A COMPARATIVE STUDY OF UPSTREAM AND DOWNSTREAM WATER QUALITY OF WARRI RIVER, IN DELTA STATE, SOUTHERN NIGERIA

Ozabor Famous
Dennis Osadebay University

2023
September
coou African Journal of Environmental Research *Vol 4, No. 2, 2023. pp 42-53*

A COMPARATIVE STUDY OF UPSTREAM AND DOWNSTREAM WATER QUALITY OF WARRI RIVER, IN DELTA STATE, SOUTHERN NIGERIA

OchukoUshurhe[1], Ozabor Famous[1] & Thaddeus Origho[2]

[1]*Department of Environmental Management and Toxicology Dennis Osadebe University, Asaba*

[2]*Department of Urban and Regional Planning University of Delta, Agbor*

Email: famous.ozabor@dou.edu.ng

Abstract

Warri River is a major river in Southern Nigeria which serves several poor communities' water demands. As such the water from this river serves domestic, industrial and agricultural purposes. The river also serves as a means of transportation for people, companies and communities that exist on the islands that dot the Niger Delta Region. The importance of this river necessitated this study on 'comparative Study of Upstream and Downstream Water Quality of Warri River'. The study was carried out by collecting water samples from the river between January 2022 to December 2022 using systematic sampling techniques at both the up and downstream sections of the river. A total of 48 water samples (using 100 meters apart) were collected and analysed for physicochemical and biological indices. The results showed that variations exist in the concentration of physicochemical and biological parameters in the upstream and downstream sections of the river. While such parameters as EC, temperature, TDS, TSS, BOD, COD, Na, Calcium, Potassium showed higher concentrations in the downstream section, others such as pH, DO, Zn and Fe recorded higher concentrations in the upstream section of the river. As a result of the characteristics observed,it was recommended that routine monitoring of human activities and testing of the river water be done from time to time, to harness the full capacity of the river and ensure eco-sustainability.

Keywords: Warri River, Water Pollution, Water Quality, Water Resources

INTRODUCTION

Surface water (rivers inclusive) represents one of the most viable resources, if properly managed (Obisesan & Ozabor, 2016). Its development refers to the act of making its physical, chemical and biological characteristics suitable for more use by locals (Diersing, 2009; Iwegbue et al., 2023). It is common to measure water (in this case river) using its chemical, biological and bacteriological qualities (Darko et al., 2022). Therefore, water resources development and quality can be assessed using either or all avenues, namely: chemical, biological and bacteriological characteristics

(Hodgson, 2006; Mishra et al., 2022). The most common standards used to assess water resources relate to drinking water, safety of human contact and for the health of eco-systems (USEPA, 2006; du Plessis, 2022).

Chemical investigation of water resources of some Nigeria rivers reported by Ajayi and Osibanjo (1981), Adeniyi and Mbagu (1983), Imevbore (1970), Asuquo (1989), Efe (2002), Ibor et al., (2023) and Ololade et al., (2023) reveal that water which, was once an abundant natural resource is rapidly becoming scarce both in quantity, and quality in many places. Factors responsible have been listed by these authors to include population increase, rapid industrialization, pollution and rural/urban migration. Pollution of freshwater bodies is mostly experienced because of industrial discharge, municipal domestic sewage disposal, surface run-off from farmlands, underground water, salt water intrusion and inundation (Asuquo, 1989; Ogidiaka et al., 2022). Generally, natural water bodies will vary in response to environmental conditions and perturbations. Therefore, researchers are interested in identifying the source and fate of contaminants on fresh water bodies. Researchers and policy makers work to ensure that water is maintained at an appropriate quality for its identified use (Hodgson, 2006; Carey et al., 2022), hence this study examines water resources management at both the upstream and downstream sections of Warri River in Southern Nigeria.

