until it reaches the coast (see Fig. 2). The basin is approximately 70 km long and 30 km wide and has an area of 2,200 km^2, or about 28% of the Selangor

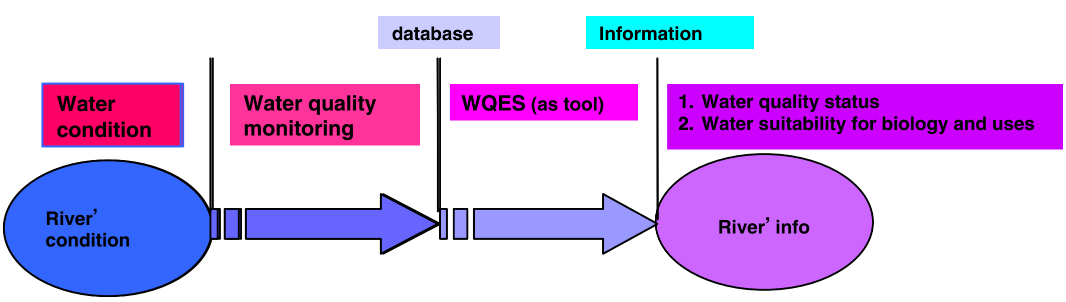

Fig. 1 Link of the river water quality condition to river water quality information

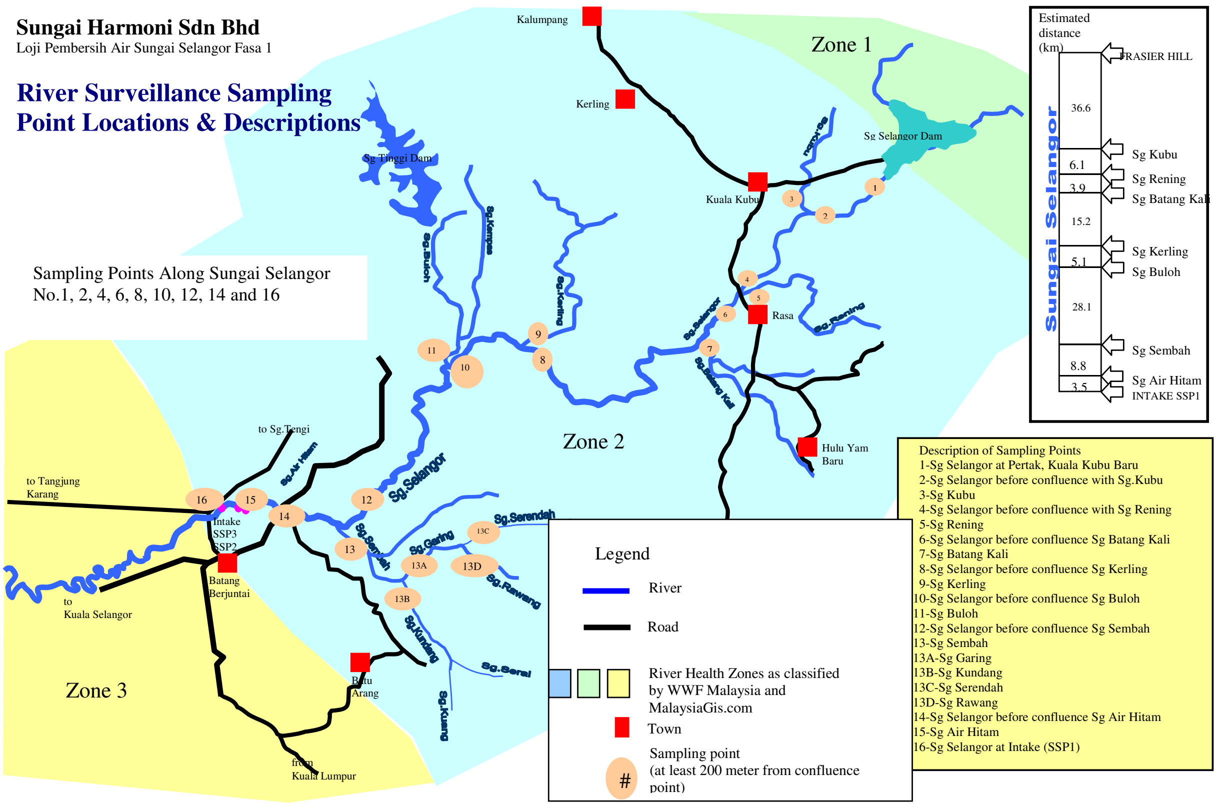

Fig. 2 Sampling stations along the Selangor

state, inhabited by about 406,000 people in 2006. Since 1948, stream flow of Selangor River has been recorded at two stations, i.e., Rasa and Rantau Panjang with catchment areas of 321 and 1,450 km^2, respectively. The annual average flows are 12.6 m^3/s at Rasa and 63.4 m^3/s at Rantau Panjang. The seasonal variation in the stream flow matches the rainfall pattern. The highest flows occur during the northeast monsoon from October to December and monthly average stream flow recorded during this period was 40–50 million cubic meters (MCM) per month at Rasa and 193–264 MCM per month at Rantau Panjang. Low flows that occurred during July and August were about 24 MCM per month at Rasa and 94–97 MCM per month at Rantau Panjang. The lowest stream flow ranging from 0.7 to 6.2 m^3/s was recorded at Rasa station during 1965–1970 (DID 2007). The major use of water resources in the basin is for portable water supply transfer interbasin to provide the water over four million people and industries in Kuala Lumpur, Petaling, Gombak, and Hulu Selangor (DID 2007). Most human activities in the basin affect water quality, directly through discharge of sewage and other wastewater or indirectly through land use changes. A change in land use/land covers in association with seasonal and location variation significantly affected stream water quality (Tsegaye et al. 2006).

