CENTRAL ASIAN JOURNAL OF THEORETICAL AND APPLIED SCIENCE

https://cajotas.centralasianstudies.org/index.php/CAJOTAS

Volume: 06 Issue: 02 | February 2025 ISSN: 2660-5317

Article

Analysis Of Physico-Chemical Properties of Rainwater and Groundwater in Gas Flare Environments in Rivers-East and Rivers-West Senatorial Districts of Rivers State

Onugha, A. C[1], Okwakpam[2], I. O, Onugha, C[3]

1. Department of Geography and Environmental Studies, Ignatius Ajuru University of Education, Port Harcourt, Rivers State, Nigeria
2. Department of Geography and Environmental Studies, Ignatius Ajuru University of Education, Port Harcourt, Rivers State, Nigeria
3. Great Faith International School, Port Harcourt, Rivers State, Nigeria

* Correspondence: chimeebere16@gmail.com

Abstract: This study analyzes the physico-chemical quality of rainwater and groundwater in gas flare environments in Rivers East and West Senatorial Districts during the wet season of 2024. Four water samples (2 rainwater and 2 groundwater) were collected at 100 and 300 meters from the Olo or Rumuekpe and Ebocha, respectively, gas flare environments and analyzed for various parameters. Results showed that groundwater had higher mean concentrations for EC (81.83 ms/cm), TDS (92.50 mg/L), total alkalinity (10 mg/L), phosphate (1.08 mg/L), nitrate (1.73 mg/L), sulphate (7.33 mg/L), pH (7.07), DO (9.39 mg/L), BOD (13.27 mg/L), total hardness (44.51 mg/L), and COD (38.37 mg/L) compared to rainwater. Rainwater had higher turbidity (3.98 mg/L), temperature (28.86 °C), chloride (48.52 mg/L), and TSS (109.38 mg/L). The study recommends that the Rivers State Ministries of Health and Environment should strictly supervise borehole drilling to ensure compliance with safe drinking water standards that would prevent the occurrences of diarrhea, cholera and other waterborne diseases and public health issues associated with unsafe drinking water.

Keywords: Physico-chemical Properties, Gas Flare Environment, Rainwater, Groundwater, Rivers State.

Citation: Onugha, A C. Analysis Of Physico-Chemical Properties of Rainwater and Groundwater in Gas Flare Environments in Rivers-East and Rivers-West Senatorial Districts of Rivers State. Central Asian Journal of Theoretical and Applied Science 2025, 6(2), 117-128.

Received: 10th Jan 2025
Revised: 11th Jan 2025
Accepted: 24th Jan 2025
Published: 27th Feb 2025

1. Introduction

Gas flaring in oil exploration violates regulations and causes severe environmental issues, contaminating rainwater and groundwater. This affects water safety for domestic, agricultural, and industrial uses, impacting human health, biodiversity, and the environment. Contamination from gas flaring worsens global water safety debates, with pollutants like nitrates, sulfates, and phosphates exacerbating unsafe water issues. Contamination from rainwater and groundwater has severe environmental, social, economic, and health issues, especially in developing countries like Nigeria. Pollutants from gas flaring release harmful chemicals that impair groundwater renewal (Famiglietti, 2014; National Ground Water Association, 2024). Gas flaring emits noxious gases, polluting air, soil, and water quality (Obafemi, 2014; Monday, 2018; Nazmuz-Sakib, 2021).

Rainwater and groundwater are vital global water sources. Rain is atmospheric moisture falling as droplets or snow. Rainwater, collected from roofs, is considered pure but can be contaminated if it contacts surfaces, impacting its quality and use (Bagel et al., 2017; Button, 2017; Palmas & Petrucci, 2018; Kumar, 2019). In specificity, rainwater is used for irrigation, agriculture, washing, bathing, and drinking due to its purity. It's sustainably harvested, stored, or directed to replenish groundwater (Palmas & Petrucci, 2018; Ibrahim et al., 2019; Onugha, 2022). Rainwater is very useful for households in parts of Asia and Africa, including Nigeria (Amos et al., 2018).

Groundwater is formed from precipitation seeping into soil and rocks, it makes up 30% of global freshwater (MacDonald et al., 2021). It is often cheaper and less contaminated than surface water (Famiglietti, 2014; Lall et al., 2020; IGAC, 2022; NGWA, 2024). Groundwater is the largest potable water reservoir (Aiyesammi et al., 2004; Woke & Babatunde, 2015). Groundwater, stored in aquifers, is accessed through taps, pipes, wells, or artesian wells for various uses (Zhu, 2015; Kumar, 2019; MacDonald et al., 2021; IGAC, 2022). Also, groundwater is tasteless, while rainwater is acidic and low in sodium aids digestion (Ratnayaka & Johnson, 2009; Zhu, 2015). Groundwater is renewable, but renewal rates depend on environmental conditions.

However, unethical waste disposal contaminates both, threatening these essential natural resources (Odukoya et al., 2002; Woke & Babatunde, 2015). Both are crucial for agriculture and domestic use, especially in developing countries like Nigeria (Zhu, 2015; Button, 2017; Amos et al., 2018). Contaminated rainwater or groundwater is considered polluted and introduces toxins that increase blood acidity. Unlike surface water, it's harder to clean, causing severe social, health, and economic challenges, requiring purification (Famigliettti, 2014; Zhu, 2015; Palmas & Petrucci, 2018; MacDonald et al., 2021). Gas flares releases gases, causing acid rain (pH 5.5) that contaminates groundwater leading to unsafe water for domestic and commercial uses (Kumar, 2019; Jiang et al., 2020; Lall et al., 2020). Groundwater contamination arises from improper waste disposal, gas flaring, weak regulations, and sources like industrial chemicals, landfills, fertilizers, pesticides, and sewage (Obafemi, 2014; Amaechi-Onyerimma, 2021; IGAC, 2022.

