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Impact of Human Activities on Rainwater Quality in South-South Region of Nigeria

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Authors' contributions

This work was carried out in collaboration of the entire authors. Authors GAE and HSE designed the work while author CIE did the collation of results and data treatment for the production of first draft with assistance from author EUD. All the authors read and approved the final manuscript.

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ABSTRACT

The first three spills of rainfall in 2016 were harvested from areas impacted by gas flaring and exhaust emissions namely: Ibeno, Eket, Onna, Mkpat Enin and Uyo local government areas south-south of Nigeria. Control samples were harvested from Ibiono Ibom local government area where anthropogenic source of air contaminants is negligible. These samples and Control were treated and analysed using standard procedures for their pH, electrical conductivity, turbidity, nitrate, total suspended solids, total dissolved solids, Fe, Zn, Cu, Pb, Cd and Ni levels. Mean concentrations of all parameters assessed in studied rainwater were higher than their corresponding levels in the Control revealing anthropogenic inputs of these properties in the ambient air. Mean concentration of all properties determined except those of pH, Fe, Pb, Cd and Ni were within their acceptable limits. Consequently, rainwater harvested from studied areas should be treated before consumption to avoid health implications associated with acidity, Fe, Pb, Cd and Ni. This study has also shown that, human activities executed within studied areas impacted negatively on the quality of rainwater harvested. All the parameters examined exhibited strong association and common source in ambient air except pH with strong negative correlation with all the properties.

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1. INTRODUCTION

Rainwater is the purest form of naturally occurring water but the presence of contaminants in the atmosphere has rendered untreated rainwater unsafe for human consumption. Obaidy and Joshi [1] reported that chemical composition of rain water signifies the quantity and quality of air emissions supplied to the atmosphere from natural and anthropogenic sources. Anthropogenic sources such as electric utility facilities, gas flaring, metal mining, industrial plants, car exhausts and pesticides release several contaminants into ambient air [2]. These sources have also raised the level of metals in the air, terrestrial and aquatic environments even when they locate far away from point source [3-6]. Anthropogenic sources have elevated levels of metals in the atmosphere and the presence of metals in rainwater affects soil physicochemical properties and soil-microbial relationship [7]. Rainwater is a known channel for metal toxicity in human and may result in adverse health implications [8-9]. Olukoya [10] noted that Nigeria is the world's biggest flarer of associated gas with more than 1,000 gas flaring points that release over 23 billion/m^3 of gas per annum. Most of these flaring points are in the Niger Delta and this has resulted in acidic nature of rainwater harvested from the region [10-16]. Rainwater from Niger Delta region of Nigeria is very aggressive due to its low pH thus; can attack everything it comes in contact with including metallic containers thereby elevating the metallic contents of the harvested rainwater. Ebong et al. [17] attributed high concentrations of metals in rainwater harvested from different rooftops within the studied area to acidic nature of rainwater in the area. Studies have shown that intensive gas flaring in the Niger Delta region of Nigeria is becoming a serious threat to the quality of rainwater harvested from the area [18-24]. Nevertheless, more than 884 million people in the world mostly in the developing nations including Nigeria lack potable water for drinking and domestic use [21,25]. WHO [26] also reported that, Potable drinking water is not available to 75 – 80 percent of the citizens in rural areas of many developing countries including Nigeria. Hence, rainwater serves as alternative source of water for drinking and domestic use in these areas [27-28]. Even in some areas where potable water is supplied, rainwater is still an important supplementary source of drinking water and for domestic use. In Niger Delta, residents of semi-urban and rural areas depend on the raw rainwater for drinking and domestic use since their surface water has been heavily contaminated by the activities oil companies operating in the area. Nonetheless, consumption of contaminated water may result in diseases such as typhoid, dysentry and diarrhea [29-30]. It has also been reported that, over 2.2 million people die each year from diseases related to consumption of contamination water [29]. Consequently, rainwater should be properly treated to eliminate physicochemical and microbial contaminants before consumption. Radaideh et al. [31] reported that the concentration of contaminants in rainwater were higher in the first spill of rain in comparison with subsequent spills. This study was undertaken to assess the quality of rainwater in the Niger Delta area thereby determining the impact of human activities on the ambient air quality. It also aimed at ascertaining the potability or otherwise of rainwater harvested from the region for human consumption and domestic use. This research will indirectly examined the quality of ambient air environment in studied locations thereby exposing the negative impact of gas flaring and other human activities within these areas.

