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Physicochemistry of Iko River Channel in Nigeria and the Related Human Health Problems

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ABSTRACT

Background and Objective: Potable water is essential for all lives on earth however, the quality of water available in the oil producing area of Nigeria has been seriously degraded. This work was conducted at Nda Uko, Kampe, Utapete Flow Station, Iko, Emereoke and Jaja Creek along Iko River to establish its pollution status, cancer and non-cancer health risks associated with human exposure to the river. **Materials and Methods:** During this study, water samples were obtained at Nda Uko, Kampe, Utapete flow Station, Iko, Emereoke and Jaja Creek along Iko River in Eastern Obolo, Nigeria. Collection of samples was done for twelve months and a total of thirty-six composite samples were obtained and used for this study. Some parameters were determined *in situ* while other parameters were analysed in the laboratory using appropriate equipment. Samples for dissolved oxygen (DO), Biochemical Oxygen Demand (BOD) and chemical oxygen demand (COD) were obtained using brown BOD bottles while samples for metals analysis were treated with 1 mL of concentration HNO_3 before analysis. Data and multivariate analyses were performed with IBM SPSS Statistics 20. **Results:** The TDS, DO, EC, turbidity, TH, Cl^-, SO_4^{2-}, NO_2^-, PO_4^{3-}, Fe, Ni, Pb, Cd and Mn were higher. This was attributed mainly to the anthropogenic factor. Daily intake rates of Cd and Pb obtained were higher than the recommended reference daily doses. The Cd and Pb showed high potential for the non-cancer risks in both the children and adult populations. The total hazard indexes for both populations were higher than one. Cancer risks of Ni, Cd and Cr were very high however, the children were more susceptible. **Conclusion:** The total cancer risks (TCR) for both populations were higher than the acceptable limit with Ni being the main contributor.

KEYWORDS

Iko River, cancer and non-cancer risks, water quality, water pollution, oil exploration, Nigeria

INTRODUCTION

The alterations of the stratosphere by human activities have caused serious devastation tothe environment all over the world[1]. According to Dinka[2], water is one of the universal vital resources available on earth for human life. However, having access to unpolluted water sources mostly in developing nations such as Nigeria is still a serious problem[3].The aquatic ecosystem within the Niger Delta Region of Nigeria has been seriously degraded by the activities of oil companies[4-6]. Consequently, the studied Iko within the Niger Delta Area of Nigeria is highly contaminated by domestic, agricultural and industrial wastes. It has been

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reported that about 3.4 million lives mostly young ones are lost yearly to water-associated ailments [2]. In Nigeria about 68,000 children less than five years old die of water-related diseases[7]. Nigeria is the third among the top ten countries where most people lack access to potable water[8]. An unclean water body has loads of disease causing agents and inorganic and organic contaminants and people without access to safe water sources and sanitation are prone to suffer severe health problems, especially children[9,10]. Prolonged exposure to unsafe water sources either directly or indirectly is responsible for about 80% of diseases globally and it kills more than other sources of death[11-13].

It has been reported that the people in Iko lack access to potable water as their water sources have been seriously polluted by the activities of oil companies in the area[14]. Studies have been conducted to evaluate the impact of anthropogenic activities on the microbial loads of the studied Iko River[15-17]. Other researchers concentrated on the metal loads in water, aquatic organisms and sediments from Iko River[18-20]. Dickson *et al.*[21] studied the effects of climate change on the phytoplankton composition and variability in Iko River. These studies previously carried out in Iko River the studied aquatic ecosystem confirmed the poor quality of water from Iko River.

For this reason, this study was conducted to assess the water quality and the associated cancer and non-cancer health risks related to human exposure to the studied Iko River. As water is very important for the survival of all living things including human, a routine assessment of water quality is a necessary tool for the evaluation of pollution status and provide data for planning the sustainable utilization of water resources globally[22,23]. Consequently, this study was conducted to assess the pollution status and health problems related to exposure to Iko River and provide information for the government on the proper planning of the provision of social resources. Previous studies never assess and established the source of contaminants in the river. This study conducted a multivariate analysis to identify the sources of contaminants in the studied aquatic ecosystem.

MATERIALS AND METHODS

Study area: Iko River channel, in Nigeria was the study area and is located in the oil producing part of the country. The river starts off from Qua Iboe River and connects Atlantic Ocean by Bight of Bonny. The shoreline of the river is characterized by mudflat during low tide. Iko River traverses through mangrove and freshwater swamps. This aquatic ecosystem which is used for intensive fishing activities has been seriously degraded by crude oil exploration activities, domestic wastes and runoff from agricultural farms. According to Bassey *et al.*[24] the Iko fishing area of the local government area examined has an estimated population of 107,520. The area investigated lies between latitude 4°30'01.33" and longitude 8°30'01.5". The dominant plant species at each location are as follows: Station 1 (NdaUko) is the upper part of the river with Nypa palm (*Nypa fruticans*) as the dominant plant species. Station 2 (Kampe) is a fishing settlement with oil palm (*Elaeis guineensis*) and coconut Palm (*Cocos nucifera* L.) as the dominant plant species. The Station is located in mid-stream of the study area. Station 3 (Utapete flow station) is an abandoned flow station by an oil company with red and white mangroves (*Rhizophora racemosa* and *Avicermia germinae*) as the main plant species. Station 4 (Iko) is downstream of the river with some abandoned oil well heads dominated by *Rhizophora racemosa*, *Avicermia germinae* and *Cocus mucifera*. Station 5 (Emereoke) is also downstream of the river with some abandoned oil well heads dominated by *Nypa fruticans*, *Rhizophora racemosa* and *Avicermia germinae*. Station 6 (Jaja Creek) is a settlement where fishing activities are carried out with *Nypa fruticans* as the major plant species.

