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Evaluation of water quality variation in lakes, rivers, and ex-mining ponds in Malaysia (review)

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ABSTRACT

Threat posed by the heavy metals has been increasing globally rendering many water bodies unfit for human consumption. This could be due to the increase in concentrations of these metals above natural background. This article reviews the literature data on variation of water quality in rivers, lakes, and ex-mining ponds in Malaysia and other selected countries. World Health Organization (WHO), United States Environmental Protection Agency, and Malaysian water quality standards (INWQS) are used as the baseline for the pollution and health risk assessments. It illustrates that concentrations of Pb, Cd, and As in lakes and ex-mining ponds, and Mn, Cd and Pb in rivers exceed permissible limits for direct consumption. The levels of dissolved oxygen, TSS, and chemical oxygen demand (COD) are not within WHO and INWQS limits, pH of lakes and ex-mining ponds are lower than reference standards while that of rivers are high. Principal component analysis reveals that TSS, COD, BOD, Pb, and As are highly associated with ex-mining ponds. Cluster analysis shows similarity in pollution source between lake and ex-mining ponds. Risk assessment revealed that high chronic daily intake and metal index were beyond acceptable limit indicating high risk and exposure to toxic metals.

Keywords: Water quality index; Ex-mining pond; Lake; River; Health risk assessment; Pollution; Chemometric

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1. Introduction

As a nation aims at achieving its vision in the year 2020 to turn into a developed nation by the implementation of its plan of industrialization and urbanization, the requests for water supply increase sharply. More prominent weight is put in place to discover the optional course of activities to enhance water quality. The Malaysian economic development strategy after the introduction of New Economic Policy has facilitated the development processes [1]. The negative impacts on the environment were not considered in the course of pursuing developmental processes, that are, effects of development on lakes and rivers. Sources of water such as lakes, canals, and rivers constitute the major part of drinking water in the world but the increase in the industrialization and urbanization results in pollution of the existing drinking water sources [2].

The World Health Organization (WHO) reveals that all diseases (80%) contracted by human beings are from water sources [3], therefore regular monitoring of the quality of the ground and surface water resources and adopting ways and policies to preserve them become imperative.

About 73 lakes were created in Malaysia to meet the nation high needs and demands of water. Studies of lakes showed that most of the lakes were classified as polluted [4]. Based on several analyses, it was found that important water quality parameters were beyond the permitted level set by the Department of Environment (DOE) Malaysia. Another major source of water supply to the Malaysian public is the river, but there has been an increasing rate of river pollution which prompted exploration of other sources of good quality drinking water to support the already existing ones [5]. Therefore, it is of great interest to fully monitor the quality of river water since it accounts for about 98% of consumable water supply to the country, unlike other countries that depend on underground water or desalinated the sea water [6,7]. River water influences the health of public and aquatic life [8]. Myriad of factors that affect water quality standard had been reported, and these include anthropogenic and natural influences, hydrological, and climatic and geological factors. These factors affect the quality of water and determine its quantity in the environment.

An attempt was made by the Selangor authority to utilize the water from the ex-mining ponds for drinking purposes during the period of water scarcity. This resulted in arguments among researchers on the safety of the water considering that most ex-mining ponds are polluted with heavy metals especially arsenic.

Among the major pollutants that negatively affect the aquatic environment are heavy metals. Metals with densities greater than 5 g/cm^3 are generally referred to as heavy metals [9], for example cobalt (Co), copper (Cu), lead (Pb), etc. Arsenic, which is a metalloid, is regarded as a heavy metal because of its similar environmental and chemical behavior to metals [10]. These metals are classified as potentially toxic [11], and their effect is chronic at a certain level of concentration or exposure [12]. A significant concentration of heavy metals from polluted water and animal feed accumulates in fishes and subsequent consumption poses a health risk to humans [13]. Some of these metals are essential nutrients for humans but very harmful when present in high concentration [14]. Heavy metal pollutants are distributed in the sediment layer and react by precipitation, adsorption, and ion exchange [15]. The mechanisms of the metal intake by the sediments are biological intake, physicochemical absorption from water and metal accumulation [16]. Heavy metals cannot be degraded, and are very harmful to animals and plants when the exposure period is high [17]. Various human activities such as mining, agriculture, and industrialization produce these metals which are being discharged into receiving systems such as water, sediment and soil [18–25]. Very low concentrations of the metal contaminants are observed when the source is from weathering of rock and soil [25]. The concerns of heavy metal dispersion into these receiving systems through these sources have also been raised [5,26,27].

Many chemical, physical, and biological parameters are considered the determining factors of water quality in the aquatic ecosystem [28]. Therefore, parameters or variables such as dissolved oxygen (DO), pH, total dissolved solids, faecal coliform, and chemical oxygen demand (COD) are measured and the results are used in the assessment and classification of water quality [29]. The variability in these water quality parameters are usually due to anthropogenic and other natural factors [30].

The National Water Quality Standards are formally used in the development of water quality index (WQI). The WQI is used for the monitoring and assessment of different water bodies. However, the developed index is limited to river water only hence cannot accommodate other water bodies. WQI was recommended in 1974 by the Department of Environment to regulate the pollution levels in the Malaysian Rivers. The purpose of establishing the WQI is to assess the status and choice of water for beneficial uses. This is achieved by comparing water quality parameters with the operating water guideline or standards and the indices will identify the parameter(s) that exceed the approved standards as well as the degree of the deviation from the standard value [31].

The Department of Environment Malaysia (DOE) made a frantic effort to monitor and maintain the reasonable level of pollution around the reservoir catchment areas. Almost 1,063 stations that monitor water quality were selected in 2009, and about 577 water bodies were studied, 54% of which were classified as clean, 36% were "slightly polluted," while 10% were classified as polluted water [32].

Although mining and smelting activities contribute positively to the local and national economic development, there is a lack of good control management in their practice thus resulting in severe environmental problems, especially heavy metal pollution [33,34]. Previous methods such as Open cast and Panning, and Lampanning and dredging have been used for mining exploration of the tin after its discovery in Malaysia [35]. Among these methods, the lampanning mining process was considered a very destructive method of tin mining due to its siltation of water bodies in mining areas and close catchments [36]. After completion of the mining operations, the environmental consequences are polluted lakes and ponds. And these can be acceded by the substantial impairment to water quality observed in abandoned mining sites worldwide [37,38]. After the mining operations cease, oxygen-rich groundwater floods abandoned mine pits and can promote oxidation of pyrite (FeS_2) and other metal sulfide minerals. This incurs water acidity and production of sulfate and releases co-occurring trace metals. Over time, seepage from mines can emerge aboveground as metal-rich acid mine drainage [39].

The data obtained from water quality assessments and sources of pollution from ex-mining ponds, lakes, and rivers can be evaluated and interpreted using multivariate analysis such as, the factor analysis (FA), principal component analysis (PCA), and cluster analysis (CA). These techniques of multivariate data analysis have been utilized to categorize or rank water quality data and also identify parameters or variables that are statistically similar [40–42].

PCA is a data reduction method; it interprets the variances in a substantial set of variables that are inter-correlated and converts them into a set of independent variables [43]. PCA enables researchers to understand the parameters of significance that represent a particular set of data, reduce the data size, and give a summary of the correlation among different variables or parameters in a given sample of data-set with negligible change in the original data [44]. PCA technique has been applied to the data rearrangement in a correlation matrix and provided information on the structure of the available set of data. PCA also recognizes the sources of pollution [41,45,46]. CA is the classification of similar variables or parameters into groups based on their characteristics [47]. The hierarchical cluster analysis produces similar correlation among the samples and the available data-set using a dendrogram.

Thence, this review highlights the variation in heavy metals and physicochemical parameter distribution, and its impact on the quality and health risks upon intake of water from selected lakes, rivers, and ex-mining ponds.

2. Background of the data

This review analyzed studies related to the assessment of heavy metals and other physicochemical parameters in lakes, rivers, and ex-mining ponds in Malaysia and comparison was made to similar studies in other parts of the world (Tables 1 and 2). The priority heavy metals in this study are Cu, As, Pb, Cd, Zn, and Mn, which are among the major heavy metal pollutants as specified by the Malaysian DOE and WHO, and six general water quality parameters, namely pH, conductivity, DO, COD, BOD, and TSS. These selected pollutants are of concern and frequently studied in the pollution assessment of Malaysian lakes [26,48,49], and rivers for water quality assessments and index classification for different uses [31,50,51]. The mining operation is associated with toxic metal pollutants and water quality impairment due to high suspended solids (SS), electrical conductivity (EC), and COD [52–55]. Ex-mining ponds, lakes, and rivers were selected based on the presence and distribution of the parameters in Malaysia and comparison was made to some selected countries of the world.

Among the ex-mining ponds in Malaysia, the Bestari Jaya ex-mining pond is selected due to its close catchment to the Udang River and Ayer Hitam River which are subsequently linked to the Batang Berjuntai water treatment plants SSP1 and SSP2. The two water treatment plants are the main distribution channel to Putrajaya and Kuala Lumpur (Federal Capital), and the state of Selangor which is the most populous state in Malaysia [56]. Another studied lake was the Kelana Jaya Lake which is near a recreational park surrounded by housing and commercial centers, but the lake is heavily polluted by an overflow of sewage waste; as a result many fishes were found dead, floating, and rotten [4].

