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Integrated River Basin Management: incorporating the use of abandoned mining pool and implication on water quality status

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ABSTRACT

Exploring alternative water resource has been an option in an Integrated River Basin Management approach for Selangor River Basin, Malaysia. This includes the use of abandoned mining pool water as additional raw water resource to downstream water treatment plants. Monitoring of water quality along Selangor River was performed at selected locations within the river basin including active (sand mining) and abandoned mining pools to evaluate on current water quality status of the river for raw water supply. Measured variables were compared with the recommended acceptable value by the Ministry of Health (MOH) for guideline compliance. Generally, the abandoned mining pools were classified as Class II according to Water Quality Index sufficient to be used as alternative water resource in terms of water quality and have metal contents below the recommended acceptable values. The water intake point of the water treatment plant downstream the river basin indicated satisfactory water quality level and in compliance with the MOH guidelines despite partly sourced from the abandoned mining pool.

Keywords: Alternative water resource; Mine water; Integrated river basin management; Water quality index, water supply

1. Introduction

Integrated river basin management (IRBM) within Selangor River Basin ensures that natural resources of Malaysia are managed on a long-term sustainable basis using an integrated river basin approach to resource management. Among the aims are to ensure sufficient and clean water and to protect against flood. The Selangor River Basin is the most important water resource in the state of Selangor that provides over 60% of the water used in Klang Valley [1]. The demand for water is increasing fast with population growth and economic development. There is therefore,

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a need to increase supply from the river basin to cater for the increased demand. In securing sufficient raw water supply, the state is making effort towards protecting natural resources, making better use of existing resources and also seeking alternative water resources. This includes increasing emphasis on demand management, increasing the use of groundwater resources, making better use of surface water, restoring wetlands and exploring additional resources [2].

Under alternative water resources initiative, the state water authority is seeking potential use of suitable lakes, ponds, ex-mining ponds and groundwater to be developed as alternative water resources during water crisis or drought [3]. The aim is also to ensure clean water for water supply and for the environment generally by reducing pollution from existing sources and prevent pollution from new sources. Several sources of pollutions have been identified across the river basin such as domestic wastewater, e.g. public sewage treatment plant, individual septic tank and direct discharge, industrial wastewater, wet markets, and other urban wastewater, e.g. restaurants and food stalls, animal husbandry, freshwater aquaculture, soil erosion and sand mining [2]. The water quality at the main water intakes must be at Class II to ensure clean water (see Table 1 for definition of water quality classifications according to Water Quality Index (WQI) of National Water Quality Standards). The Selangor River Basin comprises 10 sub-basins of which two sub-basins under Class I, five sub-basins under Class II and three sub-basins under Class III.

The recent water crisis in the state of Selangor has prompted the state water authority to use water resource from the abandoned mining pool as an additional source of alternative raw water. Bestari Jaya which is the catchment area within Selangor River Basin has abundance of former mining pools; more than 20 abandoned mining pools. The state water authority has proposed that the water from selected abandoned mining pools (excess rainfall and stormwater) being pumped into the main river (Selangor River) as an alternative solution to provide sufficient supply of raw water to the water treatment plants (WTPs) within the catchment. The water authority has also proposed that the supply from abandoned mining pools to be developed on a larger scale alongside the river water, and also seeking the potential use of groundwater under a so-called hybrid-off river augmentation system (HORAS) project. HORAS is a combination of the off-river storage (ORS) and groundwater system to accumulate excess stormwater from Selangor River [1]. Apparently, this is in line with the IRBM approach that has been introduced almost a decade ago for the river basin. It is mainly to reduce large dependency on river water and the fact that the capacity of the existing reservoirs may not be sufficient to cater the demand at extreme occasions, e.g. during drought or dry weather period [4].

In this study, we would like to evaluate on the current water quality status of the main rivers within Bestari Jaya, especially after incorporation of the alternative raw water resource from the abandoned mining pools. The implication would be on the quality of water that is used for raw water supply to downstream WTPs. Apart from providing additional supply of water, the approach would be a good example of IRBM incorporating natural available resources.

