ORIGINAL ARTICLE

From tap to table: An assessment of drinking water quality in Perak, Malaysia

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ABSTRACT

Introduction: A study on the quality of drinking water was conducted at Air Kuning Treatment Plant In Perak, Malaysia, based on a sanitary survey in 14 sampling points stations from the intake area to the auxiliary points. This was to ensure the continuous supply of clean and safe drinking water to the consumers for public health protection. The objective was to examine the physical, microbiological, and chemical parameters of the water, classification at each site based on National Drinking Water Standards (NDWQS) and to understand the spatial variation using environmetric technique; principal component analysis (PCA).

Materials and Methods: Water samples were subjected to in situ and laboratory water quality analyses and focused on pH, turbidity, chlorine, Escherichia coli, total coliform, total hardness, iron (Fe), aluminium (Al), zinc (Zn), magnesium (Mg) and sodium (Na). All procedures followed the American Public Health Association (APHA) testing procedures.

Results: Based on the results obtained, the values of each parameter were found to be within the safe limits set by the NDWQS except for total coliform and iron (Fe). PCA has indicated that turbidity, total coliform, E. coli, Na, and Al were the major factors that contributed to the drinking water contamination in river water intake.

Conclusion: Overall, the water from all sampling point stations after undergoing water treatment process was found to be safe as drinking water. It is important to evaluate the drinking water quality of the treatment plant to ensure that consumers have access to safe and clean drinking water as well as community awareness on drinking water quality is essential to promote public health and environmental protection.

KEYWORDS:
Drinking water quality, National Drinking Water Quality Standard, enviromentric technique

INTRODUCTION

The availability of water is critical for the existence of life, as it is a vital component of natural resources and used extensively in various industries such as aquaculture, livestock farming, irrigation, and drinking.[1] However, water contamination poses a significant threat to the survival of all species, as it can contain physical, chemical, and biological impurities that must be eliminated. It must also be tasteless, odorless, and colorless.[2-3] In Malaysia, surface water supplies account for the majority of residential water consumption, with groundwater providing the rest. Municipal needs utilize 30% of Malaysia's internal water resources, estimated to be 580 km^3/year.[4-5] Tap water, bottled drinking water, and bottled mineral water are the most common ways drinking water and this is processed and distributed in Malaysia primarily sourced from surface and groundwater.[6] According to a 2017 report by the World Health Organization (WHO), access to clean and safe drinking water is not only a basic human right but also a crucial component of effective public health policy.[7]

Various types of pollutants such as acute organic waste, heavy metals, suspended particles, and chemicals are well-known for contaminating water.[8] The relevance of water, sanitation, and hygiene in promoting development and health has been highlighted by various international policy platforms.[9] This issue is also significant at the national, regional, and local levels for promoting health and development.[10] In some regions, investing in water supply and hygiene improvements has been reported to have a positive economic impact.[5]

According to the WHO, inadequate sanitation, contaminated water, or a lack of access to water are responsible for up to 80% of all diseases and epidemics worldwide. Additionally, a review by the World Bank of 28 studies has shown that the quality and quantity of water sanitation provided to users are linked to several water-borne diseases.[11] Rahmanian et al.[12], stated that there are about 780 million people who lack access to potable water. As a result, 6 to 8 million people per

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year pass away from diseases brought on by contaminated water.

Water quality factors such as temperature, pH, salinity, and nutrient loads can influence the way biochemical processes occur in surface water systems. Even when present in small amounts, chemical pollutants from various sources, especially persistent compounds, can pose significant health risks to humans. Concerns have been raised by environmentalists, governmental organizations, and health professionals regarding the presence of harmful indigenous pathogens and toxic heavy metals such as Pb, Cd, Cr, and Hg in environmental systems.[13] Therefore, it is crucial to assess the quality of drinking water to ensure that people have access to safe drinking water, even in the absence of scientific data on water quality and the potential sources of water pollution.[14]

The objective of this study was to assess the physico-chemical parameters of water quality such as chemical, physical and microbiological factors, in different locations across Perak, Malaysia. The aim is to compare these parameters with the National Drinking Water Quality Standards of Malaysia (NDWQS) (Table I) and establish a baseline understanding of water quality. Additionally, multivariate statistical techniques were utilized to identify patterns in the data, evaluate similarities and differences between the sampling locations, and predict potential sources of pollution.

