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RESEARCH ARTICLE

An Insight Into the Importance of Application of Geophysical Methods In Agriculture For National Economic Development

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Abstract
One of the keys to national development in developing countries like Nigeria is the diversification of economy. Nigeria's economy depends majorly on crude oil. The oil sector continue to face challenges like price drop in international market, corruption, reduced quantity of production as forecasted (although new oils are been drilled). These among others makes it necessary for the country to diversify its economy. Agriculture is one of the areas Nigeria have started investing into. New methods are necessary for fast improvement in the sector among which is geophysics. The need for Agricultural Geophysics to be considered for national economic development is discussed. Geophysics as a branch of science that deal with physical processes and phenomena occurring in the earth and its vicinity is applicable to many fields that contribute to the development of the economy of any nation. Such fields include oil, Agriculture, natural resources among others. Geophysical methods applicable in Agriculture like resistivity, electromagnetic induction, and Ground penetrating radar are discussed with their applications in agriculture. The various geophysical methods that are useful in agriculture are reviewed and necessity of their application is also emphasized.

Keywords: Geophysics; Agriculture; Economy; Development

Introduction

Many factors are responsible for decrease in production of Agricultural products. These include water erosion, poor soil biology, decreased yield reduced plant growth, reduced sustainability and soil degradation among others (Newell and Ken, 2014). An effort to address the aforementioned problems will have positive influence on all matter and living organisms on earth including soils and plants which are the main interest for agriculturists. Soil properties are of high importance in many human activities, such as agriculture, forestry, landscaping, environmental protection, recreation, and civil engineering.

Soil survey for different applications requires quick and non-disturbing estimations of numerous soil properties, such as salinity, texture, stone content, groundwater depth, and horizon sequences in soil profiles. A perfect assessment of properties of soil is convoluted due to their variability. Measurements of soil with a high sampling density is expensive and consumes time because conventional methods of analysing soil for precision agricultural mapping requires mostly disturbing the soil through removal of soil samples and subjecting them to laboratory analysis. This implies that, through the aforementioned practice, the sampling costs would exceed the potential benefits. Geophysical methods, conversely, tolerate quick measurement of soil properties, such as electrical conductivity, resistivity, and potential, from surface of soil straight to any depth without disturbing the soil. Precision Agriculture is the modern practice that allows farmer to make measurements so that he will know the exact deficiency of his land and plants.

Literature review

Little practice of Geophysical methods is done in Nigeria for Agricultural practice specially to observe soil fertility. Some of the available researches include Oladunjoye that used Ground Penetrating Radar (GPR) to characterize valley bottom soil at ilora (Oladunjoye et al., 2021), Yusuf that employed geophysical and geochemical aproaches to investigate ground water quality and soil cultivation viability in mokwa (Yusuf et al., 2018) among others. Leti described Agro geophysical methods to identify soil pipes (Leti et al., 2021). We still need to know more about the field and its impact in agriculture. This paper simply focused on describing the commonest geophysical methods applied in Agriculture. The choice of method depends on one's interest. Perhaps, some researchers may decide to use multiple methods, interestingly, using multiple methods will add more certainty and efficiency to the result (Alhassan et al., 2021).

Electrical Geophysical Method

Electrical resistivity is a geophysical method that uses the electrical properties of soil to infer about the temperature, water content and salt content of the soil. Such properties include resistivity and conductivity. There is a relationship between electrical conductivity measured with four-electrode probe and conductivity of soil solution (Nadler, 1982). These are given in equations 1 & 2.

By ohm's law, $\mathrm{ER} = \mathrm{K}\frac{\Delta \mathrm{U}}{1}$ (1)

U=elecrical potential

$\mathrm{EC} = \frac{1}{\mathrm{ER}}$ (2)

The method of four-electrode probe was also used for the calculation of further soil properties such as soil water content, soil structure, bulk density, porosity, and texture, stone content, etc. (Larisa et al., 2007; Oladimeji et al., 2014; Yusuf et al., 2018; Kayode et al., 2022).

In conditions where one or two soil properties have influence on measured electrical properties, electrical conductivity (EC) method can be used to estimate such properties. The resistivity of rocks is much higher (about 104 -1012 ohm m) than that of soil horizons with any texture. Therefore, high ER will designate the presence of stones in soil profiles irrespective of soil type and geographical region. Vertical electrical sounding (VES) method can be used in studying several processes for instance melting, freezing, wetting-drying and solution transport in soils (Yusuf et al., 2018). The mobility of electrical charges can increase significantly when the topsoil materials have higher water holding capacity, such as clay and silt, and especially water logging conditions which can also cause significant decrease in ER. This implies that complex soil properties influencing plant growth, plant health and yield can be identified and mapped with electrical geophysical methods. (Yusuf et al., 2018). The electrical geophysical methods when Compared with conventional methods of soil analysis allows the evaluation of groundwater table, salt and stone content, depth and thickness of soil horizons, polluted/disturbed layers in soil profiles, and content with an estimation error (Kayode et al., 2022).

Soil properties influencing Density of mobile electrical charges in summary are:

- Chemical properties (Salt content, humus content etc) stones and oil are intrusions of high resistivity.
- Physical properties (bulk density, water content, temperature, texture, water movement based on soil compaction or mixing)

Applications of ER/EC in Agric

Changes in one soil property can be monitored (drying-wetting, freezing-melting, solution transport)

Mapping of the soil properties which highly influence electrical parameters (salinity, stone content, hardpan, oil pollution, ground water table)

Evaluate complex effect of many soil properties on measured electrical parameter, develop management zones or study soil cover structure. (Richard and Dualem, 2014)

Electrical resistivity is Fast, Portable, Versatile, Affordable and In depth.

Ground Penetrating Radar

Ground Penetrating Radar (GPR) uses seimic method and serves as a quality control tool to determine the presence, depth and lateral extent of diagnostic subsurface horizons, Improve interpretations by providing estimates of different soil types composing a soil map unit and Characterize spatial and temporal variations in soil properties (Doolite, 2014).

GPR generates a sequence of trigger pulses which are sent via a control cable through the antenna. Each cable transmits into a bipolar transmit pulse. The transmitted pulses are the directed into the soil by the antenna which is fold below the surface. The energy is radiated in a pattern roughly 90° front to back and 60° side to side. It passes different materials with different properties. The dielectric constant changes when change in Electrical conductivity of soil is experienced. Some of the pulse bounces back to the antenna. The received signals are then sent back to the receiver where they are processed. The data are displayed on a coloured map and can be stored on internal hard drive for later play back.

GPR results depend mainly on two electrical properties of soil namely electrical conductivity and relative dielectric permittivity or dielectric constant. Electrical

conductivity (EC) is the ability of a material to conduct an electric current. It controls the signal penetration. EC increases with increasing water, clay and size of soil contents (Doolite, 2014). On the other hand, Dielectric constant is the measure of the capacity of a material to store charge when an electric field is applied to it. It controls the strength of the signal reflection. Different subsurface materials have different dielectric constant.
Three general soil/landscape factors affect water and crop growth :

- Available water storage (soil texture, organic matter)
- Rate of water infiltration and recharge (Soil surface porosity, layers of impermeability, slope)
- Water redistribution within the field (relative elevation, curvature, slope) Newell kitchen. (Barry et al., 2010)

Electro Magnetic Method

Electro Magnetic (E-M) wave creates sinusoidal E-M field that induces E-M current. E-M reaches 1km depth and exhibits both time domain and frequency domain techniques. (Richard and Dualem, 2014). Electromagnetic induction (EMI) possess the potential in assisting agricultural applications (Binley et al.,2015). The method has the ability to provide a suitable alternative by measuring apparent electrical conductivity of soil which can be used to estimate soil properties such as water content, textural properties, mineralization, porosity, and residual pore water content (Brogi et al., 2021).

Remote Sensinsing Method

Remote sensing acquires information about an object without making physical contact with that object. Remote sensing gives the soil moisture data and helps in determining the quantity of moisture in the soil and hence the type of crop that can be grown in the soil. Remote sensing technology plays an important role in the analysis of crop health which determines the overall crop yield. When all of this data is combined it gives almost accurate estimates of the crop yield. Because of the predictive nature of the remote sensing technology, farmers can now use remote sensing to observe a variety of factors including the weather patterns and the soil types to predict the planting and harvesting seasons of each crop. Remote sensing has also played an important role in crop identification especially in cases where the crop under observation is mysterious or shows some mysterious characteristics (Grindgis, 2018).

Conclusion

Characterizing soil spatial variability at immediate (field) scale is a major challenge in soil investigation. This paper brought on board the advantage of geophysical methods over other methods in precision Agriculture. Electrical Method, Ground Penetrating Radar and Electro Magnetic methods are discussed as the most commonly used Geophysical methods in Agriculture. This allows the observation and recommendation of using the methods more than it has been applied in the farm especially in Nigeria.

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RESEARCH ARTICLE

Characterisation of Physico-Chemical Properties and heavy metal concentrations of Surface Water receiving effluent from champion breweries PlC in Uyo, Akwa Ibom State, Nigeria

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Abstract
Physico-chemical properties and heavy metal concentrations of surface water receiving effluent from Champion Breweries Plc, Uyo, Akwa Ibom State were analysed to evaluate the effect of the effluent on the physico-chemical properties and heavy metal concentrations of the surface water. The water samples were collected using polyethylene bottles that were initially rinsed with 10% hydrochloric acid (HCl) then with the sample water. Two samples were collected at each sampling point. One was for physicochemical properties determinations while the other sample was for heavy metal analysis. HNO_3 was added in the samples for heavy metal analysis for preservation of the metals. The collected samples were stored in an ice-packed cooler kit and taken to the laboratory for analysis. The results showed that the temperature of the water was within the permissible limit. Mean pH was lower than the permissible range for drinking water especially during the dry season. Turbidity was above the permissible limit in both dry/wet seasons. Dissolved oxygen was below the permissible limit. Mean biochemical oxygen demand was above the permissible limit. The result of the ratio of chemical oxygen demand to biochemical oxygen demand showed that the compounds in the water were relatively biodegradable. Total suspended solid was above the permissible limit. Mean total dissolved solid was below the permissible limit. Mean electrical conductivity was also below the permissible limit. The concentration of NH_4 was at toxic level. The concentrations of nitrate, nitrite, phosphate and sulphate were below the permissible limits indicating non-toxicity and lack of these nutrient elements in the water. The contents of Fe, Pb, Zn, Cd, Cr, Co and Mn were above permissible levels. The effluent from Champion breweries is considered to be one of the major sources of pollutants of surface water in this area, which efficient treatment of effluent before disposal is recommended.

Keywords: Champion Breweries; surface water; effluent; pollution

Introduction

Contamination of surface water quality such as streams, springs and rivers has been evident over the years in areas where industrial, agricultural and other intensive human activities are carried out (Abua and Okpiliya, 2005). As observed by Asthana and Asthana (2001), thousands of industrial plants discharge effluents into sewage plants that are unequipped to process many of the industrial pollutants, which are then discharged into the natural environment. Accordingly, industrial establishments, end up in discharging various heavy or trace metals, organic and inorganic compounds and acids into surface waters thus altering their pH, other parameters as well as upsetting the biological system (Sule, 2001). Equally, research conducted on surface and groundwater from the coastal areas of Oron, Mbo, Ibeno and Ikot Abasi both in Akwa Ibom State, indicated anomalous occurrence of coliform bacteria (*Escherichia coli*) heavy metals in surface and groundwater sources and the values were far in excess of the World Health Organisation (WHO) stipulated standards (Amah *et al.*, 2007).
In line with the research topic, Ekhaise and Anyasi (2005), assessed the extent of pollution on surface water due to effluent discharged from the two brewery industries in Benin City. The population of total coliform bacteria in all the water samples obtained from Ikpoba river were generally high likewise some physico-chemical properties whose values were higher than the WHO tolerant level while Adediran et al. (2004) reported of pollution of streams, well-water and soil with cadmium, chromium, copper and nickel by a brewery industry

located in Ibadan, Oyo State, Nigeria. It is quite glaring that effluent discharged into surface water, underground water and soil from brewery plants is capable of causing pollution. Brewery effluent is comprised of wastewater from washing bottles, water treatment plant, carbon dioxide generating plant, bottling and production hall and general wastewater from domestic washing. Losses in beer production process and the clean-in-place (CIP) located in the brewery house, cellar house and bottling house also form part of the effluent from brewery plants (Techobanoglous *et al*., 1991).

Untreated brewery effluent contains basically, suspended solids in the ranges of 10-60 mg/l, biochemical oxygen demand (BOD) in the range of 1000 – 1500 mg/l, chemical oxygen demand (COD) in the range of 1800 – 3000 mg/l and nitrogen in the range of 30-100mg/l (Alao *et al*., 2010). The effluent also contains organic materials such as spent grains, waste yeast, spent hops and grit. The average range of effluent pH is about 7 for combined effluent but can fluctuate from 3-12 depending on the use of acid or alkaline cleaning agent (World Bank, 1997). Pollutants arising from brewery effluent have the potentials to affect aquatic ecosystem. The productivity and growth of aquatic organisms depend on the physical, chemical and microbiological characteristics of the water body (Olagbemide, 2017). Maximum productivity of aquatic lives can only be obtained in water with optimal level of physical, chemical and microbiological parameters (Olagbemide, 2017). It is therefore very essential and important to test water before it is used for drinking, other domestic agricultural or industrial purposes.

Therefore, this study was carried out to evaluate the physicochemical parameters and heavy metal concentrations of surface water receiving effluent from Champion Breweries, Uyo and to assess the quality of this water to aid in decision making and policy formulation.

Materials and methods

Study Area

The study was carried out at Aka-Offot Industrial Layout in Uyo Metropolis where Champion Breweries Plc is located. It lies between longitudes 7^0 55" E - 7^0 56" E and latitudes 5^0 00" N -5^0 01" N (Figure 1). The area has a humid tropical climate with an annual rainfall ranging from 2500-3000mm and annual mean temperature of about 27^0C and the relative humidity ranging from 75% to 79%. The topography of the area is low-lying with coastal plain sand as parent material (Petters *et al*., 1989). It has a level to gently undulating topography with a gradient of less than five per cent (Tahal, 1979; Okoji, 1988). The surface geology is unconsolidated Sand Formations ranging from Coarse to Fine Sands.

Water Sampling Method

The water samples were collected using polyethylene bottles that were initially rinsed with 10% hydrochloric acid (HCl) then with the sample water. Two samples were collected at each sampling point. One sample was used for physicochemical properties determinations. The other sample was for heavy metal analysis. Nitric acid (HNO_3) was added in the samples for heavy metal analysis for the preservation of the metals. Electrical conductivity, pH, temperature of the samples were determined in the field using standard equipment (Century Water Analysis Kit). The collected samples were stored in an ice-packed cooler kit and taken to the laboratory for analysis. The samples were collected in both wet and dry seasons. A total of 18 samples were collected at 9 locations in each season for laboratory analysis.

Laboratory analysis

In the laboratory, analysis was done by volumetric analysis using standard methods given in APHA, (1992). Atomic absorption spectrophotometer UNICAM model 93 was used in carrying out heavy metal analysis using Whitehead (1979) method.

Results and Discussion

Physico-chemical properties

Physical parameters

The physical parameters of the surface water of the study area for both dry and wet seasons are presented in Table 1

Temperature

The temperature of the surface water in the study area varied from 30.0 to 37.0 ^{0}C with a mean of 35.1 ^{0}C in the dry season and 32.0 to 37.1^{0}C with a mean of 33.9 ^{0}C in the wet season. Mean temperature was higher in the dry season than wet season. There was no significant difference ($p < 0.05$) in temperature between the permissible limit and that of the surface water during both wet and dry seasons in the study area... Temperature affects the amount of dissolved oxygen in water, rate of photosynthesis in plant, the metabolic rate of aquatic animals and so on. The moderate temperature of the surface water in the study area could be attributed to the temperature of the environment (Gupta *et al.,* 2003).

Turbidity

The turbidity of the surface water within the study area varied from 304.0 to 910.0 NTU with a mean of 668.9 NTU in the dry season and 250.0 to 1702.0 NTU with a mean of 756.6 NTU in the wet season. Mean turbidity was higher in the wet season than dry season. Mean turbidity of the surface water of the study area was significantly higher ($p < 0.05$) than the permissible limit of 5.0 for drinking water (Nigerian Standard for Drinking Water Quality, 2015) during both wet and dry seasons. Turbidity is a measure of the ability of light to pass through water. It measures water's murkiness which gives an estimate of suspended solids in the water. High turbidity prevents sufficient light from entering the water for photosynthesis by submerged plants (Gupta *et al.*, 2003). The high turbidity in the study area could be attributed to the effluent discharged into the surface water by Champion Breweries Plc.

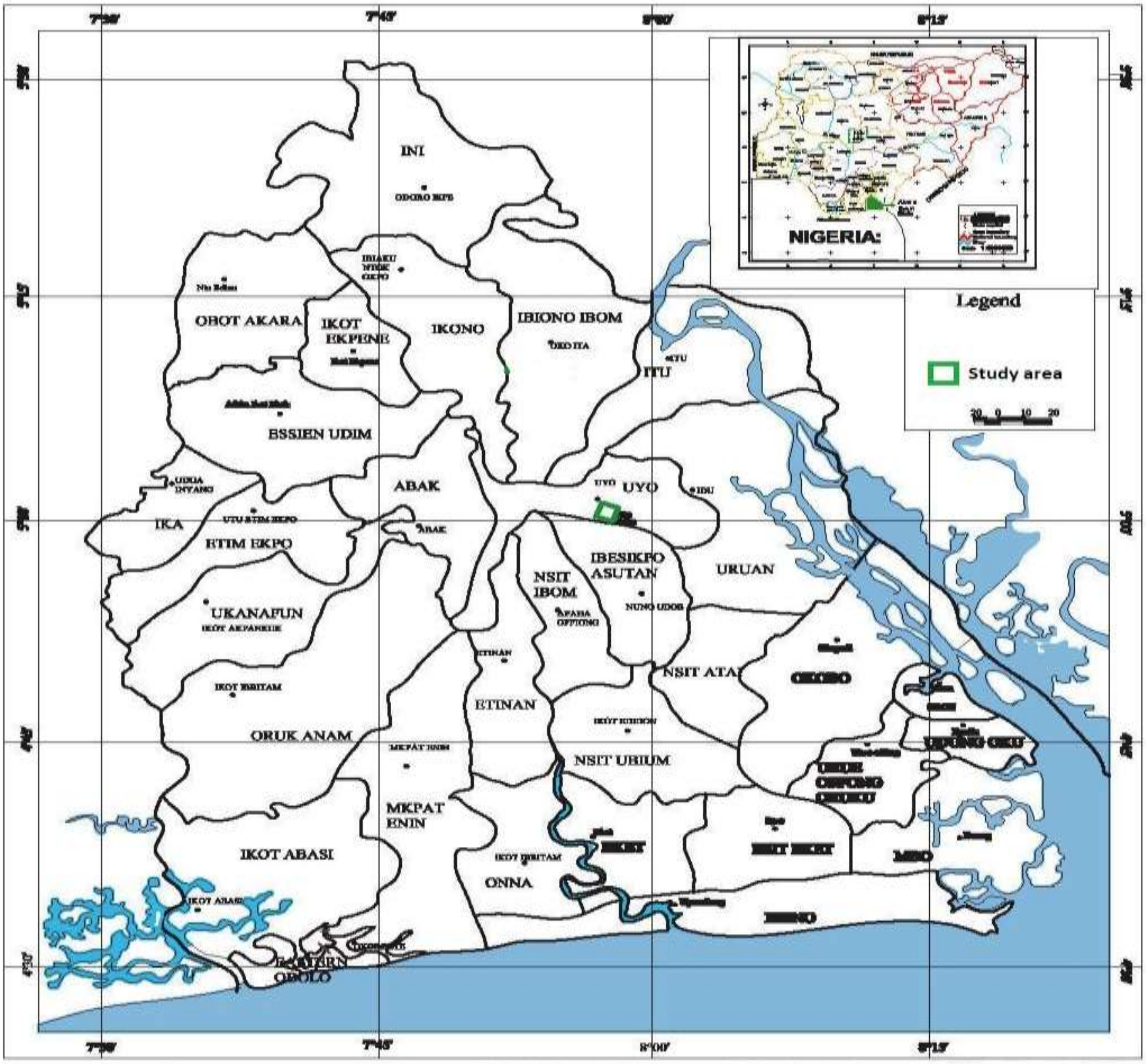

Figure 1: Map of Akwa Ibom State showing Champion Breweries Plc, Uyo (study area).
Source: Agate Geographic Services (2008).

