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Impairment of the water quality status in a tropical urban river

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ABSTRACT

The rapid development and urbanization within river catchments and along river corridors have created many problems, such as flooding and water pollution. The Penchala River Basin located in Petaling Jaya, Selangor, Malaysia, is noted as being under environmental stress due to several pollution sources, which has amplified the intention to assess the water quality. Six water quality parameters from four stations along the Penchala River were used for measurement, and the water quality index (WQI) was calculated. The average of the WQI values showed the water quality was Class I upstream, and it decreased to Class IV downstream. Land use and human activities in the basin contribute significantly to the downstream river water quality.

Keywords: Pollution; Tropical urban river; Water quality

1. Introduction

In Malaysia, more than 95% of the water supply is from rivers [1]. The morphology, fluid dynamics, and land use of most river basins have altered to fulfill various development needs. Over the past three–four decades, the country has developed very rapidly. All major cities and towns have undergone dramatic urbanization [2]. Urbanization is generally followed by an escalation of impervious surfaces and various discharges resulting from construction clearance and development. Therefore, the habitat and water quality of urban streams are deteriorating with the urbanization process.

The uncontrolled release of point and non-point sources of pollution continues to affect developing countries. Suspended solid loading is a result of impervious surface runoff and the basin's topography [3]. The consequences of urban river pollution in Malaysia may be contributed from irresponsibility and a lack of civilization among river basin stakeholders. River stretches become solid while liquid waste disposal sites and open wastewater sewers as well as other point and non-point sources along the river.

In 2011, the Department of Environment Malaysia (DOE) registered water pollution sources as

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comprising 77% sewage treatment plants, 14% animal farms, 5% agro-based industries, and 4% manufacturing industries, altogether contributing 1.4 million kg/d of load into the rivers [4]. Worldwide, two-thirds of the sewage from urban areas is pumped untreated into lakes, rivers, and coastal waters; in developing countries, this figure climbs to 90%. Asia is no exception; as a result, 40% of the global death toll due to unsafe or inadequate supply of water, sanitation, and hygiene occurs in Asia [3].

The water quality can be defined as a conventional ensemble of physical, biological, and bacteriological features that are expressed as values and allow for the framing in a certain category, which expresses the possibility of its anthropogenic usage to meet a certain purpose [5]. Therefore, the monitoring water quality is an important component of water resource conservation, management, and treatment [6–9]. It is practiced to understand and evaluate water availability and quality to control and minimize the incidence of pollutant-oriented problems as well as provide water of appropriate quality to various water practices such as urban water supply and irrigation [9–11].

Two major seasons can be recognized in the Malaysia, namely the southwest monsoon and northeast monsoon. The southwest monsoon is a dry season starting from May until September. The northeast monsoon is a wet season from November until March. April and October are considered as intermonsoon where the weather is quite unstable.

The water quality index (WQI) was developed to give criteria for river water classification based on the use of standard parameters for water characterization [12]. The WQI has been used to quantify the quality of surface water based on measuring parameters for water specification [13]. WQI is a mathematical instrument used to transform large quantities of water quality data into a single number to evaluate river water quality. The WQI contains unit-less, single-dimensional numbers between 0 and 100, with a higher index value representing good water quality. A numerical index is utilized as a management tool in water quality assessment. Many countries employ the WQI method to assess overall river status. These indices differ from country to country but share a similar concept, in that a few important parameters are selected and compounded to numerical rating for the evaluation of river water quality. The common parameters used are DO, pH, turbidity, TSS, nitrates, and phosphates [9,14].

River pollution is one of the most serious issues in Malaysia, with more than half the rivers polluted [9,15].

Sungai Penchala (Penchala River) is the shortest but most polluted tributary of the Klang River, passing through highly developed Kuala Lumpur–Selangor areas. Continuous monitoring has been carried out, but there have been no findings regarding the effectiveness of river management with the current land use. The analysis trend from the continuous monitoring from year 2005–2010 indicated that the WQI falls in Class IV category.

