

## The effect of solid waste disposal on Nworie river

O.L. Nwaneri,<sup>1</sup> M.I. Nwachukwu,<sup>1</sup> N. Ihua,<sup>2</sup> C.E.I. Nwankwo,<sup>3,\*</sup>

<sup>1</sup> Department of Microbiology, Imo State University, Owerri, Imo State, Nigeria.

<sup>2</sup> Department of Medical Laboratory Science, Rivers State University, Port Harcourt, Rivers State, Nigeria.

<sup>3</sup> Department of Microbiology, Rivers State University, Port Harcourt, Rivers State, Nigeria.

ORIGINAL RESEARCH ARTICLE

### ABSTRACT

Generally, there is a marked decrease in the volume of surface water due to reasons ranging from global warming to anthropogenic activities. The present study evaluated the effect of waste disposal on Nworie River. The potability of the river was studied in terms of bacteriological and physicochemical parameters. A cross-sectional descriptive study design was used. Sample collection from surface and sediment at three different points of the river and at three different times were performed. Conventional microbiological methods of culture, morphological and biochemical assays for isolation and identifications were used. Also, APHA standard analytical methods for the physicochemical assay were employed. Total heterotrophic bacterial count was highest at point A ( $4.4 \times 10^3$  CFU/mL) and lowest at C ( $3.0 \times 10^1$  CFU/mL). Similarly, all other examined bacteria (Coliform, Shigella and Vibrio) were highest at point A and lowest at point C. There was an even distribution of all bacteria both in the surface and sediments across all sampling points A, B and C. Most physical and chemical attributes of the river studied had deviated from acceptable limits for potable water. The domestic and other wastes dumped into Nworie River adversely affected the water body standard. The presence of certain pathogenic bacteria, as well as indicator organisms, has compromised the potability of Nworie River. Further, the physico-chemical properties support the contamination of this water body and suggest unsuitability for human consumption.

### KEYWORDS

Bacteriological, Nworie River, Physico-chemical, Potable, Waste

## 1. INTRODUCTION

An adult human consists of up to 60% water (Mitchell et al., 1945). This water is usually taken up by man from various sources. Of all the water resources available, the fresh water is of a low percentage. Surface water presents an important source of the fresh water (Akoteyon et al., 2011) and the sources include rivers, lakes and streams in Sub-Saharan Africa, including Nigeria (Santos et al., 2017). However, the volume of water available to all life forms from these surface water bodies is constantly declining (Neff et al., 2000). This is due to various reasons ranging from global warming to anthropogenic activities (Munishi and Sawere, 2014). World Health Organization (2006) reports that surface

water sources are reducing drastically due to pollution. Massive population growth, matched with increased waste generation has become a global challenge, especially in developing nations (Marques et al., 2012). Momodu et al (2011) indicate that solid waste management is a pressing environmental and public health issue in Nigeria, worsened by urbanization (Aguwamba, 2003). Other studies estimate a per capita waste generation of 119 million tons per annum (Nkwocha et al., 2011).

With the recent increase in global population, waste disposal has impacted negatively on surface water bodies (Akoteyon et al., 2011). Marques et al. (2012) reported that waste account for a reasonable level of water contamination. These contaminants in turn influence important physical, chemical and

Corresponding author: C.E.I. Nwankwo

Tel: +2348036503227

E. mail: ononanzennia@hotmail.com

Received: 05-03-2018

Revised: 16-03-2018

Accepted: 23-03-2018

Available online: 01-04-2018

biological quality parameters of the water, and thereby affect human health (Marques et al., 2012).

Consequently, there is a need for proper waste disposal measures. Various Government regimes have set up waste management bodies to tackle the challenge. This has led to massive but insufficient improvements with an evident litter of waste everywhere in the environment. A study by Nkwocha and Emeribe (2004), identified up to 150 dump sites in the South-East and South-South Nigeria. This study indicated that some of the waste dump sites were illegal and haphazardly managed. Some of the sites were inadequately sited, uncovered and some even close to or inside surface water bodies such as rivers. These poor practices pose a public health risk, contributing to vector proliferation as well as leachate that may seep to underground water and farmlands (Momodu et al., 2011; Nkwocha et al., 2011).