Regular water infrastructure maintenance is crucial to prevent diseases like typhoid and cholera (Kumar, 2019; Sibe et al., 2019; Lall et al., 2020). Increased concentrations of carbon monoxide, ozone, nitrates, sulfates, temperature, dissolved oxygen, and turbidity in rainwater cause acid rain (Aboyeji, 2013; Amaechi-Onyerimma & Onugha, 2021; Onugha, 2022). Acid rain leads to building corrosion, vegetative discolouration, and waterborne diseases like typhoid and cholera, while also affecting biodiversity and increasing global disease risks (Osuoha, 2017; Seiyaboh & Izah, 2017; Kumar, 2019; Amaechi-Onyerimma, 2021). Safe water is crucial but can be compromised by pollution, increasing disease and pollutants (Woke & Babatunde, 2015). Strategic policies, such as gas re-injection, are needed to prevent gas flaring and its negative effects. This issue highlights the need to assess the effects of physico-chemical properties of rainwater and groundwater in selected gas flare environments in Rivers-East and Rivers-West Senatorial Districts of Rivers State.

2. Materials and Methods

The study was conducted in Rumuekpe (4° 54′ N, 6° 53′ E) and Ebocha (4° 53' 29.18" N, 6° 56' 10″ E) communities in Emohua and Ogba/Egbema/Ndoni Local Government Areas respectively, Rivers State as represented in figure 1 and 2. The release of noxious substances from oil installations in the study areas lead to poor groundwater quality (Nwankwoala, 2013). The static water level ranges from 0-1 m in the rainy season and 1-3 m in the dry season. Groundwater is recharged primarily by direct precipitation, with annual rainfall reaching 3,000 mm, infiltrating through permeable sands (Nwankwoala & Udom, 2011; Nwankwoala & Youdeowei, 2017).

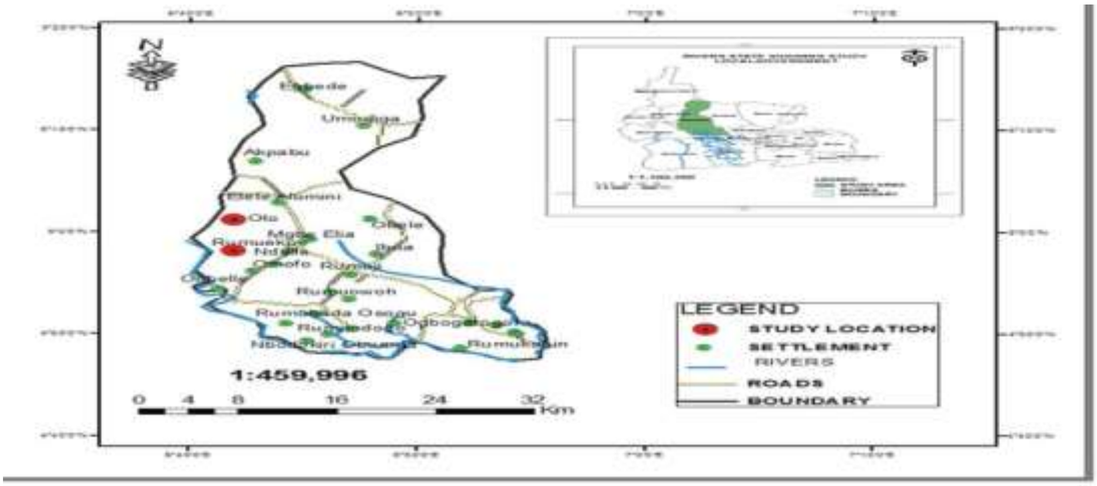

Figure 1. Rivers State showing Emohua Local Government Area (insert), and Emohua Local Government Area showing Rumuekpe Community

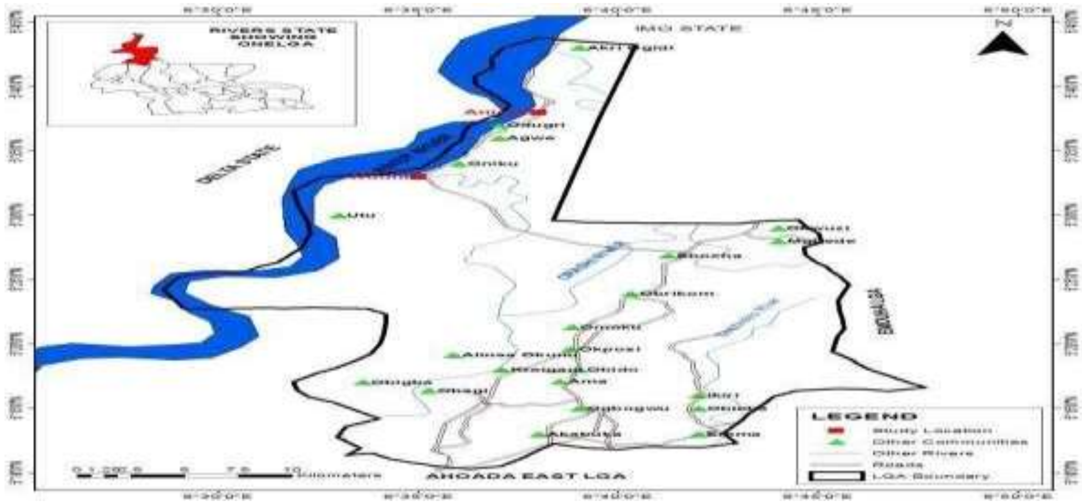

Figure 2. Rivers State showing Ogba/Egbema/Ndoni Local Government Area (insert), and Ogba/Egbema/Ndoni Local Government Area showing Ebocha Community

The study areas accounts for the presence of oil installations like flow stations that are operated by the SPDC (i.e. Shell) and NAOC (i.e. Agip) respectively in Rumuekpe (Olo) and Ebocha respectively. Thus, the foregoing makes the study areas to somewhat be the beehive of social, economic, educational, trading, hospitality, transportation, and artisan activities and services that are littered around the roadsides and suburbs around Rumuekpe and Ebocha communities in Rivers East and Rivers West Senatorial Districts respectively.