2. Methods

2.1. Site description

Selangor River Basin has a catchment area of 2,200 km^2 which is about 28% of the state area. It is the third largest river basin after Langat River and Bernam River Basins. The Selangor River Basin emerges from the foothill of Fraser's Hill and traverses

Table 1
National water quality standards (NWQS) class definitions

Class	WQI range	Uses
I	>92.7	Conservation of natural environment; water supply 1-practically no treatment needed except for disinfection; fishery 1-very sensitive to aquatic species
IIA	76.5–92.5	Water supply II-conventional treatment needed; fishery II-sensitive aquatic species
IIB		Recreational use with body contact
III	51.9–76.5	Water supply III-extensive treatment needed; fishery III-common of economic value and tolerant species livestock drinking
IV	31–51.9	Irrigation
V	<31.0	None of the above

the north-east region of Selangor for 110 km until the coast. The main tributaries with the river basin are Sembah River, Kanching River, Kerling River, Rawang River and Tinggi River. The river basin has 10 sub-basins, Tanjung Karang, Rawang, Kuala Selangor, Sg. Tinggi, Rantau Panjang, Hulu Selangor, Hulu Rening, Sg. Batang Kali, Kuala Kubu and Kerling sub-basins (Fig. 1). Fifty-seven per cent of the river basin is still covered by natural forest, 22% is used for agricultural activities, 17% development areas and 4% water. The basin is also rich in natural and ecological systems and is known for world-renowned firefly colony at the lower stretches of the river. Selangor River and its tributaries are the main source of raw water to several WTPs within the river basin. The streams receive relatively high flow of water, i.e. average of 20 m^3/d (Department of irrigation and drainage) and experience only little variations in water flow year-round. The treatment plants include Batang Kali Water Treatment Plant, Rasa Water Treatment Plant, Rantau Panjang Water Treatment Plant and Selangor River Water Supply Scheme. The Selangor River Water Supply Scheme is the largest water supply scheme currently in Malaysia which is developed in three phases (SSP1, SSP2 and SSP3). The total nominal capacity is 2,700 million litres per day (MLD) which is about 60% of the total water demand in Klang Valley. Bestari Jaya is a former tin mining catchment and has a total of about 442 ex-mining lakes and ponds of different sizes [5]. These lakes and ponds are the results of dredging operations and other methods of tin mining over 30 years ago [6]. On the upper catchment, there are two supplying reservoirs, i.e. Sg. Selangor Dam and Sg. Tinggi Dam. The HORAS project includes two phases: the first phase is expected to supply 600–700 MLD of water, and phase two will be able to supply 3,000–5,000 MLD by 2020 [1]. During the period of this study, phase one has been in operation (S9 and S10 in Fig. 2) as to cope with increasing water demand in the state, but the main pond (S11) is still undergoing the construction works to complete the phase.

2.2. Sampling

Sampling of water was carried out at 16 locations as shown in Fig. 2. The water sampling was undertaken at the HORAS project sites (abandoned mining pools, S9 and S11), another ex-mining pool (S4), at an active sand mining pool (site of active mining, S1, S2, S3) and water sampling at the rivers (S5, S6, S6, S7, S8, S10, S12, 13, 14, S15). Note that S15 is the point before the raw water intake to WTPs (SSP1, SSP2 and SSP3). The sampling was performed three times (i.e. between June and August 2013, on the same occasion in 2014 and between March and April 2015, and the mean values of the data are reported.

Water samples were basically collected for the determination of WQI that requires measurements of biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), ammoniacal nitrogen (NH_3-N), pH and dissolved oxygen (DO). In addition to these variables, on-site measurements of electrical conductivity, redox potential (Eh), total dissolved solids (TDS) and temperature were also taken using a calibrated Myron L Ultrameter 6P. DO was measured using a calibrated YS 52 DO metre. Alkalinity was measured in the field by a two-step titration method against sulphuric acid with phenolpthalein

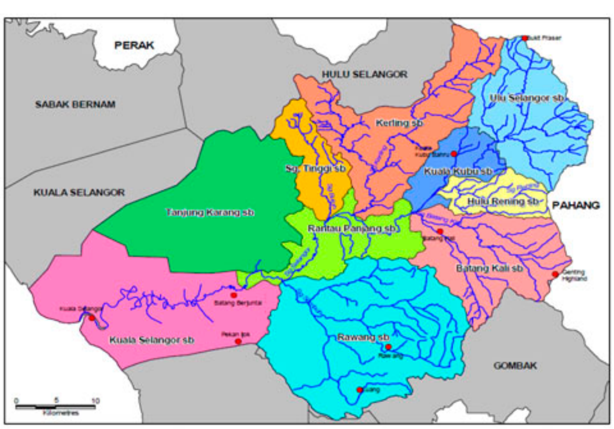

Fig. 1. Selangor River Basin and its sub-basins (source: Selangor waters management authority, Dialog WEPA, 2008).

