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Full Length Research Article

ASSESSMENT OF PHYSICO-CHEMICAL PROPERTIES AND WATER QUALITY OF RIVER KANDAMI NEAR THE ADUDU LEAD MINING SITE IN NASARAWA STATE, NIGERIA

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ABSTRACT:
Pollution of Rivers by heavy metals are prone to potential health risk, especially in mining sites where they affect the quality of the water for domestic use. Therefore, the quality of water is of utmost importance because it determines the suitability of water for use domestically, industrially or otherwise. The physico-chemical properties and quality of water from River Kandami was determined by the analysis of thirty (30) samples for physicochemical parameters using standard AOAC methods and heavy metals using atomic absorption spectrophotometer, AAS. The WQI and MI of water were evaluated to ascertain its suitability for the desired purposes. The results obtained were; physicochemical parameters: temperature (27.08±1.36 ºC), turbidity (0.68±0.12 NTU), TDS (793.92±105.13 mg/L), TSS (25.97±1.32 mg/L), pH (7.54±0.40), EC (342.28±31.65 μS/cm), total hardness (8.63±0.84 mg/L), alkalinity (1.45±0.32 mg/L), chloride (0.86±0.09 mg/L), nitrate (0.68±0.0.24 mg/L) and sulphate (6.62±1.68 mg/L). Heavy metal concentrations (mg/L) were Cd (14.88mg/L), Cr (1.70 mg/L), Cu (0.63 mg/L), As (4.03mg/L), Pb (11.72mg/L), Mn (42.7mg/L), Ni (0.84mg/L), Se (2.40mg/L), Ag (7.03±0.10mg/L), Co (0.86mg/L), Hg (2.76mg/L) and Zn (11.78mg/L). All physicochemical parameters were below WHO recommended standards and for the heavy metals Cd, Cr, Fe; and Mn concentrations were higher than the standard values. WQI for the water was 15.28, an indication that the water is of good quality however, MI for metals such as Pb (1172), Cd (64958.333), Hg (1460.1667), As (483.4) and Mn (106) were higher than the recommended WHO limit, an indication of metal contamination. The results also showed that there was a strong positive correlation between turbidity and chloride and between copper and manganese. Therefore, there is an urgent need for the regulation of indiscriminate dumping of domestic wastes, runoffs from farmlands, mining locations into surface water bodies, since these are the likely sources. Regular monitoring of the water quality should be ensured and water from River Kandami should be treated before use.

Keywords: Water quality; heavy metals; contamination; metal index; water quality parameter

INTRODUCTION
Mining activities, notwithstanding their financially viable prominence, are well documented as one of the major sources of heavy metal pollution. (Sun *et al;* 2018; Sihotang *et al;* 2021). These heavy metals are distributed into the environment as a result of the mining activities via erosion, weathering, and leaching (Rodríguez *et al;* 2009) and they can be accumulated in key organs such as the kidney, liver, brain, liver, and bones for many years, once absorbed by the body, hence causing serious health challenges (Kabata-Pendias, 2011; Yuan *et al;* 2014). For instance, acute exposure to arsenic can led to nausea, abdominal pain, muscle spasms and diarrhea, while chronic exposure can cause diabetes. On the other hand, Lead can cause renal cancers and inhibits the normal performance of the reproductive and nervous systems (Ebrahimi *et al;* 2020). Furthermore, it was reported by Kim *et al;* (2016) that mercury can harm the endocrine system, cause kidney damage and respiratory failure. Cadmium has been related to breast, hepatic, pancreatic, lung, and skin cancers (Buha *et al;* 2017). Asthma and shortness of breath are caused by inhaling high levels of chromium (IV) compounds. Similarly, nickel is known to cause both oral and intestinal cancer. It is also linked to depression, heart attacks, hemorrhages, and kidney problems. Even though zinc is essential for human life, excessive consumption may have non- carcinogenic effects on human health. It has the potential to impair growth and reproduction (Cao *et al;* 2010). Therefore, exposure to heavy metals by people living near the mining area are reported to have a detrimental effect on human and animals (Halatek *et al;* 2014).