MATERIALS AND METHODS

Study Area

Perak, which has a land area of 21,006 square kilometers, is the second-largest state in Malaysia. The climate is tropical rainforest, characterized by a lack of a dry season. The Perak Water Board (PWB) is responsible for providing safe drinking water to the entire state by operating two dams, Sultan Azlan Shah and Air Kuning located at Ulu Kinta, Ipoh, and Taiping, respectively. PWB manages a total of 47 water treatment facilities with a capacity of 1774 million liters per day, currently producing 1081 million liters per day. Water distribution of water is 100% to urban regions and 98% to rural areas, facilitated by a pipeline network spanning 10792 kilometres. Taiping is an oldtown with built up area including commercial areas, residential and small factories such as paper mills and ceramics factory.

Data Collection

In 2021, water samples were collected from various stages of the drinking water supply chain (river water, water treatment plant (WTP), and post-filtration water) at Air Kuning TPO, Taiping Perak (Table II). A total of 42 water samples, were collected, with three replicates taken from each of the 14 sampling stations. The samples were collected in 1-liter polyethylene (PE) bottles, which had been cleaned twice with deionized water after being washed with a 5% nitric acid solution for a day. The water sampling, preservation of samples, in-suite measurements, and laboratory tests were all conducted following established water testing procedures (APHA 1988).

Prior to collecting water samples, in situ measurements of physical parameters were conducted at each processing site, including pH, turbidity, free residual chlorine, and total hardness. The pH of water samples was determined using a color comparator (Lovibond Aqua Comparator), turbidity was measured using a turbidimeter (model HACH 2100Q Portable Turbidimeter), and free residual chlorine was measured using a colorimeter (model HACH Pocket Colorimeter II). Chemical parameters; iron (Fe), aluminum (Al), zinc (Zn), magnesium (Mg), and sodium (Na) were analyzed using Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-OES), which is available at the Department of Chemistry, Perak laboratory. The membrane filter technique as per the APHA (1988) standard was used to measure both fecal coliform and total coliform levels.

Statistical Analysis

Statistical analysis of data was done using SPSS version 20. For each sampling point, the mean was calculated to give the average result. Analysis of one sample t-test was carried out to determine the significant differences between sampling points. Additionally, principal component analysis (PCA) was performed with Origin Pro 2017. In PCA, the original variables are projected onto a new coordinate system after being linearly transformed into uncorrelated variables. The anticipated variables are the main components (PCs).[15]

Ethics Approval and Informed Consent

No ethics approval is needed.

RESULTS AND DISCUSSION

Physical Parameters

pH

pH is an essential indicator of water quality, as it measures the concentration of hydrogen ions (H+) in water to determine its acidity or alkalinity. A low pH can cause corrosiveness, while a high pH can cause taste issues.[16] Aquatic life thrives best within the pH range of 6.5 to 9.0. Although both high and low pH values can negatively impact aquatic ecosystems, it is crucial to maintain the pH level within this range.[17-18] The pH of water samples collected from all sources and sites, regardless of treatment, ranged from 7.0 to 7.6 (Figure 1). The lowest pH value of 7.0 was recorded at Buloh River intake (A4 and A5), raw water tanks (A7), TPO Kolam Air Kuning (A10), and Changkat Larut (A11). The highest pH value was observed after treatment at A9. The pH range for treated water samples (A9 to A14), was similar to that of untreated water samples, and significant differences ($p<0.001$) were observed among all sampling points in Table III.

Previous studies conducted at Sekamat River, Kajang, and Langat River,[6,19] have reported similar findings. These studies have shown that very low pH levels (less than 4.0) can cause harm to aquatic life and erosion of rocks, metals, and plumbing systems in the water.[12] On the other hand, high pH levels can lead to an increase in the concentration of ammonia which can be toxic to water. NDWQS recommends pH levels for raw water between 5.5 to 9.0 and for drinking water between 6.5 to 9.0. The pH levels of the water samples collected from various locations in this study fall within the acceptable range set by the NDWQS.

