Water Quality Index Assessment for the Skudai Watershed and its Tributaries

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Abstract
It is very important to develop a rehabilitation plan for the watersheds that have been degraded because of increased development activities and high urbanization. Identifying the most vulnerable parts of a watershed is challenging and can be done if water quality in the river was determined in different sections from the upstream to the downstream of a watershed. In this study, we delineated the Skudai watershed into 25 sub-watersheds using ArcGIS technique. Later, we identified tributaries in each sub-watershed. The sub-watersheds were grouped into three main categories, i.e. natural, semi-urban, and urban sub-watersheds. Water quality samples were collected at different tributaries from all three categories of sub-watersheds. The paper presents water quality analysis results. The Skudai River (natural part) was classified into natural sub-watershed. The Senai and Kempas rivers were classified into sub-urban watersheds while Melana and Danga rivers were classified into urban watersheds. The water quality index (WQI) for the Skudai River (Natural) was 95.2 and falls in class I category, i.e. clean. The Senai River had WQI of 84.5 and Class II category, i.e. slightly polluted. However, Kempas River which was also in the sub-urban watershed had calculated WQI of 54.4, in Class III and polluted. Melana River had was also polluted river with WQI of 68.8 (Class III). The Danga River was also polluted river with WQI value as 55.2.

Keywords
Skudai watershed; rehabilitation of watershed; water quality; natural sub-watersheds; urban sub-watersheds; GIS

INTRODUCTION

Depending on 97% of surface water as water supply, Malaysia is considered blessed as it has abundant rainfall and vast river systems (Compendium of Environment Statistic, 2013). As the population is increasing, the demand for water is also increasing. More rivers will be used as source of water thus they need to be in acceptable quality. Although river water quality has been a topic that is always investigated by many researchers, in reality, the quality of rivers in this country is not improving. Finding out the quality of the river is not adequate in solving the problem. We should observe the problem holistically, for example, observing the whole watershed area not just the river itself so that we can find the source of problem and solve it in a more efficient manner. Furthermore, river water quality is closely related to the land use and human activities carried out in the vicinity of the river. In watershed management, with the limited source of funding, prioritization is a good approach which can help the decision makers to focus on the most vulnerable area first before the problem gets worse. Delineating a watershed into smaller parts brings advantages for the management purposes and gives us better understanding of the watershed as we manage to observe or to study the watershed in a more detailed way (Chung and Lee, 2009; Tripathi *et al*., 2003; and Stephen *et al*., 2014).

Water quality index (WQI) is used for determining the river water quality. Combining several important water quality parameters with their respective weights in one index makes it easier to analyse the condition of the rivers. However, the WQI used differs from one country to another as different conditions causes different important and contributing water quality parameters. In

Malaysia, we use the WQI derivation developed by the Department of Environment which consists of six parameters, i.e. biochemical oxygen demand (BOD), dissolved oxygen (DO), chemical oxygen demand (COD), suspended solids (SS), ammoniacal nitrogen (AN) and pH along with the respective weights obtained from experts (see Eq. 1). Aside from these parameters, there are also other water quality parameters that can be observed for rivers such as total phosphate, nitrate and temperature. Aweng *et al.* (2011), Cleophas *et al.* (2013) and Hossain *et al*. (2013) analysed water quality in their researches by using the Malaysian WQI derivation.

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

Water quality benchmark

Water quality benchmarks are the acceptable limits of water quality parameters based on the river usage which can help assessing the quality of water through comparisons. In its website for the Pesticide National Synthesis Project, the U.S. Geological Survey defined water quality benchmarks for pesticides as threshold values against which measured concentrations can be compared in assessing the effects of pesticides on water quality in a hydrologic system. U.S Environment Protection Agency has listed the water quality benchmarks based on the designated uses, whether it is for aquatic life or human health criteria. Malaysia through the National Water Quality Standard has also set the limits for the water quality parameters and these are based on the classes of river (Table 1).