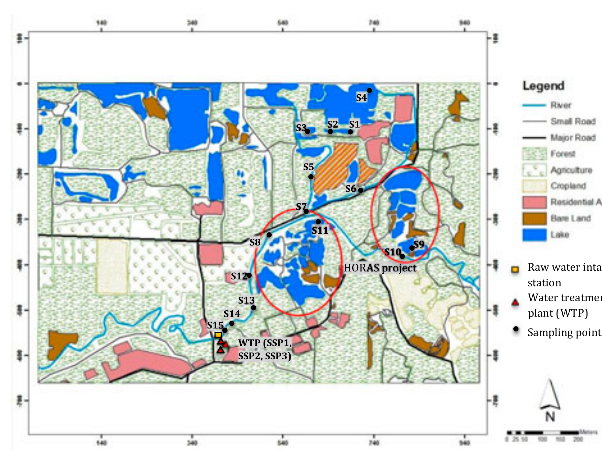

Fig. 2. Map of sampling locations in Bestari Jaya, Selangor River Basin (Rantau Panjang sub-basin).

Table 2
Status of dams in Selangor River Basin

Dam	Year completed	Height (m)	Catchment area (km^2)	Capacity (million litre)	Maximum level (m)	Current water storage (%)
Sg. Tinggi	1995	40	40	103	59.5	85
Sg. Selangor	2011	110	197	235	220.0	75

and bromcresol green-methyl red indicators using a HACH alkalinity kit (AL-AP). Turbidity was measured using an Orion Aquafast turbidity metre. Laboratory analysis of BOD, COD, TSS and NH_3-N and the sample preservation were carried out according to APHA Standard Methods for the examination of water and wastewater [7].

Samples for trace metal analysis were collected in pre-washed (soaked overnight in 10% by volume nitric acid (HNO_3), washed three times with tap water, then three times with 18.2 Ω MilliQ deionised water) polypropylene bottles. The water samples were collected in 125 mL bottles; acidified with 1% by volume concentrated HNO_3 for total cations and metal analysis, and unacidified samples for anions analysis. All samples were kept cool at 4˚C prior to analysis and analysed within 1 week of sampling [7]. Trace metals (Fe, Mn, Zn, Cu, Pb and Zn) were analysed using a Varian Vista MPX Inductively Coupled Plasma—Optical Emission Spectrometer (ICP-OES). Reliability of sample analyses was tested by charge balance calculations. An electro-neutrality within ±5% was considered to be of suitable accuracy but up to ±10% is acceptable [8].

3. Results and discussion

3.1. Raw water resource scenario in Selangor River Basin

As noted earlier, Selangor River Basin supplies more than 60% of the water demand for the state of Selangor and Federal Territory (Kuala Lumpur and Putrajaya), i.e. Klang Valley. Table 2 shows the status of the two dams within the river basin, i.e. Sg. Tinggi Dam and Sg. Selangor Dam that currently holds 85 and 75% of water storage, respectively. Downstream

Table 3
Designed and distributable capacity of water treatment plants (WTPs) in Selangor River Basin

Water treatment plant	Designed capacity (MLD)	Distributable capacity (MLD)	Mitigation project	Additional capacity (MLD)
Kuala Kubu Bharu	6.7	6.7		
Batang Kali	20.3	20.3		
Sg. Rangkap	9.0	9.0		
Rantau Panjang	31.5	31.5		
[a]Sg. Rasa[b]	250.0	150.0	Capacity redistribution	100
[a]Sg. Selangor SSP1[b]	950.0	800.0	Intake refurbishment	100
			Plant upgrading-capacity redistribution	50
[a]Sg. Selangor SSP2[c]	950.0	965.0		
[a]Sg. Selangor SSP3[b]	800.0	700.0	Capacity redistribution	120
Alternative resource				
HORAS	3,000	–	–	3,000[d]

Source: SPAN (Suruhanjaya Perkhidmatan Air Negara) & LUAS (Lembaga Urus Air Selangor).
[a]Major water treatment plant.
[b]WTP operating below the designed capacity.
[c]WTP operating above the designed capacity (overloading).
[d]Predicted capacity by 2020.

