International Journal of Academic Engineering Research (IJAER)
ISSN: 2643-9085
Vol. 8 Issue 8 August - 2024, Pages: 32-38

Effect of Pit Latrines on Groundwater in Selected Areas of Etche Local Government Area

Davidson D. Davis[1], Unyeawaji Brownson Ntesat[1]*, Erewari Ukoha-Onuoha[1] and Peace Ufuoma Ebbah[1],

[1]*Department of Agricultural & Environmental Engineering, Faculty of Engineering, Rivers State University, Port-Harcourt, Nigeria*

*Corresponding author: brownson.ntesat@ust.edu.ng, +2348038717021

Abstract: *This study aims to assess the effects of pollutants infiltration from pit latrines on groundwater contamination at Chokocho community. Water samples were collected from seven boreholes, designated as P_1, P_2, P_3, P_4, P_5, P_6, and P_7, at 17.7, 21.8, 7.1, 16.7. 7.6, 18.6, and 14.4 m distances, respectively, from randomly selected borehole. Physical and biochemical analysis were applied to the samples using standard techniques and protocols. The mean pH value for all samples tested was found to be 6.3, which is within the limit (6.5 - 8.5) established by The Nigerian Standard for Drinking Water Quality (NSDWQ) and World Health Organization (WHO). The mean values of the other measured physico-chemical properties, namely total dissolved solids (TDS), sulphate, nitrate, and chloride, were all found in concentrations below the NSDWQ and WHO standards. There was variation in the concentration of all bacteriological loads within the samples. There was no trace of feacal coliform bacteria in most of the analyzed samples, except in P_4 and P_6. Sampled water analysis showed that P4 and P6 were contaminated with faecal counts of 0.1 MPN/100ml and 0.2 MPN/100ml, respectively. Total heterotrophic bacteria (THB) counts were found to be above the recommended limit (100 cfu/ml) in samples P_2 (110 cfu/ml), P_4 (160 cfu/ml), and P_7 (240 cfu/ml). Results from water quality index, indicated that some of the borehole waters P_1, P_2, P_3, P_6, P_7 (Grade B) were good for drinking and to some extend may not have been influenced by the proximity of the pit latrine intrusion, while P_4 and P_5 (Grade C) which was at a distance of 16.7 m and 7.6 m, respectively, were poor and may be declared unfit for consumption. Further studies are needed on the health risk of such unpalatable groundwater with respect to bacteriological contamination.*

Keyword: Groundwater, pollutant infiltration, borehole, pit latrine.

1. INTRODUCTION

Water is one of the basic necessities for life sustenance, and its impact cuts across all areas of life. In many parts of the world, including Nigeria, groundwater is the preferred source of drinking water supply, irrigation and industrial purposes. Due to its proximity to the surface, groundwater obtained from springs and wells continues to be attractive as a source of water supply to most rural dwellers [1]. Peri-urban areas are often characterized by heavily compromised groundwater, with excess levels of nitrate, chloride and microbial pathogens. An estimated 2.6 billion people lack access to improved sanitation [2]. The Niger Delta region in Nigeria, relies on groundwater for both domestic and industrial uses. According to [3], there were around 65,000 boreholes in Nigeria extracting an estimated amount of 6,340,000 m^3/day in 2013. Before the 1970's, the major cities in the region were served by well planned, relatively deep boreholes whose water was widely reticulated to individual homes and factories. However, with increasing user population, urbanization and industrialization, coupled with funding constraints, governments' capacity to sustain potable water supply was jeopardized. The failure of government to meet the water supply needs of the population resulted in individual's taking responsibility for their water supply needs [4]. Notably, these inadequacies of Government at all levels has resulted in poor sanitation within and around target settlements.
Improved sanitation includes water-based toilets that flush into sewers, septic systems, or pit latrines; simple pit latrines; and ventilated improved pit latrines. There is strong evidence that access to improved sanitation can reduce diarrhea morbidity and mortality as well as soil-transmitted helminths [5]. Underground water contamination can be caused by several sewage effluents that by-pass the earth's geological filters and other adsorption processes. Domestic sewage effluents are of great concern to public health when untreated and their leachability remains unchecked by relevant bodies. For instance, effluents from conventional septic tanks have been known to contain significant amounts of biological contaminants such as total heterotrophic bacteria (THB), faecal coliform bacteria (FCB), total coliform bacteria (TCB), chemical oxygen demand (COD) and biological oxygen demand (BOD) [6]. Individual household sewage disposal systems often referred to as septic tank, soakaway, cesspool, or sewerage is the most community-based domestic wastewater disposal methods, especially in underdeveloped and developing countries. Domestic sewage that is discharged into septic tank has been reported to negatively influence organic and inorganic contamination of groundwater [7].