Chemical parameters

The chemical parameters of the surface water of the study area for both dry and wet seasons are presented in Table 2.

pH

The pH of the surface water in the study area varied from 5.23 to 5.52 with a mean of 5.5 in the dry season and 5.49 to 6.79 with a mean of 6.5 in the wet season. Mean pH was higher during the wet season than dry season. This means that the surface water was more acidic in the dry season than wet season. Mean pH of the surface water of the study area was significantly lower ($p < 0.05$) than the permissible range of 6.5-8.5 for drinking water (Nigerian Standard for Drinking Water Quality, 2015) during the dry season but no significant difference from the permissible range during the wet season. Water pH is the measure of hydrogen ion concentration in water. Better fish production is possible in water with pH range of 6.5 to 9.0 (Olasoji *et al*., 2019). The lower pH of the surface water during the dry season than the permissible limit may be attributed to acid cleansing agent in the effluent discharged from Champion Breweries Plc (Olasoji *et al*., 2019).

Dissolved oxygen (DO)

The dissolved oxygen of the surface water in the study area varied from 1.20 to 2.20 mg/l with a mean of 1.40 mg/l during dry season and 1.10 to 2.20 mg/l with a mean of 1.52 mg/l during wet season. Mean dissolved oxygen was higher during the wet season than dry season. Dissolved oxygen is a measure of the amount of oxygen in water. Mean dissolved oxygen of the surface water of the study area was significantly lower ($p < 0.05$) than the permissible limit of 6.0 mg/l for drinking water (United States Environmental Protection Agency, 2022) during both wet and dry seasons. The values indicate that the amount of oxygen in the water was not within the permissible limit. The low amount of oxygen in the surface water in the study area could be attributed to organic pollutants, inorganic reductants and other oxidizable substances in the effluent from the Champion Breweries Plc that consumes large amount of dissolved oxygen in the water (Olasoji *et al*., 2019).

Biochemical Oxygen Demand (BOD)

The biochemical oxygen demand of the surface water in the study area varied from 0.00 to 10.8 mg/l with a mean of 6.1 mg/l during dry season and 3.14 to 11.19 mg/l with a mean of 6.6 mg/l during wet season. Mean biochemical oxygen demand was higher during the wet season than dry season. Biochemical oxygen demand measures the amount of oxygen that bacteria take from water when they oxidized organic matter. It determines the amount of oxygen required for biological oxidation of organic matter with the help of microbial activities. High BOD above permissible limit indicated the polluted status of the water. The mean biochemical oxygen demand of the surface water in the study area was significantly higher ($p < 0.05$) than the permissible limit of 2.0 mg/l for drinking water (United States Environmental Protection Agency, 2022) during both wet and dry seasons. The high biochemical oxygen demand of the surface water of the study area could be attributed to the organic pollutants from the effluent discharged from the Champion Breweries Plc (Olasoji *et al*., 2019).

Chemical Oxygen Demand (COD)

The chemical oxygen demand of the surface water in the study area varied from 0.50 to 1.60 mg/l with a mean of 1.24 mg/l during dry season and 0.40 to 0.80 mg/l with a mean of 0.61 mg/l during wet season. Mean chemical oxygen demand was higher during the dry season than wet season. Chemical oxygen demand is a measure of the oxygen equivalent of the organic matter content of water sample that is susceptible to oxidation by a strong oxidant. It is a measure of combined effect of many industrial pollutants. High COD above permissible limit indicates the polluted status of the water. The mean chemical oxygen demand of the surface water of the study area was significantly lower ($p < 0.05$) than the permissible limit of 150 mg/l for drinking water (United States Environmental Protection Agency, 2022) during both wet and dry seasons. The low chemical oxygen demand of the surface water in the study area could be attributed to the low inorganic pollutant from the effluent discharged from Champion Breweries Plc (Olagbemide, 2017).

Table 1: The physical parameters of the surface water of the study area during dry and wet seasons

Parameter	Minimum	Maximum	Sample Mean	Permissible Limit	T-test Value	Significance ($p < 0.05$)
				Dry season		
Temperature (^{0}C)	30.0	37.0	35.1	Ambient (35.0)	0.078	0.94 NS
Turbidity (NTU's)	304.0	910.0	668.9	5.0	9.614	0.001S
Total suspended solid (TSS) (mg/l)	786.0	1960.0	1384.9	25	12.905	0.001S
Electrical conductivity (μS/cm)	218.0	551.0	470.6	1000	-15.913	0.001S
				Wet season		

Temperature (^{0}C)	32.0	37.1	33.9	Ambient (35.0)	-2.0104	0.07 NS
Turbidity (NTU's)	250.0	1702.0	756.6	5.0	5.237	0.001S
Total suspended solid (TSS) (mg/l)	11.58	2015.0	1137.7	25	6.450	0.001S
Electrical conductivity (µS/cm)	340.0	833.0	450.0	1000	-10.636	0.001S

Table 2: Chemical parameters of the surface water of the study area during dry and wet seasons

Parameter	Minimum	Maximum	Sample Mean	Permissible Limit	T-test Value	Significance ($p < 0.05$)
				Dry season		
pH	5.23	5.52	5.5	6.5	-13.964	0.001S
Dissolved oxygen (DO)(mg/l)	1.20	2.20	1.40	6.0	-44.773	0.001S
Biochemical oxygen demand (BOD)(mg/l)	0.00	10.8	6.09	2.0	3.409	0.001S
Chemical oxygen demand (COD)(mg/l)	0.50	1.60	1.24	150	-1314.38	0.001S
Ratio of COD to BOD		0.15	0.20			
Total dissolved solid (TDS) (mg/l)	151.0	276.0	242.2	500	-20.212	0.001S
Ammonium (NH_4) (mg/l)	0.00	12.61	4.71	0.05	3.615	0.001S
Nitrate (NO_3) (mg/l)	0.72	1.34	1.098	50.0	-771.28	0.001S
Nitrite (NO_2) (mg/l)	0.00	0.02	0.0096	0.20	-156.79	0.001S
Phosphate (PO_4) (mg/l)	0.03	0.51	0.42	0.5	-1.394	0.001S
Sulphate (SO_4) (mg/l)	8.08	27.9	23.4	100	-38.528	0.001S
Iron (Fe) (mg/l)	0.11	4.97	2.75	0.3	5.252	0.001S
Lead (Pb) (mg/l)	0.03	4.62	3.47	0.01	7.523	0.001S
Zinc (Zn) (mg/l)	0.07	5.67	3.92	3.0	1.604	0.147NS
Cadmium (Cd) (mg/l)	0.01	0.31	0.15	0.003	4.350	0.002S
Chromium (Cr) (mg/l)	0.01	6.42	4.80	0.05	7.389	0.001S
Cobalt (Co) (mg/l)	0.04	7.69	4.39	0.02	6.344	0.001S
Manganese (Mn) (mg/l)	0.03	5.72	3.62	0.2	5.826	0.001S

Wet season

Parameter	Minimum	Maximum	Sample Mean	Permissible Limit	T-test Value	Significance ($p < 0.05$)
pH	5.49	6.79	6.5	6.5	0.290	0.779NS
Dissolved oxygen (DO)(mg/l)	1.10	2.20	1.52	6.0	-39.709	0.001s
Biochemical oxygen demand (BOD)(mg/l)	3.14	11.19	6.60	2.0	4.60	0.002S
Chemical oxygen demand (COD)(mg/l)	0.40	0.80	0.61	150	-2649.6	0.002S
Ratio of COD to BOD	0.13	0.07	0.09			
Total dissolved solid (TDS) (mg/l)	125.0	357.0	203.9	500	-6.404	0.001S
Ammonium (NH_4) (mg/l)	3,19	13.05	6.77	0.05	4.987	0.001S
Nitrate (NO_3) (mg/l)	0.42	0.93	0.63	50.0	-795.26	0.001S
Nitrite (NO_2) (mg/l)	0.01	0.01	0.0097	0.20	-284.25	0.001S
Phosphate (PO_4) (mg/l)	0.04	0.04	0.04	0.5	-1889.47	0.001S
Sulphate (SO_4) (mg/l)	3.21	57.0	23.56	100	-11.94	0.001S
Iron (Fe) (mg/l)	0.23	1.22	0.995	0.3	6.843	0.001S

Lead (Pb) (mg/l)	0.04	0.08	0.057	0.01	8.784	0.001S
Zinc (Zn) (mg/l)	0.16	0.31	0.20	3.0	-166.649	0.001S
Cadmium (Cd) (mg/l)	0.00	0.01	0.005	0.003	3.333	0.001S
Chromium (Cr) (mg/l)	0.00	0.04	0.008	0.05	-10.304	0.001S
Cobalt (Co) (mg/l)	0.03	0.05	0.04	0.02	8.068	0.001S
Manganese (Mn) (mg/l)	0.10	0.15	0.11	0.2	-15.322	0.001S

Source: Researchers' fieldwork (2021)

Ratio of Chemical Oxygen Demand to Biochemical Oxygen Demand (COD: BOD) (Biodegradability index)

The ratio of chemical oxygen demand to biochemical oxygen demand of the surface water in the study area was 0.20 during the dry season and 0.09 during the wet season. The ratio was higher during the dry season than the wet season. The ratio of chemical oxygen demand to biochemical oxygen demand assesses whether the compounds in water are biodegradable. It helps in monitoring the presence of toxic and non-degradable substances in water. A ratio greater than 100 means that the compounds in water are relatively non-biodegradable and a ratio of less than 10 means that the compounds are relatively degradable. The ratio of chemical oxygen demand to biochemical oxygen demand of the surface water in the study area shows that the compounds in the surface water are relatively biodegradable (Olagbemide, 2017).

Total Dissolved Solid (TDS)

The total dissolved solid of the surface water in the study area varied from 151.0 to 276.0 mg/l with a mean of 242.2 mg/l during dry season and 125.0 to 357.0 mg/l with a mean of 203.9 mg/l during wet season. Mean total dissolved solid was higher during the dry season than wet season. Total dissolved solid is a measure of the amount of dissolved salts in water. Salty water conducts electricity more readily than pure water. The mean total dissolved solid of the surface water in the study area was significantly lower ($p < 0.05$) than the permissible limit of 500 mg/l for drinking water (Nigerian Standard for Drinking Water Quality, 2015) during both wet and dry seasons. The values indicate that the amount of dissolved salts in the water was not up to the level that constitutes danger to human health and aquatic life (Olasoji *et al*., 2019). Total dissolved solid just like electrical conductivity serves as a tool for assessing the purity of water.

Ammonium (NH_4)

The ammonium (NH_4) content of the surface water in the study area varied from 0.00 to 12.61 mg/l with a mean of 4.71 mg/l during dry season and 3.19 to 13.05 mg/l with a mean of 6.77 mg/l during wet season. Mean NH_4 content was higher during the wet season than dry season. Ammonium (NH_4) is a source of nitrogen in water. High concentration is toxic to aquatic life. The mean NH_4 content of the surface water of the study area was significantly higher ($p < 0.05$) than the permissible limit of 0.05 mg/l for drinking water (United States Environmental Protection Agency, 2022) during both wet and dry seasons. The values indicate that the NH_4 content in the surface water of the study area was at toxic level. This concentration is toxic to aquatic life. This could be attributed to the effluent discharged into the surface water by Champion Breweries Plc (Olasoji *et al*., 2019).

Nitrate (NO_3)

The nitrate (NO_3) content of the surface water in the study area varied from 0.72 to 1.34 mg/l with a mean of 1.1 mg/l during dry season and 0.42 to 0.93 mg/l with a mean of 0.6 mg/l during wet season. Mean NO_3 content was higher during the dry season than wet season. Nitrate is a source of nitrogen in water. High concentration causes excessive growth of algae and water weeds. It can contribute to eutrophication in aquatic ecosystem. The mean NO_3 content of the surface water of the study area was significantly lower ($p < 0.05$) than the permissible limit of 50.0 mg/l for drinking water (Nigerian Standard for Drinking Water Quality, 2015) during both wet and dry seasons. The values indicate that the NO_3 content in the surface water of the study area was not up to the level that constitutes danger to human health and aquatic life (Olasoji *et al*., 2019)

Nitrite (NO_2)

The nitrite (NO_2) content of the surface water in the study area varied from 0.00 to 0.02 mg/l with a mean of 0.0096 mg/l during dry season and 0.01 to 0.01 mg/l with a mean of 0.0097 mg/l during wet season. Nitrite (NO_2) is a source of nitrogen in water. High concentration could be toxic to aquatic life. The mean NO_2 content of the surface water in the study area was significantly lower ($p < 0.05$) than the permissible limit of 0.02 mg/l for drinking water (Nigerian Standard for Drinking Water Quality, 2015) during both wet and dry seasons. The values indicate that the concentration of NO_2 in surface water in the study area was not up to the level that constitutes danger to human health and aquatic life (Olasoji *et al*., 2019).

Phosphate (PO_4)

The phosphate (PO_4) content of the surface water in the study area varied from 0.03 to 0.51 mg/l with a mean of 0.42 mg/l during dry season and 0.04 to 0.04 mg/l with a mean of 0.04 mg/l during wet season. Mean PO_4 content was higher during dry season than wet season Phosphate (PO_4) is a source of phosphorus in water. High concentration is associated with eutrophication in water. The mean PO_4 content of the surface water of the study area was significantly lower ($p < 0.05$) than the permissible limit of 0.5 mg/l for drinking water (Nigerian Standard for Drinking Water Quality, 2015) during both wet and dry seasons. The values indicate that the PO_4 content of surface water in the study area was not up to the level that can cause eutrophication in water (Olasoji *et al*., 2019).

Sulphate (SO_4)

The sulphate (SO_4) content of the surface water in the study area varied from 8.08 to 27.9 mg/l with a mean of 23.4 mg/l during dry season and 3.21 to 57.0 mg/l with a mean of 23.6 mg/l during wet season. Sulphate (SO_4) is a source of sulphur in water. High concentration can impair photosynthesis and increase respiration. The mean SO_4 content of the surface water in the study area was significantly lower ($p < 0.05$) than the permissible limit of 100 mg/l for drinking water (Nigerian Standard for Drinking Water Quality, 2015) during both wet and dry seasons. The values indicate that the concentration of SO_4 of in the surface water in the study area was not up to the level that constitutes danger to human health and aquatic life (Olasoji *et al*., 2019).

A. Heavy metal concentrations

Iron (Fe)

The iron (Fe) content of the surface water in the study area varied from 0.11 to 4.97 mg/l with a mean of 2.75 mg/l during dry season and 0.23 to 1.22 mg/l with a mean of 0.99 mg/l during wet season. Iron (Fe) content was higher during dry season than wet season. The mean Fe content of the surface water in the study area was significantly higher ($p < 0.05$) than the permissible limit of 0.3 mg/l for drinking water (Nigerian Standard for Drinking Water Quality, 2015) during both wet and dry seasons. The values indicate that the concentration of Fe in surface water of the study area was up to the level that constitutes danger to human health and aquatic life (Olasoji *et al*., 2019).

Lead (Pb)

The lead (Pb) content of the surface water in the study area varied from 0.03 to 4.62 mg/l with a mean of 3.47 mg/l during dry season and 0.04 to 0.08 mg/l with a mean of 0.057 mg/l during wet season. Lead (Pb) content was higher during the dry season than wet season. The mean Pb content of the surface water in the study area was significantly higher ($p < 0.05$) than the permissible limit of 0.01 mg/l for drinking water (Nigerian Standard for Drinking Water Quality, 2015) during both wet and dry seasons. The values indicate that the concentration of Pb in the surface water of the study area was up to the level that constitutes danger to human health and aquatic life (Olasoji *et al*., 2019).

Zinc (Zn)

The zinc (Zn) content of the surface water in the study area varied from 0.07 to 5.67 mg/l with a mean of 3.92 mg/l during dry season and 0.16 to 0.31 mg/l with a mean of 0.20 mg/l during wet season. The mean zinc (Zn) content was higher during the dry season than wet season. The mean Zn content of the surface water in the study area was significantly higher ($p < 0.05$) than the permissible limit of 3.0 mg/l for drinking water (Nigerian Standard for Drinking Water Quality, 2015) during dry season and below the permissible limit during the wet season. The values indicate that the concentration of Zn in the surface water of the study area was up to the level that constitutes danger to human health and aquatic life during dry season and not so during wet season (Olasoji *et al*., 2019).

Cadmium (Cd)

The cadmium (Cd) content of the surface water in the study area varied from 0.01 to 0.31 mg/l with a mean of 0.15 mg/l during dry season and 0.00 to 0.01 mg/l with a mean of 0.005 mg/l during wet season. The mean cadmium (Cd) content was higher during dry season than wet season. The mean Cd content of the surface water in the study area was significantly higher ($p < 0.05$) than the permissible limit of 0.003 mg/l for drinking water (Nigerian Standard for Drinking Water Quality, 2015) during both wet and dry seasons. The values indicate that the concentration of Cd in the surface water of the study area was up to the level that constitutes danger to human health and aquatic life (Olasoji *et al*., 2019).

Chromium (Cr)

The chromium (Cr) content of the surface water in the study area varied from 0.01 to 6.42 mg/l with a mean of 4.80 mg/l during dry season and 0.00 to 0.04 mg/l with a mean of 0.008 mg/l during wet season. The mean chromium (Cr) content was higher during dry season than wet season. The mean Cr content of the surface water in the study area was significantly higher ($p < 0.05$) than the permissible limit of 0.05 mg/l for drinking water (Nigerian Standard for Drinking Water Quality, 2015) during dry season and below the permissible limit during the wet season. The values indicate that the concentration of Cr in the surface water of the study area was up to the level that constitutes danger to human health and aquatic life during dry season but not so during wet season (Olasoji *et al*., 2019).