The study used an experimental design, specifically a completely randomized block design (CRBD), to control variables influenced by subjects, experimenters, tools, and environmental factors. The study utilized four sampling stations distributed across Rumuekpe and Ebocha communities. Sampling points were purposefully selected at specific distances around the Olo and Ebocha flow stations: Station A (100m upstream) and Station B (300m downstream) in Rumuekpe, and Station C (100m upstream) and Station D (300m downstream) in Ebocha. The coordinates for these points range from 4°54′12″N, 6°53′07″E to 4°53′16.9″N, 6°56′23.5″E.

Plate 1. One of the Vertical Flare Stack or Point in the Rumuekpe (Olo) Flow Station

Plate 2. The Triple Vertical Flare Stacks or Points in the Ebocha Flow Station

3. Results

Five instruments were used in the study: 1500 ml screw cap containers for groundwater, a plastic bucket for rainwater, a GPS device for recording coordinates, an Extech Meteorology Meter for measuring temperature, color, pH, and conductivity, and a measuring tape for labeling samples. The GPS and Extech Meter were pre-calibrated to ensure quality assurance in assessing the physico-chemical properties of rainwater and groundwater around the Rumuekpe (i.e. Olo) and Ebocha flow stations. Rainwater samples were collected in triplicate during peak rainfall in April- May 2024 using a plastic basin on a tripod. Groundwater samples were taken from boreholes at laminar flow in pre-washed 1500 ml containers after allowing taps to run for 3 minutes. Temperature, pH, and conductivity were measured in-situ. Samples were transported on ice to a lab for further analysis. Physico-chemical parameters, including turbidity, dissolved oxygen, nitrates, etc. were analyzed per APHA standards and compared with Niger Delta, NIS, and WHO safe drinking water limits. The results obtained from the analyzed physico-chemical parameters represented the data that was analyzed using statistical tools like mean, and clustered column chart.

Table 1. Comparison of the values for the physico-chemical properties in rainwater in the gas flare environments in Rivers-East and Rivers-West Senatorial Districts of Rivers State with NIS/WHO Approved Limits

Gases	Olo Gas Flare Environment		Ebocha Gas Flare Environment			
	SPT A (100m)	**SPT A (300m)**	**SPT C (100m)**	**SPT D (300m)**	**NIS/WHO**	**Decision**
Turbidity (mg/L)	3.98	3.76	3.61	3.94	5	WAPL
Electrical Conductivity (ms=cm)	49.46	78.84	49.64	81.83	500	WAPL
Total Dissolved Solids (mg/L)	85.07	88.43	92.50	87.58	500	WAPL
Total Alkalinity (mg/L)	7	8	9	10	30	WAPL
Phosphate (mg/L)	0.86	0.97	1.08	0.76	5	WAPL
Nitrate (mg/L)	1.39	1.25	1.73	1.52	200	WAPL
Sulphate (mg/L)	6.81	6.67	7.14	7.33	250	WAPL
Temperature (^{O}C)	27.52	28.86	27.69	28.84	27-30	HAPL
pH	6.73	6.89	6.92	7.07	6.5-8.5	HAPL
Dissolved Oxygen (mg/L)	7.71	7.62	8.58	9.39	>5	HAPL
BOD (mg/L)	9.26	9.08	13.27	10.49	2	HAPL
Chloride (mg/L)	47.37	48.52	46.91	48.37	250	WAPL
Total hardness (mg/L)	41.66	42.39	39.65	44.51	150	WAPL
COD (mg/L)	34.61	35.52	38.37	35.82	50	WAPL
TSS (mg/L)	96.74	109.38	79.62	78.90	30	HAPL

Note: AAPL (Above Approved Permissive Limit), WAPL (Within Approved Permissive Limit)

Source: Researchers Analysis and Computation, 2024.

As shown in table 1, the distinct values of the various physico-chemical properties or parameters in the rainwater sample equitably collected across four different points around the Olo and Ebocha flow stations showed that turbidity ranged with 3.61-3.94 mg/L, EC ranged from 49.46-81.83 ms=cm, TDS ranged from 85.07-92.50 mg/L, Total Alkalinity ranged from 7-10 mg/L, Phosphate ranged from 0.76-1.08 mg/L, Nitrate ranged from 1.25-1.72 mg/L, Sulphate ranged from 6.67-7.33 mg/L, Chloride ranged from 47.37-48.57 mg/L, total hardness ranged from 36.55-44.51 mg/L, and COD ranged from 34.61-38.37 mg/L. These range of values were all within the NIS/WHO approved permissive limits of 5 mg/L, 500 mg/L, 500 mg/L, 30 mg/L, 5 mg/L, 200 mg/L, 250 mg/L, 250 mg/L, 150 mg/L, and 50 mg/L for turbidity, EC, TDS, Total Alkalinity, Phosphate, Nitrate, Sulphate, Chloride, total hardness, and COD respectively in rainwater.

Furthermore, the values of other physico-chemical parameters in rainwater across the four sampling points in Olo and Ebocha gas flare environment showed that Temperature had range of values from 27.52-28.86 OC, pH had range of values from 6.73-7.07, Dissolved Oxygen had range of values from 7.62-9.39 mg/L, BOD had range of values from 9.08-13.27 mg/L, and TSS had range of values from 78.90-109.38 mg/L. These range of values were all above the range of NIS/WHO approved permissive limits of 27-30 OC, 6.5-8.5, 5 mg/L, 2 mg/L, and 30 mg/L for Temperature, pH, DO, BOD, and TSS respectively in rainwater. Hence, the graphical representation of Table 1 was presented in Fig. 3.

