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Research Article

Analysis of Physiochemical Parameters to Evaluate the Drinking Water Quality in the State of Perak, Malaysia

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The drinking water quality was investigated in suspected parts of Perak state, Malaysia, to ensure the continuous supply of clean and safe drinking water for the public health protection. In this regard, a detailed physical and chemical analysis of drinking water samples was carried out in different residential and commercial areas of the state. A number of parameters such as pH, turbidity, conductivity, total suspended solids (TSS), total dissolved solids (TDS), and heavy metals such as Cu, Zn, Mg, Fe, Cd, Pb, Cr, As, Hg, and Sn were analysed for each water sample collected during winter and summer periods. The obtained values of each parameter were compared with the standard values set by the World Health Organization (WHO) and local standards such as National Drinking Water Quality Standard (NDWQS). The values of each parameter were found to be within the safe limits set by the WHO and NDWQS. Overall, the water from all the locations was found to be safe as drinking water. However, it is also important to investigate other potential water contaminations such as chemicals and microbial and radiological materials for a longer period of time, including human body fluids, in order to assess the overall water quality of Perak state.

1. Introduction

Water plays a significant role in maintaining the human health and welfare. Clean drinking water is now recognised as a fundamental right of human beings. Around 780 million people do not have access to clean and safe water and around 2.5 billion people do not have proper sanitation. As a result, around 6–8 million people die each year due to water related diseases and disasters [1]. Therefore, water quality control is a top-priority policy agenda in many parts of the world [2]. In the today world, the water use in household supplies is commonly defined as domestic water. This water is processed to be safely consumed as drinking water and other purposes. Water quality and suitability for use are determined by its taste, odor, colour, and concentration of organic and inorganic matters [3]. Contaminants in the water can affect the water quality and consequently the human health. The potential sources of water contamination are geological conditions, industrial and agricultural activities, and water treatment plants. These contaminants are further categorized as microorganisms, inorganics, organics, radionuclides, and disinfectants [4].

The inorganic chemicals hold a greater portion as contaminants in drinking water in comparison to organic chemicals [5]. A part of inorganics are in mineral form of heavy metals. Heavy metals tend to accumulate in human organs and nervous system and interfere with their normal functions. In recent years, heavy metals such as lead (Pb), arsenic (As), magnesium (Mg), nickel (Ni), copper (Cu), and zinc (Zn) have received significant attention due to causing health problems [2]. Moreover, the cardiovascular diseases, kidney-related problems, neurocognitive diseases, and cancer are related to the traces of metals such as cadmium (Cd) and chromium (Cr) as reported in epidemiological studies [6]. The Pb is known to delay the physical and mental growth in infants, while As and mercury (Hg) can cause serious poisoning with skin pathology and cancer and further damage to kidney and liver, respectively [2, 7]. According to the International Agency for Research on Cancer (IARC), Hg and inorganic Hg compounds are classified in group 3 carcinogens [8, 9]. Moreover, the presence of toxic and radioactive elements like uranium in the groundwater is another serious concern in many parts of the world such as USA, Canada, Germany, Norway, Greece, and Finland. It has high chemical toxicity and lethal effects on human skeleton and kidney [10, 11].

A number of scientific procedures and tools have been developed to assess the water contaminants [3]. These procedures include the analysis of different parameters such as pH, turbidity, conductivity, total suspended solids (TSS), total dissolved solids (TDS), total organic carbon (TOC), and heavy metals. These parameters can affect the drinking water quality, if their values are in higher concentrations than the safe limits set by the World Health Organization (WHO) and other regulatory bodies [2]. Therefore, the investigation of the drinking water quality by researchers and governmental departments has been performed regularly throughout the world [8–12].

In Malaysia, the main water sources are rivers and streams, which depend heavily on rainfall. The annual range of rainfall in Malaysia on average is in between 2000 mm and 2500 mm [5]. According to Pillay et al. [13], the water demand will be 14 billion m^3 in 2020. The groundwater covers only 1% of the total water demand. The clean water supplies are managed by each state separately [5]. The Department of Environment (DOE) monitors the river basins for major contaminant sources [14], while the quality of the raw water reservoir is monitored by state water monitoring and controlling authorities [15]. The concentration of inorganic elements in drinking water samples of 12 different states of Peninsular Malaysia was carried out by Azrina et al. [5]. The concentrations of all elements were below the international safe limits, except for iron (Fe) and Pb in Kelantan and As in Perlis state. Hasbiyana [16] analyzed the tap water samples from industrial, agricultural, and residential areas of Shah Alam, Selangor, and showed all heavy metals concentration exceeded the standard of National Drinking Water Quality Standard (NDWQS) [17]. The concentration of As and Pb was also found to be exceeding in comparison to respective countries guidlines and international standard [18–21]. Besides the drinking water source (tap water), another common source is the bottled mineral water. Previously, the research studies [22, 23] have shown that the quality of bottled mineral water is not always superior to the tap water.