Sample collection and analysis: Sampling was done between July, 2017 and June, 2018 to cover the dry and wet seasons of the study area. Water samples were collected at six designated locations namely: Nda Uko, Kampe, Utapete Flow Station, Iko, Emereoke and Jaja Creek along the river using standard procedures by APHA[25]. The samples collected were preserved following the procedures of APHA *et al.*[26]. Samples for BOD analysis were collected in dark brown BOD bottles without trapping air, followed by the

Table 1: Methods for the determination of physicochemical properties and trace metals in the studied river

Parameter	Method	References
pH	pH Meter Hanna CE 198107 Model	Ma *et al.*[27]
TSS (mg L^{-1})	Filtration and Gravimetric	Adjovu *et al.*[30]
TDS (mg L^{-1})	TDS Meter Model CE 1703037	APHA *et al.*[26]
DO (mg L^{-1})	DO Meter Hanna H19146-04 Model	Ma *et al.*[27]
EC (µS cm^{-1})	EC Meter Hanna CE 1703035	Ma *et al.*[27]
Salinity (mg L^{-1})	Titrimetric H 18733	Verma and Singh[31]
Turbidity (NTU)	Spectrophotometry	APHA *et al.*[26]
Total hardness (mg L^{-1})	Titrimetric Hanna	Verma and Singh[31]
BOD (mg L^{-1})	Incubation	Verma and Singh[31]
COD (mg L^{-1})	Titrimetric	Wu *et al.*[32]
Chloride (mg L^{-1})	Argentometric	Cai *et al.*[33]
Sulphate (mg L^{-1})	Spectrophotometry	Cai *et al.*[33]
Nitrite (mg L^{-1})	Spectrophotometry	Verma and Singh[31]
Nitrate (mg L^{-1})	Spectrophotometry	APHA *et al.*[26]
Phosphate (mg L^{-1})	Spectrophotometry	Cai *et al.*[33]
Trace metals (mg L^{-1})	Spectrophotometry	Dkhar *et al.*[34]

TSS: Total suspended solids, TDS: Total dissolved solids, DO: Dissolved oxygen, EC: Electrical conductivity, BOD: Biochemical oxygen demand, COD: Chemical oxygen demand and APHA: American Public Health Association

addition of 2 mL of alkaline potassium iodide (KI)[27]. Water samples for total trace metal analysis were collected with polyethylene bottles. The samples collected were acidified with 1 mL of concentrated HNO_3[28,29]. The pH, dissolved oxygen (DO) and electrical conductivity (EC) were determined in situ using standard methods indicated in Table 1. Samples for the determination of other physicochemical properties and trace metals were always transported to the laboratory of the University of Uyo in an icebox. The determination of parameters in the studied river was done using the procedures indicated in Table 1.

Water quality index (WQI) assessment: The individual pollution index (Pi) which uses a water quality single parameter to assess water quality comprehensively based on the class of the water quality[35] was computed using Eq. 1:

$$P_i = \frac{C_i}{S_i} \tag{1}$$

The Pi is classified as follows: 0-0.20 is clean, 0.21-0.4 is sub clean, 0.41-1.00 = slightly polluted, 1.01-2.0 indicate moderately polluted and ≥2.01 is severely polluted[36].

Human health risk assessment via exposure to trace metals in the studied river: The health risks associated with exposure to individual trace metal was based on the extent of problems indicated as carcinogenic and non-carcinogenic human health hazards[37]. The chronic daily intake (CDI), hazard quotient (HQ) and total hazard index (THI) were computed to assess the non-cancer risks while the incremental lifetime cancer risk (ILCR) and total cancer risk (TCR) were used to assess the cancer risks).

Chronic daily intake: The chronic daily intake (CDI) of trace metals due to the ingestion of water from Iko River by the adults and children populations was computed by the means of Eq. 2:

$$CD = \frac{C \times DI}{BW} \tag{2}$$

In Eq. 2, C indicates the concentration of trace metals in water from the studied river, DI signifies the average daily intake rate which is 1 L/day for a child and 2 L/day for an adult, BW is the body weight which is 10 kg for a child and 70 kg for an adult[14].

Hazard quotients: The hazard index (HQ) of trace metals for the exposure of both the adults and children populations via the ingestion of water from the river was calculated using Eq. 3:

$$HQ = \frac{CDI}{RfD} \quad (3)$$

where, CDI is the chronic daily intake rate calculated and RfD signifies the oral reference dose which are given as Zn (0.3), Fe (0.70), Ni (0.02), Cu (0.04), Pb (0.004), Cd (0.001), Cr (1.5) and Mn (0.14) mg/kg/day by Emmanuel *et al.*[38].

Total hazard index: The total hazard index (THI) was computed with Eq. 4:

$$THI = \Sigma HQ = HQZn+HQFe+HQNi+HQCu+HQPb+HQCd+HQCr+HQMn \quad (4)$$

In Eq. 4, ΣHQ is the sum of all the hazard quotients (HQ) of the metals determined.

Incremental lifetime cancer risk: Incremental lifetime cancer risk (ILCR) for the carcinogens for both the adult and children populations was calculated using Eq. 5:

$$ILCR = CSF \times CDI \quad (5)$$

In Eq. 5, CSF denotes the cancer slope factor for the carcinogens and are 1.70E+00, 8.50E-03, 5.00E-01 and 5.01E-01 (mg/kg/day)-1 for Ni, Pb, Cd and Cr, respectively[39]. However, there were no cancer slope factors for the calculation of ILCR for Zn, Fe, Cu and Mn. The CDI is the calculated chronic daily intake in mg/kg BW/day.

Total cancer risk: Total cancer risk (TCR) for the exposure of both the adults and children populations to the carcinogens via water from the studied river was estimated using Eq. 6:

$$TCR = \Sigma ILCR=ILCRNi+ILCRPb+ILCRCd+ILCRCr \quad (6)$$

where, indicates the summation of individual carcinogen incremental risk. The total cancer risk is classified as follows: 1.0E-01-1.0E-03 is very high cancer risk class, 1.0E-04 is high cancer risk class, 1.0E-05 is medium cancer risk class, 1.0E-06 is low cancer risk class and TCR less than 1.0E-06 is in the negligible cancer risk class[40].

Statistical analysis: The analysis of numerical data obtained from the analysis was carried out by means of IBM SPSS Statistics 20 (IBM USA). Principal component and Cluster analyses were executed by Duncan's Multiple Range Tests at 0.01 confidence limits. Factor analysis was done by means of Varimax rotation method on twenty-three parameters and values from 0.505 and higher were deemed significant. The Cluster analysis was performed with Dendrograms to categorize groups with common sources and properties.

RESULTS AND DISCUSSION

Physicochemical properties of water: Results of the physicochemical properties of the studied Iko River were shown in Table 2. The pH of water decides most of the biochemical processes taking place in a particular water body and time. The pH of the river investigated varied from 6.41 to 6.55 with a mean of 6.48±0.05. This range is within the acceptable limit of 6.5-8.5 by Omer[41]. According to Inam *et al.*[14] the pH values reported are favourable for optimal aquatic activities in the studied river. Consequently, the oil exploration activities in the water body may not have impacted significantly on the pH.