The Selangor state government is aiming for the WQI of Penchala River to achieve Class II by year 2015 [16]. In view of this problem statement, the objective of this research was to characterize the water quality of a tropical urban river by means of the WQI and to determine the effect of land use and human activities on the WQI.

2. Study area and methodology

2.1. Study area

Penchala River is one of the tributaries of the Klang River, which flows through south-western parts of Petaling Jaya city, in the district of Petaling, Selangor, Malaysia. It covers a catchment area of around 28 km^2 and is about 12 km long. The upper reach is mountainous and the lower section is characterized by low to undulating terrain. Fig. 1 shows the study area location.

The main land use within the river catchment is industrial and residential areas, constituting about two-thirds of the municipality's total land area. Nearly 70% of the Penchala River length has been concrete-lined as it passes through residential and industrial regions [17]. The upper area of the Penchala River Basin can be categorized as a recreational areas. The middle and downstream of the river basin consist of a combination of residential, commercial, and industrial areas. Fig. 1 shows the catchment of the Penchala River.

2.2. Methodology and data collection

2.2.1. Water quality data

Water quality monitoring is an essential component of water resource conservation, management, and treatment. The location selection for monitoring is a crucial aspect in the network construction for water quality monitoring. Currently, there is only water quality station located within the catchment. The water quality station is located near the downstream of the Penchala River (St. 14) as shown in Fig. 1. It is located at the downstream of the Penchala River in a

