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Hydrocarbon-Based Contaminants in Drinking Water Sources and Shellfish in the Soku Oil and Gas Fields of South-South Nigeria

Ifeanyichukwu Clinton Ezekwe[1], Christian Livingstone Otiasah[1], Morufu Olalekan Raimi[2*], Iyingiala Austin-Asomeji[3]

[1]Department of Geography and Environmental Management, University of Port Harcourt, Amassoma, Nigeria
[2]Department of Community Medicine, Faculty of Clinical Sciences, Niger Delta University, Amassoma, Nigeria
[3]Department of Community Medicine, Faculty of Clinical Sciences, College of Medical Sciences, Rivers State University, Port Harcourt, Nigeria

Email: *morufuolalekan.raimi@gmail.com

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Abstract

Environmentally unfriendly Oil exploration activities have been ongoing in the Soku area of the Niger Delta of Nigeria since 1956. This study evaluated the concentration of hydrocarbons and heavy metals in Shellfish and drinking water sources in the study area. It revealed the absence (<0.001 mg/l) of most heavy metals (Ni, Ch, Cd, Pb mg/l) in the water column; a high concentration of the major ion composition of seawater (sulphates 5 - 1018; calcium 0.502 - 53.502; sodium 1.247 - 63.337; potassium 0.508 - 102.745; magnesium 0.354 - 42.574 mg/l); and high PAHs (<0.001 - 0.032 mg/l) levels occurring above WHO limits (0.007 mg/l) with some risk of exposure to cancer. Results from the analysis of shellfish showed that concentrations of chromium and zinc were below permissible limits while cadmium concentrations were slightly above permissible limits of the European Community. Nickel and lead were above permissible limits in the fish samples in all standards while PAHs occurred at the cancer risk levels of 10^{-6}. A review of the public health situation in the Soku area with a view to understanding current trends, sources of perturbations and preferable solutions to the potential public health challenges raised in this study is hereby recommended. Also, this study recommends that relevant agencies and developmental partners should launch a national drive to create awareness among people/environmental/public health professionals'/health workers/administrators on this regional concern.

Keywords

Niger Delta, Oil and Gas Production, Oil Pollution, Periwinkle, Rural

Livelihoods, Water Quality

1. Introduction

The Soku Oil Field operations consist of the Soku Flow Station, Soku Gas Plant, the Oil Rim Development Project, oil and gas wells and several kilometres of delivery pipelines. The Soku Gas Plant that provides feedstock gas to the Nigeria Liquefied Natural Gas Plant Limited (NLNG) in Bonny, Rivers State, Nigeria; became operational in 1996. From inception of oil and gas operations in the Soku area in 1956 till date, several environmentally unfriendly activities such as dredging, oil and gas well drillings, pipe laying, gas flaring and oil spills (both from authorised operations and oil theft) have adversely affected the environment [1]-[12]. This has been complicated by human and industrial waste mismanagement of chemicals, discharge of drilling fluids, metal cuttings, artisanal refineries, and condensate bunkering activities [13] [14] [15].

The Soku flow station and nearby gas plant is one of the major oil field facilities in the Niger Delta of Nigeria and a very important National asset as it is not only located within the delicate ecology of three tidal and semi tidal river systems (Sombriero, San Bartholomeo and Orashi) but also supply the bulk of the feed gas to the Nigerian LNG Complex in Bonny [16]. With the expansion of oil exploration and production activities, incidence of oil spills has increased considerably in the region. Spills occur accidentally (operational spills) and through activities of oil theft. Oil theft is carried out across the Niger Delta by militant youths in protest of the neglect of the zone by the Federal Government of Nigeria. They also engage in this illegal business for economic gains. They sabotage pipelines, oil wells and manifolds to siphon crude for export in the international black market and for local artisanal refineries [17] [18].

Available record shows that over 9000 oil spills occurred between 1975-2003, with a loss of nearly four million barrels of spills in the Niger Delta [19]. Watts and Zalik [20], however, opine that the national picture of oil spills (2006-March 2020) is a total of 13,091 spill events and a total release of 692,761 barrels. Of these events, 71.5% of the incidents pertained to crude oil accounting for 95.7% of total spill contaminants. The spatial distribution of spill events and spill volumes vary sharply across states with Rivers State alone (where the study is located) accounting for just under 30% of all spill incidents.

Also, the harmful practice of oil theft and artisanal refining and transportation of crude oil products otherwise called "Asari-fuel" in local parlance, has caused untold damage to the fragile aquatic and marine ecosystem of the Niger Delta, and has caused the death of over 2000 men/women in and around the Soku Oil and Gas Fields. The human casualties who were engaged in their livelihood expeditions died from condensate surface fires due to its flashpoint and other prevalent characteristics. These explosions, oil fires and untreated effluents freely discharged into the ecosystem have affected mangrove vegetation, aquatic plants and organisms, ecosystem diversity, habitats, and ambient air quality. Furthermore, improper discharges of drilling and other industrial wastes, microbiological contaminants, dredging excavations into the marine environment adversely affect water and sediment quality with impact on demersal (benthic and pelagic) fauna and flora [8] [9] [21].