The sources of pollutants are due to point sources such as the pollutants from industrial and domestic wastewater and nonpoint sources such as pollutants from agricultural activities and erosion. The existing data are insufficient to precisely estimate the pollutant loads quantitatively. As mentioned in the Selangor River Basin Management Plan 2007–2012, the pollutant loads of 10.5 t BOD/day discharge the main river and its tributaries from the outlet of public and private sewerage treatment plants, individual septic tanks, industrial estates, wet markets, landfills, and aquacultures. Hence, the pollutant loads of 2.1 t BOD/day comes from the effluent of public wastewater treatment plants (WWTP) and of 5.0 t BOD/day originates the desludged septic tanks (DID 2007). This may be categorized as pollutants due to point sources. Untreated domestic wastewater of the entire the river basin was estimated at 24 t BOD/day discharged into the stream. The various types of WWTP found at the entire river basin are mechanical, aeration pond, primary settlement, and septic tank. The treatment efficiencies have large differences ranging from about 90% for mechanical and aeration pond system to 40% for primary settlement and septic tank (DID 2007). The industrial estates release a major part of metal loads. It was estimated that the respective metal loads of 181.4 and 912 kg/day are from discharged mineral micropollutants (As, B, Cd, Cr, Cu, Hg, Ni, Pb, Sn, and Zn) and mineral pollutants (Fe and Mn), respectively, coming from 11 industrial estates. Hence, two estates (Rawang Integrated Industrial Estate and Kawasan Industri Bukit Beruntung) contribute 97% of total mineral micropollutants and 99% of total mineral pollutants in the basin. The total production of animal waste was estimated at 228 t/day of which 41% is from poultry, 36% from cattle, 19% from swine, and 4% from others (DID 2007). River sand mining is another source of pollution. This affects the increase of sedimentation and pollution downstream and also creates the degradation of the riverbed, riverbanks, and riparian vegetation and change of hydraulic profile. It was estimated that three locations of sand mining alone contributes about 33 t of SS/day (DID 2007).

In 2000, the DOE decided to regularly monitor the stream water quality of 16 stations located in the Selangor River system. This consists of nine stations along the Selangor River and seven stations in its tributaries. The parameters of BOD, NH_4^+, Fe, and SS monitoring at station 16, “Selangor River at the intake of SSP1,” during the period of 2000–2006 were reported to vary from year to year. The BOD values vary from 1 to 12 mg/L and tend to increase in the recent years. The highest BOD values were monitored in 2005 for the polluted tributaries, i.e., 30 mg/L in Sembah River and 46 mg/L in Kundang River. The NH_4^+ values range from 0.2 to 2.5 mg/L with an average value of 0.90 mg/L. The highest NH_4^+ values were measured in three tributaries, i.e., 3.2, 4.9, and 8.9 mg/L in Sembah, Kundang, and Garing rivers, respectively. The Fe values in the stream were reported to range from 0.6 to 6.1 mg/L. The SS values were to vary from 23 to 375 mg/L with an average value of 92 mg/L. The highest SS value of 3,810 mg/L in Kundang River was reported (DID 2007).

Scientifically founded plans of water resources use and conservation should be based on a balance approach to the assessment of available water supply sources and on the forecast of their interconnected change in the future in close association with the forecast of the whole economy and culture of the studied region (Green 1974). The first important role of WQES to assess the status of water degradation in the stream is to provide the decision support system (DSS) for the local authority in managing water quality. This status is commonly referred to as WQI. In spite of the difference in concept, the WQI was used to assess spatial and long temporal variations in water quality over the last 25 years in the Río Lerma Basin, Mexico (Sedeño-Díaz and López-López 2007) and to evaluate the quality of raw water for drinking purposes in the Netravathi River, Mangalore, South India (Avvannavar and Shrihari 2008). The second important role of WQES is to identify the suitability of water, referred to as WQA, for different uses and its ecosystem. This information is useful for water users to correctly allocate water in accordance with the available quality such as agriculture, fishery, livestock watering, etc., and for the local authority to set up priority programs in accordance with urgent requirements. The aim of this paper is limited to the use of the WQES to assess the WQI for Selangor River in Malaysia and to briefly evaluate the profile of certain water quality parameters along the river and the models which have occurred in the stream.

3 Methodology

3.1 WQI According to the WQES

The WQIs are intended to describe on one range of value, from 0 to 100, the water quality assessed by quality classes with the relationships that are: (1) WQI inferior to 20 corresponds to a red quality class, referred to as index 5; (2) WQI between 20 and 40 corresponds to an orange quality class, referred to as index 4; (3) WQI between 40 and 60 corresponds to a yellow quality class, referred to as index 3; (4) WQI between 60 and 80 corresponds to a green quality class, referred to as index 2; and (5) WQI over 80 corresponds to a blue quality class, referred to as index 1 (see Fig. 3) (Oudin et al. 1999 and Fulazzaky 2005).

Fig. 3 Classification of WQI

Index (range)	Class	Quality
1 (> 80 - 100)	blue	excellent
2 (> 60 - 80)	green	good
3 (> 40 - 60)	yellow	moderate
4 (> 20 - 40)	orange	bad
5 (0 - 20)	red	very bad

3.2 Models

To simplify the calculation of the indexes, models with two coefficients, i.e., α and β, have been selected. It has been necessary to use four different types of templates to reply to the different cases met with the physicochemical and bacteriological parameters regrouped in the 15 alterations studied. The four different types of templates are:

1. type 1, $L{=}\alpha C{+}\beta$ (linear model for intervals between two quality classes limits);
2. type 2, $L = \alpha C^{\beta}$ (increasing exponentially if $\beta{>}0$ or decreasing if $\beta{<}0$);
3. type 3, $L = 100 - -\alpha C^{\beta}$ (exponentially increasing or decreasing); and
4. type 4, $L = 100 - -\alpha\,(P - -C)^{3} - -\beta\,(P - -C)^{2}$

where L is the value of the indexes, C is the value of the parameter, and P is the pole value.