The major source of water for consumption and irrigation purposes in Ipoh in the state of Perak is Kinta River, and is the second most important source of water in Perak [31]. Other water sources from different countries were also selected for comparison

Table 1
Comparison of mean concentration of selected heavy metals (mg/L) in lake, river, and ex-mining pond

Country	Source	As	Cd	Pb	Cu	Zn	Mn	Refs.
M'sia	Ex-Mp	66.00	–	69.460	75	87.800	48.000	[53]
M'sia	Ex-Mp	–	–	–	11.06	6.56	7.17	[80]
M'sia	Ex-Mp	0.040	0.10500	0.0750	–	0.0750	–	[81]
M'sia	Ex-Mp	2.540	1.10000	1.0300	1.0	7.3700	–	[49]
M'sia	Ex-Mp	0.07	0.0000	0.0000	0.010	0.010	0.001	[82]
M'sia	Ex-Mp	77	–	96	80	–	48.000	[83]
M'sia	Ex-Mp	1.670	0.54000	55.800	78.3	48.700	8.1700	[84]
Bangladesh	Ex-Mp	–	–	–	0.0007	0.0007	0.0008	[85]
India	Ex-Mp	–	0.065	0.41	0.18	–	0.22	[86]
Nigeria	Ex-Mp	–	0.001	0.004	0.006	0.017	–	[87]
Indonesia	Ex-Mp	–	0.010	0.010	0.030	0.040	–	[88]
Ghana	Ex-Mp	7.200	–	0.2000	7.8	0.1000	–	[58]
Mexico	Ex-Mp	0.100	0.04000	–	0.09	10.710	6.6500	[79]
S/Africa	Ex-Mp	–	–	0.1000	0.1000	1.500	6.2000	[89]
M'sia	Lake	0.067	–	0.0139	0.0132	–	1.0831	[65]
M'sia	Lake	–	0.00020	0.0004	0.0034	0.0110	–	[90]
M'sia	Lake	–	0.00042	0.0024	0.0008	0.0051	0.0292	[91]
M'sia	Lake	–	0.00334	0.0280	0.0135	0.5760	0.0104	[92]
M'sia	Lake	–	0.00043	0.0072	0.0009	0.0061	–	[93]
M'sia	Lake	–	0.13600	–	0.0040	0.0000	0.0340	[26]
M'sia	Lake	–	0.11000	7.5200	3.7900	–	–	[94]
M'sia	Lake	–	–	0.0015	0.0004	0.0043	0.0096	[95]
Brazil	Lake	–	–	0.0006	0.0009	0.0096	0.0127	[96]
India	Lake	–	0.1100	2.900	1.4000	–	0.1900	[97]
Ethiopia	Lake	1.8000	0.4200	1.010	–	–	–	[77]
Kenya	Lake	–	0.0723	0.0649	0.0669	–	–	[98]
Rwanda	Lake	–	0.0260	0.2920	–	0.0410	0.3400	[76]
S/Africa	Lake	–	–	0.2000	5.6000	4.8500	5.2333	[99]
Cameroon	Lake	–	0.0070	0.0016	0.0080	0.0120	0.3070	[100]
M'sia	River	–	0.0500	0.6000	0.0030	0.0210	0.0200	[101]
M'sia	River	0.0065	0.0001	0.0017	0.0281	0.0152	0.0871	[102]
M'sia	River	–	0.0006	0.0120	0.0019	0.0348	0.0487	[103]
M'sia	River	0.0073	–	–	–	0.0348	–	[31]
M'sia	River	–	–	–	0.0016	0.0074	0.0279	[104]
M'sia	River	–	–	0.0277	0.0160	0.0079	–	[105]
M'sia	River	0.0069	0.0112	0.0101	–	0.0368	–	[51]
M'sia	River	–	–	–	0.00007	0.00014	0.00014	[106]
M'sia	River	0.0435	0.00058	0.0023	0.0860	0.0389	0.0112	[107]
Mexico	River	0.1600	0.0140	0.8400	–	–	4.6200	[61]
Tanzania	River	BDL	BDL	0.01	0.01	BDL	–	[108]
Nigeria	River	–	0.0520	0.2070	0.0560	0.0787	0.1810	[109]
India	River	–	–	–	27.441	53.954	21.708	[110]
Bangladesh	River	0.0120	0.0720	–	0.2010	–	–	[111]
Turkey	River	0.0023	0.0001	0.0030	0.0320	0.0016	0.3880	[42]
Kenya	River	–	–	0.4600	0.1800	0.7000	–	[112]

Notes: Ex-Mp = ex-mining pond and M'sia = Malaysia.

based on their proximity to the major industrial areas or serving as a source of water for domestic and recreational purposes.

About 59 abandoned mining areas were assessed in Serbia, due to the proximity to the main rivers upstream and downstream from the mining sites. The water samples collected for chemical analysis from the abandoned mines and rivers had been analyzed for continuous monitoring and protection of public health [45].

Table 2
Comparison of mean values of selected water quality parameters (mg/L), pH (no unit), and EC (μS/cm)

Country	Source	pH	EC	DO	COD	BOD	TSS	Refs.
M'sia	Ex-mp	5.71	1,707	6.5	–	–	2,870	[53]
M'sia	Ex-mp	7.16	304.4	1.7	–	–	445.1	[85]
M'sia	Ex-mp	9.0	140	–	14	–	93.80	[5]
M'sia	Ex-mp	4.64	0.66	4.64	–	–	–	[84]
M'sia	Ex-mp	7.55	–	2.47	267.09	20.94	–	[150]
M'sia	Ex-mp	7.23	168	–	–	–	114.64	[82]
M'sia	Ex-mp	6.91	353	3.32	–	–	–	[49]
M'sia	Ex-mp	5.50	31.6	4.70	–	–	–	[14]
M'sia	Ex-mp	5.00	1,756	6.82	–	–	–	[83]
M'sia	Ex-mp	6.12	456	–	–	–	–	[151]
Bangladesh	Ex-mp	7.16	304.3	1.70	–	–	–	[85]
Swaziland	Ex-mp	7.76	457.2	–	–	–	–	[152]
India	Ex-mp	8.30	838	0.83	145	70	1,098	[86]
Mexico	Ex-mp	8.49	2,500	6.27	–	–	187.26	[153]
Ghana	Ex-mp	9.80	4,560	4.60	1,240	4.30	14,300	[58]
Morocco	Ex-mp	6.79	7.280	–	–	–	1,200	[54]
M'sia	Lake	7.04	112.1	7.25	–	–	–	[154]
M'sia	Lake	6.71	5.60	–	1.61	–	–	[155]
M'sia	Lake	7.24	1,208	–	–	–	592.25	[156]
M'sia	Lake	6.00	32.70	5.3	–	–	–	[18]
M'sia	Lake	7.32	40.19	6.73	15.52	1.42	7.03	[157]
M'sia	Lake	7.015	–	5.77	65.52	4.656	–	[26]
M'sia	Lake	5.50	158	0.69	–	–	–	[158]
M'sia	Lake	6.53	23.97	6.31	16.49	1.52	15.45	[48]
Ghana	Lake	6.60	–	–	–	42.60	2,392	[159]
Mexico	Lake	8.80	586.00	–	17.30	–	–	[160]
India	Lake	8.42	235.70	8.380	–	–	167.70	[161]
Nigeria	Lake	7.40	14.70	8.700	1.90	1.10	9.70	[162]
Brazil	Lake	6.71	84.06	0.070	–	–	–	[163]
M'sia	River	6.68	180.30	6.250	–	–	–	[164]
M'sia	River	7.28	–	4.140	59.23	4.06	9.83	[165]
M'sia	River	5.30	110.8	6.2	100	2.1	33	[166]
M'sia	River	6.97	352.62	4.317	38.251	5.663	393.89	[31]
M'sia	River	6.91	26.67	6.34	8.260	0.460	17.33	[103]
M'sia	River	6.77	–	4.57	4.300	0.71	–	[167]
M'sia	River	6.50	–	4.78	35.73	1.33	14.95	[168]
M'sia	River	7.78	–	5.50	–	–	49.61	[106]
M'sia	River	7.66	240	6.34	3.50	0.69	8.44	[169]
M'sia	River	6.67	14,550	3.25	–	–	–	[170]
Bangladesh	River	7.50	175.60	3.90	–	37.50	78.35	[171]
India	River	7.68	213.00	9.65	–	0.80	191.71	[172]
S/Africa	River	8.30	73,000	8.80	–	–	–	[173]
Thailand	River	6.75	461.96	3.85	–	3.34	69.09	[174]
Zimbabwe	River	8.42	45.00	–	–	2.40	42.00	[175]
Nigeria	River	7.01	86.90	1.80	178	8.23	183.00	[176]

Notes: Ex-mp = ex-mining pond and M'sia = Malaysia.