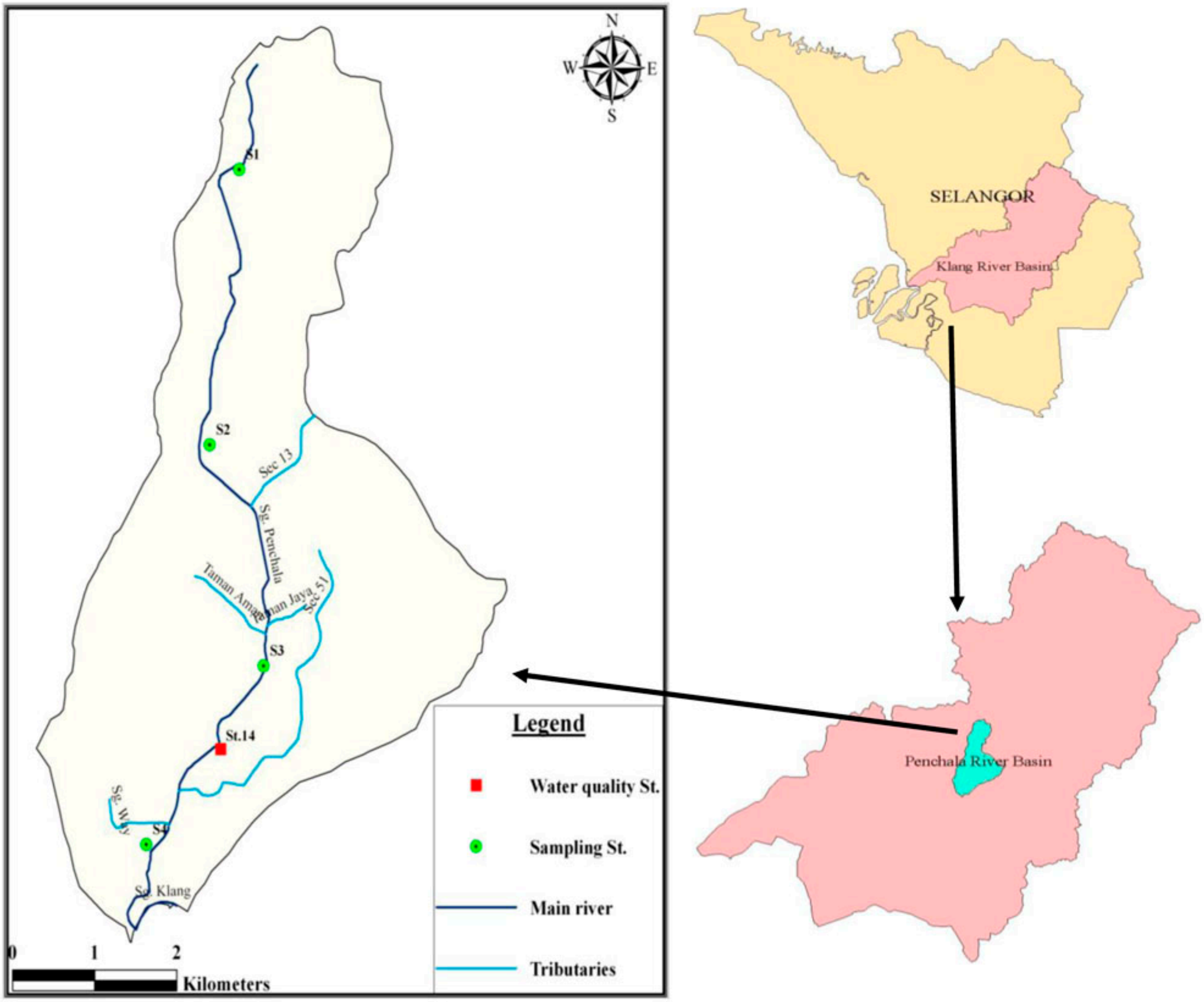

Fig. 1. The catchment of Penchala River with the locations of water quality station and sampling stations.

congested industrial area. Historical water quality data from this station will be used to determine the trend of the WQI in this catchment.

2.2.2. *Sampling data*

In order to assess the water quality of the river from upstream to downstream, four stations have been chosen along the Penchala River. Water samples were collected every two months started from August 2012 to August 2013 (i.e. seven samplings). Several parameters were measured at the station which includes pH and dissolved oxygen (DO) and temperature. Laboratory analyses were performed to determine the other parameters, that is, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solid (TSS), and ammoniacal nitrogen (AN).

2.2.3. *WQI calculations*

The WQI considers six parameters to evaluate the overall status of river water. The WQI consists of DO, BOD, COD, TSS, AN, and pH. DO is defined as the amount of oxygen dissolved in water when oxygen gas and water are mixed together. DO is one of the most important parameters for calculating WQI, since it is used to measure the amount of gaseous oxygen available in water for biochemical activity. BOD is another important water quality parameter, and it is defined as the total amount of gaseous oxygen removed from water biologically or chemically in a specific time and at a specific temperature. The index gives information about the total DO concentration required during the degradation and oxidation process of some organic compounds in water. COD is defined as the amount of organic matter that is prone to oxidation by a strong chemical oxidant [18]. COD is an essential parameter for measuring water quality and is useful to determine the amount of organic pollutants found in surface water or wastewater. Another essential parameter is TSS, which regularly consists of a large amount of suspended organic matter. These composites are discharged into the environment through different sources such as sewage treatment, agricultural activity, and waste ignition. AN is defined as the amount of ammonia and ammonium compounds. These compounds are transferred into the environment out of the different sources such as waste incineration, sewage treatment, cattle excrement, and car exhausts. Surface water requires a specified pH to protect aquatic life and control undesirable chemical reactions. WQI calculation is based on the above six parameters, as shown in Eq. (1). The largest portion is carried by the DO index with 0.22, and pH is the smallest portion contributing 0.12 in the equation. The WQI equation eventually comprises the sub-indices calculated according to the best-fit relationships given in Table 1.

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

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.

Based on the WQI value, the water quality can be categorized into five classes in regards to its suitability of use (Table 2). Class I water quality is considered safe for direct drinking, Class II requires treatment for drinking purposes and is safe for swimming, Class III calls for intensive treatment for drinking, Class IV is only suitable for plant and domestic animal uses, and Class V cannot be used for the purposes listed in Classes I–IV. The quality of the water can also be classified based on its level of pollution into three categories: Clean slightly polluted and polluted as shown in Table 3. Water quality categories are highly affected by varying characteristics in the surrounding areas.