Water, as a vital constituent of life, serves as a carrier of heavy metals as well as a medium for heavy metals to spread to water bodies (Adedeji *et al;* 2019). Heavy metals in water are potential environmental threats that can affect human and animal's health through consumption (Wu *et al;* 2017). Water sources closed to mining sites are contaminated by effluents and tailings from the mining areas (Wang *et al;* 2019). Several studies have underscored the importance of soil physico-chemical properties on water quality (Keskin and Makineci, 2009; Fashola *et al;* 2020). These concentrations of the heavy metals hinged on the physico-chemical properties like pH, electrical conductivity, organic matter, and cation exchange (Bhatti *et al;* 2016).

For this reason, this study was aimed at investigating the physico-chemical properties and heavy metal contamination levels of water from the Rivers around Lead Mining Sites of Adudu, Obi Local Government Area of Nasarawa State Nigeria. The study will provide baseline data on the degree of heavy metal contamination of the River from the water study area for use by policy-makers, mining companies, and the general public.

MATERIALS AND METHODS
All analytical grade reagents were used throughout the study without further purification in preparing of the solutions. Glass and plastic wares were soaked overnight in 10.00 % (v/v) nitric acid, washed three times with distilled water and finally three times with deionized water (Wang *et al;* 2019). Agilent Fast Sequential (FS Varian 2400 AA) atomic absorption spectrophotometer was used for the determination of heavy metals in water samples.

Sample Collection

Water samples were collected from Rivers at an interval of 30 days. A total number of 60 water samples were collected; from twenty points (three times) at a distance of about 0.5 km and the samples were taken 5.0 cm below the water surface (to minimize the contamination of the water sample by surface films). The samples were taken into 1000 cm^3 plastic bottles that had been washed and rinsed with concentrated HNO_3 to prevent the adsorption of metal ions in water samples on the walls of the containers (acid rinsing of bottles is particularly meant for samples to be used for metal analysis)

Sample digestion

Exactly 500 cm^3 of the filtered water sample in a 1000 cm^3 beaker was placed on a hot plate and evaporated to about 50 cm^3. It was allowed to cool and transferred into a 250 cm^3 beaker. 5 cm^3 of concentrated HNO_3 was added and the resulting solution was heated at 85 ^0C until a clear solution was obtained (Wang *et al;* 2019). The digested sample was allowed to cool, then transferred into a 100 cm^3 volumetric flask and made up to mark with distilled deionized water. This solution was then used for the heavy metals analysis using Atomic Absorption Spectrophotometer (AAS).

Description of the Study Area

The study area is located in Adudu, North Central Nigeria, between latitudes 08˚10'00"N and 08˚19'00"N and longitudes 08˚55'00"E and 09˚6'30" E (Figure 1). It is bounded to the west by Keana, north by Lafia and to the east by Awe. The area is accessible by the Lafia-Obi roads, minor roads and footpaths. It is a town under Obi Local Government Area.

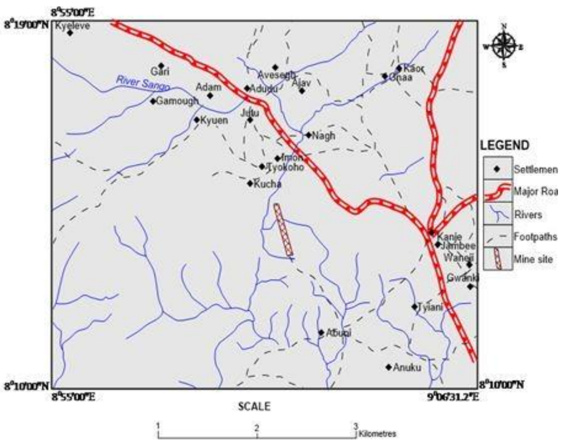

Fig. 1: The study area.

The physicochemical parameters for water samples were determined using standard methods of analysis. Electrical conductivity (EC), pH, temperature, turbidity, and total dissolved solids (TDS) were determined in situ using electrical conductivity meter JENWAY – 430, pH meter JENWAY – 430, mercury bulb thermometer, SGZ 200BS turbidity meter, and TDS meter JENWAY – 430 respectively (Opaluwa *et al*., 2020). Parameters such as total suspended solids (TSS) was determined by gravimetric method, total hardness (TH) by EDTA titrimetric method, alkalinity, and chloride by titrimetric method, nitrate and sulphate were determined by methods prescribed by AOAC, 1990 and adopted by Ademoroti (1996).