Perak is one of largest, historical, and tourist states of Malaysia. The state was famous for minerals and tin-mining activities until very recently. There is no information available in the scientific literature on drinking water quality and potential sources of water contamination. As the region is currently the center of tourism, therefore this is crucial to evaluate the drinking water quality of the state in order to assure safe drinking water for local residents and tourists. The present study aimed to evaluate the drinking water quality including tap and bottle water of Perak state, Malaysia. A detailed physical and chemical analysis was carried out by taking water samples from different residential and commercial areas of the state. The parameters such as pH, turbidity, conductivity, total suspended solids (TSS), total dissolved solids (TDS), and heavy metals such as Cu, Zn, Mg, Fe, Cd, Pb, Cr, As, Hg, and tin (Sn) were analysed in each water sample. The results of each parameter were compared to the guidelines and standards set by the WHO [2] and local standards such as NDWQS [17].

2. Material and Methods

2.1. Study Area. Perak is the second largest land area (21,006 km^2) state of Malaysia among the 14 states. The state is sourrounded by Kedah and Thai state (from the North), Strait of Malacca (from the West), Kelantan and Pahang (from the East), and Selangor (from the South). The city of Ipoh is the state capital. Perak has tropical rainforest climate and there is no dry season. The temperature fluctuates on average from 32°C to 34°C during the summer, while it ranges from 22°C to 24°C during the winter time. Perak Water Board (PWB) is the agency responsible for supplying clean water to the whole state of Perak. The raw water resources are rivers such as Perak River and mountain and dam waters. The PWB is operating two dams such as Sultan Azlan Shah and Air Kuning dams located in Ulu Kinta, Ipoh, and Taiping, respectively [23]. PWB has 47 water treatment plants with total capacity of 1774 million litres per day. The current production of plants is 1081 million litres per day. The water distribution is 100% to the urban areas and 98% to the rural areas with the pipeline system extended to an area of 10792 km [24].

2.2. Selection of Sampling Points. The criteria of selecting sampling points were based on the population density, areas of industrial or anthropogenic activities such as minerals and mining activities, and the river catchment areas. As mentioned earlier that Perak was famous for its minerals and mining activities, therefore it was significant to see the water quality in such areas, especially where the rivers are flowing and crossing the mining areas. Studies have shown that disused tin-mining areas pose potential health hazards due to high amount of inorganic arsenic and other heavy metals [26]. Therefore, 8 different locations in Perak state were chosen based on designed criteria. These locations were Bandar Universiti (BU), Bandar Seri Iskandar (BSI), Siputeh (SIP), Tronoh (TRO), Taman Maju (TM), Batu Gajah (BG), Universiti Teknologi PETRONAS (UTP), and Ipoh (IP) (Figure 1).

2.3. Sample Collection. All of the drinking water samples were taken from the tap water of residential and commercial areas. All of the sampling premises are open for public such as restaurants and private houses. In addition, samples of bottled mineral water (MW) purchased from local super market and reverse osmosis (RO) water were collected. The bottled mineral water was selected because it is not always better than tap water [19, 22]. The samples were numbered from 1 to 10 against their locations and sources (Table 1). The samples

Figure 1: The map of sample locations in Perak state, Malaysia. Source: https://www.maps.google.com/.

Table 1: Drinking water sample numbers, locations, and their sources.

Number	Locations	Source
1	Bandar Universiti (BU)	Tap water
2	Bandar Seri Iskandar (BSI)	Tap water
3	Siputeh (SIP)	Tap water
4	Tronoh (TRO)	Tap water
5	Taman Maju (TM)	Tap water
6	Batu Gajah (BG)	Tap water
7	Universiti Teknologi PETRONAS (UTP)	Tap water
8	Ipoh (IP)	Tap water
9	Mineral water (MW)	Mineral water
10	Water dispenser (RO)	RO water (reverse osmosis)

were collected in 1-liter polyethylene (PE) bottles, which were washed with deionized water before use. These sample bottles were sealed and placed in a dark environment at a constant temperature range of 4–10°C to avoid any contamination and the effects of light and temperature. For chemical analysis of collected water samples including pH, total suspended solids (TSS), total dissolved solids (TDS), turbidity, and conductivity, a representative water sampling was carried out from each location during the summer and winter times in a period of one year. During the summer, the temperature at the time of sampling was 33°C, while it was 23°C during the water sampling in winter. The average values of duplicate samples were used for graphical illustration. Each of the duplicate samples were analysed for a number of parameters in the laboratory to determine the overall drinking water quality.

2.4. Analytical Instruments

2.4.1. On-Site Analysis. On-site analyses of pH, conductivity, and turbidity were carried out at the site of sample collection following the standard protocols and methods of American Public Health Organization (APHA) [27] and American Society for Testing and Materials (ASTM) using different calibrated standard instruments [6]. The pH of the water samples was measured by using a pH meter (model HI 98130 HANNA, Mauritius, Iramac Sdn. Bhd.). The pH meter was calibrated, with three standard solutions (pH 4.0, 7.0, and 10.0), before taking the measurements. The value of each sample was taken after submerging the pH probe in the water sample and holding for a couple of minutes to achieve a stabilized reading. After the measurement of each sample, the probe was rinsed with deionized water to avoid cross contamination among different samples.

The conductivity of the samples was measured using a conductivity meter (model HI 98130 HANNA, Mauritius, Iramac Sdn. Bhd.). The probe was calibrated using a standard solution with a known conductivity. The probe was submerged in the water sample and the reading was recorded after the disappearance of stability indicator. After the measurement of each sample, the probe was rinsed with deionized water to avoid cross contamination among different samples. The turbidity of the water samples was measured using a turbidity meter (model 2100P Turbidimeter HACH, Colombia, USA, Arachem (M) Sdn. Bhd.). Each sample was poured in the sample holder and kept inside for a few minutes. After achieving the reading stability, the value was recorded.