Table 4
Mean water quality data in active mining pools, ex-mining pools and rivers

Location	pH	Temp. (°C)	TDS (mg/L)	TSS (mg/L)	Cond. (μS/cm)	Alkalinity (mg/L as $CaCO_3$)	Turbidity (NTU)	DO (mg/L)	BOD (mg/L)	COD (mg/L)	NH_3-N (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Pb (mg/L)	Zn (mg/L)
S1-Mining pond (first discharge)	3.7	31.5	187	102	292	0	159.6	3.5	0.9	20	0.11	0.013	11.27	0.727	0.034	0.360
S2-Mining pond (seconnd discharge)	3.29	31.7	215	63	334	0	3.7	3.9	1.0	17	0.07	0.003	0.875	0.647	0.027	0.239
S3-Mining pond (final discharge)	3.16	33.9	298	34	456	0	1.4	4.5	0.6	14	0.03	<0.001	1.021	0.735	0.036	0.294
S4-Ex-mining pond	6.9	27.8	74	32	117	16	571.0	6.2	0.5	9	0.01	0.004	0.091	0.039	0.019	0.013
S5-Stream A	6.13	32.5	115	47	183	25	1.2	6.3	1.1	18	0.15	<0.001	0.103	0.125	0.006	0.056
S6-Stream B	6.98	30.2	86	26	136	38	25.1	6.4	0.5	10	0.06	0.002	0.076	0.325	0.006	0.019
S7-Confluence of stream A and Selangor river	7.17	31.8	85	31	136	23	32.7	6.2	0.7	7	0.00	0.003	0.108	0.318	0.008	0.048
S8-Selangor river	7.01	29.7	44	20	70	31	187.7	5.5	<0.1	9	0.03	0.004	0.098	0.095	0.008	0.017
S9-Hang tuah pond (ex-mining pond)	6.12	34.4	41	28	67	17	31.3	6.1	0.6	12	0.05	<0.001	0.079	0.165	<0.001	0.087
S10-Hang tuah pond to Selangor river	6.54	33.7	41	27	65	34	24.6	6.6	0.6	16	0.08	<0.001	0.066	0.143	0.001	0.042
S11-Horas pond (ex-mining pond)	6.6	35.7	177	65	280	68	73.1	6.3	1.0	11	0.03	<0.001	0.006	0.405	<0.001	0.025
S12-Selangor river	6.15	27	39	29	41	9.2	26	4.9	0.9	8	0.00	0.019	0.98	0.088	0.002	0.051
S13-confluence of Sembah river and Selangor river	6.10	28	115	86	193	30.7	33	3.5	5.9	17	0.02	0.02	1.49	0.217	0.004	0.146
S14-confluence of air hitam river and Selangor river	6.26	27.7	84	52	67	10	80	4.7	1.1	47	0.18	0.022	4.10	0.232	0.004	0.109
S15-upstream of water intake station	6.09	31.4	71	40	73	12	28	4.3	1.8	26	0.01	0.018	0.98	0.123	0.003	0.091
MOH (2009) (untreated raw water)	5.5–9.0	[b]	1,500	[b]	[b]	[b]	1,000	[b]	6	10	1.5	1.00	1.00	0.20	0.10	5.00
MOH (2009) (treated water)	6.5–9.0	[b]	100	[b]	[b]	[b]	5	[b]	[b]	[b]	1.5	1.00	0.30	0.10	0.05	5.00
WHO (2009) and USEPA (2009)	6.8–9.2	[b]	500	[b]	[b]	[b]	5	[b]	[b]	[b]	[b]	1.00	0.30	0.05	0.05	5.00
EU drinking water standards (EU directive 98/83/EC	6.5–9.5	[b]	[b]	[b]	2,500	[b]	[b]	[b]	[b]	[b]	[b]	2.00	0.25	0.05	0.01	[b]

[a]Data presented are mean data for all variables.
[b]not specified.

of these dams, water is supplied to several WTPs, Sg. Rasa WTP and Sg. Selangor WTPs (SSP1, SSP2, SSP3) being the major WTPs in the river basin (Table 3). The Sg. Rasa WTP, SSP1 and SSP3 are currently operating at a capacity below the designed capacity. SSP2 is operating at 2% above the designed capacity. Efforts have been made upon improving the water resource services for the catchment areas through a series of mitigation projects including water intake refurbishment, plant upgrading and capacity redistribution [9]. With these projects in place, additional supply capacity has been secured by about 6–17%. However, pollution cases in some occasions have become a risk to secure raw water production, e.g. pollution associated with high ammonia level, leachate and industrial discharge containing some metal compounds [10]. This has sometimes resulted in immediate shutdown of plant operation whenever final treated water requirements are not met, often due to inability of the plant to treat the contaminants.

