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Heavy Metals Analysis and Physicochemical Characterization of Groundwater at a Battery Recycling Site in South-western Nigeria

Adeniyi T. Adeleke[1,2], Rasaki K. Odunaike[1], Shamsideen K. Alausa[1], Idris O. Olayiwola[3], Adetoro T. Talabi[1], Qasim A. Adeniji[1,4], Adejumobi C. Adeniyi[1,5]

[1]Department of Physics, OOU, Ago-Iwoye, Ogun State, Nigeria.

[2]Department of Science Laboratory and Technology, Federal College of Fisheries and Marine Technology, Victoria Island, Lagos.

[3]Centro de Investigación en Materiales Avanzados, S.C. (CIMAV), Miguel de Cervantes 120, C.P. 31136 Chihuahua, Chih., Mexico

[4]Federal University of Health Science, Ila-Orangun, Osun State, Nigeria.

[5]Department of Science Laboratory and Technology, The Oke-Ogun Polytechnic, Saki, Oyo State, Nigeria.

Corresponding Author: adeleke@fcfmt.edu.ng

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Abstract

Indiscriminate dumping of battery waste is a huge issue that endangers human health and the environment. This study aimed at analysing the health impacts of exposure to pollution from spent battery recycling in Ogun State, which houses a diverse range of battery recycling industries. At this study site, forty water samples were studied over the Wet and Dry seasons to assess the impact of battery recycling waste on groundwater. Except for the TSS, the physiochemical parameters of the groundwater vary with season and are within the permissible limits. The electrical conductivity (EC), turbidity, Phosphorus, Biochemical oxygen demand (BOD), Dissolve oxygen (DO), and Total suspended solid (TSS) within the study year ranges from 51.00 - 178.22 S/cm, 2.26 - 2.36 NTU, 0.089 - 0.66 mg/L, 13.3 - 14.2 mg/L, 5.06 - 5.67 mg/L, and 78.0 - 88.4 mg/L, respectively. Furthermore, the average concentrations (in ppm) obtained for Mn, Cu, Zn, Ni, Cd, As, Fe, Pb, Cr, and Co are 0.407 – 0.42, 0.355 – 0.369, 0.179 – 0.225, 0.061 – 0.265, 0.366 – 0.464, 0.488 – 0.631, 0.544 – 0.601, 0.481 – 0.576, 0.284 – 0.334, 0.3 – 0.382. The Heavy Metal Pollution Index (HPI) values ranging from 3.880 to 4.528 indicate minimal levels of heavy metal contamination, but water quality index (WQI) scores ranging from 124.68 to 131.46 indicate potential environmental hazards.

Keywords: Battery wastes, Heavy metals, physicochemical parameters and Battery recycling.

Introduction

Poor waste management, as well as indiscriminate waste collection and disposal, is one of the primary reasons of the myriad difficulties affecting the Nigerian environment (Anzene 2019). Improper trash disposal is constantly on the rise, owing mostly to increased economic activity and industrialization (Salami et al. 2018). Ogun State in Nigeria's south-western region is noted for having exacerbated trash disposal difficulties near residences and other public spaces. Massive dumpsites are frequently discovered near residential areas along major and secondary highways, leading to soil and water pollution. Numerous inorganic chemicals accumulate in plants and are hazardous to both people and animals, causing anaemia and kidney damage (Calzavara et al. 2020). Water is precious and necessary for a sustainable economic development of an area as it is very important to life after air is considered. Drinking water contaminated with heavy metals has become a major health issue. The use of heavy metals contaminated water has been reported to be responsible for high morbidity and mortality rate all over the world (Ravindra and Mor 2019).

Heavy metals are metals and metalloids such as Zn, Cd, Pb, Hg, Cr, Ni, Cu, and As with densities typically higher than 5 g/cm^3 (Caserta et al. 2013). Most of them are group of naturally occurring elements that are toxic to humans and other living organisms. They can enter the environment through a variety of sources, including mining, industrial activities, and the disposal of waste. Once in the environment, heavy metals can accumulate in soil, water, and air; the physicochemical characteristics of these medium can also influence the bioavailability of heavy metals. Also, the pH, temperature, and salinity of water can all affect how easily heavy metals are absorbed by living organisms (Talabi et al. 2023). Heavy metals in water can have a variety of harmful consequences on the environment and human health. Numerous health issues, such as cancer, renal damage, and neurological issues, can be brought on by heavy metals. They can also damage aquatic ecosystems and contaminate food sources (Salami et al. 2021; Talabi et al. 2023).

