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Effects of Gas Flaring On Air and Groundwater Quality in Ebedei and Ashaka, Located in Ukwuani, Delta State, Nigeria

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Abstract

This research examines the effects of gas flaring on air and groundwater quality in Ebedei and Ashaka, located in Ukwuani, Delta State, Nigeria. Data on air pollutants, including sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and carbon dioxide (CO_2), as well as groundwater quality parameters, were collected during both the wet and dry seasons through systematic sampling techniques. The findings indicate that levels of SO_2 and NO_2 exceeded the permissible limits set by the World Health Organization (WHO), posing significant threats to air quality and public health. Conversely, CO_2 concentrations remained within acceptable ranges. Groundwater analysis revealed slightly acidic pH levels, elevated biochemical oxygen demand (BOD), and high concentrations of iron, lead, and phosphates, all surpassing WHO standards and pointing to contamination caused by industrial emissions and acid rain. Statistical analyses demonstrated strong links between SO_2 and NO_2 emissions and groundwater quality, highlighting their harmful effects. Seasonal differences in pollutant levels were minor, suggesting that human activities are the primary source of pollution. The study emphasizes the urgent need for stricter environmental policies, effective pollution control measures, and ongoing monitoring to protect local communities and ecosystems.

Keywords: WHO, Ukwuani Settlements, Pollution, Groundwater Quality.

Introduction

Crude oil exploration and exploitation leads to gas flaring which a foremost industrial problem in Nigeria (Adeola et al., 2021). Carbon dioxide, sulphur dioxide, and nitrous oxides are released into the environment during the flaring process. Flared gases react with rain to form harmful acid rain, which harms vegetation and aquatic life (Elijah, 2022). Acid rain corrodes metals and weakens cloth fabrics and roofing sheets, among other things. Acid deposition is caused by the release of flaming gases like SO_2, NO_4, NH_3, and CO_2 into the atmosphere (Olobaniyi & Efe, 2007). When acid rain falls to the earth's surface, it is corrosive and causes significant environmental damage. Efe (2010) discovered that the majority of inhabitants in gas flare zones complain of excessive levels of particulate matter in their water supply shortly after every downpour.

One issue in Ukwuani communities is obtaining a sufficient quantity of water due to the high incidence of environmental pollution and degradation. Residents in Ebedei and Ashaka are not left they find it difficult to obtain drinking water due to a scarcity caused by the area's high-flaring activities as earlier opined by (Abubakar, 2019). As a result, they waste significant man-hours searching for and retrieving water from remote sources, often of poor quality. Poor water source has long been known as having a harmful effect on public health in both developing and affluent countries (Aragaw et al., 2023). Most residents of Ukwuani villages rely on the rivers and streams in the area for their daily water needs, and drinking contaminated water can cause diseases such as typhoid fever, dysentery, cholera, and other intestinal ailments (Atubi, 2011).

The total impact of water contamination, however, is far more visible on the surface than in atmospheric and subsurface water bodies (Dami et al., 2012). Gas flaring elevates greenhouse gas quantity due to insufficient facilities to collect and preserve the gas for marketing (Ismail & Umukoro, 2012). Nigeria's obsolete equipment contributes to significant gas flaring emissions, which pollute the air and water in oil-producing states and refineries. The country has repeatedly extended gas flaring deadlines, emphasising the importance of a reporting structure. However, gas emissions in Ukwuani communities have been disregarded in Delta State making it required for additional studies to be conducted.

Conceptual Issues

The distance decay concept, which highlights that the quality and quantity of the impact decrease with increasing distance from the source of the evidence, is the foundation of the research. Up until now, spatial development analysis has made use of the distance decay concept (Murayama & Thapa, 2011). The notion of distance decay is used to investigate the adverse relationship between detachment and comparison (Ozabor & Obisesan, 2015). Brown (2023) reiterated that regions near refineries are more affected by flares. Understanding the phenomena is necessary to accurately assess how distance decay affects spatial distributions (Pun-Cheng, 2016).