Table 2: Results of physicochemical properties of water from the studied river

Parameters	NU	KP	UT	IK	EM	JC	Min	Max	Mean	SD
pH	6.55	6.49	6.50	6.49	6.45	6.41	6.41	6.55	6.48	0.05
TSS	0.34	0.42	0.38	0.38	0.38	0.29	0.29	0.42	0.37	0.05
TDS	3866.00	3621.91	3754.81	3866.00	3534.98	3022.8	3022.80	3866.00	3500.33	326.13
DO	5.12	5.10	4.97	5.03	5.13	4.81	4.81	5.13	5.03	0.12
EC	6036.44	5867.17	5468.11	5822.69	5700.29	5008.88	5008.88	6036.44	5650.60	366.87
Salinity	5.45	5.95	6.24	6.33	5.85	5.44	5.44	6.33	5.88	0.38
Turbidity	20.04	26.30	32.29	34.52	24.33	18.32	18.32	34.52	25.97	6.47
TH	168.07	209.08	226.65	221.05	201.30	140.94	140.94	226.65	194.52	33.36
BOD	2.98	3.21	3.76	4.13	3.28	2.79	2.79	4.13	3.36	0.50
COD	10.55	12.79	16.15	16.84	12.40	10.05	10.05	16.84	13.13	2.82
Chloride	473.75	545.87	569.39	600.35	532.55	472.77	472.77	600.35	532.45	51.31
Sulphate	0.21	0.12	0.15	0.15	0.13	0.11	0.11	0.21	0.15	0.04
Nitrite	174.07	183.64	197.58	203.01	180.46	164.80	164.80	203.01	183.93	14.32
Nitrate	0.14	0.12	0.12	0.13	0.12	0.11	0.11	0.14	0.12	0.01
Phosphate	17.13	21.12	24.79	25.66	19.81	15.83	15.83	25.66	20.72	3.97

NU: Nda Uko, KP: Kampe, UT: Utapete flow station, IK: Iko, EM: Emereoke, JC: Jaja Creek, TSS: Total suspended solids, TDS: Total dissolved solids, DO: Dissolved oxygen, EC: Electrical conductivity, TH: Total hardness, BOD: Biochemical oxygen demand and COD: Chemical oxygen demand

Total suspended solids (TSS) in the studied river ranged between 0.29 and 0.42 mg L^{-1} with a value of 0.37±0.05 mg L^{-1}. This is within the recommended limit of 0.75 mg L^{-1} by Omer[41], for potable water. Consequently, the levels of TSS obtained may not interfere negatively with the normal aquatic life within the river. The human activities within and around the studied aquatic environment may not affect TSS contents considerably.

A range and mean concentrations of 3022.80-3866.0 and 3500.33±326.13 mg L^{-1}, respectively were recorded for Total Dissolved Solids (TDS) in the river examined. Levels of TDS obtained exceeded the stipulated limit (500.0 mg L^{-1}) by Omer[41]. Hence, the oil exploration activities in the area may have introduced very high levels of inorganic and organic matter into the water channel. Accordingly, this high level of TDS may have a negative impact on the water quality and normal aquatic activities[42,43]. Exposure of humans to this water source either directly or indirectly may also result in cardiovascular disease, cancer, arteriosclerotic heart disease and coronary heart disease[44].

Dissolved oxygen (DO) of the river assessed ranged between 4.81 and 5.13 mg L^{-1} (Table 2). The DO is an important property that sustains aquatic life and is used to evaluate the extent of freshness in a water channel[45,46]. The mean DO obtained (5.03±0.12 mg L^{-1}) is above the recommended limit of 4.0 mg L^{-1} by Omer[41]. Thus, the activities of oil companies within the study area might have elevated the dissolved oxygen of the river. This may affect the chemistry and microbiological activities of the aquatic ecosystem examined[47].

The electrical conductivity (EC) levels of the studied river ranged from 5008.88 to 6036.44 μS cm^{-1} (Table 2). The mean EC level (5650.60±366.87 μS cm^{-1}) reported in this study is much higher than the 1000.0 μS cm^{-1} recommended for an unpolluted water body by Omer[41]. Consequently, the anthropogenic activities within the study area have been impacted negatively on the EC level of the water body severely. The high EC levels of the water channel examined could be attributed to the elevated dissolved solids reported and is an indication of the high pollution status of the aquatic ecosystem[48,49].

The salinity of the aquatic ecosystem investigated ranged between 5.44 and 6.33 mg L^{-1} with a mean value of 5.88±0.38 mg L^{-1}. The obtained range is below the acceptable range of 10-25 mg L^{-1} for unpolluted water by Omer[41]. Thus, the human activities within the study area may have impacted the electrical charges of cations and anions in the water channel[50].The low salinity recorded may accelerate the water-wetting capacity of the river bed[51].

Table 3: Results of total trace metals in water from the studied river

Parameters	NU	KP	UT	IK	EM	JC	Min	Max	Mean	SD
Zn	0.13	0.15	0.19	0.22	0.15	0.14	0.13	0.22	0.16	0.03
Fe	1.23	1.30	1.37	1.39	1.29	1.20	1.20	1.39	1.30	0.08
Ni	0.08	0.09	0.18	0.12	0.10	0.08	0.08	0.18	0.11	0.04
Cu	0.15	0.14	0.19	0.19	0.15	0.14	0.14	0.19	0.16	0.02
Pb	0.13	0.16	0.23	0.28	0.12	0.12	0.12	0.28	0.17	0.07
Cd	0.24	0.13	0.02	0.02	0.01	0.17	0.01	0.24	0.10	0.10
Cr	0.06	0.07	0.08	0.84	0.06	0.05	0.05	0.84	0.19	0.32
Mn	0.26	0.27	0.36	0.40	0.40	0.22	0.22	0.40	0.32	0.08

NU: NdaUko, KP: Kampe, UT: Utapete Flow Station, IK: Iko, EM: Emereoke and JC: Jaja Creek

Turbidity of the studied river channel varied from 18.32 to 34.52 mg L^{-1}. The average value of turbidity obtained (25.97±6.47 mg L^{-1}) is higher than the recommended limit of 5.00 NTU by Omer[41]. This shows that human activities within the study area may have resulted in the reported high levels of turbidity. Changes in the turbidity of a water body may impact the temperature, chemistry and microbial activities within the water channel[52]. Thus, the high level could be an indication of elevated levels of pathogens in the aquatic environment[53].