Table 1. Water quality benchmark

	Unit	Classes				
		I	II	III	IV	V
Biochemical Oxygen Demand	mg/L	< 1	1-3	3-6	6-12	> 12
Chemical Oxygen Demand	mg/L	< 10	10-25	25-50	50-100	> 100
Dissolved Oxygen	mg/L	> 7	5-7	3-5	1-3	< 1
pH	-	> 7	6-7	5-6	< 5	< 5
Ammoniacal Nitrogen	mg/L	< 0.1	0.1-0.3	0.3-0.9	0.9-2.7	> 2.7
Suspended Solid	mg/L	< 25	25-50	50-150	150-300	> 300
Total Dissolved Solid	mg/L	< 500	1000	1000-4000	4000	>4000
Turbidity	NTU	5	50	>50	>50	>50
Conductivity	µS/cm	1000	1000	1000-6000	6000	>6000
Temperature	^{o}C	Normal + 2^{o}C				

Source: Water Environment Partnership in Asia (WEPA)

METHODOLOGY

Study area

The Skudai watershed consists of urban, semi-urban and natural areas and there are the Skudai River, Senai River, Melana River, Danga River and Kempas River in the watershed. Danga River and Kempas River are located in the urban sub-watershed areas and Senai River and Melana River are in sub-watersheds that are categorized as semi-urban. The natural part is represented by the Skudai River (natural).

River water sampling

The water samples from the selected locations were collected for laboratory tests and in-situ water quality parameters for the water samples were also carried out. The sample locations are shown in Figure 1. The equipment used was Horiba where in-situ parameters such as pH, temperature and dissolved oxygen. The samples were then sent to the laboratory for analysis using the APHA methods. Table 2 shows the details about the rivers and sub-watersheds in the Skudai watershed.

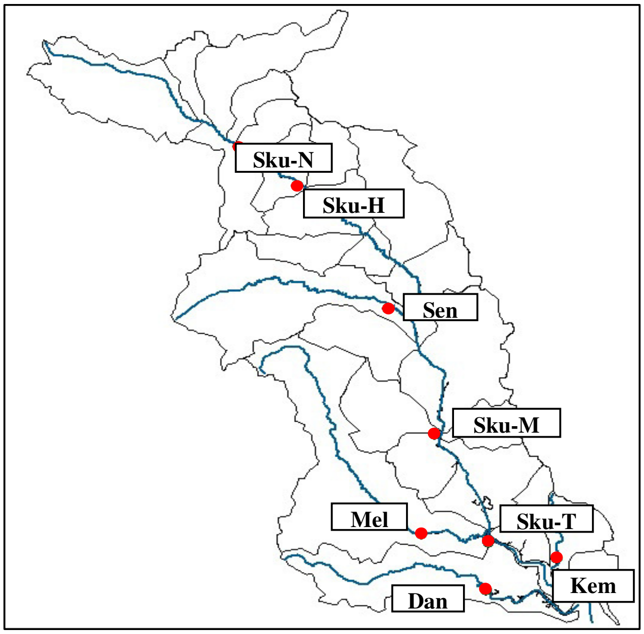

Figure 1: Sampling points in the Skudai Watershed

Table 2. Rivers and sub-watersheds in Skudai Watershed

River & River Code	Length (km)	Sub-watershed area (km^2)	Main Landuse (percent of total land use in the basin)
Skudai River- Natural (Sku-N)	46		
Skudai River- Head (Sku-H)	46		
Senai River (Sen)	15	33	Barren land (21%), Forest land (27%), Residential (27%)
Skudai River- Middle (Sku-M)	46		
Melana River (Mel)	20	47	Residential (29%), Transportations, communications and utilities (31%)
Skudai River- Tail (Sku-T)	46		
Kempas River (Kem)	7	8	Commercial and Services (23%), Residential (36%), Transportation, communications and utilities (30%)
Danga River (Dan)	17	27	Residential (39%), Transportations, communications and utilities (29%)