Cobalt (Co)

The cobalt (Co) content of the surface water in the study area varied from 0.04 to 7.69 mg/l with a mean of 4.39 mg/l during dry season and 0.03 to 0.05 mg/l with a mean of 0.04 mg/l during wet season. The mean cobalt (Co) content was higher during dry season than wet season. The mean Co content of the surface water in the study area was significantly higher ($p < 0.05$) than the permissible limit of 0.02 mg/l for drinking water (United States Environmental Protection Agency, 2022) during both wet and dry seasons. The values indicate that the concentration of Co in the surface water of the study area was up to the level that constitutes danger to human health and aquatic life (Olasoji *et al*., 2019).

Manganese (Mn)

The manganese (Mn) content of the surface water in the study area varied from 0.03 to 5.72 mg/l with a mean of 3.62 mg/l during dry season and 0.10 to 0.15 mg/l with a mean of 0.11 mg/l during wet season. The mean manganese (Mn) content was higher during dry season than wet season. The mean Mn content of the surface water in the study area was significantly higher ($p < 0.05$) than the permissible limit of 0.2 mg/l for drinking water (Nigerian Standard for Drinking Water Quality, 2015) during dry season and below the permissible limit during the wet season. The values indicate that the Mn content in the surface water of the study area was up to the level that constitutes danger to human health and aquatic life during dry season but not so during wet season (Olasoji *et al*., 2019). Chronic manganese exposure resulting from inhalation of manganese dioxide over a period of years, attacks the human nervous system (Asthana and Asthana, 2001).

Conclusion/ Recommendation

The study reveals that the temperature of the surface water was within the permissible limit. The average pH of the surface water in the study area was lower than the permissible range for drinking water especially during dry season. This implies that the water was acidic for optimal use by human and aquatic lives. Turbidity of the surface water was above the permissible limit in both wet and dry seasons, indicating low light penetration into the water. Dissolved oxygen (the amount of oxygen in water) was below the permissible limit, indicating lack of sufficient oxygen in water in both wet and dry seasons. Mean biochemical oxygen demand of the surface water was above the permissible limit, indicating high level of organic pollutants in the water. The ratio of chemical oxygen demand to biochemical oxygen demand of the surface water in the study area shows that the compounds in the surface water were relatively biodegradable. Total suspended solid in surface water was above the permissible limit, indicating low water clarity. Mean total dissolved solid of the surface water was below the permissible limit, indicating low amount of dissolved salts in water. Mean electrical conductivity of the surface water was also below the permissible limit, equally indicating low amount of dissolved salts in water during wet and dry seasons. The concentration of NH_4 in the surface water was at toxic level. The contents of nitrate, nitrite, phosphate and sulphate were below permissible limits, indicating non-toxic and lack of these nutrient elements in water. The contents of Fe, Pb, Zn, Cd, Cr Co and Mn were above permissible levels, implying that these elements were at various toxic levels in the surface water. Therefore, the effluent from Champion breweries Plc is considered to be one of the major sources of pollutants of the surface water in this area, with the tendency of affecting human health, aquatic organisms and soil contamination as well.

However, the management of Champion Breweries Plc should as a matter of urgency, improve upon their effluent treatment method by installing anti-pollution equipment for the treatment of their effluent before disposal, which is based on the Best Available Technology (BAT).

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and material

All data are contained within the manuscript

Competing interests

All authors declare zero financial or inter-personal conflict of interest that could have influenced the research work or results reported in this research paper.

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RESEARCH ARTICLE

Groundwater Quality Assessment In Aka-Offot Industrial Layout, Uyo, Akwa Ibom State, Nigeria

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Abstract
Groundwater quality assessment was carried out on water samples from five boreholes collected through simple random sampling method during wet and dry seasons within Aka-Offot Industrial Layout, Uyo and a non-industrialized area (control site). The aim was to assess their quality by determining their physico-chemical properties and heavy metals for comparison with the control site and the world's threshold standards. Water samples were collected with polyethylene bottles that were initially rinsed with 10% hydrochloric acid then with sample water. Two samples were collected from each borehole. One was for physico-chemical properties determinations while the other one was for heavy metal analysis. HNO_2 was added in the samples for heavy metal analysis for preservation of the metals. The samples were stored in an ice-packed cooler kit to the laboratory for analysis. The results revealed that the temperature of the water was slightly above WHO standard but fell below FEPA standard; turbidity and electrical conductivity fell within the permissible limits. The water was acidic because the mean pH value was lower than the permissible limit; dissolved oxygen was significantly low while biological oxygen demand was higher than the permissible limit signifying high load of organisms and impurities in the water. The total dissolved solid, ammonium, nitrate and sulphate were below the permissible limits. The mean values of Fe, Pb, Zn, Cr and Co fell below the permissible limits. For Cd, it's dry season mean value was a little above WHO permissible limit but fell below FEPA standard while the dry season mean value of Mn was above FEPA's permissible limit but all of them fell within the WHO limit. However, industrial wastes disposed in this area have had adverse effects on the groundwater. Therefore, adequate waste management method is one of the recommendations prescribed for a healthy and sustainable environment.

Keywords: Groundwater quality; Physico-chemical properties; heavy metals; permissible limits

Introduction

Water is one of the essential needs of man. Security access to potable water supply is a central issue of concern not only in urban areas but much more in rural areas (Atser and Akpabio, 2015). The importance of water supply for domestic use cannot be compromised not only because of its social and economic values (Atser and Udoh, 2014), but also, because water based sources of livelihood have become critical to the survival and health of both urban and rural households, providing valuable contributions to them (Bain *et al.*, 2014). Water is therefore a very strategic socio-economic asset especially in poor economies where wealth and survival are measured by the level of an access to water. Access to water supply is therefore one of the key factors that enhance the well-being of the households (Yange *et al.*, 2013). In Nigeria, water supply like in other developing countries is facing serious challenges many of which are economic and socio-political in nature (Alayande, 2005).

Groundwater is one of the earth's most widely distributed, replenishable resources. It is about 0.6% of the total global water resources and out of this, only 0.3% is being used for economic purposes (Raghunath, 2007). In most countries, people depend on groundwater as the only source of drinking water because, groundwater is comparatively much clean and free from pollution than the surface water (Mangukiya *et al.*, 2012). Contamination and over exploitation are the major reasons for groundwater deterioration (Yadav *et al.*, 2012). Though recent years shift in usage from surface water to groundwater has controlled problems of microbiological and trace elements to a certain extent, but the same has led to newer problems of fluorosis, arsenicosis and salinity due to over-exploitation of groundwater (Singh *et al.*, 2013). Moreso, the extensive use of fertilizers, pesticides, discharge of industrial effluents, domestic sewage and solid waste dump, landfills and many other anthropogenic activities are the major sources of groundwater contamination mostly in the third world countries. This is rising day by day across the world due to extreme residential, municipal, commercial, industrial and intensive agricultural practices because the rate of discharge of pollutants into the groundwater is higher than the rate of purification

(Murhekar *et al.*, 2012). Therefore, it has become important to protect the groundwater resource against contamination in recent time, because it has negative effects on human beings, plants and animals (Caliman *et al.*, 2011; Srinivas *et al.*, 2011). Above all, it is of great concern to act swiftly by carrying out this study since it may take years for the contaminated aquifer to be flushed out because of the rather slow flow (Esu and Amah, 1999).

Materials and Methods

Study Area

The study was carried out at Aka-Offot Industrial Layout in Uyo, Akwa Ibom State. It lies between longitudes 7° 55" E - 7° 56" E and latitudes 5° 00" N -5° 01" N (Figures 1). The area has a humid tropical climate with an annual rainfall ranging from 2500-3000mm and annual mean temperature of about 27°C and the relative humidity ranging from 75% to 79%. Ikot Ayan village, Ediene is in Ikono Local Government Area of Akwa Ibom State, which was considered as a non-industrialized area was chosen as the control site. It lies between longitudes 7°45'E - 8°00'E and latitudes 5°05'N -5°15'E (Figure 1). The topography of the study area is low-lying with coastal plain sand as parent material (Petters *et al.*, 1989).
The surface geology is unconsolidated sand formation ranging from coarse to fine sands (Tahal, 1979; Okoji, 1988). The soil is generally very porous and weakly structured with moderate nutrient and high water retention capacity, thus, the motivation in carrying out this study because of the fact that these boreholes which are sources of water supply to inhabitants of this area, are located within this Industrial Layout.

Methods of Data Collection

With the aid of global positioning system (GPS) and measuring tape for establishment of points, groundwater samples were collected from five (5) boreholes selected through simple random sampling method within Aka-Offot Industrial Layout, Uyo during wet and dry seasons. Water samples were equally collected from a borehole at the control site.
The study sites were: (i) The Nigerian Security and Exchange Commission premises with Field Code (NSEP), which is located 640 metres away from Champion Breweries wastewater disposal site and 905 metres away from Plasto Crown waste disposal site; (ii) Central Bank of Nigeria premises with field code (CBNP) which is located 460 metres away from Champion Breweries wastewater disposal site and 902 metres away from Plasto Crown waste disposal site; (iii) private compound with field code (PC) which is located 310 metres away from Champion Breweries wastewater disposal site and 540 metres away from Plasto Crown waste disposal site; (iv) Champion Breweries premises with field code (CBP) which is located 210 metres away from Champion Breweries wastewater disposal site and 250 metres away from Plasto Crown waste disposal site and (v) Plasto Crown premises with field code (PCP) which is located 420 metres away from Champion Breweries wastewater disposal site and 110 metres away from Plasto Crown waste disposal site. New plastic bottles labelled with waterproof marker were used for collecting the water samples. They were first washed with 10 per cent hydrochloric acid (HCl), rinsed with tap water and finally rinsed with distilled water. At the sample collection point, the plastic bottles were rinsed twice with the water to be collected. The boreholes were pumped and allowed to run for some time (15-20 minutes) prior to the collection of the water.
The water samples were collected in clean 200 ml polyethylene plastic bottles from both the study area and the control site. Two samples were collected at each location; one for physico-chemical properties determinations, while the other one was for heavy metal analysis. Samples collected for heavy metal analysis were preserved by adding a drop of nitric acid (HNO_3) after collection so as to preserve the metals. Electrical conductivity, hydrogen ion concentration (pH) and temperature of the sampled water were determined at the field with the aid of the following equipment listed in Table 1. The samples were stored in an ice-packed cooler kit and transported to the laboratory for prompt analyses within 24 hours, using standard scientific methods (Table 1).

Results and Discussion

The results of the physico-chemical properties, and heavy metal concentrations of the water samples collected from the boreholes of the study area as well as the control site are presented in Tables 2 & 3, for comparison with the control site and the world's permissible standards (FEPA, 1988 and WHO, 2006).

Physico-chemical properties

Physical parameters

Temperature

The Temperature of groundwater from the study area varied from 25.3 – 26.2°C with a mean temperature of 26.10°C while the control site had 25.2°C during dry season (Table 2) and the wet season varied from 25.5°C – 26.0°C with a mean of 25.80°C and the control site had 25.0°C (Table 3). The temperature of water from the study area for both dry and wet seasons was higher than the one of the control site. The temperature of water from the study area was slightly above the 25.0°C permissible limit of WHO (2006) and significantly below the 30°C stipulated by FEPA (1988). Temperature affects the amount of dissolved oxygen in water, metabolic rate of aquatic animals and so on. Therefore, the temperature of water from the study area was slightly moderate.

Turbidity

The turbidity of water from the study area (mean) was 1 NTU during dry season and 1 NTU (mean) during wet season while the control site equally had 1 NTU for both dry and wet seasons (Table 2 and 3). There was no significant difference between the turbidity values of the water from the study area, the control site and the world's permissible limit of 1 NTU (FEPA, 1988). High turbidity in groundwater is usually caused by particulate matter in suspension which results from land surface erosion. Therefore, the average turbidity value in the groundwater of the study area was due to the fact that when water seeps downwards or percolates through the ground (mostly the coastal plain sands of the study area) most of the organic matter or suspended particles that are be picked near the ground surface have been gradually removed (Esu and Amah, 1999). This observation is explained by the "filti-plant function" of aquifers which states that "the unsaturated overlying an aquifers can act as a waste treatment system" (Fetter, 1980; Esu and Amah, 1999).

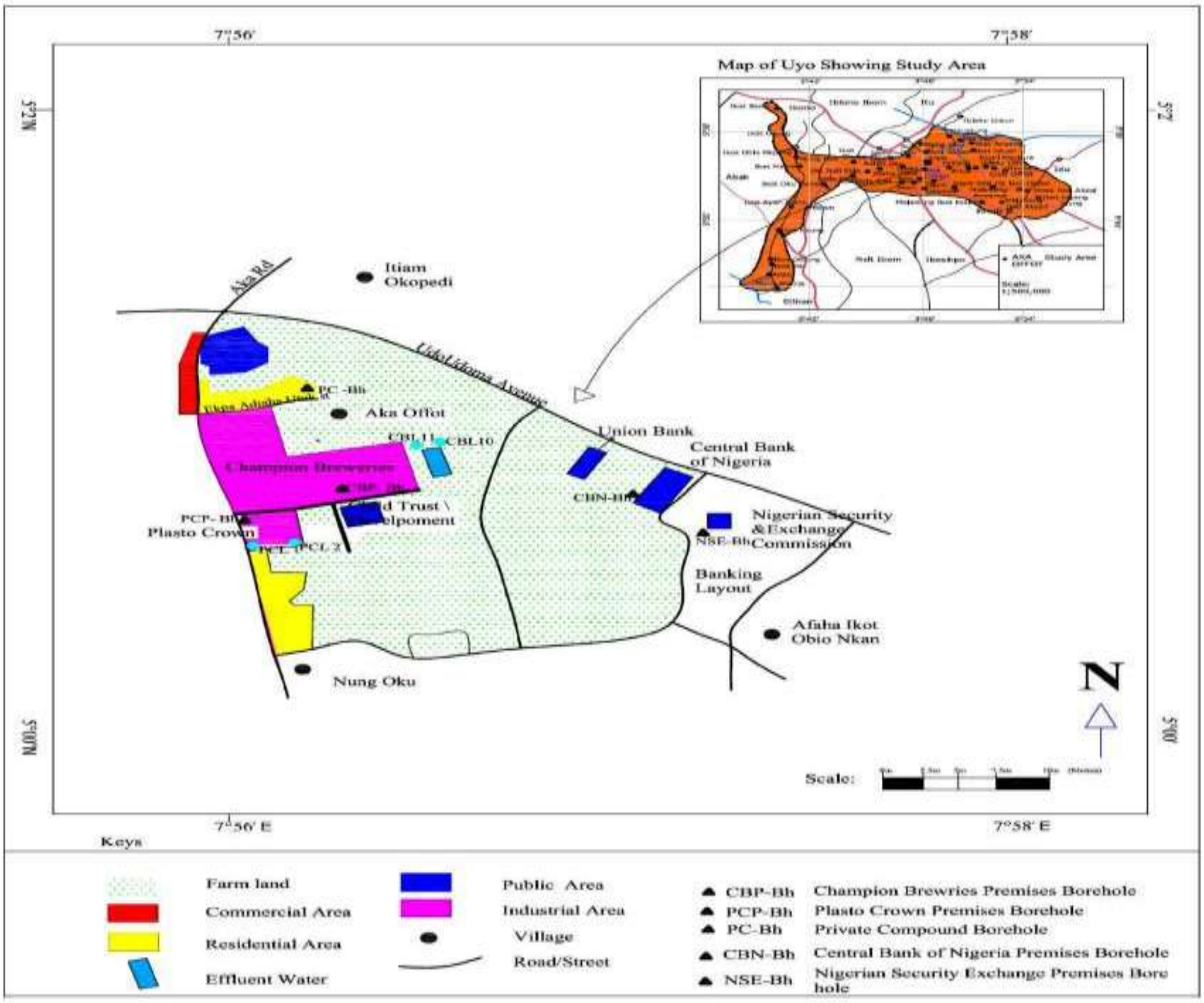

Figure 1: Map of Akwa Ibom State showing study area and control site.
Source: Agate Geographic Services (2008)

Table 1: Methods and equipment used for physico–chemical properties, nutrients and heavy metal analyses

Analytical equipment/ Method of Reference		Parameter
Cyberscan pH 20 meter		pH
Cyberscan low 20 conductivity meter		Conductivity, Temperature Total Dissolved Solid (TDS)
Microprocessor Oximeter 196	-	Dissolved Oxygen (DO)
Atomic absorption spectrophotometer (AAS) (Whitehead 1979, method)	-	Heavy metals
Spectrophotometrically by		

(a) Turbidimetry using baricum chloride (APHA, 1993)	-	Sulphate, So4
(b) As nitrate after reduction in a reduction calcium system (Parsons et. al., 1984)	-	Nitrate (No_3)
(c) Formazine standards	-	Turbidity (NTU)
(d) Nesslerizaiton method	-	Ammonium (NH_4)
Difference between initial oxygen concentration in sample and concentration after 5 days incubation in dissolved oxygen (DO) bottles at 20°C (APHA, 1993)	-	Biochemical oxygen demand (BOD_5)

Source: Adapted from Whitehead (1979); Parsons *et al.* (1984) APHA, (1993).

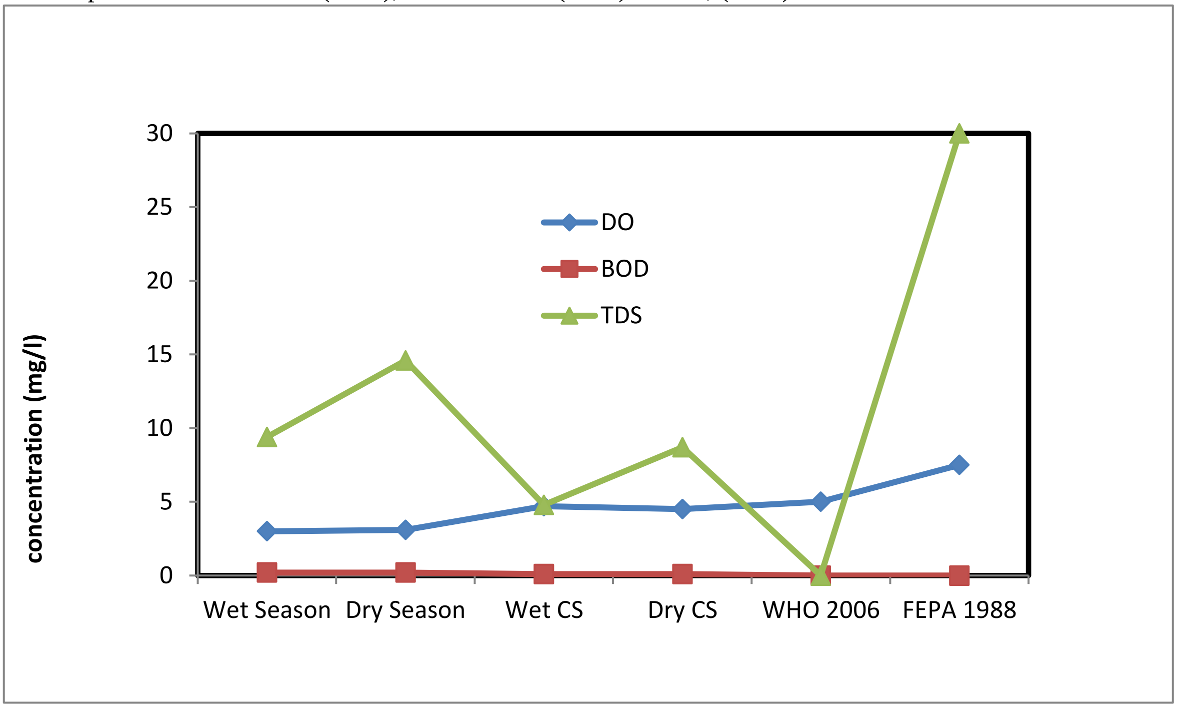

Figure 2: DO, BOD and TDS levels of the water collected from boreholes within Aka-Offot Industrial Layout, Uyo versus the one from the control site (CS) and the world's threshold standards.