Linglong gold mine area of China is one of the most important gold mining districts whose surface water is seriously polluted by Hg, Zn, and Cd. This poses a threat to the nearby residents and stream water quality deterioration [57].

Construction of several boreholes in Ghana was made to monitor the discharge of heavy metals from the tailing ponds of the central Africa Gold Mining Limited. Rivers Mpokwampa, Mensin, Kyirayaa and Pamunu are the main rivers in the district.

Mensin river is the principal river draining the central Africa Gold concession [58].

Lake Dianchi with about 200 ponds around it is close to the Kunning city which is the largest township in the Yunnan Guizhou plateau. There is a speedy increase in population and resulted in the continuous discharge of large quantities of industrial waste water [59].

Shahid Rajaei reservoir is one of the main reservoirs utilized for drinking water purposes in Northern Iran. It supplies Sari, the provincial capital of Mazandaran Purinee. Therefore, the considerable usage of this reservoir, and continuous water quality assessment including the analysis of dissolved heavy metals is of great importance [60].

San Pedro River is one of the most important rivers in Mexico, which includes four municipalities and the river reaches the boundary between the United States of America and Mexico [61].

One of the world's largest rivers in terms of drainage basin and sediment load is the Pakistan Indus River, which is used for domestic and agricultural purposes but it is feared to have undergone a trace of metal influx [62].

3. Data processing

All the statistical data analyses were performed using the JMP Pro12 software; SAS. The mean values of the heavy metals and physicochemical parameters found in lakes, rivers, and ex-mining ponds in Malaysia and other selected countries were collated for comparison (Tables 1 and 2). The comparison of a 50th and 95th percentile of heavy metal concentrations was also done and used for risk analysis.

4. Water quality assessments

The rapid increases in population and improper disposal of sewage and waste water into lakes and rivers have contributed significantly to the pollution of the water bodies. For this reason, there is eminent need to embark on routine water quality assessment and implement pollution control measures to restore and preserve the water bodies.

The absence of industrial and/or domestic activities around the catchment area of the water bodies maintains the good water quality of the water. Ahning reservoir has good water quality and is suitable for water supply and industrial use because it is surrounded by intact natural forest vegetation [63]. A change in rainfall pattern and intensity due to global warming also affects reservoirs and lakes in Malaysia due to challenges in the function of the lakes for controlling flood and drought [64]. Industrial activities at Padang Basar also contributed to the pollution of the lake [65].

Many lakes and rivers in Malaysia are termed "eutrophic" [31], where a review of water quality assessment of about 90 lakes reveals that 60% are eutrophic [64]. High concentration of ammonia, phosphorous, and nitrogen was found in the Bera Lake, which is an indicator of the degradation of its quality [66]. The presence of high coliform and faecal coliform is also alarming, where the total coliform and faecal coliform counts significantly exceeded the guideline set by the Malaysia interim national water quality standard. This could be as a result of human excretion due to inappropriate sanitation facilities in the local villages. The lake was classified as class II which allows for only body contacts and recreational activities. This could be due to the revival of abandoned mines and rapid expansion of agricultural land for palm oil plantation close to the shore of the water body. The presence of heavy metals was recorded in the Bukit Merah Lake due to the infrastructural development and agricultural activities near the river source; hence, it is classified as class III. The depletion in DO concentration and high BOD and COD were also observed in the Merah, Jelutong, and Kurau rivers which might be due to the influx of pollutants from private residences and railway construction [26]. The ex-mining ponds in Bestari Jaya Malaysia were classified as polluted, with heavy metals of main concern that normally exceeds the water quality guideline such as lead, arsenic, zinc, manganese, copper, iron, and nickel, which are associated with mining operation [53,67]. Elevated concentrations of As, Pb, Mn, and Zn were found in the water and sediment of the ex-mining lakes in the central Kuala Lumpur, resulting in pollution of the interconnecting lakes [68].

A study of water quality assessment of Perak and Kinta Rivers revealed that water samples were turbid with elevated concentrations of arsenic and lead. This could be due to the agricultural activities and soil erosion along the river banks. The rivers are fully utilized for the supply of water to the state of Perak [5]. The important pollution sources in agricultural waste water are fertilizers containing heavy metals such as Cu, Cr, Cd, Zn, and Pb, high turbidity, and TSS from animal husbandry. Industries and large-scale manufacturers directly discharged pollutants usually rich in toxic chemicals and heavy metals along with the organic wastes [69]. Algaecides and fungicides applied in fish farming contain pollutants such as copper compounds [70]. The Langat river was among the 42 tributaries classified as polluted in the Malaysian peninsular [71], the rivers were polluted as a result of human activities such as agriculture, construction, and industry at the tributaries [72]. Major sources of pollutants in the Malaysian rivers are small- to medium-scale industries and sewage disposal as these industries were not fully equipped with functional effluent treatment system [73]. The largest pollutant discharged into the Malaysian river is the palm oil mill effluent, resulting in high TSS, turbidity, COD, BOD, and low DO [74].

The high pollution level was discovered in the Timah Tasoh lake Perlis and classified as class III due to the high Mn concentration above 100 μg/L, and this requires extreme treatment. The Kelana Jaya lakes were polluted due to the overflow of sewage waste from untreated sewage oxidation ponds, and high concentration of dissolved Cd which could be from the car wash and electroplating industries. The lakes were classified as polluted, unhealthy, and unsuitable for body contacts [75]. Previous research carried out has classified the lakes as class V which exceeded the permitted level of pollutants by the Malaysia department of environment (DOE) [4].

Located in central Rwanda, Lake Mahazi is one of the main sources of water for domestic and agricultural activities, but has been characterized by both urban and rural pollution. The increase in heavy metal loading from different sources threatened the water quality [76]. Lake Awassa and Koka in Ethiopia were affected by industrial effluents in their catchments, thereby making them perfect study sites. These lakes run from north to south of the eastern side of the African continent. Industrial effluents significantly affect the quality of surface water by introducing heavy metals and other pollutants [77].

The impacts of mine water on rivers in many areas of United Kingdom affect the surface water quality, where about 6% of the rivers in England and Wales were affected by discharges from abandoned mines with an enrichment of significant concentration of dissolved Zn, Pb, and Cd [78]. The effect of acid mine drainage on water results in impaired quality in the central Mexico was as a result of acid leachate in the abandoned mines, high concentrations of Cd, As, Pb, and Mn exceeding the permissible limit for human consumption [79].

4.1. Water quality changes in Malaysian lakes and rivers

Rivers and lakes are the major sources of water for domestic and industrial needs in Malaysia, but there were changes in the water quality as a result of natural and human influences. Lake Chini is situated in Pahang and one of the largest natural lakes in Malaysia. The Chini Lake flows directly to the Chini River that connects to the Pahang River, the longest river in the Peninsular Malaysia. The deterioration in water quality trend of the lake was studied in 1992, 1993, and 1998. A study conducted between May 2004 and April 2005 revealed seasonal variation in water quality due to activities around the lake. Total rainfall of 553.5 mm was recorded in October 2004 with a total of 2,095.69 mm in the study period which showed a negative correlation with DO in a range from 1.91 to 7.92 mg/L. The pH did not show a drastic change with means of 6.69 obtained in the study with the range of 5.72–7.38. BOD and COD were in the range of 0.03–5.25 mg/L and 6.25–29.85 mg/L which are indicators of pollution [48]. A study of Bukit Merah Lake which is the oldest man-made lake in Malaysia revealed slightly polluted status. The pH of the lake was 6.45–7.8 within the acceptable range of INWQS, BOD, COD, and DO that are 3.08–6.32 mg/L, 25–97 mg/L, and 2.06–12.5 mg/L respectively. The source of the pollutants was from agricultural and recreational development near the Merah and Kurau lake and river inlets that flow into the lake [26]. A similar study of the Chini Lake from October 2004 to July 2005 revealed variations in the levels of Pb, Cd, Cu, and Zn in water samples with a pH range of 4.8–5.5 [94]. The assessment of water quality of Selangor river in 2008 using WQI showed deterioration of water quality as a result of the flow of municipal wastes and pollutant load from poultry farms [50]. The annual rainfall received by the Langat River located in the south and south eastern of Selangor is about 1,500 to 2,900 mm. As one of the most important water source for domestic, agricultural, and manufacturing in the Selangor state, its water quality monitoring and variations are of great importance. The study was carried out in December 2010 covering the three major river estuaries of the Semenyih, Labuh, and Mantin Rivers. The rivers were polluted and the possible pollution sources were identified as the industrial and agricultural pollution as well as geological weathering processes. pH, EC, DO, As, Al, and Pb were 6.67, 14,550 μS/cm, 3.25 mg/L, 8.54, 290.07, and 1.07 μg/L, respectively [102]. In the northwest coast of the Peninsular Malaysia, a study carried out in 2006 at the Juru and Jejawi estuaries in the Penang state revealed that the study area was polluted as a result of metal influx into the river from industries [69]. A similar study in 1994 showed elevated concentrations of metals in the river water [113]. The Malaysian Department of Environment confirmed the presence of many industries in the Prai industrial area in Penang [114]. The analysis of the results of the Gombak and Penchala rivers in Kuala Lumpur from 1997 to 2009 showed that metal concentrations were generally high but not critical. The Gombak River is a tributary of the Klang River, and the Penchala River passes through the densely populated area of Petaling Jaya. The results were obtained from DOE monitoring stations along the river banks. The pollution of the two rivers was attributed to the discharge of domestic, agricultural, and industrial effluents. The high organic loadings in the Klang River increased significantly, and the river was categorized as class III in 1997 according to the water quality parameters measured by DOE, but was assessed to be class IV in 2009 [51].