Pit latrine is a common method of excreta disposal in the developing world. It is popular and widely used in urban slums as well as rural areas probably because it is the simplest, cheapest and the most efficient excreta disposal method that is within the reach of the poor [1]; [5]. Pit latrines belong to on-plot sanitation system that dispose of human excreta without treatment. The use of pit latrines naturally raises concern about pollution of groundwater and especially shallow wells sited within the plot which are being used as drinking water source. In such a situation, the use of pit latrines is not recommended unless the water table is extremely low and soil characteristics are not likely to contribute to the susceptibility of groundwater pollution [8]. [9] reported that pit latrine is one of the major contributing factors of groundwater pollution mostly located near water sources such as shallow wells and boreholes.

Households within and around Chokocho in Etche Local Government Area of Rivers State rely on hand-dug shallow wells and a few boreholes for water supply while the sanitation option is mainly pit latrines (most worrisome, this latrine is dug up to the aquifer and as well receives all forms of wastes in every household in contrast to the conventional pit latrines). Thus, a threat of cholera outbreak may be possible in Chokocho Community. Beside the environmental degradation further caused by heavy dredging and abattoir activities within and around the Otamiri river boundaries on surface and groundwater, little is known about the impact of pit latrines on groundwater quality in squatter settlement areas of Etche local Government Area, especially the direct impact on the study area (Chokocho Community). Therefore, this study aims to evaluate the possible impacts of the pit latrines on groundwater quality around the affected study site. Specifically, there is need to understand the levels of physical and biochemical properties on groundwater wells with great proximity to the pit latrines, as well as how the variation of distance from the pit latrine to the well could affect the groundwater quality.

2. MATERIALS AND METHODS

2.1. Field Sample Procedure

The peri-urban settlement of Chokocho was selected as the study area as it is one of the largest peri-urban settlements with serious water supply and sanitation challenges in Etche Local Government Area. A total of seven (7) pit latrine sampling points, with respective borehole points were selected. The average depth of the shallow wells in the settlement ranges from 6 - 10 m, while boreholes were 25-35 m deep. The wellheads are not adequately protected in most cases and were only lined for 20 cm into the well.

2.2 Physical and Biochemical Analysis

The physiochemical parameters that were analyzed include, hydrogen ion concentration (pH), electric conductivity (EC), total dissolved solids (TDS), sulphate, nitrate, ammonia and chloride. The study adopted standard procedures recommended in HACH 8051 and APHA 3111B [10] for water analyses. Borehole water samples were collected and preserved in an ice chest for analyses in a standard laboratory. The boreholes distance from the pit latrine sites were measured with global positioning system (GPS). Standard procedures for water sampling were strictly followed to measure *instu* parameters such as pH and EC, while water sample parameters which were not measured on site were carefully taken to the laboratory for analyses. Biological parameters such as faecal coliform bacteria (FCB), total coliform bacteria (TCB) and total heterotrophic bacteria (THB) were measured in accordance to [11], [12] and [13] in order to determine the potability of water in selected sampled borehole water. A ten-fold serial dilution was used to arrive at an appropriate dilution of the samples. In the case of THB, aliquots of the established dilutions were plated in duplicates onto the surface of dried sterile nutrient agar platform. Suitable amounts of undiluted water samples were inoculated into a tube of MacConkey Broth medium. All growth media were nurtured at 37 ºC for a period of 24 hours.

2.3 Water Quality Index (WQI)

Water quality index is a single unitless number that describes the overall quality of water. Since the first water quality index was developed [14], water quality index has become an effective global tool in the assessment of various water sources. Presently, there are several water quality indices in use in different regions of the world. These include the Horton index, Brown index also known as the weighted arithmetic mean index, the National Sanitation Foundation water quality index (NSF-WQI), the Canadian Council of Ministers of the Environment water quality index (CCMEWQI) and the Bhargava or Iraqi index. [15] list the locations and purposes of application of these indices with the CCMEWQI and Weighted arithmetic mean index as the most used in various regions of the world.

