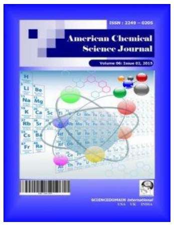

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Assessment of Rainwater Quality in Ayanfuri, Ghana

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Authors' contributions

This work was carried out in collaboration between all authors. Authors NA and NB designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors SJC and ABD managed the analyses of the study and the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The present study assessed the quality of rainwater in Ayanfuri in the Upper Denkyira West District, Central Region of Ghana.
Study Design: Triplicate samples were collected from three sampling points.
Place and Duration of Study: Triplicate rainwater samples were collected within the two months (February and March, 2014) in Township.
Methodology: Physico-chemical and trace metal analyses of the samples were carried out at the Council for Scientific and Industrial Research - Water Research Institute Laboratory, Tamale using standard methods.
Results: The physico-chemical values recorded were within World Health Organization limits for potability except pH and turbidity. The mean concentrations of the trace metals that include total iron (0.51 mg/l), lead (0.28 mg/l) and cadmium (0.12 mg/l) in the rainwater samples exceeded WHO permissible limits for potability except manganese (0.28 mg/l).
Conclusion: The study shows that rainwater may not be suitable for drinking and other domestic purposes unless it is treated. The compromised rainwater quality could be influenced by

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anthropogenic activities such as mining that has increased the concentration of pollutants in the atmosphere. The quality of rainwater can be improved if monitoring authorities step-up their activities.

Keywords: Ayanfuri; cadmium; mining; rainwater quality; pollutants.

1. INTRODUCTION

Mining activities generate a lot of dust and gases into the atmosphere which can compromise the quality of rainwater. Ayanfuri in the Central Region of Ghana has experienced high intensive mining activities in both large-scale and small-scale. These activities encourage the migration of many people into the town to engage in mining, which has resulted in an upsurge in rate of environmental degradation, pollution, and increased the demand for potable water supply.

Water is a resource that is precious and vital to the existence of all living organisms, but this cherished resource is increasingly being threatened as human populations grow and demand more water of high quality for domestic purposes and economic activities [1]. Safe drinking water is a human birth right as much as clean air, however much of the world's population does not have access to safe drinking water [2]. Rainwater functions as a major sink for both gaseous and particulate matter including trace metals in the atmosphere and therefore plays an important role in controlling the concentrations of these species [3]. The monitoring of collected rainwater is of great concern as it has potential for health risk because of the presence of chemical and microbiological contaminants [4].

Anthropogenic sources of potential pollutants in the atmosphere include combustion of fuels for energy generation, transport, heating and industrial needs, wind-blown soils from arid and agricultural regions, volatilization from agriculture, waste disposal and previously polluted sites [5]. Rainwater is relatively free from impurities except those picked up by rain from the atmosphere. However, the quality of rainwater may be degraded during harvesting, storage, and household use [6]. Rainwater could be contaminated by wind-blown dirt, leaves, faecal droppings from birds and animals, insects and contaminated litter on the catchment areas, which might lead to health risks from the consumption of contaminated water from storage tanks [7]. Rainwater harvesting is necessary in areas having significant rainfall but lacking conventional water supply systems. Rainwater is an important source of fresh water especially for those who live in rural areas. Concerning the safety of water, research show that many low income countries are off-track to reach target 7c of the millennium development goals for water supply and sanitation, aimed at reducing by half the proportion of people without sustainable access to safe drinking-water and basic sanitation by 2015 [8].