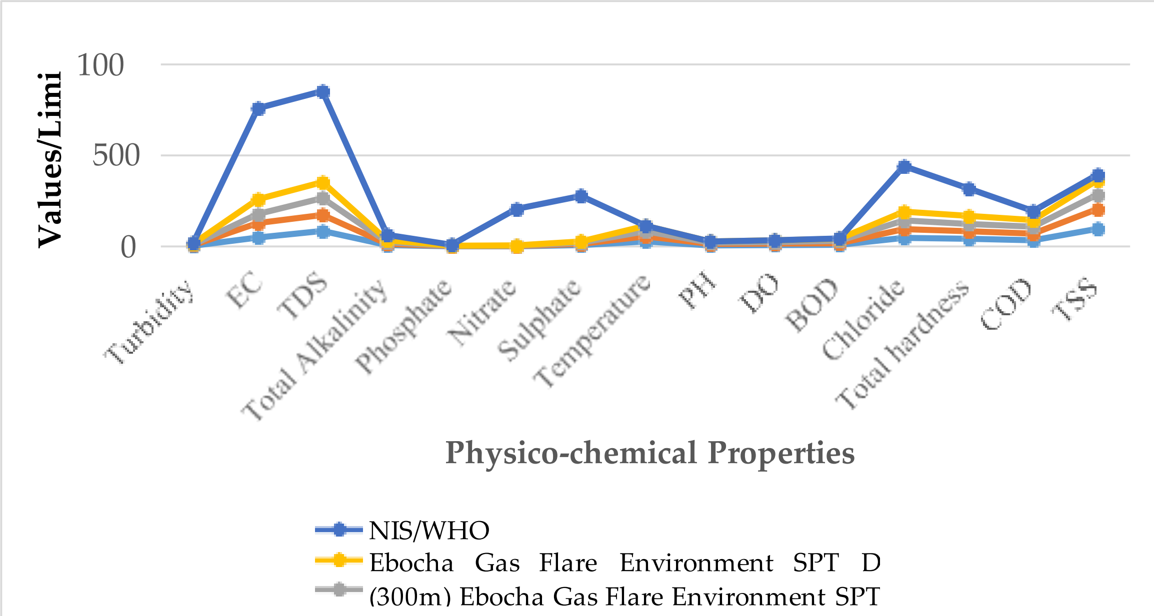

Figure 3. Comparison of the values for the physico-chemical properties in rainwater in the gas flare environments in Rivers-East and Rivers-West Senatorial Districts of Rivers State with NIS/WHO Approved Limits

Table 2. Comparison of the values for the physico-chemical properties in Groundwater in the gas flare environments in Rivers-East and Rivers-West Senatorial Districts of Rivers State with NIS/WHO Approved Limits

Gases	**Olo Gas Flare Environment**		**Ebocha Gas Flare Environment**			
	SPT A (100m)	**SPT A (300m)**	**SPT C (100m)**	**SPT D (300m)**	**NIS/WHO**	**Decision**
Turbidity (mg/L)	4.13	3.57	4.25	3.93	5	WAPL
Electrical Conductivity (ms=cm)	33.72	95.82	54.38	37.26	500	WAPL
Total Dissolved Solids (mg/L)	91.44	88.17	106.28	117.03	500	WAPL
Total Alkalinity (mg/L)	8	10	13	15	30	WAPL
Phosphate (mg/L)	1.05	1.23	1.11	0.97	5	WAPL
Nitrate (mg/L)	1.62	1.30	1.84	1.63	200	WAPL
Sulphate (mg/L)	7.38	6.92	6.71	8.37	250	WAPL
Temperature (^{O}C)	27.51	28.41	28.33	30.16	27-30	AAPL
pH	6.90	6.54	7.71	7.83	6.5-8.5	AAPL
Dissolved Oxygen (mg/L)	8.02	8.63	11.14	10.72	>5	AAPL
BOD (mg/L)	13.28	9.16	12.74	9.18	2	AAPL
Chloride (mg/L)	41.26	42.41	45.66	43.18	250	WAPL
Total hardness (mg/L)	40.53	45.27	43.21	44.36	150	WAPL
COD (mg/L)	31.24	32.47	37.16	33.05	50	WAPL
TSS (mg/L)	88.05	101.60	64.42	79.17	30	AAPL

Note: AAPL (Above Approved Permissive Limit), WAPL (Within Approved Permissive Limit)

Source: Researchers Analysis and Computation, 2024.

Table 2 show the individual values of the various physico-chemical properties or parameters in the groundwater sample equitably collected across four different points around the Olo and Ebocha flow environments. The values across the sampling points showed that turbidity ranged with 3.57-4.25 mg/L, EC ranged from 33.72-95.82 ms=cm, TDS ranged from 88.17-117.03 mg/L, Total Alkalinity ranged from 8-15 mg/L, Phosphate ranged from 0.97-1.23 mg/L, Nitrate ranged from 1.30-1.84 mg/L, Sulphate ranged from 6.71-8.37 mg/L, Chloride ranged from 45.26-45.66 mg/L, total hardness ranged from 40.53-45.27 mg/L, and COD ranged from 31.24-37.16 mg/L. These range of values were all within the NIS/WHO approved permissive limits of 5 mg/L, 500 mg/L, 500 mg/L, 30 mg/L, 5 mg/L, 200 mg/L, 250 mg/L, 250 mg/L, 150 mg/L, and 50 mg/L for turbidity, EC, TDS, Total Alkalinity, Phosphate, Nitrate, Sulphate, Chloride, total hardness, and COD respectively in groundwater.

Furthermore, the values of other physico-chemical parameters in groundwater across the four sampling points in Olo and Ebocha gas flare environment showed that Temperature had range of values from 27.61-30.16 OC, pH had range of values from 6.54-7.83, Dissolved Oxygen had range of values from 8.02-11.14 mg/L, BOD had range of values from 9.16-13.28 mg/L, and TSS had range of values from 64.42-101.60 mg/L. These range of values were all above the range of NIS/WHO approved permissive limits of 27-30 OC, 6.5-8.5, 5 mg/L, 2 mg/L, and 30 mg/L for Temperature, pH, DO, BOD, and TSS respectively in groundwater. Hence, the graphical representation of Table 2 was presented in Fig. 4 below.