The weighted arithmetic mean water quality index was employed in this work to determine the true status of individual sampling borehole water within and around the selected boreholes. The water quality rating as per weighted arithmetic water quality index were in accordance to [13] and [16] using Equations 2.1-2.6 and related to Table 2.1 below:

$$R = {V_n - V_{io}}/{S_n - V_{io}} \qquad 2.1$$

$$W_n = {K}/{S_n} \qquad 2.2$$

$$Y = {1}/{S_n} \qquad 2.3$$

$$K = {1}/{Y} \qquad 2.4$$

$$Q = R \times 100 \quad (2.5)$$

$$WQI = W_n \times Q \quad (2.6)$$

Where: WQI = water quality index; Sn= Standard permissible for nth parameter; K= Proportionality constant using formula; Vn= Estimated value of the nth parameter of the given sampling station; Vio = ideal value of nth parameter in pure water; Wn= unit weight for the nth parameter.

Table 2.1: Water Quality Classification as per Weighted Arithmetic Water Quality Index [16]

WQI Values	Rating of Water Quality	Boreholes	WQI values	Grade
0-25	Excellent			A
26-50	Good			B
51-75	Poor			C
76-100	Very Poor			D
Above 100	Not potable			E

2.4 Statistical Evaluation

Analyzed values were subjected to standard protocols to evaluate water pollution index for each of the studied borehole water and hand-dug wells. Sampled parameters were analyzed and results averaged using Excel® 2010.

3. RESULTS AND DISCUSSION

3.1 Physical and Biochemical Characteristics of Groundwater near Pit Latrines

The results of the studied boreholes are presented in Table 3.1 and Table 3.2. Table 3.1 presents the sampling points, GPS coordinates and distance between sited boreholes from pit latrines. While in Table 3.2 are the results of measured physicochemical and biological parameters compared with [12] and [13] permissible benchmarks.

Table 3.1: GPS Coordinates and Pit Latrine Distance from Borehole

Locations	GPS Coordinates	Pit Latrine Distance from Borehole (m)
P_1	007^{0}03’102.2” E; 04^{0}58’59.1” N	17.7
P_2	007^{0}03’04.6” E; 04^{0}59’0.25” N	21.8
P_3	007^{0}03’03.8” E; 04^{0}59’0.2” N	7.1
P_4	007^{0}03’01.5” E; 04^{0}59’00.8” N	16.7
P_5	007^{0}02’58.9” E; 04^{0}58’59.6” N	7.6
P_6	007^{0}02’54.8” E; 04^{0}58’58.8” N	18.6
P_7	007^{0}03’05.2” E; 04^{0}59’00.9” N	14.3

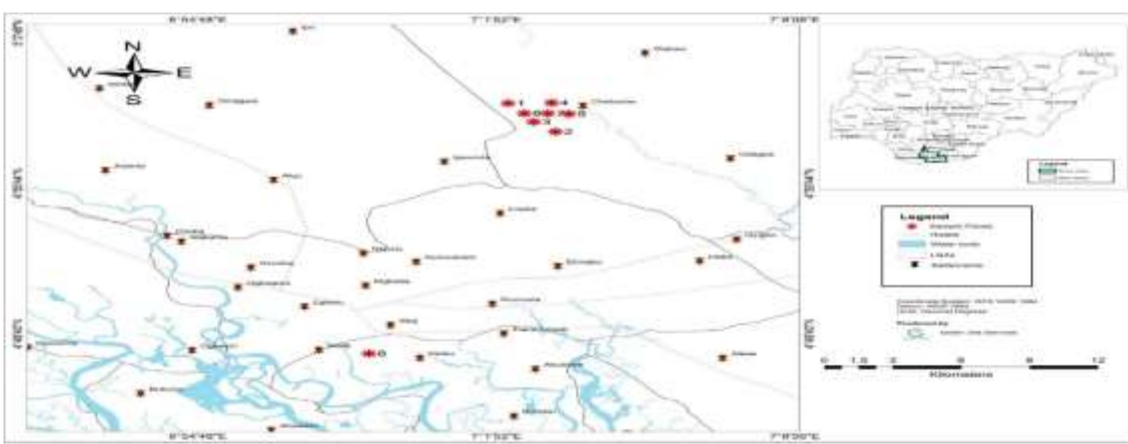

Figure 1: Map of the Study Area along with the sampling locations

3.1.1 Pit Latrine Distance from Borehole

According to the survey, the distances between the boreholes and pit latrines ranged from 7 to 21.8 m with virtually all the pit latrines not lined and with no mechanism of dislodging the pit when filled. Also, very few households in the study area were found in dueling places with septic tanks (septic systems) which were seen as poorly built and/or undersized.