Water Quality Index (WQI):

The water quality index for River Kandami was evaluated from eleven parameters; turbidity, TDS, TSS, pH, EC, total hardness, alkalinity, chloride, nitrate and sulphate using the mean values of the parameter from the ten sampling locations along the stretch of the river to assess the suitability of the water for drinking. WQI was evaluated using the weighted arithmetic water quality index method proposed by Horton (1965), and adopted by Ewaid and Abed (2017). Water parameters were multiplied by a weighting factor and are then aggregated using simple arithmetic mean by the following equations:

$$Qi = \frac{(Mi - Ii)}{(Si - Ii)} \times 100 \qquad (1)$$

$$Wi = \frac{K}{Si} \qquad (2)$$

$$WQI = \sum_{i=1}^{n} \frac{wiQi}{\sum_{i=1}^{n} Wi} \qquad (3)$$

Where Qi is the sub-index of the ith parameter, Wi is the unit weight of the parameter, n is the number used, Mi is the monitored value of the parameter, Ii is the ideal value and Si is the standard value of the ith parameter. Ideal value for pH = 7, dissolved oxygen = 14.6 mg/L, and for all other parameters is zero (Chowdhury *et al*., 2012). Wi the weight unit of each parameter was evaluated as an inverse proportion of the standards (Si) of the World Health Organisation (WHO, 2011).

Metal index

The metal index of water from River Kandami was evaluated by using the method described by Akpoveta *et al*. (2011) and adopted by Aloke *et al*. (2019) which is as given below;

$$MI = \frac{M_c}{MAC} \qquad (4)$$

Mc is for the observed metal concentration of ith metal in the water sample, MAC is the minimum permissible concentration of metal in drinking water prescribed by WHO (2011). MI value >1 is an indication of the significant degree of metal contamination and MI < 1 shows no metal contamination. The metal indices for each metal give information about their relative contaminations contributed to the samples of water from the Kandami River (Aloke *et al*., 2019).

Statistical Analysis

The data obtained from the research work were subjected to SPSS software for statistical evaluation. The results were discussed and compared with the World Health Organization (WHO) standards for water quality with respect to the associated health risk.

RESULTS

Table 1: Physicochemical parameters of water from River Kandami,

Parameters	Sample Sites KDM1	KDM2	KL	KDM4	KDM5	KDM6	KDM7	KDM8	KDM9	KDM10	Mean	SD	WHO (2011)
Temperature (°C)	23.66	23.50	23.70	23.88	24.05	24.70	26.00	25.80	24.25	27.01	27.08	1.36	Ambient
Turbidity (NTU)	0.44	0.49	0.60	0.70	0.52	0.89	0.71	0.59	0.66	0.58	0.68	0.12	5.00
TDS (mg/L)	740.60	721.50	700.20	690.00	585.90	807.00	562.00	792.00	700.00	940.00	793.92	105.13	500.00
TSS (mg/L)	23.70	23.40	23.60	25.00	23.88	21.09	24.11	25.50	23.10	23.20	25.97	1.32	25.00
pH	6.70	6.50	6.70	6.89	6.94	7.20	6.66	7.20	6.48	7.66	7.54	0.40	6.50
EC(μS/cm)	301.40	293.10	310.20	400.56	298.35	300.89	320.30	298.20	300.70	298.40	342.28	31.65	1000.00
Total Hardness (mg/L)	8.90	7.45	7.24	7.69	7.68	6.90	8.88	6.35	8.56	8.04	8.63	0.84	150.00
Alkalinity (mg/L)	1.09	1.17	1.17	1.20	2.08	1.15	1.23	1.80	1.20	1.18	1.45	0.32	200.00
Chloride (mg/L)	0.99	0.87	0.76	0.66	0.79	0.78	0.77	0.74	0.68	0.83	0.86	0.09	250.00
Nitrates (mg/L)	0.07	0.99	0.85	0.45	0.69	0.73	0.56	0.43	0.66	0.71	0.68	0.24	50.00
Sulphates(mg/L)	3.80	5.90	4.56	6.10	8.67	8.44	6.98	7.91	4.07	5.66	6.62	1.68	100.00