The distance-decay parameter is a behavioural indicator of the relationship between interaction and distance that quantifies how strongly interaction patterns are related to distance (Fotheringham, 1981). However, more recent concept suggest that interactions and spatial organisation affect distance-decay parameter estimates. This has caused debate since it is clear from research on the link between geographic structure and estimated distance-decay parameters for greenhouse gas emissions (GHGEs) that changes in spatial structure have a major role in the observed variability in parameter values. The forecasting of interactions is significantly hampered by the heterogeneity in parameter estimates across geographical dimensions.

Methods and Materials

The Ebedei and Ashaka localities are in Ukwuani community, Delta State which embraces Ukwuani, Ndokwa East and Ndokwa West Local Government Areas (see Fig. 1). The climate is tropical equatorial, with an average annual temperature of 27.4°C and a relative humidity of 70%-80%.

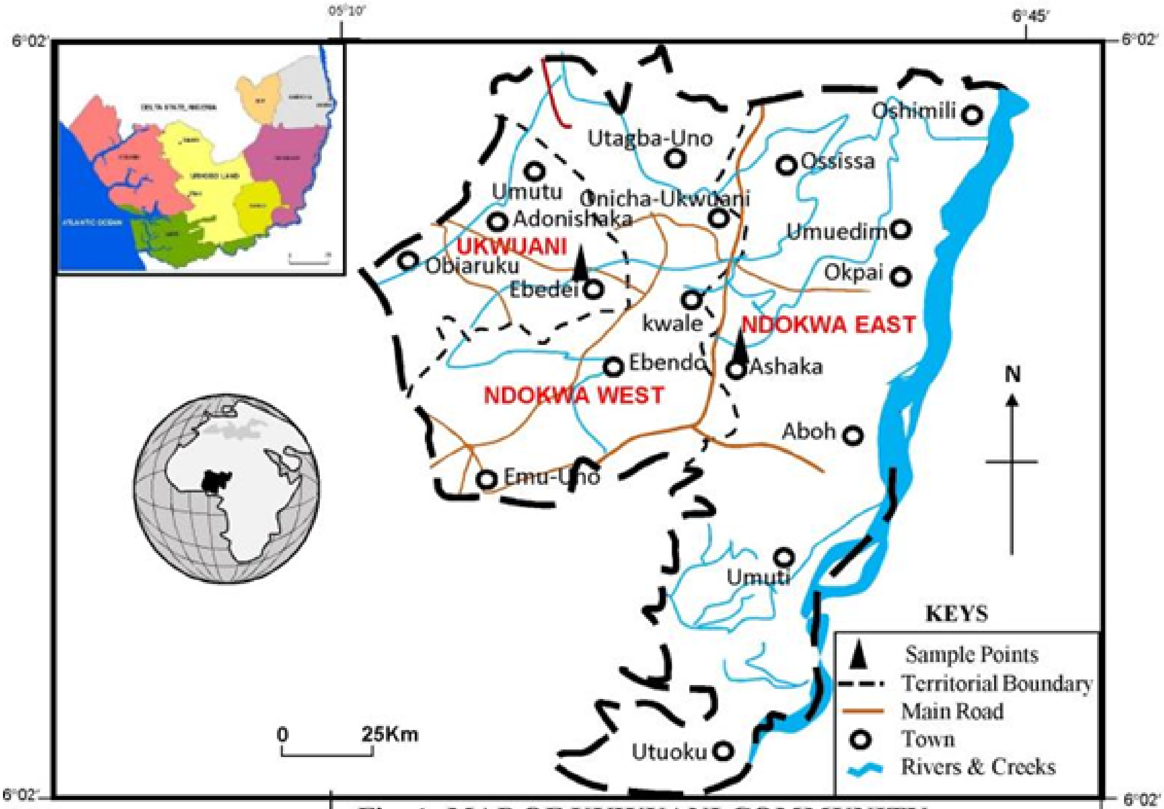

Fig. 1: MAP OF UKWUANI COMMUNITY

Source: *Ministry of Lands, Surveys & Urban Development, Asaba, (2008)*

Flat topography, high elevation, and hydromorphic soils characterise Ebedei and Ashaka. With the same habits, beliefs, and cultures, the population has expanded from 103,000 in 1991 to over 119,034 in 2015 and is projected to be 163,100 in 2022. Fishing, crop cultivation, vegetable growing, and petty trading are among the socioeconomic activities in the area. Field measurements of emitted gases and groundwater quality analyses in Ebedie and Ashaka were part of the inquiry. Gas emissions, water quality data, temperature, conductivity, and heavy metal concentration were all primary sources as used in previous study by (Filonchyk et al., 2024). Gases were evaluated based on their dominance and ability to be effectively trapped. The study locations were preferred over 50m from the flare stack in Ebedie and Ashaka which are close to gas flare locations using a systematic selection procedure as suggested in previous studies of (Nwosisi et al., 2021). For sampling, two sampling sites (Ebedei and Ashaka) were chosen. The study used simultaneous measurements of released gases and groundwater samples to analyse gas emissions during the wettest and dry seasons. Data were collected at two-week intermissions in each month, representing the break between rainfall peak and unusual rains. Gases were measured in the early morning and evening, allowing for easy trapping of volatile vapours. The gases were averaged and likened to WHO standards at each designated sample sites.