2.4.2. Laboratry Analysis. The measurements of TSS and TDS in water samples were carried out according to the standard methods of APHA [27] and Sawyer et al. [28] by the filtration process. Therefore, the accuracy and precision of following methods are well approved and cited in the scientific literature. A fixed volume of water sample was poured on a preweighed glass fiber filter of a specified pore size before starting the vacuum filtration process. The filter was removed after the completion of the filtration process and placed in an aluminium dish in an oven at 100°C for 2-3 hours to completely dry off the remaining water. The filter was then weighed, and the gain in filter weight represented the TSS contents, expressed in mass per volume of sample filtered (mg/L). The TDS of the water samples were determined by the gravimetric method. After filtration for TSS analysis, the filtrate was heated in oven at above 100°C until all the water was completely evaporated. The remaining mass of the residue represents the amount of TDS in a sample.

The analyses of ten heavy metals such as Cu, Zn, Mg, Fe, Cd, Pb, Cr, As, Hg, and Sn were carried out based on ASTM standards [29–37], which are approved by APHA using Flame Atomic Absorption Spectrometer (FAAS) (AAS, Perkin Elmer Analyst 400, available at Universiti Sains Malaysia, USM). For analysis of Cd, Cr, and Pb, direct extraction/air-acetylene flame method was used, while manual hydride generation AAS method was used in determination of As in the samples. Cold-vapor AAS method was applied in determination of Hg and for Sn direct air-acetylene flame method was used. The presence of all ten heavy metals has been studied in all the water samples. The standard solution for each tested element was prepared according to

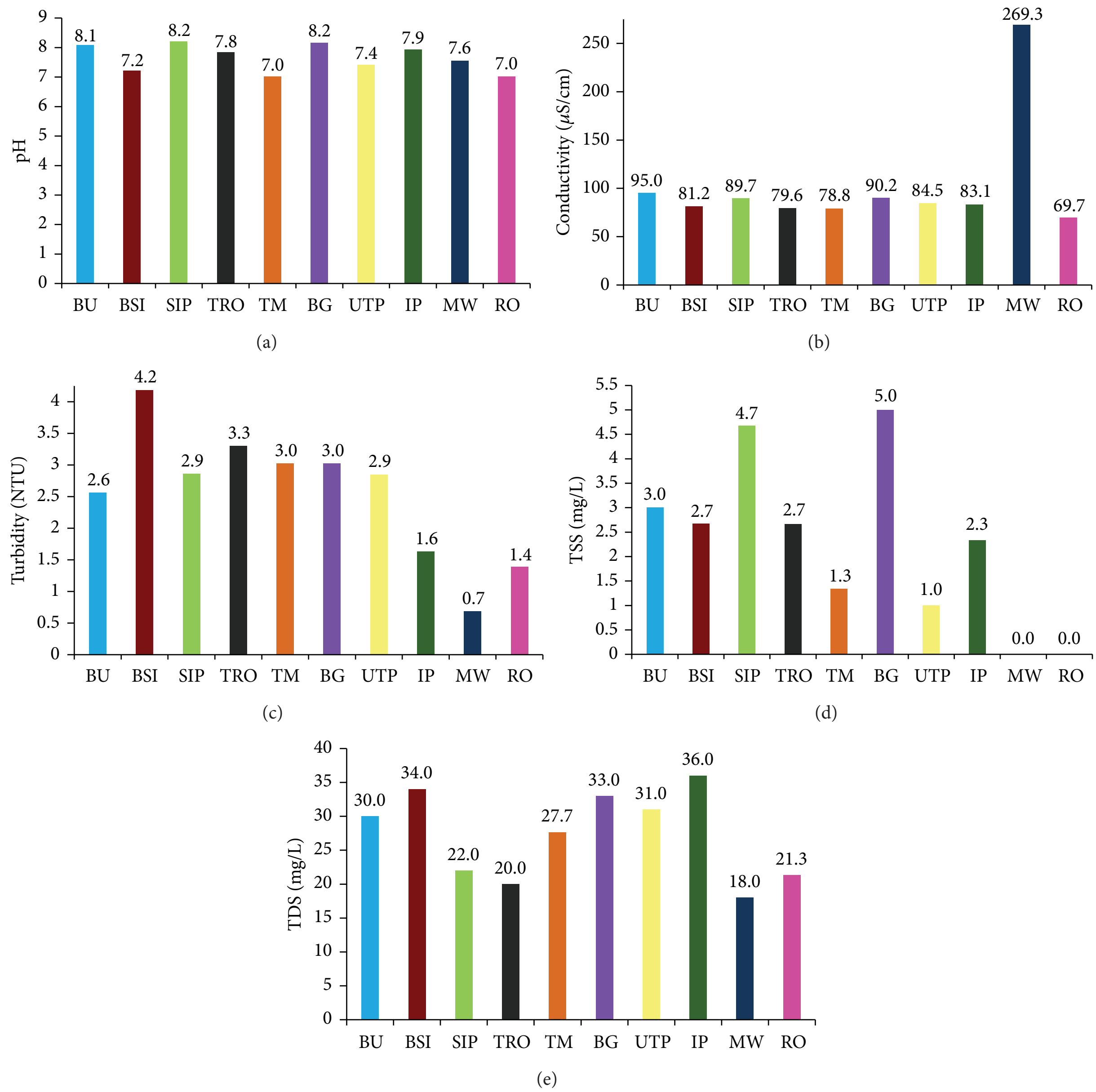

Figure 2: Various physical-chemical parameter analysis of drinking water samples in Perak state, Malaysia. (a) pH, (b) conductivity, (c) turbidity, (d) TSS, and (e) TDS.

its concentration and used to calibrate the system before analyzing each water sample. The results were recorded automatically on a computer connected with the AAS system.