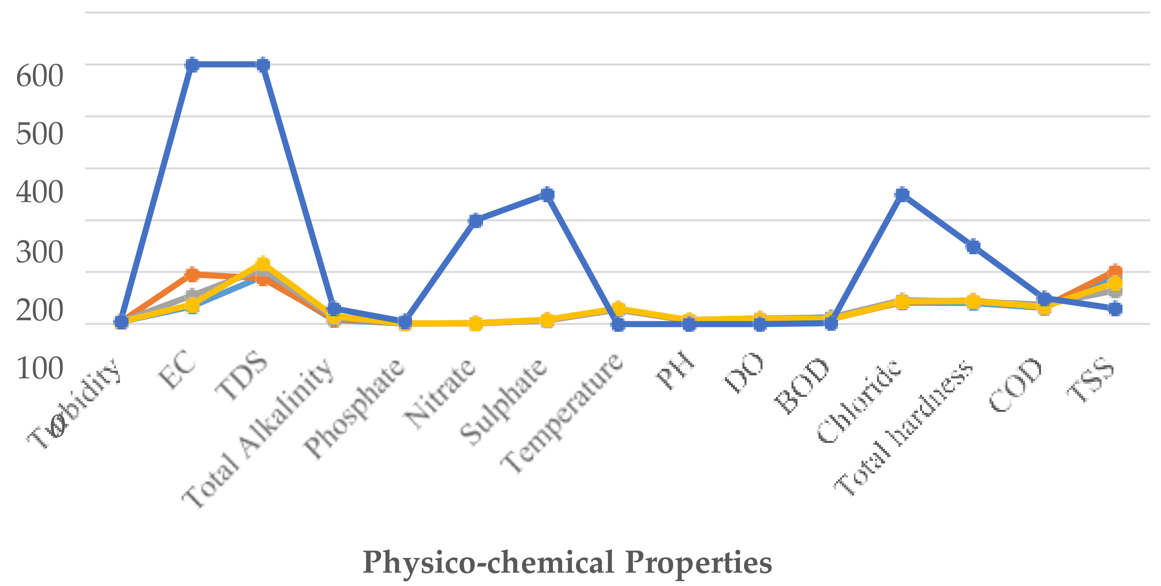

Figure 4: Comparison of the values for the physico-chemical properties in groundwater in the gas flare environments in Rivers-East and Rivers- West Senatorial Districts of Rivers State with NIS/WHO Approved Limits

Olo Gas Flare Environment SPT A (100m) Olo Gas Flare Environment SPT A (300m) Ebocha Gas Flare Environment SPT C (100m) Ebocha Gas Flare Environment SPT D (300m) NIS/WHO

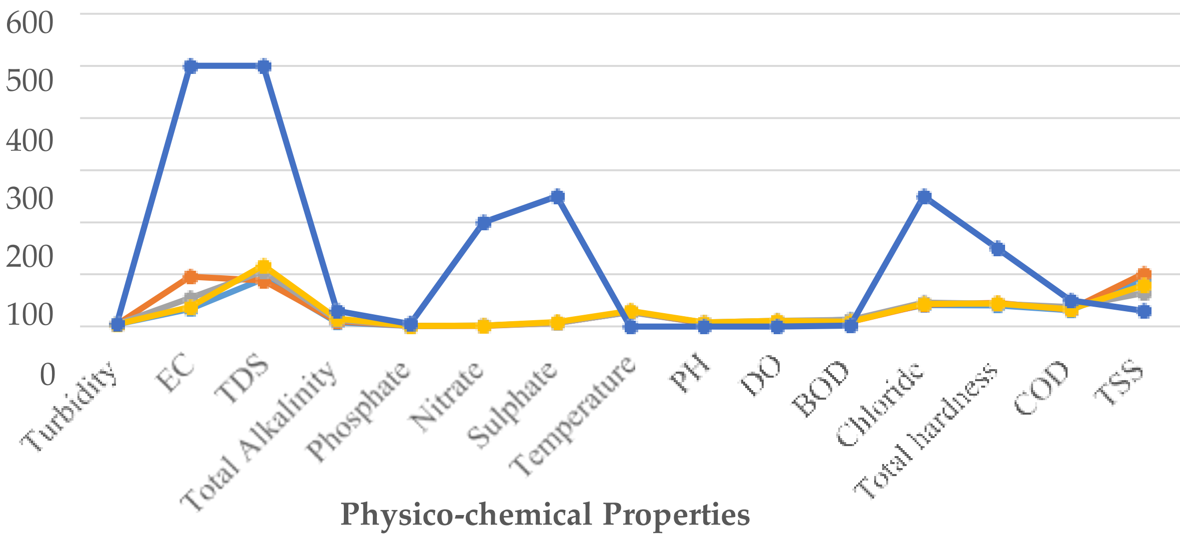

Figure 5: Comparison of the values for the physico-chemical properties in groundwater in the gas flare environments in Rivers-East and Rivers- West Senatorial Districts of Rivers State with NIS/WHO Approved Limits

Table 3. Comparison of the mean concentration of the physico-chemical properties in rainwater and groundwater in the gas flare environments in Rivers-East and Rivers-West Senatorial Districts of Rivers State

Gases	**OGFE Mean Rainwater**	**EGFE Mean Rainwater**	**OGFE Mean Groundwater**	**EGFE Mean Groundwater**
Turbidity (mg/L)	3.98	3.76	3.61	3.94
Electrical Conductivity (ms=cm)	49.46	78.84	49.64	81.83
Total Dissolved Solids (mg/L)	85.07	88.43	92.50	87.58

EGFE with groundwater highest mean concentration of 42.39 mg/L for total hardness from the same EGFE. Groundwater had the highest mean concentration of 38.37 mg/L for COD from the OGFE with rainwater highest mean concentration of 35.52 mg/L for COD obtained from the EGFE. Equally, rainwater had the highest mean concentration of 109.38 mg/L for TSS from the EGFE with the groundwater highest mean concentration of 79.62 mg/L for TSS from the OGFE.