The illustration of all the situations which have occurred in the stream water is presented in Fig. 4, i.e., (1) the combination of increasing models of types 1, 2, and 3 (see Fig. 4a); (2) the combination of

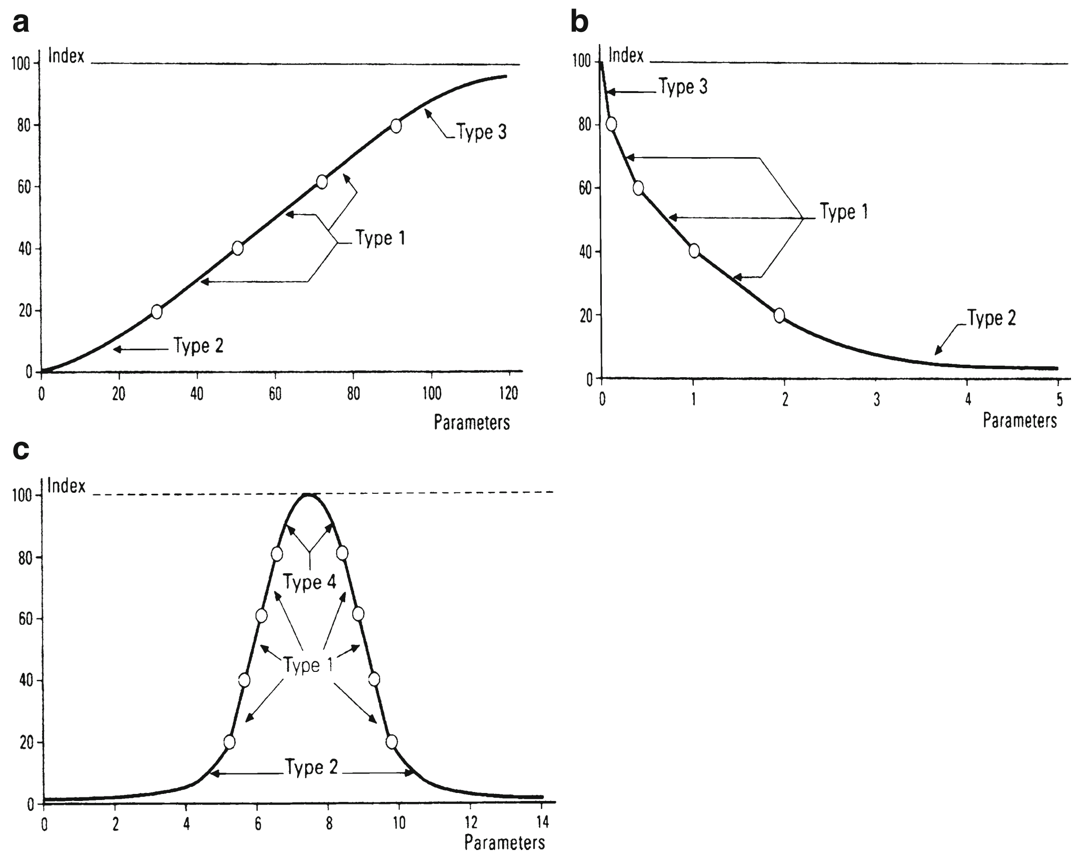

Fig. 4 **a**–**c** Illustration of all the situations which have occurred in the stream water (source: Oudin et al. 1999)

Table 1 Water quality parameters in accordance with their alteration

No.	Alteration	Parameters
1	Oxidized organic matter	O_2, $\%O_2$, COD, $KMnO_4$, BOD, DOC, NKJ, NH_4^+
2	Nitrogen matter	NH_4^+, NKJ, NO_2^-
3	Nitrates	NO_3^-
4	Phosphorus matter	PO_4^{3+}, P total
5	Suspended particles	SS, turbidity, transparency
6	Color	Color
7	Temperature	Temperature
8	Mineralization	Conductivity, salinity, hardness, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, K^+, Na^+, TAC
9	Acidification	pH, dissolved Al
10	Microorganisms	Total coliforms, fecal coliforms, fecal streptococci
11	Phytoplankton	ΔO_2, ΔpH, $\%O_2$, pH, chlorophyll a+pheopigments, algae
12	Mineral micropollutants in raw water	As, Hg, Cd, Cr total, Pb, Zn, Cu, Ni, Se, Ba, CN
13	Metals in bryophytes	As, Hg, Cd, Cr total, Pb, Zn, Cu, Ni
14	Pesticides in raw water	List of pesticides (see Oudin et al. 1999)
15	Organic micropollutants nonpesticides in raw water	List of organic micropollutants nonpesticides (see Oudin et al. 1999)

Source: Oudin et al. (1999)

decreasing models of types 1, 2, and 3 (see Fig. 4b); and (3) the combination of the type 4 model, the increasing models of types 1 and 2, and the decreasing models of types 1 and 2 (see Fig. 4c) (Oudin et al. 1999).

3.3 WQES Steps in Checking the WQI

Using the WQES, the following successive steps are used to check the WQI:

- grouping the parameters of water quality into 15 alterations that classify in accordance with their similar nature and its impact on the environment (see Table 1);
- defining the thresholds of each parameter for five classes with the respective colors of blue, green, yellow, orange, and red to express the excellent quality of unpolluted water, good water quality, moderate water quality, bad water quality, and unusable water quality of very polluted water, respectively (an example for oxidized organic matter is shown in Table 2);
- formulating the classes and WQI in accordance with the degradation of water quality that ranges from 0 to 20 for index 1, greater than 20 to 40 for

Table 2 Oxidized organic matter alteration to assess the WQI

Parameter	Unit	Thresholds for WQI classification				
		Index 1 80	Index 2 60	Index 3 40	Index 4 20	Index 5
DO	mg/L O_2	8	6	4	3	<3
Sat. O_2	$\%O_2$	90	70	50	30	<30
BOD	mg/L O_2	3	6	10	25	>25
COD	mg/L O_2	20	30	40	80	>80
PV	mg/L O_2	3	5	8	10	>10
DOC	mg/L C	5	7	10	12	>12
NH_4^+	mg/L NH_4	0.5	1.5	2.8	4	>4
NTK	mg/L N	1	2	4	6	>6