Mere looking at the vast majority of surface water on the planet will not tell whether the water in question is potable or toxic. Water quality assessment, therefore, tells whether water is polluted or not. In fact, water resource management is a very complex subject, in part, because water is a complex medium intrinsically tied to the ecology of the earth (USEPA, 2002; Cunha, 2023).There are also traditional and sentimental attachments to water bodies, with claims of how such water bodies are abodes for local gods which people serve or worship (Adeyemi et al., 2022). On the other hand, industrial pollution is a major cause of water pollution, as well as run-off from agricultural areas (from fertilizer and soil additives), urban stormwater, tanks and pipeline leakages, animal waste and discharge of treated and untreated sewage (especially in the developing countries of the world); and in more recent times, from vandalised oil pipelines (Aigberua et al., 2020). Thus, water resource management is guided by its intended use. Works in water resource development and management tend to be focused on water that is treated for human consumption. However, because of infiltrations and underground water interactions, water for human consumption may be contaminated by micro-organisms (from open water sources) such as viruses and bacteria, inorganic contaminants such as salts and metals, pesticides and herbicides, organic chemical contaminants from industrial processes and petroleum use and radioactive contaminants (USEPA, 2006). Therefore, water resource management should cover the local geology and ecosystem, as well as the need for which humans use water (Diersing, 2009; Okumagba & Ozabor, 2014).

On the course of the Warri River lies several communities, with so many poor people who can’t afford to sink personal boreholes for domestic water demands. Similarly, there are agricultural activities that require the use of water (such as cassava processing, vegetable processing etc) that the locals rely on the Warri River for. Sadly, despite the level of pollution, they are stuck with using the Warri River for agricultural, economic, and domestic uses. The use of such contaminated water can cause serious health challenges and, in some cases, lead to death. As such, it is important to regularlyassess the water quality there, in addition to existing research (Okumagba & Ozabor, 2014; Tegu et al., 2023). Therefore, this study was aimed at examining the quality of water from the upstream and downstream sections of Warri River, so as to advise the public on the implications of its use. To achieve thisaim, the following objectives were pursued;

a. Examine the quality of water at the upstream section of Warri River.
b. Examine the quality of water at the downstream section of Warri River.
c. Determine the difference in water quality at both the upstream and downstream sections of Warri River.
d. Describe the best use to put the water based on quality discovered, while recommending ways to improve the water quality.

Therefore, the hypothesis to be tested in this study is, ‘there is no significant difference in quality between the upstream and downstream sections of Warri River’.

MATERIALS AND METHODS

Study Area

The study area is Warri River in Southern Nigeria. Warri River is located within latitudes 50 21' North and 60 00' North of the Equator and Longitudes 50 24' East and 60 21' East of the Greenwich Meridian. The Warri River flows from Utagha-uno, covering a surface area of about 255sq. km. with a length of about 150km (Netherlands Engineering consultants (NEDECO), 1961), and runs in a south-west direction passing through Amai, Otorho-Abraka, Oviorie, and Ovu inland, as well as southwards through Agbarho to Otokutu, and Ugbolokposo (Egborge, 2001). It stretches to Effurum and forms a “W” shape between Effurun and Warri. The Warri River also flows through such settlements as Enerhen, Igbudu, Ovwian, and Aladja. The river empties its water into the Atlantic Ocean through the Forcados estuary (Figure 1). Thus, the settlements of Warri and Enerhen are found in the downstream section of the river, while Utagba-uno and Ukabi are found in the upstream section of the river. The communities that are located along the Warri River are highly populated, and full of poor people who must rely on the river for their domestic and economic needs. Pollution of the water body doesn’t only lead to thedepreciation of one of their sources of livelihood, but is also a direct threat on their health.