These unfriendly activities pollute the rivers in the area that serve as the only source of water for consumption by the inhabitants and aquaculture. Condensate bunkering fires frequently destroys vast vegetations, occasioning loss of lives and other aquatic biota like sub-tidal and inter-tidal periwinkle (*Litorina Littorea*, and *Tympatonamus Fuscatus*); common tilapia (*Tilapia Zilli*) and the Mudskippers of family *Gobiidae* in the surrounding swamps. These species are particularly endemic in the intertidal zones of the brackish water environment and are more visible and active during low tides [22]. Apart from the killing of aquatic and marine biota, oil derived pollutants including Polycyclic Aromatic hydrocarbons and heavy metals bioaccumulation in the food chains and may finally affect man the ultimate consumer of the fish and water [23] [24].

The environmental effects of oil pollution and gas flaring are well known locally and internationally, and may include forest degradation, depletion of aquatic flora and fauna, destruction of ecosystems biodiversity, long term impacts on water bodies and mangrove swamp loss with a cumulative effect on fisheries, reduction of the resilience of biota with overall implications on environmental and public health [14] [25]-[30]. Thus, this study evaluated the concentration of hydrocarbon and heavy metal in Shellfish and drinking water sources in the study area. This study attempts to provide useful information about Shellfish and drinking water sources towards improving comprehensive understanding as well as to provide a scientific basis for the sustainable development and management of hydrocarbon and heavy metal in this region.

2. Study Area

2.1. Location and Extent

The Soku area for the purpose of this study covers the whole area influenced by Rivers San Barthlomeo, Sombreiro and Orashi including Allagoakiri, Soku town, Soku fishing communities, Elem-Sangama, the Soku Gas Plant and adjoining facilities, Rushia, Pangapingi, Obukiri, and Ekineama fishing settlements up to Sego and Egoribiri Creeks. This covers an area of up to 99 km^2, between Lat 4˚42'20.00"N and Lat 4˚27'00"N and Long 6˚32'00"E and Long 6˚30'46"E and 6˚50'33.00"E (**Figure 1** & **Figure 2**).

The inhabitants of Soku with a population of less than 30,000 people made up of mainly women and children are predominantly fishermen and petty traders. The men folk always engage in fishing whereas the women are more domiciled to picking periwinkle and mat weaving from the abundant mangrove and Raphia swamps in the area. The Soku people equally depend entirely on the

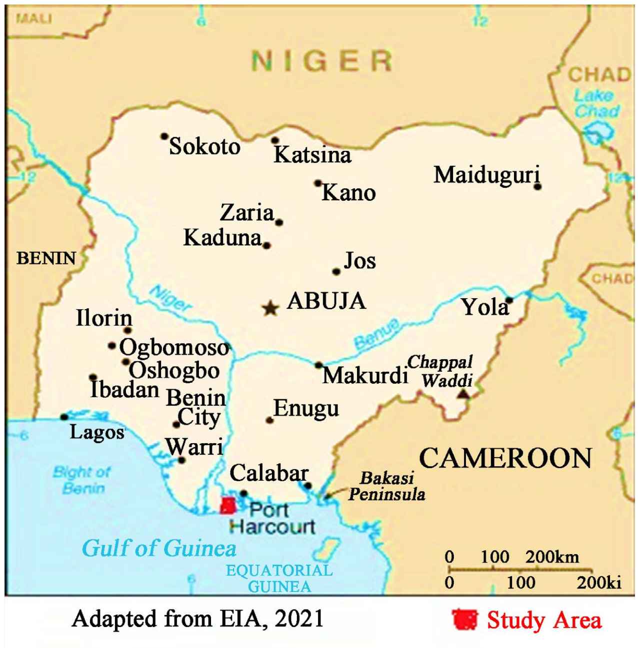

Figure 1. Map of Nigeria showing study area.