3. Result and Discussion

3.1. Chemical Analysis. Chemical analysis includes the on-site analysis (pH, turbidity, and conductivity) and in-laboratory analysis (TDS and TSS).

3.1.1. pH. pH is classed as one of the most important water quality parameters. Measurement of pH relates to the acidity or alkalinity of the water. A sample is considered to be acidic if the pH is below 7.0. Meanwhile, it is alkaline if the pH is higher than 7.0. Acidic water can lead to corrosion of metal pipes and plumping system. Meanwhile, alkaline water shows disinfection in water. The normal drinking water pH range mentioned in WHO and NDWQS guidelines is between 6.5 and 8.5 (Table 2). The pH values of all the drinking water samples are found to be in the range between 7.01 and 8.21 (Figure 2(a)), where the lowest and highest values are from samples 5 (Taman Maju (TM)) and 3 (Siputeh (SIP)), respectively (Table 3). For MW sample, the measured pH is 7.4 which is almost the same as the pH stated by the manufacturer on the labeled of the container, that is, 7.33. This indicates that the manufacturer did not provide any inaccurate information on the label.

Table 2: The safe limits of WHO and NDWQS for determining drinking water quality.

Parameter	WHO limits	NDWQS limits
pH	6.5–8.5	6.5–9
Conductivity (μS/cm)	—	1000
Turbidity (NTU)	5	—
TSS (mg/L)	—	25
TDS (mg/L)	1000	1000
Cu (mg/L)	2	1
Zn (mg/L)	None	3
Mg (mg/L)	None	150
Fe (mg/L)	0.3	0.3
Cd (mg/L)	0.003	0.003
Cr (mg/L)	0.05	0.05
Pb (mg/L)	0.01	0.01
As (mg/L)	0.01	0.01
Hg (mg/L)	0.006	0.001
Sn (mg/L)	—	—

3.1.2. Electrical Conductivity. Electrical conductivity is the ability of any medium, water in this case, to carry an electric current. The presence of dissolved solids such as calcium, chloride, and magnesium in water samples carries the electric current through water. The measured conductivity values of all the drinking water samples are plotted in Figure 2(b). According to NDWQS [17], the maximum allowable level of conductivity is 1000 μS/cm. The results show that the measured conductivity of all water samples ranges from 69.7 μS/cm to 269.3 μS/cm, and the average conductivity value is 102.1 μS/cm (Table 3). The lowest and highest conductivity values correspond to RO and MW samples, respectively. This can be explained as the reverse osmosis treatment technique is used to remove dissolved solids, turbidity, colloidal matters, and others, and thus it gives lowest conductivity value. Similarly, it is expected to find high mineral contents in mineral water, which resulted in higher conductivity value (Table 3). Moreover, according to Azrina et al. [5], the wide differences among the values of the electrical conductivity of tap water are not yet known. Scatena [38] explained the differences based on various factors such as agricultural and industrial activities and land use, which affect the mineral contents and thus the electric conductivity of the water. Conductivity does not have direct impact on human health. It is determined for several purposes such as determination of mineralization rate (existence of minerals such as potassium, calcium, and sodium) and estimating the amount of chemical reagents used to treat this water [18–21]. High conductivity may lead to lowering the aesthetic value of the water by giving mineral taste to the water. For the industrial and agricultural activity, conductivity of water is critical to monitor. Water with high conductivity may cause corrosion of metal surface of equipment such as boiler. It is also applicable to home appliances such as water heater system and faucets. Food-plant and habitat-forming plant species are also eliminated by excessive conductivity [7–13].

3.1.3. Turbidity. Turbidity is the cloudiness of water caused by a variety of particles and is another key parameter in drinking water analysis. It is also related to the content of diseases causing organisms in water, which may come from soil runoff. The turbidity results for all 10 drinking water samples studied are shown in Figure 2(c). The standard recommended maximum turbidity limit, set by WHO and NDWQS, for drinking water is 5 nephelometric turbidity units (NTU) [2, 17]. The lowest turbidity values of 0.69 NTU and highest value of 4.6 NTU were found for samples 9 (MW) and 2 (Bandar Seri Iskandar (BSI)), respectively (Table 3). The mineral water, which was expected to be the cleanest water, thus had lowest turbidity values. The results indicate that the turbidity of all the samples studied was below the maximum standard limit of 5 NTU. Water from RO dispenser machine is also expected to have low turbidity value due to the filtration system, which is possessed to ensure efficient removal of undesired solids and organisms from turbid water.