SD= Standard Deviation

Table 2: Water Quality Index of River Kandami

Parameters	Standard value (si)	Ideal value (Ii)	Monitored value (Mi)	Sub-Index (Qi)	Weight Unit (Wi)	Wi*Qi
Turbidity (NTU)	5.00	0.00	0.68	11.25	0.2000	2.2500
TDS (mg/L)	500.00	0.00	793.92	145.00	0.0020	0.2900
TSS (mg/L)	25.00	0.00	25.97	92.98	0.0400	3.7192
pH	6.50	7.00	7.54	2.37	0.1540	0.3650
EC(μS/cm)	1000.00	0.00	342.28	31.18	0.0010	0.0312
Total Hardness (mg/L)	150.00	0.00	8.63	5.09	0.0067	0.0341
Alkalinity (mg/L)	200.00	0.00	1.45	0.62	0.0050	0.0031
Chloride (mg/L)	250.00	0.00	0.86	0.21	0.0040	0.0008
Nitrates (mg/L)	50.00	0.00	0.68	0.04	0.0200	0.0008
Sulphates(mg/L)	100.00	0.00	6.62	2.07	0.0100	0.0207
					Σwi = 0.4427	ΣwiQi = 6.7655

Table 3: Water Quality Index Categories

Range	Quality
0 - 25	Excellent
26 - 50	Good
51 - 75	Poor
76 - 100	Very poor
>100	Unsuitable for drinking

Table 4: Concentrations of heavy metals in water from River Kandami, Adudu Lead-Mining Site

Parameter	Sample Sites										Mean	WHO (2011)
	KDM1	KDM2	KL	KDM4	KDM5	KDM6	KDM7	KDM8	KDM9	KDM10		
Pb (mg/L)	11.42	11.67	12.00	13.06	12.06	11.00	11.13	11.03	11.87	11.96	11.72	0.01
Cu (mg/L)	0.34	0.55	0.54	0.66	0.74	0.88	0.01	0.91	0.79	0.88	0.63	2.00
Cr (mg/L)	1.74	1.79	1.97	1.34	1.54	1.45	1.25	1.48	2.19	2.28	1.70	0.05
Ni (mg/L)	0.76	0.89	0.88	1.09	0.59	0.67	0.35	0.70	1.21	1.30	0.84	0.07
Mn (mg/L)	45.13	42.67	43.54	39.87	40.76	41.00	42.13	41.03	45.58	45.67	42.74	0.40
Cd (mg/L)	15.67	15.78	15.09	14.98	13.67	12.98	15.24	13.01	16.12	16.21	14.88	0.00
Ag (mg/L)	6.06	7.01	6.98	9.40	5.74	7.91	6.47	7.94	6.51	6.60	7.06	0.10
Co (mg/L)	0.87	0.90	0.66	0.88	0.87	0.67	0.36	0.70	1.32	1.41	0.86	NA
Hg (mg/L)	2.56	2.89	2.76	2.83	2.74	2.67	2.35	2.70	3.01	3.10	2.76	0.01
As (mg/L)	4.09	5.01	5.70	5.11	4.98	4.89	4.47	4.92	4.54	4.63	4.83	0.01
Se (mg/L)	2.29	2.45	2.35	2.78	2.55	2.01	1.91	2.04	2.74	2.83	2.40	0.04
Zn (mg/L)	11.07	11.67	12.05	11.98	10.98	12.89	11.13	12.92	11.52	11.61	11.78	NA

Table 5: Metal Index of the Heavy Metals in water from River Kandami

Metals	Mc	MAC	MI
Pb (mg/L)	11.72	0.01000	1172
Cu (mg/L)	0.63	2.00000	0.31515
Cr (mg/L)	1.70	0.05000	34.06
Ni (mg/L)	0.84	0.07000	12.05714
Mn (mg/L)	42.74	0.40000	106.845
Cd (mg/L)	14.88	0.00300	4958.333
Ag (mg/L)	7.06	0.10000	70.608
Co (mg/L)	0.86	NA	NA
Hg (mg/L)	2.76	0.00600	460.1667
As (mg/L)	4.83	0.01000	483.4
Se (mg/L)	2.40	0.04000	59.875
Zn (mg/L)	11.78	5.00000	2.3564