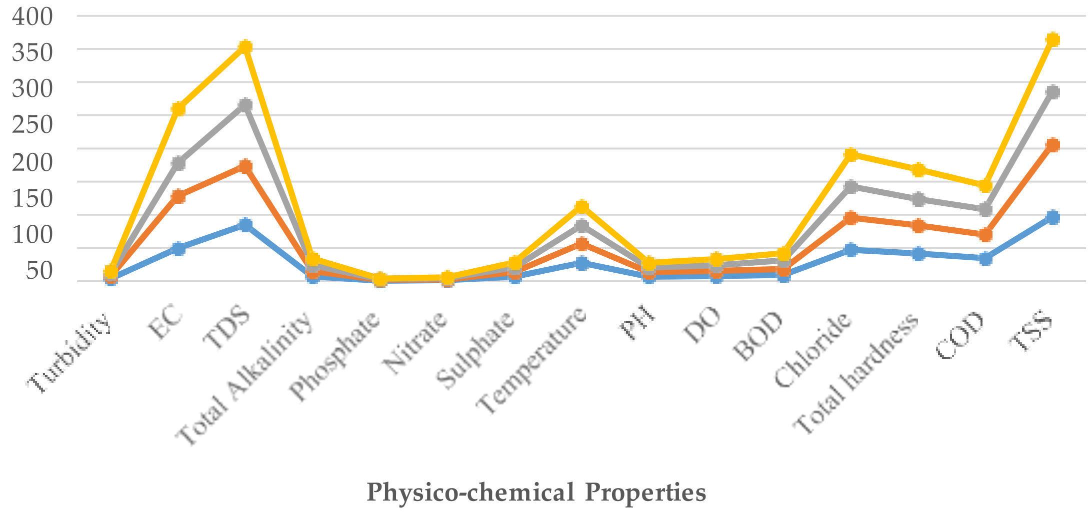

Figure 6: Mean concentration of the physico-chemical properties in rainwater

4. Discussion

The result in Table 1 revealed that rainwater had the range of values: turbidity (3.61-3.94 mg/L), EC (49.46-81.83 ms=cm), TDS (85.07-92.50 mg/L), total alkalinity (7-10 mg/L), phosphate (0.76-1.08 mg/L), nitrate (1.25-1.72 mg/L), sulphate (6.67-7.33 mg/L), chloride (47.37- 48.57 mg/L), total hardness (36.55-44.51 mg/L), and COD (34.61-38.37 mg/L) in both the Olo and Ebocha gas flare environments that were still within the NIS/WHO approved permissive limits of 5 mg/L, 500 mg/L, 500 mg/L, 30 mg/L, 5 mg/L, 200 mg/L, 250 mg/L, 250 mg/L, 150 mg/L, and 50 mg/L for turbidity, EC, TDS, Total Alkalinity, Phosphate, Nitrate, Sulphate, Chloride, total hardness, and COD respectively in rainwater. This finding is aligns with the studies by (Obafemi, 2014; Monday, 2018; Nazmuz-Sakib, 2021), which observed that the presence of chemicals like nitrate, COD, phosphate, sulphate, total alkalinity, and turbidity in rainwater would stir pollution that leads to acidic rain and in-turn alter the quality of the rainwater for irrigation and other uses.

Conversely, the result in Table 1 also revealed that rainwater in both the Olo and Ebocha gas flare environment had range of values: Temperature (27.52-28.86 OC), pH (6.73-7.07), Dissolved Oxygen (7.62-9.39 mg/L), BOD (9.08-13.27 mg/L), and TSS (78.90-109.38 mg/L) that were above the NIS/WHO approved permissive limits of 27-30 OC, 6.5-8.5, 5 mg/L, 2 mg/L, and 30 mg/L for Temperature, pH, DO, BOD, and TSS respectively in rainwater. This finding is consistent with the position of Kumar (2019) that gas flaring leads to the release of sulphate, DO, BOD, and TSS resulting to pH values higher than 5.5 that triggers the contamination of rainwater leading to the occurrence of acid rain. This finding also aligns with Lall et al. (2020) that the seepage of acid rain into the groundwater aquifer could become the pathway for the presence of unsafe water for the domestic, agricultural and other uses.

The result in Table 2 revealed that groundwater had range of values: turbidity (3.57-4.25 mg/L), EC (33.72-95.82 ms=cm), TDS (88.17-117.03 mg/L), total alkalinity (8-15 mg/L), phosphate (0.97-1.23 mg/L), nitrate (1.30-1.84 mg/L), sulphate (6.71-8.37 mg/L), chloride (45.26-45.66 mg/L), total hardness (40.53-45.27 mg/L), and COD (31.24-37.16 mg/L) in both the Olo and Ebocha gas flare environments that were still within the NIS/WHO approved permissive limits of 5 mg/L, 500 mg/L, 500 mg/L, 30 mg/L, 5 mg/L, 200 mg/L, 250 mg/L, 250 mg/L, 150 mg/L, and 50 mg/L for turbidity, EC, TDS, Total Alkalinity, Phosphate, Nitrate, Sulphate, Chloride, total hardness, and COD respectively in groundwater. This finding is in agreement with the earlier studies by (Agbalagba et al., 2011; Fashola et al., 2013; Eze & Eze, 2015), which found that the presence of sulphate, phosphate, nitrate, TDS and conductivity in groundwater increased the acidic nature of the groundwater in Port Harcourt and Yenagoa environs. This finding aligns with the views of Jiang et al. (2020) that gas flares lead to the release of nitrate, COD, phosphate, sulphate, total alkalinity, turbidity and carbon monoxide (CO) into the troposphere which correspondingly increases the occurrence of acid rain that stirs pollution when it percolates into the groundwater.

Equally, the result in Table 2 also revealed that groundwater in both the Olo and Ebocha gas flare environment had range of values: Temperature (27.61-30.16 OC), pH (6.54-7.83), Dissolved Oxygen (8.02-11.14 mg/L), BOD (9.16-13.28 mg/L), and TSS (64.42-101.60 mg/L) that were above the NIS/WHO approved permissive limits of 27-30 OC, 6.5-8.5, 5 mg/L, 2 mg/L, and 30 mg/L for Temperature, pH, DO, BOD, and TSS respectively in groundwater. This finding is consistent with the finding by Amaechi-Onyerimma (2021) that the presence of nitrate, sulphate, carbon monoxide, ozone, BOD, TSS, Temperature, and Dissolved Oxygen in groundwater samples heightens their pollution from the earlier formed acidic rain that seeps into groundwater. This finding aligns with the studies by (Fashola et al., 2013; Eze & Eze, 2015) that the acidic nature of groundwater samples was as a result of dissolved oxygen during aquifer recharge by rain water in Port Harcourt and Yenagoa.