Source: Oudin et al. (1999)

DO dissolved oxygen, *BOD* biochemical oxygen demands, *COD* chemical oxygen demands, *PV* permanganate value, *DOC* dissolved organic carbons, *NH_4^+* ammonium, *NTK* nitrogen total Kjeldahl index 2, greater than 40 to 60 for index 3, greater than 60 to 80 for index 4, and greater than 80 to 100 for index 5 (see Fig. 3);

- assessing the value of each parameter and putting it into the respective WQI class to represent the water quality status of the related parameter;
- verifying the lowest quality of parameter(s) of each alteration and choice to represent the quality of the related alteration; and
- identifying the lowest quality of alteration(s) and choice to represent the WQI or the water quality status of the location monitored.

3.4 Classifying the Parameters to Alterations

Advanced water quality or ecologically based standards that integrate physical, chemical, and biological numeric criteria offer the potential to better understand, manage, protect, and restore water bodies (Magner and Brooks 2008). Hence, more parameters needed to evaluate more information will be provided. To assess the WQI classes, 151 water quality parameters are grouped into 15 alterations. The alteration classifies the parameters in accordance with their similar nature and its impact on the environment. The 15 alterations are (1) oxidized organic matter, (2) nitrogen matter, (3) nitrate, (4) phosphorous matter, (5) suspended particles, (6) color, (7) temperature, (8) mineralization, (9) acidification, (10) microorganisms, (11) phytoplankton, (12) mineral micropollutants in raw water, (13) metals in bryophytes, (14) pesticides in raw water, and (15) organic micropollutants non-pesticides in raw water (see Table 1) (Oudin et al. 1999).

3.5 WQI Classes in Accordance with the Water Quality Condition

3.5.1 WQI Assignment

The assignment of WQI to assess the water quality condition in the river expresses index 1, index 2, index 3, index 4, and index 5 (Fulazzaky 2005). Index 1 means the class of excellent quality of unpolluted stream water and represented by the color blue, index 2 means the class of good quality of stream water and represented by the color green, index 3 means the class of moderate quality of stream water and represented by the color yellow, index 4 means the class of bad quality of stream water and represented by the color orange, and index 5 means the class of unusable quality of very polluted water and represented by the color red (Oudin et al. 1999; Fulazzaky 2005).

3.5.2 Method to Define the WQI

Every parameter has thresholds for each class index (see example in Table 2). To evaluate the data of water quality, the selection of the lowest quality of the parameter(s) for each alteration to represent the WQI of the related alteration should be initiated, and then to identify the lowest quality of alteration(s), the WQI class of the river water at the monitoring location is enacted.

4 Data and Parameters used to Classify the WQI for the Selangor River

The interim national water quality standards (INWQS) consisting of 17 parameters is used as the water quality standards for the Selangor River. It compares the environmental quality standards for priority substances and certain other pollutants in Europe consisting of 33 micropollutants parameters already introduced as the standards for inland surface waters and other surface waters (see Annex 1, Directive 2008/105/EC). The INWQS distinguishes the quality of stream water by five classes. The key parameters of the standards are DO, BOD, COD, NH_4^+, SS, and pH (DOE 2003; ILBS 2005). To date, the equation developed to classify the quality of surface water in Malaysia including the Selangor River is based on six key parameters (DOE 2003; DID 2007; Shuhaimi-Othman et al. 2007; Sari and Wan Omar 2008). This approach is still not comprehensive enough to qualify the status of stream water.

The data that are used in this study to classify the WQI of the stream water were monitored by the Sungai Harmoni Sdn. Bhd. on November 20, 2007. Table 3 shows that the data monitoring used 27 parameters to evaluate nine stations along the Selangor River, which are: 01 Pertak Kuala Kubu Baru, 02 Selangor River before confluence with Kubu River, 04 Selangor River before confluence with Rening

Table 3 Application of WQES to assess the WQI in Selangor River

Alteration	Results of WQI analysis								
	01 i	02 i	04 i	06 i	08 i	10 i	12 i	14 i	16 i
Oxidized organic matter	2	2	2	2	3	3	3	3	2
Nitrogen matter	1	1	1	2	3	3	3	3	3
Nitrate	2	2	2	2	2	2	3	2	2
Phosphorous matter									
Suspended particles	2	2	4	4	5	5	5	5	5
Color									
Temperature									
Mineralization	1	1	1	1	1	1	1	1	1
Asidification	1	2	2	1	1	1	1	1	1
Microorganisms	3	5	5	5	5	5	5	5	5
Phytoplankton	1	1	1	1	1	1	1	1	1
Mineral micropollutants in raw water	1	1	1	1	3	3	3	4	4
Metals in bryophytes									
Pesticides in raw water									
Organic micropollutants nonpesticides in raw water									
WQI	3	5	5	5	5	5	5	5	5
Number of parameter analysis	27	27	27	27	27	27	27	27	27

01 Pertak Kuala Kubu Baru, *02* Selangor River before confluence with Kubu River, *04* Selangor River before confluence with Rening River, *06* Selangor River before confluence with Batang Kali River, *08* Selangor River before confluence with Kerling River, *10* Selangor River before confluence with Buloh River, 12 Selangor River before confluence with Sembah River, *14* Selangor River before confluence with Air Hitam River, *16* Selangor River at intake of the Sungai Selangor phase 1 (SSP1), *i* index

river, 06 Selangor River before confluence with Batang Kali River, 08 Selangor River before confluence with Kerling River, 10 Selangor River before confluence with Buloh River, 12 Selangor River before confluence with Sembah River, 14 Selangor River before confluence with Air Hitam River, and 16 Selangor River at the intake of SSP1. Because of the lack of data monitoring, six alterations, i.e., phosphorous matter, color, temperature, metals in bryophytes, pesticides in raw water, and organic micropollutants nonpesticides in raw water are not included in the evaluation in this study (see Table 3).