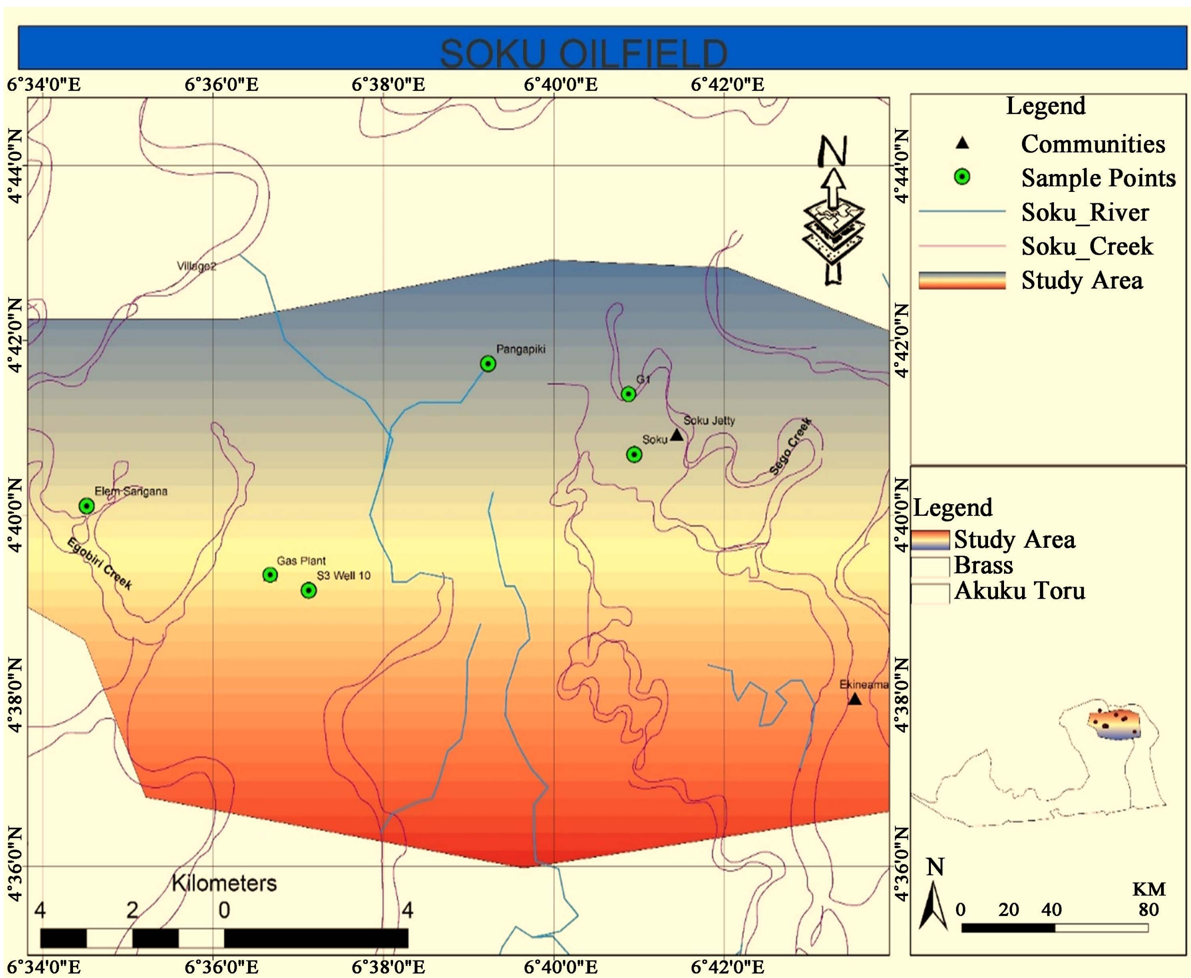

Figure 2. Map of study area showing sampling locations.

fishes from these rivers for their daily protein needs [31]. The people depend on the surrounding environments for their energy needs and livelihoods [14].

Consequently, there is the need to analyse the quality of the waters in the area with a view to ascertaining its standard in line with permissible levels of the World Health Organization (WHO), the United States Environmental Protection Agency (USEPA) and Federal Environmental Protection Agency (FEPA), to know its suitability for human consumption and aquaculture. Also, there is the need to analyse the aquatic biota, like the common tilapia and periwinkle to determine the level of hydrocarbon-based pollutants in them in line with standard levels allowable by WHO, USEPA and FEPA to know whether the inhabitants of Soku are consuming poisoned fishes and water or otherwise.

2.2. Physiography

The area is a low-lying intertidal zone scarcely higher than 6 metres above sea level. It usually characterised with heavily flooded flat-bottomed rivers and creeks and a permanently waterlogged rain and mangrove forest sections. The vegetation is floristically diverse and structurally complex, with several layers of trees. Trees that feature in the rain forest include *Pentaclethra macrophylla, Chrysophyllum albidum* and *Irvingiaga bonenesis*. The two last mentioned tree species are fruit trees, which are numerous due to its unique hydrological characteristics, and are important as sources of income and dietary supplement for rural people. The freshwater swamp is influenced by the Orashi River and high rainfall during the rainy season [14].