The World Health Organization has announced that the world is on course with meeting safe drinking water needs (WHO, 2006). However, this report regrets that the world is lagging in terms of meeting sanitation goals, noting only a 1% improvement as at 2004. Unhealthy sanitation and waste management procedures have left surface water contaminated and consequently reservoirs for disease vectors and germs (Momodu et al., 2011; Nkwocha et al., 2011; Acholonu et al., 2008; WHO, 2006). This 2006 WHO report implicate poor sanitation and unsafe water for the death of up to 1.6 million children globally. In the case of Sub-Saharan Africa, from 1990-2004, there was a 23% increase in the number of people without safe drinking water.

The need for safe waste disposal practices as a way of protecting the water resources as well as the environment is therefore high. This is owing to the integral place of the water bodies as a source of water supply for many in both urban and rural communities (Nkwocha et al. 2011). Maintaining global water standards will also reduce vector proliferation in water (Aboyeji, 2013). Key to maintaining the recommended water quality standard is to ascertain the impact of waste discharged and dumped into these water bodies. Studies show that a good understanding of pollutants is key to reducing its effects on flora and fauna in an environment (Abollino et al., 2002; Thakali et al., 2006).

The Nworie River is significant on the Map of Owerri, Imo State. It is first order river that runs 5 km across Owerri to empty into the Otamiri River (Alex et al., 2008). It has been considered a key source of water to Owerri residents. However, this important

water source is also at the receiving end of various anthropogenic activities. A visit to the River shows that domestic and industrial wastes are discharged into the water body. The need for a study to ascertain the quality of the water from Nworie River is thus high, considering public health as well as its inhabiting biota. The potability of water depends on its biological, physical and chemical properties (Nkwocha et al. 2011; Acholonu et al., 2008; WHO, 2006). The physico-chemical properties impact on the biota of the water body.

The present study was aimed at obtaining the effect of wastes and other domestic activities on the potability of Nworie River. The specific objectives were to:

- i. Identify important sampling points of the Nworie river.
- ii. Obtain water samples
- iii. Test for potability of the river on the basis of microbiological, physical and chemical parameters.

## 2. MATERIALS AND METHODS

Nworie river is located in Owerri, Imo state at latitudes 5°25'–5°30'N and longitudes 7°00'–7°05'E, covering an area of 1135 km<sup>2</sup>. Nworie river measures approximately 9.2 km in length. The river is subject to rigorous domestic human and industrial activities. This contributes to contamination and pollution of the river although, it was a source of drinking water in time past by those who had no access to drinking water, particularly when the public water supply system fails (Acholonu et al., 2008). It serves as a source of water used for other domestic and industrial activities. However, human activities have negatively affected the river. It has been observed that the waste disposal widely practiced by residents of Owerri is to open dump solid wastes directly into the river (Ishaku and Ezeigbo 2010; Acholonu et al., 2008).

A cross-sectional descriptive study design was used in this present study. Sample collection was from three different points of the river at different times; the first point sampled was the Central point of Nworie river (point A), followed by the Oparanozie axis of the river by Edede dump site (point B) and lastly Upper/Solitary point of Nworie river also at Egbeada-third point (point C). Representative specimens were collected from the Nworie river and used for analysis. The water samples were collected from the sediment and surface levels of the Nworie river. The samples

were examined using conventional microbiological methods of culture, morphological and biochemical assays for isolation and identifications according to those reported early (APHA, 1992; Cheesebrough, 2000). For the physicochemical assay, water samples were collected and analyzed according to APHA (1992) and Cheesebrough (2000) standard analytical methods of the physicochemical assay (APHA, 1992). GraphPad calculator and SPSS version 21 were used to analyze data for mean, standard deviation and t-test at 0.05 level of significance.

### 3. RESULTS AND DISCUSSION

The present study highlights the quality of the Nworie River. The three components for obtaining water potability (biological, physical and chemical) were studied as recommended by the previous studies (Acholonu et al., 2008).