Gas emission measurements were conducted in congested areas of high-rise buildings, where wind was not a factor. Air samples were collected twice a day at each site using a Sage thermal mass flow metre positioned three metres above the ground, as employed in earlier studies (Yu & Hahne, 2005; Ilusanya et al., 2020; Santarpia et al., 2020). Data on the groundwater quality in Ukwuani communities were gathered using water samples from wells and boreholes. Borehole taps water were positioned in cups, and plastic buckets were used to scoop the well water. The storage cans were cleaned with distilled water so as to disinfect the cans. The water samples collected kept cold, and sent to the laboratory for investigation. To estimate the effect of flared gases on the water quality in the study area, water samples were taken in July and December 2023 during stages of high and low rainfall. The collection of water samples was repeatedly carried out every three weeks and a total of six samples were collected in Ebedei, and Ashaka. The well water samples were collected between 6am and 7am, when the well water had not been fetched. Efe & Mogborukor (2012) suggests that gas flares' influence on acid rain may alter groundwater quality, similar to gas emissions. In order to compare water samples to WHO water quality requirements, they were examined for cations, anions, and trace metals. Tables and diagrams were used to present the results of the data analysis procedure, using means and percentages as previously utilised in (Divecha et al. 2023) investigations. Simple descriptive analyses and variable cross-tabulation were performed. Data were entered into SPSS version 21 and double-checked before analysis.

Results and Discussion

Table 1: Emitted gases in Ukwuani Communities

Air Pollutants	Parts Per Million (PPM)		
	SO_2	NO_2	CO_2
Mean Observed Pollutants	0.62 ± 0.086	0.096 ±0.025	8.59 ±1.47
WHO Standards	±0.00-0.01	±0.03-0.06	±3-10

Source: Fieldwork (2023)

Table 1 presents the concentrations of Sulphur Dioxide (SO_2), Nitrogen Dioxide (NO_2), and Carbon Dioxide (CO_2) in Ukwuani communities, measured in parts per million (PPM). The data includes the World Health Organization (WHO) standards for each pollutant, enabling comparison. Sulphur Dioxide levels in Ukwuani communities are significantly above the WHO guideline for acceptable concentrations, indicating that SO_2 pollution in this area exceeds the safe threshold. Prolonged exposure to high levels of SO_2 can lead to acid rain, which can harm ecosystems and water bodies. Nitrogen Dioxide levels in Ukwuani are higher than the WHO recommended range of 0.03-0.06 PPM, but still exceed the safe levels. CO_2 levels in Ukwuani fall within the WHO guideline ranges of 3-10 PPM, indicating that CO_2 levels are within the acceptable limits. Both SO_2 and NO_2 levels in Ukwuani exceed the WHO air quality standards, suggesting compromised air quality and potential health risks for the local population. The air quality in Ukwuani communities is compromised due to high levels of sulphur dioxide and nitrogen dioxide. They also contribute to acid rain, which damages vegetation, soil, and water bodies, and ground-level ozone, a significant component of smog, which reduces air quality and harms ecosystems.