As with the rest of the Niger Delta, the climate of the study area is humid subequatorial with a long-wet season lasting from March to October that alternates with a shorter dry season that lasts from November to February. Annual rainfall is high throughout the study area, usually up to 2500 mm in southerly locations such as Ekineama, Rushia, Opukiri. Annual temperature average in the study area is about 27˚C with no marked seasonal departure from the average temperature as the annual range of temperature is quite small rarely exceeding 3˚C. The general humid tropics characteristic of Rivers State affects the climate of the area with its short distance from the Atlantic Ocean and prevailing tropical maritime air mass which blows over the region most months of the year [32].

3. Materials and Methods

3.1. Water Sampling and Analysis

Surface water samples for physiochemical, biological, and heavy metals analysis were collected from 5 purposively selected locations (to ensure full coverage of the study area) in pre-rinsed 1-litre plastic containers after rinsing the containers three times with the water being sampled for the physicochemical analysis. All the samples were labelled appropriately according to the sampling stations and were securely sealed and placed in a cooler containing icebags and were properly conveyed to ensure sample integrity, in the field colour and odour were determined using human senses. The samples for the heavy metal analyses were placed in 150 ml plastic containers, concentrated nitric acid (HNO_3) was added to adjust the pH to preserve the oxidation states of metals and hydrocarbons. Samples for hydrocarbon analysis were collected in pre-treated sample bottles (250 ml) and treated with HCL to avoid oxidation changes of constituents. Biochemical oxygen demand (BOD) samples were collected in 250 ml brown reagent bottles, sealed to exclude air bubble. All samples were collected and preserved following international standards for sampling of water and wastewater [33] [34].

Each sampling point was marked and geo-located using Geographical Positioning System (Garmin—12GPS). Sampling locations was selected in such a manner as to adequately represent the entire study area. To ensure the integrity of some unstable physiochemical parameters in-situ measurements of temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), total dissolved substance (TDS), turbidity and total dissolved solids (TDS) were carried out in the field using the HANNA Water Quality Checker in line with the American Public Health Associations Standard for the Analysis of water and wastewater [33] [34].

Shellfish samples were collected from three sample locations which are Elem-Sangama, Pangapiki and Soku Jetty. This was done by the researcher by diving. The fishes were wrapped in aluminium foils and waterproofed before placing them in the iced packed coolers for preservation. They were sent to the laboratory were extraction and analysis were carried out within 48 hours for hydrocarbons and heavy metals.

3.2. Laboratory (Analytical) Procedures

Laboratory methodologies for wastewater were from Standard Methods for the Examination of Water and Wastewater 19th Edition, 1998. Investigations involving heavy metals concentrations were carried out using atomic spectrophotometer (AAS Unicam 969). Exchangeable cations and anions were measured using flame photometer and UV/Visible spectrometer (Unicam Helios Gamma, UVG 073201; Spectronic 21D). Briefly, the methods that were employed are as follows: pH, Electrical conductivity, Turbidity, Dissolved solids, Temperature and Salinity: Measured using Horiba Water Checker (Model U-10) after calibrating the instrument with the standard Horiba solution. The units of measurement are µS/cm, NTU, mg/l, ˚C and ‰; respectively for conductivity, turbidity, temperature, and salinity.

Dissolved Oxygen (APHA-4500 C): The dissolved oxygen (DO) was determined by the Modified Azide or Winkler's method [34]. To a 70 ml BOD bottle filled with sample. 0.5 ml manganous sulphate (Winkler I) solution and 0.5 ml alkali-iodide-azide reagent (Winkler II) shall be added, stopper (excluding air bubbles) and mixed by several inversions. After about 10 minutes, 0.5 ml conc. H_2SO_4 shall be added, re-stopper and mixed for complete dissolution of precipitate. The fixed sample shall be taken to the laboratory for further analysis.

Bio-chemical Oxygen Demand (APHA-5210-B): Known portion of the water sample shall be collected and diluted with oxygenated and incubated at 20˚C for five days. At the end of the incubation period the samples shall be treated in the same manner as they DO samples stated above. Detection limits 2.0 mg/l. Total Alkalinity (API-RP 45) and Chloride (APHA 4500-CL B): were determined by titration; Sulphate (APHA 4500SO42-E/AST MID516) by the turbidimetry method [34] while Phosphate (APHA 4500-PE/ASTM D515). Nitrate, Total Hydrocarbon Content (THC) and PAHs were determined using ASTM D3921 (Extraction/Spectrophotometry) methods. Heavy metals (Cr, Cu, Pb, Fe, Cd, Zn, Nickel, Vanadium) were determined using an Atomic Absorption Spectrophotometer as described in API-IA 3111B and ASTM D3651.

