ISSN Print: 2394-7500
ISSN Online: 2394-5869
Impact Factor: 8.4
IJAR 2022; 8(4): 114-118
www.allresearchjournal.com
Received: 02-01-2022
Accepted: 06-03-2022

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Heavy metals concentration and well water quality index in artisanal gold mining areas of Zamfara state, Nigeria

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Abstract
Heavy metals and water quality indices of wells from three artisanal gold mining areas and control were assessed to ascertain the impacts of gold mining in the study area. Mine A (05°45.49'E–11°59.66'N), Mine B (06°19.56'E–12°21.45'N), Mine C (06°22.43'E–12°20.26'N) and mine D (control) (06°08.71'E–12°13.56'N) respectively were measured in order to determine the suitability of the water for consumption. Samples were collected and analysed for physicochemical parameters following the procedures outlined in the standard methods for the examination of water and wastewater while heavy metals were analysed using Atomic Absorption Spectrophotometer (GFAAS-AA240FS). The results showed that highest pH was 6.53 in D, the control site while the lowest was 5.02 in Mine C with no significant difference (P>0.05). Among all the sampling stations, highest and lowest DO were 5.25 mg/l and 4.31 mg/l in D and C respectively with a significant difference ($P< 0.05$) among the sampling stations, while most of the physicochemical parameters were not in compliance with the World Health Organization standards for drinking water. The highest occurring metal was Pb with a concentration of 107.69 mg/l and the lowest was as with a concentration of 1.25 mg/l. All the metals assessed during the duration of study exceeded the World Health Organization's (WHO) maximum permissible limit in drinking water. Water quality indices showed that Mine C and D wells were poor while A and B wells were very poor for drinking which indicates the impact of artisanal mining carried out in the area and calls for its regulation and provision for safer mining practices to prevent heavy metals poisoning in the mining area.

Keywords: Concentration, gold mining, Heavy metals, physicochemical parameters, water quality index

1. Introduction

Water is one of the most important natural resources on earth that is essential for survival of all life forms. It has so many usages ranging from cooking, washing, recreation, transportation and agricultural as well as industrial and other uses. Water is an indispensable component of metabolic processes and serves as a solvent for many bodily solutes thereby forming approximately 70% of the human body by mass (Hank, 1987; Benelam and Wyness, 2010; Geetinder *et al*., 2018) [6, 14]. Despite the planet earth having about 71% of its surface covered with water, only about 2.5% of this is freshwater out of which one third is groundwater (Mishra and Dubey, 2015) [22]. Ground water is water that fills pores and fractures in the ground reaching the water table, a very important part of the Global water cycle that constitutes more than half of all drinking water worldwide and supports about 40 per cent of the world's food production through irrigation agriculture (FAO, 2016; FAO, 2017; Fienen and Arshad, 2016) [11, 12, 10]. It is harnessed by drilling boreholes or digging wells and may appear on the surface in form of springs.

Drinking water or potable water is water of sufficiently high quality that is safe enough to be consumed by humans and animals or used with low risk of immediate or long-term harm (WHO, 2011) [30]. Oludairo and Aiyedun (2015) [25] stated that potable water should be without disagreeable taste, colour or odour and should be free from contamination and pathogens. The demand for potable water worldwide is on the rise at an alarming rate due to the geometrical increase in world population, urbanization and increase in per capita water consumption driven by development. A report of the Population Institute (2010) estimated the annual global population expansion to be 80 million people and projected that global population will reach 9 billion people by 2050, 90% of which will be living in developing countries where there's scarcity of potable water already. This increase in population has significant effects on water quality through agricultural and industrial activities that result in the discharge of so many pollutants. Water is said to be polluted when it does not support human use or undergoes a marked shift in its ability to support its biotic constituents (Etukubo and Abowei, 2011; Kahime *et al*., 2019) [8, 17].

Heavy metals occur in the earth's geological structures and can be mobilized into ground water through mining and other activities which lead to consequences such as acid mine drainage (Mahipal *et al.*, 2016) [19]. They are naturally occurring inorganic chemical pollutants with long term health effects and tremendously influence the physical and chemical parameters of a water body which in turn determine the overall quality of the water (Lawson, 2011) [18]. The persistent characteristic of these inorganic elements makes them accumulate in the soft tissues, some of which injure the kidneys and cause symptoms of chronic toxicity (Bate and Sam-Uket, 2019) [5].

Water quality index (WQI) provides a single value that shows the overall quality of water at a specific location and time, using several water parameters (Douglas *et al*., 2011). It is a means of comparing water from different sources and communicating to the public what generally is the problem with water from a particular source. WQI is mathematically computed and takes into account the most important physical and chemical parameters of water. WQI and human health are inextricably linked (Fredrick *et al.*, 2012) [13].