#### 3.1. Microbial load of Nworie river

The bacterial load and coliform count of Nworie river were studied at various points. Bacterial load is used as an indicator of potable water, whereas coliform count is used as fecal contamination indicator. The total heterotrophic bacteria count was highest at the central point of Nworie River and least at the upper point. Similarly, the coliform count and Salmonella/ Shigella count were also highest at the central point and least at the upper point. Also, Total Vibrio Count (TVC) was highest at Oparanozie axis of the river by Edede dump site as obtained from the surface water, whereas Upper/Solitary point of Nworie River also at Egbeada point exhibited the least TVC from the sediment (Table 1).

The bacterial load at the various sampling points were higher than acceptable levels in water according to National Food and Drug Administration and Control (NAFDAC) and World Health Organization (WHO) standards (NAFDAC, 2001; WHO, 2001). This is likely from the waste dumped into the water body. Previous studies have implicated the discharge of domestic waste for the increase in the bacterial load of water (Nkwocha et al., 2011; Acholonu et al., 2008). The presence of coliform in detectable levels indicates fecal contamination (Acholonu et al., 2008). This may be due to the discharge of feces into the water body or direct defecation into the water. A visit to the Nworie river shows that residents, including children, take their bath in this stream. It could be that the children discharge their waste as they take their bath. Some domestic waste discharged in the river also includes diapers and others. This is another source of coliform and bacteria recorded in the water.

The occurrence of pathogenic bacteria was also checked. Of the four species studied, only *E. coli* was present at all sampling points. *Salmonella* spp occurred at the Central and Oparanozie points, *Vibrio* was found only at the upper sampling point while *Shigella* spp didn't occur at any of the sampling points at a detectable level (Table 2).

Furthermore, though the surface water appeared to have higher bacterial counts (Figure 1) in all the three locations when matched with the sediment water, the study which hypothesized no variations retained the null hypothesis as the comparative analysis of the mean bacterial counts obtained in this study revealed no evidence of statistical significance ( $p > 0.05$ ) in all the parameters investigated (Table 3).

The total heterotrophic bacterial count was also high. Bacteria play a key role in the degradation of organic waste (Repeta et al., 2016). Results from

**Table 1.** Frequency distribution of the bacterial load of Nworie river

Sample Point	Depth	THBC (CFU/mL)	TCC (CFU/mL)	SSC (CFU/mL)	TVC (CFU/mL)
Point A	Surface	$4.4 \times 10^3$	$2.5 \times 10^3$	$2.3 \times 10^3$	$2.2 \times 10^2$
	Sediment	$3.1 \times 10^3$	$2.2 \times 10^3$	$2.1 \times 10^3$	$2.1 \times 10^2$
Point B	Surface	$4.4 \times 10^1$	$2.5 \times 10^2$	$2.4 \times 10^2$	$3.1 \times 10^2$
	Sediment	$4.1 \times 10^1$	$2.1 \times 10^2$	$2.2 \times 10^2$	$2.5 \times 10^2$
Point C	Surface	$3.4 \times 10^1$	$2.3 \times 10^1$	$2.0 \times 10^1$	$2.1 \times 10^1$
	Sediment	$3.0 \times 10^1$	$2.1 \times 10^1$	$1.8 \times 10^1$	$1.9 \times 10^1$

this study revealed elevated biological oxygen demand (BOD) and chemical oxygen demand (COD) values. These indicate the presence of organic pollutants (Heddam et al., 2016). The presence of these organic materials would make for the proliferation of degrading organisms such as bacteria (Repeta et al., 2016). This may explain the high bacterial load in Nworie river in this study. The bacterial population sampled included both pathogenic and non-pathogenic strains. There was no significant difference in the bacterial load between the surface water and sediments sampled. This indicates prolonged contamination by solid waste aided by easy miscibility associated with surface water bodies like Nworie river.

including cholera, typhoid fever, diarrhea (Kulinkina et al., 2016), as well as parasitic infections (Ikpeama et al., 2016). The even distribution of all organisms across the sampling points (A, B & C) and depth (surface and sediment) indicates prolonged exposure to contamination and a characteristic of an even distribution of substances present on water bodies.