RESULTS AND DISCUSSION

Physical water quality parameters

The physical water quality parameters assessed in the Skudai watershed were temperature, conductivity, turbidity, total dissolved solids and suspended solid. Conductivity levels of the rivers in the Skudai watershed ranged between 74 to 444 μS/cm. Kempas River recorded the highest conductivity among all rivers in the watershed but according to the water quality benchmarks set by the National Water Quality Standard (NWQS), a water sample should be less than 1000 μS/cm thus conductivity is not a problem to these rivers. The temperature values were between 26.46 to 30.7 ^{o}C. The total dissolved solids readings recorded at all sampling points were in the range of 48 to 289 mg/L (Figure 2a) which mean that all rivers are in Class I according to the benchmark for TDS only. Figure 2b shows that the highest value of turbidity was recorded at the Skudai River (Tail) followed closely by the Senai River. Turbidity which measures the cloudiness of water is related to suspended solids. Figure 2c shows that the highest suspended solids in the Skudai watershed and was recorded at the Senai River and the lowest suspended solids was 29 mg/L for the Kempas River. Senai River falls in Class III and the Kempas River in Class II according to the TDS values. Among factors that contributed to suspended solids are soil erosion and urban runoff. High suspended solids value causes low water clarity which can affect the aquatic lives in the river. Based on the water quality results, the comparison between suspended solid and turbidity shows that when the suspended solid was high, the turbidity was also high. For example, the Kempas River with 29 mg/L value of SS (Figure 2d) had low turbidity value with only 48.4 mg/L and the Senai River with high value of SS recorded a relatively high value of turbidity.

Chemical water quality parameters

According to US EPA, the acceptable values of pH are between 6.5 and 8.0. Although four rivers in the Skudai watershed showed values of pH below the minimum acceptable standard, the values were not diverted far away except for the pH for the Senai River. In Malaysia, the alarming values of pH for any river water are below 5.0, where values below 5.0 are categorized in Class IV and V according to NWQS. Based on the pH values, all rivers in the Skudai watershed were considered acceptable for aquatic species as none of the rivers showed pH of less than 5.0. Figure 2f shows the level of ammoniacal nitrogen in all rivers in Skudai watershed. Three rivers, which are Kempas River, Danga River and Melana River showed ammoniacal nitrogen values exceeding the critical level that is more than 2.7 mg/L (Figure 2f). These rivers are in Class V. Ammoniacal nitrogen is contributed by various sources such as wastewater discharges and surface runoff. The high AN values in three rivers might be contributed by the wastewater discharges from the domestic, industrial and commercial areas surrounding those rivers.

The biochemical oxygen demand (BOD) values for the Melana, Kempas and Danga rivers were 3 mg/L, 24 mg/L and 4 mg/L, respectively while other rivers had undetected BOD values (i.e. less than 2 mg/L). Based on the level of BOD, Melana River was in Class II while the Danga River was in Class III. The Kempas River samples which contained 24 mg/L of BOD indicated that it was polluted with high amount of organic matter. Since the concentration of BOD was high and exceeded the limit of 12 mg/L, it was classified as Class V. The analysis of water samples for chemical oxygen demand (COD) identified that the Kempas River was highly polluted with organic matters (78 mg/L) and the Skudai River (Natural) was the least polluted one as it was in Class IV. Most rivers in the watershed were in Class III. Higher dissolved oxygen (DO) shows better water quality as there is more oxygen for aquatic lives in the river. Kempas River had only 3.44 mg/L value of DO. The DO value is generally affected by the several factors such as river flow, temperature and dissolved or suspended solids. The total solids (sum of dissolved solids and suspended solids) for the Kempas and the Danga rivers were high thus contributed to the low dissolved oxygen. The highest nitrate was recorded at the Skudai River (Middle) with 11.1 mg/L. The highest value for total phosphorus among all rivers was 2.5 mg/L at the Skudai River (tail). Although it is known that high levels of nitrate and total phosphorus bring negative impacts such as accelerating algae bloom and eutrophication and it has becoming a problem to the water quality in Malaysia, the benchmark value for these two have not been set by the National Water Quality Standard. The U.S. Environment Protection Agency suggests that water should not exceed 10 mg/L of nitrate and 0.1 mg/L of total phosphorus.

Water Quality Index (WQI)

Water quality index that has been used in Malaysia for assessing water quality contains six water quality parameters that have different weights which were obtained by the Department of Environment through expert opinions. Dissolved oxygen (DO) has the highest weight (0.22), followed by BOD (0.19). COD (0.16), AN (0.16), SS (0.16), pH (0.12). The sub-index values contributes overall WQI for a river.