3.3. Determination of Heavy Metals and Hydrocarbons in Shellfish

The methods used in this analysis are as previously described in [35]. The fleshy parts of the shellfish were dehydrated to a constant weight using an oven (Tecnocalor) at 50˚C and later pulverized. Two grams (2 g) of ground oven dried total body weight were weighed using a high precision microscale and put in a digestion flask and digested with a mixture of 10 ml of concentrated nitric acid and 2 ml of concentrated perchloric acid. The contents of the flask were, for each case, digested gently and slowly, by heating in a water bath until the contents got to near dryness. It was then set aside to cool. The digest was filtered into a 50 ml volumetric flask, made up to mark with distilled water and the concentration of selected metals was determined by Atomic Absorption Spectrophotometry using Buck Scientific Model 200A Spectrophotometer.

For Hydrocarbon analysis, 10 ml of 5% Sodium Chloride and 30 ml Ethanol were measured and added to 5 g of whole fleshy part of fish. Each mixture was refluxed for one hour, and then allowed to cool. The refluxed sample was later transferred into a separating funnel. 20 ml of dichloromethane was added and shaken for 30 minutes in a mechanical shaker. The mixture was allowed to separate out, and the lower layer was of the dichloromethane extract was received and used for GC-MS analysis.

The standard procedure as described validated and recommended for Polycyclic Aromatic Hydrocarbons [33] analysis was followed. Polycyclic Aromatic Hydrocarbons was extracted from the fish, by digested alcoholic solution of Potassium hydroxide and extraction with 1,1,2-trichlorotrifluoroethane (TCTFE). The extracts will further be purified to avoid interferences by aliphatic hydrocarbons using alumina as an adsorbent in and subsequently eluted with hexane to remove aliphatic hydrocarbons. A second eluant was benzene, which was used to remove the aromatic components further with sufficient purity for the Capillary Gas Chromatographic analysis.

4. Results and Discussion

4.1. Physico-Chemical Parameters in Water

The results of the physico-chemical analysis for water quality of the various water samples collected from the different sampled locations in the area is presented in the Table 1 below.

Dissolved oxygen (DO mg/l) level of the different water sources available to the people in the area ranges between 1.23 and 16.50, with the river water from Soku Jetty area accounting for the lowest with a value of 1.23 mg/l and river water from Soku Gas Plant area accounting for 16.50 mg/l which is the highest, although the result shows that pH value differs significantly from one water source location to another.

Table 1. Physico-chemical parameters in Soku oil field.

S/N	Parameter (s)	River water Elem Sagama	Well water Soku town	River water (Soku Gas Plant)	River water (Pangapiki)	River water (Soku Jetty)	WHO
1.	Nickel, Ni (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.01
2.	Chromium, Cr (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05
3.	Cadmium, Cd (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.001	0.005
4.	Lead, Pb (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.001	0.01
5.	Zinc, Zn (mg/l)	0.028	0.056	0.040	0.021	0.048	1.0
6.	Calcium, Ca (mg/l)	0.579	52.793	16.198	0.502	53.502	1.0
7.	Magnesium, Mg (mg/l)	0.354	8.927	41.509	0.539	42.574	0.2
8.	Sodium, Na (mg/l)	1.247	63.337	601.45	1.970	2259.80	<200
9.	Potassium, K (mg/l)	0.672	20.949	25.158	0.508	102.745	0.01
10.	PAH (mg/l)	0.379	<0.001	0.223	0.139	0.128	0.007
11.	THC (mg/l)	117.3	<0.001	23.8	5.71	2.66	
12.	Phosphate, PO_4^{3-} (mg/l)	1.73	2.0	0.31	1.30	0.79	
13.	Sulphate, SO_4^{2-} (mg/l)	7	68	558	5	1,018	250
14.	Nitrate, NO_3^- (mg/)	1.2	<0.1	0.2	0.7	0.3	10.0
15.	BOD (mg/l)	0.032	0.015	0.540	0.165	0.888	10
16.	DO (mg/l)	5.09	4.48	5.31	4.58	4.94	6.0
17.	Alkalinity (mg/l)	16	0	26	15	46	200
18	Hardness (mg/l)	9	395	1100	8	3300	100 - 300
19	Turbidity (NTU)			20	40	40	<4
20	(TDS, ppm)	101	680	540	30	ADL	>600
21	ORP (Mv)	97	226	267	94	485	
22	pH	7.9	7.71	7.03	7.37	7.43	6.6 - 8.5
23	Salinity (g/kg)	10	4.80	380	20	8160	
25	Temp (˚C)	28.1	31	25	30.6	28.3	27 - 29
26	Electrical Conductivity (uS/cm)	23.9	98.0	87 - 7	47.2	16 - 40	

(Adapted from Otiasah *et al.*, [21]).