Generally, the temporal variations in water quality of lakes and rivers are due to the anthropogenic activities which properly monitored can minimize the pollution of the water sources.

4.2. Water consumption in Malaysia

The demand for water in Malaysia has risen up at an alarming rate since independence and the rainwater harvesting system was introduced to supplement the river water sources as it was realized that with minimal treatment process, rainwater can be used for drinking and irrigation purposes [115]. Five states (Selangor, Kelantan, Perlis, Terengganu, and Pahang) have been combining the existing surface water with ground water to meet up with the increasing demand. Though the rainfall is abundant throughout the year, especially in the east coast region, extreme northwestern part of Malaysia experiences dry season and often suffers low water supply. It is therefore not uniformly distributed throughout the year. With an annual rainfall of between 2,000 and 3,000 mm, the relatively small size of the country and its interior steep terrain, rivers are short and swift, as such rainfall runs off into the sea quickly [116]. About 57% of the rainfall ends up as a surface run-off, 37% lost to evaporation, and 6% ground water recharge. It was estimated that Malaysian total water consumption for domestic, irrigation, and industrial uses was 8.7 billion cubic meters in the year 1980 [117]. The demand for agriculture declined from 76% by 1999 to 70% of the total water consumption by the year 2000. The demand for water was expected to rise from 9,543 m^3/d in the year 1995 to about 15,285 m^3/d in 2010, and 20,338 m^3/d in the year 2020 [118]. About 97% of fresh water in Malaysia comes from surface water such as rivers, while the number of clean rivers decreased by 12.5% from 80 in 2005 to 70 in 2009 (Fig. 1). Furthermore, the increase in water demand is not compensated by the corresponding increase in water reserve, as the Malaysian water reserve per capita per day declined at the rate of 5.8% per year. This could lead to very limited or no reserve by 2025 (Fig. 2) [119].

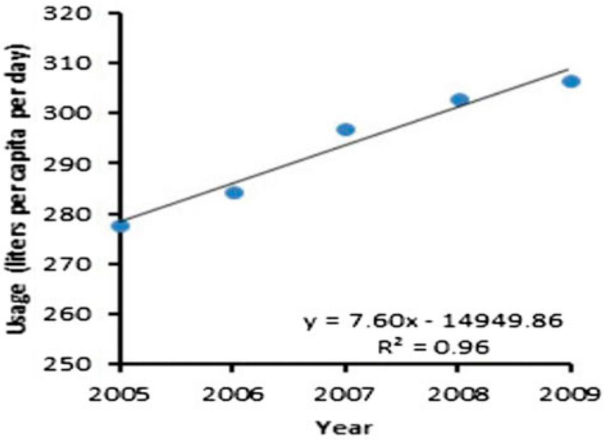

Fig. 1. Increasing water consumption in Malaysia (2005–2009) [119].
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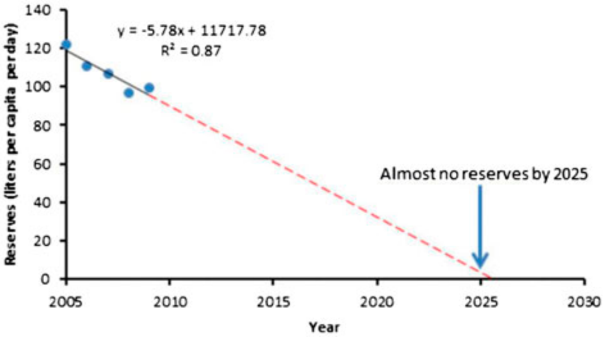

Fig. 2. Gradual decrease in Malaysian water reserve (2005–2009) [119].
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Besides the emphasis on the quantity of rain water received, the quality is of great importance which is influenced by the rainwater chemistry in the region. Rapid growth in industrialization and housing, and increase in number of vehicles resulted in deterioration of the air quality. Acid precipitation and increase in metal concentrations in the rainwater have received much concern due to the high emissions in major industrial and urban centers in Asian cities such as Kuala Lumpur, Hong Kong, Jakarta, Bangkok, Seoul, and Singapore [120]. This affects rainwater quality due to the complete or partial solubility of the air pollutants. There was an increase in sulfate and nitrate concentrations over the past two decades in Malaysia from 0.41 to 3.32 mg/L and 0.39 to 3.26 mg/L for nitrate and sulpfate, respectively. The chemical composition of rainwater in Kuala Lumpur between April and June 2009 was 2.27, 4.03, and 4.17 mg/L for chloride, nitrate, and sulfate ions, respectively [121]. The total nitrate and sulfate concentrations in Kuala Lumpur increased by a factor of 10 in 1996 compared to Cameron highland in Malaysia, island of Sumatra in Indonesia and Charles point in Northern Australia. The findings showed a consistent increase in sulfate and nitrite ion concentrations between 1982 and 1996. It was generally accepted that oxides of nitrogen and sulfur are significant to the acid nature of rainwater. The study carried out in Petaling Jaya revealed that a decrease in average pH was noticed between 1982 and 1991 [122]. Furthermore, the measured pH of 5.6 in Setapak, Malaysia was higher than the study carried out in Singapore between November 1999 to December 2000, and Petaling Jaya, Malaysia between 1981 and 1991 [121]. A short-term study on the chemical composition of rainwater in Singapore revealed acidic rain water with pH of 4.2 and concentrations of major cations, sulfate, and ammonium ion varied monthly. A study of rainwater chemistry in Huanjiang China revealed a high concentration of SO_4^{2-}, Ca^{2+}, and NH_4^+ derived from sea salt, Na^+, Cl^-, Ca^{2+}, and Mg^{2+} from earth crust, and SO_4^{2-} and NO_3^- from industrial and vehicle emissions [123]. Spatial and temporal variations in chemical components of rainwater were studied; nitrate and sulfate were the predominant anions which are much associated with metallic cations than hydrogen ions [124]. Acid rain significantly affects surface water quality and aquatic organisms by mobilizing aluminium and accumulating nitrogen in the water. Acid rain lowers the pH of rivers and lakes and increases the possibility of liberating aluminum from acidic soil and water which are highly toxic to humans and aquatic organisms. Nitrogen in the acidic rain is known to affect water quality by depleting the oxygen level as a result of eutrophication. A decrease in oxygen concentrations results in the death of fishes and other aquatic organisms [125]. DO in water is one of the major water quality parameters considered in Malaysian drinking water standard, and has the highest weightage of 0.22 in the river WQI [32].

4.3. General water quality guideline and legal limits

Water quality guidelines are formulated to ensure a safe drinking water supply by monitoring harmful pollutants or any hazardous substances in water. This is achieved by developing and implementing a risk management technique. The guidelines give logical minimum requirements of the benign application to safeguard the health of consumers and obtain numerical "guideline values" for parameters or components of water that indicate water quality [126]. There may be a variation in the standards of drinking water with respect to countries or regions; there is also no distinct universal applicable approach. It is pertinent to consider the health and locality in the planning and implementation of the current and revised legislation related to water, and assessment of ability in developing and implementing legislation. The method or procedure that is applicable in a particular country or region will not necessarily be applicable in other countries or regions. It is therefore a requirement that each country evaluate its needs and capacities in creating a regulatory scheme. In spite of the fact that guidelines illustrate a quality of water that is acceptable for long-term consumption, the creation of these guidelines, incorporating guideline numerical values, should not be considered as indicating that drinking water quality may degenerate to the prescribed level. A relentless attempt should be made to maintain the quality of drinking water at the highest possible level. The fundamental prerequisites to certify the safety of potable drinking water are a "scheme" for safe drinking water, incorporating health based objectives formed by a recognized health authority, sufficient infrastructure, and effective planning and management.

Water quality guideline can best be monitored in many industrialized nations, as well as some developing nations by basing limits for environmental discharge of pollutants. Such water pollutants which are considered hazardous include heavy metals that bioaccumulate and are poisonous at low concentrations; teratogenic and carcinogenic. Proper environmental practices protect water bodies from non-point sources of pollutants. In many countries, authorities in the agricultural and environmental sector encouraged the need for the best environmental practices and management [127].