3.1.2 pH and Electric conductivity (EC)

The mean pH value for the borehole water samples was 6.3 which is within the limit (6.5 - 8.5) established by [12] and [13]. Conductivity in water is due to dissolved solutes. The EC values were very low compared to the permissible standards (1000 µs/cm) of [12] and [13]. This is in agreement with the findings of [17] who reported values of 19-88 µs/cm.

3.1.3 Total dissolved solids (TDS)

The measured TDS value in all samples were equally far below the maximum allowable limits of 500 mg/l and 600-1000 mg/l established by [12] and [13], respectively. This could possibly explain the corresponding low values of electrical conductivity in the water samples. From the perspective of TDS, the respective borehole water may be good for drinking purpose as low TDS makes water potable for drinking [8].

3.1.4 Sulphate and Nitrate

Sulphate concentrations found in the study samples was noted to be very low (<1.0 – 1.0 mg/l) and substantially below the maximum allowable limits of 100 mg/l and 250 mg/l guideline values by [12] and [13], respectively. These low concentrations of sulphate may be due to the low permeability of geologic formation [18];[19]. Meanwhile, high concentration in water is harmful to human health as this may lead to dehydration and diarrhea in children more than in adults according to [20]. Meanwhile, concentration of nitrate in all the samples tested was found to be at safe values (0.05 – 2.38 mg/l), far below the maximum tolerable limit of 50 mg/l established by [12] and [13], respectively. This level of nitrate concentration corroborates with the findings of [21] and [17], who reported values between 0.26-7.8 mg/l in their respective study sites. Even as the nitrate concentration is still within the safe permissible limit, it should be constantly monitored due to the continuous impact of pit latrines and other unsafe waste management practices in the study area. High concentration of unchecked nitrate in drinking water may lead to blue baby disease (methemoglobinamia), cancer and urinary tract disorder [22].

3.1.5 Chloride

Similar to sulphate and nitrate, chloride concentration in all the samples analyzed was found between <1.0 – 2.8 mg/l, is far below 250 mg/l limit established by [12] and [13]. No health-based guideline value is proposed for chloride in drinking water. However, high concentrations of chloride give a salty taste to water and beverages which is increasingly likely to be detected by taste at concentrations in excess of 250 mg/l [13].

3.1.6 Dissolved Oxygen (DO) and Total Dissolved Solids (TDS)

DO was 5.67 mg/l on an average less than the permissible limits (6.5 mg/l) except for target groundwater of P_6 (6.7 mg/l) and P_7 (7.3 mg/l) that were above the permissible limits of 6.5 mg/l for both [12] and [13]. A low DO may lead to the anaerobic condition [23]. Also, [24] and [25] accounted that reduced level of DO in water may be as a result of dissolved organic materials. The maximum values of TDS observed could possibly explain the corresponding low values of electrical conductivity in the water samples. In Chokocho, 100% of the groundwater samples had TDS below the maximum allowable limit of [26] and [27] guideline values of 500 mg/l and 600 mg/l, respectively. Therefore, from the perspective of TDS, the water may be good for drinking purpose as low TDS makes water palatable for drinking [8].

3.1.7 Biological Oxygen Demand (BOD)

The groundwater concentration values at the studied pit latrines/groundwater proximity were moderately low across every sampled site except sample P_7 which recorded concentration of 6.8 mg/l higher than the permissible limits of the [12] and [13] of 5 mg/l and was equally higher when compared to other studies within Port Harcourt metropolis as confirmed by [28] and [29] indicating low biodegradability.

3.1.8 Feacal and Total Coliform Bacteria (FCB)

Zero values are specified for faecal and total coliform in drinking water [12] and [13]. Results from the study indicated that two of the borehole water samples analyzed, P_4 and P_6, have faecal coliform bacteria count of 0.1 and 0.2 cfu/ml, respectively. These values suggested high infestation of disease-causing microorganisms from faeces in the groundwater of the studied borehole [30];[31]. Water from those boreholes (P_4 and P_6) are therefore rendered not fit for drinking without treatment. [30] reported that pit latrines and building density have been found as a potential determinant for faecal pollution in domestic wells. High total coliform bacteria in groundwater may cause illness, and their presence in drinking water indicates that disease-causing organism can be in the water samples [30;31].