Battery recycling might similarly result in heavy metal contamination when material handling is ineffectively done. Batteries contain several heavy metals, including lead, cadmium, and mercury. During battery recycling, certain heavy metals may be released into the environment. It is therefore very vital to monitor heavy metal concentrations in water near battery recycling plants in order to protect both human health and the environment (Afolayan 2018). The era of wastes and new types of toxins has been greatly expanded by the rapid industrial development and urbanization. The modern insurgency, which was followed by the development of data innovation in the last century, has fundamentally altered people's way of life. Despite the fact that this advancement has benefited humanity, blunder has given rise to new problems of contamination and defiler. For instance, electronics contain components that are extremely dangerous, such as plastics and additives made of plastic, lethal gases, poisonous metals, naturally dynamic materials, acids, and chlorinated and brominated substances; including battery wastes. These materials' hazardous component poses a natural and health risk (Su 2014).

Hence, the objective of the current study is to assess the health consequences of exposure to pollution from spent battery recycling in Shagamu Local Government, Ogun State, which is home to numerous industries, including recycling industries. Human activities like recycling electronics waste, such as batteries, crushing stone in cement plants, mining operations, and radioactive activities, such as fumes coming out of their chimney, all contribute to increasing environmental pollution. This could result in exposure to the elements outside due to contamination that is present in all soils at trace levels (Kapdan et al. 2011). This study therefore focuses on the assessment of heavy metal levels and physicochemical qualities of water in the studied area.

A number of indices have been devised to convey data on water quality in an easy-to-understand format. The Water Quality Index (WQI), developed by Horton in the early 1970s, is simply a mathematical approach for calculating a single value from a set of test results (Akhtar et al. 2021). The degree of water quality of a certain water basin, such as a lake, river, or stream, is reflected by the index result. Following in the footsteps of Horton, other academics from around the world developed the WQI, which is based on assessments of various water quality indicators. The WQI tries to provide a mechanism for presenting a numerical expression that identifies a given level of water quality and is obtained cumulatively. WQI has been widely used to assess the water quality of both river and coastal waters.

(Kumar and Dua 2009, Barbulescu et al. 2021).

Materials and Methods

Location and geology of study area

The research was carried out in PZ estate Onijagun Ogijo Shagamu road, which falls under the Shagamu Local Government Area (LGA) of Ogun state in South-western Nigeria. It is close to the settlements of Logbara and Orile-Imo. Ogijo has a population of 214,558 people and is located between the latitudes 6° 43' 35.00" N and 6° 42' 40.00" N, as well as the longitudes 3° 31' 0.00" E and 3° 31' 60.00" E (see Figure 1). Shagamu is a collection of thirteen towns located between Lagos and Ibadan between the Ibu River and Eruwuru Stream. In the middle of the nineteenth century, the Remo branch of the Yoruba people built it in South-western Nigeria. The administrative centre of the LGA is at Shagamu, which is well-known for its economic and industrial activities.