Table 2: Seasonality of Gas Emission in Ukwuani Communities

Air Pollutants	Seasonal Concentrations in Parts Per Million (PPM)	
	Dry	Wet
SO_2	0.623 ± 0.0883	0.617 ± 0.0877
NO_2	0.09 ± 0.026	0.09 ± 0.0236
CO_2	8.6 ±1.766	8.59 ±1.234

Source: Fieldwork (2023)

Table 2 presents the seasonal concentrations of three major air pollutants - Sulfur Dioxide (SO_2), Nitrogen Dioxide (NO_2), and Carbon Dioxide (CO_2) - in Ukwuani communities. The data is analysed during the Dry and Wet seasons, providing concentrations in PPM to illustrate measurement variation. Sulfur dioxide (SO_2) levels remain nearly identical in both seasons, with a very small difference (0.623 PPM in the dry season vs. 0.617 PPM in the wet season). This suggests that SO_2 levels in Ukwuani communities remain relatively stable throughout the year, irrespective of seasonality. Factors like industrial emissions, vehicular traffic, or localized sources of pollution might contribute consistently to SO_2 levels year-round. Nitrogen Dioxide (NO_2) levels remain consistent across both seasons, with no significant difference between the dry and wet periods (0.09 PPM in both seasons). Seasonal stability indicates a consistent source of NO_2 emissions throughout the year, possibly due to traffic emissions, industrial activities, and other anthropogenic sources that persist across both seasons. Elevated NO_2 levels are harmful to respiratory health, contributing to the development or exacerbation of asthma, bronchitis, and other lung conditions. CO_2 levels are nearly identical in both the dry (8.6 PPM) and wet (8.59 PPM) seasons, with a minute difference within the margin of error, suggesting that the concentration remains fairly stable year-round in the community.

Stable CO_2 emissions suggest that local sources of CO_2, such as vehicular emissions, combustion of fossil fuels, and industrial processes, are consistent throughout the year. While CO_2 itself is not toxic at these levels, prolonged exposure to elevated concentrations in confined spaces can pose risks. There is a lack of seasonal variation in pollution control measures, suggesting that measures should be applied consistently throughout the year, focusing on regulating industrial emissions, transportation, and other sources of anthropogenic air pollutants (Zhang et al., 2024). The analysis of seasonal concentrations of SO_2, NO_2, and CO_2 in Ukwuani communities reveals that these pollutants remain relatively constant throughout the year, without significant seasonal variation as opined by (Gordon et al. 2024). This suggests that anthropogenic sources of pollution, rather than weather patterns, are the primary drivers of air quality in the region (Arihilam & Arihilam, 2019). Although

CO_2 levels are within safe limits, the persistent presence of SO_2 and NO_2 at elevated concentrations highlights the need for continuous air quality management, health monitoring, and pollution control measures to protect both public health and the environment (Brooks, 2020).

Table 3: The average values of physicochemical parameters in bore-hole water

Parameters	Mean Values ± Std. Deviation	WHO Limits
pH	5.69 ± 0.93	7.0 – 8.5
Temperature (^{0}C)	28.6 ± 0.51	30
Conductivity (uS/cm)	42.32 ± 7.18	50
Turbidity (N.T.U)	3.93 ± 3.76	5
B O D	4.34 ± 0.60	2
C O D (mg/l)	4.20 ± 0.35	<4.0
T D S (mg/l)	33.92 ± 10.02	500
Magnesium	2.67 ± 1.37	30
Iron (mg/l)	0.65 ± 0.43	0.3
Lead (mg/l)	< 0.03	0.01
Chloride (mg/l)	26.31 ± 12.31	50
Sulphate (mg/l)	4.16 ± 3.62	200
Phosphate (mg/l)	2.15 ± 1.31	0.5
Nitrate (mg/l)	2.41 ± 1.79	50
Sodium (mg/l)	15.9 ± 6.47	50
Potassium (mg/l)	7.07 ± 3.94	10