3.1.9 Total heterotrophic bacteria (THB)

The abundance of THB varies widely (9 – 240 cfu/ml) in all the samples of borehole water analyzed. Prominent among them are the level of contamination in P_2 (110 cfu/ml), P_4 (160 cfu/ml), and P_7 (240 cfu/ml). These high THB present a breeding ground for more dangerous bacteria such as escherichia coli and legionella, that can cause foul taste water, and leads to corrosion and slime growth in the pipe [29]. This analysis showed that proximity of pit latrines to shallow wells substantially contributed to the bacteriological contamination of groundwater. This finding is in agreements with the research of [32] and [8].

Table 3.3-3.9 below, present the summary of computed water quality indices for each of the sampled analyzed boreholes. The implication of the analysis indicated that some of the boreholes water P_1, P_2, P_3, P_6, P_7 (Grade B) were good for drinking and to some extend may not have been influenced by the proximity of the pit latrine intrusion, while P_4 and P_5 (Grade C) which was at a distance of 16.7 m and 7.6 m, respectively, were poor and may be declared unfit for consumption. This intrusion may be reasoned to the soil formation within and around the sampled locations in Chokocho and not necessarily the proximity between the pit latrines and boreholes. Other factors that may influenced the pollution noticed in the P_4 and P_5, may be attributed to improper waste disposal sites, agricultural runoff and landfill leachate. The results of this study is in consonant with the account of [25] who reported that pit latrine density within a certain area, has the possible intrusion of groundwater contamination. Therefore, this may infer to have influenced the contamination of groundwater through the proximity of the pit latrine. Also, these data and evaluations are in agreement with the works of [6; 33; 34].

3.2 **Water Quality Index (WQI)**

As shown in Table 3.3, all samples except P_4 and P_5 were graded as good for drinking with WQI values ranging from 46.4 - 49.6 while the WQI values of P_4 and P_5 were 60.6 and 51.6, respectively resulting in a poor water quality grade. Table 3.3 also presented parameters with the most impact on each sample quality including DO, PO_4^{3-} , BOD, TCB and pH. DO rating ranged between 27 – 36, while PO_4^{3-} rating was 12 for all samples except P_4 with a rating of 22. The high rating of DO in drinking water is both beneficial and detrimental. High DO improve drinking water taste while on the other hand it can cause corrosion in water pipes. However, with the use of PVC pipes, the issue of corrosion can be well averted. BOD and pH rating ranged between 0.5 – 6 and 1 – 1.7 while TCB rating ranged between 1.7 - 2.8, respectively. The poor water quality of P_4 and P_5 was attributed primarily to DO, PO_4^{3-}, and BOD.

Table 3.2: Result of Laboratory Analysis of the Physical and Biochemical Parameters of Selected Borehole Waters at Chokocho, Etche Local Government Area, Rivers State.

Parameters	P_1	P_2	P_3	P_4	P_5	P_6	P_7	Control	NSD WQ (2015)	WHO (2022)
pH	6.00	6.24	6.36	6.42	6.55	6.32	6.51	5.91	6.5	6.5
EC (µS/cm)	74	15	12	12	50	13	18	87	1000	1400
TDS (mg/l)	52	11	9	9	35	10	13	61	500	600
SO_4^{2-} (mg/l)	<1.0	<1.0	<1.0	1	1	1	1	1	100	250
PO_4^{3-}(mg/l)	<0.05	<0.05	<0.05	0.09	<0.05	<0.05	<0.05	<0.05	0.3	0.3
NO_3^- (mg/l)	2.38	0.21	0.06	<0.05	1.05	0.54	0.26	2.72	56	56
NH_4^+ (ug/l)	0.11	<0.02	<0.02	0.1	0.03	<0.02	<0.02	0.11	<5	<5
Cl^- (mg/l)	1.1	<1.0	1	1	1.3	2.8	2.8	3	250	250
DO (mg/l)	5.2	6.1	5.4	5.6	4.9	6.7	7.3	3.8	6.5	6.5
BOD (mg/l)	0.6	1.2	1.5	2.1	2.7	4	6.8	3.3	5	5
FCB (MPN/100ml)	0	0	0	0.1	0	0.2	0	0	0	0
TCB (MPN/100ml)	0	0	0	0.2	0	0.3	0.5	0	0	2
THB (cfu/ml)	39	**110**	9.0	**160**	55	47	**240**	64	100	100