Electrical conductivity (EC)

Electrical conductivity of water from the study area varied from 11-29 µs/cm with a mean of 21µs/cm while the control site had 16µs/cm for dry season and the wet season varied from 10-27 µs/cm with a mean of 20µs/cm from the study area and 15µs/cm for the control site (Table 3). The EC mean value that of the control site, and equally the same situation during the wet season. However, the electrical conductivity permissible limits for groundwater were not supplied by WHO (2006) and FEPA (1988). But from the TDS values of water from the study area, the amount of dissolved salts in the water did not constitute any danger to human health and aquatic life implying that the electrical conductivity derived from the water of this area was in order (Olasoji et al., 2015).

Chemical parameters pH

The pH of water from the study area varied from 4.91-5.71 with a mean of 5.35 while the control site had 6.02 for dry season (Table 2) and wet season varied from 5.16 – 5.91 with a mean of 5.54 from the study area and 6.08 for the control site. As indicated in the water from the study area, there was significant level of acidity as compared to the control site for both dry and wet seasons, likewise the world's threshold standard of 6.5-8.5 pH for drinking water (FEPA, 1988 and WHO, 2006). This range of pH may impair the potable state of groundwater from the study area. Low pH and high content of carbon dioxide in water suggest that the natural state of water in such areas are corrosive to iron and steel and could attack carbonate minerals (Esu and Amah, 1999).

Dissolved oxygen (DO)

The dissolved oxygen of water from the study area varied from 3.0 – 3.20 mg/l with a mean of 3.10 mg/l while the control site had 4.5 mg/l for dry season and the wet season had 3.0 -3.1 mg/l with a mean of 3.0 mg/l for the study area and 4.7 mg/l for control site. The result shows that the DO values of the water from the study area for both dry and wet seasons were lower than that of the control site. Equally when compared to 5.0 mg/l recommended by WHO (2006) and 7.5 mg/l recommend by FEPA (1988) for drinking water, implies that the amount of DO of water from the study area was significantly low; (low oxygenation) which could be attributed to the load of impurities and organisms in the groundwater occasioned by industrial effluent. This is also evident in the result of the biological oxygen demand (BOD).

Biological oxygen demand (BOD)

The biological oxygen demand of water from the study had a mean of 0.2 mg/l while the control site had 0.05 mg/l for dry season and the wet season varied from 0.1-0.2 mg/l with a mean of 0.2 mg/l and the control site had 0.5 mg/l. The BOD values from the study area were higher than that of the control site for both dry and wet seasons and significantly higher than the world's permissible limit of 0 mg/l by FEPA (1988) and WHO (2006) for drinking water, signifying high level of algae and other organisms in the groundwater with attendant decrease of oxygen in this water.

Total dissolved solid (TDS)

The total dissolved solid of water from the study area varied from 10.60-17.80 mg/l with a mean of 14.60 mg/l while the control site had 8.7 mg/l for dry season and the wet season varied from 5.8 – 14.7 mg/l with a mean of 9.40 mg/l from the study area and the control site had 4.8 mg/l. The TDS values of the water from the study area were a bit higher than that of the control site but significantly lower than the FEPA (1988) and the Nigerian Standard for Drinking Water Quality (2015) permissible limit of 500 mg/l. Total dissolved solid is a measure of the amount of dissolved salts in water. Salty water conducts electricity more readily than pure water. The values of TDS of the water from the study area indicate that the amount of dissolved salts in the water was not up to the level that constitutes danger to human health and aquatic life (Olasoji et al., 2019). TDS just like electrical conductivity, serve as tool for assessing the purity of water (United States Environmental Protection Agency, 2022).

Ammonium (NH_4^+)

The ammonium (NH_4^+) content of water from the study area varied from 0.031 – 0.045 mg/l with a mean of 0.039 mg/l while the control site had 0.025 mg/l for dry season and the wet season varied from 0.031 – 0.041 mg/l with a mean of 0.036 mg/l and the control site had 0.023 mg/l (Table 3). The mean contents of both dry and wet seasons from the study area were a bit higher than the ones from the control site but fell below the permissible limits of 0.2 – 0.3 mg/l by WHO (2006) and 1.0 mg/l by FEPA (1988). Ammonium is a source of nitrogen in water. There is need to control the way effluent is being disposed in this area to avoid water pollution from ammonium because its high concentration in water is toxic to aquatic life (Olasoji et al., 2019).

Nitrate (NO_3)

The nitrate content of water from the study area varied from 1.982 – 2.086 mg/l with a mean of 2.029 mg/l while the control site had 1.893 mg/l for dry season and the wet season varied from 1.980 – 2.081 mg/l with a mean of 1.890 mg/l and the control site had 1.890 mg/l. The mean content of nitrate in water from the study area during dry season was higher than the one from the control site while the mean value of nitrate in water from the study area, during wet season was the same with one from the control site but all of them fell below the 50 mg/l WHO (2006) permissible limit and 10.0 mg/l stipulated by FEPA (1988). Nitrate is a source of nitrogen in water but its high concentration causes excessive growth of algae and eutrophication in aquatic ecosystem (Olasoji et al., 2019).

Sulphate (S_4^2)

The sulphate content of water from the study area varied from 0.853 – 1.458 mg/l with a mean of 1.130 mg/l for dry season while the control site had 0.883 mg/l and the wet season varied from 0.824 – 1.433 mg/l and the control site had 0.798 mg/l (Table 3). The mean contents of sulphate from the study area was higher than the ones from the control site but fell below the permissible limits of 400 mg/l by WHO (2006) and 500 mg/l by FEPA (1988). Sulphate is a source of sulphur in water, but its high concentration can impair photosynthesis and increase respiration (Olasoji et al., 2019).

Heavy metal concentration

Iron (Fe)

The iron content of water from the study area varied from 0.042 – 0.182 mg/l with a mean of 0.104 mg/l while the control site had 0.025 mg/l for dry season and the wet season varied from 0.020 – 0.173 mg/l with a mean of 0.034 mg/l from the study area and 0.024 mg/l for the control site. The mean values of Fe from the study area for both dry and wet seasons were a bit higher than the control site but fell below the permissible limit by 0.30 mg/l (WHO, 2006) and 1.0 mg/l for (FEPA, 1988) for drinking water.

Lead (Pb)

The Pb content of water from the study area varied from 0.002- 0.008 mg/l with a mean of 0.004 mg/l while the control site had 0.002 mg/l for dry season and the wet season varied from 0.001 – 0.004 mg/l with a mean of 0.002 mg/l from the study area and 0.001 mg/l for the control site. The mean value of Pb for dry season was a bit higher than that of wet season but fell below the permissible levels of 0.01 mg/l (WHO, 2006) and 0.05 mg/l stipulated by FEPA (1988).

Zinc (Zn)

The Zn content of water from the study area varied from 0.105- 0.343 mg/l with a mean of 0.207 mg/l while the control site had 0.043 mg/l for dry season and the wet season varied from 0.057–0.340 mg/l a mean of 0.192 mg/l from the study area and 0.039 mg/l for the control site (Table 3). The mean contents of zinc from the study area were higher than the ones from the control site for both dry and wet seasons but fell below the FEPA (1988) permissible limit of 1.0 mg/l for drinking water.

Cadmium (Cd)

The cadmium content of water from the study area varied from 0.002 – 0.007 mg/l with a mean of 0.004 mg/l while the control site had 0.002 mg/l for dry season (Table 2) and the wet season varied from 0.001 – 0.003 mg/l with a mean of 0.002 mg/l and the control site had 0.001 mg/l (Table 3). The mean concentration of Cd in the dry season was higher than the one of the wet season. Moreso, the mean values of Cd in water from the study area for both dry and wet seasons were higher than the control site. It is observed that the mean Cd value of 0.004 mg/l of the study area during dry season was above the WHO (2006) permissible limit of 0.003 mg/l but all of them fell below the FEPA (1988) limit of 0.01 mg/l for drinking water.

Chromium (Cr)

The chromium content of water from the study area varied from 0.001 – 0.004 mg/l with a mean of 0.002 mg/l while the control site had 0.001 mg/l for dry season (Table 2) and the wet season varied from 0.001- 0.002 mg/l with a mean of 0.002 mg/l and the control site had 0.001 mg/l (Table 3). The mean values of Cr in water from the study area were above the values of the control site for both dry and wet seasons but fell below the WHO (2006) and FEPA (1988) permissible limit of 0.05 mg/l for drinking water.

Cobalt (Co)

The cobalt content of water from the study area varied from 0.011-0.038 mg/l with a mean value of 0.020 mg/l while the control site had 0.004 mg/l for dry season (Table 2) and the wet season varied from 0.009 – 0.019 mg/l with a mean of 0.013 mg/l and the control site had 0.003 mg/l (Table 3). The mean values of Co in water from the study area were above the values from the control site. Though the Co permissible limit in drinking water was not supplied by WHO (2006) and FEPA (1988), the value of Co from the study area was the same with the United States Environmental Protection Agency (2022) limit of 0.02 mg/l for surface water.

Manganese (Mn)

The manganese content of water from the study area varied from 0.014 – 0.073 mg/l with a mean of 0.33 mg/l while the control site had 0.013 mg/l for dry season (Table 2) and the wet season varied from 0.009 - 0.061 mg/l with a mean of 0.026 mg/l and the control site had 0.009 mg/l (Table 3). The mean values of Mn in water from the study area were above the values of the control site for both dry and wet seasons but fell within the 0.4 mg/l permissible limit of WHO (2006) while the value from the study area during dry season was above the FEPA (1988) limit of 0.05 mg/l for drinking water. However, strict measures in controlling wastes from this area should be applied. For instance, the implication for areas with high concentrations of Fe^{2+} and Mn^{2+} is that the waters will not only have taste but will stain laundry and plumbing fixtures and cooking utensils. Incrustation of well screens and plugging of pipes are other adverse effects. Apart from the problem of taste, manganese also enhances growth in reservoir filters and distribution systems (Todd, 1980; Esu and Amah, 1999).

Conclusion/Recommendations

The study submits that the temperature of water from the study area was slightly moderate because it was a little above WHO permissible limit but below FEPA limit. The turbidity of water from the study area fell within the permissible limit as well as the electrical conductivity. The water from the study area was acidic because the pH was lower than the permissible level. The dissolved oxygen in the water was significantly low which was attributed to high load organisms which equally manifested in the higher biological oxygen demand value which was above the permissible limit. This was attributed to high level of algae and other organisms with attendant decrease of oxygen in the water. The total dissolved solid of water from the study area was below the permissible limit as well as ammonium, nitrate and sulphate. In terms of heavy metals, the values of iron, lead and zinc fell below the permissible limits. For cadmium, it was observed that its mean value during dry season in the study area was a little above the WHO permissible limit but all of them fell below the FEPA allowable limit. Equally, the chromium and cobalt values of water from the study area fell below the permissible limits while manganese mean value of water from the study during dry season was above the FEPA permissible limit but all of them fell within the WHO limit.

In summary, some of the parameters of water from the study area were above the ones from the control site as well as the world's threshold standards. It is concluded that industrial wastes from industries in this layout, have had adverse effects on the groundwater of this area. Therefore, to safeguard the health and safety conditions of the inhabitants of this area and to operationalize a functional policy framework for industries in this Industrial Layout, the following recommendations are prescribed:

The management of industries operating in this area should as matter of urgency, install anti-pollution equipment for the treatment of their effluent in line with FEPA Act (Cap 131 of 1991), which states that "every industry shall install anti-pollution equipment for the detoxification of the

Table 2: Physio-chemical properties nutrients and heavy metal concentrations in water sampled from existing boreholes around Champion Breweries and Pasto Crown **Company**

					Dry season			**Tolerable limits**
Parameters	**Range**	**Mean**	**SD**	**CV (%)**	**SE**	**Control site**	**WHO (2006)**	**FEP (1988)**
A. Physical properties								
Temperature (°C)	25.3 – 26.2	26.10	0.2160	0.8275	0.0881±26.0666	25.2	25.0	30.0
Turbidity (NTU)	-	1	0	0	0±1	1	NS	1.0
Conductivity(μs/cm)	11 -29	21	6.0221	28.6766	2.4558±21.3333	16	-	-
B. Chemical properties	4.91 – 5.71	5.35	0.3395	6.3457	0.1386±5.3533	6.02	6.5 – 8.5	6.5-8.5
pH	3.0 – 3.20	3.10	0.0752	2.4258	0.0307±3.0833	4.5	5.0	7.5
Dissolved Oxygen (mg/l)								
BODS (mg/l)	-	0.2	0.0417	0.6725	0.0224±0.2010	0.05	0	0
TDS(mg/l)	10.60-17.80	14.60	2.3978	16.4232	0.9789±14.6166	8.7	NL	500
NH^{+}_{4} (mg/l)	0.031-0.045	0.039	0.0048	12.3076	0.0019±0.0386	0.025	0.2- 0.3	1.0
NO_{3-} (mg/l)	1.982-2.086	2.029	0.0437	2.1537	0.0178±2.0286	1.893	50	10.0
SO_4^{2-} (mg/l)	0.853-1.458	1.130	0.2084	18.4424	0.0836±1.1301	0.883	NS	500
C. Heavy Metals								
Fe (mg/l)	0.042-0.182	0.104	0.0584	56.1538	0.0238±0.1043	0.025	0.30	1.0
Pb (mg/l)	0.002-0.008	0.004	0.0020	50.00	0.0008±0.0041	0.002	0.01	0.05
Zn (mg/l)	0.105-0.343	0.207	0.0784	37.8743	0.0320±0.2066	0.043	NS	1.0
Cd (mg/l)	0.002-0.007	0.004	0.0019	47.50	0.0007±0.0038	0.002	0.003	0.01
Cr (mg/l)	0.001-0.004	0.002	0.0010	50.00	0.0004±0.0023	0.001	0.05	0.05
Co (mg/l)	0.011-0.038	0.020	0.0095	47.50	0.0039±0.0200	0.004	NS	NS
Mn (mg/l)	0.014-0.073	0.033	0.0248	75.1515	0.0111±0.0326	0.013	0.4	0.05

premises and control site for wet season

Note: WHO – World Health Organization (2006). FEPA = Federal Environmental Protection Agency (1988);
ND = not detected; NL= no limit; NS= not supplied; SD = standard deviation; Cv = Coefficient of variability SE= standard error.

Source: Author's Fieldwork (2021)

Table 3: Physico-chemical properties, nutrients and heavy metal concentrations in water sampled from existing boreholes around Champion Breweries and Plasto Crown Company premises and control site for wet season

Parameters	Range	Mean	SD	CV%	SE	Control site	WHO (2006)	FEPA (1988)
A. Physical properties								
Temperature (°C)	25.5 –26.0	25.80	0.2097	0.8127	0.0856±25.800	25	25.0	30.0
Turbidity (NTU)		1	0	0	0±1	1	-	1.0
Conductivity (µs/cm)	10-27	20	5.8793	29.3965	2.4002±20.1666	15	-	-
B. Chemical properties								
pH	5.16 –5.91	5.54	0.3101	5.5974	0.1266±5.5433	6.08	6.5 – 8.5	6.5 – 8.5
TDS(mg/l)	5.8 –14.7	9.54	3.2234	34.2914	1.359±9.3666	4.8	NL	500
Dissolved Oxygen(mg/l)	3.0-3.1	3.0	0.0516	1.7200	0.0210±3.0333	4.7	5.0	7.5
BODs (mg/l)	0.1 –0.2	0.2	0.0516	0.6339	0.0210±0.1666	0.05	0	0
NH^{+}_{4} (mg/l)	0.031-0.041	0.036	0.0034	9.4444	0.0014±0.0361	0.023	0.2 – 0.3	1.0
NO_{3-} (mg/l)	1.980–2.081	2.025	0.0431	2.1283	0.0176±2.0246	1.890	50	10.0
SO_4^{2-} (mg/l)	0.824-1.433	1.097	0.2196	20.0182	0.0896± 1.0968	0.798	400	500
C. Heavy Metals/ Toxic Substances								
Fe (mg/l)	0.020-0.173	0.034	0.0683	200.8823	0.0278±0.0840	0.024	0.30	1.0
Pb (mg/l)	0.001-0.004	0.002	0.0011	55.00	0.0004±0.0021	0.001	0.01	0.05
Zn (mg/l)	0.057–0.340	0.192	0.0923	48.0729	0.0376±0.1916	0.039	NS	1.0
Cd (mg/l)	0.001-0.003	0.002	0.0009	45.00	0.0004±0.0018	0.001	0.003	0.01
Cr (mg/l)	0.001-0.002	0.002	0.0005	25.00	0.0002±0.0016	0.001	0.05	0.05
Co (mg/l)	0.009-0.019	0.013	0.0034	26.1538	0.0014±0.0133	0.003	NS	NS
Mn (mg/l)	0.009-0.061	0.026	0.0175	67.3076	0.0078±0.0132	0.009	0.4	0.05

Note: WHO – World Health Organization (2006). FEPA = Federal Environmental Protection Agency (1988);
ND = not detected; NL= no limit; NS= not supplied; SD = standard deviation; Cv = Coefficient of variability SE= standard error.

Source: Author’s Fieldwork

effluent and chemical discharges emanating from their industries". The installation of such equipment shall be based on Best Available Technology (BAT), the Best Practical Technology (BPT) or the Uniform Effluent Standard (UES).

Further studies should be carried on the groundwater of this industrial complex, most especially the microbial studies.

Appropriate treatment should be given to water from boreholes in this area before drinking. For instance, consumers of borehole water should always boil such water before drinking.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and material

All data are contained within the manuscript and electronic supporting information (ESI)

Competing interests

All authors declare zero financial or inter-personal conflict of interest that could have influenced the research work or results reported in this research paper.