### 3.2. Physico-chemical parameters of Nworie river at different sample points

The physico-chemical parameters as a measure of water quality of Nworie River was studied. The pH was slightly acidic at points A and B whereas slightly basic at point C (Table 1). Temperature was uniform across the sampling points with the BOD relatively high at 22, 23 and 25 for points A, B and C respectively. The high BOD values indicate pollution as well as the presence of organic matter. Similarly, the chemical oxygen demand was high across all study points (Table 4).

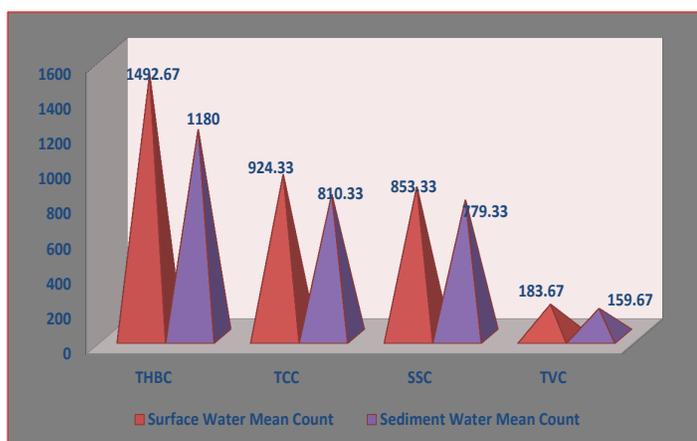


Figure 1. Chart showing mean distribution of bacterial counts

Table 2. Occurrence of pathogenic bacteria from different sampling points

Isolates	Point A	Point B	Point C
<i>Salmonella</i> spp.	+	+	-
<i>Vibrio</i>	-	-	+
<i>Shigella</i> spp.	-	-	-
<i>Escherichia</i> spp.	+	+	+

The presence of *E. coli* and other pathogenic bacteria at most sampling points in the river makes it unfit for human use. The WHO (2001) and NAFDAC water potability standard (2001) insists that there must be zero *E. coli* in potable water (Nkwocha et al. 2011). The presence of this organism in the water further shows contamination by anthropogenic activities such as bathing. The presence of *E. coli* and other coliform bacteria is of great public health concern. These organisms have been implicated for several diseases

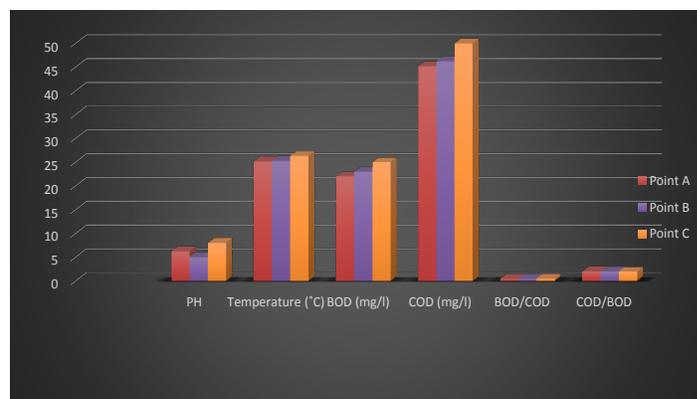


Figure 2. Mean distribution of physiochemical properties of Nworie river water sample.

In this study, a t-test was used to compare the physico-chemical parameters; Points A and B showed no significant difference between these two points for the parameters studied (Table 5). Conversely, a similar test between Point A and C returned significant difference in all parameters studied except temperature and COD/BOD (Table 6). This is in line with the raw data, as no difference in temperature was noticed across the sampling points (Table 4; Figure 2).