3. Results and discussion

The annual WQI trend from the historical data (2005–2010) is summarized and shown in Fig. 2. The WQI trend shows that the Penchala River was Class IV from 2005 to 2010 according to the DOE WQI classification (Table 2). It can be seen from the figure that there is slight improvement of the WQI in 2006 before it deteriorates for 3 years and slightly improved again in 2010. The WQI is hovering around 41–49 which lies in Class IV according to Table 2 and is considered as polluted as given by Table 3. The results of this can also be linked to the land use of the Penchala River. As indicated by Fig. 4, urbanization and point sources are concentrated from the middle stream to downstream region. The increasing pollution sources, such as sewage treatment plants, agro-cultural activity, and

Table 1
Sub-index calculations

Sub-index parameter	Value	Conditions
SI_{DO}	0	DO < 8
	100	DO < 92
	$-0.395 + 0.030DO^2 - 0.00020DO^3$	8 < DO < 92
SI_{BOD}	100.4−4.23BOD	BOD < 5
	$108e^{-0.055BOD} - 0.1BOD$	BOD > 5
SI_{COD}	−1.33COD + 99.1	COD < 20
	$103e^{-0.0157COD} - 0.04COD$	COD > 20
SI_{AN}	100.5−105AN	AN < 0.3
	$94e^{-0.573AN} - 5\,\vert AN-2\vert$	0.3 < AN < 4
	0	AN > 4
SI_{SS}	$97.5e^{-0.00676SS} + 0.05SS$	SS < 100
	$71e^{-0.0016SS} - 0.015SS$	100 < SS < 1,000
	0	SS > 1,000
SI_{pH}	$17.2 - 17.2pH + 5.02pH^2$	pH < 5.5
	$-242 + 95.5pH - 6.67pH^2$	5.5 < pH < 7
	$-181 + 82.4pH - 6.05pH^2$	7 < pH < 8.75
	$536 - 77.0pH + 2.76pH^2$	pH > 8.75

Source: DOE, Malaysia.

Table 2
DOE WQI classification

Parameters	Unit	Classes				
		I	II	III	IV	V
WQI	Unit	>92.7	76.5–92.7	51.9–76.5	31.0–51.9	<31.0

Source: DOE, Malaysia.

Table 3
DOE water quality classification based on WQI

Index range	WQI value
Clean	81–100
Slightly polluted	60–80
Polluted	0–59

Source: DOE, Malaysia.

industrial waste, are the main contributors to the incremental pollutant load and consequent WQI reduction. According to statistics, pollutant load in the country increased dramatically from 18,724 to 1,393,528 kg/d from 2005 to 2011 [4,19].

In order to assess the current water quality status, water quality sampling was done from August 2012 to August 2013. Four stations have been selected as mentioned previously, and the results have been presented in Fig. 3 and Table 4. Table 4 shows the WQI values, average, maximum, and minimum of each station for a year. As the Penchala River is located in an urban area, the water quality varies from upstream to downstream according to land use. Fig. 3 shows the water quality trend and Fig. 4 shows the land use of the Penchala River catchment. It can be seen from Fig. 3 and Table 4 the WQI varies from Classes I to IV as the river travels from upstream to downstream area. In general, the WQI drops drastically from Class I at St. 1 to Classes III and IV at St. 2. Therefore, it continues to degrade to Class IV at St. 3 and St. 4.