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RESEARCH ARTICLE

Assessment of Some Heavy Metal Concentration in Fish, Water, And Sediment Of River Ndakotsu, Lapai, Niger State

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Abstract
This research was conducted to assess the levels of heavy metals in fish tissue, sediment and water body, at river Ndakotsu, Lapai, Niger state, Nigeria. River Ndakotsu is the major river that serve as a boundary between Lapai local government and Agaie local government and is useful to surrounding towns and villages for irrigation farming fishing and domestic purposes. Due to this, it is necessary to monitor the level of heavy metals contamination in the water body, sediment and aquatic species tissue habiting this environment. The study water samples were collected using water sampler in three different locations. Equally, In-situ water physicochemical parameters such as temperature, ph and dissolve oxygen were determined using portable multi probes meter. Fish samples were collected from fishermen immediately they arrived from fish exploration and specimen were digested using concentrated nitric acid in wet digestion technique. The level of selected heavy metal in samples were determined by the use of Atomic Absorption Spectrophotometer (AAS model: Accusys 211 USA) after samples dilution. The water quality of the river was within the acceptable range for fresh water species. The concentration of heavy metals, cadmium (Cd), lead (Pb), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn). From the results obtained from this study, the concentrations of heavy metals (Mn, Zn, Cd, Cu, Pb and Fe.) found in all the water samples are lower than that in the fish sample species and higher in sediment sample than fish sample.

Keywords: Heavy metal; sediment; River Ndakotsu

Introduction

Heavy metal is a major pollutant in freshwater which may be through daily human activities such as farming, fishing, and domestic activities or from natural source. Some heavy metals like cobalt, copper, iron, manganese and zinc are essential for enzymatic activity and in various biological processes. while metals, like cadmium, lead, and mercury, are not known to play important roles in the body and are toxic even in little quantity (Looi, et al., 2013; Yi, & Zhang, 2012; Copat, et al., 2013 & Shuhaimi-Othman, et al., 2010) Generally, research on heavy metals is important on two main fronts, from a public health perspective and from an aquatic environment perspective. Heavy metals are found in the aquatic environment and can amass laterally with the food chain. Moreover, the little quantity of absorbed metals may either be kept for metabolic use for vital organic processes or detoxified to an inactive metabolic level and temporarily or permanently stored in the body (Copat, et al., 2013& Alina, et al., 2012) A number of environmental factors, particularly physicochemical parameters and water hardness, can contribute significantly to the accumulation of heavy metals in living things to dangerous amounts and harm to the ecosystem (Alhassan et al. 2022; Kumar, & Achyuthan, 2007). Substantial metal danger can bring about lower vitality levels and harm blood arrangement, liver, lungs, other crucial organs and kidneys, decreased or harmed focal and mental anxious capacity or even reason malignancy (Fernandes et al., 2008). This may result in bio-collection of substantial metals in man utilizing water and eating fish from this waterway. River Ndakotsu is the major river that serve as boundary between Lapai local government and Agaie local government and is useful to bordering towns and village for irrigation farming, fishing and domestic purposes. However, daily activities around the river by surrounding town and villages may lead to anthropogenic effect this regime of operation go back to farm and availability of fertilizers and chemical for weeds and insecticides provided by government at the affordable prices. This, made it is necessary to monitor the quality and level of heavy metals pollution in the water body, sediment and aquatic species habiting this environment. Analysis of heavy metal should be taken in to consideration because metals may be contained in the fish as they feed on the water body. This study primarily aimed at to determine the concentration of some heavy metal in fish, water, and sediment of river Ndakotsu.

Materials and Method

Description of the Study Area

The area being sought that was used in this investigation is River Ndakotsu located in Lapai Local Government Area of Niger state, approximately between latitudes 9°.34"N and longitude 6°.30"E.

Fig. 1 MAP OF LAPAI SHOWING RIVER NDAKOTSU

Material and Method

Collection Of Samples

Fish, sediment and water samples were collected between the periods of July-Sept 2018 from river Ndakotsu, Lapai, Niger State, Nigeria. The fish, sediment and water samples collected for analyses of heavy metal were immediately packed in to Ice cooled box and transported to Ibrahim Badamasi Babangida University laboratory for identification of fish to species level and further preparation of sediment and water samples collected follows. Samples were collected and prepared in triplicates.

Preparation of the fish sediment and water samples for heavy metal analysis

0.5 gram of fish, 1g of sediment and 50mL were processed with nitric corrosive and perchloric corrosive at proportion 3 to 1. That is, 15mL of nitric corrosive and 5mL of perchloric corrosive were added to 1g of test in an assimilation tube, it was put in a Kiedjal warming square and warmed at 150°C until blend explains (turns dreary – This could take 2-3h). Refined water was added and resulting to cooling. The samples were analyzed for copper, manganese and magnesium using the Atomic Absorption Spectrophotometer (AAS model: Accusys 211 USA).

Data Analysis

Descriptive statistics was used to calculate ranges, means and standard deviations from the data. The differences in mean were compared at ($P < 0.05$). The package used in the statistical analysis was SPSS. (Scientific package for social sciences).

Results

The heavy metal concentration of river Ndakotsu water is reported below, including the concentration of lead, copper, Cadmium, iron, zinc and manganese. From the result below There were no cadmium and lead in the water of river Ndakotsu, but copper was present in station 1 and absent in station 2 and 3, zinc was found the highest heavy metals concentration follow by iron and manganese at last.

Table 4.1 Heavy Metal Concentration Of River Ndakotsu Water

Parameters	Location 1	Location 2	Location 3
Cadmium	0.0±0[a] (0.00-0.00)	0.0±0[a] (0.00-0.00)	0.0±0[a] (0.00-0.00)
Lead	0.0±0[a] (0.00-0.00)	0.0±0[a] (0.00-0.00)	0.0±0[a] (0.00-0.00)
Copper	0.89±0.06[b] (0.83-0.95)	0.0±0[a] (0.00-0.00)	0.0±0[a] (0.00-0.00)
Iron	3.67±0.409[a] (3.20-3.92)	10.2±0[a] (10.1-10.44)	2.56±0[a] (2.55-2.56)
Manganaze	0.67±0.06[a] (0.66-0.67)	0.65±0.015[a] (0.63-0.66)	0.124±0.6[a] (0.12-0.13)
Zinc	4.08±0.05[a] (4.04-4.13)	6.36±0.15[a] (6.27-6.49)	5.76±0.55[a] (5.70-5.81)

Table 4.2 Scientific Classification of this species above

SPECIES	KINGDON	CLASS	GENUS	SPECIES
Clarias gariepinus	Animalia	Actinopterygii	Clarias	C. gariepinus
Heterobranchus bidorsalis	Animalia	Actinopterygii	Clarias	H. bidorsalis
Clarias anguillaris	Animalia	Actinopterygii	Clarias	C. anguillaris

The heavy metal concentration of river Ndakotsu fish is reported below, including the concentration of Cadmium, lead, copper, iron, manganese and zinc. From the result below There were no cadmium lead and copper in the fish of River Ndakotsu, but there was present of zinc which was found the highest heavy metals concentration follow by iron and manganese at last.

Table 4.2.1 Species of Fish Counted At The Stations

SPECIES OF FISH	STATION 1	STATION 2	STATION 3
Clarias gariepinus	7	_	_
Heterobranchus bidorsalis	_	6	_
Clarias angullaris	_	_	10
T0TAL	7	6	10

Table 4.2.2 Heavy Metal Concentration of River Ndakotsu Fish

PARAMETERS	STATION 1	STATION 2	STATION 3
Cadmium	0.0±0[a] (0.00-0.00)	0.0±0[a] (0.00-0.00)	0.0±0[a] (0.00-0.00)
Lead	0.0±0[a] (0.00-0.00)	0.0±0[a] (0.00-0.00)	0.0±0[a] (0.0-0.0)
Copper	0.0±0[a] (0.00-0.00)	0.0±0[a] (0.00-0.00)	0.0±0[a] (0.0-0.0)
Iron	16.04±0[a] (15.6-16.5)	10.85±0[a] (10.7-11.0)	17.62±0[a] (17.29-17.88)
Manganaze	0.44±0.03[a] (0.42-0.47)	0.33±0.02[a] (0.32-0.35)	0.43±0.02[a] (0.41-0.45)
Zinc	68.87±1.72[b] (67.30-70.70)	89.47±1.21[c] (88.20-90.60)	65.27±1.32[b] (64.10-66.70)

The heavy metal concentration of river Ndakotsu sediment is reported below, including the concentration of Cadmium, lead, copper, iron, manganese and zinc. From the result below There was cadmium in station 2 but absent in station 1 and 3, also lead and copper was present in station 1 and 2 but absent in station 3 in the sediment of river Ndakotsu, but also zinc was found the highest heavy metals concentration follow by iron and manganese at last.

Table 4.3 Heavy Metal Concentration of River Ndakotsu Sediment

PARAMETERS	STATION 1	STATION 2	STATION 3
Cadmium	0.0±0^{a} (0.00-0.00)	0.17±0.06^{b} (10-.20)	0.0±0^{a} (0.00-0.00)
Lead	11.73±1.67^{a} (10.40-13.60)	19.20±0.87^{a} (18.20-19.80)	0.0±0^{a} (0.00-0.00)
Copper	1.48±°C (1.40-1.60)	21.37±0^{d} (20.60-22.10)	0.0±0^{a} (0.00-0.00)
Iron	3054±22.6^{c} (3029-3074)	10.34±251.8^{d} (141.30-146.6)	1474.4±5.60^{b} (1469.3-1480.4)
Manganaze	233.3±6.14^{c} (228.2-240.1)	239.4±5.96^{d} (235.1-246.2)	56.47±2.60^{b} (53.90-59.10)
Zinc	483.3±7.40^{e} (475.8-490.6)	571.97±3.97^{f} (569.1-576.5)	318.8±1.65^{d} (317.2-320.5)

Table 4.4 Physico-Chemical Parameters of River Ndakotsu Water

Parameters	Location 1	Location 2	Location 3
TEMPERATURE (°C)	28°C	26°C	28°C
pH (m)	8.3 m	7.8 m	6.0 m
DISSOLVED OXYGEN (pp/m)	1.7 ppm	6.3 ppm	6.0 ppm

Discussion Conclusion and Recommendation

Discussions

Fish samples

The results of heavy metals concentration in fish were shown in table 3 above. The result revealed that certain heavy metals are present in fish samples.

The species of fish found across the three station of the rivers are: Clarias gariepinus in station one, Heterobranchus bidorsalis in station two and Clarias anguillaris in station three. Therefore, Clarias gariepinus was present in station one but absent in station two and three while Heterobranchus bidorsalis was present in station two and absent in station one and three and finally Clarias anguillaris was present in station three and absent in station one and two.

From the analysis obtained from concentration of river Ndakotsu Lapai Niger State, it was found that cadmium, lead and copper was absent across the three station of the rivers.

Concentrations of Zn and Fe was found to be higher in all fish samples.Its concentration ranges from Zn 68.87±1.72^{b}mg/kg, 89.47±1.21^{c}mg/kg and 65.27±1.32^{b}mg/kg across the three station of the river. This finding is supported by the report of Oluseye et al. (2012), Although These figures were much higher than the general guidelines limit of 50mg/kg for Zn in food recommended by UK Ministry of Agriculture, fishes and food (2007). In spite their higher values, these concentrations were statistically significant at $p<0.05$ and can induce infections. This finding is however in dissimilar with the findings of Tabinda et al. (2013).

Fe, its Concentration ranges from 16.04±0^{a}mg/kg, 10.85±0^{a}mg/kg and 17.62±0^{a}mg/kg This finding is however negated by the report of Oluseye et al. (2012), who revealed that High concentrations of Fe in fish samples could be due to pollution that occur/intake of these polluted particles by the fish samples in the water.

Mn was found to be the lowest concentration of heavy metals across the three station of the river, ranges from 0.44±0.03^{a}mg/kg, 0.33±0.02^{a}mg/kg and 0.43±0.03^{a}mg/kg and they all have the same significant differences across the three station of the river, this finding is supported by the report of Oluseye et al. (2012), who also recorded low concentration for Clarias garienpinus and Oreochromis niloticus. However, Mn fish helps in fish reproduction and normal functioning of nervous system (Olowoyo et al., 2011). the findings of this research shows that concentration of Mn was significant at $p<0.05$. Cu and Pb was found absent across the three station of the rivers.

Water samples

The concentration of Zn and Fe, was found as the highest range, Zn range from (4.08±0.05^{a}), (6.36±0.15^{a}) and (5.06±0.55^{a}) for Fe ranges from 3.67±0.41^{a}mg/l, 10.2±0^{a} to 2.56±0^{a}mg/l having the highest value and were significant at $p<0.05$. Although, station 2 and station 1 had the highest values across the three station and were significant at $p<0.05$. These concentrations were greater than 0.03mg/l which was the standard concentration of Iron in water according to NESREA (2011) for drinking water. Based on my finding is due some anthropogenic activities that take place at the river such as washing of cloths, bathing, washing of plate etc. also fertilizer used in agricultural activities and block industries found close to the river also flush down the waste product in to the river causes pollution to the aquatic organism

Low concentrations Mn was obtained, based on this finding they range from (0.67 ± 0.06^a), ($0.65\pm0.0.02^a$) and 0.12 ± 0.6^a were significant at $p<0.05$ except for Cu least concentration which was not significant. The report of this research is in line with the findings of Tabinda et al., (2013), who reported similar ranges of these heavy metals in their research carried out on Riverine water and fishes. According to the approved standard by NESREA (2011). Mn is a mineral required by the body in trace amount for manufacturing of enzymes necessary for metabolism. Excess amount of it may lead to poor bone formation, impair fertility and also causes death (Mergler et al., 2009).

Cu was found as the lowest range, Cu was also found only in station 2 with range of (0.89 ± 0.06^b) and absent in station 2 and 3 which their standard concentrations were 3.0mg/l, 2.0mg/l and <2.0mg/l for Cu respectively. This signifies low concentration in River Ndakotsu Lapai, Niger state and cannot be consumed at moderate rate with effect of Cu, related diseases. Although, the metals when consumed at higher rate may lead to Liver, kidney and circulatory problems in human being (Wachira, 2007). high concentrations observed for Mn and Fe may render River Ndakotsu Lapai water undrinkable because they can induce cancer related disease, despite the fact that high concentration were observed for Zn. To be at the safer side it is however no recommended for consumption based on the findings of this research.

Sediment Sample

Heavy metals concentration of River Ndakotsu Sediment, according to this research cadmium was found only in the sediment of the river and absent in water and fish sample the concentration ranges from 0.17 ± 0.06^b in station 2 only and absent in station 1and 3.

The concentration of cadmium was found at lowest range all over the three station of the river,

Concentration of Zn, Fe and Mn was found the highest range from Zn (483.3 ± 7.40^e), (571.97 ± 3.97^f) and (318.8 ± 1.65^d) Fe range from (3054 ± 22.6^c), (10.34 ± 251.8^d) and (1474.4 ± 5.60^b) then Mn range from (233.3 ± 6.14^c), (239.4 ± 5.96^d) and (56.47 ± 2.60^b).

This finding is supported by the report of Oluseye et al. (2012), In spite their higher values, these concentrations were statistically not significant across the three station and can induce infections. This finding is however in contrast with the report of Tabinda et al. (2013).

Concentration of Cu and Pb was found at station 1 and 2 but absent in station and also at low range from Cu (1.48±°C) and (21.37 ± 0^b) Cu was statistically not significant Pb (11.73 ± 1.67^a) and (19.20 ± 0.87^a), Pb was statically significant. The low concentration for Cu. The concentration could be attributed to bioaccumulation of pollutant over a long period of time from other pollutant source. However, low concentrations of Pb inhibit inactive transport mechanisms involving ATP and also suppress cellular oxidation-reduction reaction (Olowoyo et al. 2011).

Physico chemical parameters of River Ndakotsu water

This analysis was carryout at the sampling station with the used of equipment such as thermometer, pH meter (manual) and dissolved oxygen meter across the three stations of the river,

Temperature

Temperature was found the highest value of 28°C in station 1 and 3, in station 2 it was 26°C which is found at low value. The water quality parameters were within the acceptable range for temperature (Swann, 2006). According to Federal Ministry of Environment FME (2006) the temperature of 20 - 33°C is recommended as permissible limit standard for aquatic life.

Hydrogen Concentration

Hydrogen concentration (pH) was found the highest value of 8.3m in station 1 follow by 7.8m in station 2 and the lowest value was 6.00m in station 3. The pH can also affect fish health. For most freshwater species, a pH range between 6.5 - 9.0 is ideal, but most marine animals typically cannot tolerate as wide range pH as freshwater animals, thus the optimum pH is usually between pH 7.5 and 8.5 (Boyd, 1998).

Dissolved Oxygen

Dissolved oxygen (pp/m) in station 1, 7.2 ppm was found as the highest value follow by 6.3 ppm in station 2 and 6.0ppm in station 3 which was found as the lowest value. (FME, 2006) reported the permissible limit standard of dissolved oxygen for aquatic life is 6.8-10 ppm.

Conclusion

From the results obtained from this study, the concentrations of heavy metals (Mn, Zn, Cd, Cu, Pb and Fe.) found in all the water samples are lower than that in the fish sample species and higher in sediment sample than fish sample, this may be as a result of bioaccumulation over a long period of time. The bio-accumulation of some metals in the fish gills were due to polluted water from river Ndakotsu containing various municipal wastes from the village inhabitant.

Recommendation

The need for regular checkups of the heavy metal concentrations in River Ndakotsu, selected tributaries since the river serves as source of irrigation and fish for the local inhabitants in the study area. Vegetation covers of riverine characteristics is pertinent to be established along the river for heavy metal absorption from the water and sediments.