DISCUSSION

The results of the physicochemical parameters of water samples from River Kandami are presented in Table 1. The mean temperature of water samples from River Kandami was 27.08±1.36ºC. The parameter is important in water analysis because it gives the idea of regulating temperatures based on seasonal variations (Nguyen and Huynh, 2020). When the Temperatures are high, it can have an adverse effect on the aquatic animals because it reduces dissolved oxygen that could cause the mortality of fish and other aquatic organisms (Usman, 2016). It is however; higher than 26.3ºC recorded for water from River Mkomon, Benue State, Nigeria (Ioryue *et al*., 2018). The mean temperature from the current research is in the range of the ambient (25 ºC) recommended by WHO (15ºC to 25ºC) and therefore, is suitable for aquatic organisms. Warm stream water is can affect the aquatic life in the stream. Warm water holds less dissolved oxygen than cool water, and may not contain enough dissolved oxygen for the survival of different species of aquatic life. Some compounds are also more toxic to aquatic life at higher temperatures (Ioryue *et al*., 2018). Turbidity of water from River Kandami had mean value of 0.68±0.12 NTU. Turbidity of the water can be due to indiscriminate dumping of wastes into the water body, run-offs, or as a result of turbulent flow which could stir up nonliving matters, silt, and sand at the bottom of the river (Gupta *et al*., 2017). The turbidity from the research work below the WHO standard (5.00 NTU) and might be probably due to the period of the sampling and therefore, constitutes no danger to water quality. The turbidity mean value from the current research is in agreement with the value (0.68 NTU) reported elsewhere (Gupta *et al*., 2017) and it is lower compared to 1.20 NTU observed for pond and river water in Lumding town of Assam, India (Madhab *et al*., 2011). The mean value of TDS for water samples from River Kandami was 793.88±105.13 mg/L. This value is above the value stipulated by WHO of 500mg/L and could be ascribed to sewage discharge and other anthropogenic activities along the river bank. TDS are composed of mainly inorganic compounds, organic matter, salt, and other particles (Ioryue *et al*., 2018). TDS of the water tends to be diluted when the flow is turbulent and the results obtained from this work is higher compared to 350 mg/L recorded for pond and river water in Lumding town of Assam, India (Madhab *et al*., 2011).

Also, these results are higher than that obtained (60.8 mg/L) for water from River Mkomon Kwande, Benue State, Nigeria (Ioryue *et al.*, 2018).

The results for the TSS had a mean value of 25.97±1.32 mg/L for water from River Kandami. This is slightly lower than the recommended tolerable limit by WHO (25 mg/L) and it is relatively high due to runoff and the direct discharge of wastes and effluents into the river. This mean value of TSS is with the range values of TSS 17.03±0.48 – 36.00 mg/L observed for water from selected rivers 31.85±1.74 mg/L for water from Ajiwa Reservoir, Katsina State, Nigeria (Usman, 2016). On the other hand, the mean pH of water from River Kandami was 7.54±0.40 and this is within the range of 6.50 – 8.50 recommended by WHO. This result is very important to the aquatic ecosystem because the metabolic activities of organisms in the aquatic ecosystem are dependent on the pH. It is an index for water quality determination and is indicative of the extent of pollution. High pH affects the solubility of many nutritive and toxic chemicals; and therefore, reduces the availability of these chemicals to the aquatic organisms. Increased acidity makes many metals present in water more soluble and more toxic. It also leads to increased toxicity of cyanide and sulphide (Akpan, 2004). The pH value is higher compared to the range values of 6.69±0.1 obtained for Iko River (Usoro *et al.*, 2013) and lower compared to 8.48 obtained from River Narmada, Madhya Pradesh, India (Gupta *et al.*, 2017). The electrical conductivity of water from River Kandami was 342.28±31.65µS/cm. This result is very high and could be ascribed to discharge from the mining streams and runoff from domestic and other anthropogenic activities along the river bank. The EC from this work is far below the recommended limits by WHO and therefore, does not affect the water quality and eventually poses no form of danger to the use of the water domestically.

The total hardness of water from River Kandami had a mean value 8.63±0.84 mg/L. The hardness of the water is low based on the classification of water in terms of softness and hardness; 0 – 50 soft, 50 – 100 moderately hard, and 100 – 150 mg/L above hard (Efe *et al.*, 2005). This implies that the discharge into the river does not really have constituents that could cause hardness. The hardness of water from River Kandami is lower compared to 40.9 mg/L recorded for water in Benue, Nigeria (Okenyi *et al.*, 2016) as well as 200.00 mg/L observed for Pond and River in Lumding town of Assam, India (Madhab *et al.*, 2011). This result less than the recommended limits by WHO of 150 mg/L.