Government of Ghana's vision for the water sector is that all people living in Ghana will have access to adequate, safe, affordable and reliable water service, practice safe sanitation and hygiene and that water resources are sustainably managed. However, Ghanaians still suffer from water shortages, 50% of the population uses unimproved sources of drinking water. This figure is 10% higher than the average for the African continent, where 40% lack access to improved drinking water supply [9]. The presence of atmospheric pollutants that result through natural and anthropogenic means (such as mining, heavy traffic among others) can contribute to the contamination of rainwater. The main objective of this study was to assess the rainwater quality in Ayanfuri, so as to promote rainwater harvesting and safeguard public health.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted at Ayanfuri in the Upper Denkyira West district (Fig. 2). Its geographical coordinates are 5° 58' 0" North, 1° 54' 0" West. The district is bordered in the North West by Bibiani-Anhwiaso-Bekwai district, North East by Amansie West and Amansie Central districts, South West by Wassa Amenfi East and Wassa Amenfi West districts and South by Upper Denkyira East Municipal. The district has a population of about 31,300 of which 3,935 of the population reside in Ayanfuri. The district has two main cropping seasons (bimodal rainfall pattern). The major rainy season spans from April to July with short dry spell in August followed by a minor season from September to December. These seasons are warm but humid and facilitate two cropping seasons in a year [10]. The average temperature in Ayanfuri is 26.4ºC. About 1347 mm of precipitation falls annually (Fig. 1) [11]. The driest month is January, with 32 mm of rain. Most of the precipitation here falls in June, averaging 236 mm. March is the warmest month of the year. The temperature in March averages 27.6ºC. August is the coldest month, with temperatures averaging 24.6ºC (Fig. 1) [11].

2.2 Rainwater Sampling

Random sampling technique was used to select the sampled locations; Kyeremekrom (AYK), Parkiso (APK) and Nzongo (AZ) in Ayanfuri. Triplicate samples were collected within the two months (February to March, 2014) from three sampling points making a total of nine samples. Ayanfuri experience bimodal rainfall all year round. Rainwater samples were collected into 100 ml sterilized plastic containers by placing the container on a raised platform of height 1.5 meters above ground level in an open environment to contamination. The samples collected were kept in ice chest (4ºC) and transported to Council for Industrial Research-Water Research Institute Laboratory, Tamale for the analysis of considered parameters. Samples used for the determination of trace metal were kept in an acid-washed bottles and acidified with 1 ml of 5% ultra-pure HNO_3 to prevent adsorption of the trace metals. All the samples were kept in well-labeled sealed containers and refrigerated at 4ºC prior to analysis.

2.3 Physico-chemical Parameters

All reagents and chemicals used were of analytical grade and distilled-deionized water was used in all preparations and analyses. pH, temperature, electrical conductivity, total dissolved solids and turbidity of the rainwater were determined using portable pH-meter, a JENWAY 4520 combined conductivity/ TDS meter and a Partech model DRT 100B turbidimeter respectively. Total alkalinity, total hardness, calcium, magnesium and chloride concentrations in the rainwater were determined using titrimetric methods. Nutrients (such as nitrate, phosphate, fluoride and sulphate) in rainwater were determined by UV / Visible spectrophotometer in accordance with APHA 4500. Potassium and sodium were analysed with flame atomic absorption spectrophotometer (FAAS) in accordance with APHA [13]. Samples were analysed by direct aspiration in an air/ acetylene flame at specified wavelength for each potassium and sodium.