This research was conducted in Zamfara state of Nigeria where artisanal gold mining has been carried out for a very long time as a result of which there were several cases of reported heavy metals pollution and the inhabitants of the area rely mostly on hand dug wells for their water supply. The research, therefore was conducted to find out the impacts of gold mining on the quality of well water in the area in order to assess its suitability for human consumption.

2. Materials and Methods

2.1 Study Area

Zamfara State of Nigeria is located between latitude 12°10'N and 12°167'N, and longitude 06°15'E and 06°250'E, it has a total area of 39,762 square kilometers and a warm tropical climate (Mas'ud *et al.*, 2017) [20]. Wells from four gold mining areas, namely Mine A (05°45.49'E–11°59.66'N), Mine B (06°19.56'E–12°21.45'N), Mine C (06°22.43'E–12°20.26'N) and D (06°08.71'E–12°13.56'N) were selected for the study.

2.2 Sample Collection

Samples of well water from each of the mining sites were collected monthly for a period of six months making a cumulative total of 24 samples. The water samples were collected from representative wells with an average depth of 10 meters using a rope and plastic containers that were washed with water and detergent, soaked in 10% HNO_3 and rinsed with deionized water according to Water Research Council (WRC, 2017) [29].

2.3 Analysis of Samples

2.3.1 Analysis of Physicochemical parameters in Water Sample: The physicochemical parameters of water samples (pH, Electrical conductivity (EC), Total Dissolved Solid (TDS), Total Hardness (TH), Nitrates, Sulphates, Chlorides, Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) were determined following the procedures outlined in the Standard Methods for the Examination of Water and Wastewater (APHA, 1998; Patil *et al*., 2012) [3, 26].

2.3.2 Analysis of Heavy Metals in Water Sample

50 ml of each water sample was digested by addition of 2.5 cm^3 of $1 mol.dm^{-3}$ HNO_3 which was heated on a hot plate until colorless solution was obtained and allowed to cool before its content was filtered into 50 ml standard volumetric flask and filled up to the mark by adding distilled water according to (Kabir *et al.*, 2017) [16]. The analysis was then done using Atomic Absorption Spectrophotometer (GFAAS-AA240FS) to determine the concentration of heavy metals: Pb, Cd, As, Cr, Al and Fe in each water sample.

2.4 Statistical Analysis

Analysis of variance (ANOVA) was used to determine whether significant difference exist among the values of different heavy metals and the physicochemical parameters across the four mining areas.

2.5 Water Quality Index

The WQI of the various wells was calculated using the weighted arithmetic index method as expressed in equation one according to Mas'ud *et al*. (2017) [20].

$$WQI = \frac{\sum_{i=1}^{n} QiWi}{\sum_{i=1}^{n} Wi}$$ Where;

n is the number of parameters,

Wi is the relative weight of the ith parameter

Qi is the water quality rating of the *ith* parameter.

There's an inverse relationship between the unit weight (*wi*) of various water quality parameters and the recommended standards according to Mehra *et al.* (2017) [21] and the value of *qi* is calculated using the formula in equation two:

Wi = 1/ Si

$$Qi = 100\left[\frac{Vi - Vid}{Si - Vid}\right]$$ Where;

Vi is the observed value of the *ith* parameter

Si is the standard permissible value of the *ith* parameter

Vid is the ideal value of the *ith* parameter in pure water.

All parameters' ideal values (*Vid*) are taken as zero in drinking water except pH and DO that are taken as 7.0 and 14.6 mg/l respectively (Mehra *et al*., 2017) [21].

The calculated water quality indices were compared with the Weighted Arithmetic water quality scale shown in table 1.

Table 1: Weighted Arithmetic Water Quality Classification

WQI	Status
>100	Unsuitable for drinking
76 – 100	Very poor
51 – 75	Poor
26 – 50	Good
0 – 25	Excellent

Source: Douglas *et al*., (2015) [7]

3. Results

3.1 Physico–chemical Parameters of Well Water from the Mining Areas

The highest mean pH was 6.53 found in well D from the control site while the lowest was 5.02 in well C with no significant difference (P>0.05) among them but the mining sites water pH were below the World Health Organization (WHO) standard. Mean DO was also highest (5.25 mg/l) in well D and lowest (4.31 mg/l) in well C with a significant difference ($P< 0.05$) among the sampling sites and only the control site fell within the WHO limit. Mean BOD values significantly differed ($P< 0.05$) among sampling sites with the highest being 6.32 mg/l in Mine C and the lowest was 4.97 mg/l in D which was the only value within WHO limit. Mean TDS values in the mining sites exceeded the WHO limit for drinking water while the control was below the limit with no significant difference (P>0.05) among the values. Average electrical conductivity (EC) values did not differ significantly (P>0.05) and all exceeded the WHO limit exception of the control site. All mean turbidity values fell within the WHO limit with no significant difference (P>0.05) among them. Table two shows the mean physicochemical parameters of well water from the three mining areas and the control in Zamfara state, Nigeria with their statistical test of difference and comparison against WHO standards.