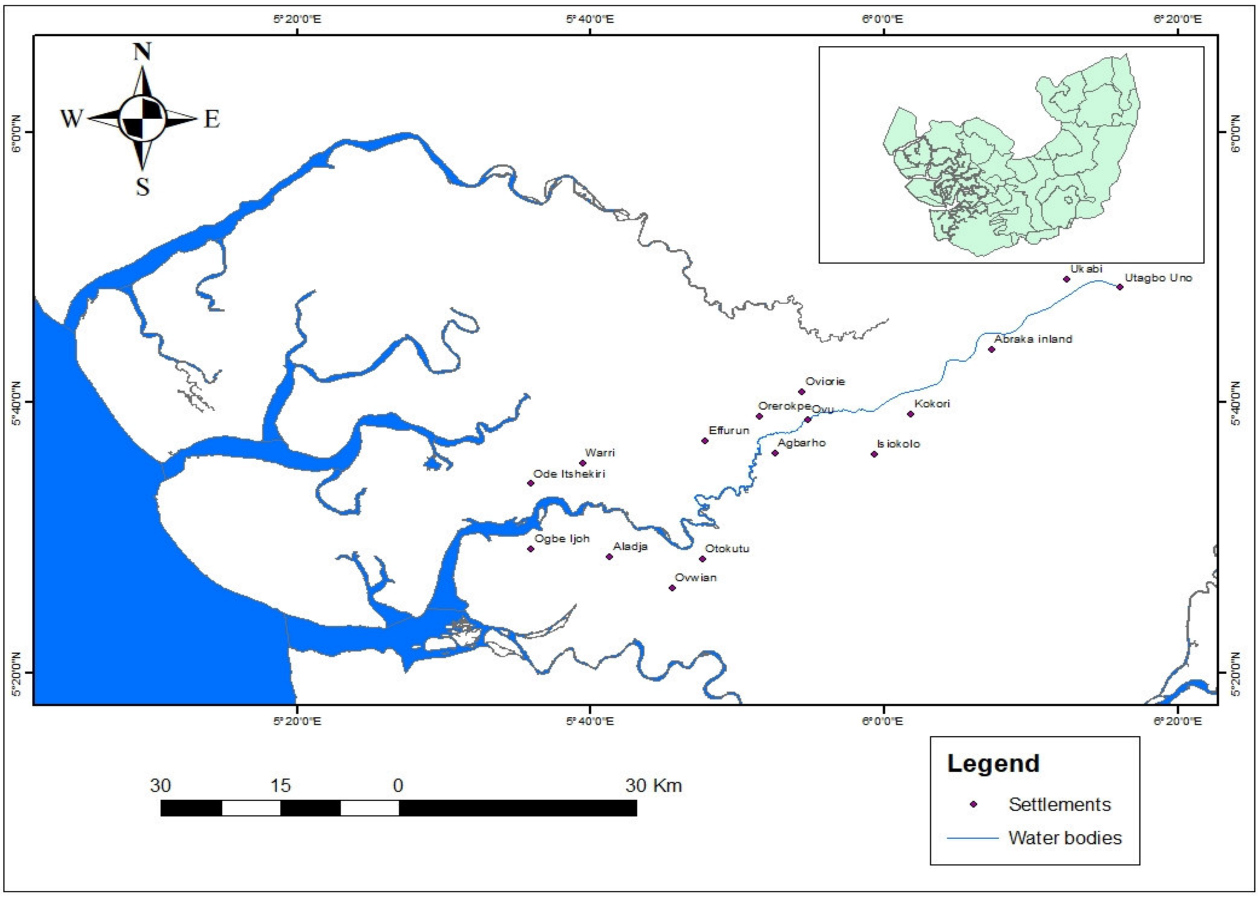

Figure 1: Warri River showing the host communities.
Source: Adapted from Egborge (1994)

RESEARCH METHODS

The study is an empirical research work that involved field survey, collection of water samples from the upstream and downstream sections of Warri River, and laboratory analysis of the water samples collected. The systematic sampling technique were adopted for the study. The systematic sampling technique was used for the collection of water samples. Four settlements, two each in the upstream and downstream sections of the river were used for the study. The settlements are Utagba-uno and Ukabi in the upstream, and Warri and Enerhen in the downstream. A total of 48 water samples were collected from January 2022 to December 2022 from the four settlements located along the course of the river, at a distance of 100 meters apart. The water samples were collected once each month from the determined sample sites. The water samples were collected from the surface and sub-surface of the river at a depth of 5 meters apart following the example of Edegbene and Akamagwuna (2022). The water samples were collected using sterilized 2-litre plastic cans fitted with information tags for identification, between the hours of 6am and 9am. Water samples in plastic cans were securely corked and stored in ice-packed containers before transporting them to the laboratory for analysis. All collected water samples were allowed to settle down for about four hours before any form of laboratory analysis was carried out on them (Uzoekwe & Oghosanine, 2011; Dewangan et al., 2022).