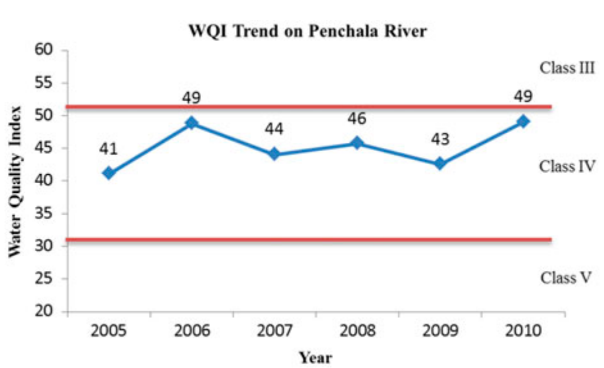

Fig. 2. Annual WQI trend year 2005–2010.
Source: DOE, Malaysia.

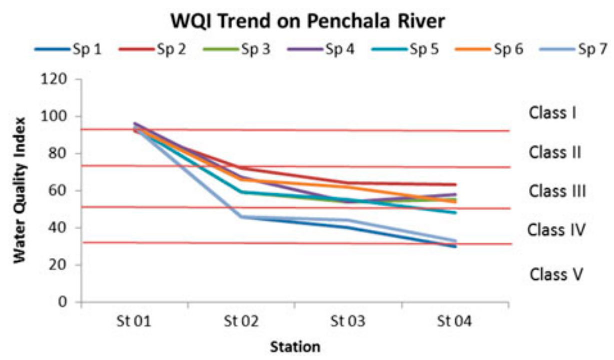

Fig. 3. WQI trend from August 2012 to August 2013.

The WQI values for the upstream river section (St. 1) indicate Class I, except in October 2012 where it is between Classes I and II. The average WQI value was 94 registered as Class I, the maximum WQI value was 96 (Class I), and the minimum WQI value was 92 (Class II) as presented in Table 4 for St. 1. The upstream section is located at the recreational area with not much activities as can be seen from the land use figure as given by Fig. 4. Station 1 was considered as clean water according to Table 3.

The WQI value changes drastically to Class III (51.9–76.5) toward the middle of the river (St. 2 and St. 3). However, for Sp 1 and Sp 7, WQI values decreased to Class IV with WQI values 46, 40, and 46, 44 for St. 2 and St. 3, respectively, as tabulated in

Table 4
WQI of Penchala River

WQI Month	Station 1	Station 2	Station 3	Station 4
Sp 1	94	46	40	30
Sp 2	92	72	64	63
Sp 3	94	59	54	55
Sp 4	96	67	54	58
Sp 5	94	59	55	48
Sp 6	94	66	62	54
Sp 7	94	46	44	33
Average	94	59	53	49
Maximum	96	72	64	63
Minimum	92	46	40	30