Table 3.3: Water Quality Index Values and Grading

Samples	WQI	GRADE	RATING OF MOST IMPACTFUL PARAMETERS ON WQI				
			DO	PO_4^{3-}	BOD	pH	TCB
P1	49.6	Good	35	12	0.5	1.7	0
P2	46.4	Good	31	12	1.1	1.3	0
P3	48.9	Good	34	12	1.3	1.1	0
P4	60.6	Poor	34	22	1.9	1	1.1
P5	51.6	Poor	36	12	2.4	0.8	0
P6	48	Good	29	12	3.6	1.2	1.7
P7	49.6	Good	27	12	6	0.9	2.8

4. CONCLUSION

This study has shown that groundwater from boreholes within the vicinity of pit latrines in the study area is generally acidic, with negligible electric conductivity and total dissolved solids. It is also characterized by insignificant amount of sulphate, nitrate, and chloride concentrations. However, there is significant variation in the concentration of bacteriological loads within the samples tested, with alarming occurrences of faecal bacteria and heterotrophic bacteria infestations. Therefore, remedial approach of boiling, ultra violet, upward slow sand filtration and chlorination of the borehole water are hereby recommended as cheap but effective option for rural settlers, especially those within and around the studied site, in Chokocho, Etche Local Government Area in Rivers State.

REFERENCES

[1] Faruk, U.U., & Babale, A. (2020). Impact of pit latrine on groundwater quality in some communities of Nguru town, Nguru Local Government Area, Yobe State, Nigeria. East African Scolars Multidisciplinary Bulletin. Published by East African Scholar Publisher, Kenya. 3(5), 1-8.

[2] WHO/UNICEF (2016). Meeting the MDG Drinking Water and Sanitation Target the Urban and Rural Challenge of the Decade. World Health Organization and UNICEF, Geneva, Switzerland.

[3] Japan International Cooperation Agency (JICA) (2014). The project for review and update of Nigeria National water Resources, Master Plan, Vol.2. Japan International Cooperation Agency, Yachiyo Engineering Co., Ltd., CDI Engineering International Co., Ltd., Sanyu Consultants Inc., Japan.

[4] Abam, T.K.S., & Nwankwoala, H.O. (2020). Hydrogeology of Eastern Niger Delta: A Review. *Journal of Water Resources and Protection*, 12(9), 741-777.

[5] Graham, J. P. & Polizzotto, M. L. (2013). Pit latrines and their impacts on groundwater quality: a systematic review. *Environmental Health Perspectives*, 121, 521–530.

[6] Ugbebor, J.N., & Ntesat, B. (2019a). Investigation of borehole water contaminant profile at Igwuruta solid waste dumpsite, Rivers State, Nigeria. *Nigerian Journal of Technology*, 38(2), 532-539.

[7] Bouderbala, A. (2019). Human impact of septic tank effluent on groundwater quality in the rural area of Ain Soltane (Ain Defla), Algeria. *Environmental & Socio-economic Studies*, 7(2), 1-9.

[8] Ahaneku, I. E., Adeoye, & P.A. (2014). Impact of pit latrine on groundwater quality of Fokoslum, Ibadan, Southwestern. *British Journal of Applied Science & Technology*, 4(3), 21-31.

[9] Ernest, A.A. (2013). Effect of pit latrines on dug well water quality - a case study of the asankrangwa community in the wassa amenfi west district of Ghana. Department of Environmental Science; College of Science. Kwame Nkrumah University of Science and Technology.

[10] American Public Health Association (APHA) (2006). Standard Method for Examination of Water and Wastewater" APHA, Washington, D. C.

[11] Obire, O., & Wemedo, S. A. (1996). The effect of oilfield wastewater on the microbial populations of soil in Niger Delta. *Biologia*, 1, 77-85.

[12] Nigerian Standard for Drinking Water Quality (NSDWQ) (2015). Nigerian Industrial Standard, NIS: 554, 1-14.

[13] World Health Organization (WHO) (2022). Guidelines for drinking water quality: First addendum to the Fourth Edition, IWA Publishing, London, 564P.

[14] Horton, R.K. (1965). An index number system for rating water quality. *Journal of Water Pollution Control Fed.*, 37(3): 300-305.