A further comparative study between points B and C returned with no difference in parameters studied except pH (Table 7). In addition, the physico-chemical qualities of the river suggest pollution. Acholonu et al. (2008) reported a high BOD while suggesting the need for microbiological studies to further confirm the state of the water. The present study also reported high

**Table 3.** Comparative mean, standard deviation (SD) and t-test distribution of TCC, SSC, TVC and THBC between surface and sediment

Parameters	N=3; Mean ± SD Surface	N=3; Mean ± SD Sediment	t-value	df	p-value
THBC	1.4x10 <sup>3</sup> ±2.5x10 <sup>3</sup>	1.2x10 <sup>3</sup> ±1.7x10 <sup>3</sup>	0.6190	2	0.5990
TCC	9.2x10 <sup>3</sup> ±1.4x 10 <sup>3</sup>	8.1 x10 <sup>2</sup> ±1.2 x10 <sup>3</sup>	1.2174	2	0.3476
SSC	8.5x10 <sup>2</sup> ±1.6x10 <sup>3</sup>	7.8 x10 <sup>2</sup> ±1.2 x10 <sup>3</sup>	1.1706	2	0.3624
TVC	1.8 x10 <sup>2</sup> ±1.4x10 <sup>2</sup>	1.6 x10 <sup>2</sup> ±1.2x10 <sup>2</sup>	1.3225	2	0.3170

Note: Table showing a combination of all the various points i.e. point A, B and C for both surface and sediment water samples.

**Table 4.** Frequency Distribution of Physico-Chemical Parameters

Parameters	Point A	Point B	Point C	Aggregate Mean±SD
pH	6.26±0.379	5.04±0.757	8.05±0.567	6.45± 0.567
Temperature (°C)	25.20±0.597	25.30±0.701	26.30±0.621	25.60± 0.639
BOD (mg/L)	22.00±0.986	23.00±1.325	25.00±1.392	23.33± 1.234
COD (mg/L)	45.20±1.837	46.20±2.38	50.00±1.038	47.13± 1.751
BOD/COD	0.487±0.05	0.498±0.076	0.500±0.003	0.495± 0.043
COD/BOD	2.055±0.030	2.009±0.028	2.00±0.030	2.021± 0.029

**Table 5.** Mean, standard deviation and t-test of physico-chemical parameters of Point A and B

Parameters	Point A Mean±SD	Point B Mean±SD	t-value	DF	P-value
pH	6.26±0.379	5.04±0.757	2.461	4	0.07
Temperature (°C)	25.20±0.597	25.30±0.701	0.1881	4	0.86
BOD (mg/L)	22.00±0.986	23.00±1.325	1.0487	4	0.35
COD (mg/L)	45.20±1.837	46.20±2.38	0.5761	4	0.59
BOD/COD	0.487±0.05	0.498±0.076	0.2094	4	0.84
COD/BOD	2.055±0.030	2.009±0.028	1.9415	4	0.12

**Table 6.** Mean, standard deviation and t-test of physico-chemical parameters of Point A and Point C

Parameters	Point A Mean±SD	Point C Mean±SD	t-value	DF	P-value
pH	6.26±0.379	8.05±0.567	4.5460	4	0.01
Temperature (°C)	25.20±0.597	26.30±0.621	2.2118	4	0.09
BOD (mg/L)	22.00±0.986	25.00±1.392	3.0461	4	0.04
COD (mg/L)	45.20±1.837	50.00±1.038	3.9402	4	0.02
BOD/COD	0.487±0.05	0.500±0.003	3.8616	4	0.02
COD/BOD	2.055±0.030	2.00±0.030	2.2454	4	0.09

COD and BOD. The average BOD of the present study (23.33± 1.234) across the sampling points surpassed the NAFDAC/WHO standard of 0.3 (Nkwocha et al., 2011). Biological Oxygen Demand (BOD) is used as an index for determining the amount of decomposing

organic matter as well as the rate of biological activities in water (Nartey et al., 2012). This is based on the knowledge that decomposing organisms require oxygen for respiration. The high concentration of BOD in this study indicates the presence of organic matter.

**Table 7.** Mean, standard deviation and t-test of physico-chemical parameters of Point B and Point C

Parameters	Point B Mean±SD	Point C Mean±SD	t-value	DF	P-value
pH	5.04±0.757	8.05±0.567	5.5122	4	0.01
Temperature (°C)	25.30±0.701	26.30±0.621	1.8495	4	0.14
BOD (mg/L)	23.00±1.325	25.00±1.392	1.8025	4	0.15
COD (mg/L)	46.20±2.38	50.00±1.038	2.5349	4	0.06
BOD/COD	0.498±0.076	0.500±0.003	0.0455	4	0.97
COD/BOD	2.009±0.028	2.00±0.030	0.3799	4	0.72

This supports the high THBC, TCC, TVC as well as SSC recorded in this study (Table 1).