The mean value of alkalinity for River Kandami was 1.45±0.32 mg/L. From all the sampling points, the total alkalinities for the samples were low. This could be that contaminant that would have caused increased alkalinity was not much in the different discharges and runoffs received by the river. The value is far lower than the recommended limit by WHO. The result is less than the range values 210.05±20.34 – 281.16±23.70 mg/L reported for water from Urban River, Bangladesh (Arafat *et al.*, 2021) as well as 23 – 800 mg/L reported by Madhab *et al.* (2011).

Chloride in water samples from River Kandami had a mean concentration 0.86±0.09 mg/L. The chloride concentration is very low and could be attributed to runoffs from sources; domestic sewage and other effluents which do not contain a good amount of chloride to contribute to its level in the water from the river. It is far less than the WHO recommended permissible limits for chloride in water and therefore, does not affect the water quality. The value from the present study is lower than the range values 55.2±1.35 mg/L reported by Ioryue *et al.* (2018) as well as 32.1 mg/L for River Benue reported by Okenyi *et al.* (2016). Nitrate concentration above 50 mg/L, the limit set by WHO causes a disease known as methemoglobinemia (blue baby syndrome) (Ibrahim *et al.*, 2019). The mean nitrate from the water of River Kandami was 0.68±0.24 mg/L and therefore, below the recommended permissible limit. There is, therefore, no effect on the quality of water and also no health danger posed by using the water for domestic purposes. High nitrate level is caused by an inflow of nutrients most especially, from runoffs from agricultural farmland, effluents from the abattoir, septic tanks that have failed and municipal effluents (Ibrahim *et al.*, 2019). The chloride level of River Kandami is below 68.15±2.21 mg/L reported by Usman (2016) as well as 7.7±1.3 mg/L reported by Nienie *et al.* (2017). The sulphate mean concentration of water samples from Kandami River was 2.03±0.08 mg/L. This value is very low and could be attributed to the river receiving domestic discharge containing low sulphur contaminants in runoffs and other sources. This concentration of sulphate is far below the WHO recommended permissible limits and therefore, constitutes no negative effect on the water quality and eventually poses no health challenges. However, high concentrations of sulphate could cause high acidity in water.

Water Quality Index (WQI)

The WQI measures the scope, frequency, and amplitude of water quality exceedances and then combines the three measures into one score. Table 2 shows the evaluation of the water quality index of water from River Kandami and Table 3 shows the WOI categories. The water quality index gives a nominal number that represents the overall quality of water from a given location and time and it is based on parameters that determine water quality. The water quality index converts complex water quality data into information more detailed and useful to the public. WQI present water quality in terms of index number and provides very useful information to the public on the water for any use or to help reduce pollution where it is eminent as well as water quality management (Qureshimatva *et al.*, 2015). The WQI for water from River Kandami was evaluated to be 15.28 and from Table 3 it could be categorised to be of excellent quality. This value is in the same category for water from Owo River in Lagos with WQI 19.62 (Akoteyon *et al.*, 2011) but it is, however, lower compared to the WQI 821.5 for water from surface water sources from Warri Metropolis, Nigeria (Asibor and Ofuya, 2019) and the water falls under the category of water that is unsuitable for use domestically. Consumption of >30 mg of iron per day in drinking water was associated with a reduced risk of anemia in individuals without thalassemia (Qureshimatva *et al.*, 2015).

Concentrations of the Heavy Metals

Cadmium mean concentration in water from River Kandami was 14.88 mg/L. This is relatively high and could be attributed to runoffs from farmlands, mining sites and anthropogenic inputs. The possible source of cadmium in surface water includes atmospheric fall-outs, fossil fuel combustions and the release of sediment-bound metals (Dan *et al.*, 2014). Cadmium concentration in the study area is higher compared to the range concentrations 0.002±0.01 mg/L for water from Nzehelele River, South Africa (Edokpayi *et al.*, 2017). The value is also higher compared to 0.005±0.001 mg/L obtained for cadmium in water from Sanguling