Additionally, alternative water resource development has also been initiated by introducing the hybrid off-river augmentation system (HORAS). The aim is to increase the production yield up to 3,000 MLD and is undertaken by phases (phase 1 and phase 2). These alternative ponds also serve to reduce the risk of downstream flooding and to store residual flow within Bestari Jaya. Phase 1 has already started during the course of this study (HORAS 600) that includes development of filter ponds and a so-called reservoir (main pond) (Fig. 2) capable of supplying additional 600–700 MLD of water when completed. The main pond was not yet operational and is still undergoing construction. The project also aims to reduce huge reliance on the release of dam water and surface water, and can also act as emergency storage in case of water shortages.

3.2. Water Quality

Securing water quality is essentially important to ensure sufficient raw water supply to the WTPs [11]. The mean data of the water quality variables measured at specified locations along Selangor River are presented in Table 4. Notably, the water quality data are variable on site-by-site basis. The data can be categorised as active mining sites (S1, S2, S3), ex-mining sites (S4, S9, S11) and streams/rivers (S5, S6, S7, S8, S10, S12, 13, 14, S15). Apparently, pH of active mining pools is greatly different from the ex-mining pools and the rivers (differences are significant, $p < 0.01$). TDS and conductivity also indicate significant differences between the active mining pools and the ex-mining pools and the rivers ($p < 0.01$). Extremely Low pH at the active sand mining sites is indicative of the highly acidic water coupled with high ion contents

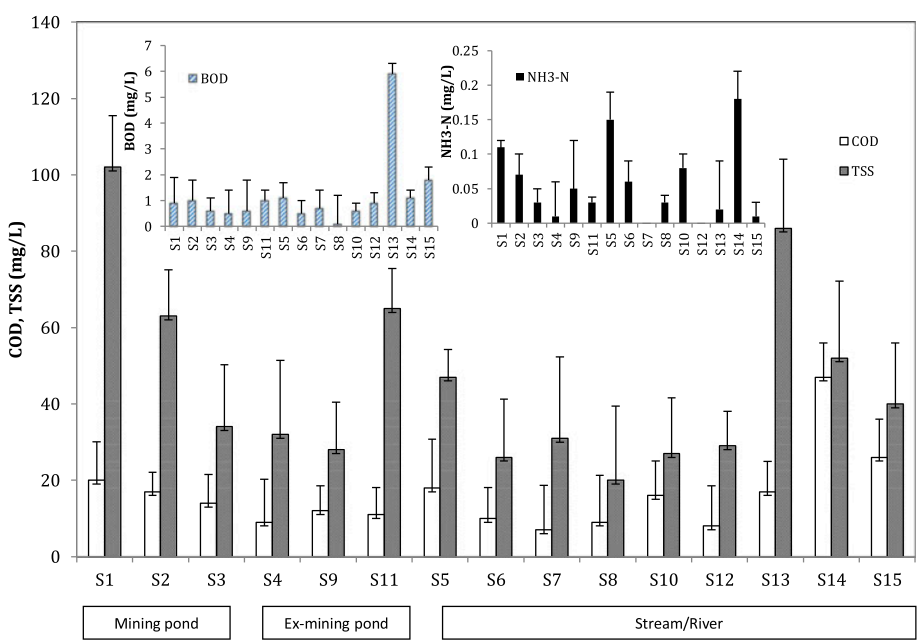

Fig. 3. Mean values of organic constituents (TSS, BOD, COD) and NH_3-N content in the mining ponds, ex-mining ponds and in the rivers.