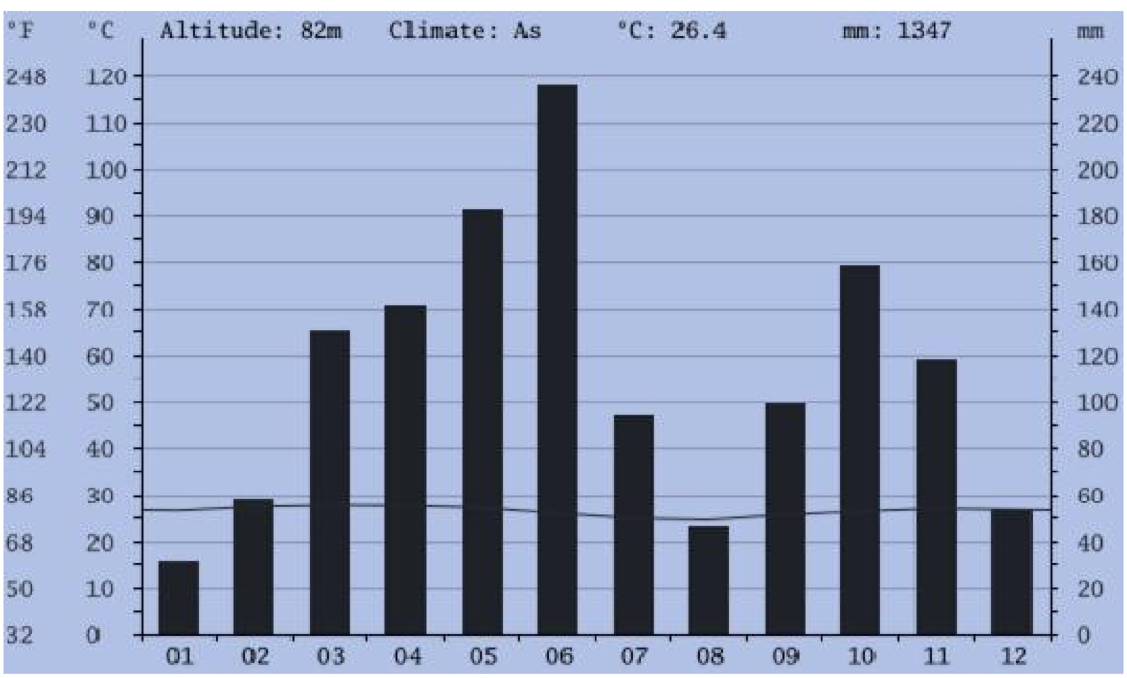

Fig. 1. Shows climatic condition of Ayanfuri [11]

Fig. 2. Map of Ghana showing Ayanfuri in the central region (Payne et al. [12])

2.4 Heavy Metals Analysis

An aliquot of 5 ml of concentrated nitric acid was added to 50 ml of sample of water in a 100 ml beaker. This mixture was heated on a hotplate to boil until the colour of the solution became pale and clear and its volume got to about 20 ml. Another 5 ml of concentrated nitric acid was added and the beaker was covered with a watch glass and the heating continued for about 10 more minutes. A final 5 ml acid was used to rinse the slides of the beaker. The solution was poured into a 50 ml volumetric flask and topped with distilled water to the mark. The concentrations in mg/l of four metals were determined using the Atomic Absorption Spectrophotometer (AAS), Shimadzu model AA 6300. The flame used for the analysis was air-acetylene mixture. Standard solutions ranging from 0.2 to 5.0 mg/l were prepared for calibration curves of the various metals. A blank analysis was performed with distilled water treated to the sample treatment. The trace metal concentrations of rainwater samples were determined one after the other using their respective hollow cathode lamps (HCL) and calibration curves. Air-acetylene wave flame was used for all the analysis. The values were then measured at their respective wavelengths. Statistical analysis was performed using SPSS version 16.0. The data was subjected to normality tests by fitting them with Normal and Lognormal distributions, on the premise that the observations were independent and identically distributed over the areas and sampling period. The data was also subjected to Pearson's correlation analysis to determine the mutual relationship that exists between the parameters.

3. RESULTS AND DISCUSSION

Total dissolved solids concentrations that ranged from 7.59 to 12.20 mg/l with a general mean of 9.30 mg/l compared to WHO limit of 1000 mg/l (Table 1). Total dissolved solids concentrations were within the WHO limit for potability. Rainwater samples recorded values less than 600 mg/l indicating the rainwater is good and palatable. Since WHO [8] reported that water with TDS level less than 600 mg/l is more palatable and generally considered to be good while at level greater than 1000 mg/l implies significantly and increasing unpalatable. The mean TDS concentration is slightly higher as compared with similar study conducted in Tamale metropolis, Ghana which recorded mean TDS value of 6.5 mg/l [14]. This finding is consistent with Hari and Krishna [15] that reported that TDS in rainwater, originating from particulate matter suspended in the atmosphere usually range from 2 to 20 mg/l. Bivariate analysis shows strong positive correlation of TDS with EC, total alkalinity, SO_4^{2-}, PO_4^{3-}, Ca^{2+}, Na^{+}, Mg^{2+} and Cl^{-} at 5% indicating that particulate matter is the common source of their concentration in the atmospheric air or the interact effectively which is statistically significant (Table 2).