Reservoir, West Java Province, Indonesia (Eka *et al*., 2018). Cadmium exposure in humans. Occurrence levels in drinking water are usually less than 1 mg/L Elinder (1985). The value of cadmium in water from the present study is higher than the WHO recommended permissible limits 0.003 mg/L and therefore, the water is said to be polluted with cadmium. The mean concentration of chromium in water from River Kandami was 1.7mg/L. This value is high and could be attributed to waste dumps in the river and agricultural lands. Some part of it might also be from runoffs from mining locations. The value is within the range concentration 0.87 mg/L for chromium in water from River Mkomon in Benue State, Nigeria (Ioryue *et al*., 2018). But the value from the present study is far higher compared to 0.10 mg/L for chromium in water sources from Tejgaon industrial area, Bangladesh (Mondol *et al*., 2011). However, the mean concentration of chromium in water from Kandami River is far more than the WHO recommended permissible limit 0.05 mg/L which signifies the water source is polluted with chromium. Exposure of extremely high doses of chromium to humans can result in severe cardiovascular, respiratory, hematological, gastrointestinal, renal, hepatic and neurological effects and possibly death (Engwa *et al.,*2018).

Copper had a mean concentration of 0.63 mg/L in water from River Kandami. The recommended permissible concentration of copper for drinking water is 2.00 mg/L therefore; it implies that the observed mean value is below the permissible level for drinking water and does not portend any potential health risks. This result is compared with the concentrations of copper 0.01, 0.07, and 0.05 mg/L in Rivers Buriganga, Turag, and Shitalakhya respectively (Chowdhry *et al*., 2007) when compared to the mean value from the present study indicate that the latter showed increased concentration. Lead is a highly toxic metal in water particularly, when present in concentrations that are beyond the recommended permissible limits set by regulatory bodies. Lead was observed to be higher (11.72mg/L) than the recommended limit by WHO (0.01mg/L). This observation is similar to the level of lead recorded for water from River Sokoto in both dry and wet seasons (Raji *et al*., 2016). This poses great potential health danger to the water from this source with respect to lead. Manganese had a mean concentration 42.74 mg/L in water samples from River Kandami. Manganese is present in the environment naturally due to rock and soil weathering as well as from anthropogenic sources such as domestic waste dumps, landfill leaching, mining, and industrial discharge. Manganese from the present study is higher compared to 0.20±0.12 mg/L in water from Mada River, Nigeria (Tukura, 2015) and falls within 0.65 mg/L in water from Calabar River, Cross River State Nigeria (Ewa, *et al*., 2013). The mean manganese concentration in water from River Kandami is far more than 0.40 mg/L the WHO recommended permissible limit for drinking water. This is indicative of manganese contamination of the water source. Nickel in water samples from River Kandami was below the detectable limit as reported. The primary source of nickel in the surface water is leaching from metals that are in contact with metals. It could also be from sea beds that might have nickel ore-bearing rocks. The result observed for nickel in water from River Kandami is similar to that obtained for nickel in water from Calabar River, Cross River State Nigeria (Ewa, *et al*., 2013). Zinc had a mean concentration 11.78±0.01 mg/L in water from River Kandami. This low level of zinc is an indication of low waste streams from zinc, and run-off from soil containing zinc that is discharged into the water body. The value of zinc from this research work is higher compared to the range values of zinc 0.36±0.06 mg/L in water from Mada River (Tukura, 2015). Zinc mean concentration in the present work falls far below the WHO recommended permissible limit in drinking water and therefore, poses no potential health risks with respect to zinc.

Metal Index

Metal index (MI) is based on a total trend evaluation of the present status. The higher the concentration of a metal compared to its respective MAC value, the worse the quality of the water. Table 5 shows the metal indices for Cd, Cr, Cu Pb, Mn, Ni, and Zn. The metal indices for Pb (1172), Cd (64958.333), Hg (1460.1667), As (483.4 and Mn (106) in water from Kandami River indicate significantly that they are above the WHO permissible limit while the metal indices for Cu and Zn are within WHO permissible limit.

CONCLUSION

The physicochemical parameters of water from River Kandami analyzed were within the threshold of WHO recommended limit except for TDS. WQI calculated revealed that the water from River Kandami is of good quality. For the heavy metals determined Pb, Cr, Mn, Cd, Ag, Hg, As, and Se concentrations were higher than the WHO recommended permissible limit whereas Cu and Zn were within the WHO threshold. The metal index revealed heavy contamination of the water from River Kandami with Cd, Cr, Fe, and Mn. High concentrations of these heavy metals above the permissible limits are highly carcinogenic and can cause serious public health problems.

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