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

Parameter	WHO	NDWQS
pH	6.5 – 8.5	6.5 – 9
Conductivity µS/cm	-	1000
Turbidity NTU	5	-
Total suspended solids (TSS) mg/L	-	25
Total dissolved solids (TDS) mg/L	1000	1000
Copper (Cu) mg/L	2	1
Zinc (Zn) mg/L	None	3
Magnesium (Mg) mg/L	None	150
Iron (Fe) mg/L	0.3	0.3
Cadmium (Cd) mg/L	0.003	0.003
Chromium (Cr) mg/L	0.05	0.05
Lead (Pb) mg/L	0.01	0.01
Arsenic (As) mg/L	0.01	0.01
Mercury (Hg) mg/L	0.006	0.001
Stannum (Sn) mg/L	-	-

Table II: Sampling points starts from the water intake point to the water supply distribution system in Taiping, Perak

Sampling Points	Details
A1	1500 metres from Larut River intake
A2	750 metres from Larut River intake
A3	Larut River intake
A4	1500 metres from Buloh River intake
A5	750 metres from Buloh River intake
A6	Buloh River intake
A7	Raw water tank
A8	Post filtration treatment at Air Kuning TP
A9	Post Treatment at Air Kuning TP
A10	Air Kuning Treatment Plant Outlet
A11	Changkat Larut distribution
A12	Jalan Simpang 2
A13	Jalan Kota
A14	Jalan Simpang 1

Table III: Mean physical parameters of water distribution at 14 sampling points

Parameters	Mean (SD)	t-statistic (df)	p-value*
pH	7.19 (0.18)	150.09 (13)	<0.001**
Turbidity	3.11 (0.89)	13.03 (13)	<0.001**
Free residual chlorine	1.04 (1.25)	3.11 (13)	0.008*

*one sample t-test

Table IV: Mean value of microbiological of water quality parameter

Sampling stations	E. coli MPN Index 100 mL-1	Total coliform MPN Index 100 mL-1
A 1	330	3500
A 2	330	9200
A 3	260	16000
A 4	940	>16000
A 5	180	16000
A 6	790	9200
A 7	460	>16000
A 8	18	1100
A 9	Nd	nd
A 10	Nd	nd
A 11	Nd	nd
A 12	Nd	nd
A 13	Nd	nd
A 14	Nd	nd

nd = not detected

Table V: Mean chemical parameters of water distribution at 14 sampling points

Parameters	Mean (SD)	t-statistic (df)	p-value*
Total hardness	9.29 (4.84)	7.18 (13)	<0.001**
Iron	0.36 (0.31)	4.37 (13)	<0.001**
Aluminium	0.06 (0.02)	9.96 (13)	<0.001**
Zinc	0.03 (0.03)	4.14 (13)	0.001*
Magnesium	0.70 (0.11)	22.95 (13)	<0.001**
Sodium	2.36 (0.50)	17.74 (13)	<0.001**