2. MATERIALS AND METHODS

2.1 Study Area

Akwa Ibom is a state in Nigeria named after the Qua Iboe River. It is located in the coastal South-South part of the country, lying between latitudes 4º 32′ and 5º 33′ North and longitudes 7º 25! and 8º 25′ East (Fig. 1). The State is bordered on the east by Cross River State, on the west by Rivers State and Abia, and on the South by the Atlantic Ocean and the Southern – most tip of Cross River State. The state has basically two distinct seasons namely the wet and dry. The wet season lasts between 8 to 9 months starting from mid-march till the end of November. The dry season has a short duration of between the last week of November or early December and last till early march. Akwa Ibom State is located within the humid tropics, this attribute and its closeness to sea makes the state generally humid. On the basis of its geographical location the climate of the state is a tropical rainy type which experiences abundant rainfall with very high temperature. The mean annual temperature of the state lies between 25°C and 29℃, while mean annual rainfall ranges from 2,000 mm to 3,000 mm, depending on the area. Akwa Ibom State is one of the major oil producing States in the Niger Delta region of Nigeria. Thus, gases are flared directly into the ambient air by oil companies operating in the state. This study was conducted at the onset of rainy season by harvesting the first three spills of rainfall from the following local government areas Ibeno (04º 57! N and 07º 98! E), Eket (04º 38! N and 07º 55! E), Onna (04º 37! N and 07º 51! E), Mkpat Enin (04º 44! N and 07º 45! E) and Uyo (05º 02! N and 07º 56! E). The first three (3) spills of rainfall were also harvested in Ibiono Ibom local government area (05º 14! N and 07º 53! E) and used as Control (See Fig. 1).

2.2 Sample Collection and Analysis

For the identification of actual quality of rainwater in studied areas, rainwater samples were collected in plastic basins previously washed with distilled water and placed 1m meter above the ground in an open space as described by Okoye et al. [32]. Rainwater samples and Control were collected from open space to avoid additional contaminants mostly metals from rooftops as reported by Ebong et al. [17]. The first three spills of rain in each of these local government areas in the year 2016 were used for this study to avoid dilution of these air particulates [31]. Studied samples were obtained from Uyo; Mkpat Enin; Eket; Onna and Ibeno south-south region of Nigeria where impacts of gas flaring and other anthropogenic activities are experienced. Control samples were obtained from Ibiono Ibom local government area in the same south-south region where impact of human activities on the atmosphere is drastically minimized. At each of the studied local government area and Control, rainwater was obtained at three (3) separate locations and merge together to represent the location. A total of eighteen (18) sub-samples and three sub Control samples were obtained and merged up to obtain six (6) composite samples (one composite sample for one location) and one (1) Control for the study. Rainwater samples and Control were treated and preserved according to standard procedures by APHA [33]. pH of obtained rainwater samples and Control was determined using pH meter after standardization with buffer solution following Standard methods of APHA [33]. Electrical conductivity and turbidity were analysed for in rainwater samples and Control using the procedures of APHA [34] and Kus [35]. Recommended procedures of APHA [36] were employed for the spectrophotometric determination of nitrate in samples and Control. Gravimetric method of analysis was used for the determination of total suspended solids and total dissolved solids in both samples and Control following standard methods of Ademoroti [37] and APHA [33]. Concentrations of iron, zinc, copper, lead, cadmium and nickel in samples and Control were determined using flame atomic spectrophotometer as described in standard methods of APHA [33] and Kus [35]. Statistical