The result in Table 3 revealed that rainwater samples from Olo and Ebocha gas flow environments had higher mean concentration for turbidity with 3.98 mg/L, Temperature with 28.86 OC, chloride with 48.52 mg/L, and TSS with 109.38 mg/L than the mean concentration of 3.76 mg/L, 78.846 ms=cm, 48.37 mg/L, and 79.62 mg/L for turbidity, Temperature, chloride, and TSS respectively for groundwater. This finding is consistent with the position of Amaechi-Onyerimma (2021) that the presence of turbidity, TSS, Temperature, and chloride in rainwater samples heightens the formation of acid-rain that leads to the corrosion of buildings and vegetative discoloration.

Also, the result in Table 3 revealed that groundwater samples from Olo and Ebocha gas flow environments had higher mean concentration for EC with 81.83 ms=cm, TDS with 92.50 mg/L, total alkalinity with 10 mg/L, phosphate with 1.08 mg/L, nitrate with 1.73 mg/L, sulphate with7.33 mg/L, pH with 7.07, DO with 9.39 mg/L, BOD with 13.27 mg/L, total hardness with 44.51 mg/L, and COD with 38.37 mg/L than the mean concentrations of 78.846 ms=cm, 88.43 mg/L, 8 mg/L, 0.97 mg/L, 6.81 mg/L, 6.89, 7.71 mg/L, 9.26 mg/L, 42.39 mg/L, and 35.52 mg/L for EC, TDS, total alkalinity, phosphate, sulphate, pH, DO, BOD, total hardness, and COD respectively in rainwater samples in the Olo and Ebocha gas flare environments. This finding is consistent with the earlier studies by (Osuoha, 2017; Seiyaboh & Izah, 2017; Kumar, 2019) that the concentration of conductivity, TDS, total alkalinity, phosphate, nitrate, sulphate, pH, DO, BOD, total hardness, and COD in groundwater can expose humans to water borne diseases like typhoid, cholera, etc. Also, this study aligns with the finding by (Aboyeji, 2013; Amaechi-Onyerimma & Onugha, 2021; Onugha, 2022) that the presence of physico-chemical parameters in groundwater increases the pollutants that triggers a cycle of pollution that affects the biodiversity by-products like rabbits, monkeys, yam, cassava etc. causing disease prevalence and fatality to humans in the environment.

5. Conclusion

The assessment of the physico-chemical properties of rain and ground water in Olo and Ebocha gas flare environments in Rivers East and Rivers West Senatorial Districts of Rivers State showed that groundwater had higher mean concentration of majority of the physico-chemical parameters like total alkalinity, phosphate, nitrate, sulphate, pH, DO, BOD, total hardness, and COD than rainwater with the mean concentration of turbidity, Temperature, chloride, and TSS. This implies that the acidic nature of groundwater with impurities triggers water borne diseases like typhoid, cholera, etc. that could cause sicknesses, harm and death to humans in the environment.

6. Recommendations

Based on the findings of the study, the following recommendations were proffered:

1. Rainwater should be collected or harvested from an elevated position rather than near ground surface or level that could heighten the infiltration of certain chemicals that leads to acid rain that poses great risk to even the groundwater that such rainwater seeps into.
2. The Federal and Rivers State Governments should partner towards the enforcement of “Zero Flaring of Gas” that heightens the release of nitrate, sulphate, BOD, TSS, DO, pH, COD, among other pollutants that percolates leading to acid rain that seeps or conveys impurities down to individual aquifers and wells causing water pollution in the environment.
3. The Rivers State Ministries of Health and Environment should strictly supervise the drilling of boreholes by individuals and companies with a view at ensuring compliance to regulatory approved limits for safe drinking water that would prevent the occurrences of diarrhea, cholera and other water borne diseases and public health issues or problems.

REFERENCES

[1] O. O. Aboyeji, "Freshwater pollution in some Nigerian local communities; Causes, consequences and probable solutions," *Academic Journal of Interdisciplinary Studies*, vol. 2, no. 13, pp. 68-77, 2013.

[2] O. E. Agbalagba, O. H. Agbalagba, C. P. Ononugbo, and A. A. Alao, "Investigation into the physicochemical properties and hydrochemical processes of groundwater from commercial boreholes in Yenagoa, Bayelsa State, Nigeria," *A. J. Environ. Sci. Technol.*, vol. 5, no. 7, pp. 473-481, 2011.

[3] A. F. Aiyesanmi, K. O. Ipinmoroti, and I. I. Oguntimehin, "Impact of automobile workshop on groundwater quality in Akure metropolis," *J. Chem. Soc. Nig.*, Supplement to 2004 proceedings, pp. 420-426, 2004.

[4] C. N. Amaechi-Onyerimma, "Abattoir waste effluents and underground water quality in Port Harcourt metropolis Rivers State," Ph.D. dissertation, Ignatius Ajuru University of Education, Port Harcourt, 2021.

[5] C. N. Amaechi-Onyerimma and A. C. Onugha, "Impact of flared gases on biotic and abiotic components of the environment around Agbada flow station, Rivers State," *African Journal of Health & Environmental Sciences, Entrepreneurship, Engineering & Agriculture*, vol. 4, no. 1, pp. 113-129, 2021.

[6] C. C. Amos, A. Rahman, F. Karim, and J. M. Gathenya, "A scoping review of roof harvested rainwater usage in urban agriculture: Australia and Kenya in focus," *Journal of Cleaner Production*, vol. 202, pp. 174-190, 2018.

[7] R. Bagel, L. Stepan, and J. K. V. Hill, *Water, knowledge and environment in Asia: Epistemologies, practices and locales*, McGraw Hill, 2017.

[8] C. Button, "Domesticating water supplies through rainwater harvesting in Mumbai," *Gender & Development*, vol. 25, no. 2, pp. 269-282, 2017.