5 Assessment of Water Quality Status

To measure the flow rate and concentration of water quality parameters for the Selangor River and its tributaries as well as all the effluent entry of the main river, it is possible to propose the following equation to predict water quality for each monitoring station:

$$\mathrm{BOD} = \sum_{1}^{n} \frac{Q_\mathrm{e}\mathrm{BOD}_\mathrm{e} + Q_\mathrm{r}\mathrm{BOD}_\mathrm{r}}{Q_\mathrm{e} + Q_\mathrm{r}} - \mathrm{BOD}_\mathrm{p} \qquad (1)$$

where:

BOD is the BOD at the monitoring station (in milligrams per liter)

n is the number of effluent or tributary discharged to the main river (dimensionless)

BOD_e is the BOD in the effluent or tributary (in milligrams per liter)

BOD_r is the BOD in the main river (in milligrams per liter)

BOD_p is the BOD deduction due to the purification after mixing along the main river from the first effluent to the monitoring station (in milligrams per liter)

Q_e is the flow rate of the effluent or tributary (in cubic meters per second)

Q_r is the flow rate of the main river (in cubic meters per second).

A similar equation can be used to certain other parameters. This needs more measurement practically in the river system and is expensive. Hence, the direct monitoring of water quality at the stations is preferable. Besides this, the theoretical approach may be promoted as an alternative equation to predict the quality of stream water that is:

$$\mathrm{BOD} = \frac{\sum_{1}^{n}\left(\mathrm{LBOD_{ps}} - \mathrm{DBOD_{ps}}\right) + \sum_{1}^{m}\left(\mathrm{LBOD_{nps}} - \mathrm{DBOD_{nps}}\right)}{Q_{\mathrm{r}}} \tag{2}$$

where:

BOD	is the BOD at the monitoring station (in milligrams per liter)
n	is the number of point sources pollutant discharged to the river (dimensionless)
$\mathrm{LBOD_{ps}}$	is the BOD loads from the point sources pollutant (in kilograms per day)
$\mathrm{DBOD_{ps}}$	is the BOD loads deduction from the point sources to the monitoring station (in kilograms per day)
m	is the number of nonpoint sources pollutant discharged to the river (dimensionless)
$\mathrm{LBOD_{nps}}$	is the BOD loads from the nonpoint sources pollutant (in kilograms per day)
$\mathrm{DBOD_{nps}}$	is the BOD loads deduction from the nonpoint sources to the monitoring station (in kilograms per day)
Q_{r}	is the flow rate of the river at the monitoring station (in cubic meters per second).

To use Eq. 2, it is necessary to completely support the related data. A calibration can be made regularly by measuring the quality of water at the cited station.

The INWQS categorizes surface water in Malaysia into six classes that are classes I, IIA, IIB, III, IV, and V. Class I means water is acceptable to use for conservation of natural environment water supply I: practically no treatment and fishery I: very sensitive aquatic species; class IIA for water supply II: conventional treatment required and fishery II: sensitive aquatic species; class IIB for recreational use with body contact; class III for water supply III: extensive treatment required and fishery III: common, of economic value, and tolerant species livestock drinking; class IV for irrigation; and class V: water not provided for any uses. According to the INWQS, the status of Selangor River water may be categorized as: (1) the river segments upstream of station 01 classified as classes IIA and IIB defined by the worst parameter of total coliforms, (2) the river segments immediately downstream of station 01 until station 06 classified as class III defined by the worst parameters of *E. coli* and total coliforms, and (3) the river segments immediately downstream of station 08 until station 16 classified as class V defined by the worst parameters of *E. coli*, total coliforms, and turbidity.

5.1 WQI Analysis to Assess the Selangor River

The earlier study using a different WQI analysis approach observed that the main cause of deterioration in water quality for Netravathi River in Mangalore South India was due to the lack of proper sanitation, unprotected river sites, and high anthropogenic activities (Avvannavar and Shrihari 2008). The effects of disinfectant discharge, river dilution capability on a short spatial scale, and use of different endpoints are discussed in terms of river stretch quality (Mattei et al. 2006). Although the fecal streptococci may thus in certain cases provide a better estimate of the probable virus content in lightly contaminated water than the total coliforms and *E. coli* (Cohen and Shuval 1973), this study analyzes two latest indicators to assess the water quality status of Selangor River. The results of the WQI analysis conclude that the alterations of microorganisms represented by total coliforms and *E. coli* and suspended particles represented by turbidity are the principal pollutants affecting the degradation of water quality for the Selangor River, judging that index 5 for these alterations was verified. The increasing of SS from upstream to downstream affecting the increase of BOD is due to the suspended particles that trap organic matter, judging from the WQI classes of oxidized organic matter degradation from green to yellow (see Table 3).

A major part of microorganisms and suspended particles loading the river is suggested to originate from the animal waste and from the domestic wastewater especially the wet markets. Wastewater sometimes flows to the ponds, but more often discharges to the stream or seeps into the ground. It was reported that, in 2004, the productivity of poultry farms was RM 64 million; this reflects 41% of the total animal waste production (DID 2007). Although the closed poultry farms generate a low discharge of wastewater originally, the cleaning of cages and sheds of four to six times per year can produce the suspended particles and microorganisms finally discharged into the river. The open poultry farms discharge the pollutants to the river due to surface rain-off that drags the manure from the pens. Because poultry is the most important animal husbandry in the Selangor River basin, the pollutant from this activity loading the stream is more remarkable. This verifies that the microorganisms define the WQI in the river. The water quality status along the Selangor River is classified as unusable quality of polluted water, excluding upstream of station 01; judging from the WQI, the locations monitored from stations 02 to 16 are classified as index 5 (see Table 3). Furthermore, the other pollutant loads of point sources and nonpoint sources considerably affect the decrease of stream water quality. This is due to the pollutant loads of 10.5 t BOD/day remarkably discharged into the stream from the effluents of different activities, while the solid loads of 33 t SS/day are produced from three locations of sand mining. The degradation of water quality is justified by the immediate increase of suspended particles and oxidized organic matter from station 02 to station 08 (see Fig. 5a and c), judging the WQI classes of suspended particles alteration gradually change from green (index 2) for the stations 01 and 02 to orange (index 4) for stations 04 and 06 and red (index 5) for stations 08, 10, 12, 14, and 16 and