Total dissolved solids (TDS ppm) level of the different water sources available to the people in the area ranges between 30 and 680, with the river water from Pangapiki accounting for the lowest with a value of 30 ppm and well water from Soku town accounting for 680 ppm which is the highest, although the result shows that TDS value differs significantly from one water source location to another. Particularly the TDS value for river water from Soku Jetty was above equipment determination level, this implies that the TDS level however was above those of the other water sources been studied.

Oxygen reduction potential (ORP mv) level of the different water sources available to the people in the area ranges between 94 mv and 485 mv, with the river water from Pangapiki accounting for the lowest with a value of 94 mv and river water from Soku Jetty accounting for 485 mv which is the highest, although the result shows that ORP value differs significantly from one water source location to another.

pH level of the different water sources available to the people in the area ranges between 7.03 and 7.9, with the river water from Soku gas plant area accounting for the lowest with a value of 7.03 and river water from Elem Sangama accounting for 7.9 which is the highest, although the result shows that pH value differs significantly from one water source location to another.

Salinity level of the different water sources available to the people in the area ranges between 4.80 g/kg and 8160 g/kg, with the well water from Soku town accounting for the lowest with a value of 4.08 g/kg and river water from Soku Jetty accounting for 8160 g/kg which is the highest, although the result shows that salinity value differs significantly from one water source location to another

Temperature level of the different water sources available to the people in the area ranges between 250˚C and 310˚C, with the river water from Soku gas plant area accounting for the lowest with a value of 250˚C and well water from Soku town accounting for 310˚C which is the highest, although the result shows that temperature value differs significantly from one water source location to another.

Table 1 also shows the chemical and biochemical analysis of water quality parameters in the study experiment. From the analysis as presented in the table above, Nickel, Chromium, Cadmium and Lead were below detectable limits (<0.001). In the case of Zinc, Calcium, Magnesium and Sodium, it is revealed that Zinc has a value that ranges between 0.021 and 0.056 with well water from Soku having the highest amount of zinc while river water from Pangapiki has the lowest with a value of 0.021. Calcium value ranges between 0.502 mg/l to 53.502 mg/l with river water from Elem Sangama having the lowest concentration of calcium with a value of 0.502 mg/l and river water from Soku jetty having the highest with a value of 53.502 mg/l. Magnesium concentration ranged between 0.354 mg/l and 42.574 mg/l, river water from Elem Sangama had the lowest concentration and river water from Soku Jetty having the highest, with a value of 53.502 mg/l.

Sodium concentration in the water from the different locations showed that the values ranged between 1.247 mg/l and 63.337 mg/l. River water from Elem Sangama had the lowest concentration with a sodium value of 1.247 mg/l and well water from Soku town had the highest concentration of sodium with a value of 63.337 mg/l. Potassium, PAH and THC concentration in the waters from the different water sources and location revealed that Potassium concentration in the different locations ranged between 0.508 mg/l and 102.745 mg/l with river water from Elem Sangama and river water from Soku Jetty having the highest concentration of Potassium, hence it reveals that potassium concentration varies from one location to another. THC concentration as revealed ranged between <0.001 mg/l and 0.379 mg/l with well water from Soku well having the least concentration having a value of <0.001 mg/l and river water from Elem Sangama having the highest with a value of 0.379 mg/l. THC concentration as revealed ranged between <0.001 mg/l and 117.3 mg/l. Well water from Soku well has the least concentration with a value of <0.001 mg/l and river water from Elem Sangama have the highest with a value of 117.3 mg/l.

Phosphate, Sulphate and Nitrate concentration in the waters from the different water sources and location revealed that Phosphate concentration ranged between 0.31 mg/l and 1.73 mg/l, with river water from Soku Gas Plant having the least amount of concentration while river water from Elem Sangama had the highest concentration level of phosphate in the water. Sulphate as revealed had value ranged between 5 mg/l and 1018 mg/l. Here, the concentration of Sulphate was least in the river water from Pangapiki. Lastly, Nitrate concentration in the water from the different location ranged between <0.1 mg/l and 1.2 mg/l, with well water from Soku accounting for the least with a value of <0.1 mg/l and river water from Elem Sangama had the highest concentration level of nitrate concentration.

Concluding this section, BOD, DO, alkalinity, and hardness of water from the different sources and location were analysed and this revealed that biological oxygen Demand (BOD) concentration ranged between 0.015 mg/l and 0.888 mg/l. The least concentration was observed in the well water from Soku accounting for 0.015 mg/l concentration and the highest in the river water from Soku Jetty. Dissolved oxygen concentration ranged between 4.49 mg/l and 5.31 mg/l with well water from Soku accounting for the least with a value of 4.49 mg/l and river water from Soku Gas Plant accounting for the highest in concentration of DO with a value of 5.31 mg/l. Alkalinity of the water from the different locations ranged between 0 and 46 with well water from Soku accounting for the least with a value of 0 and river water from Soku Jetty accounting for the highest with a concentration value of 46. Conclusively, hardness of water from the different locations ranged between 8 and 3300 with river water from Pangapiki having the least value in terms of hardness while river water from Soku Jetty had the highest concentration in terms of water hardness.