Total hardness (TH) of the studied river ranged between 140.94 and 226.65 mg L^{-1} (Table 2). The average value of TH obtained (194.52±33.36 mg L^{-1}) is beyond the permissible limit of 150.0 mg L^{-1} by Omer[41]. According to Sengupta[54], the water channel has elevated levels of calcium and magnesium and belongs to the very hard class of water hardness. Exposure to water from the studied aquatic environment may result in several health problems in the consumers as reported by Akram and Fazal-ur-Rehman[55]. The high level of hardness reported in this study could be attributed to the anthropogenic activities of oil and associated companies within the study area.

The biochemical oxygen demand (BOD) in the water body investigated ranged from 2.79 to 4.13 mg L^{-1} (Table 3). The range of BOD reported in this study classifies the water body as moderately clean water according to Musa *et al.*[56]. The average value of BOD recorded (3.36±0.50 mg L^{-1}) is lower than the 6.0 mg L^{-1} recommended by Omer[41] for an unpolluted water body. This indicates the low level of organic matter in the water channel examined[46]. Accordingly, the activities of oil and oil-related companies in the study area may not have introduced a high volume of organic waste into the ecosystem.

The chemical oxygen demand (COD) of the studied river channel varied from 10.05 to 16.84 mg L^{-1}. According to Rao and Mogili[57] the range of COD obtained in this study classify the aquatic system as being moderately polluted. The COD indicates the extent to which a water body has been contaminated by biodegradable matter[58]. The mean value of COD obtained (13.13±2.82 mg L^{-1}) is below the recommended 30.0 mg L^{-1} limit by Omer[41] for unpolluted water. Despite the low levels of COD reported, the water body has been contaminated by the anthropogenic activities in the area. This may have resulted in the low COD values reported.

Chloride content of the studied river channel ranged between 472.77 and 600.35 mg L^{-1} (Table 2). Chloride in surface water comes from both natural and anthropogenic sources however, the natural contribution is low[59]. The average value of chloride in the studied river (532.45±51.31 mg L^{-1}) is above the recommended limit (350.0 mg L^{-1}) by Omer[41]. Thus, oil exploration and exploitation activities in the area may have resulted in the high chloride content of the water channel evaluated[60]. Consequently, the reported high chloride content may affect both the aquatic life and human beings exposed to untreated water from the studied river[61].

The level of sulphate at the different locations along the studied river varied from 0.11 to 0.21 mg L^{-1}. The mean value obtained (0.15±0.04 mg L^{-1}) is far below the 500.0 mg L^{-1} standard for unpolluted water by Omer[41]. This shows that both natural and anthropogenic sources of sulphate contributed very low levels to the water body investigated. The low sulphate content of the studied river might result in low plant growth, especially algae in the ecosystem[62].

Nitrite in the studied river varied from 164.80 to 203.01 mg L^{-1} with an average concentration of 183.93±14.32 mg L^{-1}. Studies have shown that the main routes of soluble nitrite in surface water are nitrogen-containing fertilizers and wastes from animal farms and industries[63,64]. The mean level of nitrite reported is higher than the 3.00 recommended by Golaki *et al.*[65]. Consequently, prolonged exposure to untreated water from this source may result in health problems such as colorectal cancer and methemoglobinemia[66,67]. The obtained result has also revealed that human activities in the study area might have resulted in the elevated nitrite content of the water body examined.

Nitrate in the studied river ranged between 0.11 and 0.14 mg L^{-1} with a mean value of 0.12±0.01 mg L^{-1}. The levels of nitrate reported in this study are less than the recommended limit of 50.0 mg L^{-1} by Omer[41] in an unpolluted water bodies. Hence, the level of nitrate reported may not pose any environmental health problems. The low levels of nitrate obtained could be attributed to the impact of denitrifying bacteria on nitrate[68]. The luxuriant Nypa palm growth in the study area could also reduce the nitrate content of the river channels[69,70].

Levels of phosphate in the river assessed ranged from 15.83 to 25.66 mg L^{-1}. The mean value obtained (20.72±3.97 mg L^{-1}) is above the acceptable limit of 3.5 mg L^{-1} in a potable water channel by Omer[41]. Thus, human activities within the area studied may have introduced substantial amounts of phosphate into the aquatic ecosystem. The high level of phosphate reported may result in eutrophication in the aquatic system and can cause acidosis in those exposed to the untreated water for a long time[71,72].

Trace metals in the studied aquatic ecosystem: Results of the distribution of total trace metals in the studied river were shown in Table 3. The results showed that Zn varied between 0.13 and 0.22 mg L^{-1} with a mean concentration of 0.16±0.03 mg L^{-1}. The mean concentration of the metals is below the recommended limit of 3.0 mg L^{-1} by Omer[41]. Hence, Zn may not have any harmful effect on the aquatic ecosystem and human beings exposed to the raw water from the studied river. Rather the level of Zn obtained in this work could be essential for both the human and aquatic lives[73]. This is also an indication that human activities within the studied system may not have contributed a significant quantity of Zn to the environment.

Iron (Fe) concentrations at the different locations along the studied river ranged from 1.20 to 1.39 mg L^{-1}. The average concentration of 1.30±0.08 mg L^{-1} of Fe obtained is higher than 0.5 mg L^{-1} recommended for an unpolluted water body by Omer[41]. This can alter the physical status (colour, taste and odour) of the water body[74]. Overexposure to Fe via untreated water can cause diabetes mellitus, Parkinson's disease, cardiovascular disease, hemochromatosis, pigmentation changes, huntington disease, Alzheimer's disease and respiratory, kidney, liver and neurological disorders[75,76]. The level of Fe obtained in this study may also affect the aquatic life in the studied ecosystem[77]. The result obtained is an indication of the negative impact of anthropogenic activities on the quality of the water channel.

Table 3 shows the range and mean concentrations of nickel (Ni) in the studied river as 0.08-0.18 mg L^{-1} and 0.11±0.04 mg L^{-1}, respectively. Concentrations of Ni at all the studied locations were higher than the recommended 0.01 mg L^{-1} by Omer[41]. Improper disposal of industrial wastes and aerial depositions are the major sources of Ni in the aquatic environment. However, runoffs and rock weathering are other important sources of a water channel[78-80]. The high levels of Ni reported can cause health problems such as cancer, allergy and improper functioning of the lungs[81]. It has also been reported that a high level of Ni has detrimental effects on aquatic organisms[82]. The reported high level of Ni might have contributed to the studied ecosystem through the anthropogenic activities in the area.