Conductivity values that ranged from 13.45 to 19.04 µS/cm with a general mean of 15.75 µS/cm (Table 1). The average conductivity value is higher than that of rainwater studied in Tamale metropolis [14], but lower than the average conductivity value of rainwater in Obuasi, Ghana [3]. The low electrical conductivity concentrations of rainwater show less pollution of the atmosphere with particulate matter. This finding is consistent with Cobbina et al. [14] that reported low rainwater conductivity in Tamale metropolis that indicates good atmospheric environmental quality.

pH values obtained ranged from 5.88 to 7.01 pH-unit with a general mean of 6.62 pH-unit compared to WHO limits of 6.5 to 8.5 pH-unit (Table 1). The pH values are supposed to all fall within the range of 4.5 to 6.5 pH-unit for pH of rainwater usually but increases slightly after falling on the roof and during storage in tanks [16]. The study recorded pH values higher than 6.5 pH-unit that was directly collected hence the higher pH indicates atmospheric pollution perhaps heavily influenced by the mining activities.

The average pH was slightly higher as compared with similar study in Obuasi, Ghana which recorded mean pH of value of 4.67 pH-unit [3], but lower than mean value of 7.18 pH-unit reported by Cobbina et al. [14] in their study in Tamale metropolis, Ghana. pH correlated negatively against fluoride and total iron at 1% significant level contrasting their sources of contamination or interacting in the rainwater. However, pH correlated positively with cadmium at 5% significant level indicating common sources of contamination (perhaps particulate matter and CO_2 in the atmospheric air) or they interact effectively in the rainwater samples.

Turbidity values obtained ranged from 3.98 to 9.54 NTU with a general mean of 5.98 NTU compared to WHO limit of 5 NTU (Table 1). The high levels of turbidity could be attributed to the presence of particulate matter in the atmospheric air that is highly influenced by anthropogenic activities such as mining among others in Ayanfuri. Some of the turbidity values exceeded WHO limit of 5 NTU for potabiltity and show high tendency of causing treatment problems and harbouring of micro-organism. High level of turbidity can protect micro-organisms from the effect of disinfection, stimulate the growth of bacteria and give rise to significant chlorine demand [17]. Turbidity values were a bit low in ranges (3.98 to 9.54 NTU) as compared with a similar study in Tamale metropolis in Ghana which ranged from 4.0 to 12.4 NTU [14]. Fig. 3 shows mean values of pH and turbidity of the rainwater from the various sampling points.

Temperature values obtained ranged from 24.78 to 26.80ºC with a general mean of 25.99ºC. The total alkalinity concentrations obtained ranged from 5.40 to 16.00 mg/l with a general mean of 10.24 mg/l compared to WHO limit of 1000 mg/l (Table 1). According to Ayodele and Aturamu [18] generally alkalinity is caused by HCO_3^{-}, CO_3^{2-} and OH^{-} component in a raw or treated water supply. The chloride concentrations obtained ranged from 2.0 to 6.01 mg/l with a general mean of 4.05 mg/l compared to WHO limit of 200 mg/l (Table 1). Chloride ions are essential for life and in small concentrations they are not harmful to humans in drinking water. Unlike well water, rainwater is adversely affected by local air pollution and debris in the rainwater catchment and conveyance areas.

Total hardness concentrations obtained ranged from 4.57 to 20.0 mg/l with a general mean of 9.94 mg/l compared to WHO limit of 500 mg/l (Table 1). Calcium concentrations obtained ranged from 0.83 to 5 mg/l with a general mean of 2.14 mg/l compared to WHO limit of 250 mg/l (Table 1). Magnesium concentrations obtained ranged from 0.18 to 2.40 mg/l with a general mean of 0.89 mg/l compared to WHO limit of 150 mg/l (Table 1). Total hardness, calcium and magnesium concentrations of the rainwater were within WHO limits for potability. Calcium and magnesium are important minerals in human nutrition. Calcium is required for blood clotting and strong bones while magnesium acts as a cofactor and activator of hundreds of enzymatic reactions. The presence of calcium and magnesium ions makes water hard. However, there is no evidence of adverse effects specifically attributable to these ions in drinking water [19].