Table 1 also compares the water quality parameters of the different water sources and the WHO standard. Results show that Nickel, chromium, cadmium were be below detectable limits. For calcium it is revealed the volume was within acceptable limits in Pangapiki and Elem Sangama while the other three has volumes of calcium that are above the WHO acceptable limits. Magnesium as revealed showed that all the water sources had magnesium value above the WHO acceptable limits, while sodium content in water from the different sample points and sources showed that river water from Soku gas plant and river water from Soku jetty were higher that the WHO acceptable limits. From all the water sources, it was observed that the volume of potassium was higher than the WHO acceptable limits, hence renders the water impure. PAH volume in water from the different water sources revealed that only well water from Soku met the WHO standard for water quality, while the others were above the acceptable limits.

Sulphate content in water as revealed showed that only the river water from Soku jetty was above the WHO standard, hence the others were within the acceptable limits for water quality. Nitrate, BOD, DO and Alkalinity as revealed showed that from the different water sources the WHO standard is above the value of the parameters. Hence their values fell within the acceptable limits. Hardness in water as revealed showed that only the river water from Soku jetty was above the WHO standard, hence the others were within the acceptable limits for water quality.

Turbidity as revealed showed all the water sampled were above the WHO standard. TDS as revealed showed that only well water from Soku town was above the WHO acceptable limits while the others were within the acceptable limits for water quality while, Water PH for all the water sources were within the WHO standards for water quality.

These results reveal the following effects on the quality of the water in the study area. The first remarkable influence is sea water incursion. Being an intertidal area, southerly areas including Soku Gas Plant, Soku Jetty and Soku Well water have a high concentration of salts including sulphates and chlorides of calcium, sodium, potassium, and magnesium characteristic of major ion composition of seawater [36] [37]. This is also manifested in very high levels of hardness. This is in contrast with Pangapingi and Elem-Sangama which are affected by and receive fresh water from the Sombreiro and Orashi river systems. As a matter of fact, the people of Soku go to Pangapingi to fetch fresh water for their domestic needs.

The second influence on Soku area water quality id oil production. This is evidenced in the very relative high concentrations of total and polycyclic aromatic hydrocarbons in the Elem-Sangama areas, Soku Gas Plant and Pangapingi. While the Gas Plant area and Elem-Sangama hosts the Nigerian government and Shell Petroleum joint venture facilities, the Elem-Sangama areas hosts artisanal oil refining facilities and provides river routes for transportation of crudely refined products. The Pangapingi also provides a gateway for transportation of stolen crude and refined products in badly constructed ferry boats which normally has plenty leakages and contribute to oil pollution of the delicate river ecosystem.

Thirdly, the presence of saltwater intrusion into the freshwater system of the Sombreiro, San Barthlomeo and Orashi systems enhances the biochemical removal of heavy metals from the water column due to the biochemical process of chelation, complexation, and adsorption. Sea water is known to remove heavy metals by complexation and adsorptive reactions [38]. A recent study by Mrozinska and Bakowska [39] in the Brackish Coastal Lake Łebsko on the Southern Baltic Coast revealed that the total concentration of the analysed heavy metals (Cr, Pb, Ni, Cu, and Al) in water was comparable in the central and western parts with no sea water influence but lower in the eastern side that is subject to the impact of seawater incursion. Therefore, we deduce that the low concentration of heavy metals in the Soku area may be due to saltwater influence.

4.2. Heavy Metals & PAH in Biota (Periwinkle) in the Soku Oil Fields

Table 2 revealed chemical analysis of biota (periwinkle). The amount of Nickel in the biota ranged between 2.06 mg/kg and 4.91 mg/kg, but more was found in periwinkle in the Pangapiki river section of Soku.

Chromium value as indicated was the same in the river sections with a concentration value of <0.001 mg/kg. Cadmium concentration in the biota ranged between 0.67 mg/kg and 0.81 mg/kg but the highest was observed at Elem Sangama. Lead in biota also ranged between 4.52 mg/kg and 5.05 mg/kg with the

Table 2. Heavy metals in Biota (Periwinkle) in Soku oil fields.