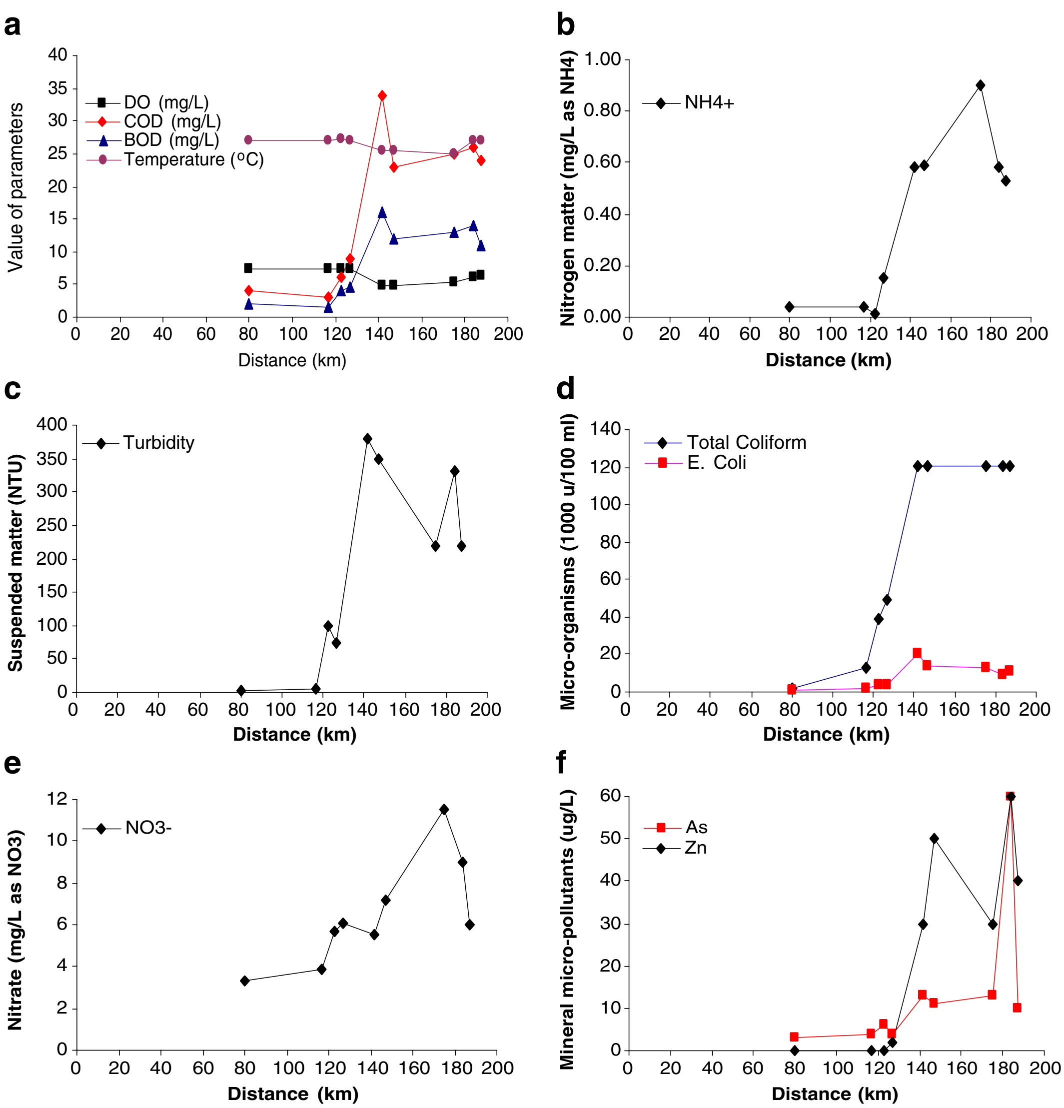

Fig. 5 **a**–**f** Evolution of certain water quality parameters along the Selangor River

the WQI classes of oxidized organic matter alteration change from green (index 2) for stations 01, 02, 04, and 06 to yellow (index 3) for stations 08, 10, 12, and 14 (see Table 3).

According to the results of the WQI analysis, to improve the water quality status for the Selangor River, this study recommends to facilitate firstly the WWTP for the poultry farms and the municipal WWTP to reduce the pollution loads from the wet markets for each city to the entire Selangor River basin area. Improvement of river water quality related to mineral micropollutants, including oxidized organic matter, envisages improvement of the industrial WWTPs to minimize the pollution loads from industry and mining activities correctly.

5.2 Water Quality Profile for the Selangor River

Because the Kuala Kubu wet market discharges the pollution loads of 54.4 kg BOD/day to the Kubu River, the pollution of the main stream (Selangor River) increases suddenly when the Selangor River confluences with the Kubu River, the parameters of COD, turbidity, total coliforms, and NO_3^-, as shown in Fig. 5, increase significantly from stations 02 to 04 (see Fig. 5a, c–e). In contrast, the tendency of DO is decreasing (see Fig. 5a). Since the Rasa wet market discharges the pollution loads of 14.8 kg BOD/day to the Rening River, the turbidity in the main stream decreases from stations 04 to 06 when the Selangor River confluences with the Rening River. This is due to the flow rate of Rening River with the low turbidity that penetrates the main stream (see Fig. 5c). It is about 30,000 layer chickens with the total of 210,000 broiler chickens concentrated in the region between stations 06 and 08. This contributes to the high loading of pollutants into the main river, the sharp slope for the parameters of COD, NH_4^+, turbidity, total coliforms, *E. coli*, As, and Zn was verified (see Fig. 5a–d, f). The decrease of turbidity from stations 10 to 12 is due to the clear water from Sungai Tinggi dam that penetrates the main stream when the Selangor River confluences with the Buloh River (see Fig. 5c). The shape of the water quality profile may explain the interaction amongst the water quality parameters. It is evident, as shown in Fig. 5a, c, d, that COD and total coliforms are proportionate to turbidity. We suggest that organic matter and micro-organisms in the river are captured by suspended solids. This is to consider the measurements of these parameters using unsettled water sample. The nitrification timely oxidizes NH_4^+ to NO_3^- because of the presence of O_2 in the river water, judging that NO_3^- increases later than NH_4^+ (see Fig. 5b, e).