[9] C. L. Eze and E. M. Eze, "Investigation of possible groundwater contamination from septic system siting in Port Harcourt, Nigeria," *J. Nat. Sci. Res.*, vol. 5, no. 10, 2015.

[10] J. S. Famiglietti, "The global groundwater crisis," *Nature Climate Change*, vol. 4, no. 11, pp. 945-948, 2014

[11] F. I. Fashola, H. O. Nwankwoala, and A. C. Tse, "Physico-chemical characteristics of groundwater in Old Port Harcourt Township, Eastern Niger Delta," *Int’l J. Phy. Sci.*, vol. 1, no. 3, pp. 047-055, 2013.

[12] O. G. Fawole, X. M. Cal, and A. R. MacKenzie, "Gas flaring and resultant air pollution: A review focusing on black carbon," *Environ. Pollut.*, vol. 216, pp. 182-197, 2016.

[13] G. R. F. Ibrahim, A. Rasul, A. H. Azad, A. Arieann, Z. F., and A. A. Dewana, "Suitable site selection for rainwater harvesting and storage: Case study using Dohuk Governorate," *Water*, vol. 11, no. 4, pp. 864-894, 2019.

[14] International Groundwater Assessment Centre (IGAC), "What is groundwater?" IGAC Publication, 2022.

[15] D. Jiang, L. Chen, and N. Xia, "Elevated atmospheric CO2 impact on carbon and nitrogen transformations and microbial community in replicated wetland," *Ecol Processes*, vol. 9, p. 57-68, 2020.

[16] A. Kumar, "Water conservation technologies," in *Hydraulic Rubber Dam: An Effective Water Management Technology in Plastics Design Library*, pp. 11-24, 2019.

[17] U. Lall, L. Josset, and T. Russo, "A snapshot of the world's groundwater challenges," *Annual Review of Environment and Resources*, vol. 45, no. 1, pp. 171-194, 2020.

[18] A. M. MacDonald et al., "Mapping groundwater recharge in Africa from ground observations and implications for water supply," *Environmental Research Letters*, vol. 16, no. 3, p. 034012, 2021.

[19] D. S. Monday, "An investigation of selected air quality parameters in Gokana Local Government Area of Rivers State," MSc dissertation, Ignatius Ajuru University of Education, 2018.

[20] National Ground Water Association (NGWA), "Groundwater fundamentals," NGWA Publication, 2024.

[21] S. M. Nazmuz-Sakib, "The impact of oil and gas development on the landscape and surface in Nigeria," *Asian Pacific Journal of Environment and Cancer*, vol. 4, no. 1, pp. 9-17, 2021.

[22] O. C. Nwankwo, *A practical guide to research writing for students in education and social sciences*, 6th ed., M & J Grand Orbit and Communication Ltd, 2016.

[23] H. O. Nwankwoala, "Evaluation of hydrochemical characteristics of groundwater in Port Harcourt, Nigeria," Ph.D. dissertation, University of Port Harcourt, Nigeria, 2013.

[24] H. O. Nwankwoala and G. J. Udom, "Studies on chemistry and hydrochemical processes of groundwater in Port-Harcourt, Southern Nigeria," *Journal of Spatial Hydrology*, vol. 11, pp. 35-37, 2011.

[25] H. O. Nwankwoala and P. O. Youdeowei, "Soil and water microbiological characteristics of Olo flowstation and Rumuekpe metering station, Rivers State, Nigeria," *International Journal of Water Resources*, vol. 7, no. 3, pp. 286-289, 2017.

[26] A. A. Obafemi, "Environmental pollution," in *Perspectives on the Human Environment*, W. I. Bell-gam, S. B. Arokoyu, and J. E. Umeuduji, Eds., Amethyst and Colleagues Publishers, 2014.

[27] O. A. Odukoya, T. A. Arowolo, and O. Bamgbose, "Effect of solid waste landfill on underground and surface water quality at Ring Road, Ibadan," *Global J. Environ. Sci.*, vol. 2, no. 2, pp. 235-242, 2002.

[28] A. C. Onugha, "Assessment of soil properties of land uses in urbanizing wetlands in Port Harcourt metropolis, Rivers State Nigeria," Ph.D. thesis, Ignatius Ajuru University of Education, Rivers State, 2022.

[29] C. A. Osuoha, "Gas flaring in Niger Delta region of Nigeria: Cost, ecological and human health implications," *Environmental Management and Sustainable Development*, vol. 6, no. 2, pp. 390-410, 2017.

[30] S. Palmas and E. Petrucci, "Practical aspects on electrochemical disinfection of urban and domestic wastewater," in *Electrochemical Water and Wastewater Treatment*, ScienceDirect, 2018.

[31] D. D. Ratnayaka and M. K. Johnson, *Water supply: Storage, clarification and chemical treatment*, 6th ed., McGraw Hill, 2009.

[32] E. I. Seiyaboh and S. C. Izah, "A review of impacts of gas flaring on vegetation and water resources in the Niger Delta Region of Nigeria," *International Journal of Economy, Energy and Environment*, vol. 2, no. 4, pp. 48-55, 2017.

[33] L. Sibe, L. C. Osuji, and A. I. Hart, "Physico-chemical alterations of interstitial water quality by artisanal refining operations at K-Dere coastal plain, South-Eastern Nigeria," *Intl. J. of Sci. and Eng. Res.*, vol. 10, no. 12, pp. 194-205, 2019.

[34] G. N. Woke and B. Babatunde, "Assessment of groundwater quality in Emohua Local Government Area, Rivers State, Nigeria," *Journal of Natural Sciences Research*, vol. 5, no. 24, pp. 8-15,2020

[35] D. Wokoma, "Hydrogeochemical characteristics of groundwater in parts of Port Harcourt metropolis, Rivers State, Nigeria," *J. Environ. Sci. Technol.*, vol. 8, pp. 39-46, 2020.

[36] S. P. Zubairu, "Influence of urbanization on water quality of surface waters in Ilorin, Nigeria," *Int'l J. of Applied Science & Engineering*, vol. 6, no. 4, pp. 125-135, 2021.