*one sample t-test

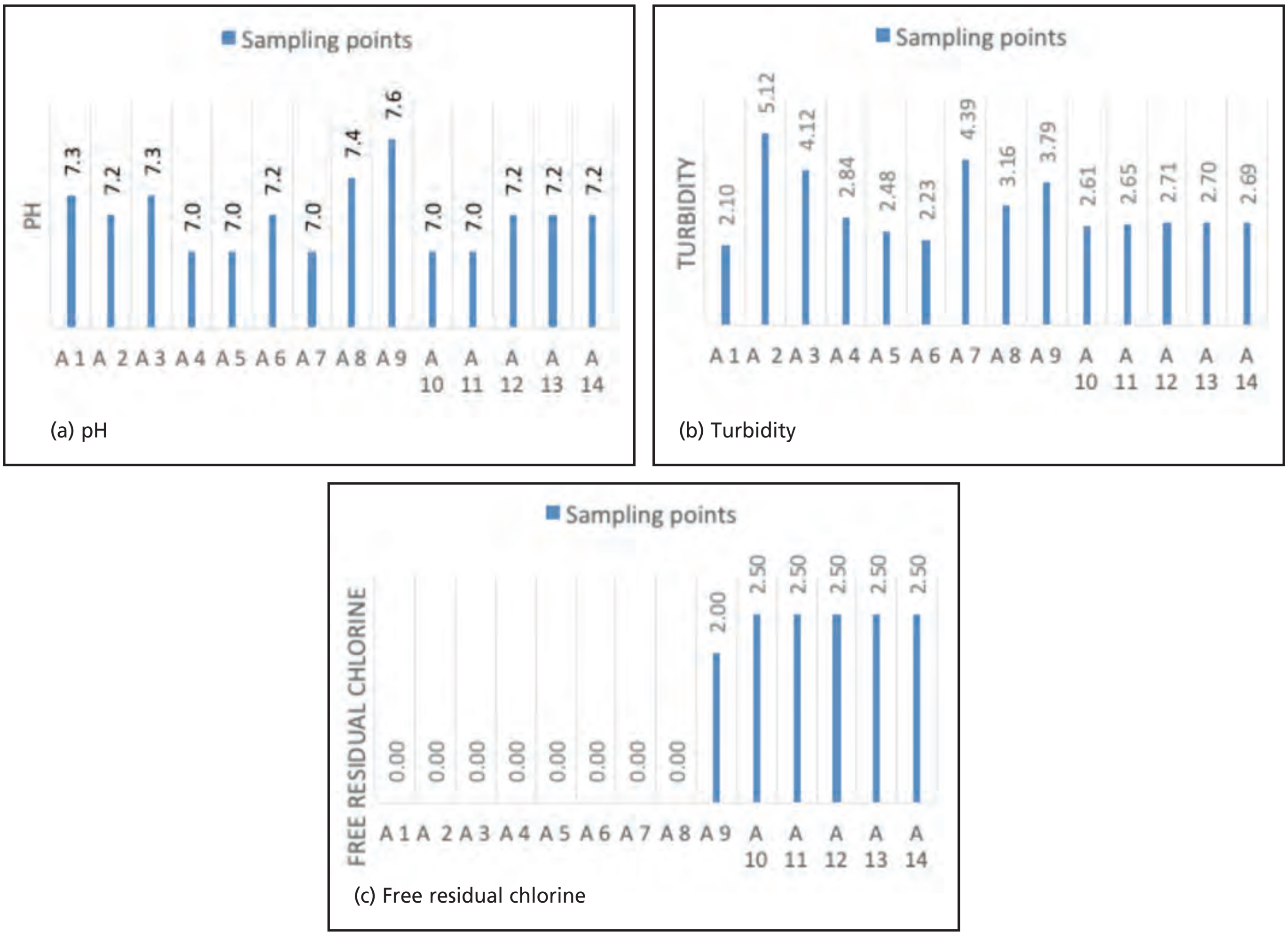

Fig. 1: Distribution of values for (a) pH, (b) turbidity and (c) free residual chlorine

Turbidity

The level of turbidity in water is greatly influenced by seasonal variations (April-May) when high stream flow and surface run-off can increase turbidity level. [20] However, other factors such as surface runoff and riverbed sediment erosion can also affect turbidity.[21] As shown in Figure 1(b), the turbidity values in the studied water samples were within the acceptable range according to NDWQS guidelines. The highest turbidity value was observed at A2, which is located 750 meters downstream from Buloh River intake. This may be due to increased concentrations of suspended solids.[20] Additionally, table III showed significant differences in turbidity concentration were observed among sampling points (p<0.001).

Turbidity is an important parameter for assessing drinking water quality as it measures the ability of water to absorb or disperse light and indicates the cloudiness of water due to various particles.[22] High turbidity can pose health risks, make water appear unappealing, and complicate water supply operations. Suspended substances in water can also provide a protective barrier for bacteria, making it difficult to eliminate them with chlorine treatment. NDWQS recommends a maximum turbidity limit of 5 NTU for drinking water and 1000 NTU for raw water. The analyzed water samples in this study were found to be within the acceptable limit of the NDWQS.