Water has been classified on the basis of hardness by WHO as follows; soft (0 to 50 mg $CaCO_3$/l), moderate soft (50 to 100 mg $CaCO_3$/l, slightly hard (100 to 150 mg $CaCO_3$/l), moderate hard (150 to 200 mg $CaCO_3$/l), hard (200 to 300 mg $CaCO_3$/l) and very hard (over 300 mg $CaCO_3$/l) [20]. Based on this it can be concluded that rainwater is soft which implies potable for normal growth, health and indicate palatability of the water. However, the low concentrations of these minerals in the rainwater have the tendency of causing disease burden as the fall under the range of soft water. Donato et al. [21] reported that soft water (that is water low in calcium and magnesium) is associated with increased morbidity and mortality from cardiovascular diseases (CVDs) compared to hard water as well as water high in magnesium. Calcium and magnesium at 1% showed significant correlation with TDS, total alkalinity and SO_4^{2-} and PO_4^{3-} at 5% significant level (Table 2) indicating possible common source of pair parameters or effective interacting among them.

Sodium concentrations obtained ranged from 0.05 to 2.01 mg/l with a general mean of 0.64 mg/l compared to WHO limit of 200 mg/l (Table 1). Potassium concentrations obtained ranged from 0.01 to 0.50 mg/l with a general mean of 0.24 mg/l compared to WHO limit of 30 mg/l (Table 1). Sodium and potassium concentrations obtained in this study were within WHO limits for potability. Potassium at 5% showed significant correlation with PO_4^{3-}, Ca^{2+} and Mg^{2+} that indicates common sources of contaminates or effective interaction between the parameters (Table 2). Sulphate concentrations obtained ranged from 11.53 to 18.36 mg/l with a general mean of 15.11 mg/l compared to WHO limit of 400 mg/l (Table 1). Nitrate concentrations obtained ranged from 0.46 to 2.23 mg/l with a general mean of 1.04 mg/l compared to WHO limit of 10 mg/l (Table 1). Phosphate concentrations obtained ranged from 0.19 to 0.38 mg/l with a general mean of 0.28 mg/l compared to WHO limit of 2.5 mg/l (Table 1). Nutrients such as sulphate, nitrate and phosphate were all within WHO limits for potability in the rainwater hence pose no threat human health.

Fluoride concentrations obtained ranged from 0.54 to 0.86 mg/l with a general mean of 0.68 mg/l compared to WHO limit of 1.5 mg/l (Table 1). Fluoride concentrations fall within WHO limits for potability indicating more benefit will be derive for drinking the rainwater than its disease-related burden in terms of fluoride concentration. Drinking water containing 0.7 to 1.2 mg/l natural or added fluoride is helpful to children during the time they are developing permanent teeth [22]. Waldbott [23] indicates that excessive fluoride intake causes fluorosis, cancer, arthritis, and other diseases. Some researchers reported that elevated concentration of fluorine affects human intelligence mostly among children who very vulnerable to early fluoride toxicity. The optimal concentration recommended by the Centre for Disease Control for New Hampshire is 1.1 mg/l. Below 0.5 mg/l there is little tooth decay protection whilst above 1.5 mg/l, prevents little tooth decay. In the range of 2.0 to 4.0 mg/l of fluoride, staining of tooth enamel is possible. Studies have shown that above 4.0 mg/l, skeletal fluorosis as well as the staining of teeth is possible [24].

Total iron concentrations obtained ranged from 0.15 to 0.79 mg/l with a general mean of 0.51 mg/l compared to WHO limit of 0.3 mg/l (Table 1). Some of the rainwater samples obtained total iron concentrations that exceeded WHO limit for potability. Manganese concentrations obtained ranged from -0.03 to 0.52 mg/l with a general mean of 0.28 mg/l compared to WHO limit of 0.4 mg/l (Table 1). Some of the rainwater samples obtained manganese concentrations that exceeded WHO limit for potability. The lead concentrations obtained ranged from 0.14 to 0.36 mg/l with a general mean of 0.27 mg/l compared to WHO limit of 0.01 mg/l (Table 1). Fig. 4 shows mean values of total iron and manganese of the rainwater from the various sampling points. The rainwater samples obtained lead concentrations that exceeded WHO limit for potability indicating that the anthropogenic activities such as mining, heavy traffic among other are affecting the rainwater quality. The action of wind in entraining particulates into the atmosphere could lead to high levels of heavy metals in rainwater Akhionbare [25] and perhaps as a result of high traffic density and industries [26]. Elevated lead concentrations can cause diseases such as renal and gastrointestinal diseases [27].