Source: Fieldwork (2023)

Table 3 presents the mean values of physicochemical parameters measured in borehole water compared to the World Health Organization (WHO) limits for safe drinking water. The pH below the WHO Limit of 7.0-8.5, which indicates slightly acidic water, which can cause corrosion of plumbing and leach metals into the water, leading to contamination and potentially harming health over time. Temperature is within the permissible range, indicating typical ambient conditions for groundwater in tropical climates. Conductivity is below the WHO Limit of 50 µS/cm, reflecting low levels of dissolved ionic substances (Walton, 1989). Turbidity levels are within the permissible range but show significant variability, with some samples potentially approaching the limit. Biochemical Oxygen Demand (BOD) is above the WHO Limit of 2 mg/L, suggesting organic pollution or microbial activity (Rekrak et al., 2020).

Chemical Oxygen Demand (COD) slightly exceeds the WHO Limit of <4.0 mg/L, indicating chemical contamination (Li et al., 2018). Total Dissolved Solids (TDS) is well below the WHO Limit, indicating minimal dissolved substances in the water. Magnesium concentration is far below the WHO Limit, indicating safe levels. Iron concentration exceeds the WHO Limit, causing discoloration of water, metallic taste, and staining of plumbing fixtures. Lead concentration exceeds the WHO Limit, posing severe health implications, particularly for children and pregnant women. Chloride levels are well within the permissible range, contributing to water taste and being essential in moderation. Sulphate levels are significantly below the WHO Limit, indicating a lack of contamination from industrial or agricultural runoff. Phosphate levels exceed the WHO Limit, promoting algal blooms and affecting water quality. Sodium levels are within the WHO Limit, contributing to the water's taste.

Table 4: Mean values of the physicochemical parameters of well water

Parameters	Mean Values ± Std. Deviation	WHO Limits
pH	5.50 ± 0.93	7.0 – 8.5
Temperature (^{0}C)	28.52 ± 0.54	30
Conductivity (uS/cm)	43.42 ± 7.64	50
Turbidity (N.T.U)	3.95 ± 3.76	5
B O D	4.30 ± 0.60	2
C O D (mg/l)	4.17 ± 0.31	<4.0
T D S (mg/l)	33.66 ± 11.32	500
Magnesium	2.87 ± 1.26	30
Iron (mg/l)	0.77 ± 0.37	0.3
Lead (mg/l)	<0.01	0.01
Chloride (mg/l)	26.29 ± 12.35	50
Sulphate (mg/l)	4.15 ± 3.64	200
Phosphate (mg/l)	2.11 ± 1.28	0.5
Nitrate (mg/l)	2.40 ± 1.77	50
Sodium (mg/l)	15.91 ± 6.43	50
Potassium (mg/l)	6.89 ± 3.76	10

Source: Fieldwork (2023)

Table 4 presents the mean values of physicochemical parameters measured in well water compared to the World Health Organization (WHO) limits for safe drinking water. The parameters include pH, temperature, turbidity, and various chemical and mineral indicators. The pH (5.50 ± 0.93), which is well below the recommended range, indicating that the well water is acidic. This can cause corrosion of pipes and leaching of harmful metals, affecting water safety and infrastructure longevity. Temperature (28.52 ± 0.54 °C) is within the permissible limit. Conductivity (43.42 ± 7.64 µS/cm) is slightly below the limit, indicating low levels of dissolved ions, reflecting a low mineral content, which is generally desirable for drinking water. Turbidity (3.95 ± 3.76 NTU) is within permissible limits but shows high variability, suggesting suspended particles, potentially including organic matter or microbial contaminants. Biochemical Oxygen Demand (BOD) exceeds the WHO limit, indicating organic pollution or microbial activity. Chemical Oxygen Demand (COD) is slightly above the limit, suggesting some chemical contamination. Total Dissolved Solids (TDS) is significantly below the WHO limit, indicating good water quality in terms of salinity and mineral content. Magnesium levels are well below the WHO limit, with no risk of hardness issues in water. Iron levels exceed the