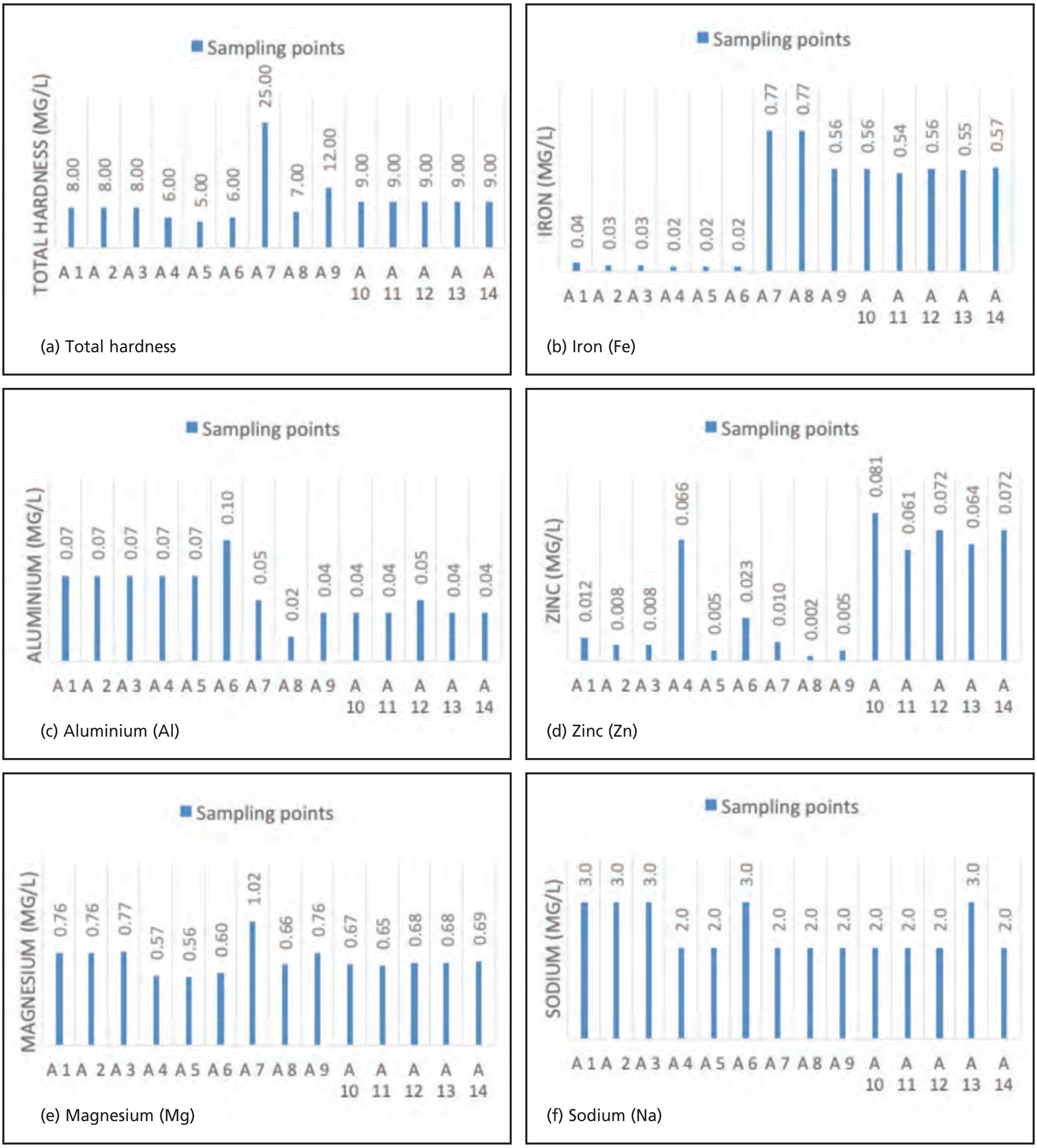

Fig. 2: Distribution of chemical water quality parameters for (a) total hardness, (b) iron (c) aluminimum, (d) zinc, (e) magnesium, and (f) sodium