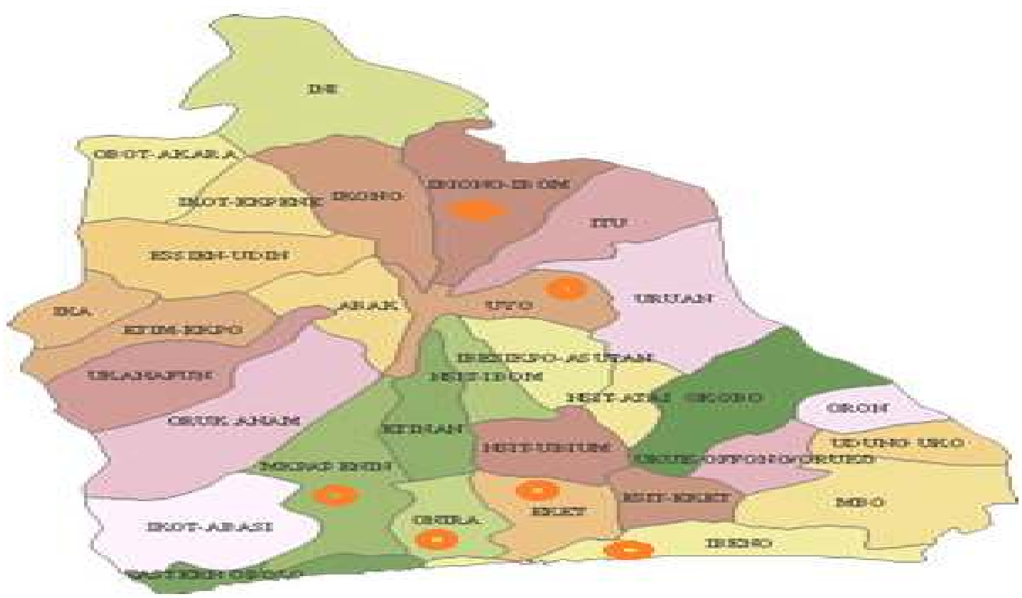

Fig. 1. Map of Akwa Ibom State showing studied areas and control

and Pearson correlation analyses of properties determined were done using SPSS for windows (version 20.0).