In 1988, a decree was promulgated in Nigeria in favor of Federal Environmental Protection Agency (FEPA) to protect Nigerian environment, and to restore and preserve the entire ecosystem. The agency was also empowered to formulate and prescribe water quality standards to safeguard public health and improve water quality. In the absence of national comprehensive scientific data, FEPA also had no detailed water quality data which prompted the agency to review standards and water quality guideline of selected countries among which are developed by international organizations such as WHO and EC, and eventually compared with the water quality of Nigeria. Some of the standards examined are those of India, Australia, Tanzania, USA, and WHO. The set of these water quality data were harmonized and utilized to create Interim National Water Quality Standards for Nigeria [128].

The water quality management and regulation policy of the Vietnam authority emphasize the demand for availability of potable water, sufficient in quantity and quality for all gainful uses, and for the monitoring of pollution sources (point and non-point). The national water quality standard for drinking, aquatic, and agricultural purposes has been established [129].

Thailand has legislations on water quality monitoring and management which were created by various organizations based on their respective responsibilities. These include acts, ministerial notifications, and laws. To maintain and control water quality, public health protection and conservation of natural environment and entire ecosystem among others are the main objectives of setting standards for Thailand water quality requirements [129,130].

Analysis of reviewed data reveals that concentrations of Pb, Cd, and As show similar distribution in lake and ex-mining ponds (Table 1). The metal concentrations are high with variations in the studied areas and exceeded maximum permissible limits in Malaysian drinking water standard of 0.01, 0.003, and 0.05 mg/l, respectively, for As, Cd and Pb [131]. Concentrations of the most of the metals analyzed also exceed WHO limits, European commission and the United States environmental protection agency (USEPA) [132–134]. The metal concentrations in Malaysian ex-mining ponds [49,53,83] were found to be higher than that reported in Indonesia, Mexico, and Nigeria [79,87,88]. However, the concentrations of metals in the lake waters under review were lower than that obtained in Malaysia, Ethiopia, and India [77,94,97]. High concentrations of Pb, As, Cu, Cd, and Zn in the surface sediment of the lake was also reported in China [135].

Concentrations of heavy metals beyond toxicity limits result in the deprivation of water quality making it unsuitable for drinking and other beneficial purposes [136]. Since the values obtained are higher than critical values for the protection of freshwater aquatic life, aquatic organisms are also endangered [137]. High concentrations of heavy metals like As, Cd, and Pb are mostly associated with mining operations leaving the surface water polluted [21,57].

As, Cd, Mn, and Pb concentrations in some of the selected river water in this review were higher than the acceptable limits in the reference standards. This could be due to the continuous increase in the industrial activities and urban expansion along the river banks in Malaysia [131]; it is known that the industrial and domestic sewage are major sources of pollution of river water [51,138,139].

The concentrations of the metals studied were higher in ex-mining ponds and lakes compared to the river water. This could be due to the fact that about 30 to 98% of the river metal load is transported in sediment making it rich in metal concentrations compared to the surface water [140–142].

Generally, the combined pollution of heavy metals was noticed at various degrees, where serious pollution of the surface water was due to As, Mn, and Pb, moderate pollution was due to Zn, while Cu and Cd least pollute the water bodies (Fig. 3).

4.4. Physico-chemical parameters

A study of general water quality parameters (Table 2) shows that low DO and high total suspended solid (TSS) based on WHO and Malaysian drinking water quality standard [143,144] are the common characteristics of ex-mining ponds and lakes. Low DO values might be a result of reduced aquatic plant activities of such as photosynthesis, and presence of high organic matter as manifested in the corresponding values of the Biological Oxygen Demand (BOD) and COD, which similar results were obtained [145,146]. The waste assimilative capacity of water can be assessed using the DO level [147], and its extent of depletion signifies a certain level of pollution in water [148]. Flooded water lowers the DO level in lake Chini [48], and lake Bera, Malaysia [149]. High TSS, COD, and BOD were found in the river waters in this study. This is an indication of pollution because these parameters describe the higher potential of water to utilize or exhaust more oxygen through the decomposition of organic matter, as well as organic and inorganic substances by reducing the oxygen level of the water. Parameters of importance that indicate the level of contamination with organic matter are BOD and COD. High TSS could possibly originate from sediment

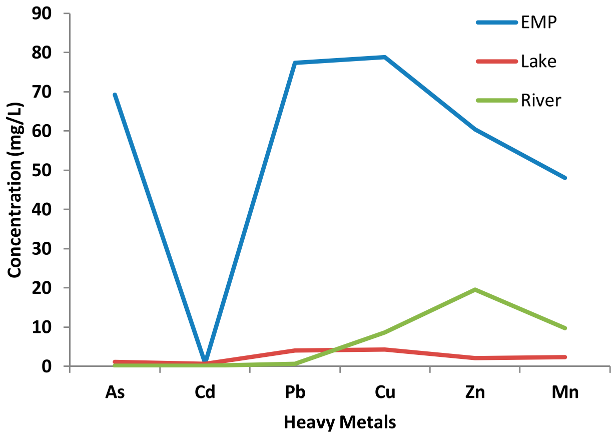

Fig. 3. Heavy metal distribution in Lakes, rivers, and ex-mining ponds in Malaysia.

suspension and pollutant point sources, and impact on water quality by reducing its clarity.

The acceptability nature of a water body is considered at a pH range of 6.0–8.5 [177]. The pH of water of some ex-mining ponds in this review was slightly below the range of 6.5–8.5 stipulated for municipal use [131], which is considered acidic and slightly polluted. Higher or lower pH impacts negatively on water taste, and affects skin and eyes [147]. The pH value above 9.0 is also not tolerable for fish and other aquatic species. The DO and BOD are reduced at high pH and would threaten the life of aquatic organisms [26,178]. Lower pH is also known to precipitate most of the heavy metals in solution.

EC of water in the ex-mining ponds is observed to be high. EC impacts on the user acceptance of the water as potable by significantly changing the taste [134,179]. EC is the measure of cations present in the water sample [180].

4.5. Water quality index (WQI)

The parameters included in the formulation of the WQI are monitored according to the water quality guideline of a particular locality. The sensitivity or importance of a parameter in terms of weightage is inversely proportional to its standard permissible value in the recommended water quality guideline [181]. Reference is made to the guideline which is formulated with the intention to support the development and implementation of risk management strategies [134]. An index is a dimensionless number that expresses rating or relative extent of a state or condition [182]. WQI forms a discrete figure that represents a general quality of selected water samples in a given location with respect to certain selected water quality parameters [183]. WQI is used in the decision-making with respect to design and organization of water resources programs, as well as to communicate relevant information to the general public [184]. The river water quality ranking in Malaysia is assessed using WQI formulated by the Department of Environment. However, the river WQI does not accommodate important health related parameters especially microbial parameters e.g. *Escherichia coli*, and toxic heavy metals [32]. As such the index cannot be applied to other surface water bodies such as lakes and ex-mining ponds. This prompted the need to develop a new index that bridges the above-stated gap.

In developing the WQI of lakes and ex-mining ponds in Malaysia, toxic metals associated with mining activity must be taken into consideration. They include As, Cd, Pb, Cu, Zn, and Mn [39,52,55,185–187]. On the other hand, physicochemical properties that must be selected are pH, DO, BOD, COD, EC, and TSS [5,68].

Since most lakes in Malaysia are ex-mining ponds [188], the same considerations must be given in terms of parameter selection. Weighted arithmetic index method can be used [189], and assigned to each parameter a weightage as an inverse proportion of its permissible limit in the Malaysian drinking water standard [143,180,181,190]. The subindices can be measured using methodology in Eqs. (1) and (2) [189]:

$$Q = 100 \times \frac{C}{S} \tag{1}$$

where Q is the quality rating or sub index, C is the concentration of the parameter in (mg/L), S is the permissible value of the parameter in drinking water (mg/L), and Q for DO and pH are given by Eq. (2).

$$Q = 100 \times \frac{(C - V)}{(S - V)} \tag{2}$$

where V is the ideal value, considered to be 14.6 and 7.0 for DO and pH, respectively.

The weightage is calculated using Eq. (3):

$$W \propto \frac{1}{S} = \frac{K}{S} \tag{3}$$

where S is the standard permissible value of the parameter in drinking water (mg/L).

4.5.1. Metal-based indices

Toxicity of metals has been a longstanding issue in the formulation and implementation of drinking water quality standard and guideline, due to their major public and environmental health concern [191]. The quality of water for drinking and aquatic life is monitored by certain metal indices which play a major role in the decision and acceptability of water. This is due to the toxic nature of the metals even at low concentrations which undergo continuous bioaccumulation and biomagnification in the body of plants and animals [13]. It is thus important to monitor the presence of metals in water and identify the hazard and risk associated with its use [192].

4.5.1.1. Metal index. The maximum allowable concentration of metals in drinking water guideline forms the basis of the metal index (MI) evaluation. Assessment and classification of water quality for human consumption can be achieved using the MI technique [193].

MI takes into account heavy metals with possible effects on human health. An expression for calculating MI was proposed [194]:

$$\mathrm{MI} = \sum \left[\frac{C}{(\mathrm{MAC})} \right] \tag{4}$$

where C is the mean concentration of each metal, and MAC is the maximum permissible concentration of the metal in drinking water. The higher the value of C with respect to MAC the more deteriorated the water quality is. Hence, $\mathrm{MI} > 1$ signifies a threat to human health [193,195,196].