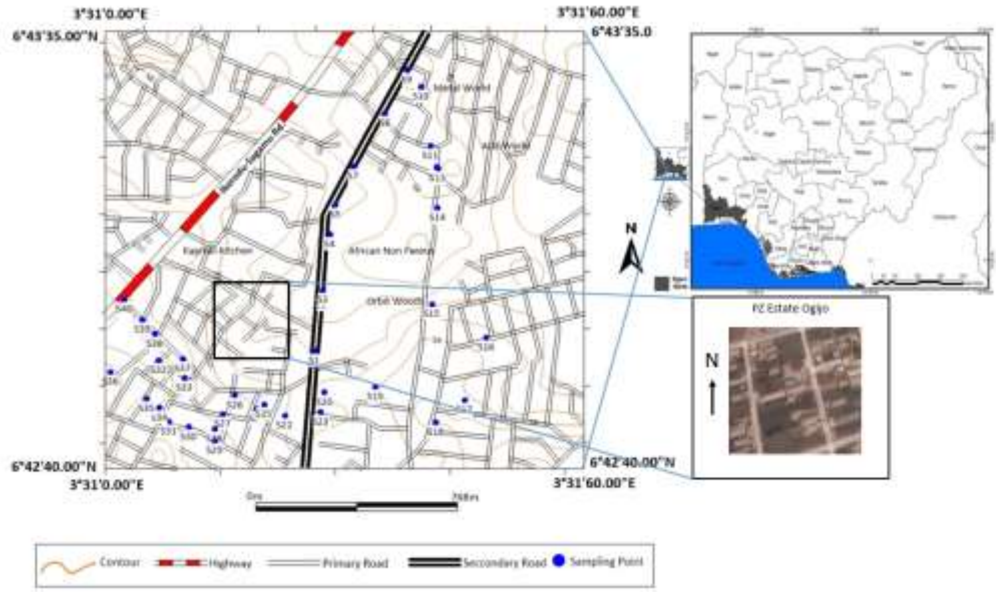

Figure 1: The Nigeria map showing the sample collection points.

Samples collection

Forty water samples were collected from various sites between 5 and 10 meters from the study site. During the dry and wet seasons, samples were collected for comparative analytical studies. Cleaning the grinders, sieves, mixers, and other instruments before using them on a new sample reduced the risk of cross-contamination. To guarantee that the decontamination was efficient in preventing contamination, the equipment was washed with ethanol to remove any remaining contaminants from the used containers.

Sample preparation

The standard techniques were utilised, this method involved transferring 50 ml of the water sample into a one 100 ml beaker. 5 ml of concentrated nitric acid (HNO_3) were added and given a thorough stir, the mixture was slowly boiled and evaporated on a hot plate until 5 ml were left for precipitation to determine the proportions of metals in the water samples using the nitric acid digestion method. For background correction, a control experiment was run with distilled water using the same steps as above (Ohimain et al. 2012). The digested samples were then examined using buck scientific model PG 990 Flame Atomic Absorption Spectrophotometer.

Determination of Physicochemical Properties

Analysis for the determination of 10 water physicochemical parameters using standard techniques by Ademoroti (1996), and calculations, measurements of the water's pH, total suspended solids, total dissolved solids, total alkalinity, phosphate (PO_4^{3-}) concentration, nitrate (NO_3^-) concentration, sulphate (SO_4^{2-}) concentration, electrical conductivity, chemical oxygen demand, and biochemical oxygen demand were made.

Assessment of heavy metal pollution in water

Water Quality Index

The Water Quality Index (WQI) provides a numerical representation of the overall quality of water for any intended use. It is described as a score that reflects the combined impact of various water quality parameters that were taken into account when calculating the (WQI). The indices are among the best tools for informing the public, policymakers, and those in charge of managing water quality about trends in water quality (Giri and Qiu 2016). The intended use of the water determines the relative importance of various parameters in the formulation of the water quality index. The main consideration is whether it is fit for human consumption. The following steps were used to calculate the WQI using the weighed arithmetic index method (Bouslah et al. 2017).

Given n water quality parameters, the quality rating (Q_n) for the nth parameter is a number that reflects the parameter's relative value in the polluted water compared to its maximum permissible value. The values of Q_n were computed using equation (1) (Dagar et al. 2022).

$$Q_n = \frac{[100 \times (V_n - V_i)]}{V_s - V_i} \qquad (1)$$

Where, V_s is the standard value, V_n is the observed value, and V_i is the ideal value.

All the ideal values (V_i) are taken as zero (0) for drinking water for all other parameters except the parameter pH, where it is 7.0 and dissolved oxygen is 16.6 mgdm^{-3} (Bouslah et al. 2017). Calculation of unit weight: The Unit weight (W_n) to various water Quality parameters are inversely proportional to the recommended standards for the corresponding parameters.

$$W_n = \frac{K}{S_n} \qquad (2)$$

Where, W_n is the unit weight for nth parameter S_n is the standard permissible value for nth parameter, and k is the proportionality constant. The unit weight W_n values in the present study are taken from Krishnan et al. (1995).

WQI is calculated by the following equation.

$$WQI = \sum_{n=1}^{n} W_n Q_n \qquad (3)$$

The suitability of WQI values for human consumption according to Singh et al. (2018) are rated as follows.

Table 1: Ratings of water in WQI (Source: Brown *et al.*, [1972], Balan *et al*. [2012]).