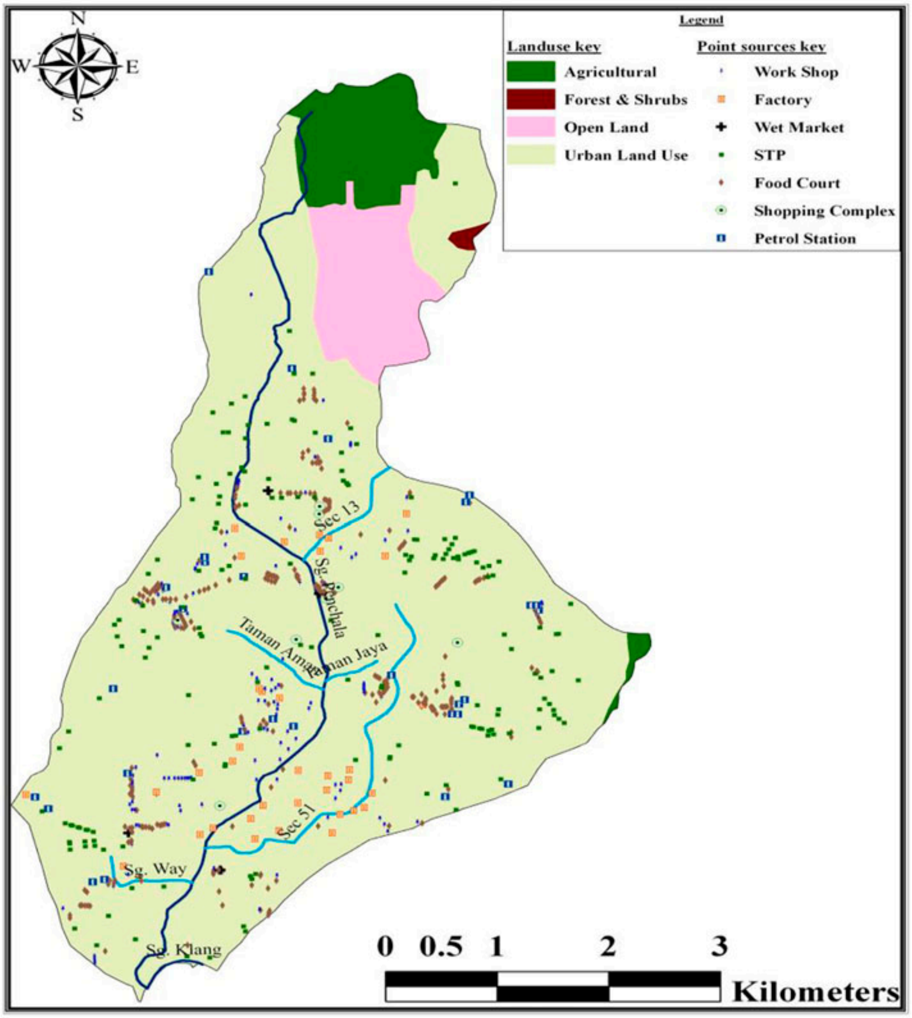

Fig. 4. The land use of Penchala River catchment.

Table 4. The degradation of the WQI for these samplings was perhaps due to the dry season. Meanwhile, for the downstream section, the WQI value at St. 4 was on average Class III except Sp 5, and Sp 7 where it degrades to Class IV with WQI readings 48 and 33. The WQI for Sp 1 was even worst at 30 which is Class V and categorized as polluted water. The degradation of the water quality from the middle stream to the downstream region is much affected by the land use and activities within this area. It can be seen from Fig. 4 that the urban area and the point sources are located from the middle to downstream region. The degradation of river water quality can be linked and are influenced by both natural and human activities along the Penchala River. The land use in geographic areas that river water resources is increasingly recognized as an important factor affecting water quality and, consequently, the health of human and ecological communities sustained [20].

From the results of this study, it can be concluded that the Penchala River is polluted, and its system contributes significantly to transport of pollutants to Klang River. Comparing the historical data (from 2005–2010) with the current data (2012–2013) at the downstream station, not much improvement can be seen. Station 14 on overage is registering Class IV, while the readings St. 4 indicates that WQI varies from Class III to Class IV according to the sampling months. The WQI reading is worst during the dry season.

4. Conclusions

This study has suggested that the human activities as well as the land use of the catchment do have some effect on the river water quality status and the WQI. It can be said that the different land use types and human activities do contribute to the degradation of river water quality. The upstream region is clean and registering Class I, however as the river travels downstream; the water quality degrades to Classes III and IV. In some cases, it further deteriorates to Class V. The findings have also been compared to the historical trend of the WQI, and it has shown not much improvement on the WQI can be seen at the downstream region. On overage it lies in Class IV, WQI value of 49, and is classified as polluted river.

It is also interesting to note that the water quality of the river is also affected by the different seasons. The WQI gives lower values during dry season especially in August and in certain case in April. August is the middle of the dry season, while April is in intermonsoon season.

Penchala River is still far from the targeted of a Class II river. Much needs to be done to improve the river's condition and to bring it to the targeted class. Continuous monitoring, proper planning, and control on human activities are needed to ensure that the river water quality would not degrade further. In addition, improvement efforts and policies as well as instilling people's awareness of the need to preserve and protect our rivers are urgently needed.

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List of abbreviations

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

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