Copper (Cu) is one of the essential elements for human and aquatic life but toxic at high concentrations[83,84]. It is widely spread in the environment since the metal emanates from both natural and anthropogenic sources. Table 4 indicates that, Cu varied from 0.14 to 0.19 mg L^{-1} in the studied aquatic ecosystem. The mean value obtained (0.16±0.02 mg L^{-1}) is below the recommended limit of 1.0 mg L^{-1} by Omer[41] for an unpolluted water body. The low levels of Cu at all the studied locations could be attributed to the ability to form complexes with dissolved organic matter in water[85].

Lead (Pb) concentrations varied from 0.12 to 0.28 mg L^{-1} with a mean value of 0.17±0.07 mg L^{-1} in the studied river. Concentrations of Pb at all the locations were higher than 0.01 mg L^{-1} recommended for an unpolluted water system by Omer[41]. Lead is found in air, soil and water due to its widespread applications[86]. It is a well-known element due to its toxicity even at minimal concentration[87,88]. The Pb emanates from both natural and anthropogenic sources; the major anthropogenic sources include urban, agricultural and industrial wastes. It is also a component of mining and crude exploration processes[59,89]. The outcome of this study indicates that oil-related and other human activities in the study area might have accelerated the Pb content of aquatic ecosystems. Long-term exposure to the high level of Pb reported in the studied river can cause several health problems including death in both the children and adult populations[90-92]. It can also impact negatively on the aquatic life of the studied ecosystem[93].

Cadmium (Cd) in the studied aquatic environment ranged between 0.01 and 0.24 mg L^{-1}. An average concentration of 0.10±0.09 mg L^{-1} was obtained for Cd and is above the permissible limit of 0.01 mg L^{-1} in unpolluted water by Omer[41]. The main sources of Cdin aquatic environment are aerial deposition, combustion of fossil fuels, industrial wastes and Cd-related fertilizers in runoffs from adjoining farms[94,95]. The level of Cd obtained in this study could be detrimental to human and aquatic organisms exposed to the studied river for a long time[96,97]. Consequently, anthropogenic activities including crude oil exploration carried out within the study area may have contributed a significant level of Cd to the environment.

The range and mean concentration of chromium (Cr) in the studied aquatic environment as shown in Table 4 are 0.05-0.84 and 0.19±0.32 mg L^{-1}, respectively. According to Tumolo *et al.*[98], the main sources of Cr in aquatic environments are natural and anthropogenic. Nevertheless, the level of Cr obtained in the studied aquatic ecosystem is below the recommended level of 0.5 mg L^{-1} by Omer[41]. Accordingly, this level of Cr may not have an adverse effect on human and aquatic organisms rather it will be beneficial to both[99]. Thus, the level of Cr associated with oil exploration and other anthropogenic activities within the study area may not have an immediate negative impact on the environment.

Manganese (Mn) is an essential element that is required by both aquatic organisms and humans for functioning[100,101]. In this study, Mn varied from 0.22 to 0.40 mg L^{-1} with an average concentration of 0.32±0.08 mg L^{-1}. The mean concentration reported is higher than 0.2 mg L^{-1} recommended for unpolluted water by Omer[41]. The level of Mn obtained in the studied river can cause the malfunctioning of intellectual and neurobehavioural function in young generations over time[102,103]. The level reported can also have negative effects on the studied aquatic ecosystem[104]. The Mn in surface water emanate from both natural and anthropogenic sources[101,105]. Consequently, these sources might have supplied significant amounts of the metal to the studied aquatic environment.

Table 4: Pollution index of parameters determined in the studied river

Parameter	Mean	Pollution index value	Rating
pH	6.48	0.76	Slightly polluted
TSS (mg L^{-1})	0.37	0.49	Slightly polluted
TDS (mg L^{-1})	3500.33	7.00	Severely polluted
DO (mg L^{-1})	5.03	1.26	Moderately polluted
EC (Ms/cm)	5650.60	5.65	Severely polluted
Salinity (mg L^{-1})	5.88	0.24	Sub clean
Turbidity (NTU)	25.97	5.19	Severely polluted
TH (mg L^{-1})	194.52	1.30	Moderately polluted
BOD (mg L^{-1})	3.36	0.56	Slightly polluted
COD (mg L^{-1})	13.13	0.44	Slightly polluted
Chloride (mg L^{-1})	532.45	1.52	Moderately polluted
Sulphate (mg L^{-1})	0.15	0.0003	Clean
Nitrite (mg L^{-1})	183.93	61.31	Severely polluted
Nitrate (mg L^{-1})	0.12	0.0024	Clean
Phosphate(mg L^{-1})	20.72	5.92	Severely polluted
Zn (mg L^{-1})	0.16	0.05	Clean
Fe (mg L^{-1})	1.30	2.60	Severely polluted
Ni (mg L^{-1})	0.11	11.00	Severely polluted
Cu (mg L^{-1})	0.16	0.16	Clean
Pb (mg L^{-1})	0.17	17.00	Severely polluted
Cd (mg L^{-1})	0.10	10.00	Severely polluted
Cr (mg L^{-1})	0.19	0.38	Sub clean
Mn (mg L^{-1})	0.32	1.6	Moderately polluted

TSS: Total suspended solids, TDS: Total dissolved solids, DO: Dissolved oxygen, EC: Electrical conductivity, TH: Total hardness, BOD: Biochemical oxygen demand and COD: Chemical oxygen demand

Trend in the distributions of the physicochemical properties and total trace metals of studied aquatic ecosystem: The general results for the physicochemical properties and total trace metals in the studied aquatic ecosystem indicated high standard deviations for TDS, EC, turbidity, TH, chloride, nitrite, Cd and Cr (Table 2 and 3). This revealed that these parameters had some values higher than the mean obtained. It may be due to the high spatio-temporal variations among the studied locations along the river[106,107]. The study revealed higher levels of physicochemical properties and total trace metals in the upstream and midstream regions than in the downstream as reported by Čiuldienė *et al.*[108] and Xie *et al.*[109]. This could be attributed to the dilution of the concentration of contaminants as the water flows downward[110,111]. This indicated that the contaminants in the studied water channel were diluted by the flow of the river[112,113].