Range of values of WQI	Rating	Possible usage
0-25	Excellent	Drinking, irrigation and industrial
26-50	Good	Drinking, irrigation and industrial
51-75	Bad	Irrigation and industrial
76-100	Very Bad	Irrigation
100 & above	Unfit for drinking and domestic use	Well treated before use

Furthermore, the quality of the water samples from the study area was evaluated using the weighted arithmetic Water Quality Index (WQI). The water quality index is a rating index number that expresses the general water quality based on a number of water physicochemical parameters. The weighted arithmetic WQI was calculated as:

$$\text{WQI} = \frac{\Sigma Q_i W_i}{\Sigma W_i} \qquad (4)$$

Where Q_i is the quality rating (sub-index) of the i^{th} water parameter and it was calculated using equation (5)

$$Q_i = \frac{V_a}{V_s} \times 100 \qquad (5)$$

Where, V_a is the actual value of water quality parameter obtained from the data and V_s is the prescribed standard value of the parameter, WHO (2017).

With values ranging from 0 to 1, W_i of the various water quality parameters were inversely related to the suggested standards for the corresponding parameters, reflecting the relative significance of each quality under consideration. According to the Canadian Council of the Ministers of the Environment CCME (2001), a water quality index is a way to consistently report water quality data to management and the general public in simple terms (such as excellent, good, poor, very poor, and unsuitable for drinking). Eight water quality parameters such as temperature, pH, dissolve oxygen, total dissolve solid, turbidity, alkalinity, nitrate and biological oxygen demand were used for the calculation of WQI in this study.

Equation (6) as expressed the Heavy Metal Pollution Index (HPI) was used to assess the level of heavy metal contamination in water samples taken from the study area. This was done in order to analyse the combined impact of each heavy metal found on the water's overall quality and suitability for human consumption., HPI was first proposed by Mohan et al. (1996). The HPI was computed using equation (6), Jazza et al. (2022).

$$HPI = \frac{\Sigma Q_i W_i}{\Sigma W_i} \qquad (6)$$

Where Q_i is the quality rating (sub-index) of the i^{th} water parameter as expressed in equation (7)

$$Q_i = \frac{V_i}{V_s} \times 100 \qquad (7)$$

Where V_s is the parameter's recommended standard value as stated by WHO (2017) and V_i is the monitored value of the i^{th} heavy metal. W_i is the i^{th} parameter's unit weight.

The classification of the heavy metal pollution index, as proposed by Edet and Offiong (2002), is shown in Table 1 on a modified scale.

Table 2: Categorization of heavy metal pollution index.

HPI	< 15	15 - 30	30 >
Class	Low	Medium	High

Higher values in water samples make them unfit for consumption and constitute a serious threat to human health (Jazza et al. 2022).

Heavy metal pollution index (HPI)

Table 3: Standards for drinking water and relative weight of parameters (PRÜSS-USTEN CORVALAN [2006]).

No	Parameter [a]	Standards WHO (S_n)	$1/S_n$	K	Relative weight (W_n)
1	pH	6.5 - 8.5	0.1176	1.6667	0.1961
2	Electrical conductivity (EC)	300.0	0.0033	1.6667	0.0056
3	Total hardness	300.0	0.0033	1.6667	0.0056
4	Calcium	75.0	0.0133	1.6667	0.0222
5	Magnesium	30.0	0.0333	1.6667	0.0556
6	Chloride	250.0	0.0040	1.6667	0.0067
7	Nitrate	50.0	0.0200	1.6667	0.0333

8	Sulphate	200.0	0.0050	1.6667	0.0083
9	Dissolve oxygen	5.0	0.2000	1.6667	0.3333
10	Turbidity	5.0	0.2000	1.6667	0.3333

All the parameters are in $mgdm^{-3}$ except pH, EC (µS·cm–1) and turbidity (NTU).
Table 3 was used as WHO standard to compute WQI and HPI.

Results and Discussion

Figure 2 indicates the physicochemical parameters of the water samples. While the details of the inherent heavy metals, the heavy metal contamination index and the water quality index are presented in Tables 4, 5 and 6.