Similarly, the average COD in this study (47.13±1.751) surpasses the acceptable limit of 40 by NAFDAC/WHO (Nkwocha et al., 2011). This again shows the high level of contamination in the river. All sampling points and tested areas were high in COD values.

The current study records high temperatures at all sampling points with an average of 25.60±0.639oc. Increased temperature increases respiration. This leads to increased oxygen consumption and increased decomposition of organic matter (Nartey et al., 2012). Water temperature affects the concentration of biological, physical, and chemical constituents of water. The relatively high temperatures recorded in this study explains the high COD and BOD recorded. These are indicators of presence and breakdown of organic matter. Furthermore, the high bacteria load of the tested water is explained by appropriate breeding temperature for the organisms. It is even more alarming to note that if nothing is done to forestall the trend, the bacterial and phytoplankton would double in a very short time. This is in consonance with the findings of the previous study by Nartey et al. (2012).

The pH values recorded in the present study were within the stipulated limits by NAFDAC/WHO. The pH values recorded may be due to direct disposal of refuse into Nworie river as recorded in previous studies (Nartley et al., 2012). This high pH may be due to the presence of pollutants in the water.

## 4. CONCLUSIONS

The present study showed that Nworie river is unfit for human use. This is based on the indices for ascertaining the potability of water. The values of microbial load, physical and chemical parameters indicate pollution. The microbial load across all sampling points were too high compared to acceptable limits. The presence of

coliforms in the river also proves fecal contamination as so renders the water unsafe. Similarly, all the samples of river failed to meet quality test based on other physical as well as chemical parameters studied. The river is, therefore, a public health risk. It is important that the public is made aware of the state of the water while efforts are made for further studies. Remediation of this water body is possible with a clear picture of the level and source of contamination provided by this research.

## REFERENCES

- Abollino, O., Aceto, M., Malandrino, M., Mentasti, E., Sarzanini, C., Barberis, R. (2002) Distribution and mobility of metals in contaminated sites. *Chemometric investigation of pollutant profiles*. *Environmental Pollution*, 119, 177-193.
- Aboyeji, O.O. (2013) Freshwater pollution in some Nigerian local communities, causes consequences and probable solutions. *Academic Journal of Interdisciplinary Studies*, 2, 111.
- Acholonu, A.D.W., Okorie, P.U., Fipps, M.N., Davis, K.L. (2008). Chemical profile of Nworie river in Owerri Imo state. 93rd ESA annual meeting at the Midwest Airlines Center Milwaukee, Wisconsin USA.
- Agunwamba, J.C. (2003). Optimization of solid waste collection system in Onitsha, Nigeria. *International Journal of Environmental Issues*, 1, 124-135.
- Akoteyon, I.S., Omotayo, A.O., Soladoye, O., Olaoye, H.O. (2011) Determination of water quality index and suitability of urban river for municipal water supply in Lagos-Nigeria. *European Journal of Scientific Research*, 54, 263-271.
- Alex, D.W., Peter, U.O., Melissa, N.F., Kelly, L.D. (2008) PS 1-20: Chemical profile of Nworie River in Owerri, Imo State, Nigeria. 93rd ESA annual meeting at the Midwest Airlines Center Milwaukee, Wisconsin USA.
- American Public Health Association, APHA. (1992) Standard Methods for the Examination of Water and Wastewater; APHA – AWWA – WEF, 18<sup>th</sup> Ed. Washington D.C.
- Cheesebrough, M. (2000) District laboratory practice in tropical countries part 2. Cambridge University Press, 76-100.
- Heddiam, S., Lamda, H., Filali, S. (2016) Predicting effluent biochemical oxygen demand in a wastewater treatment plant using generalized regression neural network based approach: a comparative study. *Environmental Processes*, 3, 153-165.