Table 1. Summary results of rainwater analysed

Parameters	Mean	Min	Max	Std. D	Variance	Skewness	Kurtosis	WHO guideline
TDS	9.30	7.59	12.20	1.64	2.70	0.78	-0.74	1000
EC (µS/cm)	15.75	13.45	19.04	2.34	5.49	0.71	-1.61	-
pH (pH-unit)	6.62	5.88	7.01	0.46	0.22	-1.01	-0.73	6.5-8.5
Turbidity (NTU)	5.98	3.98	9.54	2.24	5.01	0.89	-1.25	5
Temp	25.99	24.78	26.80	0.87	0.76	-0.59	-1.87	-
Alkalinity	10.24	5.40	16.00	4.02	16.19	0.24	-1.50	1000
Bicarbonate	13.66	9.46	20.41	4.48	20.06	0.80	-1.57	-
Sulphate	15.11	11.53	18.36	2.36	5.55	-0.16	-1.18	400
Chloride	4.05	2.00	6.01	1.34	1.79	0.22	-0.85	200
Nitrate	1.04	0.46	2.23	0.57	0.32	1.18	1.23	10
Phosphate	0.28	0.19	0.38	0.06	0.004	0.29	-0.65	2.5
Fluoride	0.68	0.54	0.86	0.11	0.01	0.24	-1.09	1.5
Calcium	2.14	0.83	5.00	1.62	2.62	0.97	-0.90	250
Magnesium	0.89	0.18	2.40	0.93	0.86	1.07	-0.76	150
Sodium	0.64	0.05	2.01	0.85	0.72	0.93	-1.38	200
Potassium	0.24	0.01	0.50	0.21	0.04	0.03	-2.20	30
Silica	10.13	7.70	12.01	1.75	3.06	-0.68	-1.62	250
Hardness	9.94	4.57	20.00	7.08	50.17	0.85	-1.67	500
Ca2+	5.69	2.35	10.21	3.34	11.14	0.75	-1.68	-
Mg2+	4.11	1.43	9.90	3.48	12.11	0.95	-1.24	-
Iron	0.51	0.15	0.79	0.25	0.06	-0.71	-1.41	0.3
Manganese	0.28	-0.03	0.52	0.23	0.05	-0.72	-1.70	0.4
Lead	0.27	0.14	0.36	0.08	0.01	-0.50	-1.51	0.01
Cadmium	0.12	-0.38	0.30	0.23	0.05	-1.57	2.21	0.003