3. RESULTS AND DISCUSSION

3.1 Concentration of Physicochemical Properties and their Relationship in Studied Rainwater

pH of harvested rainwater ranged between 5.61 and 6.16, this pH range indicates the acidic nature of rainwater in areas studied. This could be attributed to the intensive gas flaring, bush burning and exhaust emissions in these areas and dissolution of these gases in rainwater increase the acidity [18,38]. The acidic nature of rainwater has destroyed roof tops, car paint, ornaments, flora and fauna in terrestrial and aquatic ecosystem within the region [39-41]. It has also been reported that, consumption of acidic water may result in acidosis and leukaemia in human [19,42-43]. The obtained pH range is lower than that reported in Tamale, Ghana by Cobbina et al. [25] but higher than that range reported in rainwater from Akwa Ibom State, Nigeria by Ubuoh et al. [23]. The mean pH value (5.88±0.25) obtained is lower than 6.87 reported in the Control thus, signifying the negative influence of anthropogenic activities on the quality of rainwater from studied areas. The obtained pH range is lower than 6.5–8.5 recommended by WHO [44] for drinking water. Consequently, untreated rainwater from studied areas is not potable for drinking and is unfit for domestic use as it can affect human health and other household items it comes in contact with. Correlation studies revealed that, all parameters determined except copper may have contributed considerably to the reduction of pH in studied rainwater samples as indicated by their significant negative r values in Table 2. Electrical conductivity (EC) in studied rainwater varied between 56.51 µS/cm and 64.84 µS/cm which is an indicative of quantity of soluble ions (anions and cations) in rainwater studied [25]. This EC range is higher than that reported for rainwater samples in Warri, Nigeria by Olowoyo [18] but much below the EC range recorded in rainwater from Misurata, Libya by Mayouf [45]. The mean EC value obtained (61.58±3.18 µS/cm) is much higher than 38.41 µS/cm recorded in Control indicating presence of anthropogenic sources of ions in the air environment of studied areas. These sources may include industrial, commercial and agricultural activities within these areas. However, this mean is negligible when compared with WHO [44] standard of 1000.00 µS/cm thus; the level of soluble ions in studied rainwater may not impart negatively on the rainwater quality. The relationship between EC and all the other rainwater properties studied except copper indicated significant positive correlation as shown by the strong correlation coefficients in Table 2. This indicated the strong association and common source for these properties in the atmosphere except copper [22,46]. Though, the electrical conductivity of studied rainwater may have impacted negatively on the pH as revealed by the significant negative correlation coefficient of -0.965. Turbidity of studied rainwater varied between 3.97 NTU and 4.63 NTU and this specifies the amount of suspended solids in the analysed samples [47]. This is lower than range reported in rainwater harvested in Wales, Australia by Kus et al. [35] but; higher than turbidity range recorded in rainwater harvested in Uyo, Nigeria by Moses et al. [22]. The mean turbidity value obtained (4.40±0.26 NTU) is lower than 1.89 NTU recorded in Control sample. Thus, human activities in the studied areas may have contributed significant amounts of suspended solids into the ambient air. These anthropogenic sources may include gas flaring, bush burning, construction works and exhaust emissions [25]. Nevertheless, this mean is below 5.0 NTU limit for turbidity in potable water by WHO [44] hence; the turbidity levels in studied rainwater may not pose environmental or health problems. Result in Table 2 has shown strong positive correlation for turbidity with other properties in rainwater except copper thereby revealing their common source (r values in Table 2). The relationship between turbidity and pH in studied rainwater was inversely proportional indicating negative influence of turbidity on pH ($r = -0.929$). Concentrations of nitrate in studied rainwater ranged from 2.62 mg/l to 3.26 mg/l. This is higher than that reported by Mohammed et al. [48] in Niger Delta, Nigeria but lower than range obtained in Jordan by Radaideh et al. [31]. Nitrate in studied rainwater may be due to emission of nitrogen oxides from combustion of fossil fuel in the area [49-50]. The mean nitrate concentration obtained (2.90±0.25 mg/l) is higher than 1.15 mg/l recorded in the Control. This may be attributed to the impact of gas flaring and other human activities in areas studied. However, the mean is lower than 10.0 mg/l limit for potable water by WHO [44]. Thus, nitrate concentrations in studied rainwater may not pose any environmental or heath threat associated with it. Nitrate exhibited strong positive correlation with all properties studied except copper indicating that concentrations of other properties except copper were directly proportional to that of nitrate (r values in Table 2). The relationship