Table 5
Correlation coefficients of the water quality variables

	pH	Temp.	TDS	TSS	Cond.	Alkalinity	Turbidity	DO	BOD	COD	NH_3-N	Cu	Fe	Mn	Pb	Zn
pH	1.000															
Temp.	−0.235	1.000														
TDS	−0.818[a]	0.384[a]	1.000													
TSS	−0.477[a]	−0.008	0.481[a]	1.000												
Cond	−0.787[a]	0.425[a]	0.987[a]	0.480[a]	1.000											
Alk	0.644[a]	0.300[b]	−0.241[b]	−0.089	−0.173	1.000										
Turb	0.230[b]	−0.381[a]	−0.176	−0.054	−0.154	−0.036	1.000									
DO	0.673[a]	0.320[a]	−0.442[a]	−0.661	−0.384[a]	0.594[a]	0.153	1.000								
BOD	−0.009	−0.295[b]	0.044	0.552[a]	0.062	0.093	−0.188	−0.521	1.000							
COD	−0.165	−0.205	0.042	0.321[a]	−0.091	−0.298[b]	−0.152	−0.397[a]	0.179	1.000						
NH_3-N	−0.188	0.031	0.091	0.296[b]	0.030	−0.152	−0.169	−0.042	−0.120	0.705[a]	1.000					
Cu	−0.004	−0.678[a]	−0.204	0.386[a]	−0.299[b]	−0.318[a]	−0.049	−0.658[a]	0.543[a]	0.584[a]	0.087	1.000				
Fe	−0.485[a]	−0.136	0.287[b]	0.710[a]	0.245[b]	−0.436[a]	0.083	−0.596[a]	0.060	0.415[a]	0.430[a]	0.438[a]	1.000			
Mn	−0.834[a]	0.387[a]	0.893[a]	0.518[a]	0.882[a]	−0.317[a]	−0.263[b]	−0.477[a]	−0.075	0.047	0.141	−0.170	0.506[a]	1.000		
Pb	−0.825[a]	0.081	0.776[a]	0.347[a]	0.772[a]	−0.614[a]	0.219[b]	−0.484[a]	−0.182	−0.042	0.058	−0.166	0.497[a]	0.789[a]	1.000	
Zn	−0.933[a]	0.145	0.753[a]	0.635[a]	0.722[a]	−0.647[a]	−0.189	−0.768[a]	0.147	0.257[b]	0.228[b]	0.169	0.707[a]	0.842[a]	0.813[a]	1.000

[a]significant at $p < 0.01$.
[b]significant at $p < 0.05$.

[12]. Notwithstanding this, the pHs of the water in the abandoned mining pools and in the rivers are in the circumneutral range. Details on the hydrogeochemistry of the waters are presented in [13].

Fig. 3 shows the mean values of the organic constituents in water, i.e. BOD, COD and TSS concentrations and the ammoniacal nitrogen content in the active mining pools, ex-mining pools and in the rivers. The BOD and NH_3-N values satisfy the recommended acceptable value (Ministry of Health, MOH) for all locations. However, COD values exceed the recommended acceptable value at most locations. This may suggest the presence of high amount of organics and inorganic chemicals in the water, though the values are comparably lower than typical wastewaters [14]. It was found that there are significant correlations ($p < 0.01$) between TSS and BOD ($r = 0.552$) and COD ($r = 0.321$) (Table 5), reflecting the influence of the organic and inorganic suspended materials on the oxygen requirements of the biological and chemical reactions in water.

Many studies have been associated with heavy metals speciation and its accumulation in water and soil within former mining area in the country [15–18] and elsewhere [19–22]. However, less attention has been given on the composition of heavy metals in abandoned mining ponds used for alternative resource of water supply. The heavy metal contents (Cu, Fe, Mn, Pb and Zn) in the water are presented in Fig. 4. Except for Fe and Mn, all other metal elements measured are well below the recommended acceptable values by the MOH. Results were also compared with the mineral contents in drinking water [23].

At some locations, Fe has values exceeding the acceptable value, i.e. at active sand mining site (S1) and at downstream river locations (S13 and S14). Classification by metal element indicates Class V water with regard to Fe content at these locations. This however, has been anticipated because Fe is produced or released during mining processes, e.g. during excavation and interaction with other mineral compounds, oxygen and water. Discharges from S13 and S14 are from developed areas mainly associated with multiple downstream industries. Manganese was detected above the acceptable value at the active sand mining site (also Class V water with regard to Mn content) and a few locations in the rivers (S6, S7, S13 and S14). Mn was also found exceeding the acceptable value at the HORAS pond (S11). Note that at S11, the HORAS pond was undergoing construction and refurbishment works for the development of the so-called storage reservoir and none of the water flowed into the river. Generally, the presence of manganese may be attributable to the presence of Fe, and