Comparison of the pollution assessment with respect to the MI (Table 3) indicates a poor water quality in the lake, river and ex-mining pond with respect to all the metals under study at 95th percentile, except Zn in lake water (Fig. 4).

4.5.1.2. Heavy metal pollution index (HPI). The influence or effect of a specific heavy metal on the overall water quality may be rated using the heavy metal pollution index (HPI). The rating scale is a value from 0 to 100 showing quality considerations and comparison to the standard recommended water quality guidelines in inverse proportion [181,197]. HPI is computed using the equation below:

$$\mathrm{HPI} = \frac{QW}{W} \tag{5}$$

where Q is the quality rating of the parameter and W is the weightage of the parameter with respect to its maximum permissible limit.

HPI is considered as critical when it equals 100, and in this review the standard value is considered from WHO, INWQS, and USEPA [133,134,144,190].

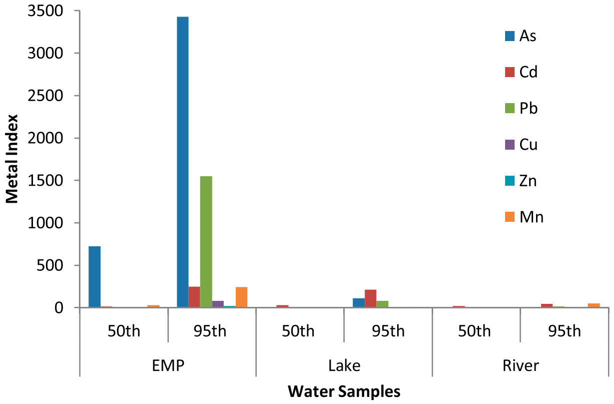

Fig. 4. Comparison of the pollution assessment with respect to MI in lakes, rivers, and ex-mining ponds in Malaysia.
Note: EMP: ex-mining pond.

4.5.1.3. Degree of contamination. Maximum permissible values of water quality parameters are used in the evaluation of the degree of contamination. The effects of several water quality parameters are summarized to assess the degree of contamination; these parameters are considered harmful to household water and will subsequently affect humans [198]. The degree of contamination (C_d) can be calculated:

$$C_d = \sum_{i=1}^{n} C_{ft} \tag{6}$$

where $C_{ft} = (C_A/C_N) - 1$.

C_{ft} is the contamination factor; C_A and C_N are the analytical value and maximum permissible value of the parameter.

4.5.2. Physical indices

Physical parameters perform an important role in the rating and monitoring of water quality to ensure

Table 3
Comparison of the pollution assessment with respect to MI in Malaysia

	EMP		Lake		River	
Heavy metal	50th	95th	50th	95th	50th	95th
As	724.8	3,430	6.7	113.1	0.70	17.60
Cd	13.3332	245.8	30.383	210	17.333	46.23
Pb	2.64	1,548.4	0.929	81.10	1.04	12.96
Cu	1.0	78.81	0.0106	4.2425	0.019	8.681
Zn	0.5	20.143	0.0096	0.7121	0.0116	6.516
Mn	31	240	1.165	11.640	0.435	48.604

Note: EMP = ex-mining pond.

its conformity with standard water quality guidelines. Several indices were formulated based only on physical parameters which are included in virtually all the water quality standards and indices, but with differences owing to variations in the environmental features and climate.

4.5.2.1. DOE-WQI. An indexing system of water quality classification has been introduced in Malaysia based on only six parameters that appeared in the Interim National Water Quality Standard (INWQS) to monitor the water quality of rivers by the authorities concerned [199]. The WQI currently used in Malaysia (Referred to as the DOE-WQI) was formulated using the Delphi method in which opinion poll by panel of experts was considered on the parameter selection and assigning of weightage to each parameter based on its perceived importance [200]. Parameters chosen for the WQI are COD, pH, ammoniacal nitrogen (AN), SS, biochemical oxygen demand (BOD_5), and DO. Sub-indices are used in the calculations of the selected parameters, and named SIBOD, SIDO, SIAN, SISS, SIPH, and SICOD:

$$\begin{aligned}\text{DOE–WQI} = {} & 0.16 \times \text{SICOD} + 0.15 \times \text{SIAN} + 0.22 \\ & \times \text{SIDO} + 0.16 \times \text{SISS} + 0.12 \times \text{SIPH} \\ & + 0.19 \times \text{SIBOD}\end{aligned} \tag{7}$$

The application of WQI in the assessment of Malaysian river water system is related to the national sanitation foundation water quality index (NSFWQI) approach [201,202]. The identification of the weaknesses and proposal of an upgraded model of the current index were carried out [203].

4.5.2.2. National sanitation foundation index. The development and application of the National Sanitation Foundation Water Quality Index (NSFWQI) was pioneered and led to many derivatives of NSFWQI [204,205]. The index is similar to the Horton index, however, it has a higher precision in parameter selection, with the scale and weightage assigned based on the Delphi method. This achievement was much promoted by the National Sanitation Foundation (NSF) and due to this the Brown's index is also called NSF-WQI. It is one of the most commonly used indexes comprising nine water quality parameters: faecal coliform, biochemical, pH, oxygen demand (BOD_5), temperature change, nitrate, total phosphate, DO, turbidity, and total solids. Its major advantage is that the number of parameters formulated is selected in relation to the water quality objectives of interest. However, specific water functions such as for drinking water supply, industry, and agriculture were not recognized and incorporated into the index. The arithmetic and additive formulations, although simple to comprehend and compute, have no sensitivity to the effects of a deplorable parameter value on the overall WQI. A modified multiplicative index was formulated to propose a variation in NSF-WQI [206].

4.5.2.3. Canadian water quality index (CWQI). The Canadian Council of Ministers of the Environment (CCME) established a subcommittee that developed the index which has been adopted and applied in water management divisions of various countries. It utilizes a total of 14 parameters: DO, temperature, faecal coliform, total suspended solids, phosphate, nitrate, oil and grease, arsenic, mercury, copper, cadmium, chromium, lead, and tributyltin [192,207]. This index is an adaptation of the British Water Quality Index (BCWQI) and utilizes all relevant parameters for which standards can be referred to, including those related to the safety of aquatic species [207]. There are three factors in the index, each of which has been scaled between 0 and 100. It entails the extent of water quality non-compliance and amplitude of deviation from the standards. The major advantage of CCME is that it is able to utilize as many variables as there are in the existing corresponding environmental standards. The major weakness is the insensitivity of a particular water quality parameter in the process of aggregation, but an effort had been made to address this deficiency [208]. The global drinking WQI was also formulated based on the rating of CCME WQI [209]. CCME WQI has also been proposed to be the basis for the formulation of WQI for drinking purposes in Malaysia [210].

Another methodology formulated an index called the fuzzy WQI [211,212] which handles temperature, salinity, DO, and pH was found to be more sensitive than CCME [213]. In a more recent study, the suitability of five water quality indices was compared, among which are NSF-WQI and CCME-WQI for the use in automated sampling networks. The authors found that CCME-WQI is the best suited for the purpose [214]. Notwithstanding its success, CCME-WQI does not take into account the presence of toxic chemicals which may be diluted by other parameters and may render the quality of the water acceptable. In view of this, CCME-WQI approach is subjected to situations where the presence of one "bad" parameter is compensated by other "good" parameters [215].

4.5.3. Combined indices

Proper analysis of water quality especially for drinking purposes can be achieved by incorporating biological, physicochemical parameters, and heavy metals in the water quality model. Universal water quality index (UWQI) accommodates the above-stated parameters which include pH, DO, BOD, total coliform, fluoride, cadmium, mercury, cyanide, selenium, arsenic, nitrate–nitrogen, and total phosphorous. The advantage of UWQI over other pre-existing indices is its specific use for the purpose of drinking instead of general supply, and the supranational standard was considered in the development of the index. Most indices were developed based on the national standards of any particular country and this limits their application to within the country of origin [192].

4.6. General limitations of the indices

Most of the operational indices developed had no defined procedure for understanding sensitivity analysis due to the alteration of the component parameter (s), which is considered essential in index development. Furthermore, sensitivity analyses of the indices to different weightages are not considered, instead, the Delphi method was used for weightage assignment resulting in subjectivity. The importance of index sensitivity was emphasized [216,217]. Moreover, sources and methods of data collection and evaluation of missing data determine the integrity of the indices [218]. Little or no concern was given to how data sources can affect the assessment of index as mostly secondary data sources were used which are simple and easily available. In addition, there was an opinion that data from such source may be unreliable [219]. In spite of these weaknesses, few indices used primary data collection in their formulation [220].