- Ikpeama, C.A., Obiajuru, I.O.C., Ogomaka, A.I. (2016) The impact of refuse disposal dump sites on the spread of intestinal Helminthiasis in Owerri metropolis, IMO state, south eastern Nigeria. *International Journal of Clinical Chemistry and Laboratory Medicine*, 2, 13-18.
- Ishaku, J.M., Ezeigbo, H.I. (2010) Groundwater quality monitoring in Jimeta–Yola area, Northeastern Nigeria. *Water Resources*, 20, 1–14.
- Kulinkina, A.V., Mohan, V.R., Francis, M.R., Kattula, D., Sarkar, R., Plummer, J.D., Naumova, E.N. (2016) Seasonality of water quality and diarrheal disease counts in urban and rural settings in South India. *Scientific Reports*, 6, 20521.
- Marques, R.F.D.P.V., Silva, A.M.D., Rodrigues, L.D.S., Coelho, G. (2012) Impacts of urban solid waste disposal on the quality of surface water in three cities of Minas Gerais-Brazil. *Ciência e Agrotecnologia*, 36, 684-692.
- Mitchell, H.H., Hamilton, T.S., Steggerda, F.R., Bean, H.W. (1945) The chemical composition of the adult human body and its bearing on the biochemistry of growth. *Journal of Biological Chemistry*, 168, 625-637.
- Momodu, N.S., Dimuna, K.O., Dimuna, J.E. (2011) Mitigating the impact of solid wastes in urban centres in Nigeria. *Journal of Human Ecology*, 34, 125-133.
- Munishi, L. K., Sawere, P. C. (2014). Climate change and decline in water resources in Kikuletwa Catchment, Pangani, Northern Tanzania. *African Journal of Environmental Science and Technology*, 8, 58-65.
- Nartey, V.K., Hayford, E.K., Ametsi, S.K. (2012) Assessment of the impact of solid waste dumpsites on some surface water systems in the Accra metropolitan area, Ghana. *Journal of Water Resource and Protection*, 4, 605-615.
- National Agency for Food, Drug Administration and Control, NAFDAC. (2001) Ministry Safety Bulletin, Lagos Nigeria.
- Neff, R., Chang, H., Knight, C.G., Najjar, R.G., Yarnal, B., Walker, H.A. (2000) Impact of climate variation and change on Mid-Atlantic region hydrology and water resources. *Climate Research*, 14, 207-218.
- Nkwocha, E.E., Emeribe, A.C. (2004) Proliferation of unsanitary solid waste dumpsites in urban and sub-urban areas in Nigeria: need for the construction of regional sanitary landfills. *Journal of Environmental Systems*, 31, 315-331.
- Nkwocha, E.E., Mbano, E.C.P., Nnaji, A.O. (2011) Effect of solid waste dump on river water quality: a paradigm in a Nigerian tropical environment. *International Journal of Science and Nature*, 2, 501-507.
- Repeta, D.J., Ferron, S., Sosa, O.A., Johnson, C.G., Repeta, L.D., Acker.M., Delong, E.F., Karl, D.M. (2016) Marine methane paradox explained by bacterial degradation of dissolved organic matter. *Nature Geoscience*, 9, 884–887.
- Santos, S.D., Adams, E.A., Neville, G., Wada, Y., Sherbinin, A., Bernhardt, S.B. (2017). Urban growth and water access in sub-Saharan Africa: progress, challenges and emerging research directions. *Science of the Total Environment*, 607-608, 497-508.
- Thakali, S., Allen, H.E., Di Toro, D.M., Ponizovsky, A.A., Rooney, C.P., Zhao, F., McGrath, S.P. (2006) A terrestrial biotic ligand model. 1. Development and application to Cu and Ni toxicities to barley root elongation in soils. *Environmental Science & Technology*, 40, 7085-7093.
- World Health Organisation, WHO. (2001) Guidelines for Drinking Water Quality, Recommendations, Geneva.
- World Health Organization, WHO. (2006). Meeting the MDG Drinking Water and Sanitation Target: the Urban and Rural Challenge of the Decade.