[15] Aljanabi, Z.Z., Al-Obaidy, A.M., & Hassan, F.M (2021). A brief review of water quality indices and their applications. IOP Conference Series: Earth and Environmental Science, 779, 012088, doi: 10.1088/1755-1315/779/1/012088.

[16] Chandra, K., Gopi, K.C., Roa, D.V., Valarmthi, K., & Alfred, J.R.B. (2017). Current Status of freshwater faunal diversity in India: 1-624 (Published by the Director, Zoological Survey, India, Kolkata)

[17] Ngah, S.A., & Opurum, C.N. (2018). Study on groundwater quality of shallow aquifers and implications for human health in parts of Etche, Rivers State, Nigeria. *The International Journal of Science and Technoledge*, 6(2), 78-84.

[18] Arzu, A.U.; Tamer, A. (2017). Assessment of water quality of Yaglidere stream (Turkey), using Multivariate statistical techniques. *Polish Journal of Environmental Studies*, 26(4): 1715-1723.

[19] Bora, M., Goswami, D.C. (2017). Water quality assessment in terms of water quality index (WQI): Case Study of the Kolong River, Assam, India. *Applied Water Sciences*, 7(6): 3125-3135.

[20] Zhang, Q., Xu, P., & Qian, H. (2019). Assessment of Groundwater Quality and Human Health Risk (HHR) Evaluation of Nitrate in the. *International Journal of Environmental Research and Public Health*, *16(1)*, 1–16. https://doi.org/10.3390/ijerph16214246.

[21] Udom, G.J., Nwankwoala, H.O., & Jephthah, H.A. (2013). Seasonal variations in groundwater chemistry in parts of Yenagoa, Bayelsa State, Nigeria. *International Journal of Innovative Environmental Studies Research*, 1(2), 40-54.

[22] Shah, K.A., & Joshi, G.S. (2017). Evaluation of water quality index for Rivers Sabarmati, Gujarat, India. *Applied Water Science*, 7(3), 1349-1358.

[23] Ugbebor, J.N., & Ntesat, B. (2019b). A comparative study on the effects of leachate on groundwater in selected dumpsites in Rivers State, Nigeria. *Asian Journal Environment & Ecology*, 11(1), 1-13.

[24] Muhammad, K., Halimat, S.E., & Mohammed, S. (2020). Occurrence of coliform bacterium in boreholes water. *Bima Journal of Science and Technology*, 3(2), 1-3.

[25] Gwenzi, W., Marumure, J., Makuvara, Z. Simbanegavi, T., Njomou-Ngounou, E.L., & Nya, E.L. et al. (2023). The pit latrine paradox in low-income settings: A sanitation technology of Choice or a pollution hotspot? *Science of the Total Environment*, 879, https://doi.org/10.1016/j.scitotenv.2023.163179

[26] Dzwairo, B. (2018). Multi-date trends in groundwater pollution from pit latrines. *Journal of Water, Sanitation and Hygiene for Development*, 8(4), 607-621.

[27] World Health Organization (WHO) (2017). Guidelines for drinking water quality: First addendum to the Fourth Edition, IWA Publishing, London, 564P.

[28] Jenkins, W.M., Cumming, O., & Cairncross, S. (2015). Pit latrine emptying behavior and demand for sanitation services in Dar Es Salaam, Tanzania. *International Journal of Environmental Research Public Health*, 12, 2588-2611.

[29] Sokolo, R.S., Atagana, H & Akani, N.P. (2020). Effects of heavy metals in well water on biodegradation of petroleum hydrocarbon by consortia of bacteria and fungi. *African Journal of Microbiology Research*, 14(11), 637-643.

[30] Wright, J. A., Cronin, A., Okotto-Okotto, J., Yang, H., Pedley, S., & Gundry, S. W. (2013). A spatial analysis of pit latrine density and groundwater source contamination. *Environmental Monitoring and Assessment*, 185(5), 4261–4272.

[31] Bakari, S.S., Suleiman, Z.N., Ali, H.R., & Kai, K.H. (2023). Impacts of pit latrines on groundwater quality in squatter settlements in Zanzibar. Research Square, 1-17. Doi: https://doi.org/10.21203/rs.3.rs-2652203/v1.

[32] Dzwairo, B., Hoko, Z., Love, D., & Guzha, E. (2006). Assessment of the impacts of pit latrines on groundwater quality in rural areas. A case study from Mawendera District, Zimbabwe. *Physics and Chemistry of the Earth*, 31, 779-788.