4.7. Risk-based indices

The environmental monitoring analysis and assessment of potential trends in the level of toxic metals with reference to the international guidelines forms the basis for health risk analysis, which were computed using risk-based indices. The assessment of the tendency for occurrence of any health complication as a result of short- or long-term exposure to certain substances is termed as risk assessment. In surface water, the assessment is investigated either by direct ingestion or through skin (Dermal) route [196,221]. In light of the above-stated routes, the doses of the exposure are calculated using the equations below:

$$\mathrm{Exp}(\mathrm{ing}) = \frac{C \times \mathrm{EF} \times \mathrm{IR} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \tag{8}$$

$$\mathrm{Exp}(\mathrm{der}) = \frac{C \times \mathrm{Ksp} \times \mathrm{SA} \times \mathrm{ED} \times \mathrm{EF} \times \mathrm{CF} \times \mathrm{ET}}{\mathrm{BW} \times \mathrm{AT}} \tag{9}$$

where Exp(ing) is exposure dose by ingestion of water (μg/kg/d), Exp(der) is exposure through skin absorption (μg/kg/d), C is the concentration of the metal in water sample (μg/L), EF is the exposure frequency (360 d), IR is the water ingestion rate (2.2 L/d), ED is the duration of exposure (30 years), AT is the average time (10,950 d), BW is the average body weight (70 kg),

ET is the exposure time (0.6 h/d), SA is the skin surface area exposed (28,000 cm^2), Ksp is the dermal permeability coefficient, and CF is the conversion factor (0.001 $\mathrm{L/cm}^3$) [57,222,223].

4.7.1. Carcinogenic risk

The increased tendency of a person to develop cancer due to exposure for a period of time is called the carcinogenic risk. It is a known fact that the exposure to heavy metals results in health complications, among which is cancer [21]. Hence, it is important to analyze the carcinogenic risk upon exposure to the metals under study. The accepted range or limit of the carcinogenic risk is 1×10^{-6} to 1×10^{-4} [224]. Eq. (10) below is used in evaluating the carcinogenic risk of the metals:

$$\mathrm{CR}(\mathrm{ing}) = \frac{\mathrm{EXP}(\mathrm{ing})}{\mathrm{SF}(\mathrm{ing})} \tag{10}$$

where CR(ing) is the carcinogenic risk by means of ingestion (no unit), SF(ing) is carcinogenic slope factor, ingestion (μg/g/d) and Exp(ing) is the exposure dose through ingestion of water (μg/g/d). The SF(ing) values for Pb, As, and Cd, are 8.5, 1.5, and 6.1×10^3, respectively [195,196,225].

The analysis of exposure to selected metals at various levels in ex-mining pond, lake, and river water through ingestion and dermal routes revealed that the level of exposure from ingestion EXP(ing) and dermal EXP(der) in the ex-mining ponds was found to be in the order Cu > Pb > As > Zn > Mn > Cd. For lake water, it is Cu > Pb > Mn > Zn > As > Cd for the dermal and ingestion exposure routes, while the order with respect to river water is Zn > Mn > Cu > Pb > As > Cd for the ingestion and dermal exposure routes. The results of the exposure analysis generally portray that Zn, Cu, Pb, and As contribute more to the ingestion and dermal exposure in ex-mining pond, Mn, Pb, and Cu for the lake, and Zn, Mn, and Cu for river water. This is a threat to the health of residents because exposure to these metals could impose hazard [223].

The carcinogenic risk value for the metals studied in the ex-mining ponds, rivers, and lakes is found to be far beyond the accepted range of 1×10^{-6} to 1×10^{-4} [224]. The extensive agricultural practices along the river banks and lakes, and release of domestic waste to the system could be the most important contributing factors that affect the water quality.

4.7.2. Non-carcinogenic risk

Hazard quotient (HQ) is used to explain or assess non-carcinogenic risks, and is defined as the amount of chronic daily intake (CDI), divided by the reference dose (RfD) of a particular chemical. The HQ for the non-carcinogenic effect caused by a chemical substance is calculated using Eq. (11) below [196]:

$$\mathrm{HQ} = \frac{\mathrm{ADI}}{\mathrm{RfD}} \tag{11}$$

where ADI is the acceptable daily intake and reference dose for the chemical substance in (mg/kg/d). A hazard index (HI) is applied when assessing the general tendency for the non-carcinogenic effects of more than one chemical [226], and is calculated using Eq. (12) below [196]:

$$\sum \mathrm{HIi} = \sum \frac{\mathrm{ADIi}}{\mathrm{RfDi}} \tag{12}$$

The populations exposed to the chemical are unlikely to have adverse health effect at HI value less than one. However, the adverse health effect may occur at HI value greater than one [227]. Nevertheless, the non-carcinogenic HI value of less than 0.5 is recommended [228].

The CDI is calculated using Eq. (13) below:

$$\mathrm{CDI} = \frac{\mathrm{DI}}{\mathrm{BW}} \times C \tag{13}$$

where DI is the average daily intake rate (2.2 L/d), C is the concentration of heavy metal in water (mg/L), and BW is the average body weight (70 kg).

CDI is more significant through oral compared to dermal and air routes [229]. The CDI of the metals studied at 50th and 95th percentile was found to be less than one (Table 4), indicating lower risk which is regarded as a safe limit [230], except for As, Pb, Cu, Zn, and Mn in the ex-mining ponds at 95th percentile. Fig. 5 reveals the orders of the CDI of the metals as Cu > Pb > As > Zn > Mn > Cd, Cu > Pb > Mn > Zn > As > Cd and Zn > Mn > Cu > Pb > As > Cd for the ex-mining pond, lake, and river water, respectively.

5. Chemometric view

Most multivariate statistical techniques applied in data interpretation and analysis includes PCA, FA, and CA.

The application of PCA to about 12 parameters (heavy metals and general water quality parameters) in water samples obtained from lakes, rivers, and ex-mining ponds revealed four PCs that accounted for 65.84% of the cumulative total variance. TSS, COD, BOD, Pb, and As have similar loadings on PC1 (Fig. 6). The first PC can also be viewed primarily as a measure of TSS, COD, BOD, and Pb and As due to their high loading. Surface water from the ex-tin mine in Thailand was confirmed to contain dissolved As at

Table 4
Comparison of the risks analysis with respect to CDI in Malaysia (mg/kg/d)

	EMP		Lake		River	
Heavy metal	50th	95th	50th	95th	50th	95th
As	0.227794	2.17800	0.002106	0.035546	0.000220	0.005531
Cd	0.001257	0.03175	0.002865	0.019800	0.001634	0.004359
Pb	0.004149	2.433263	0.001460	0.127443	0.001634	0.020366
Cu	0.031429	2.476886	0.000333	0.133336	0.000597	0.272831
Zn	0.047143	1.899229	0.000911	0.067147	0.001094	0.614403
Mn	0.194857	1.508570	0.007323	0.073171	0.002737	0.305511

Note: EMP = ex-mining pond.

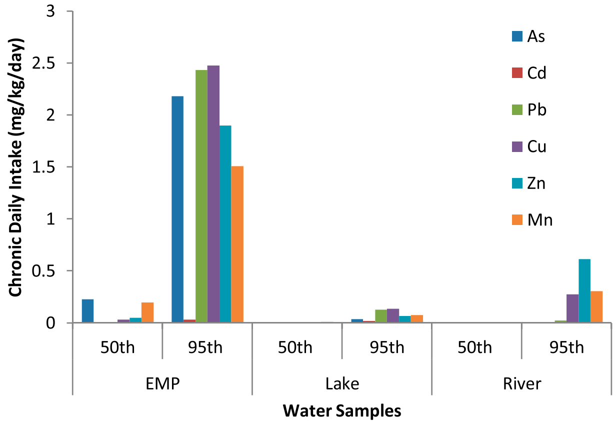

Fig. 5. CDI of water in lake, river, and ex-mining pond in Malaysia.

concentrations exceeding WHO potable water guidelines 0.01 mg/L by up to a factor of 500 [231]. The concentration of arsenic in the effluent of gold mining site was higher than the Ghana environmental protection agency water guideline. The ex-mining ponds are also associated with high TSS due to the presence of high amounts of crushed rocks and earth materials from which the mineral was extracted [52]. The origin of As in mine water is associated with As-rich sulfide minerals [232]. Contaminated tin ore also contains a significant concentration of arsenic in the form of arsenious oxide, where this byproduct is remobilized into lakes. The ex-mining regions are mostly rich in uranium and thorium bearing minerals leading to the accumulation of Pb-210 in the lake [68]. Higher values of COD is an indication of flooded organic matter which is one of the features of ex-mining ponds, indicating increased anthropogenic pressures on lakes which result in high COD values [233]. High BOD could be due to high burden and impact of organic matters [52].

Variables with similar loadings in PC2 are Zn, Cu, and Mn. The negative sign indicates an inverse relation among the parameters.

In the PCA of water samples from different sources, PC1 accounted for 26.1% of the variance, and the parameters with the largest contribution are, BOD, COD, TSS, As, and Pb, while PC2 contributes 17.8% of the total variance and is dominated by Cu and Zn.