Table 2: Mean Physico-chemical Parameters of Well Water from the Three Mining Areas and the Control, their ANOVA Test and Comparison against WHO standards

Parameters	Mine A	Mine B	Mine C	D	Mean	P–test	WHO limit
pH	5.72 ± 0.86	5.82 ± 0.99	5.02 ± 0.65	6.53 ± 0.74	6.02	P = 0.35^{NS}	6.50 – 8.50
DO (mg/l)	4.19 ± 0.47	4.18 ± 0.84	4.31 ± 0.91	5.25 ± 0.36	4.48	P = 0.04^{S}	5
BOD (mg/l)	5.87 ± 0.89	5.84 ± 0.59	6.32 ± 0.90	4.97 ± 0.53	5.75	P = 0.04^{S}	5
TDS (mg/l)	502.25 ± 87.59	579.64 ± 107.85	534.88 ± 76.59	442.89 ± 53.19	514.92	P = 0.06^{NS}	500
EC (µS/cm)	289.63 ± 48.51	296.89 ± 66.14	261.43 ± 26.54	234.29 ± 21.25	270.56	P = 0.09^{NS}	250
Turbidity (NTU)	2.67 ± 0.61	2.35 ± 0.45	2.21 ± 0.94	1.88 ± 0.61	2.28	P = 0.28^{NS}	5
Nitrates (mg/l)	45.79 ± 3.07	50.62 ± 5.86	47.71 ± 6.37	45.12 ± 5.78	47.31	P = 0.32^{NS}	50
Sulphates (mg/l)	54.77 ± 10.84	75.44 ± 40.12	67.68 ± 17.94	48.47 ± 8.92	61.59	P = 0.20^{NS}	200
Chlorides (mg/l)	84.48 ± 13.04	84.38 ± 12.92	85.02 ± 18.62	78.61 ± 12.18	83.12	P = 0.85^{NS}	250
Calcium (mg/l)	52.20 ± 9.25	52.08 ± 22.86	39.53 ± 14.19	49.96 ± 17.86	48.44	P = 0.52^{NS}	75
Magnesium (mg/l)	28.39 ± 14.19	25.89 ± 6.78	23.09 ± 6.74	26.38 ± 5.93	25.94	P = 0.79^{NS}	50

Note: Superscripts NS = No significant difference, S = Significant difference

3.2 Heavy Metals Concentration in Well Water from the Mining Areas and Control

Mine A well had the highest mean Pb concentration of 107.69 mg/l and the lowest was 21.31 mg/l in D the control site though all exceeded the WHO maximum permissible limit and there was a significant difference ($P< 0.05$) among the values. Cd was highest (4.51 mg/l) in Mine B and lowest (1.38 mg/l) in D with no significant difference (P>0.05) among them but all exceeded the WHO tolerable limit. Arsenic mean values did not differ significantly (P>0.05) across sampling stations with the highest and lowest being 4.52 mg/l and 1.25 mg. l in Mine A and D respectively and all the values observed exceeded the WHO limit. Cr was highest in Mine C and lowest in Mine B with no significant difference (P>0.05) among the values, Al also did not differ significantly and had its highest and lowest values in Mine A and D respectively while Fe differed significantly. Mean metal concentrations in well water from the mining areas and control during the study duration are shown in figure 1.

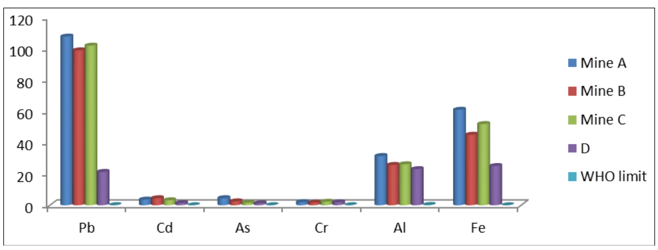

Fig 1: Heavy Metals Concentration (mg/l) in Well Water from the Mining Areas and Control.

3.3 Water Quality Indices of Wells from the Mining Areas and Control

The highest water quality index in this study was 89.85 in Mine A well water and the lowest was 70.24 in Mine C. Figure 2 shows the water quality indices of wells in the various mining areas and control.