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Appendix

Appendix 1 Row data of Heavy metal analysis of water (mg/L)

Sample	Cadmium	Lead	Copper	Iron	Manganese	Zinc
ST1 water	0.00	0.00	0.88	3.916	0.668	4.08
	0.00	0.00	0.95	3.906	0.672	4.04
	0.00	0.00	0.83	3.201	0.661	4.13
ST2 water	0.00	0.00	0.00	10.436	0.652	6.32
	0.00	0.00	0.00	10.124	0.658	6.49
	0.00	0.00	0.00	10.105	0.629	6.27
ST3 water	0.00	0.00	0.00	2.556	0.124	5.76
	0.00	0.00	0.00	2.560	0.129	5.81
	0.00	0.00	0.00	2.549	0.118	5.70

Appendix 2 Row data of heavy metal analysis of fresh fish (mg/100g)

Sample	Cadmium	Lead	Copper	Iron	Manganese	Zinc
ST1 fish	0.00	0.00	0.00	15.95	0.44	68.6
	0.00	0.00	0.00	16.53	0.47	70.7
	0.00	0.00	0.00	15.64	0.42	67.3
ST2 fish	0.00	0.00	0.00	10.82	0.33	89.6
	0.00	0.00	0.00	10.69	0.35	88.2
	0.00	0.00	0.00	11.03	0.32	90.6
ST3 fish	0.00	0.00	0.00	17.68	0.43	65.0
	0.00	0.00	0.00	17.29	0.45	66.7
	0.00	0.00	0.00	17.88	0.41	64.1

Instrument: Bulk Scientific AAS; Model: Accusys 211; Manufacturer: USA

Appendix 3 Row data of Heavy metal analysis of sediment (mg/Kg)

Sample	Cadmium	Lead	Copper	Iron	Manganese	Zinc
ST1 SD	0.00	11.2	1.45	3059.5	228.2	483.5

	0.00	13.6	1.60	3029.3	231.5	490.6
	0.00	10.4	1.40	3073.6	240.1	475.8
ST2 SD	0.20	19.6	21.4	14400.1	246.2	570.3
	0.20	18.2	22.1	14600.6	235.1	576.5
	0.10	19.8	20.6	14100.3	236.9	569.1
ST3 SD	0.00	0.00	0.00	1473.5	56.4	318.8
	0.00	0.00	0.00	1469.3	59.1	320.5
	0.00	0.00	0.00	1480.4	53.9	317.2

Instrument: Bulk Scientific AAS; Model: Accusys 211; Manufacturer: USA

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RESEARCH ARTICLE

Statistical analysis of research in the study of the implementation of the circular economy in the preservation of water resources

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Abstract

Under the current consumption model, the depletion of natural resources, specifically water, is a reality that we will face if we do not promote a paradigm shift: resources can be reused leaving behind the traditional patterns of taking, manufacturing and discarding. Under this premise, in recent years, the concept of circular economy, an economic premise interrelated with sustainability has become an alternative for responsible consumption. The objective is to maintain water sources, if possible, through controlled and responsible collection, increase the reduction of consumption through the reuse of the resource and the appropriate and optimal treatment for its return to nature. Through Research, Development and Innovation, R+D+i, it is possible to define new schemes for the reuse of water, both for industrial sectors and for local governments; for example, in relation to the management of waste water, which goes from being waste to becoming a resource again. A study of information, bibliometrics and scientometry of scientific articles associated with the circular economy of water resources was carried out to identify research trends in this topic, as well as to establish the parameters of sustainability and governance of this resource. In the management of this resource, certain social, economic, environmental processes, among others, have not been considered, which affects the issue of water governance. In the development of this work, the Scopus database (Elsevier, B.V., 2021) and the Text Mining program VantagePoint (Search Technology, Academic Version 12.0) were used. 425 records were identified, during the period 2010 – 2021, in which an increasing trend of 83% is observed. The researchers' interest is focused on applications in environmental science and engineering. As for the countries, Spain and Italy stand out with the highest number of publications. Given the growing interest and importance in the subject, it is necessary to establish which models should be adopted to optimize the use of water resources, contributing to the protection of this natural supply, key to the prolongation of life.

Keywords: Circular economy; Sustainable; water resources; engineering; Cienciometría; Energy efficiency

Introduction

The concept of circular economy has been implemented in the business environment and, more recently, in the development of public policies. His forerunner in the academic literature was Kenneth Boulding, who claimed that the maintenance of human life on Earth requires a circular model of the economy. With this perspective, it is understood that the biosphere is a closed system, while there is a limit to its ability to provide and regenerate resources to meet human needs. This concept arises in contrast to the linear economy model of production and consumption, in which there is a high extraction of raw materials, intensive use of energy and excessive generation of waste, which constitute a risk to human health and ecosystems. From this perspective, the planet is seen as an infinite means of supplying resources and each of its phases contributes to the emission of pollutants. The negative externalities of this productive model have had an impact on the degradation of the planet and have increased the inequality and vulnerability of the most marginalized populations The report Limits to Growth warns for the first time about the consequences of the ecological footprint associated with economic processes and about the carrying capacity of the planet to regenerate. However, the authors claim that it is possible to change this trend by achieving a balance of ecological and economic processes, without affecting the principle that each person can meet their material needs and ensure their individual well-being. In the seventies, the concept of circular economy gained relevance among environmental ecologists, among which Nico-las Georgescu-Roegan, Herman E. Daly, Crawford Stanley Holling, Christian Leipert, Howard T. Odum and José Manuel Naredo stand out. Through their approaches, these theorists promoted the idea that the waste stream can be reintegrated through closed production cycles (closed circuits) to prevent further extraction and reduce the amount of materials discarded. Later, in the early nineties, David W. Pearce and Kerry Turner explained the interdependencies between the ecological and economic system based on four functions of the environment: services, provision of resources, landfill of waste and emissions and life support system (1993). Generally speaking, the circular economy involves three fundamental principles (Figure 1). Water is one of the most valuable and vital resources of the environment, it follows a natural circular model that regulates the flow of water and ensures its quality. However, as proposed in human-managed systems, they follow a linear model of economic growth, where water qualitatively degrades after use, becoming unsuitable for later use by both humans and ecosystems. The stages of a linear system have reached their limits, where the depletion of a number of natural resources and fossil fuels has been demonstrated, from this point, the Circular Economy must begin to be understood as the intersection of environmental and economic issues that allows the global industry in terms of water resources to obtain water supplies, sustainable and quality for the future, proposes a new model of society that uses and optimizes stocks and flows of materials, energy and waste, and whose main objective is the efficiency of the use of resources. According to , the circular economy is a system where the focus is on the efficient use of resources through the minimization of waste, the retention of long-term value, the reduction of primary resources and closed circuits of products, portions of products and materials within the limits of environmental protection and socio-economic benefits, have the potential to lead to sustainable development and energy efficiency, as in the studies proposed by .(Tsalidis et al., 2022)(from Bridges et al., 2022)(Tsalidis et al., 2022)(Hafsi et al., 2022)(Petterson et al., 2022)(Torres-Guevara et al., 2021)(Healthy et al., 2021)(Díaz-López et al., 2021)(Hernández et al., 2021; Moreno Rocha et al., 2022).

Today, many countries are facing a water security crisis, understood as "the availability of an acceptable quantity and quality of water for health, life, ecosystems and production, along with an acceptable level of water-related risks to people, the environment and the economy". Among the issues that affect water security, it is important to highlight: The increase in the demand for basic products associated with changes in consumption patterns (greater number of inhabitants, greater energy expenditure, increase in waste generation, pollution, etc.). Supply failures (a greater number of inhabitants requires a greater infrastructure adequate to that growth). Risks due to extreme hydrological events (due to the absence of adequate contingency protocols).(Arteaga et al., 2019)(Diaz-Perez et al., 2021)

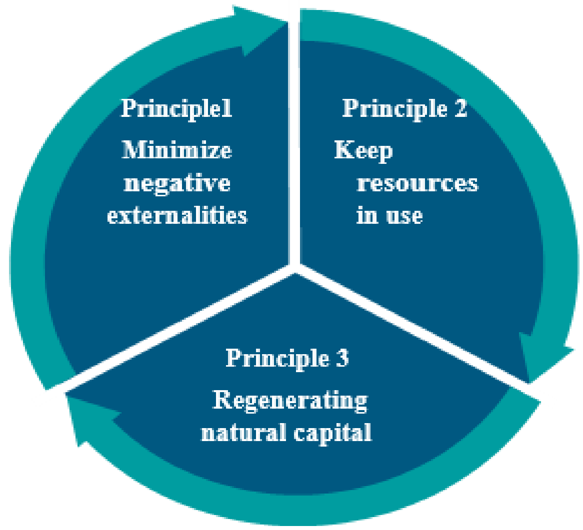


Figure 1: Principles of the circular economy

According to , the circular economy in favor of water would generate an offer of innovative products and technologies, as well as the adoption of effective collaboration models for the integration of water reuse, where norms, criteria and standards related to control and quality are established, reaching the consequent emergency of "new water". After the use of water, a new treatment is carried out, in which the complementary treatment units are organized in cyclical processes, capable of promoting the reuse of water or the new water market, to combat its scarcity. In this way, the introduction of reused water in the current consumption model makes it possible to transform the management of water resources from a linear model to a circular model.(Cervera et al., 2016a)(Cervera et al., 2016b).

The World Bank (2020) conducted the Wastewater report between 2019 and 2020; from waste to resources, in which he addresses the main challenges, opportunities and case studies in Latin America on circular economy. The study highlights the value of wastewater as a source of energy and nutrients, as well as an additional source of water, considering that many countries in the region will face crises of economic water scarcity in the medium term. This implies that, despite the high availability of water resources today, the infrastructure will not be sufficient to meet the growing demand.(Majchrowska et al., 2022)(Cervera et al., 2016c)

Circular economy and water resources

A linear management of water resources contributes to the inefficient and wasteful use of water, increases the use of matter and energy in the phases of water supply among users, increases vulnerability and social inequality in the face of scarcity and affects the degradation of aquatic ecosystems, among many other problems The effects of the linear model on water resources make it necessary to generate technological and management alternatives. The circular model around water resources is presented as a solution that involves the application of sociotechnical tools for the integral solution of these problems(Ahmed et al., 2022)(Mangmeechai, 2022)

The circular economy is proposed as an alternative model of water management, non-obsessive, its implementation depends on institutional support, financial investment for technological innovation, cooperation between key actors and sectors, and the profound socio-cultural transformations around water resources.(Dräger et al., 2022). Water is a critical resource that, while it can be considered a renewable good, is vulnerable to pressures caused by societies. Based on the circular economy perspective, it is necessary to design a closed-loop water management system to meet human needs without compromising the resilience of water-related ecosystems According to Ellen MacArthur FOundation, the principles of the circular economy can be implemented in the management of water systems (Table 1).(Mohammed et al., 2022; Uribe-Toril et al., 2022; Vyhmeister et al., 2017)(Padmanabhan et al., 2022)(Sileryte et al., 2022)

One of the main problems that can be addressed from the Circular Economy in the management of water resources is associated with the conditions of quality, governance, availability of the resource and its different types. For the integral solution of these problems, it is necessary to generate technological and management alternatives, whose objective is to close the resource loops and extend their useful life through greater use, reuse and remanufacturing. From the perspective of the Circular Economy, water reuse is a winning option, the complete wastewater management cycle is a critical component from source to distribution, collection (sewage and sanitation systems (in (Raza et al., 2022)(Pereira & Vence, 2021)(Rödl et al., 2022).

situ) and treatment for disposal and reuse, including the recovery of water, nutrients and energy.(Lambré et al., 2022).

Taking into account the above, it can be concluded that the circular economy linked to the water and sanitation sector has been having a great research interest under the sustainability approach, its incorporation into the sectoral policy seeks the optimal use of resources (water, energy and nutrients) reducing the impacts on the environment. The processes related to the management of the socioeconomic component and the management of water have a relevant impact on the applicability of the mechanisms of participation and governance of this resource, generating business opportunities that give financial sustainability to the services.(Uribe-Toril et al., 2022)(Yamaka et al., 2022).

Table 1: Circular economy principles applied to water management systems. ((Chen, 2022))

Principle 1. Minimize negative externalities	Reduce the amount of energy, minerals and chemicals in the operation of water systems relative to other systems.
	Optimize the consumptive use of water within sub-basins in relation to other sub-basins.
	Implement measures that produce the same result without using water.
Principle 2. Keep resources in use	Improve the management of reserves of different resources (use and reuse of water, energy, minerals and chemicals) within water systems.
	Decrease energy use and resource extraction in water systems and maximize their reuse.
	Optimize the value generated in the interfaces between water service providers and other production systems.
Principle 3. Regeneration of natural capital	Maximize environmental flows by reducing consumptive and non-consumptive uses of water.
	Preserve and improve natural capital (restoration, pollution prevention, effluent quality, among others).
	Ensure minimal disturbance of natural aquatic systems.

Table 2: Application of circular economy approaches around water resources. Own elaboration.

School	Applications	Success stories
Industrial Ecolog	• Wastewater exchange between different sectors for industria use. • Gives a new use to wastewater • Creation of eco-industrial parks to promote synergies between organizations.	- Hai Hua Group (China) Gujarat Maritime Board (India)
Cradle to cradle	• Reuse of wastewater and its by-products to produce goods and services. • Prevention of pollution of water bodies (sources receiving wastewater).	Las Vegas Rock (USA) Ecover (Belgium) Meuse (Netherlands)
Performance economics	• Reduction of the water footprint of industries through the efficient use of water and energy. • Water as a resource to generate goods and energy.	Suez Group (France) HyrdoQuebec (Canada) DuPont (USA) Grundfos (Denmark)
Biomimética	• Technologies and biotechnologies for water treatment. • Clean energy production. • Restoration and conservation of aquatic ecosystems.	WhalePower Corporation (Canada) Aquaporin Inside (Denmark) Applie Biomimetics (USA)
Blue Economy	• Innovation to reduce water consumption in the production o new goods. • Prevention of degradation and restoration of marine ecosystems, using waste for the production of new goods. • Generation of sustainable development around coastal regions.	Aquion emergí (USA) The Blue Circular Economy (European Union) Adidas + Parley (Alemania-EUA) Qingdao Blue Silicon Valley (China

Experimental section

To identify trends and changes in research, a technique called bibliometric analysis is used to determine different patterns related to institutions, topics, countries, and fields, among others. In addition, academic research focused on a specific topic can be quantified over time. The technique consists(Vence & López Pérez, 2021) of the development of a statistical analysis that involves variables such as authors, distribution of journals, keywords and references. For this, certain tools such as Network WorkBench, VOSviewer, HistCite and CiteSpace are available.(Prieto-Sandoval et al., 2021).
In the present work, the HistCite tool was used to perform the statistical analysis, since it has excellent visualization capabilities and is an open access software(Hall et al., n.a.). In addition, this tool is directly focused on the study of trends related to scientific research. For the data collection used in the bibliometric analysis, the Web of Science website was used, since it is one of the main databases used in this type of studies.(Serrano et al., 2020)
The collected data was downloaded from the Web of Science on November 22, 2021, ora scientometric analysis of scientific articles indexed in the Scopus database (Elsevier, B. V., 2021), with the aim of identifying the thematic lines of research of the authors. The following search equation was structured: (TITLE-ABS-KEY ("Circular Economy") AND TITLE-ABS-KEY ("Wastewater Treatment*" OR "Water Treatment*" OR "Water Reuse" OR "Waste Water Recycling" OR "Water Quality" OR "Water Resource*") AND PUBYEAR > 2009 Y (LIMIT-TO (DOCTYPE , "ar") Y (LIMIT-TO (SUBJAREA , "ENVI")). the specialized text mining program VantagePoint (Search Technology, Academic Version 12.0) was used.

Results and discussions

According to the search equation presented above, 425 articles indexed in the Scopus database were identified that relate to "circular economy", "wastewater treatment", "water resources" and "water quality", referring to studies in different fields of knowledge, such as environmental sciences are the ones with the highest activity with 43%, while the area of energy and engineering show a very similar interest of approximately 12% each, (Figure 2).
Using the Law of Solla Prices (ec. 1) (De Solla Price, 1963), the annual growth rate of works related to this topic published from 2010 to 2021 was calculated. According to equation 1, this index was 83.09% with a data correlation of R2 = 0.974.

Figure 2: Distribution of articles by areas of knowledge related to the application of the circular economy of water resources.

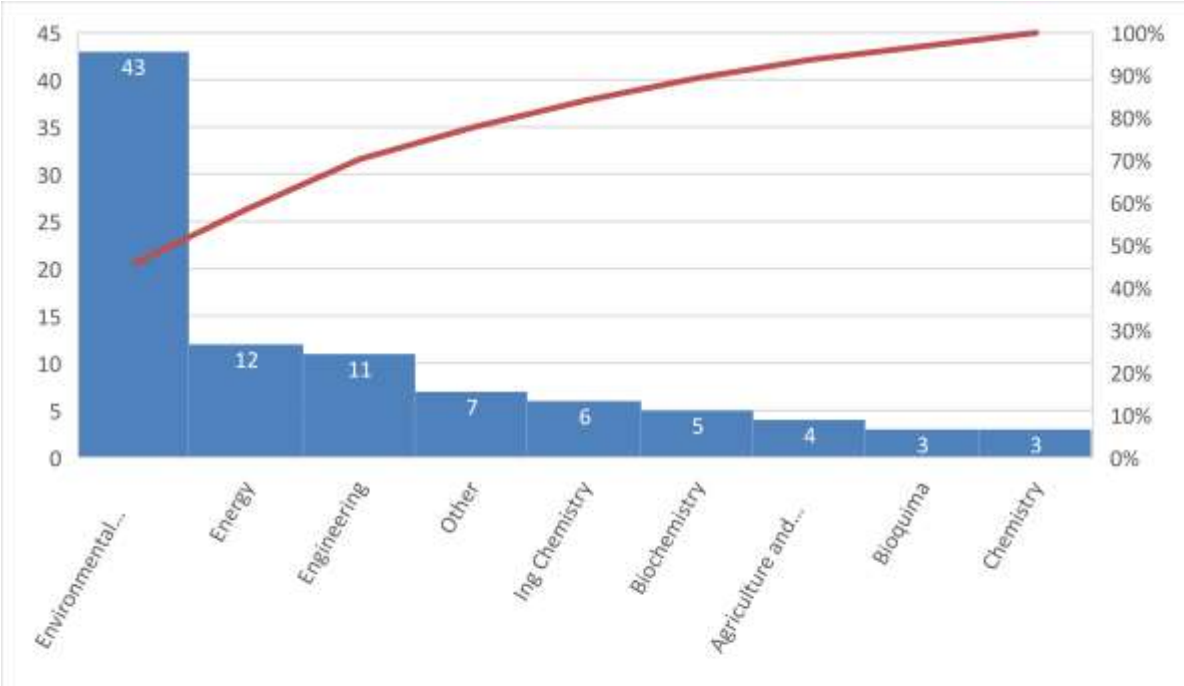
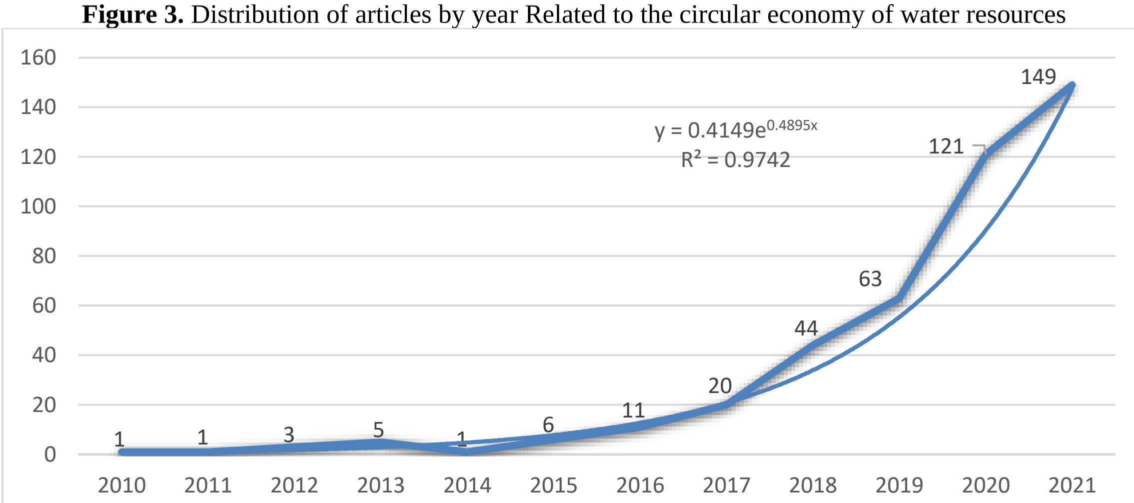


Figure 3 Presents the scientific dynamics (number of articles per year) during the period 2010 – 2021. An increasing trend is observed from the year 2015, the year of greatest activity is 2021 with 149 indexed documents.