between nitrate and pH was a significant negative one with r value of -0.955. Total suspended solids (TSS) in studied rainwater varied from 7.41 mg/l to 9.10 mg/l. This is lower than TSS range obtained in Uyo, Nigeria by Williams and Tighiri [24] and that reported in Rivers State, Nigeria by Uzoma et al. [51]. Total suspended solids in water have direct relationship with the turbidity of water and this resulted in the strong positive correlation coefficient value of 0.982 obtained in this study. The mean concentration of TSS (8.42±0.69 mg/l) recorded is lower than 4.16 mg/l obtained in the Control. Hence, human activities in areas studied may have contributed substantial quantity of solids into the atmosphere. These activities may include gas flaring, bush burning, agricultural activities and construction works within these areas. Relatively, the mean obtained is lower than 28.0 mg/l recommended limit by WHO (2011), therefore this level of TSS may not hinder its potability for human consumption. Apart from copper, total suspended solids in studied rainwater showed strong positive correlation with other properties determined (r values in Table 2). This disclosed their strong relationship and familiar source in the atmosphere as reported by Moses et al. [22]. However, TSS levels in rainwater examined may have been inversely proportional to their pH as indicated by r value of -0.881. Total dissolved solids (TDS) in studied rainwater varied from 10.18 mg/l to 17.52 mg/l. This range is lower than that reported by Egwuogu et al. [20] in rainwater from Rivers State, Nigeria but higher than that obtained in rainwater harvested in Uyo by Moses et al. [22]. Mean concentration of total dissolved solids (14.91±2.89 mg/l) obtained in studied rainwater is higher than 8.63mg/l recorded in the Control. This revealed additional source of this property in studied areas which may be mostly human activities in studied areas. Nevertheless, this range is much lower than 500.0 mg/l recommended limit by WHO [44] for potable water. Consequently, concentrations of TDS recorded in studied rainwater may not render it unsuitable for human consumption and domestic use. TDS showed strong positive correlation with other properties determined except copper indicating their common source in the atmosphere (r values in Table 2). Though results in Table 2 indicate significant negative correlation between TDS and pH (r = -0.900). Concentrations of iron (Fe) in studied rainwater ranged from 0.41 mg/l to 0.67 mg/l. This is consistent with the range obtained by Ubuoh et al. [23] in Akwa Ibom State, Nigeria, higher than that reported in Camaguey, Cuba by Alvarez et al. [52] but lower than range reported by Mayouf [45] in Misurata, Libya. Iron is a component of hemoglobin, myoglobin and many enzymes in most living cells thus, is an essential element [53]. However, when the concentration is high it may result in iron toxicity and its attendants effects. The mean concentration of iron recorded in the studied rainwater (0.54±0.10 mg/l) is higher than 0.22 mg/l obtained in Control. Consequently, there is anthropogenic addition of iron in the study area and this could be mainly burning of fossil fuel [54-55]. The mean concentration of iron obtained is also higher than 0.3 mg/l recommended for potable water by WHO [44]. Thus, iron could be regarded as a pollutant in the studied areas as the consumption of rainwater from these areas may result in iron toxicity and associated health implications in human [45]. Iron demonstrated strong positive correlation with all the other properties except copper with weak positive one at $p < 0.05$ (r values in Table 2). Thus, Fe and other properties examined exhibited strong relationship and familiar source. Nevertheless, iron showed strong negative relationship with pH indicating that high concentration of Fe may have reduced the pH of studied rainwater significantly (r = -0.853). Zinc (Zn) concentrations in studied rainwater varied between 1.62 mg/l and 1.95 mg/l. This is consistent with the range of zinc reported in rainwater from Uyo, Nigeria by Moses et al. [22] but higher than that reported in Camaguey, Cuba by Alvarez et al. [52]. Studies have shown that zinc is required in most biochemical processes that sustain life but its toxicity has alarming health implications as reported by [56]. Zinc in the atmosphere is mostly from vehicular emissions, disinfectants, deodorants and pesticides [57]. The mean concentration of zinc obtained in studied rainwater (1.80±0.12 mg/l) is higher than 0.86 mg/l reported in rainwater from Ibiono Ibom (Control). This revealed additional source of zinc in the air environment of studied areas. However, this mean is lower than 3.0 mg/l limit recommended for potable water by WHO [44]. Nevertheless, consumption of rainwater from the studied areas may pose some health problems associated with zinc deficiency to the consumers. Correlation coefficients of rainwater properties in Table 2 indicate strong positive relationship between zinc and all the other properties except copper with weak positive correlation at $P < 0.05$.