3.1.4. Total Suspended Solids (TSS). The maximum recommended TSS limit set by NDWQS is 25 mg/L [17]. The TSS values of all the drinking water samples studied are shown in Figure 2(d). The highest value of 5 mg/L was found in water samples from the Batu Gajah (BG) area. However, it is still well below the maximum standard limit of 25 mg/L. It was also found that the samples collected from two other areas, Taman Maju and Universiti Teknologi PETRONAS, showed very little TSS contents. This is because the sample collection points in these areas had filtration systems attached to the taps, thus removing all the suspended particles such as silt, clay, and other inorganic particles. The TSS values of both samples 9 (MW) and 10 (RO) are also 0, as expected from these treated waters.

3.1.5. Total Dissolved Solids (TDS). TDS are the inorganic matters and small amounts of organic matter, which are present as solution in water. Figure 2(e) shows TDS values for all 10 drinking water samples. The standard or allowable value of the TDS set by NDWQS is 1000 mg/L [17]. The values found from the drinking water samples are all within 4% of the maximum limit of 1000 mg/L. The highest TDS values of 37 mg/L and the lowest TDS values of 17.8 mg/L correspond to samples from IP and MW, respectively (Table 3).

3.2. Heavy Metals Analysis. The presence of heavy metals in drinking water higher than a certain concentration can cause detrimental impacts on human health. Therefore, the analysis of heavy metals in drinking water is an important parameter, and most of the studies on drinking water quality involve investigation of heavy metals. In the present study, the results of heavy metals such as Cu, Zn, Mg, Fe, Cd, Pb, Cr, As, Hg, and Sn (Table 4 and Figure 3) are compared with the safe limits set by WHO and NDWQS (Table 2).

According to Hanaa et al. [39], Cd occurs naturally in rocks and soils and enters water when there is contact with soft groundwater or surface water. Moreover, it may be introduced by paints, pigments, plastic stabilizers, mining and smelting operations, and other industrial operations such

Table 3: Physical-chemical parameters of drinking water samples in Perak state, Malaysia.

Number	Locations	pH		Conductivity (μS/cm)		Turbidity (NTU)		TSS (mg/L)		TDS (mg/L)	
		S1*	S2*	S1	S2	S1	S2	S1	S2	S1	S2
1	Bandar Universiti (BU)	8.08	8.06	95.03	94.53	2.56	2.5	3	3.01	32	28
2	Bandar Seri Iskandar (BSI)	7.22	7.2	81.21	81.11	4.18	4.2	2.67	2.81	34	33.96
3	Siputeh (SIP)	8.21	8.2	89.73	88.83	2.86	3.06	4.67	4.73	24	20.01
4	Tronoh (TRO)	7.83	7.81	79.63	79.49	3.3	3.21	2.66	2.46	19	21
5	Taman Maju (TM)	7.01	7	78.76	78.69	3.02	3.22	1.33	1.72	28	27.88
6	Batu Gajah (BG)	8.15	8.1	90.23	91	3.02	3.12	5	5.1	32	34
7	Universiti Teknologi PETRONAS (UTP)	7.41	7.3	84.53	83.93	2.85	2.69	1	1.1	37	36
8	Ipoh (IP)	7.93	7.91	83.08	82.8	1.63	1.83	2.33	2.19	37	36
9	Mineral water (MW)	7.55	7.61	269.33	259.3	0.68	0.59	0	0	18	17.79
10	Water dispenser (RO)	7.02	7.1	69.7	68.9	1.39	1.77	0	0	22	20.6

S1* refers to the water samples taken during the winter time.
S2* refers to the water samples during the summer time.

Table 4: Concentration of heavy metals (mg/L) in drinking water samples of Perak state, Malaysia.

Number	Locations	Cu	Zn	Mg	Fe	Cd	Cr	Pb	As	Hg	Sn
1	Bandar Universiti (BU)	0.001	0.005	0.1522	0.045	0.0002	0.0014	0.0014	0.00002	0.00001	0.0054
2	Bandar Seri Iskandar (BSI)	0	0.004	0.2889	0.032	0.0003	0.0019	0.0018	0.00007	0.00002	0.0054
3	Siputeh (SIP)	0.001	0.002	0.1192	0.07	0.0004	0.0014	0.0021	0.00004	0.00002	0.0036
4	Tronoh (TRO)	0.001	0.001	0.2138	0.067	0.0006	0.0024	0.0025	0.00003	0.00001	0.007
5	Taman Maju (TM)	0.002	0.002	0.1416	0.053	0.0002	0.0019	0.0014	0.00004	0.00002	0.0071
6	Batu Gajah (BG)	0	0.002	0.5121	0.012	0.0005	0.0024	0.0025	0.00004	0.00002	0.0036
7	Universiti Teknologi PETRONAS (UTP)	0.002	0.004	0.2113	0.048	0.0005	0.0019	0.0018	0.00004	0.00002	0.007
8	Ipoh (IP)	0.001	0.001	0.3105	0.032	0.0002	0.0024	0.0028	0.00007	0.00002	0.0036
9	Mineral water (MW)	0	0.277	0.1906	0	0.00005	0.0005	0.0003	0.00001	0.00001	0.001
10	Water dispenser (RO)	0	0.008	0.3732	0	0.00005	0.0005	0.0003	0.00001	0.00001	0.0012

as electroplating and fossil fuel, fertilizer, and sewage sludge disposal. The concentration of Cd in the water sample from Tronoh (TRO) is found to be the highest (0.0006 mg/L) in comparison to samples from other locations (Figure 3). This might be due to corrosion of galvanized steel pipe that is used for piping of water distribution over the area. These galvanized steel pipes are plated with zinc, which usually has 1% of Cd. Similarly, Cd can also come from fittings with cadmium soldering [22]. There are no other sources of Cd as TRO is not near to any industry or waste disposal sites. The high concentration of Mg (0.5121 mg/L) in the sample of Batu Gajah (BG) might be due to deposits of underground minerals [5], while the values of Mg in all locations are below the standards set by WHO and NDWQS [2, 17].