Magnesium, lead, zinc and iron concentration in the water samples were determined using Atomic Absorption Spectrophotometer (AAS) method, while calcium concentration in the water was determined titrametrically using the Argentometric titration method (Umeoguaju, et al., 2022). Sodium and potassium concentration were determined by flame photometry with the Elvi model 64 flame photometer (WHO, 2010; EPA, 2001; USEPA, 2008; American Public Health Association, APHA, 1999; Nigeria Industrial Standard, NIS, 2007; Thurston et al., 2022). The Paired T-test technique was adopted to test the hypothesis since the samples were only two kinds (upstream and downstream).

RESULTS AND DISCUSSION

The mean Physicochemical and biological parameters of the analysed water samples from the upstream and downstream sections of Warri River are shown in Table 1 and discussed.

Table 1: Summary of Mean Values of Physicochemical and Biological Parameters in the Downstream and Upstream Sections of Warri River

Parameters	**Downstream**			**Upstream**		
	Min	**Max**	**$\bar{x}$**	**Min**	**Max**	**$\bar{x}$**
pH	5.52	6.21	5.90	6.58	7.23	6.90
Electrical Conductivity	314	524	42.4	45.50	59.40	53.45
Temperature (ºC)	26.90	30.50	28.90	27.40	28.40	27.90
Salinity (%)	94.50	150.10	125.3	13.60	23.10	17.20
TDS (mg/l)	165	273	220	23.00	40.00	31.60
TSS (mg/l)	5.70	10.90	9.60	4.10	8.13	5.60
Turbidity (NTU)	4.50	16.10	15.40	3.14	5.20	4.20
DO (mg/l)	1.49	6.50	4.20	5.43	8.20	6.10
BOD (mg/l)	4.20	30.25	18.50	4.00	5.25	4.30
Ammonia (mg/l)	1.02	1.62	1.40	0.42	1.05	0.80
Nitrate (mg/l)	2.54	3.24	2.92	0.98	1.67	0.99
Hydrocarbon (mg/l)	1.05	5.86	3.56	0.79	2.45	1.01
COD (mg/l)	10.42	70.05	42.26	10.24	30.15	20.16
Alkalinity (mg/l)	33.40	54.30	46.05	0.02	21.42	9.45
Phosphate (mg/l)	0.01	0.08	0.052	0.009	0.04	0.02
Bicarbonate (mg/l)	15.50	43.58	26.54	0.06	20.14	10.75
Chloride (mg/l)	0.09	0.16	0.14	0.03	0.09	0.06

Sulphate (mg/l)	1.20	2.76	2.02	0.62	1.21	1.02
Coliform (Count/100)	15.30	58.46	37.88	10.12	15.60	12.42
Sodium (ppm)	7.24	10.15	9.10	4.09	6.20	5.10
Potassium (ppm)	3.52	6.20	4.86	2.19	4.18	3.16
Magnesium (ppm)	4.26	32.41	19.45	1.26	3.14	2.50
Calcium (ppm)	8.92	30.79	20.02	1.32	3.42	2.10
Lead (ppm)	0.002	0.010	0.006	<0.001	<0.001	<0.001
Zinc (ppm)	0.002	0.006	0.004	0.96	1.24	1.02
Iron (ppm)	0.19	0.42	0.32	0.65	1.05	0.98

Source: Fieldwork, 2022

In the Warri River, lower mean value of pH was found in the downstream section of the river with a mean pH value of 5.90 which was lower than the mean value for the upstream section, which recorded a mean pH value of 6.90. This can be attributed to industrial activities in the downstream section, propelled by the Nigeria National Petroleum Corporation (NNPC), Pipeline Production and Marketing Company, oil and paint industries, NNPC oil loading terminal, NNPC Petrochemical, sawmills, markets in the area and activities of vandals of the crude oil pipelines (Ugochukwu et al., 2022). Also, in Warri River, high electrical conductivity (EC) mean values were recorded in the downstream section of the river when compared to the upstream (42.4<53.45). This assertion is in line with the work of Aghoghovwia (2011) who recorded high EC values in the downstream section of Warri River. This also shows that the river collects most of the pollutants upstream and deposit them downstream.