Table 3 shows the WQI for all the studied rivers. The Skudai River (Natural), the Senai River and the Skudai River (head) were found as the clean rivers. Getting the WQI values from 0 to 59 makes a river classified as polluted river and in the Skudai Watershed, the Kempas River and the Danga River were in polluted class. The water quality index (WQI) for the Skudai River (Natural) was 95.2, in Class I. Senai River had the WQI of 84.5, in Class II. However, Kempas River which was also in the sub-urban watershed had WQI value of 54.4, i.e. Class III and polluted. The Melana River had the value of 68.8 for WQI, in Class III and slightly polluted and the WQI of Danga River was 55.2, in Class III and polluted. DO is not a problem to all rivers in the Skudai watershed except for the Danga River. High BOD concentration occurred in the Kempas River while other parameters was in the acceptable levels.

Table 3: Water Quality Data

Parameter	Sku-N	Sku-H	Sen	Sku-M	Mel	Sku-T	Kem	Dan
pH	6.36	6.5	5.77	6.41	6.82	6.31	6.99	6.79
DO (mg/L)	10.26	8.87	9.13	13.25	7.53	9.72	5.73	3.44
Conductivity (µS/cm)	121	157	74	133	202	155	444	416
TDS (mg/L)	79	102	48	86	131	100	289	271
Temperature (^{o}C)	27.38	28.06	26.46	27.52	28.42	28.42	30.03	30.7
Turbidity (NTU)	61.5	57.2	211.7	197.3	166	227.3	48.4	110.7
BOD (mg/L)	ND	ND	ND	ND	3	ND	24	4
COD (mg/L)	5	14	26	28	42	19	78	47
SS (mg/L)	33	34	144	97	76	114	29	40
AN (mg/L)	ND	1.3	0.1	1	4.8	1.6	7.2	7.2
TP (mg/L)	0.6	ND	0.3	ND	0.2	2.5	0.2	2.1
N (mg/L)	7.1	7.1	7.1	11.1	6.6	6.2	3.5	3.1
WQI	**95.2**	**84.4**	**84.5**	**79.1**	**68.8**	**78.8**	**54.5**	**55.2**
Class	**I**	**II**	**II**	**II**	**III**	**II**	**III**	**III**
River Status	**C***	**C**	**C**	**SP****	**SP**	**SP**	**P*****	**P**