The contamination of Cr, which is expected to be from industrial waste, is not applicable to any collected samples except for Ipoh (IP). Even for IP, the industries are located 3 km away and do not contain any steel or mill plants. However, it can be found due to erosion of natural deposits from the surrounding areas. The slight higher concentration of Pb in IP (0.0028 mg/L) than other locations may be due to the piping used for the water distribution system [3, 39] and also the surrounding soil which may have a higher amount of Pb, which may be leached into the water. The slight concentrations of Hg in samples may be due to erosion of natural deposits, which are abundantly available in these residential areas of Perak state. The other common sources of Hg can be the erosion of natural deposits, discharge of waste from refineries and related factories, and runoff from landfills and crops [10–13]. The IP is located near to a small industrial area, which can be the source of Hg despite the possible source of contamination from erosion of natural deposits.

The higher concentrations of As in the regions of IP and Seri Iskandar (SI) may be due to the chemical fertilizers used in the surrounding rice fields. Meharg et al. [40] reported the presence of As in the rice grain and the soil due to chemical fertilizers. Geographically, the IP is located near to Kinta small-medium industrial area, which may be causing

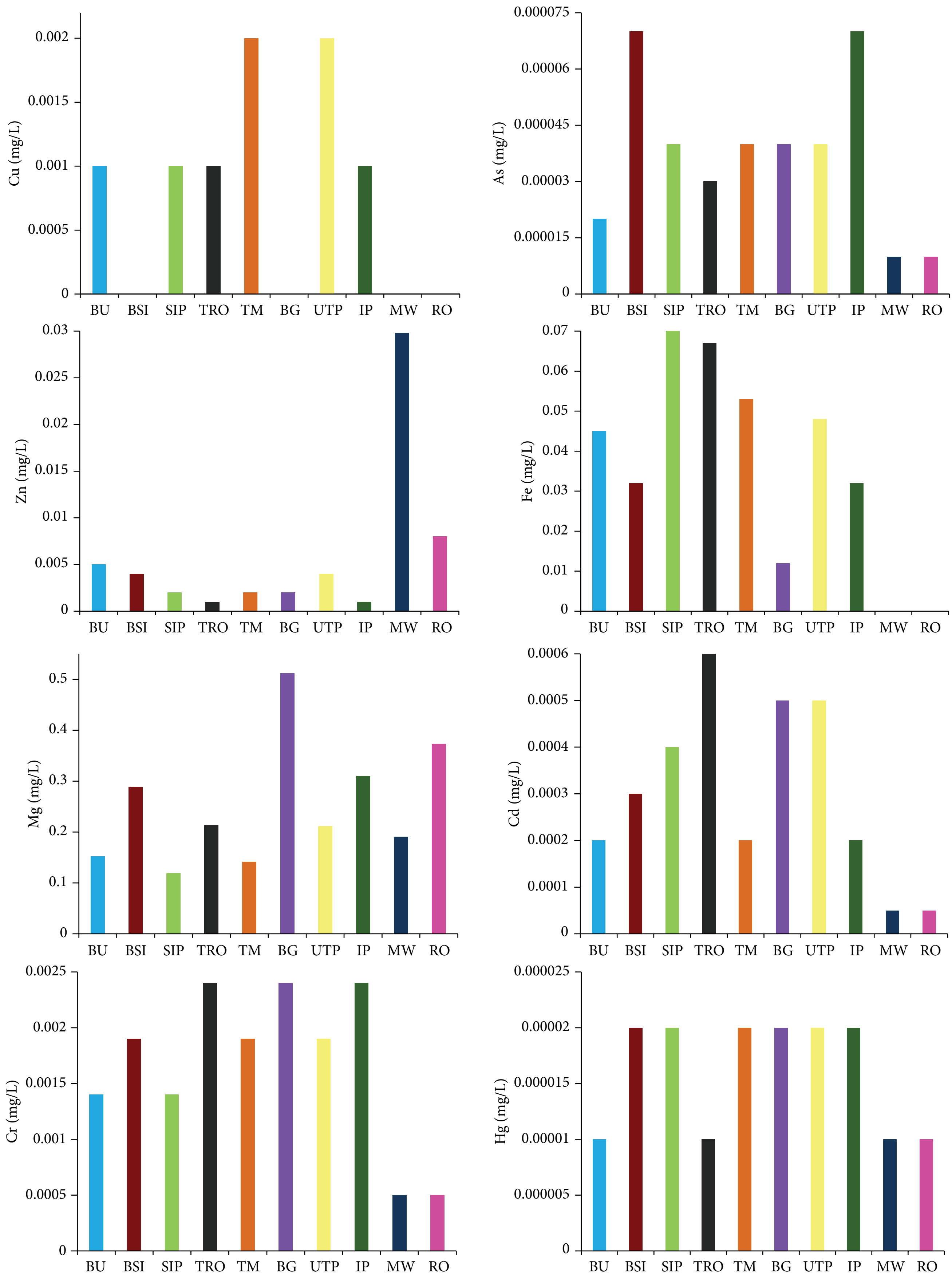

Figure 3: Continued.