Physicochemical properties of water sample

According to the outcome of the physicochemical assessment as shown in Figure 2, the pH levels in the water samples ranged from 5.16 to 8.91, with a mean value of 6.87 during the rainy season. This demonstrates that the study site's pH is slightly acidic during the wet season. The minimum and maximum readings during the dry season were 5.8 and 9.2, respectively, with a mean value of 7.4. This demonstrates that the pH is closer to neutral during the dry season than the wet season, which may be caused by runoff during the wet season. The lower the pH value, the higher its corrosiveness. The peak value for electrical conductivity in the study site was 178.22 µS/cm during the dry season which is far above the result recorded during the wet season 51.00 µS/cm. According to EPA (2018), human disturbances generally tend to increase the amount of dissolved particles that enter water, which increases electrical conductivity. The standard range for EC is between 200 µS/cm and 1000 µS/cm. However, WHO recommends that EC should not exceed 400 µS/cm as reported by Raji et al. (2021). Electrical conductivity and total alkalinity are said to positively correlate with water pH (Gupta et al. 2013).

Nephelometric turbidity units (NTU) is a measure of turbidity in drinking water, and it is determined by calculating light transmission using conventional light sources. The turbidity increases as scattered light intensity increases (Correya et al. 2011). With the values recorded in the study, 2.361 NTU was the mean value in wet season and 2.260 NTU in the dry season. Though, both values are high, they still fall within the acceptable limit. WHO (1999) stated that the turbidity of drinking water should not exceed 5 NTU and should ideally be below 1 NTU. Water's ability to neutralise acids is determined by its alkalinity. Although weak or strong bases may also be a factor, salts of weak acids are the main cause. Typically, bicarbonate, carbonate, and hydroxide have an impact on alkalinity. Our drinking water should have a high alkalinity level since it maintains the water safe for us to drink. For ordinary drinking water, the recommended alkalinity range is 20 – 200 mg/L (Naseem et al., 2022).

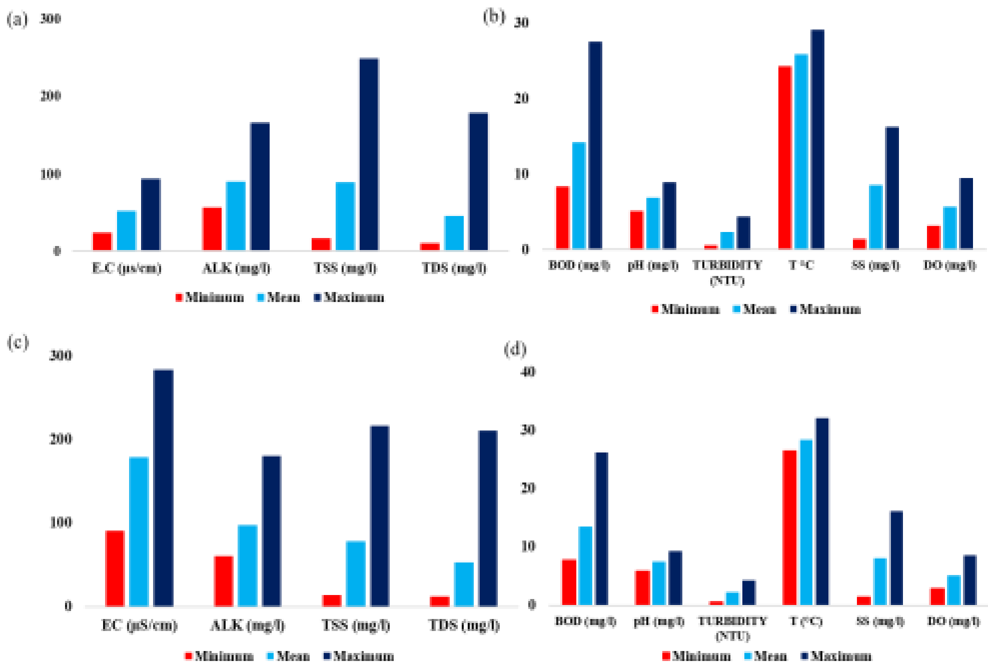

Figure 2: Physicochemical parameters of water samples during wet seasons (a) – (b) and dry seasons (c) – (d).