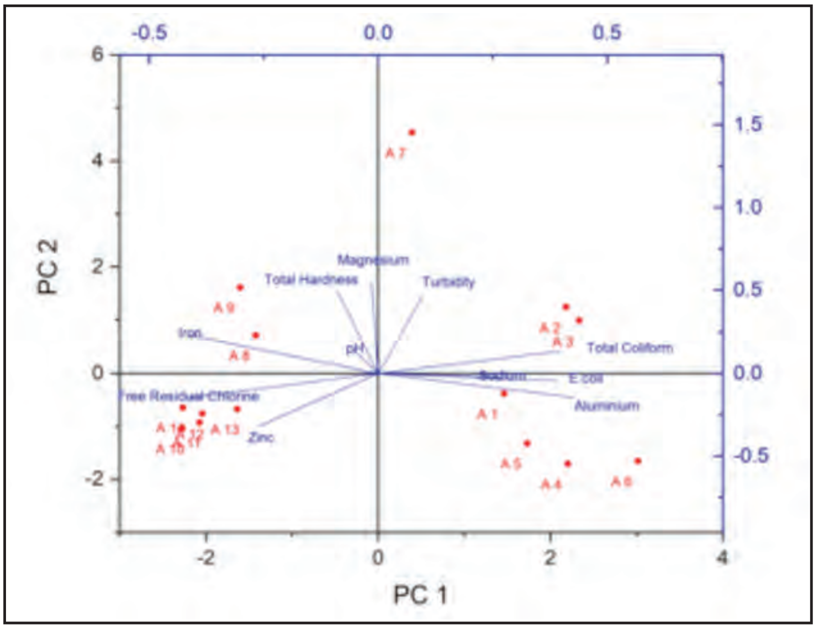

Fig. 3: PCA of Water Quality Samples

After undergoing treatment processes, water samples should have low turbidity values as undesirable particulates and organisms can efficiently remove from turbid water.[12] Previous studies have shown that the turbidity values decrease to acceptable levels after treatment.[23-24] Similar result were observed in the studied water samples, where point A8 to A14, which underwent filtration and treatment processes at the Air Kuning treatment plant, had turbidity values that complied with the recommended standards.[23]

Free Residual Chlorine
Chlorine is commonly used to treat water for human consumption, making it important to regulate the amount of free chlorine present in the water supply. High levels of free chlorine can harm the taste and odour of the water, even though the recommended range by NDWQS is 0.2 to 5.0 mg/L.[24] Figure I(c) shows the free residual chlorine levels measured in 14 water samples. No free residual chlorine was detected in A1 to A8, while the highest concentration was recorded in A10 to A14 at 2.5 mg/L, and the lowest was recorded at A9 at 2.0 mg/L.

This study found that the concentration of free residual chlorine was within the permissible limits of NDWQS and that there were significant differences in the concentration between sampling points (p=0.008) in Table III. This level of free residual chlorines provides adequate protection against microbiological contamination in the water supply system. The relatively low chlorine levels in the sample water indicate its effectiveness as a disinfectant. However, if the concentrations of free residual chlorine are too high, residents may report taste and odour problems.[24-26]

Microbiological Water Quality
The detection of bacteria in drinking water indicates the possibility of contamination from faecal matter, which could occur during disinfection or distribution processes.[27-28] This remains a significant factor in the spread of infectious diseases, both sporadically and during outbreaks worldwide. In the study, all unfiltered water samples (A1 to A7) exhibited the presence of coliforms, faecal coliforms, and *Escherichia coli*, identified by the growth of red colonies.

However, sample A8 which underwent filtration recorded a lower count of 18 MPN 100 mL^{-1}. Furthermore, filtered and post-treatment water samples (A9 to A14) did not show the presence of coliforms, faecal coliforms, or *E. coli*. These findings indicate that filtered water is safe to drink, while unfiltered water is not, and aligns with the recommended limits set by the NDWQS. Similar results were recorded in a previous study that evaluated raw and treated water in Negeri Sembilan, Malaysia where the Linggi River intake and Ngoi-ngoi intake recorded the highest number of coliforms at 7258.8 MPN 100 mL^{-1}.[29]

Coliforms are commonly found in the gut flora of humans and warm-blooded animals, which makes their identification of feces a common practice. They are used to detect the presence of harmful bacteria in aquatic environments, as they are present in higher concentrations than the pathogenic ones. Although certain coliforms are naturally found in various environments, drinking water is not one of them. As a result, their presence in drinking water should not be one of them, and their presence in treated water can be dangerous for human health. Hence, it is crucial to ensure that drinking water is free of coliforms, and their presence can indicate insufficient treatment.[16,30-3] Water treatment facilities commonly use chlorination to remove germs from the water supply, and this study demonstrates that chlorination effectively the number of microbes to less than 100 MPN (Table IV).