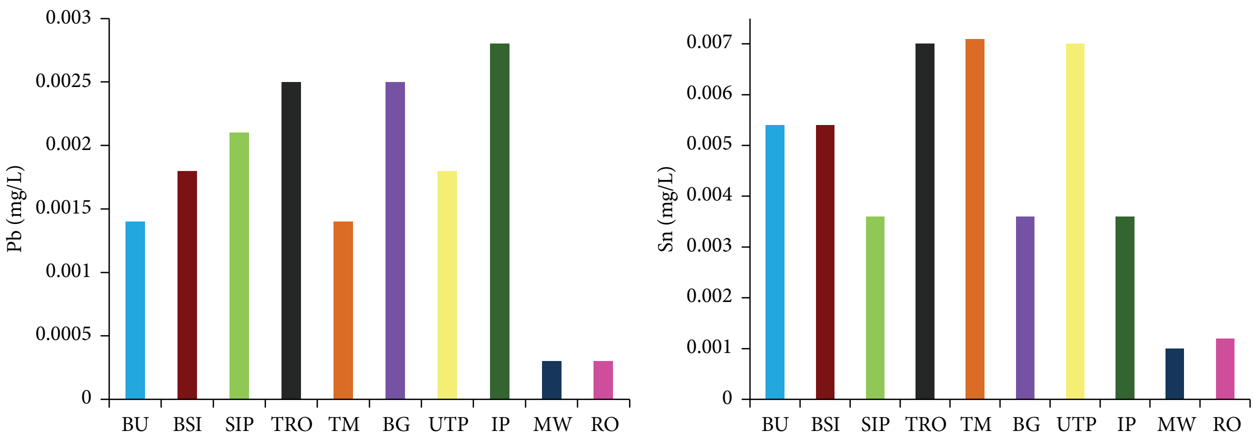

Figure 3: Heavy metals analysis of drinking water samples in Perak state, Malaysia.

the higher concentration of As in the analysed sample. The other sources of As can be erosion of natural deposits, runoff from orchards, manufacturing of semiconductor, and waste runoff from glass and electronics production plants [19–21].

In Malaysia, Perak state was known to be a land of minerals and tin-mining. Metal mining is found to be the second largest source of metal contamination in soil [41]. This includes metals such as Zn, Cu, Pb, and Sn. The highest concentration of Sn is found in three samples (UTP, TM, and TRO) with the value of 0.007 mg/L (Table 4). These areas are found to be the ex-tin-mining area or near to a tin-mining area. Rivers passing mining areas could carry with them the Sn and As. There is no maximum concentration of Sn set by WHO and NDWQS (Table 2), as it is not considered to be primary or secondary pollutants for drinking water. The metals can enter the water during the treatment process. Sn can also leach from Sn-Pb solder joints [42]. Corrosion and dissolution of the joint can be the potential source of Sn, Cd, Zn, Cu, and Pb leaching into the water. The inorganic Sn which is quantified in this study is known to have low hazard to human and animals. However, this can be converted into the second most toxic organic Sn such as methyltin through bacterial reaction [42]. Therefore, the high concentration of inorganic Sn can also pose a high risk to health as it can be converted into an organic Sn that can cause neurotoxic effect to human and animals [43]. It can be concluded that all the water is safe to drink as the values of drinking water quality parameters studied fall far below the maximum allowable limits.

3.3. Future Work. For a detailed analysis of water quality in Perak state, the monitoring and analysis should be carried out for a longer period of time. The minimum time for such monitoring should be one year in order to have a series of data or trends to confirm the study reliability. Standardization of the sampling locations would also help in making the obtained data more comparable with scientific findings. Study can be carried out in assessing concentration of Sn in the human body through analysis of urine or blood paired with health impact assessment to a population in certain locations, which may have been affected by high concentration of Sn in drinking water. The analysis of water parameters should be analysed in advanced analytical techniques such as Inductively Coupled Plasma-Mass Spectrometer (ICP-MS) in comparison to FAAS (used in current study) due to high detection limits (Table 5). Besides the chemical and heavy metal analysis, the microorganisms (protozoa parasite, algae, bacteria, and virus), radionuclides (radioactive material's such as uranium), and disinfectants should be analysed using advanced techniques such as ICP-MS.

Table 5: Comparison of detection limits of selected heavy metals using FAAS and ICP-MS [25].

Heavy metals	FAAS (μg/L)	ICP-MS (μg/L)
Cu	1.5	0.0002
Zn	1.5	0.0007
Mg	0.15	0.0001
Fe	5	0.0005
Cd	0.8	0.00007
Pb	15	0.00004
Cr	3	0.0003
As	150	0.0004
Hg	300	0.001
Sn	150	0.0002

4. Conclusions

The values of water quality parameters such as pH, conductivity, turbidity, TDS, and TSS from all samples collected from different residential and commercial areas of Perak state were found to be within the recommended limits of WHO and NDWQS. The concentrations of 10 heavy metals (Cu, Zn, Mg, Fe, Cd, Pb, Cr, As, Hg, and Sn) were also measured and found to be well below the standard maximum concentrations. Therefore, the quality of tap drinking water is good in residential areas of Bandar Universiti (BU), Bandar Seri Iskandar (BSI), Siputeh (SIP), Tronoh (TRO), Taman Maju (TM), Batu Gajah (BG), Universiti Teknologi PETRONAS (UTP), and Ipoh (IP) in Malaysia. However, it is also important to investigate other potential water contaminations such as chemicals and microbial and radiological materials for a longer period of time, including human body fluids, in order to assess the overall water quality of Perak state.