WHO limit, potentially causing water discoloration, staining of plumbing, and metallic taste. Lead levels are at or below the detection limit and within permissible limits, with no immediate health risks from lead contamination in the sampled well water. Chloride levels are well within the permissible range, with no salinity issues and no major chloride-related health concerns. Sulphate levels are significantly below the WHO limit, indicating minimal contamination from industrial or agricultural sources. Phosphate levels exceed the WHO limit, potentially leading to eutrophication. Nitrate levels are within the permissible range, indicating minimal agricultural or sewage-related contamination. Potassium levels are safe for health and consistent with normal water composition. The findings reveal that well water in the study area generally meets many WHO standards, but critical issues with pH, iron, BOD, COD, and phosphate levels highlight concerns over acidity, organic contamination, and chemical pollutants. These findings call for immediate remediation efforts to ensure safe water for consumption and mitigate health and environmental risks. While well water generally meets many WHO standards, the critical issues with pH, iron, BOD, COD, and phosphate levels highlight concerns over acidity, organic contamination, and chemical pollutants.

Table 5: Model summary for the Relationship between SO_2 and Water Quality

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	0.94.a	.999	.987	.0096216	.999	284.357	14	1	.042

Source: SPSS Output

Table 5 presents a regression analysis evaluating the relationship between sulfur dioxide (SO_2) emissions and water quality indicators. The correlation coefficient (R) is 0.94, indicating a strong positive relationship between SO_2 emissions and water quality parameters. The coefficient of determination (R^2) is 0.999, explaining the proportion of variance in water quality that is predictable from SO_2 emissions. Adjusted R^2 is 0.987, indicating the model's robustness despite minor overfitting despite the small sample size. The standard error of the estimate is 0.0096216, indicating the model's predictions are highly accurate. The F-statistic is 284.357, demonstrating a statistically significant relationship between SO_2 emissions and water quality. The degrees of freedom reflect the number of predictors and the number of samples. The significance of F Change (Sig. F Change = 0.042) is p-value (<0.05), indicating the relationship between SO_2 emissions and water quality. The findings suggest that SO_2 emissions are a major contributor to changes in water quality, aligning with known impacts of sulphur dioxide, such as acid rain, which can lower pH levels and introduce contaminants into water bodies. Policy considerations include implementing stricter air pollution standards and encouraging cleaner energy sources to control SO_2 emissions. Further research with larger sample sizes and diverse locations could help validate these findings and uncover other influencing factors.

Table 6: Model summary for the Relationship between NO2 and groundwater quality

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.993a	.985	.779	.0115244	.985	294.787	14	1	.015

Source: SPSS Output

The regression analysis shows a strong positive correlation between nitrogen dioxide concentrations and groundwater quality, with 98.5% of variation explained by NO_2 levels (see Table 6). The adjusted R^2 is 0.779, accounting for the number of predictors and sample size. The standard error of the estimate is 0.0115244, indicating a strong relationship between NO_2 and groundwater quality. The change statistics show that nearly all the variability in groundwater quality is captured by the model. The high F-statistic (294.787) and low p-value (0.015) confirm the statistical significance of the relationship, affirming that NO_2 concentrations are a reliable predictor of groundwater quality. The model's accuracy in predicting groundwater quality values based on NO_2 concentrations is low, with a low standard error of 0.0115244.

However, the adjusted R^2 suggests that while the model is robust, there may be minor overfitting due to the small sample size or the number of predictors. The study reveals that NO_2, a by-product of industrial emissions, vehicular exhaust, and agricultural activities, significantly impacts groundwater quality. Addressing NO_2 emissions through targeted policies and mitigation strategies is crucial for sustainable groundwater quality and public health.