In terms of temperature, the river recorded 28.9^0C and 27.9^0C in the downstream and upstream sections respectively. This increase in temperature in the downstream section of the river can be attributed to effect of urbanization. The region possibly heats up faster than the others because of industrial activities (Abowel, 2010; Zittis et al., 2022) and global warming. Also, in the downstream section of the river, high mean values of TDS were recorded. This can be attributed to the dispositional nature of the river in the downstream section. More so, in high TSS values were recorded in the downstream section of the river. In terms of turbidity, mean values of 15.40 NTU and 4.25 NTU were recorded in the downstream and upstream sections of the river respectively. This trend corroborates the earlier results of total dissolved solids (TDS) and total suspended solids (TSS) obtained along the course of the river. This finding also corroborates the results obtained by Aissien et al (2010) along the course of River Ethiope in Southern Nigeria. However, DO values range from 4.20mg/l in the downstream section to 6.10mg/l in the upstream section. While BOD values vary from 4.30mg/l in the upstream to 18.50mg/l in the downstream.

In the study area, mean ammonia concentration varied along the course of the river. In the downstream section, mean values of 1.40mg/l were recorded, when compared to 0.80mg/l in the upstream section. While nitrate values vary from 0.99mg/l in the upstream section to 2.92mg/l in the downstream section. In terms of hydrocarbon concentration, mean values of 3.56mg/l and 1.01mg/l were recorded in the downstream and upstream sections of the river respectively. The parameter, chemical oxygen demand (COD) recorded higher concentration in the downstream section with a value of 42.26mg/l than in the upstream section of the river with a mean value of 20.16mg/l. Arimoro et al (2008) and Aghoghovwia (2011) obtained similar results in the downstream section of Warri River. Also, alkalinity recorded higher mean concentration of 46.05mg/l in the downstream section and 9.45mg/l in the upstream section of the river. Phosphate mean concentration values were 0.052mg/l and 0.02mg/l in the downstream and upstream sections of the river respectively.

In the study area, mean values of bicarbonate were 26.54 mg/l in the downstream section and 10.75mg/l in the upstream section of the river. While 0.14mg/l and 0.06mg/l were recorded in the downstream and upstream sections for chloride respectively. Also, sulphate mean values were 2.02 mg/l and 1.02mgl in the downstream and upstream sections of the river respectively. In terms of total coliform, it ranged from 37.88count/100 in the downstream section to 12.42 count/100 in the upstream section of the river. The high concentration of coliform is attributed to the discharge of sewage into the river by people living very close to the river, abattoir activities and discharges from the Warri main market as earlier averred by Ushurhe (2014).

In Warri River, sodium concentration varied from 5.10ppm in the upstream to 9.10ppm in the downstream sections of the river respectively; while potassium mean values were 4.86ppm and 3.16ppm in the downstream and upstream sections of the river respectively. However, magnesium mean value concentration varies from 19.45ppm in the downstream section to 2.50ppm in the upstream section of the river. Calcium also recorded mean concentration values of 20.02ppm in the downstream and 2.10ppm in the upstream sections of the river; whereas, lead values range from <0.001ppm in the upstream to 0.006ppm in the downstream sections of the river. Zinc recorded a mean value of 0.004ppm and 1.02ppm in the downstream and upstream sections of the river respectively; while Iron concentration varies from 0.32ppm in the downstream to 0.98ppm in the upstream sections of the river respectively.

The paired T-test was adopted and used to test the posited hypothesis at the 0.05 level of significance. This was shown in Table 2. As shown in Table 2, the model was significant at $p<0.05$ (mean-32.3; sig-0.051) signifying that there is a significant difference in water quality between the upstream and downstream sections of Warri River.