Chemical Parameters
Total hardness
The level of water hardness, which is determined by the amount of calcium and magnesium present, may vary in

acceptability among different nations. The taste threshold for calcium is between 100 to 300 mg/L, while that of magnesium is less sensitive.[28] Out of 14 sampling points, the lowest total hardness (TH) values were found at point A5 (5 mg/L), whereas the highest was recorded at the raw water tank (A7; 25 mg/L), which is where the total hardness in water treatment plants is usually tested in the raw water source before it undergoes treatment. However, all sampling points showed no water quality issues since the hardness concentration was within the recommended limit of NDWQS.

The major sources of water hardness are dissolved metallic ions from rocks, seepage, and soil run-off.[22,32] Water exceeding 200 mg/L may result in scale build-up in distribution systems and increased soap consumption, while soft water with a hardness of less than 100 mg/L may cause heavy metal contamination due to pipe corrosion.[33-34] Although epidemiological studies suggest that magnesium or hardness may prevent cardiovascular mortality, this claim is still debated, and more research is needed. As of now, there are no recommended guidelines for minimum or maximum mineral concentrations due to insufficient data.[32]

Iron

The level of iron (Fe) in natural water can vary due to different factors, with ferrous and ferric ions being the principal components of interest.[35] High Fe content in rivers is attributable to nearby sewage or industrial effluent discharge. In water distribution systems, iron pipes are often the cause of Fe contamination, as they can corrode and create iron oxide-dominated scales and deposits. These deposits can negatively impact water quality and arise from sources such as raw water debris and pipe corrosion products.[36]

The concentration of Fe varies at different sampling points in the system, and the results indicate that Fe levels at Larut River and Buloh River intake are lower than NDWQS. However, all treated water sampling points which (A7 to A14) show Fe concentration above 0.3 mg/L, exceeding the recommended limits. Fe concentrations ranged from 0.02 to 0.77 mg/L, and there were significant differences in Fe levels among sampling points (p=0.001) as shown in Table V. The Fe value in treated water exceeds the limitations caused by the material used in the water distribution system, such as galvanized iron. This can affect the color and taste of the water, making it unsuitable for consumption.[36-38]

Aluminium

Aluminium (Al) is commonly utilized in raw water treatment as a coagulant to reduce organic matter, bacteria, color, and turbidity. The concentration of Al in the water samples ranged from 0.02 to 0.10 mg/L, with the highest value at sampling point A6 and the lowest at sampling point A8 (Figure 2 (c)), which met the NDWQS standard of 0.20 mg/L. There were significant differences among sampling points (p<0.001) as shown in Table V. Surprisingly, the Al concentration was higher at the intake area than in treated water, which is contrary to the findings of a previous study that reported higher Al concentrations in treated water than in water sources.[39] The reason for this discrepancy is attributed to the excessive use of alum during the water treatment process, which is added based on turbidity levels and not the calculated amount of Al required.

Additionally, the pH level can influence the concentration of Al in acidic water, leading to pipe corrosion and partial solubilization of the element in the water distribution system.[40] Although low levels of Al in water are unlikely to pose health risks, there is evidence linking excessive concentrations of Al to neurological disorders such as Parkinson's and Alzheimer's disease.

Zinc

Zinc (Zn) is an essential mineral for human health, but excessive consumption can be harmful. The recommended daily intake of Zn is 15 to 22 mg for adults, and the maximum tolerable daily intake is 1 mg/kg of body weight. However, the lowest concentrations of Zn were found in the Larut and Buloh rivers (Figure 2), likely due to the accumulation of Zn in river sediments. The use of zinc in alloys, as well as in the galvanization of steel and iron, can cause zinc to leach into the drinking water system, resulting in high Zn concentrations in some areas (A10 to A14). These levels, while still within recommended limits, can produce adverse effects like nausea and vomiting. There are no current health guidelines for Zn in drinking water but concentrations of around 3 ppm can cause the water to appear iridescent.