The DO sag curve describes that oxygen deficit monitoring at stations 01, 02, 04, and 06 upstream along 50 km from the foothills of Fraser's hill was less than 7% and the critical point in the stream was verified at 62 km from the foothills with 33% of DO deficit monitored at station 08: Selangor River before it confluences with Kerling River. Due to the self-purification taking place 45 km downstream of station 08 that improves the quality of water, the increase of DO value up to 6.26 mg/L or about 20% of DO deficit was verified (see Fig. 6). While the DO values that were monitored at Batang Berjuntai barrage located downstream of station 16 slightly decreases

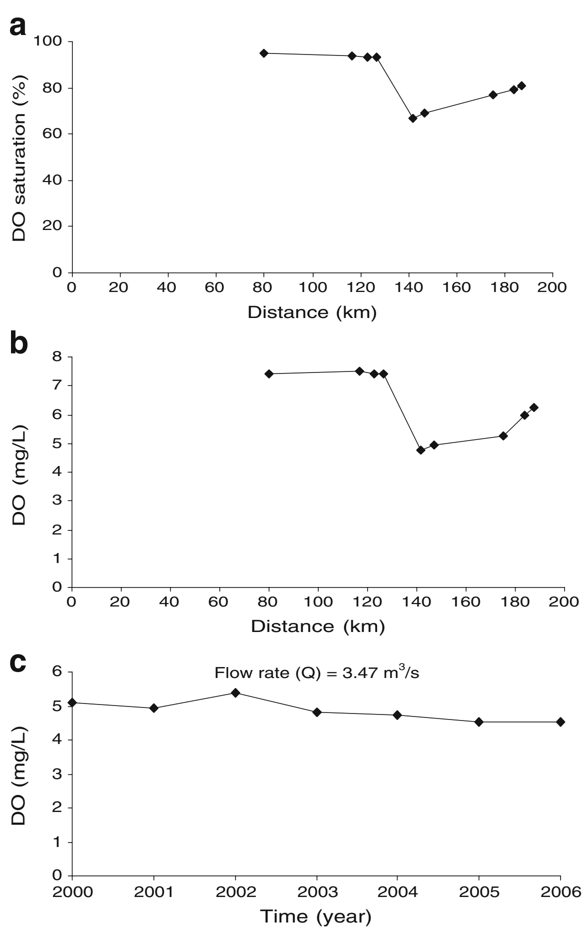

Fig. 6 **a**–**c** DO sag curve and O_2 evolution over time

from year to year (see Fig. 6c). The average annual flow rate of this location is 3.47 m^3/s. We suggest that the depletion of DO is due to the gradual increase of organic pollutants in the stream water. The curve shapes of BOD and COD similarly represent the evolution of oxidized organic matter along the river (see Fig. 5a). Water samplings of all the stations were completed on the same day, on November 20, 2007. The lowest water temperature of 25.0°C was observed at station 12 while the highest temperature of 27.2°C was at station 04 (see Fig. 5a). This is because solar radiation is different from the early morning to afternoon. Although the impact of temperature cannot be clearly explained from Fig. 5a, self-purification of stream water is normally influenced by temperature.

Although the arsenic concentrations in water storage ponds and stream sediments decrease as distance from the potential sources increase (Razo