Alkalinity is basically dissolved minerals in the water that help neutralise the water we drink. The mean value of 90.11 mg/L was recorded during the wet season, and 96.95 mg/L was also recorded during the dry season which could be as a result of human activities such as recycling process and all other industrial activities which allow for contamination due to the release of effluent into the river. Raw water contains nitrate, which is primarily a form of the molecule N_2 (or its oxidising state). The main sources of nitrate production are chemical and fertiliser manufacturers, animal waste, wilting vegetables, home waste, and industrial emission. According to WHO (1999) guidelines, 45.0 mg/L of nitrate is the ideal limit. The mean value recorded for nitrate both in dry and wet season were 0.038 mg/L and 0.0484 mg/L respectively. Increase in nitrate level during the wet season could be the level of contamination of chemicals from recycling site as well as the run off. These values still fall within the permissible limit. Sulphate ions are present in natural water, and the majority of these ions are soluble in water. By oxidising their ores, sulphate ions are created in large quantities. They are also found in industrial wastes. The amount of sulphate utilised in this investigation was measured using a UV Spectrophotometer. The ideal limit for sulphate is recommended to be between 200 and 400 mg/L (Vijaya Kumar et al. 2020). The mean value recorded for the wet season was 0.04845 mg/L and for the dry season was 0.62070 mg/L, which shows that sulphate is very negligible and has less effect on the health of inhabitants.

The study site's temperature is within the acceptable range throughout both the wet and dry seasons. In the dry season, 28.29 ℃ was recorded whereas 25.85 ℃ was recorded during the wet season. These values were perfectly acceptable. An important plant nutrient, phosphorus frequently regulates the growth of freshwater aquatic plants. Due to the poor solubility of native phosphate minerals and soils' capacity to hold phosphate, ground water often only has a minimal quantity of phosphorus. Phosphorus levels at the research site were 0.664 mg/L during the rainy season and 0.089 mg/L during the dry season, both of which were under the allowed limit of 1 mg/L set by

WHO (1999). The average total dissolved solids (TDS) was 44.8700 mg/L during the wet season, while it was a bit higher during the dry season at 52.9850 mg/L. Nonetheless, both values were within the prescribed limits. The desirable TDS is 500 mg/L. (Jothivenkatachalam et al. 2010). The discharge from nearby areas must have contributed to higher TDS. The chlorides in the electrolyte of lead acid accumulator also contributed to the TDS levels (Meunier et al. 2009).

Total suspended solid (TSS) is a measure of the turbidity of water and depends on suspended silt and soil particles. The site's TSS readings peaked during the wet season 88.435 mg/L and peaked at their lowest during the dry season 78.090 mg/L. The rising TSS levels over time demonstrate an increase in sewage discharge into the river without treatment. All of these could be caused by the discharge of untreated sewage and recycling site effluents. 4 mg/L is the recommended allowable limit (Akan et al. 2010). Although, there are no guidelines for DO in WHO (1999) records, but the range is between 6.50 mg/L and 8.00 mg/L, anything less than 1mg/L is always considered not habitable. DO recorded during the wet season was 5.6760 mg/L while that of the dry season was 5.0655 mg/L. The existence of a large organic load is indicated by the freshwater aquatic system's low DO concentration (Magadum et al. 2017). Anaerobic conditions have been caused by the direct dumping of untreated sewage into the river and are blamed on the aquatic vegetation's ability to produce oxygen through photosynthetic activity. For fish and other aquatic life to thrive, dissolved oxygen concentrations must be at least 3 mg/L (Chindo Nwankwo et al. 2014).

BOD is a measure for how much pollution is present in a body of water. It is a unit of measurement for the contamination of water by organic compounds, measured in mg/L. BOD is the quantity of dissolved oxygen needed for the oxidation of some inorganic substances, like iron and sulphites, as well as the biochemical breakdown of organic compounds. According to Kumar et al. (2010), the maximum permissible concentration for direct environmental wastewater discharge is approximately 6.0 mg/L. The concentrations of BOD in the dry and wet seasons, respectively, were 14.272 mg/L and 13.344 mg/L on average. Due to industrial effluent sharing runoff during the intense rain, this demonstrates that BOD is higher in the wet season than in the dry season. Samples revealed a significant organic burden due to the cumulative effect. The above-mentioned figures imply that the water in the research area is unfit for human consumption. When waste water (effluent) is treated improperly, it can cause bacterial growth and deplete the river's dissolved oxygen, forming an oxygen-depleted zone.

The total amount of microscopic solid particles that are suspended in water and function as a colloid is known as suspended solid (SS). One method of assessing the quality of water is to measure the suspended solids. In waste water applications, suspended solids are typical; however, they should not be confused with settleable solids, which are also referred to as SS. Untreated suspended particles can contribute to sewer pipe blockage and endanger other systems if they are not removed (Anis et al., 2019). From the observed results, 8.516mg/L was detected during the wet season while 7.953 mg/L was detected during the dry season, though lesser than the permissible limit 30 mg/L by WHO (2004) standard but not too well for domestic use.