Concentration (mg/l), unless otherwise stated

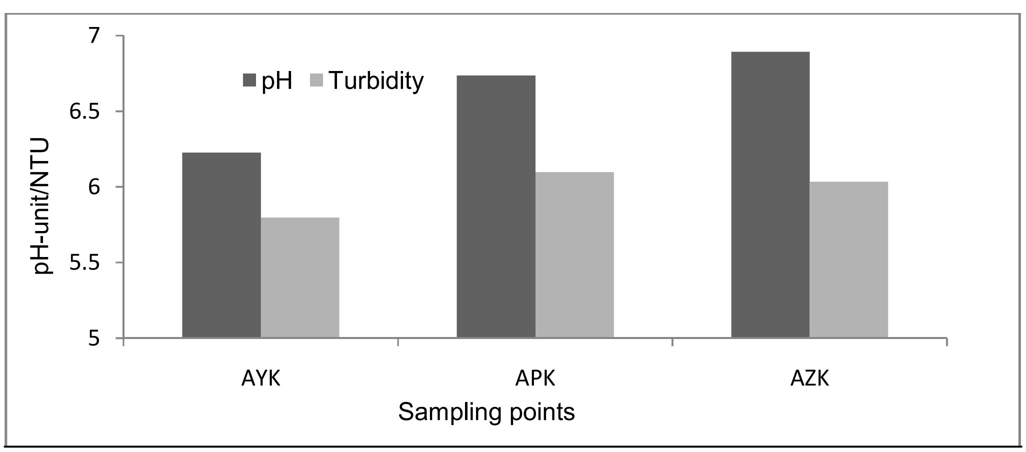

Fig. 3. pH and turbidity mean values for rainwater samples

Table 2. Illustrate relationships and interactions between pairs of variables

Parameter	TDS	Alk	SO_4	NO_3	PO_4	Fl	Ca^{2+}	Mg^{2+}	Na	K	Mn	Pb	Cd
TDS	1												
Alk	.89**	1											
SO_4	.84**	.95**	1										
NO_3	-.67*	-.83**	-.94**	1									
PO_4	.80**	.73*	.71*	-0.59	1								
Fl	.67*	0.53	0.35	-0.07	0.60	1							
Ca^{2+}	.98**	.91**	.87**	-.72*	.79*	0.56	1						
Mg^{2+}	.95**	.91**	.84**	-0.67	.82**	0.65	.98**	1					
Na	.89**	.88**	.78*	-.68*	.69*	0.50	.93**	.91**	1				
K	.70*	0.49	0.44	-0.39	.69*	0.42	.73*	.74*	.77*	1			
Mn	-.91**	-.88**	-.83**	.75*	-.69*	-0.46	-.95**	-.94**	-.97**	-.79*	1		
Pb	-0.60	-0.47	-0.48	0.46	-0.25	-0.05	-.69*	-0.62	-.72*	-.72*	.79*	1	
Cd	-.79*	-.84**	-.68*	0.52	-.78*	-.68*	-.82**	-.91**	-.86**	-.69*	.84**	0.43	1