Figure 3. Distribution of articles by year Related to the circular economy of water resources



Note. Source: Bibliometrics Unit- CRAI Santo Tomás University Library, Bucaramanga Sectional. Calculations based on information from the Elsevier database (Scopus B.V., 2021), processed with VantagePoint (Search Technology, academic version 12.0).

Ec. 1: $$R = 100\left(e^{b} - 1\right)$$

The performance and scientific output of a country, institution or research centre are directly related to the number of articles published per year (Figure 4). In terms of distribution by country at an international level, Spain stands out with 74 publications related to the circular economy of the water sector. On the other hand, China and Italy present 56 documents indexed in the database, according to the search equation used. At the Latin American level, the country that stands out is Brazil with 21 publications, while these works are related to sludge mixtures from water treatment plants for energy recovery, in these works circular economy indicators were designed as instruments for the evaluation of sustainability and efficiency in wastewater.

The co-occurrence analysis of the keywords allowed to determine the preference in the topic of interest, in this case, the circular economy in the water sector. The free program Vosviewer (2021, Center for Science and

Figure 4: Distribution of scientific production by country between 2010 and 2021 related to the circular economy of water resources

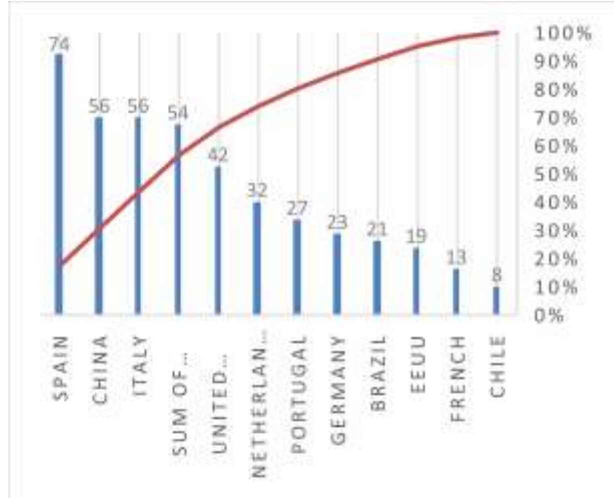
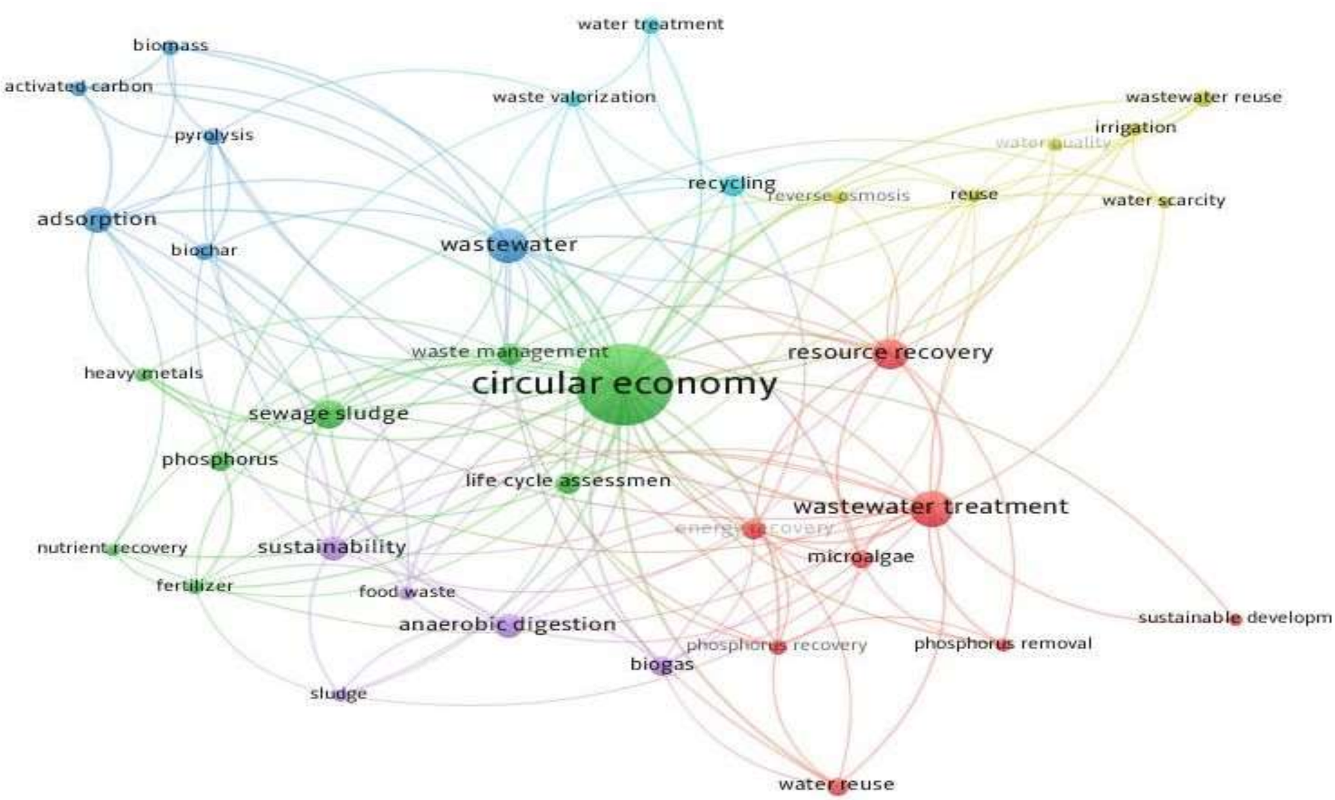


Figure 5: Keywords most used by authors related to the circular economy of water resources



Technology Studies, Leiden University, The Netherlands, version 1.6.15), was used to visualize each of the relationships presented by the keywords (Figure 5). A cluster of words shows an interdisciplinary work and all the topics studied are, for example, development and evaluation of wastewater treatments (235 records), among which reverse osmosis stands out, bioremediation methods for the recovery of water contaminated with heavy metals, pesticides, agrochemicals, among others. 222 documents are associated with the concept of circular economy, especially the recovery of resources such as energy, nutrients among others and a last group (52 documents) are aimed at the management of environmental sciences and sustainable development.

Conclusion

According to the search equation proposed for this work and the number of records obtained, it can be observed that the concept of circular economy applied to water resources is relatively new. However, it presents a high interest, which is verified through Price's law that shows a growth in the number of publications of 83.09% during the period 2010 – 2021, especially in Spain and China, countries where researchers develop work on wastewater treatment methods, the use of resources and the recovery of waste recovered from these same waters. To address water circularity, fundamental changes are needed in the way water is managed and valued, one of the current barriers to truly integrating water. The circular economy of water resources in processes is the lack of indicators, parameters and governance, tools that allow achieving the objective of sustainability by providing economic, environmental and social development. The deployment of a circular economy does not depend solely on cities, it also depends on national policies, private sector participation and a favourable innovation ecosystem. Test the permanent selectivity of ion exchange membranes that is under research consideration.

The linear economy model is not compatible with the sustainable management of natural resources, especially water resources. The principles of the circular economy propose a series of transformations and improvements to reduce pressures on water resources derived from the production, consumption and disposal of goods and services. In addition, it offers the opportunity to improve water management systems and generates development opportunities that have a positive impact on society and ecosystems. The implementation of these principles requires collaboration between producers and consumers, as well as public policies that guarantee the efficient use of materials and energy. It is expected that this work will be of great contribution to future research, which will motivate more scientists from different countries to see in the circular economy a powerful tool in the care and preservation of different energy sources.

Declaration of concurrent interest

The authors state that they have no known competitive financial or personal interest that could have seemed to influence the work re-performed in this article.

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RESEARCH ARTICLE

Slum Prevalence and Crime incidence in Calabar, Nigeria

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Abstract
The problems faced in slums go beyond defacing the city's aesthetic quality and poor housing supply but extend to crime increase. In Calabar, the weaknesses of the government/development partners towards preparing and implementing urban renewal programmes/projects has resulted in sporadic increase in the prevalence of slums. Obviously, places of functional obsolescence with derelict features create breeding ground for crime to thrive. In Calabar, areas mainly in the city core are characterized with moribund environments, deteriorating/deteriorated housing units and poor sanitation systems all of which points to slum development. Crime is prevalent in such areas hence the need to carry out this study. The study focused on ascertaining slum prevalence and crime incidence. A sample of 400 respondents was taken using Taro Yamene formular. Data were obtained from both primary and secondary sources. Questionnaire and housing/environmental quality checklists were the major instrument for data collection. Data were analysed using relative index, frequencies and percentages. It was noted in the study that slums are prevalent in the study area and it prevalence contribute to increasing crime levels. This is because the absence of certain facilities constrain security operation in the slum prevalent area. The study recommended that there should be urgent urban renewal in the study area. Facilities and infrastructure that will increase security level should also be provided

Keywords: Slum; crime; housing/environmental quality; urban renewal; sustainability

Introduction

On a general basis, slums are developments that show attributes/characteristics of overcrowding, dilapidation, deterioration and poor environmental conditions. Infrastructure, facilities and amenities are usually inadequate within such areas. In simple terms, slums are areas of severe deterioration and obsolescence. Instances of infrastructure and facilities that are usually lacking in such areas include potable water, electricity, good roads, recreational ground, schools, clinics and communication facilities. However, the absence of adequate infrastructure and facilities endanger the health, safety and general wellbeing of residents within such deteriorating neighbourhoods. In other words, slums are areas of serious environmental degradation that are characterized by absence of facilities and services that are required to make urban living meaningful (Ekundayo, Faringoro and Job, 2019). Residents within slum areas are therefore subjected to inaccessibility to basic amenities and left to dwell in derelict and areas of functional obsolescence.

Slums are caused by several factors. For instance, urbanization and population growth has been recognized as the leading cause of slums (Okafor and Onuoha, 2016; Yaode, 2019). The fact that urbanization and population growth contribute to slum prevalence suggest that slums can be described as areas that are heavily populated which shows attributes of substandard housing units and squalor. Therefore, the ever-increasing nature of human population has made it difficult to combat with the corresponding development of slums in our urban environment especially in developing countries of the world. Earlier, Roy, Lees, Palavalli, Pfeffer, and Sloot, (2014) established that over half of the population of the world are living in urban areas. They predicted that by 2050, at least 7 out of every 10 human beings will be living in urban areas. While there are serious indications that urban population will increase sporadically, there appear to be no corresponding measures to provide housing units to accommodate the teeming and existing population. At present, most urban residents turn to informal housing and squatters for shelter due to issues relating to housing inaccessibility, increased house rent, acute contention for land/building use. Due to the foregoing reasons, the urban poor have limited chances in accessing housing units with necessary facilities and amenities. Specifically, the inability of the urban poor to comfortably afford housing with necessary facilities and in required standard is not unconnected to the increasing rental values which the urban poor and even the middle class in some areas are usually unable to afford. Although there is slum prevalence in both developed and developing nations, the level at which slums are prevalent in developing countries outweigh it availability in developed nations.

Yaode (2019) reported that in 2001, there were 924 million globally. Specifically, the figure suggest that 32 percent of the world's total urban population are residing in slum. This figure therefore attest to the prevalence of slums in town and cities. Equally in 2001, about 43 per cent of the combined urban populations of all developing regions and 78.2 people of those in least developed countries were slum dwellers. The situation is not different in Nigeria. Although statistics are inexact, current realities suggest that over 45 percent of urban residents in Nigeria are slum dwellers. The figure is likely to increase especially due to inadequate attention which the housing sector is receiving coupled with the increasing poverty level in Nigeria. Clearly, urbanization and slum prevalence in our towns and cities have serious implications on city sustainability through creating diverse problems. For instance, urbanization promote alienation, traffic congestion, pollution, vulnerability, criminality and slum growth/prevalence. Earlier studies (Agbola and Agunbiade, 2007; Ola-Adisa, Enwerekowe and Ella, 2015; Yaode, 2019) have shown that there is serious criminality in slum prevalent areas. The increased level of crime is not unconnected to the fact that the residents of slum areas are economically disadvantaged and socially relegated. Equally, slums are characterized with poor inhabitants that are delinquent in nature, hence crime is relatively on the increase in slums. Most importantly, residents within slum areas are disadvantaged in terms of security. For instance, they are deprived of street lights while police protection is very minimal. All of these give a thriving ground for criminality at various levels.

In Calabar, evidences of slums abound in the city core. For instance, surveys within the study area has shown that residential districts such as Akim Neighbourhood, Ikot Ansa, Ikot Eneobong, Mbukpa, Henshaw Town, Cobham Town, Duke town and several other residential neighbourhoods are habouring slums. Further observations during pilot surveys in the study area explained that residents within this slum prevalent areas are exposed to serious crime levels. Therefore, criminal activities such as rape, robbery and stealing are increasingly high in the districts that have slums. From all indication, it is not out of place to recall that districts of poor housing environments are characterized with inadequate police protection, absence of street lights and other security gadgets which the residents of the slum prevalent areas are suffering tremendously from. From the foregoing, it is clear that slum prevalence has implications on crime incidences in Calabar, Nigeria. In spite of the fact that observations has made it clear that crime incidences abound in the study area specifically in slum prevalent areas, available studies have not been able to discuss the level of crime in slum areas, the specific causes and the effects that it has on residents of the area. Furthermore, an understanding of the level in which slum prevalence and crime incidences inter-relate will be useful in guiding policies that will be useful in guaranteeing urban sustainability. Although the term sustainability is highly contentious in it basic tenets, in this study, the term is used in understudying the level to which the environment can operate in such a way that slum prevalence will be minimized in spite of growing urbanization in the study area. most importantly, the study will contribute to existing knowledge as well as make policies that will stem the tide of slum prevalence and crime incidence in the Calabar, Nigeria.

Conceptual Framework and Literature Review

Concept of Sustainable Development

Holistically, the concept of sustainable development of sustainability is very vital to the present study. The concept is underpinned in the use of available resources in such a way that the future would not be compromised. Therefore, the basic tenets of sustainable development is the use of the resources and environment in such a way that the gains of future generations or the possibilities of future generations to make use of the environment will not be traded off. This suffice that the environment has to be used in such a way that the needs of the present generations will be achieved and future aspirations of generations will not be compromised. Therefore, Nkwocha (2014) suggested that sustainable development is a process of change in which the exploitation of resources, the direction of investment, the orientation of technological development, and institutional changes are all in harmony and enhance both current and future potentials to meet human needs and aspiration. Sustainable development thus emphasis the activities channeled towards preserving the remaining resources and rehabilitating resources that have been treated carelessly in the past.

In a broad sense, sustainable development emphasizes the provision of adequate and affordable basic needs of life such as water, forest and land for the present generation without jeopardizing the prospects of subsequent generations as well as the wise use of the environment to avoid deterioration. Sustainable development planning sense is approached as the development of the environment in such a way that different land uses such as residential, commercial, residential and industrial would operate in such a way that each would not affect the prospects of the other. Basically, the environment as an accommodating base is for facilities, infrastructure/utilities and municipal services as well as different land uses is expected to be managed in such a way that orderliness would be achieved.

The goal of sustainable development is to ensure that the needs of the future are not traded off. This supports what Gbadegesin and Aluko, (2011) considered sustainable development as a movement, a notion and an approach which has developed into a global wave of concern, study, political mobilization and organization around the issues of environmental protection. This is because of the indispensability of the concept in ensuring orderly environmental development and protection.

Sustainable development also reflects the attempt to achieve simultaneously the goals of an improved environment, better economy and a more just and participative society, rather than trading off any one of these against the others (Ilesanmi, 2010). In addition, sustainability issues are considered to ensure that the potential negative significant impacts of development are not allowed to dispute the existence of others having in mind that the environment as an accommodating base is designed to harbour different kinds of activities, infrastructures and so on which should all co – exist in harmony (Ogbazi, 2002; George, 2006).

In his study, Bamidele, Bamidele and Obaseki (2016) sees sustainable development as a socio - ecological process characterized by the fulfillment of human needs while maintaining the quality of the natural environment indefinitely. He adds that if sustainable measures are not established, the environment would face drastic deterioration which would have several negative impacts on man's health and well being. The concept of sustainable development is aimed at preventing resource waste through conservation, maximization of product utility and availability, minimization of environmental degradation and deliberately steering and directing actions and attitudes of resource producers and users towards the maintenance of safe, resilient, clean and healthy environment. Nkwocha, (2014) further asserts that the achievement of the above and more sustainable strategies in the human landscape is 'sine qua non' for the realization of development. In Town Planning, sustainable development is used to bring lasting improvements in the economic, physical, social and environmental conditions of an area. This corroborates the submission by Mbaiwa (2003) that economic viability, social acceptability, technical visibility and environmental compatibility are the key features of sustainable initiatives. In the light of the above, Ibem, Uwakonye and Aduwo (2013) concluded that the adoption of the concept of sustainability of programmes is to ensure that specific social, economic and environmental needs of the present generation are met without compromising the potential of the posterity to meet their needs.

With sustainability as a concept, it is evidently easy to ensure the orderly organization and development of our cities and towns without necessarily causing harm. The reasoning in sustainable development is to ensure that our environment is safe for human habitation and to check the adverse effects of emerging environmental problems which may be caused by parasitic, uncomplimentary and incompatible activities.

From all indication, urbanization and population growth cannot be completely discouraged hence, slum prevalence and criminality is always at the verge of occurrence unless sustainable approaches are adopted in the management of our cities and towns. This imply that adoption of sustainable development as a concept in managing slum prevalent areas will seek for ideas to build channels of crime incidence prevention/protection without necessarily discouraging population explosion in urban areas. This can be done through encouraging economic diversity such that job opportunities will be maximized in urban areas. As expected, one of the leading causes of crime incidence and habitation in slums remain urban poverty hence, giving the economic standard of living adequate attention and expanding sources of earning livelihoods can create a balance between crime, slum prevalence and population growth.

Literature Review

Slum development has become inevitable in urban areas due to the ever increasing number of persons that reside in cities together with the increasing demand for housing development and urban infrastructure/facilities. Holistically, humans have attendant needs for housing since it is a major need of man (Eteng, Mfon and Okoi, 2022). Specifically, housing is ranked second only to housing in the daily needs of man sufficing that it is only food that tops in the chart of human needs (Eteng *et al.*, 2022). Against this backdrop, the increasing number of people suggest a corresponding housing demand. More so, population increases more in the urban areas when compared to rural areas thus, slum development remains inevitable in urban areas due to the foregoing. Although there exist several definitions of slums, salient features for defining slums include inadequate shelter, poor access to basic services, facilities and amenities and low quality of life (Eni and Abua, 2014). Yaode (2019) regard slums as byproduct of the social and economic impacts of rapid urbanization. What constitute slums, it effects and characteristics differ according to scholars. For instance, Yaode (2019) noted that slums are aftermath of migration which is inhabited by the urban poor. He explained that occupants in slums are usually constrained to choose such housing facilities due to poverty, inaccessibility to good housing facilities among other reasons. In his study on the analysis of slums in Ilesa, Yaode obtained data using questionnaire. His respondents were basically slum occupants which he systematically selected. His study revealed that slums in the core area are the product of inadequate housing, lack of timely maintenance of infrastructure and structures, poor environmental quality, environmental degradation, insecurity, disappointment with the unmet need for housing and social amenities. He further showed that slums have negative implications on human health and comfort. With the observation that residents of the study area are faced with such menace, he suggested for urgent urban renewal in Ilesa. He equally recommended the adoption of an integrated planning approach that can reduce rural poverty and improve urban livelihoods since these appear to be the main causes of slum growth in developing nations.