Magnesium

Magnesium (Mg) is the eighth most abundant element found on the Earth's surface and it occurs naturally in water and minerals such as dolomite and magnetite. All living organisms require it to function properly.[11] The concentration of Mg in water samples taken from different points ranged from 0.56 mg/L to 1.02 mg/L, with the latter possibly due to underground mineral deposits.[12] The standard range based on NDWQS was not exceeded. There were significant differences in Mg levels among the sampling points. Mg is a major contributor to water hardness, and if its content is high, the calcium concentration is likely to be low.[22] This was observed in all treatment points, according to a previous study.40 The levels of other minerals, including manganese, arsenic, and fluoride, were below the threshold limits in both drinking and mineral water samples. The presence of Mg in drinking water is crucial in understanding Malaysia’s water supply system. Galvanized steel pipes containing Mg alloys might contribute to the presence of Mg in treated water.

Sodium

Sodium (Na) is typically found in water sources at low levels, usually less than 20 mg per litre. However, significant amounts of Na may enter water through various sources such as saline intrusion, mineral deposits, saltwater spray, sewage effluents, and de-icing salt used on roads.[11] In this study, Na values in water samples ranged from 2.0 mg/L to 3.0 mg/L, with the highest recorded at sampling points A1, A2, A3, A6, and A13 (3.0 mg/L). One sample T-test in Table V results indicated statistically significant differences (p<0.001) between sampling points.

The presence of Na in all water samples taken from both Larut and Buloh rivers intake can be attributed to the mineral rocks that have put ions into the water. Water treatment processes may remove cations like calcium, magnesium, potassium, and sodium, either directly or indirectly. Previous studies have reported similar results, with packaged drinking water brands containing Na within the range of 2 to 13 mg/L.[33,40]

Excessive consumption of sodium can lead to short-term effects such as nausea, vomiting, convulsions, twitching and stiffening of muscles, and swelling of the brain and lungs, and can even result in death. Moreover, excessive salt consumption can worsen chronic congestive heart failure, and adverse consequences of high sodium levels in drinking water have been reported.[33]

Principal Component Analysis (PCA)

PCA is a useful tool for identifying the most significant variables while minimizing information loss by eliminating less important factors. In Figure 3, the upper horizontal axis of principal component 1 (PC 1) revealed positive coefficients for turbidity, total coliform, sodium (Na), *E. coli*, and aluminium (Al), indicating that these factors were the primary contributors to water contamination. The increase in turbidity may be attributed to land clearing in the future.[38] The presence of total coliform and *E. coli* in PC 1 indicated that these bacteria were the main contaminants in the river water intake, especially in A1 and A2. This may be due to a combination of natural and anthropogenic factors. In contrast, principal component 2 (PC 2) showed strong positive loadings on total hardness, pH, free residual chlorine, iron (Fe), and zinc (Zn) which had the highest extractable commonalities. Fe and Zn were released from point and nonpoint sources and their connection may be due to corrosion of steel pipes in water distribution systems.[37]

CONCLUSION

The study found that the physical, microbiological, and chemical characteristics of water samples taken from the Larut River and Buloh River intake, Air Kuning Treatment Plant outlet, and distribution systems at Taiping, Perak were within the recommended limits of the NDWQS except for total coliform at point A1 to A7 which is before undergo the treatment process. Moreover, the levels of four heavy were also found to be lower than the permitted maximum levels except for Fe which show Fe concentration above 0.3 mg/L, exceeding the recommended limits. This may caused by the material used in the water distribution system, such as galvanized iron. However, it is crucial to also focus on emerging contaminants, such as new chemicals and substances that could potentially enter the environment and water sources. It is important to understand the impact of these pollutants on human health. The occurrence of exterior corrosion in water distribution systems presents significant challenges for water utilities. One primary issue is to the malfunctioning of the pipes. Another issue to consider is the pollution of water due to the transportation of soil pollutants into the distribution system. Hence, it is crucial to identify and give priority to the replacement or upgrading of ageing pipes with contemporary materials that exhibit enhanced durability and an extended lifetime. This practise not only has the potential to mitigate water loss, decrease the probability of leaks, and enhance the overall efficiency of the system, but also serves as a preventive measure against the formation of corrosion scales in water supply systems.

Additionally, building public trust and understanding of drinking water quality is crucial. Effective communication strategies can be developed to involve the public in the process. To increase public responsibility, organizations such as the government, water agencies, and NGOs can raise awareness and understanding about water. However, managing water resources in the country is challenging due to increasing demands from households, industries, and agricultural sectors, the contamination of rivers, and the destruction of water catchment regions.

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