Table 2: paired sample tests for comparison of Warri River downstream and upstream water characteristics

		Paired Samples Test Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	downstream – Upstream	32.29196	80.27204	15.74264	-.13062	64.71454	2.051	25	.051

CONCLUSION AND RECOMMENDATIONS

The study compared the quality of water in the upstream and downstream sections of Warri River in Southern Nigeria. The thrust of the study was to identify the pollution state of the river and advise the locals and government on the best use to put the river water and therefrom advise on the best practice, if the river were to be cleaned. However, the current investigation did not cover quantifying the sources of pollutants; the health implications of the polluted river; nor did it do any empirical assessment of the cleansing of the river. The concern was to point out the level of pollution of the river (Ase), which, as at the time of this study, was a major source of domestic water. Nevertheless, laboratory examination of the water samples collected and analysed showed that variations exist in the concentration of physicochemical and biological indices of the water. Thus, more parameters show higher concentration at the downstream section of the river than at the upstream. Although, some of the parameters measured revealed high concentration, they fell within the permissible limit of the WHO (2010) for domestic water consumption. However, the water examined should never be used for domestic or food processing. This is because there are certain physicochemical and biologic properties that fell grossly outside the permissible ranges; however, the river water may be used for irrigation agriculture.

Thus, the study revealed that there was a significant variation in water quality in the parameters examined in the upstream and downstream sections of the river. More parameters showed significant increases in concentration in the downstream section of the river than in the upstream. The reason for this occurrence includes the fact that there are more human/economic activities going on at the downstream section when compared to the upstream section. Also, the toxins washed off at the upstream section flow down the stream, and settle at the downstream section, whose flow velocity is low compared to the upstream section of the river. Such parameters as EC, temperature, TDS, TSS, turbidity, BOD, ammonia, nitrate, hydrocarbon, COD, alkalinity, phosphate, bicarbonate, chloride, sulphate, total coliform, sodium potassium, magnesium, calcium and lead were of higher concentrations in the downstream than in the upstream section of the river.High values of pH, DO, Zinc and Iron were recorded in the upstream section of the river when comparable to the downstream section. These possibly emanates from the processing of cassava along the river banks. The acids and cyanides contributed to the water pollution upstream.The result of the test of the hypothesis indicated that the calculated difference in water characteristics between the upstream and downstream were statistically significant.

As a result of the findings of this research, it is recommendations that surface water should be tested from time to time to identify increases or decreases in the concentration of physicochemical and biological parameters in line with approved standards. Equally, human activities along the course of the river should be monitored to check wastewater run-off that are detrimental to the quality of river. In addition, risk assessment of water sources and catchment areas should be carried out. This should take into consideration the hydrogeology and the hydraulic loading of contaminants at the surface and sub-surface of the river. Also, the locals should be discouraged from using the water for domestic purposes (especially drinking). Finally, surface water flow along the course of the river and human activities should be monitored from time to time to check impairments. This will address issues of surface water pollution in order to harness the river water for pervasive use.

REFERENCES

Abowei, J. F. N. (2010). "Salinity, Dissolved Oxygen, pH and Surface Water Temperature Conditions in Nkoro River, Nigeria". *Advanced Journal of Food, Science and Technology, 2*(1): 36-40.

Adeniyi, H. A. &Mbagu, G.I. (1983). "Study and Appraisal of the Water quality of the Kontagora and Eku Rivers", Kainji Lake Research Institute Annual Report, 17 – 22.

Adeyemi, F. M., Wahab, A. A., Oyelami, C. A., Oyedara, O. O., Titilawo, M. A., Adebunmi, A. A., & Awoniyi, I. O. (2022). Hydrology survey and water quality assessment of water sources in three selected towns in Osun State, Southwest Nigeria. *International Journal of Energy and Water Resources*, 1-14.

Aghoghovwia, O.A. (2011). "PhysicochemicalCharacteristics of Warri River in the Niger Delta Region of Nigeria". *Journal of Environmental Issues and Agriculture in Developing Countries, 3*(2): 40 – 46.

Aigberua, A., Tarawou, T., & Erepamowei, Y. (2020). Environmental assessment of Imiringi River in South- South Nigeria: the water quality index approach. *Current World Environment*, *15*(1), 59.

Aisien, E.T., Gbegbaje-Das, E. &Aisien, F.A. (2010). “Water Quality Assessment of River Ethiope in the Niger Delta Coast of Nigeria”. *Electronic Journal of Environmental, Agricultural and Food Chemistry, 9*(11): 1739 – 1745.