***. Correlation is significant at the 0.01 level (2-tailed).*. Correlation is significant at the 0.05 level (2-tailed)*

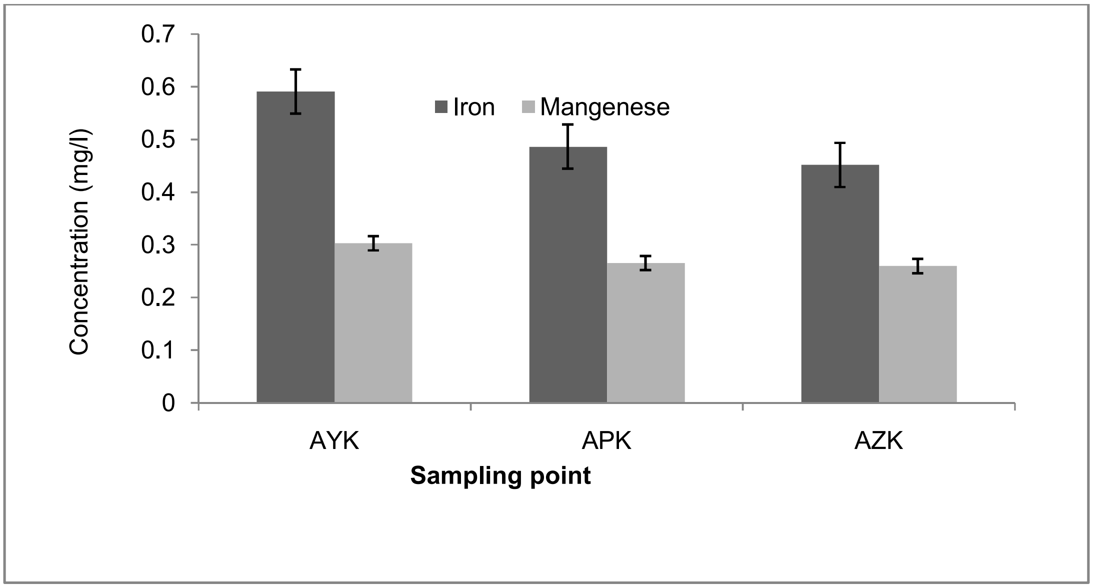

Fig. 4. Mean concentrations of total iron and manganese in the rainwater

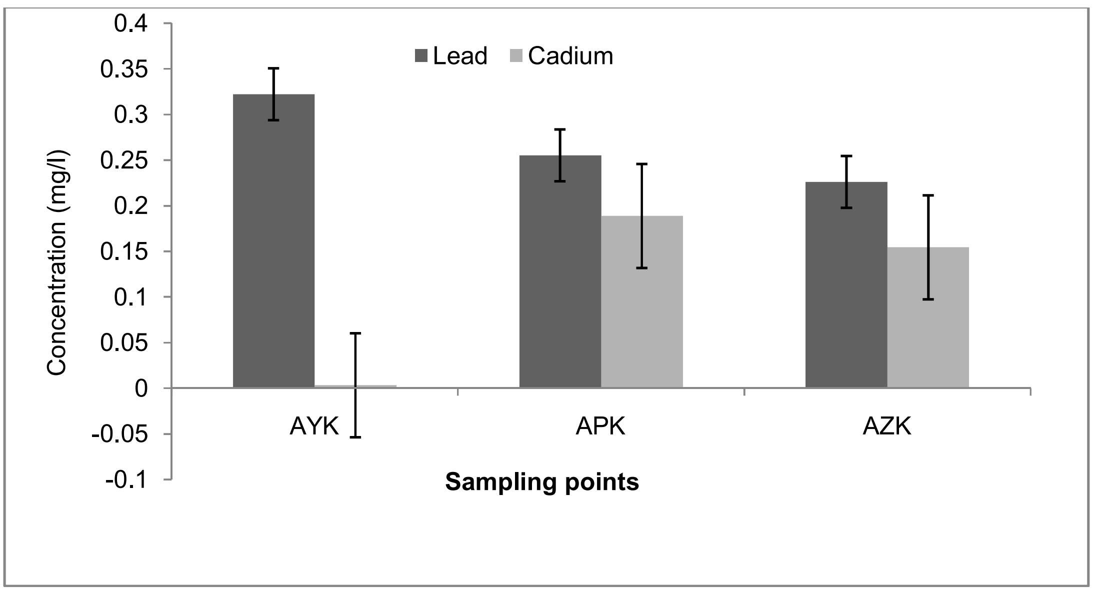

Fig. 5. Mean concentrations of lead and cadmium in the rainwater samples

Cadmium concentrations obtained ranged from -0.38 to 0.30 mg/l with a general mean of 0.12 mg/l compared to WHO limit of 0.003 mg/l (Table 1). Some of the rainwater samples obtained cadmium concentrations that exceeded WHO limit for potability. Cadmium at 5% showed negative significant correlation with TDS, K, SO_4^{2-} and PO_4^{3-} while at 1% significant level shows negative correlation with total alkalinity, Ca^{2+}, Mg^{2+} and Na (Table 2) contrasting all possible common source of contaminates or effective interacting among them. However, at 1% significant level cadmium correlated positively with Mn that is statistically significant. Cadmium accumulates in the human body affecting negatively several organs such as liver, kidney, lung, bones, placenta, brain and the central nervous system [28]. The study revealed that ambient air quality in the study area has negatively influenced the rainwater quality in Ayanfuri. Hence, the rainwater can be unsafe to drink as evidenced by the metal pollution. Fig. 5 shows mean values of lead and cadmium of the rainwater from the various sampling points.

4. CONCLUSION

The present study obtained physico-chemical parameters values that were within WHO limits for potability except turbidity and pH. The heavy metals values obtained exceeded WHO limits for potability. Anthropogenic activities such as road construction, mining activities and heavy traffic in the study area have influenced the ambient air quality negatively. The elevated heavy metals concentrations in the rainwater makes water unwholesome for drinking and could cause disease burden. It can be recommended that anthropogenic activities in the Ayanfuri should be properly monitored to conform to environmental quality guidelines, for Ghana to meet water services delivery, thus improving access to potable water services (achieve national water coverage of 80% by 2015 and 100% by 2025).

CONFLICT OF INTERESTS

Authors have declared that no competing interests exist.

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