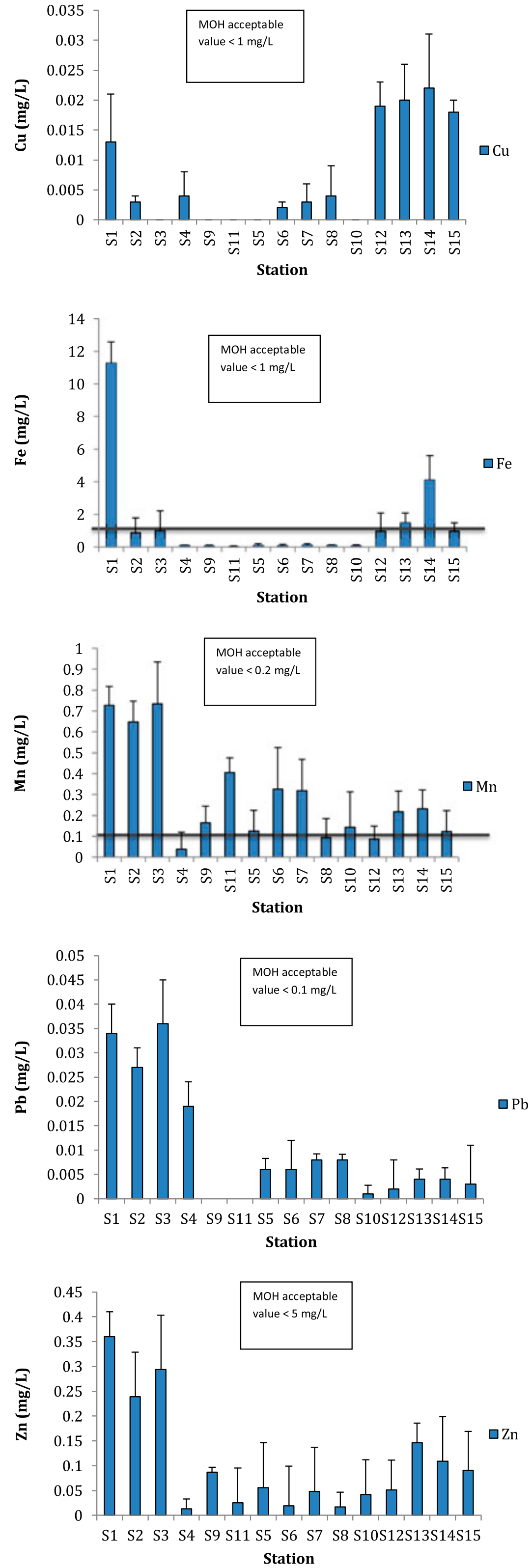

Fig. 4. Mean values of heavy metal (Cu, Fe, Mn, Pb and Zn) concentrations in sand mining pools (S1, S2, S3), abandoned mining pools (S4, S9, S11) and in streams/rivers (S5, S6, S7, S8, S10, S12, 13, 14, S15).

may also be the result of mineral leaching through various processes. Despite these, the values of Fe and Mn are still below the recommended acceptable values at the point before the raw water intake station that feeds into the WTPs (S15). Detailed explanations on these metal compounds and interaction of metal concentration in water and sediment have been discussed in [13].

It was also found that there are significant correlations ($p < 0.01$) between TSS and the metal contents (Fe, Mn, Pb, Cu and Zn) (Table 5). The highly strong correlations of TSS, Fe ($r = 0.710$) and Mn ($r = 0.518$) may suggest the influence of these metals possibly the precipitated forms that affect the composition of the suspended particles in water. The links also suggest that the overall quality of water is the reflection of all constituents in water including the organics, inorganics and the minerals (major and trace elements). Therefore, it would be beneficial to incorporate all these variables when evaluating the quality of water, rather than the simple computation of the water quality index or the mineral composition alone.

The status of the rivers is also evaluated based on the (WQI) (Fig. 5 and Table 6) [24]. The rivers are classified as clean (S5–S12; Class II) and slightly polluted (S13–S15; Class III). Clearly, the upstream locations in the river have better quality of water than the downstream locations. The deterioration of the water quality is notably associated with the discharge from downstream rivers (measured at the confluence of tributaries and the main river, Selangor River) at S13 and S15. As noted earlier, these sites are located at highly developed areas with increasing number of residential areas and industries. Consequently, the status of water quality further downstream near the raw water intake station has also been deteriorated. Notwithstanding this, all the variable values are well below the MOH recommended acceptable values except for COD. However, differences of the water quality status between the locations along Selangor River are not significant ($p > 0.05$).

Apart from the rivers, the active and abandoned mining pools were also classified according to the status of water quality. Apparently the ex-mining pools (S4, S9, S11) are classified as clean (Class II). The active sand mining pools (S1, S2, S3) on the other hand are classified as slightly polluted (Class III). Differences of water quality status between the active mining pools and the abandoned mining pools and the rivers are significant ($p < 0.05$). Overall, it is clear that the use of the abandoned mining pools is acceptable in terms of water quality, the fact that this additional resource is very important to supply more available raw water to the downstream WTPs.