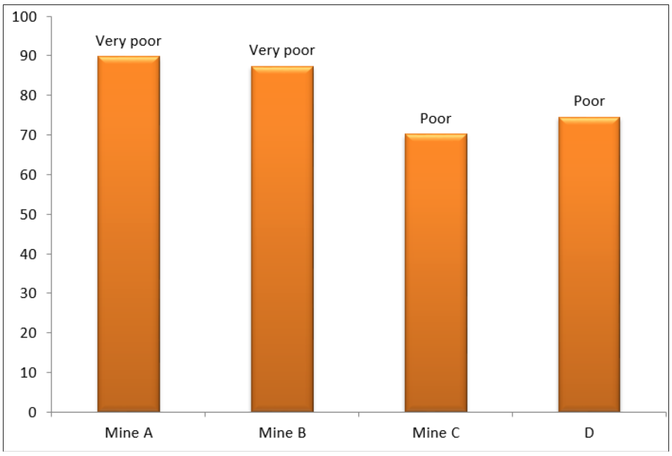

Fig 2: Water Quality Indices of Wells from the Mining Areas and Control

4. Discussion

There was no significant difference (P>0.05) among physicochemical parameters of well water from sampling locations in mining areas and the control except for DO and BOD which implies that the groundwater in the study area have a common source of contamination i.e. the mining activities. Lower pH than the WHO limit observed in all samples from the mining areas could be as a result of heavy metals contamination of the water and may lead to corrosion, skin irritation, eyes and mucous membrane irritation (Ezekwe *et al.*, 2017) [9]. Low DO and high BOD levels were observed in well water from mining sites while the control was within the WHO limit which may be attributed to the organic wastes discharge through the mining processes. Electrical conductivity (EC) is a measure of water capacity to conduct an electric charge and is a function of the mineral ions present in the water usually measured as total dissolved solids (TDS) (Anna, 2018) [2]. Both EC and TDS in well water from the mining areas were higher than the WHO limit in this study and they were reported to influence the incidence of cancer, coronary heart disease, arteriosclerotic heart disease and cardiovascular disease (Yirdaw and Bamlaku, 2016) [31]. Other physicochemical parameters include chloride, nitrate, sulphate, calcium and magnesium which were within the WHO limit. Udiba *et al.* (2013) [28] carried out an assessment of impact of mining activities on ground water quality status in Dareta village of Zamfara, Nigeria and obtained similar results with most of the physicochemical parameters higher than the World Health Organization (WHO), European Union (EU) and the Nigerian Standards for Drinking Water Quality (NSDWQ) guidelines which signifies contamination from the mining activities and possible adverse health effects if the water is consumed.

All heavy metals in well water measured in this study were above the WHO maximum permissible limits in both the mining areas and the control which is a cause for concern due to the negative health effects associated with the metals. Heavy metals pollution in water from gold mining sites in Southwestern Nigeria was assessed by (Ayantobo *et al*., 2014) [4] and they found out that most metals have values exceeding the international and national recommended limits while metal contents of the groundwater were generally higher than those from surface water. Adeniyi and Temitope (2020) [1] also found metals above recommended drinking water quality standards in Anka artisanal gold mining sites of Zamfara state and posited that these metals are released by geogenic processes and aggravated by mining. Daily intake of water from wells in the study area for a very long time therefore poses a potential health threat to the inhabitants especially children who are more prone to the risk compared to adults.

Overall water quality indices showed that well water from the mining areas and the control fell within the category of poor to very poor on the WQI scale. This is not unconnected to the fact that so many physicochemical parameters were not in line with the WHO standard that was used in calculating the WQIs. The poor water quality observed even in the non-mining area could be due to both vertical and horizontal leaching of metals into the ground water from the point of mobilization as topography of the control area is low. Ogundiran and Osibanjo (2009) [23] studied mobility and speciation of heavy metals in soil impacted by hazardous waste and observed high mobility and bioavailability especially in non–residual fractions. This exposes even the non-mining areas to the harsh realities of heavy metal pollution and put their lives at risk despite the fact that some parameters such as turbidity were within the WHO limit. The result of findings is similar to what was earlier reported by (Okanlawon *et al.*, 2017) [24] during their studies on the water quality in gold and manganese mining area in North central Nigeria, where they found out that heavy metals contaminated both surface water and hand dug wells leading to very poor water quality indices as a result of mining activities but on the contrary borehole water in the area had good WQIs.

5. Conclusion

Physicochemical parameters and heavy metals concentration of well water were generally not in compliance with the WHO standards for drinking water especially those in the mining areas leading to the overall water quality indices being poor in Mine C and the control while it was very poor in Mine A and Mine B. This calls for regulation in the artisanal mining by the concerned authorities in the area and provision for safer mining practices to prevent heavy metals poisoning and ensure safe potable water for the inhabitants.

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