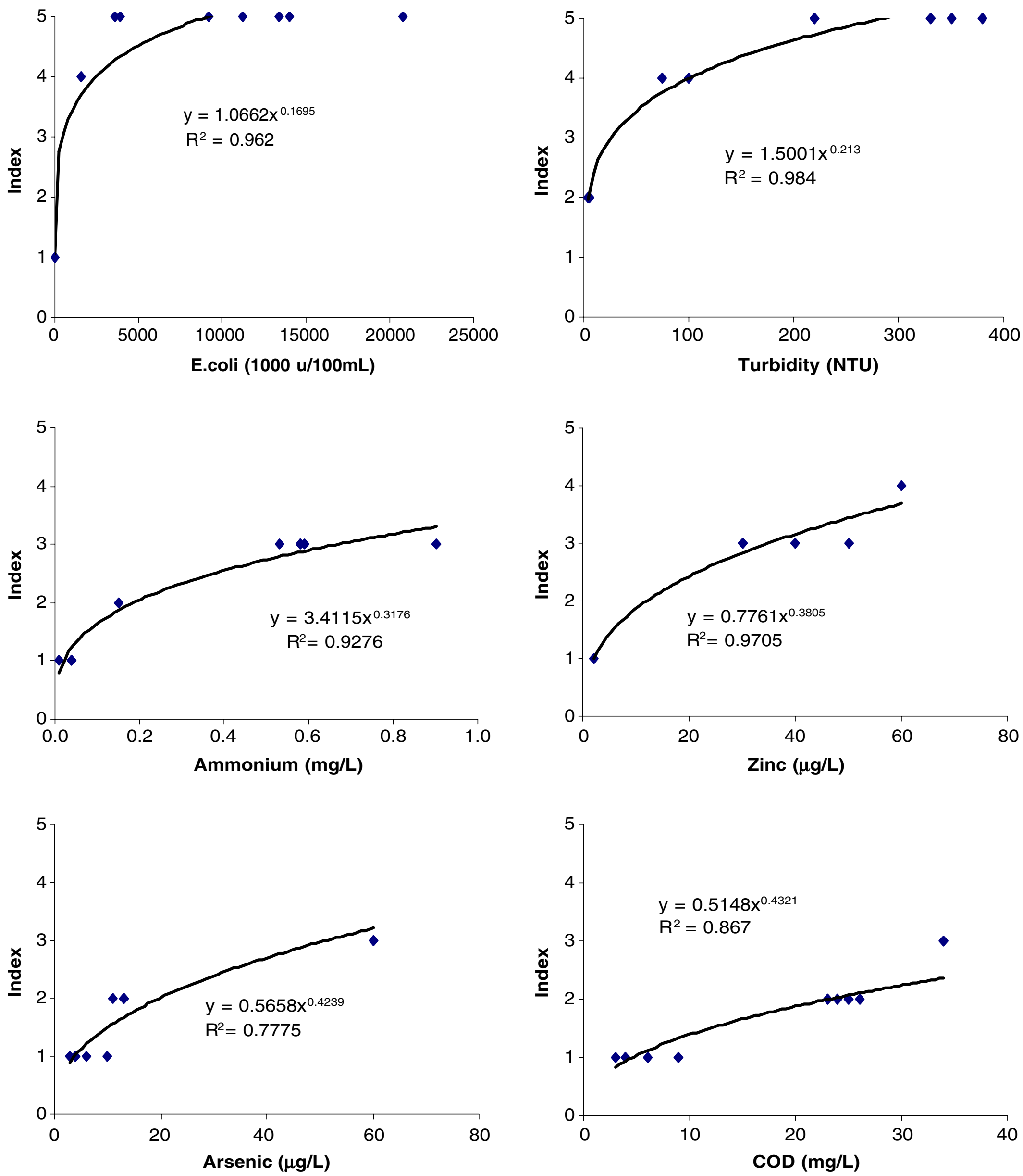

Fig. 7 **a**–**f** WQI models for certain parameters

et al. 2004), the trace element composition of stream sediments from catchments contaminated by past and present mining activities has been used to indicate the trace element status of associated waters (Aston et al. 1974). Some diatoms showed morphologically abnormal valves that may be related to the high level of metal pollution near the mining area Coval da Mó Portugal (Nunes et al. 2003). Any risks associated with high metal concentrations are, however, likely to be greatest in habitats such as arable and horticultural, improved grassland and built-up areas where soil metal concentrations are more frequently elevated. Metal distributions and risks explained by balance of sources and soil property effects on fate (Spurgeon et al. 2008). Regarding the content of As and Zn that tends to increase from upstream to downstream gradually (see Fig. 5f), this study urges detailed researches to identify the sources of metals pollution from industrial estates and mining activities correctly.

5.3 WQI Models for the Selangor River

To model the water quality status for the Selangor River, certain parameters were necessary to select from nine stations along the stream to have a minimal of three different WQI classes. According to the results of the WQI analysis, six parameters, i.e., *E. coli*, turbidity, ammonium, COD, zinc, and arsenic were possibly considered for modeling (see Fig. 7). All the models were developed in accordance with type 2, $L = \alpha C^{\beta}$, with $\beta > 0$. If we recognize that α is the WQI coefficient and β is the purifying factor, Table 4 shows that the status of water quality will improve with the increase of β. According to the models analysis, to handle the problems of pollution of the entire Selangor River, this study recommends prioritizing the improvement of water quality decrement from alterations of microorganisms, suspended particles, organic and nitrogen matter to mineral micropollutants successively (see Fig. 7a–f and Tables 1 and 4).

Table 4 The WQI coefficient, α, and the purifying factor, β, for certain parameters

Parameter	Unit	α	β	R^2
E. coli	1,000 U/ 100 mL	1.0662	0.1695	0.9620
Turbidity	NTU	1.5001	0.2130	0.9840
Ammonium	mg/L	3.4115	0.3176	0.9276
Zinc	µg/L	0.7761	0.3805	0.9705
Arsenic	µg/L	0.5658	0.4239	0.7775
COD	mg/L	0.5148	0.4321	0.8670

Since the locations of the animal husbandry are near the river, immediately downstream of station 01, the increase of microorganisms in the stream water was verified from stations 01 to 02 significantly, judging that the WQI model for *E. coli* increases suddenly from index 1 to index 4 (see Fig. 7a). To consider the total coliforms in the stream water, this confirms the increase of microorganisms immediately downstream of station 01 to station 02 from index 3 to index 5 (see Table 3). The WQIs of microorganisms' alteration categorize the class of unusable quality of polluted water along the river from station 02 to the estuary. Since the treatments of wastewater from animal husbandry are not engaged correctly, the animal waste of 228 t/day that enter the Selangor River basin area has the potential to affect the surface water, making it unusable water of high polluted WQI class.

6 Conclusion

This study used the WQES as a tool to assess the water quality status of Selangor River. The tool converts the water quality data into usable information which express the level of water quality degradation in Selangor River. To identify the types and sources of pollution, this provides the DSS for the local authorities in managing the river water quality to correctly envisage the priorities measures in accordance with the urgent requirements. The status of water quality expressed in terms of the WQI, which concluded that the stream water is of very bad quality due to high concentrations of microorganisms immediately downstream of station 02 and of suspended particles immediately downstream of station 06, was verified.

The main sources of pollution were defined as coming from poultry farms, wet market activities, and industrial wastewater. This study recommends to the government of Selangor state including all the stakeholders to envisage as first priority the problems of river pollution. This suggests the need to install the WWTP for the poultry farms and for each city of the entire the Selangor River basin catchment area to reduce the pollutants of micro-organisms and suspended particles. To improve the quality of water related to mineral micropollutants, there is a need to consider the surveillance of industries to implement the best practice of industrial WWTP effectively.

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