Acronyms and Abbrevations

As:	Arsenic
APHA:	American Public Health Association
ASTM:	American Society for Testing and Materials
BG:	Batu Gajah
BU:	Bandar Universiti
BSI:	Bandar Seri Iskandar
Cd:	Cadmium
Cu:	Copper
Cr:	Chromium
FAAS:	Flame Atomic Absorption Spectrometer
Fe:	Iron
Hg:	Mercury
Pb:	Lead
ICP-MS:	Inductively Coupled Plasma-Mass Spectrometer
IP:	Ipoh
MW:	Bottled mineral water
Mg:	Magnesium
NDWQS:	National Drinking Water Quality Standard
PWB:	Perak Water Board
SIP:	Siputeh
TDS:	Total dissolved solids
TM:	Taman Maju
TRO:	Tronoh
TSS:	Total suspended solids
UTP:	Universiti Teknologi PETRONAS
WHO:	World Health Organization
Zn:	Zinc.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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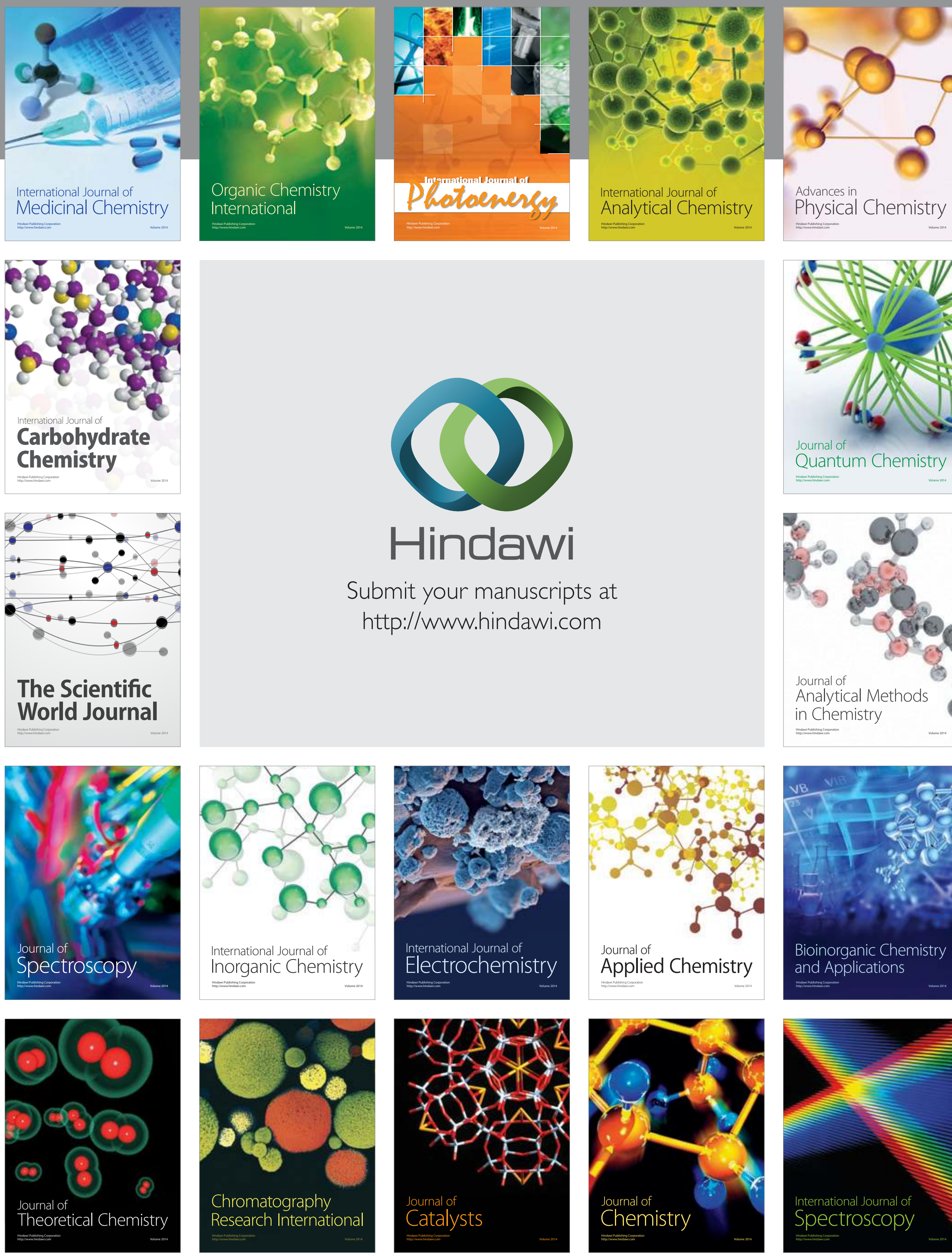
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