Ajayi, S.O. &Osibanjo, O. (1981). “Pollution Studies on Nigeria Rivers II, Water Quality of some Nigeria Rivers”. *Journal of Environmental Pollution Services,* B.1(1): 87 – 95.

American Public Health Association (1999). Standard Method for Examination of Water and Wastewater, New York.

Arimoro, F.O., Iwegbue, C.M. A. & Osiobe, O. (2008). “Effects of Industrial Wastewater on the Physical and Chemical Characteristics of a Tropical Coastal River”. *Research Journal of Environmental Science,* 2: 209 – 220.

Asuquo, F. E. (1989). “PhysicochemicalCharacteristics and Anthropogenic Pollution of the Surface Water of Calabar River, Nigeria”. *Global Journal of Pure and Applied Science,* 30: 31 – 40.

Carey, C. C., Woelmer, W. M., Lofton, M. E., Figueiredo, R. J., Bookout, B. J., Corrigan, R. S., ... & Thomas, R. Q. (2022). Advancing lake and reservoir water quality management with near-term, iterative ecological forecasting. *Inland Waters*, *12*(1), 107-120.

Cunha, M. D. C. (2023). Water and Environmental Systems Management under uncertainty: from scenario construction to Robust Solutions and Adaptation. *Water Resources Management*, 1-15.

Darko, G., Obiri-Yeboah, S., Takyi, S. A., Amponsah, O., Borquaye, L. S., Amponsah, L. O., & Fosu-Mensah, B. Y. (2022). Urbanizing with or without nature: Pollution effects of human activities on water quality of major rivers that drain the Kumasi Metropolis of Ghana. *Environmental Monitoring and Assessment*, *194*(1), 38.

Dewangan, S., Mainwal, N., Khandelwal, M., & Jadhav, P. S. (2022). Performance analysis of heat treated AISI 1020 steel samples on the basis of various destructive mechanical testing and microstructural behaviour. *Australian Journal of Mechanical Engineering*, *20*(1), 74-87.

Diersing, N. (2009). “Water Quality: Frequently Asked Questions”, http://floridakeys.noaa.gov/polfs/[wa]faf9.pdf. Retrieved on 21-04-2016.

du Plessis, A. (2022). Persistent degradation: Global water quality challenges and required actions. *One Earth*, *5*(2), 129-131.

Edegbene, A. O., & Akamagwuna, F. C. (2022). Insights from the Niger Delta Region, Nigeria on the impacts of urban pollution on the functional organisation of Afrotropical macroinvertebrates. *Scientific Reports*, *12*(1), 22551.

Efe, S.I. (2002). An Appraisal of the Quality of Rain and Groundwater Resources in Nigerian Cities: The Case of Warri metropolis. A Ph.D. Seminar Paper, Delta State University, Abraka.

Egborge, A.B.M. (1994). *Water Pollution in Nigeria: Biodiversity and Chemistry of Warri River*. Benin-City: Ben Miller Books Nigeria Limited.

Egborge, A.B.M. (2001). "The Effect of Impoundment on the Water Chemistry of Lake Asejire, Nigeria", *Freshwater Biology*, 9: 403 – 409.

Epa, U. (2001). United States environmental protection agency. *Quality Assurance Guidance Document-Model Quality Assurance Project Plan for the PM Ambient Air*, *2*, 12.

Hodgson, K.M. (2006). "A Drinking Water Framework for South Africa", *Water SA*, 32(5): 673 – 678.

Imevbore, A.M.A. (1970). "The Chemistry of River Niger in Kainji Lake Reservoir Area", *Journal of Hydrology*, 67: 412 – 413.

Ibor, O. R., Nnadozie, P., Ogarekpe, D. M., Idogho, O., Anyanti, J., Aizobu, D., ... & Arukwe, A. (2023). Public health implications of endocrine disrupting chemicals in drinking water and aquatic food resources in Nigeria: A state-of-the-science review. *Science of the Total Environment*, *858*, 159835.

Iwegbue, C.M., Faran, T.K., Iniaghe, P.O., Ikpefan, J.O., Tesi, G.O., Nwajei, G.E. &Martincigh, B.S., (2023). Water quality of Bomadi Creek in the Niger Delta of Nigeria: assessment of some physicochemical properties, metal concentrations, and water quality index. *Applied Water Science*, *13*(2), p.36.