In Akure, Omole and Owoeye (2011) assessed slum characteristics of a deplorable residential district in Akure, Nigeria. Their study adopted the tenets Burgess's planning model to describe the spatial distribution of land-use in Akure with reference to investigating the factors that are responsible for slum formation and city degradation. They further examined the existing environmental situation in Akure with reference to the housing system and the condition of infrastructure facilities. They further assessed the socioeconomic status residents of Akure, their perception of the living environments and problems experienced using questionnaires observation, housing demographic and facility survey as instruments for data collection. Their study showed a high degree of deplorable condition of living environments and the inadequacy of essential facilities for comfortable living. They also noted that the area was overcrowded with derelict buildings that lack basic household services. Due to this, residents lack access to certain facilities and services. They therefore recommended the upgrade of the residential area.

Okafor and Onouha (2016) in Asaba, Delta State observed that urban degradation is caused principally by urbanization process. They claimed that most of the environmental problems in Asaba metropolis suburbs were due to unplanned land uses, swampy nature of built areas and weak development control. Ekudayo *et al.,* (2019) conceived that slums are heavily populated urban informal settlement characterised by substandard housing and squalor. They noted that slums are unavoidable in districts that are thickly populated without corresponding supply of housing units. They showed that slums are characterized by absence of good drainage system, sanitary system, refuse disposal and waste management, sources of water, standard buildings which make living very difficult for the people and also have negative effects on the housing quality of the dwellers within the area. They revealed that slums dwellers are exposed to unhealthy and unsafe environments.

Arimah (nd) opined that the proliferation of slums and informal settlements contribute to the enduring physical manifestations of social exclusion in African cities. Arimah observed that slum dwellers are experiencing deplorable living and poor environmental conditions. Due to the characteristic nature of slums, residents within such areas are excluded from participating in the economic social, political and cultural spheres of the city. This is due to the fact that basic facilities, services and amenities are lacking in such environs. Arimah also observed that slums in Africa are derived from low income level, no financial stability and absence of investment in infrastructure. However, he pointed out that the external debt burden of African countries, high levels of inequality, unplanned and unmanaged urban growth, and the exclusionary nature of the regulatory framework governing the provision of planned residential land are the indicators to slums and squatter settlements in Africa.

From the literature, it is obvious that slums abound in major cities and towns of the world. The causes and effects of slums are multifaceted. However, literature agree to the fact that slums derive largely from urbanization and increasing population. Specifically, while people migrate, they do not move with houses implying that they demand housing units in their new areas of residence. Inadequacies in housing supply which is occasioned by increasing housing demand without corresponding supply therefore make the situation grave. The situation is not different in the study area as increase in housing demand without corresponding supply brings about congestion in existing housing properties and facilities further resulting in deterioration and dilapidation of facilities implying that slum development becomes inevitable. This study therefore seek to address the issue.

Materials and Methods

Study Area

Calabar is the capital city of Cross River State in Nigeria. Calabar is located between latitude 4º50' North and 5º67' North of the Equator and at longitude 8 º18` East and 8º26` East of the Greenwich Meridian. Between 1882 and 1906, Calabar served as the first administrative capital of Nigeria. The city has been growing astronomically over the years. Going by the population trend, the city had a total of 82,100 in 1975 while in 1978, the population had increased to 159,599. The total number of persons increase to 140,200 in 1985 and by 1991, the population was 217,800 320,862. The 2006 population census results put the total number of humans at 375,196 (Agbor *et al.,* 2022). The bulk of the population is made up of migrants from rural areas. Migration into the city has become inevitable due to disparity in the provision of facilities and services of the area when compared to the adjoining rural areas. The people are largely engaged in commercial, industrial, educational and small scale farming activities. Although urbanization is the main factor that trigger population growth in the study area, natural increase through birth rate also account for population growth. The increase in human population without corresponding provision of housing, infrastructure and facilities fast track the level of slum development in the study area.

Methods

In order to obtain data for the study, 20 residential neighbourhoods in the study area that require renewal due to slum prevalence were identified through reconnaissance surveys. From the 20 neighbourhoods, 10 residential neighbourhoods were randomly sampled out. The selection of 10 neighbourhoods represent 50 percent of the districts of serious slum prevalence in the city. In order to obtain relevant data from respondents. The population of the sampled 10 districts was obtained with reference to the 1991 population census results of the study area. According to the 1991 population census results, the sample areas had a population of 85,715. Although the 2006 population census tend to be more recent, the 1991 population results were preferred. This is because in 1991, the population census was reported on the basis on neighbourhoods while the 2006 results were reported on the basis of Local Government Areas. Furthermore, the 1991 population census of the 10 samples areas was projected to 2021 using a growth rate of 3 percent which is the acceptable growth rate for projections in urban areas in Cross River State (Bassey, Amba and Eteng, 2021). The formular is given as follows;

$$Pn = po\left(1 + {}^{r}/_{100}\right)^{n}$$

Equation 1

Where; pn = projected population, Po = existing population, 1 = constant, r = rate of growth (3%), n = number of years projected (30).

The results of the projection showed that a total of 208,288 persons were residing in the study area by 2021. Specifically, data were collected at the household level hence, to have a knowledge of the total number of households in the study area, the average household size of 6 persons was maintained which is the average household size in Calabar (Eteng and Ajom, 2021). The exercise showed that the area comprised of a total of 34,715 households. Therefore, there population of the study comprised of the total household size in the study area. Obviously, the said population is too large and obtaining data from such a large population is unrealizable. Therefore, a minimum sample was drawn from the entire population. To draw an appropriate sample, the Taro Yamene formular was used. The formular for the calculation is as follows;

$$n = \frac{N}{1+N(e)^2}$$

Equation 2

Where; n = Sample Size, N = Finite Population e = Level of Significance (Limit of tolerable error =0.05)

Therefore, $n = \frac{34,715}{1+34,715\ (0.05)^2}$

$$n = \frac{34,715}{1+34,715} \ X\ 0.0025$$

$$n = \frac{34,715}{86.79}$$

n =400

Therefore the sample size for the study was 400.

From the above calculations, 400 copies of questionnaire were administered to households in the study area. In order to deduce the sample from each neighboourhood that is, the number of questionnaire that were distributed in each neighbourhood, the number of households in each neighbourhood were divided by the total households and then, multiplied by the sampled household. Table 1 consist of the population and sample households/number of questionnaire that were distributed in the study area.

Table 1: Population and Sample Size

S/N	Neighbourhood	Population by 1991	Projected Population (2021)	Households	Sample size
1	Ikot Ishie	5825	14,155	2,359	27
2	Ikot Effanga	2747	6,675	1,113	13
3	Ikot Ansa	12057	29,299	4,883	56
4	Ikot Eneobong	1717	4,172	695	8
5	Ikot Omin	7872	19,129	3,188	37
6	Efut Uwanse	21090	51,249	8,542	98
7	Duke Town	2972	7,222	1,204	14
8	Mbukpa	15197	36,928	6,155	71
9	Anantigha	12655	30,752	5,125	59
10	Henshaw Town	3583	8,707	1,451	17
	Total	82742	208,288	34,715	400

Source: National Population Commission, 1991 and Feld Survey, 2022

From Table 1, it is obvious that 400 copies of questionnaire were distributed at the household level in slum prevalent zones of the study area. Specifically, the copies of questionnaire were systematically distributed using appropriate skipping range. Various statistical approaches were used in carrying out analysis. Specifically descriptive statistics such as frequencies and simple percentages. In order to establish the difference in the causes of slum development and it effect, the relative index (RI) was adopted. RI is mathematically represented as follows: RI = $(5n_5+4n_4+3n_3+2n_2+1n_1)$ /5N. The study adopted a five-point likert scale. The grading of the likert scale is as follow; 5 = Very high, 4 = high, 3 = medium, 2 = low and 1 = very low.

Finally, slum prevalence was judged using certain criteria (variables) for housing quality. To this end, housing condition survey checklist was designed in order to understand the quality of the house and draw inferences on the level it is in the slum classification which was adopted in the study. A guide for scoring in order to determine slum prevalence in housing units was designed. As shown in the scoring guide, values were assigned to each option depending on the state of the houses/environment. The highest number in each of the options shown in the scoring guide was used in capturing data for the most suitable element under investigation. For instance, in appraising a house whose walls were intact/sound, 7 was recorded while a cracking wall had 2 and a dilapidating wall was given 1. This was replicated among all the options in the checklist. After each house survey, the outcomes averages were taken. Any house/environment that scored from 50 and above was considered sound, those houses/environment that scored between 40 and 49 were graded as dilapidating house/environments while those that had below 40 were accepted as dilapidated houses/environments. The adoption of the scoring guide help a lot in deducing the prevalence of slums in the study area. The scoring guide is shown below;

Scoring Guide

(a) Condition of Wall

(i) Sound/intact = 7
(ii) Cracking = 2
(iii) Dilapidating = 1

Total = 10

(b) Condition of Roof

(i) Sound/intact = 5
(ii) Leaking = 3
(iii) Sagging = 1
(iv) Part missing = 1

Total = 10

(c) Toilet Facilities

(i) Water closet = 6
(ii) Pit latrine = 3
(iii) Nearby bush = 1

Total = 10

(d) Ventilation

(i) Well ventilated = 7
(ii) Poorly ventilated = 3

Total = 10

(e) Environmental conditions

(1) Drainage
(i) Free = 2
(ii) Blocked = 1

(2) Erosion
(i) Sheet = 2
(ii) Gully = 1

(3) Flood
(i) Not flooded = 2
(ii) Liable = 1
(iii) Flooded = 1

Total = 10

The outcomes were summed to determine housing quality for instance, 7+5+6+7+6

$$= \frac{31}{50} = 62$$

The qualities of the houses were determined as follows;

Sound = 50 percent and above

Dilapidating = 40 to 49 percent

Dilapidated = 39 percent and below

Results and Discussions

Table 1 shows the prevalence of slums in the study area based on certain criteria. As discussed in the methodology, the approaches for deducing the prevalence of slums was the use of housing/environmental condition survey. Housing/environment that depicted dilapidating and dilapidation based on the scoring guide that was adopted were classed as slums. From the information as contained in Table 1, slum prevalence in the study area is high. The prevalence of slums based on spatial locations explained that Henshaw Town with 82 percent drawn from the sample consisted of the largest number of slums in the study area. This is due to the fact that the area is in the city core and most of the landlords that own properties do not pay interest to upgrading/improving the structure. Most of the roles in the area are inaccessible while there is serious absence of infrastructure/facilities which are expected to contribute meaningfully to urban living. Equally, the table showed that the prevalence of slums in Efut Uwanse and Duke Town is very high. The increasing slum prevalence in the area is not unconnected to poor city planning, absence of facilities to carter for the populace and associated issues.

The table further explained that Mbukpa and Ikot Ansa neighbourhoods constitute the least percentage of slums while slums are found at high levels in Ikot Ishie, Ikot Effanga, Ikot Eneobong, Ikot Omin and Anantigha. In all, the observations in the table suggest that slums are prevalent in the study area based on different levels. The prevalence of slums basically constitute serious threat to safety, health and convenience of the residents of the area and even adjoining neighbourhoods. For instance, most residents within the area are deprived of potable water, waste management services while housing units that they are occupying are fast depreciating and deteriorating.

4.1 Level of Slum Prevalence/Housing Quality

S/N	Neighbourhood	Sample	Level of Slum Prevalence			Slum Prevalence		Remark
			Sound	Dilapidating	Dilapidated	Number	Percent	
1	Ikot Ishie	27	9	8	10	18	66.7	High
2	Ikot Effanga	13	5	5	3	8	61.5	High
3	Ikot Ansa	56	26	13	17	30	53.6	Medium
4	Ikot Eneobong	8	3	2	3	5	62.5	High
5	Ikot Omin	37	14	19	4	23	62.1	High
6	Efut Uwanse	98	27	46	25	71	72.4	Very High
7	Duke Town	14	3	6	5	11	78.6	Very High
8	Mbukpa	71	32	18	21	39	54.9	Medium
9	Anantigha	59	23	17	19	36	61	High
10	Henshaw Town	17	3	6	8	14	82	Very High
	Total	**400**	**144**	**140**	**115**	**255**	**100**	**400**

Source: Field Survey, 2022

Level of Crime Incidence

Level of crime in the study area was shown in Table 2. The table explained that crime incidences are occurring at various levels. Specifically, respondents revealed that only 14 percent are not experiencing criminal activities.

In most locations specifically in Duke Town, Henshaw Town and Efut Uwanse neighbourhoods, crime levels are increasingly very high. This is in line with the level of prevalence of slums in the area which is equally high. Increasing crime level is also associated with poor security architecture and lack of technologies for mapping out crime and managing criminal activities in the study area. In most locations within slum prevalent areas, the roads leading to residences are less accessible and as such, it is difficult for police and other security operatives to embark on patrol. Even more, streetlights in the metropolis are not functioning and there are no attempts by the government and it agencies to ensure repairs and maintenance of the streetlights.

All these give rise to unwholesome incidences of criminal activities in derelict areas of functional obsolescence in the study area. It should be noted that one critical feature for defining slum is it lack of necessary facilities/amenities hence, criminal activities are likely to abound where the above and more facilities are lacking.

Table 2: Level of Crime Incidence

Crime Rate	Frequency	Percentage
Very High	92	23
High	57	14.3
Medium	121	30.2
Low	74	18.5
No crime	56	14
Total	400	100

Source: Field Survey, 2022

Slum Prevalence: It Causes

Slums are prevalent in the study area due to certain factors. Table 3 provide detailed summary of causatives of slums in the study area based on ranks/levels. In order to understand vividly the variations in the levels/rank in terms of contribution to slum prevalence in the study area, the Relative Index (RI) was investigated using a 5-point likert scale indicating the levels. In all, it was observed that the major factor that promote slum development in the area was urbanization. Through the process of urbanization, people leave their original places of abode and relocate for reasons such as availability of opportunities, facilities and amenities. In this case, residents in adjoining rural areas migrate to Calabar. Among the indicators to urbanization include the presence of the University of Calabar, the Cross

River University of Technology, Calabar, the School of Nursing, College of Technology and several government ministries and agencies all of which exert pull factors on rural residents. Equally, Calabar play host to the two largest markets (Marian and Watt markets) in Cross River State which attract people for commercial activities.

The negligence of government towards development equally pose challenges and promote slum prevalence for instance, the government are largely unwilling to provide community development facilities/infrastructure which has adverse negative effects on survivability and general environmental conditions of certain districts fast-tracking slum development. Furthermore, poor funding for development of infrastructure, lack of partnerships and weak implementation of plans which all fall within the purview of poor funding contribute and stands as the 3rd causative factor for slums in Calabar. The public which are the project beneficiaries in most cases do not maintain the few available facilities. Sustainable approaches are not also adopted in tapping and harnessing resources which translate to unwise use of facilities that are made available for development in the study area. For instance, electricity supply materials such as cables and transformers experience loads that are above it carrying capacities based on the fact that the public continually mount pressure through extending the direction of electricity supply from such materials. The public do not also appear to be involved in adopting sustainable approaches to water supply systems, waste management systems, electricity supply systems and communication systems. Even in houses of abode, some tenants are not interested in maintaining the housing units that they are inhibiting being that they are not the real owners of the properties. The above instances were noted to be the major causes of slums in the study area.

Table 3: Causes of Slums

Variables	Very High	High	Medium	Low	Very low	RI	Rank
Urbanization	124	96	83	56	41	3.5	1st
Government neglect	99	79	132	34	56	3.3	2nd
Poor funding	111	62	71	99	57	3.2	3rd
Public attitude	65	71	65	97	102	2.8	4th
Poor planning	43	88	54	31	184	2.4	5th

Source: Field Survey, 2022

Effects of Slums on the Environment

The effects of slums on the human environment are basically negative. For instance, Table 4 noted that the major effect of slum prevalence in the study area was that slums provide hideout and habitation to criminals and thieves. As expected, house rent in slum environments tend to be affordable due to the fact that necessary facilities are lacking while the near absence of security operatives only aggravate the issues pointing towards providing hideout to criminals to promote and heighten incidences of crime within the study area. In the order of ranking, the foregoing tend to be the first in the effects of slum while general insecurity and urban/environmental decay tend to rank second and third respectively. The fact that environmental decay is an implication that is caused by the prevalence of slum suffice that there is need to ensure that the tide in which slums are evolving in out towns and cities need to be stemmed to the lowest. Environmental/urban decay has serious implications on the general livability of residents within the area. Housing shourtage which ranks fifth is also affected by the availability of slums and it prevalence within Calabar metropolis.

Table 4: Effects of Slum on the Environment

Variables	Very High	High	Medium	Low	Very low	RI	Rank
Hideout for criminals	201	98	51	21	29	4.1	1st
Insecurity	151	95	91	17	46	3.7	2nd
Environmental decay	132	87	78	91	90	3.5	3rd
Threat to development	61	123	76	98	42	3.2	4th
Housing shortage	89	56	87	86	82	3	5th

Source: Field Survey, 2022

Conclusion and Recommendations

The study focused on analyzing slum prevalence and crime incidences in Calabar. It was observed that slums are prevalent and are found in alarming rate in the level. To deduce what constitute slums, both the environment and housing quality served as indicators. In all, it was observed that slums dominate in the core areas of the city due to reasons bordering around urbanization, public attitudes towards environmental/housing maintenance and government negligence on towards facilities, infrastructure and amenities provision account for slum prevalence. Poor planning and weak enforcements were also indicators to slum development and prevalence in the study area.

The study further noted that due to the prevalence of slums, crime levels are high. In terms of spatial variations in crime, it was noted that slum prevalence and crime incidences were at par in neighbourhoods. This is due to the fact that when areas are deprived of certain amenities and infrastructure such as good roads and street lights, police patrol and other activities that can scare robbers become reduced to the minimum. Street lights which provide illuminations further scaring robbers and hoodlums are mostly absent and when found, are not functioning. All this culminate into alarming levels of crime incidences in slum prevalent areas. Based on the observations, urban regeneration measures were suggested. The best way to slow down the extent in which slums are evolving is the implementation of urban renewal programmes (Ibem *et al.,* 2013). It is therefore inferred that urban renewal plans be prepared while facilities/infrastructure that will support urban living be provided. There should also be slum clearance while site and service schemes should be introduced. Furthermore, professionals should be involved in the planning, design and development of the area. These professionals should include Town Planners, Estate Valuers/Managers, Surveyors, Engineers and Architects. Security should also given priority in slum prevalent areas of the city core.

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