The primary purpose of CA is to categorize items into clusters on the basis of their similarities. Hierarchical clustering involves the sequential formation of clusters. Objects that are most similar are first grouped; these existing groups are then merged based on their similarities. It can be inferred from Fig. 7 that CA using the ward method identified two main groups of samples. There was a high similarity among variables in water samples from lakes and ex-mining ponds, and no cluster was formed between water samples from rivers and lakes in the first cluster. This sheds light that there is a clear distinction in water quality between rivers and lakes or ex-mining ponds. Most lakes in Malaysia are ex-mining ponds, and as such, require a different technique in water quality monitoring compared to rivers.

The second cluster was dominated by subclusters from river water samples and fewer subclusters from lake water samples. Distinct clusters emerged indicating variations in the water samples (Fig. 8). In the two main clusters formed, the first cluster was dominated by water samples from the lakes and ex-mining ponds, while the second cluster was dominated by the river water samples.

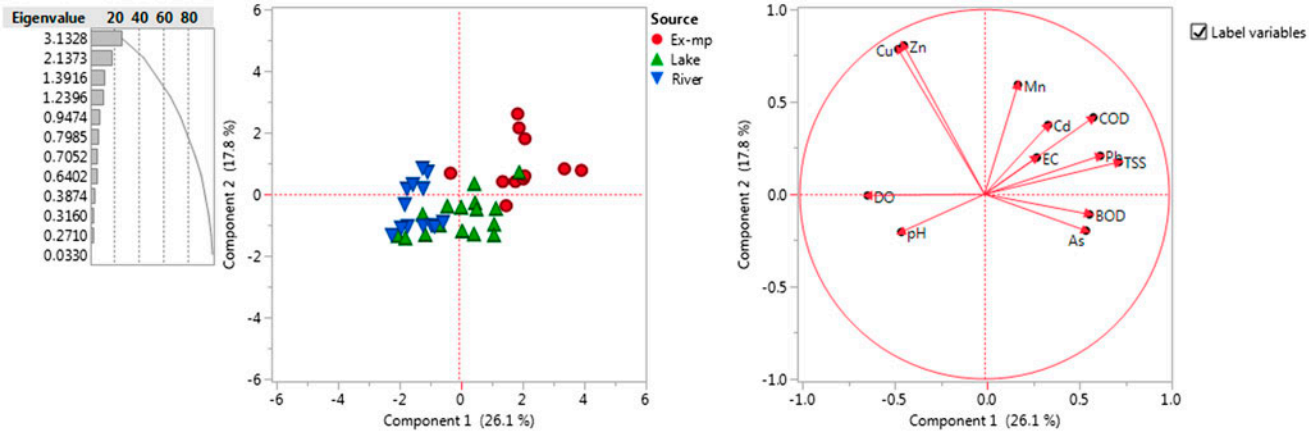

Fig. 6. PCA plot of heavy metal concentrations and physicochemical parameters in lake, river, and ex-mining ponds in Malaysia and other selected countries.

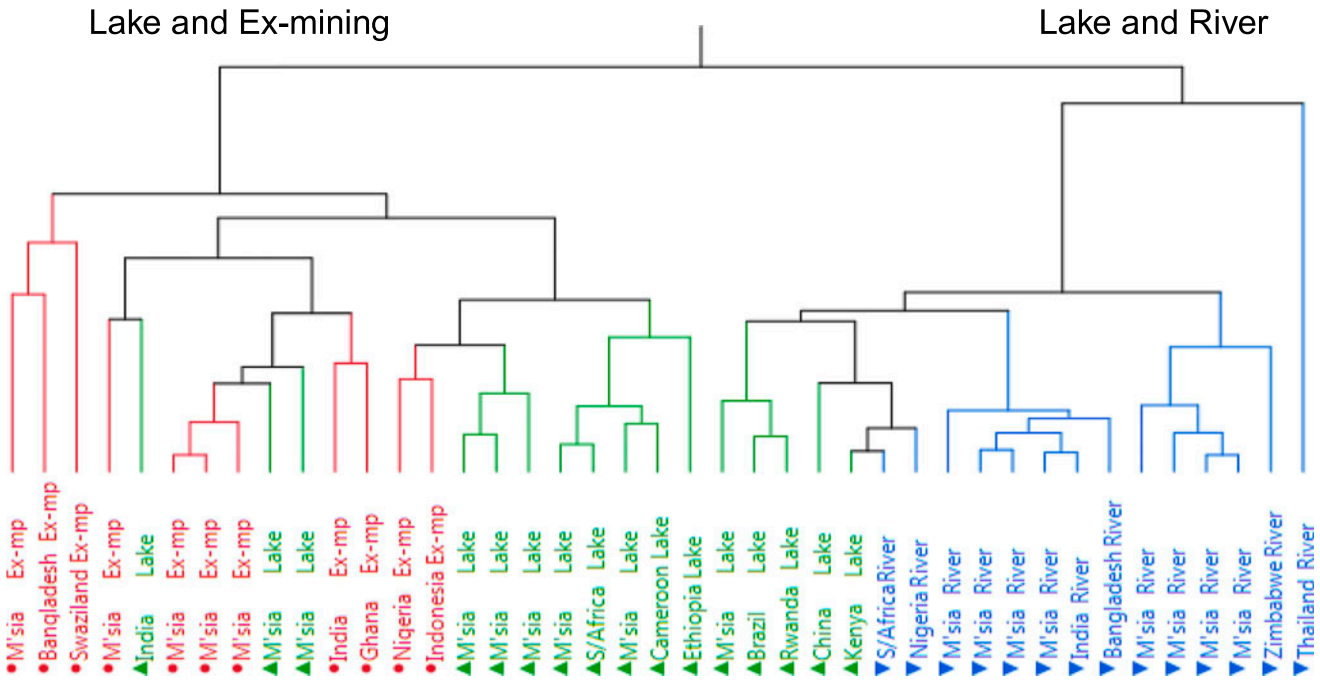

Fig. 7. Dendrogram showing clustering of sources of water with respect to their country.

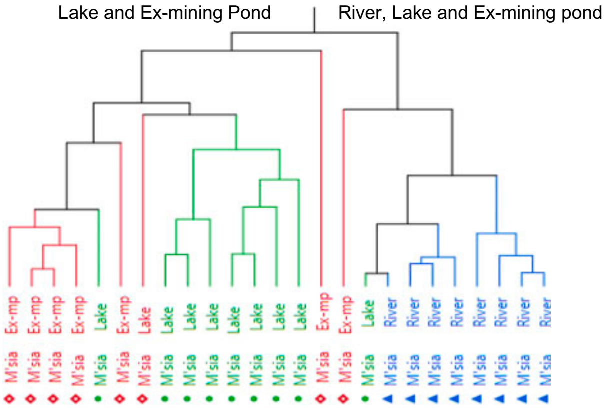

Fig. 8. Dendrogram showing clustering of sources of water in Malaysia.

6. Gaps in developing water quality index of Malaysian water bodies

Developing a new WQI is imperative in order to check and monitor the potential hazard posed by heavy metal pollutants in hundreds of abandoned mining ponds and lakes. Parameters related to metal pollutants are not accommodated in the already existing Malaysian river WQI. WQI of the selected ex-mining ponds of Bestari Jaya and Kelana Jaya based on weighted arithmetic index method revealed very low-water quality with a significant level of heavy metal concentrations beyond permissible limit, particularly the arsenic concentration [49,53]. Similar studies on hydrochemical characteristics of water in ex-mining pond in Kenya [234] revealed a high concentration of toxic heavy metals above WHO permissible limit [134]. Surface water of mine areas in India and Bangladesh were also classified unfit for human consumption in terms of physicochemical parameters [85,235].

Many rivers around the world are unsuitable for specific uses due to high or low pH value, but Malaysian river waters had no history of impairment of water quality due to pH, as such, should not be included in the existing river WQI. However, it should be included for lakes and ex-mining ponds (Table 2).

The available index (DOE-WQI) also gave no consideration for coliform-based indicators, which are very important as well and relevant in the evaluation of recreation (skin contact) and potable water supply [236].

7. Conclusions

From this review, there is clear indication that water bodies in Malaysia and around the world are exposed to pollution by heavy metals. Analysis of the level and variation in selected heavy metals in ex-mining ponds, lake and river water, and risk assessments of exposure to these metals was carried out in this review. Significant concentrations of toxic metals were identified in the ex-mining ponds and lakes which exceeded the Malaysian drinking water and WHO standards, signifying pollution. In comparison, heavy metal concentrations in river water are minimal, and similarity was observed in variable concentrations between lakes and ex-mining ponds. Carcinogenic risks in rivers, lakes, and ex-mining ponds were high and posed health threat to nearby residents and consumers. We believe there is enough evidence in this review to push for a full monitoring of metal concentrations, and regulate human activities around the existing Malaysian water bodies. It is also of great public health concern to certify the water quality status of the ex-mining ponds in order to decide on its proper utilization. This can be achieved by developing a new WQI for its proper assessment and classification. The developed index can be applied to both lakes and ex-mining ponds, and subjected to future modifications. Based on the level of polluted waters, suggestions can be made on the possible metal removing techniques so as to utilize the water for different beneficial purposes. Enough evidence was given in this review on the need to review and strengthen the existing mining policies and embark on proper environmental monitoring processes in mining areas.

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