Table 7: Model Summary for the Relationship between CO2 and groundwater quality

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.995a	.990	.852	.55368	990	7.184	14	1	.285

Source: SPSS Output

Table 7 presents the results of a regression analysis investigating the relationship between carbon monoxide (CO_2) levels and groundwater quality. The high R value (0.995) and R^2 value (0.990) indicate a strong statistical relationship between CO_2 and groundwater quality. However, the lack of significance ($p = 0.285$) suggests that this relationship could be due to random variation rather than a true causal link. The model's high R^2 (0.990) and adjusted R^2 (0.852) values suggest it explains groundwater quality variability, but the difference suggests overfitting due to sample size or complexity. Moderate prediction accuracy is indicated by the standard error (0.55368), implying that external factors beyond CO_2 might also influence groundwater quality. Insufficient statistical significance ($p > 0.05$) limits the confidence in the model's reliability. The study provides a strong positive correlation between CO_2 concentrations and groundwater quality, but the lack of significance suggests that the relationship may not be as strong or reliable as it appears. The model's high explanatory power and moderate prediction accuracy may be due to external factors beyond CO_2. The study indicates a correlation between CO_2 and groundwater quality, but lack of statistical significance suggests CO_2 may not be the primary factor influencing groundwater quality. Other factors like soil composition, pollution sources, and interaction with other pollutants should be explored. The findings emphasize the need for larger sample sizes and additional predictors to clarify CO_2's role.

To summarise, SO_2 levels above WHO standards, creating acid rain. Nitrogen Dioxide levels are greater than WHO recommendations but still exceed acceptable levels. CO_2 levels comply with WHO recommendations. SO_2 and NO_2 levels surpass WHO guidelines, creating health dangers to the local people. SO_2 values are consistent between seasons, indicating steady air quality. NO_2 levels are stable across seasons, presumably due to traffic emissions and other human causes. CO_2 levels are substantially equal in both seasons, indicating constant CO_2 sources. According to the findings, manmade sources of pollution, not meteorological patterns, are the key determinants of regional air quality. The borehole water is slightly acidic, which can cause corrosion and leach metals, and has a poor conductivity, reflecting typical tropical climate conditions. The biochemical oxygen demand (BOD) exceeds the WHO guideline, suggesting organic pollution or microbial activity. TDS, magnesium, iron, and lead concentrations are all below the WHO standard. Chloride, sulphate, phosphate, and sodium levels are all within WHO standards. The well water has an acidic pH, a temperature within permissible limits, and low conductivity and turbidity. The study shows that BOD and COD levels exceed WHO guidelines, indicating organic pollution or microbial activity, while TDS levels are below. The study reveals that SO_2 emissions are a key contributor to changes in water quality, coinciding with recognised effects of sulphur dioxide, such as acid rain. The study also found a substantial positive link between CO_2 levels and groundwater quality, but the lack of significance indicates that CO_2 may not be the key factor impacting groundwater quality.

Conclusion

Gas flaring emits toxic pollutants (SO_2 and NO_2) that exceed WHO regulations, causing health dangers to inhabitants. These pollutants, combined with insufficient petrol management and antiquated equipment, worsen air and water pollution in the region. Surface water contamination is more visible than air or subsurface pollution, but the acidic nature and organic pollution levels in groundwater raise worries about its safety for consumption. The data demonstrate that human activities have a greater influence on pollution levels than seasonal fluctuations, with borehole and well water demonstrating microbial and organic contamination. Although some criteria, like as TDS and some minerals, are below permissible limits, increased BOD and COD values suggest persistent organic contamination. The study found a significant link between SO_2 emissions and water quality degradation, highlighting the impact of air pollutants on water properties. The study emphasises the urgent need for improved regulatory mechanisms and modernised infrastructure to reduce gas flaring while protecting the environment and human health. Additional research is needed to investigate the long-term effects and develop sustainable solutions targeted to the particular issues encountered by Nigeria's oil-producing areas.

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