PARAMETER(S) (mg/kg)	Ni	Cr	Cd	Pb	Zn	PAH (mg/kg)
WHO (1989)/FEPA (2003)	0.5 - 0.6	0.15 - 1.0	2	0.5	40	
FAO (1992) Limit in fish				0.5 - 0.6		
EC (2006) limit in fish			0.05 - 0.10	0.30		
EC (2006) limit in bivalue molluses			1.0	1.5		
EC (2006) limit in crustacean excluding brown meat of crab and head and thorax meat of lobsters and similar large crustacean			0.50	0.50		
USFDA			2			
USEPA (1980) Ambient criteria to protect human health (Total PAH):						
Cancer risk level = 10^{-5}						0.028
Cancer risk level = 10^{-6}						0.0028
Cancer risk level = 10^{-7}						0.00028
BIOTA	Ni	Cr	Cd	Pb	Zn	PAH
Elem-Sangana	3.06	<0.001	0.81	5.05	28.86	0.001
Soku Jetty	2.06	<0.001	0.67	5.05	12.74	0.005
Pangapingi	4.91	<0.001	0.68	4.52	13.07	0.002

Adapted from Ezekwe, Oshionya and Demua, [35].

highest concentration of lead observed in the biota sample collected at Elem Sangama. Zinc concentration 12.74 mg/kg and 28.86 mg/kg with the highest concentration of lead observed in the biota sample collected at Elem Sangama. Lastly, PAH content in the biota ranged between 0.001 and 0.005 with the highest concentration observed in the biota sample collected from the Soku jetty section.

Analyses of the results further showed that the concentrations of chromium and zinc in the fish fell is below permissible limits [40] [41] [42] (**Table 2**) and thus do not necessarily pose any human health risk. However, cadmium recorded in the fish were slightly above permissible limit of the European Community. Nickel and lead were above permissible limits in the fish samples in all standards [41] [42] [43] [44]. These results are like those found in Catfish from the Illushi River in the western part of the Niger Delta in Edo State [45]. PAHs from shellfish in the Soku area waters also occurred at the cancer risk levels of 10^{-6} which indicates potential human carcinogenic risks associated with an increased probability of developing cancer during a person's lifetime of 1 in 1,000,000 persons [46].

5. Conclusions

This study has revealed a high level of non-conformities of surface and groundwater sampled for this study with international drinking water standards. Also, the concentration of heavy metals (N, Cd and Pb) in the shellfish (*Tympanotonus fuscatus*) a common source of daily protein in the study area were much higher than the World Health Organization (WHO) and Food and Agriculture Organization of the United Nations (FAO) maximum permissible levels of heavy metals in brackish water fishes [43] [44] [46] [47] [48]. The effects of long-term exposure to acidic and heavily mineralized waters coupled with long term ingestion of fish with very heavy metal and polycyclic aromatic hydrocarbon content need serious biomedical investigation.

High concentrations of sulphates, magnesium, and calcium salts in water apart from causing high expenditures in laundries can also bring about Laxative effects arising from the excess intake of magnesium [1]-[12] [37] [49] and dehydration and catharsis in adults especially male [50]. Sodium on the other hand was found to be higher than the WHO standard in two locations of the study which are the Soku Gas Plant and the Soku Jetty, the excess amount of sodium in water reveals that the water is polluted and hence unfit for human consumption. According to WHO [51] sodium salts are not acutely toxic because of the efficiency with which mature kidneys excrete sodium. However, acute effects and death have been reported following accidental overdoses of sodium and potassium chloride, which have the combined effects of chest tightness, nausea and vomiting, diarrhoea, hyperkalaemia, shortness of breath and heart failure [52].

As reported earlier in Ezekwe, Oshionya and Demua [35], Lead accumulates in bones and teeth, where it has a biological half-life of 20 years. Lead has adverse behavioural, physiological, and biochemical effects on humans. Foetuses and children under the age of six are most vulnerable. Lead can cross the placenta, resulting in miscarriages, stillbirths, and birth defects such as neurological damage. Neurological impacts of lead include hyperactivity, poor attention span, and low IQ, especially in children. Lead also affects enzymes activities by inhibiting haemoglobin synthesis thereby causing anaemia and concomitant learning impairment especially in children. Exposures to chromium have been associated with serious health problems including mouth ulcers, nosebleeds, kidney disease, low white blood cell counts—hence depressed immune defence systems, miscarriages, and a variety of cancers and birth defects affecting the spinal development of children [53].

Also, exposure to high levels of nickel compounds may also result in cancer especially when other chemicals that can produce cancer are present. Nickel have been reported to produce lung disease in dogs and rats and are known to affect the stomach, blood, liver, kidneys, and immune system in rats and mice, as well as their reproduction and development [54] [55] [56] [57]. It is therefore expedient, for the governments in Nigeria to review the public health situation in the Soku area with a view to understanding current trends, sources of perturbations and preferable solutions to the potential public health challenges raised in this study.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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