Mishra, A. P., Singh, S., Jani, M., Singh, K. A., Pande, C. B., & Varade, A. M. (2022). Assessment of water quality index using Analytic Hierarchy Process (AHP) and GIS: a case study of a struggling Asan River. *International Journal of Environmental Analytical Chemistry*, 1-13. Netherlands Engineering Consultants (1961). "The Waters of the Niger Delta", Report of an investigation of Netherlands Engineering Consultants (NEDECO), The Hague, 210- 228.

Nigerian Industrial Standard (2007). Nigerian Standard for Drinking Water Quality, Abuja, SON, 1 – 30.

Obisesan, A., & Ozabor, F., (2016). Factors Affecting Water Supply in Owah-Abbi, Delta State. *Open Journal of Social Sciences*, *4*(07), 137.

Ololade, I. A., Apata, A. O., Oladoja, N. A., Alabi, B. A., & Ololade, O. O. (2023). Polycyclic aromatic hydrocarbons in rivers and health risk consequences of human exposure: a Nigerian case study. *International Journal of Energy and Water Resources*, 1-18.

Ogidiaka, E., Ikomi, R. B., Akamagwuna, F. C., & Edegbene, A. O. (2022). Exploratory accounts of the increasing pollution gradients and macroinvertebrates structural assemblage in an Afrotropical estuary. *Biologia*, *77*(8), 2103-2114.

Okumagba, P. O., & Ozabor, F. (2014). The Effects of Socio-Economic Activities on River Ethiope. *Journal of Sustainable Society*, *3*(1), 1-6.

Tegu, T. B., Ekemube, R. A., Ebenezer, S. O., & Atta, A. T. (2023). Monitoring the Variability of the Pollutants Level in Urban Water Front during Dry and Wet Seasons. *European Journal of Applied Sciences–Vol*, *11*(1).

Thurston, J. R., Marshak, M. P., & Reber, D. (2022). Monitoring ion exchange chromatography with affordable flame emission spectroscopy. *Journal of Chemical Education*, *99*(12), 4051-4056.

Umeoguaju, F. U., Akaninwor, J. O., Essien, E. B., &Amadi, B. A. (2022). Heavy metal profile of surface and ground water samples from the Niger Delta region of Nigeria: a systematic review and meta-analysis. *Environmental Monitoring and Assessment*, *194*, 1-37.

Ugochukwu, U. C., Chukwuone, N. A., Jidere, C., Agu, C., Kurumeh, L., & Ezeudu, O. B. (2022). Legacy PAHs in effluent receiving river sediments near a large petroleum products depot in Enugu, Nigeria: Human health risks and economic cost of pollution. *Environmental Pollution*, *309*, 119731.

USEPA (2008). Water Quality Standards Review and Revision, Washington, Dc.

USEPA (2006). "National Management Measures to Control Nonpoint Source Pollution from Urban Areas", Document NO EPA 841 – B – 05 – 004.

USEPA (2002). "Methods of Measuring the Acute Toxicity of Effluents Receiving Waters of Freshwater and Marine Organisms", Document NO EPA – 8 – R – 02 – 012.

Ushurhe, O. (2014). "Assessment of Heavy Metals and the Prevalence of Waterborne Diseases in Rural Communities located along River Ase in Southern Nigeria". *Journal of Environment and Earth Sciences*, 4(7): 34 – 41.

Uzoekwe, S. A., &Oghosanine, F. A. (2011). The Effect of Refinery and Petrochemical Effluent on Water Quality of Ubeji Creek Warri, Southern Nigeria. *Ethiopian Journal of Environmental Studies and Management*, *4*(2), 107-116.

WHO (2010). International Standard for Drinking Water Guidelines for Water Quality, Geneva.

Zittis, G., Almazroui, M., Alpert, P., Ciais, P., Cramer, W., Dahdal, Y., ... & Lelieveld, J. (2022). Climate change and weather extremes in the Eastern Mediterranean and Middle East. *Reviews of Geophysics*, *60*(3), e2021RG000762.