Water quality index

Using the water quality index, the observed values for the wet and dry seasons are 131.46 and 124.68, respectively as shown in Table 4. These findings demonstrate that the water at the study location and its surroundings is essentially unfit for domestic use. The primary cause of pollution in the vicinity of sampling points is the direct discharge of effluent from battery recycling facilities. However, the water needs to be treated to get rid of the physical and chemical impurities, according to the value for WQI obtained from the CCME-WQI calculation. Various human activities, such as the input of direct sewage from residential and commercial enterprises in 2015, caused WQI in Koudiat Medouar Reservoir to range from 99.08 to 174.72, according to research (Bouslah et al. 2017). In addition, the water must be boiled and filtered before being drawn for drinking. In context of aquatic life, high turbidity sometimes has seen main issue. The causes could be due to upstream flow increasing turbidity and heavy rainfall causing soil erosion. Thus, watershed management techniques could reduce soil erosion, which would then lessen water turbidity, a threat to aquatic life (Lumb et al., 2006). Conversely, increased CO_2 also poses a threat to aquatic life by lowering water quality. It might occur as a result of seasonal variations in temperature and length of sunshine, with temperatures associated with sunshine slowing the decomposition of organic matter in the water and raising its carbon dioxide content (Panduranga et al. 2009).

Table 4: Water quality index (WQI)

Parameters	**Mean (V_a)**		**(V_s)**	**W_i**	**Q_i**		**W_iQ_i**	
	Wet	**Dry**			**Wet**	**Dry**	**Wet**	**Dry**
Temp °C	25.85	28.23	25.0	0.050	103.384	113.172	5.211	5.704
pH	6.870	7.41	8.50	0.148	80.820	87.100	11.978	12.908
DO (mg/L)	5.680	5.066	5.0	0.252	113.600	101.320	28.627	25.533
TDS (mg/L)	44.800	52.985	500.0	0.003	8.960	10.597	0.023	0.027
Turbidity (NTU)	2.360	2.261	5.00	0.252	47.200	45.220	11.894	11.395
ALK (mg/L	90.110	96.950	100.0	0.013	90.110	96.950	1.135	1.222
Nitrate (mg/L)	0.048	0.038	50.0	0.025	0.096	0.076	0.0024	0.002
BOD (mg/L	14.27	13.344	5.00	0.252	285.4	266.880	71.921	67.254
$\sum$				0.995			130.791	124.044
WQI(Wet)								131.459
WQI(Dry)								124.677

Where V_a is the actual value of water, V_s is the prescribed standard value of parameter given, WHO (2017), Q_i is quality rating sub-index of the i^{th} water parameter and W_i is the unit weighted for the i^{th} parameter.

Heavy metal in water samples

From the data in Table 5, it can be established that the average concentrations (in ppm) obtained for Mn, Cu, Zn, Ni, Cd, As, Fe, Pb, Cr, and Co are 0.407 - 0.42, 0.355 - 0.369, 0.179 - 0.225, 0.061 - 0.265, 0.366 - 0.464, 0.488 - 0.631, 0.544 - 0.601, 0.481 - 0.576, 0.284 - 0.334, 0.3 - 0.382. Heavy metal accumulation was also found to be somewhat higher during the wet season than during the dry season. This could be due to some heavy metals being diluted by higher water rate flow and volume, according to Edokpayi et al. (2017). The most common heavy metals discovered in the water samples tested were Cd, Pb, Fe, Ni, Cr, Co, Cu, and As. The amounts of heavy metals in the samples were found to be greater than the acceptable limits when compared to WHO (2017), except for Zn and Mn, which fall below the standard. The primary cause of the change between seasons could be run-off from a battery recycling site. In both seasons, it was found that the south of the estate as shown in the map had a comparatively higher concentration of residual heavy metals than other areas, with the exception of Pb, which is comparatively more concentrated in the south east of the estate. This could be because of the direction of erosion and wind from the battery recycling site. For information about the concentration at each sample location, see the supplementary material that is attached.

Table 5: Concentrations of heavy metals in water samples for both wet and dry season.