Quality index of the studied Iko River: The assessment of the water quality based on the pollution index of the physicochemical properties as reported by Liu *et al.*[35] and Olawusi-Peters[36] in Table 4 indicates the following:

- Studied aquatic ecosystem could be classified as being clean with regard to its sulphate, nitrate, Zn and Cu contents
- Water body could be regarded as being in the category of sub-clean considering the level of its salinity and Cr
- Water system is in the slightly polluted category based on its pH, TSS, BOD and COD content
- It could be classified as being moderately polluted considering the concentrations of DO, total hardness, chloride and Mn
- Studied aquatic water channel may also be rated in the severely polluted class due to the levels of TDS, EC, turbidity, nitrite, phosphate, Fe, Ni, Pb and Cd

Table 5: Principal component analysis (PCA) signifying relative loading for the physicochemical properties examined

Variable	PC1	PC2	PC3	PC4
pH	-0.696	-0.314	-0.510	0.375
TSS	0.637	-0.293	0.631	0.139
TDS	0.948	-0.273	-0.009	-0.109
DO	-0.737	-0.382	0.505	0.213
EC	0.782	-0.589	-0.149	0.007
Salinity	0.991	-0.105	0.020	0.037
Turbidity	0.985	0.065	-0.038	0.103
TH	0.913	-0.165	0.316	0.192
BOD	0.981	0.189	-0.018	-0.023
COD	0.991	0.053	-0.075	0.095
Chloride	0.985	-0.082	0.074	-0.072
Sulphate	-0.426	0.868	-0.033	0.251
Nitrite	0.982	0.125	0.066	0.122
Nitrate	0.088	0.809	0.530	0.234
Phosphate	0.990	0.010	0.019	0.115
Zn	0.944	0.185	-0.250	-0.110
Fe	0.994	0.007	0.065	0.087
Ni	0.753	-0.167	-0.275	0.511
Cu	0.864	0.299	-0.251	0.218
Pb	0.909	0.304	-0.228	0.058
Cd	-0.832	0.379	0.001	0.206
Cr	0.681	0.533	-0.105	-0.471
Mn	0.814	-0.041	0.271	-0.186
Total variance (%)	72.300	12.800	7.300	4.600
Cumulative (%)	72.300	85.000	92.300	96.900
Eigen value	16.600	2.900	1.700	1.100

TSS: Total suspended solids, TDS: Total dissolved solids, DO: Dissolved oxygen, EC: Electrical conductivity, TH: Total hardness, BOD: Biochemical oxygen demand and COD: Chemical oxygen demand

Multivariate analysis of parameters determined in the studied river

Principal component analysis of the parameters: The physicochemical properties obtained were subjected to Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) to establish the source and relationship among them[114,115]. Table 5 shows the result of PCA of the parameters and revealed four major factors with Eigen value above one with a total of 96.9% total variance. Factor one contributed 72.3% of the total variance with a strong influence by TSS, TDS, EC, salinity, turbidity, TH, BOD, COD, chloride, nitrite, phosphate, Zn, Fe, Ni, Cu, Pb, Cr and Mn (Table 5). This factor shows the detrimental effects of natural and anthropogenic factors on the quality of the studied river[116,117]. The second factor added 12.8% to the total variance with a strong impact by sulphate, nitrate, Cr and Cd (Table 5). This represents the negative impacts of industrial activities and natural factors on the quality of the studied ecosystem[62,118]. The third factor added 7.3% to the total variance with a strong impact by TSS, DO and nitrate (Table 5). This signifies the negative influence of anthropogenic activities on the quality of the studied aquatic ecosystem[119,120]. The fourth factor contributed 4.6% to the overall variance with a significant impact by Ni. This indicates the negative effect of agricultural and industrial wastes on the quality of the studied aquatic environment[107,121,122].

Cluster analysis of the parameters: The existing association among the physicochemical properties and trace metals of the studied river was shown in Fig. 1. The Figure displays two main clusters namely: (i) Cluster that connects all the parameters together except TDS and EC and (ii) Second cluster links TDS and EC as one. The two clusters obtained may indicate the common sources for the different parameters determined in the studied ecosystem[123,124]. Clusters formed may also show similar properties among the parameters with a common group[125].

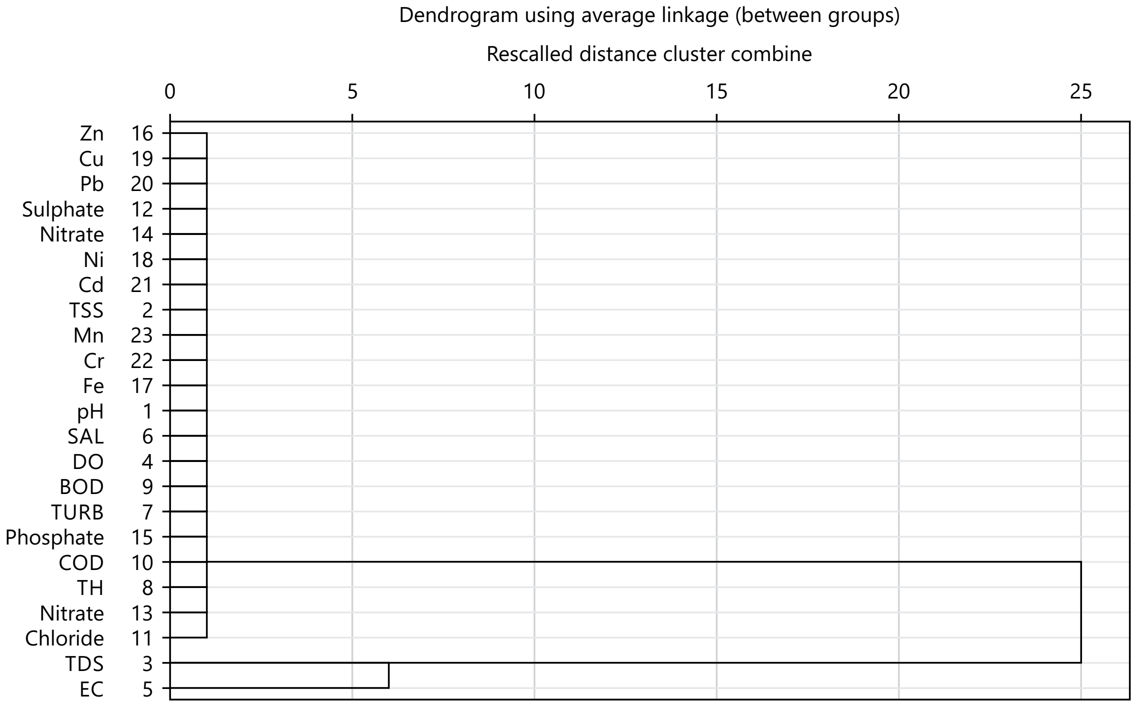

Fig. 1: Hierarchical clusters of the parameter determined in the studied river

Table 6: Results of chronic daily intake (CDI) rate and non-carcinogenic risks of trace metal in the studied river