Though, zinc exhibited strong negative correlation with pH indicating inverse relationship between these two properties (r = -0.926). Copper is needed for normal functioning of human body but if accumulated in excess it can cause health problems [58-60]. Copper (Cu) concentrations in studied rainwater ranged from 0.51 mg/l to 0.68 mg/l; this is higher than that reported in rainwater from Varanasi, India by Pandey and Singh [61]. The high copper concentrations in studied rainwater could be attributed mainly to road transportation and industrial emissions [62-64]. The mean copper concentration obtained in studied rainwater (0.57±0.07 mg/l) is higher than 0.37 mg/l recorded in the Control. Accordingly, the high traffic density and industrial activities in studied areas could have released substantial amounts of copper into the ambient air. Nonetheless, the obtained mean is lower than 2.0 mg/l limit for copper in potable water by WHO [44]. Consequently, consumption of rainwater harvested from areas studied may cause health problems associated with copper deficiency since it is essential element. Copper correlated positively but insignificantly with all the properties examined in rainwater except pH with weak negative relationship at $P < 0.05$(r values in Table 2). Levels of lead (Pb) recorded in studied rainwater ranged between 0.04 mg/l and 0.07 mg/l. This range is lower than that reported in rainwater from Jordan by Radaideh et al. [31] but higher than the range recorded by Williams and Tighiri [24] in Uyo. Lead is a highly toxic and cumulative element even at a very low concentration. It inhibits the essential functions of elements such as calcium, iron, copper and zinc in human body. Exposure to low level of lead could result in problems of heart, kidney, liver and respiratory system in human [65-66]. The mean lead concentration (0.05±0.01 mg/l) reported in studied rainwater samples is much higher than the concentration recorded in the Control (0.001 mg/l). This could be an indicative of negative impact of intensive gas flaring and exhaust emissions in studied areas on the atmosphere. The mean is also above the permissible limit of 0.01 mg/l by WHO [44] indicating the health implications associated with the consumption of untreated rainwater harvested from these areas. Lead correlated significantly and positively with all the properties determined except copper with weak positive correlation at $P < 0.05$ (r values in Table 2). The relationship between lead and pH showed a strong negative one with r = -0.839. Cadmium is poisonous and carcinogenic in nature; low concentration of the element in human body could result in adverse health implications [8,67-69]. Cadmium (Cd) levels in rainwater investigated varied between 0.22 mg/l and 0.38 mg/l. This is consistent with that reported by Pandey and Singh [61] in Varanasi, India, lower than range obtained by Ubuoh et al. [23] in Akwa Ibom State, Nigeria but higher Cd levels recorded by Alvarez et al. [52] in Camaguey, Cuba. The mean Cd concentration obtained (0.30±0.06 mg/l) is five times higher than 0.06 mg/l recorded at the Control site. These high levels of cadmium in studied rainwater could be attributed to agricultural activities and burning of fossil fuels in these areas [70-71]. Mean Cd concentration in studied rainwater is as well higher than 0.003 mg/l limit for the metal in potable water by WHO [44]. Hence, if rainwater from these areas is not treated before consumption it could result in health consequences related to cadmium toxicity. Apart from copper that showed weak positive correlation with Cd, all the other properties examined exhibited significant positive correlation with the metal (r values in Table 2). Nevertheless, pH correlated negatively and significantly with cadmium indicating the negative influence of the metal on pH of studied rainwater and vice versa (r = -0.885). Concentrations of nickel (Ni) varied from 0.02 mg/l to 0.03 mg/l in rainwater examined. This is consistent with the range of Ni reported in rainwater collected in India by Pandey and Singh [61] but lower than that reported by Kim et al. [72] in rainwater from Vietnam. The mean concentration of nickel obtained in studied rainwater (0.03±0.01mg/l) is higher than Ni concentration at the Control site which was below detectable limit. This is an indication of anthropogenic sources of Ni in areas studied and these may include refining activities, combustion of fossil fuels and motor vehicles [73-75]. The obtained mean is as well higher than 0.02 mg/l stipulated limit for Ni in potable water by WHO (2011). Consequently, untreated rainwater from studied areas is not potable for drinking and not safe for domestic use as this may result in nickel toxicity and related health problems as reported by Chang [76-77]. Nickel demonstrated strong positive correlation with all other properties determined except copper with a weak positive one at $P < 0.05$ (r values in Table 2). However, concentrations of nickel in studied rainwater may have impacted negatively and significantly on pH as indicated by r value of -0.850.