Heavy Metals (ppm)		Min	Max	Mean	STD.		Min	Max	Mean	STD.
Mn	Wet Season	0.007	1.798	0.420	0.600	Dry Season	0.020	1.860	0.407	0.515
Cu		0.015	1.368	0.369	0.508		0.030	1.408	0.355	0.519
Zn		0.020	1.120	0.225	0.346		0.017	1.562	0.179	0.415
Ni		0.003	1.443	0.265	0.481		0.017	0.569	0.061	0.118
Cd		0.022	1.206	0.464	0.407		0.032	1.061	0.366	0.347
As		0.017	1.482	0.488	0.502		0.028	1.596	0.631	0.581
Fe		0.018	1.509	0.544	0.634		0.027	1.566	0.601	0.569
Pb		0.014	1.475	0.576	0.535		0.022	1.625	0.481	0.550
Cr		0.013	1.435	0.334	0.390		0.017	1.569	0.284	0.463
Co		0.010	1.393	0.382	0.465		0.013	1.513	0.300	0.439

*Min depicts minimum, *Max depicts maximum, *Std depicts Standard deviation and the mean values.

The World Health Organization (WHO) has established acceptable standard values for the following heavy metals in drinking water: Manganese (Mn): 0.4 mg/L, Copper (Cu): 2.0 mg/L, Zinc (Zn): 3.0 mg/L, Nickel (Ni): 0.07 mg/L, Cadmium (Cd): 0.01 mg/L, Arsenic (As): 0.01 mg/L, Iron (Fe): 0.30 mg/L, Lead (Pb): 0.01 mg/L, Chromium (Cr): 0.05 mg/L and Cobalt (Co): 0.05 mg/L.

From Table 6, it could be observed that the HPI value for the wet season is 16.5% higher than that of the dry season. Nonetheless, the HPI values showed that the water samples are not heavy metal contaminated. The HPI value for wet season was 4.528 and 3.888 for dry season. The critical HPI value for drinking water above which water is declared unfit for drinking is 100 (Jazza et al. 2022).

Heavy metal pollution index

Table 6: Heavy metal pollution index (HPI) for water samples during wet and dry season

Heavy Metals (ppm)	Mean (V_i) (Wet)	Mean (V_i) (Dry)	(V_s)	W_i	Q_i(Wet)	Q_i (Dry)	Q_iW_i (Wet)	Q_iW_i (Dry)
Mn	0.420	0.407	50.0	0.0074	0.840	0.8140	0.006216	0.006024
Cu	0.369	0.355	2000.0	0.0002	0.018	0.0177	0.000004	0.000004
Zn	0.225	0.179	500.0	0.0007	0.045	0.0358	0.000032	0.000025
Ni	0.265	0.061	20.0	0.0186	1.325	0.3050	0.024645	0.005673
Cd	0.464	0.366	5.0	0.0744	9.280	7.3200	0.690432	0.544608
As	0.488	0.631	10.0	0.0372	4.880	6.3100	0.181536	0.234732
Fe	0.544	0.601	200.0	0.0019	0.272	0.3005	0.000517	0.000571
Pb	0.576	0.481	10.0	0.0372	5.760	4.8100	0.214272	0.178932
Cr	0.334	0.284	50.0	0.0744	0.668	0.5680	0.049699	0.042259
Co	0.382	0.300	10.0	0.0372	3.820	3.0000	0.142104	0.111600
$\sum$				0.2892			1.30945619	1.12442736
HPI =							4.528	3.888

Where W_i is the unit weight of i^{th} parameter, Q_i is the subindex of i^{th} parameter, V_s is the standard permissible value of the i^{th} parameter and V_i is the monitored heavy metal concentration.

Conclusion

The outcomes of the investigation revealed that the amount of heavy metals in the water at the study site was significantly lower than the maximum allowable amounts recommended by WHO. The physicochemical parameters of the water were also discovered to be within acceptable limits. The water samples proved satisfactory for excellent physicochemical properties and low heavy metal pollution. The water is however unfit for drinking and domestic use, according to the calculated WQI. As a result, the findings indicated that the battery recycling site poses a major risk to human health and the environment. Furthermore, the HPI poses no major risk to the study site because the observed findings were below the WHO (2004) guideline. However, more needs to be done to ensure proper battery waste disposal and more environmentally friendly ways to recycle batteries. In addition, it is critical to monitor heavy metal concentrations and the physicochemical characterization of water in the vicinity of battery recycling facilities regularly, and if necessary, steps should be taken to protect the environment and public health if the levels are found to be too high. The general public should also be educated on the dangers of heavy metal pollution from battery recycling and how to take appropriate safeguards.

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