	CDI Adults	CDI Children	HQ Adults	HQ children
Zn	0.004	0.016	0.013	0.053
Fe	0.036	0.130	0.052	0.186
Ni	0.003	0.011	0.150	0.550
Cu	0.004	0.016	0.100	0.400
Pb	0.005	0.017	1.250	4.250
Cd	0.003	0.010	3.000	10.000
Cr	0.005	0.019	0.003	0.013
Mn	0.009	0.032	0.064	0.229
HI		4.632	15.681	

CDI: Chronic daily intake, HQ: Hazard quotient and HI: Hazard index

Health risks assessment of non-cancer and cancer associated with exposure to the studied river

Chronic daily intake rate of trace metals via exposure to the studied river by the adult and children populations: Human health problems related to the exposure to trace metals in the studied aquatic ecosystem were examined using their daily intake rate[1]. Results for the chronic daily intake (CDI), hazard quotient (HQ) and total hazard index (THI) were indicated in Table 6. The average CDI values of Zn, Fe, Ni, Cu, Cr and Mnfor both the adult and children populations were below their acceptable oral reference doses (Rfd). However, the mean CDI values of Pb and Cd for both populations were higher than their recommended Rfds by Anyanwu and Nwachukwu[126]. Hence, Pb and Cd can pose serious health risks to those exposed to the aquatic ecosystem either directly or indirectly[127,128]. The implication is that oil exploration activities in the area may have polluted the studied aquatic ecosystem with these metals[129].

Non-cancer risks of the trace metals via exposure to the studied river by the adults and children populations: The average hazard quotients of Zn, Fe, Ni, Cu, Cr and Mn for both the adult and children populations were less than 1 (Table 7). Consequently, lifetime exposure to these metals via the consumption of water from the studied aquatic ecosystem may not cause serious non-cancer problems[130]. Nevertheless, the mean hazard quotient values of Pb and Cd for both populations were higher than 1 thus, these metals may likely pose serious non-cancer risks over lifetime exposure[131,132].

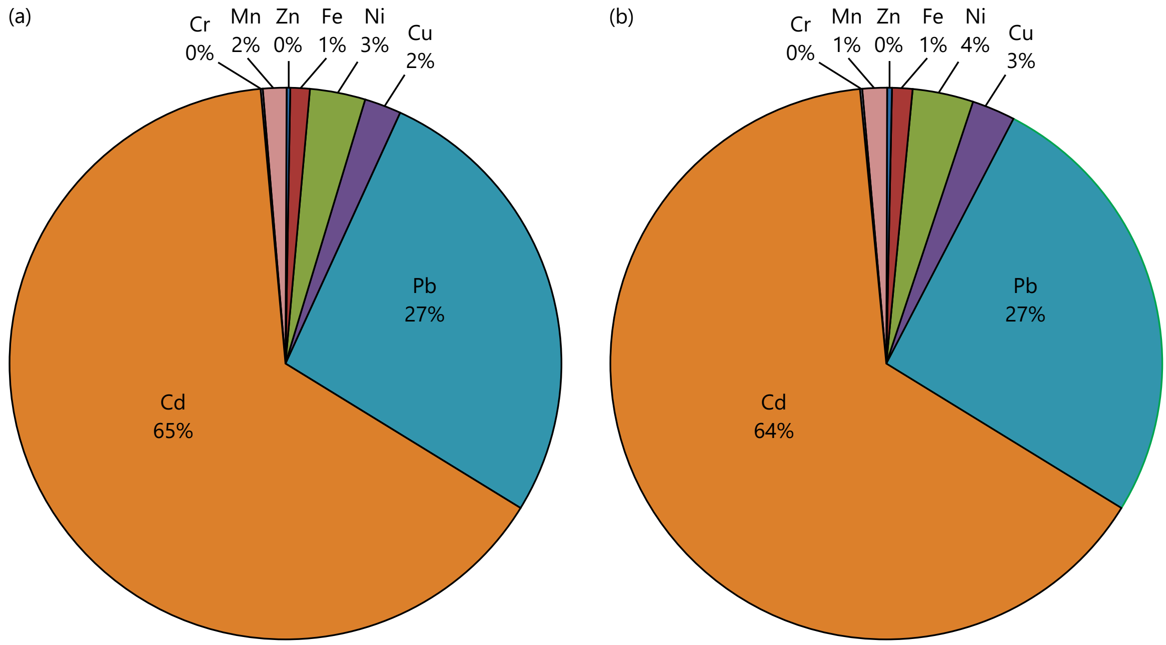

Fig. 2: Mean hazard quotient of trace metals for (a) Adults and (b) Children

Total hazard index (THI) of the trace metals through the oral ingestion of water from the studied aquatic system for the adults and children populations as indicated in Table 6 are 4.632 and 15.681, respectively. These values are greater than 1 and as such the consumers of untreated water from the studied source may be exposed to severe non-cancer problems[133]. Consequently, prolonged exposure to untreated water from the studied aquatic ecosystem may result in higher cancer risks in young ones than the adult as previously reported by Sulaiman *et al.*[134]. The average hazard index of Cd and Pb in adult contributed 92% of the entire THI value obtained (Fig. 2a). Figure 2b demonstrates that Cd and Pb added 91% to the total THI obtained. Hence, Zn, Fe, Ni, Cu, Cr and Mn donated a total of 8.0 and 9.0% to the total THI in adults and children, respectively. This shows clearly that Cd and Pb may cause serious harm to the consumers if exposed to the water source for a long time. This corroborated the findings from PCA that, these two metals may have emanated mainly from the anthropogenic activities (mainly oil exploration) in the study area.