*C for Clean; **SP for slightly polluted; ***Polluted

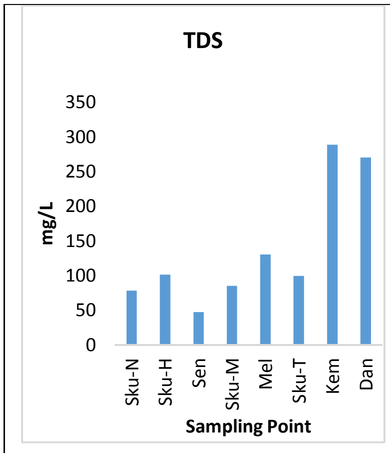

Figure 2(a): TDS values

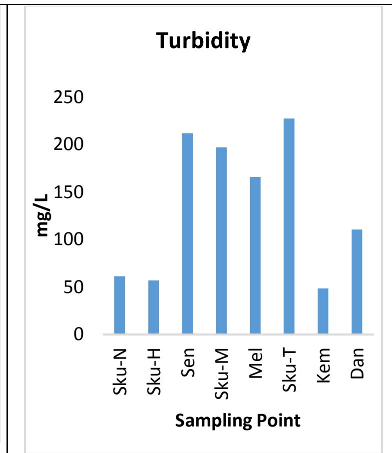

Figure 2(b): Turbidity values

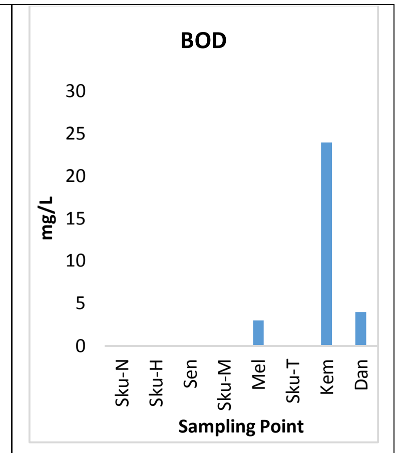

Figure 2(c): BOD values

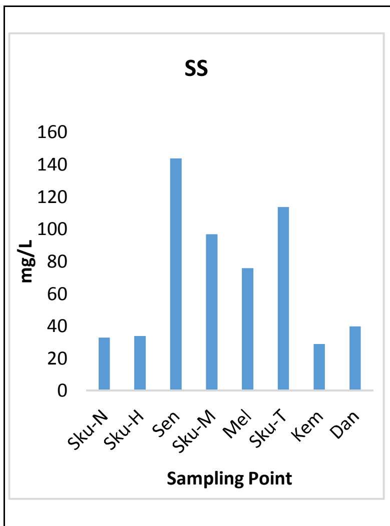

Figure 2(d): SS values

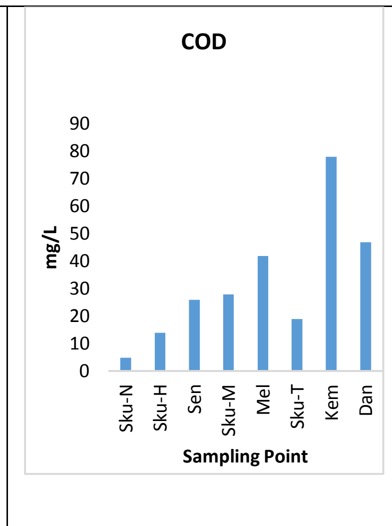

Figure 2(e): COD values

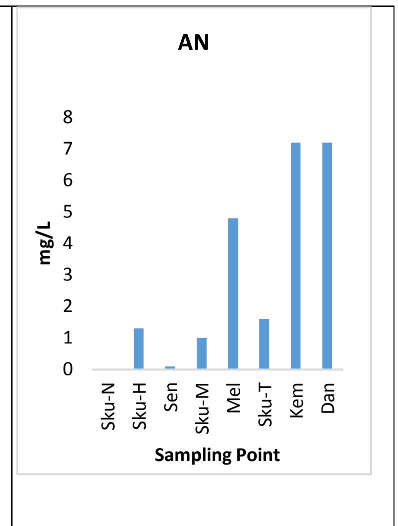

Figure 2(f): AN values

Conclusion

Assessing river water quality allows to know whether a river was clean or polluted. Having benchmark values is helpful for knowing whether pollutant concentration was still under the acceptable limits or had exceeded the limit. In the Skudai watershed, conductivity, temperature, total dissolved solids and pH were identified as non-problematic parameters since all values from these parameters were acceptable limits. All rivers in the watershed except the Skudai River (Natural) and the Senai River showed high values of ammoniacal nitrogen where mostly were in Class IV and V. The surrounding areas should be monitored since the analysis showed that with the higher values of ammoniacal nitrogen, industrial or residential that discharge wastewater to the river without proper treatment. High biochemical oxygen demand value was identified at the Kempas River thus the sub-watershed should be investigated for finding the source that contributed to high concentration of organic matters in the river. Analysis of water quality parameters and their comparison with the permissible limits helped us in knowing the parameters that have more influence on polluting river water. In Malaysia water quality benchmark, the benchmark values of total phosphorus and nitrate are not complete thus the comparisons of those parameters were not made in this study.

Water quality index (WQI) is a helpful tool for analysing water quality of the river since it shows the overall water quality by combining several water quality parameters. It is easier to see the water quality by having one value than having several values for several parameters. Therefore, the water quality parameters that are included in the WQI should be selected properly so that they can concisely represent the real water quality of a river. In Malaysian WQI, there are only six parameters included. The analysis of the rivers in the Skudai watershed showed that all parameters that are not included in the index did not show alarming values except for total phosphorus (TP) and nitrate (N). The Skudai River (Natural), the Skudai River (Head) and the Senai River that were classified as clean category from the calculated WQI values showed relatively high values of nitrate compared to other rivers. The Skudai River (Tail) was classified as slightly polluted river with the highest value of total phosphorus. Further research must be done by developing a new WQI derivation that may include total phosphorus and nitrate so that we can check whether the river class will be affected when we consider those parameters.

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