Apparently, the site-by-site water quality assessment has shown a clear pattern of water quality changes between sites. A routine monitoring of the water quality, e.g. weekly or monthly basis is very crucial during and after commissioning of the HORAS project to precisely evaluate the current water quality status. This has been a routine practice by the state water authority in ensuring safe and sufficient supply of potable water for the consumers.

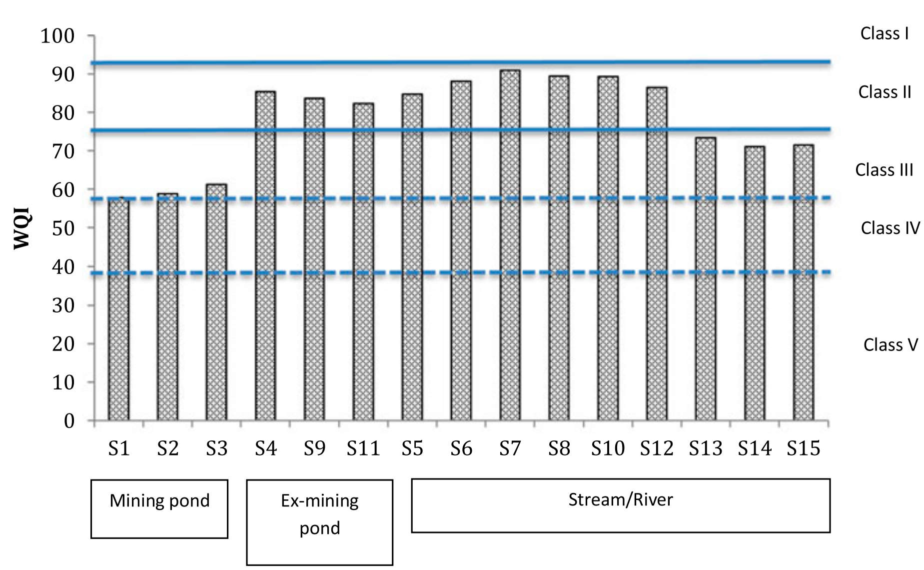

Fig. 5. Water quality index (WQI) of the monitored site.

Table 6
Water quality status and river classification

Rivers	WQI	General status	River classification
S5	84.74	Clean	II
S6	88.10	Clean	II
S7	90.97	Clean	II
S8	89.43	Clean	II
S10	89.25	Clean	II
S12	86.47	Clean	II
S13	73.32	Slightly polluted	III
S14	71.07	Slightly polluted	III
S15	71.52	Slightly polluted	III
Mining pools	WQI	General status	Classification
S1	57.85	Slightly polluted	III
S2	58.76	Slightly polluted	III
S3	61.19	Slightly polluted	III
Ex-mining pools	WQI	General status	Classification
S4	85.41	Clean	II
S9	83.64	Clean	II
S11	82.22	Clean	II

Notes: WQI = 0.22 × SIDO + 0.19 × SIBOD + 0.16 × SICOD + 0.15 × SIAN + 0.16 × SISS + 0.12 × SIpH where; SI = Sub-index variable value.

Because WQI has its limitation in that only six variables are taken into account when calculating the index; therefore, it is suggested that other variables such as the metal contents be considered as well since the raw water is supplied partly from the abandoned mining pools. This is also necessary to minimise the risk of water treatment plant failure and to avoid any cases of water disruption [25].

4. Conclusion

The IRBM for the Selangor River Basin has been seen as a beneficial approach to secure sufficient raw water supply for the state of Selangor and the Federal Territory, i.e. the Klang Valley. Exploring alternative water resources has been initiated and implemented within the catchment as an effort to increase the capacity of raw water to the downstream WTPs. With plenty of available abandoned mining pools, the option has been to develop a hybrid system, making use of both surface and ground water. More importantly, this will also provide additional raw water supply and storage during emergency, water shortages and critical water demand. Quality of such waters always plays an important role in ensuring clean and safe raw water supply for the consumers. Assessment of the water quality at selected locations along the Selangor River has shown that the quality of water at the downstream raw water intake station is at satisfactory level, i.e. below the recommended acceptable values by the MOH. Additionally, water flows from the abandoned mining pools showed clean status (Class II) and have metal content below the acceptable values. Despite this, multiple activities, especially from the industrial areas have become the plausible causes of water quality deterioration further downstream of the river basin.

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