Cancer risks of the carcinogens associated the exposure to the studied river by the adults and children populations: According to Cao *et al.*[135] toxic metals are capable of causing cancer-related risks in human beings. Hence, when human beings are exposed to metals for a long time there may be a tendency of developing cancer and cancer-related problems. This study considered Ni, Pb, Cd and Cr as potential cancer-causing agents and the level of exposure by those exposed to untreated water from the study area was evaluating using the average chronic exposure index obtained. Results obtained for the carcinogenic risks related to the exposure of the consumers to the studied water source were shown in Table 7. When the incremental lifetime cancer risk (ILCR) of a metal is less than 1×10^{-6} it is regarded as being inconsequential and can be ignored. However, if the ILCR is higher than 1×10^{-4} it could be considered as a cancer-agent and the source (studied river) should remediated[136,137]. The mean ILCR values for exposure of adults via the studied river for Ni, Pb, Cd and Cr in Table 7 are 5.00E-03, 4.25E-05, 1.50E-03 and 2.51E-03, respectively (Table 7). Consequently, the cancer risk of Ni, Cd and Cr for adults via the studied river were in the very high cancer risk class while, Pb was in the medium cancer risk class[40,138]. The mean cancer risk associated with these metals for children through exposure to the studied river varied as follows: 1.90E-02, 1.45E-04, 5.00E-03 and 9.52E-03 for Ni, Pb, Cd and Cr, respectively. Thus, the cancer risk of Ni, Cd and Cr for the children were in the very high cancer risk class whereas, Pb was in the high cancer risk category[40]. The cancer-causing potential of Ni was the highest for the adults and children populations however, that of the children class was relatively higher. Thus, children exposed to this water source are more vulnerable to cancer and cancer-related risks that the adults class.

Table 7: ILCR and total cancer risk value (TCR) of trace metals via exposure to the studied river

	ILCR (Adults)	Added to TCR (%)	ILCR (Children)	Added to TCR (%)	*Cancer slope factor
Zn	-	-	-	-	NA
Fe	-	-	-	-	NA
Ni	5.00E-03	55.0	1.90E-02	57	1.70E+00
Cu	-	-	-	-	NA
Pb	4.25E-05	0.0	1.45E-04	0.0	8.50E-03
Cd	1.50E-03	17	5.00E-03	15	5.00E-01
Cr	2.51E-03	28	9.52E-03	28	5.01E-01
Mn	-	-	-	-	NA
TCR	9.05E-03		3.37E-02	-	-

*Source: Mohammadi *et al.*[39]

Total cancer risks of the adults and children populations via exposure to the studied river: The mean total cancer risks (TCR) of trace metals in the studied aquatic ecosystem for the adults and children populations as shown in Table 7 were 9.05E-03 and 3.37E-02, respectively. The average TCR values reported for both populations are higher than the permissible limit of 1.00E-04 by Jalil *et al.*[139]. Consequently, the propensity of cancer risks among those exposed to untreated water from the studied aquatic ecosystem is high. The results obtained revealed that Ni was the highest contributor to the obtained TCR for the adults (55%) and children (57%) (Table 7). The potential of the carcinogens considered in this study follows the trend Ni>Cr>Cd>Pb for both the adults and children categories. It was also deduced from the study that nine in every one thousand adults is vulnerable to cancer while three in every one hundred is susceptible to cancer risk. Hence, the children are more vulnerable to cancer risks than the adult's category in the study area[140].

The outcome of this study has exposed the status of Iko River and the negative impact of anthropogenic factor especially oil activities on the studied river channel. The human health problems associated with long term exposure to the studied river have also been highlighted. The outcome of the study will help the government in making future policies concerning the operations of oil companies within the study area and beyond. It will also help the consumers to know the associated health risks with exposure to the river either directly or indirectly for a long time. Consequently, human exposure to untreated water from the river should be controlled and water from the river should be treated before consumption. Dumping of organic or non-biodegradable wastes in the water channel should be discouraged. Excessive application of inorganic fertilizers adjoining farmlands should be discouraged. Oil companies within the study area should operate based on the national and international laws guiding their operations. Government should provide sources of potable water for the people of the area. The assessment of the water body should be done periodically to forestall a devastating situation. Some adjoining creeks and parameters including organic contaminants not determined in this study should be examined in subsequent works. The sediments and aquatic organisms from the studied river should be examined in future study. However, the challenges faced during the study namely: Finance and insecurity along waterways in the study area should be considered when planning for future study.

CONCLUSION

The research revealed that anthropogenic activities by oil companies and other human activities have impacted negatively on the quality of the studied Iko River. Levels of most of the parameters determined were beyond their acceptable limits indicating the poor pollution status of the river. Water quality index of the parameters water from the studied river corroborated that the river was in a very bad shape. The chronic daily index of some of the trace was higher than their recommended oral doses indicating the probability of non-cancer risks inthe adult and children populations. The total hazard index for the adults and children populations were higher than one thereby confirming the high non-cancer risk associated with the exposure to the water for the river. The children were more vulnerable to both cancer and non-cancer risks associated with exposure to the trace metals via the ingestion of water from the studied river. The cancer risk of the carcinogens for both the adult and children populations was at a very risk and the children population was more susceptible to the risk. Consequently, oil companies should operate by the recommended regulations to forestall the contamination and subsequent pollution of the host environment. Dumping of domestic, agricultural or industrial wastes in the water channel should be discouraged. Remediation work should be carried out in the river to reduce the contaminants/pollutants load in the water channel. Human beings irrespective of age should refrain from exposing themselves either directly or indirectly to untreated water from the river. Water from the river should be properly treated before consumption or utilization for domestic purposes. Authorities concern should provide alternative sources of potable water for the people of the Eastern Obolo local government area to avoid the cancer and non-cancer risks on the populace.

SIGNIFICANCE STATEMENT

This research revealed the pollution status of Iko River. Results showed that TDS, DO, EC, turbidity, TH, Cl^-, SO_4^{2-}, NO_2^-, PO_4^{3-}, Fe, Ni, Pb, Cd and Mn were higher than their limits by NESREA. Anthropogenic factors especially oil activities was the major source of contaminants in river channels. Chronic daily intake of Cd and Pb were higher than their recommended limits for the children and adult populations. The Cd and Pb exhibited very high non-carcinogenic risks in both populations. The results also revealed that Cd, Cr, Ni and Pb demonstrated very high cancer risks on the consumers with the children class being more vulnerable. Water from the river should be treated before consumption. Alternative sources of potable water should be provided.

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