Table 1. Physicochemical properties of rainwater

	IBN	EKT	ONN	MPE	UYY	IBB	Mean	Min	Max	SD	WHO
pH	5.61	5.78	5.73	6.12	6.16	6.87	5.88	5.61	6.16	0.25	6.5 – 8.5
EC (µS/cm)	64.84	62.46	63.25	60.83	56.51	38.41	61.58	56.51	64.84	3.18	1000
Turb. (NTU)	4.63	4.38	4.57	3.97	4.45	1.89	4.40	3.97	4.63	0.26	5.0
NO_3^-(mg/l)	3.26	2.85	3.11	2.62	2.86	1.15	2.90	2.62	3.26	0.25	10.0
TSS (mg/l)	9.10	8.26	8.32	7.41	9.03	4.16	8.42	7.41	9.10	0.69	28.0
TDS (mg/l)	17.52	15.94	16.56	10.18	14.33	8.63	14.91	10.18	17.52	2.89	500
Fe (mg/l)	0.67	0.59	0.46	0.41	0.57	0.22	0.54	0.41	0.67	0.10	0.3
Zn (mg/l)	1.95	1.77	1.83	1.62	1.84	0.86	1.80	1.62	1.95	0.12	3.0
Cu (mg/l)	0.60	0.52	0.55	0.68	0.51	0.37	0.57	0.51	0.68	0.07	2.0
Pb (mg/l)	0.07	0.04	0.05	0.04	0.06	0.001	0.05	0.04	0.07	0.01	0.01
Cd (mg/l)	0.38	0.26	0.31	0.22	0.34	0.002	0.30	0.22	0.38	0.06	0.003
Ni (mg/l)	0.03	0.02	0.03	0.02	0.03	BDL	0.03	0.02	0.03	0.01	0.02

IBN = Ibeno; EKT = Eket; ONN = Onna; MPE = Mkpat Enin; UYY = Uyo; IBB = Ibiono Ibom

Table 2. Pearson correlation coefficient among the water properties studied

	pH	EC	Turb	NO_3^-	TSS	TDS	Fe	Zn	Cu	Pb	Cd	Ni
pH	1.000	-0.965	-0.929	-0.955	-0.881	-0.900	-0.853	-0.926	-0.661	-0.839	-0.885	-0.850
EC		1.000	0.955	0.966	0.898	0.779	0.814	0.945	0.811	0.847	0.884	0.867
Turb			1.000	0.992	0.982	0.837	0.880	0.996	0.693	0.928	0.966	0.959
NO_3^-				1.000	0.971	0.860	0.880	0.993	0.713	0.941	0.971	0.960
TSS					1.000	0.839	0.928	0.992	0.629	0.965	0.988	0.965
TDS						1.000	0.866	0.849	0.300	0.807	0.859	0.813
Fe							1.000	0.907	0.491	0.903	0.915	0.824
Zn								1.000	0.686	0.955	0.983	0.966
Cu									1.000	0.645	0.623	0.631
Pb										1.000	0.989	0.964
Cd											1.000	0.981
Ni												1.000

4. CONCLUSION

This study conducted to investigate the impact of human activities on the level of atmospheric contaminants which have direct implication on the quality of rainwater in the area revealed higher levels of physicochemical properties determined in rainwater from studied areas than in the Control. Hence, anthropogenic activities in studied areas may have contributed substantial amount of contaminants into the ambient air thereby increasing the level of these properties in rainwater harvested from the area. Mean concentration of all the parameters determined except pH, iron, lead, cadmium and nickel were within their WHO [44] stipulated limits. Thus, rainwater from the studied areas should be treated to reduce their acidity, Fe, Pb, Cd and Ni level before consumption. Consequently, anthropogenic sources of these studied properties should be closely monitored and controlled to forestall associated health implications on the consumers of untreated rainwater from the area. This research work has assessed the impact of different human activities carried out in the studied areas on the quality of rainwater. Significant positive correlation among these properties in studied rainwater has also revealed the strong relationship and common source among these properties in the atmosphere.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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