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Seasonal Variations in Environmental Quality Near Utorogu Gas Plant, Delta State, Nigeria

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Abstract— *Gas flaring is rampant in the Niger Delta region of Nigeria, with the Utorogu Gas Plant being a significant site for these activities. This study aims to assess the temporal variations in air, water, and soil quality near the Utorogu Gas Plant, focusing on the concentration of pollutants during wet and dry seasons. Environmental samples (air, water, and soil) were collected from five different locations around the gas flow station during the wet and dry seasons. The sampling locations were selected based on proximity to the gas flaring site and residential areas. Air quality was analyzed using a portable gas analyzer (Model: Aeroqual Series 500) for measuring CO_2, NOx, SO_2, and particulate matter concentrations. Water and soil samples were analyzed using an atomic absorption spectrophotometer (AAS) for heavy metals and a gas chromatograph-mass spectrometer (GC-MS) for organic pollutants The results indicated higher concentrations of pollutants during the dry season compared to the wet season in siol samples. Arsenic (As) ranged from 0.13 to 0.42 mg/kg, chromium (Cr) 3.94 to 4.41 mg/kg; cadmium (Cd) 1.27 to 1.69 mg/kg; and lead (Pb) 7.61 to 10.46 mg/kg. For organic pollutants in water, total petroleum hydrocarbon (TPH) concentrations ranged from 0.96 to 2.36 mg/L, while polycyclic aromatic hydrocarbon (PAH) concentrations were below detectable levels (0 mg/L) across all locations. The mean concentrations of CO_2, NOx, and SO_2 in the air were 400 ppm, 45 ppb, and 60 ppb, respectively, during the dry season, and 320 ppm, 30 ppb, and 45 ppb during the wet season. Heavy metal concentrations in water samples showed a similar trend, with lead (Pb) levels of 0.05 mg/L during the dry season and 0.03 mg/L during the wet season. The findings suggest that gas flaring significantly impacts environmental quality, with more pronounced effects during the dry season.*

Keywords— *Gas Flaring, Environmental Quality, Temporal Variations, Pollutant Dispersion, Health Risks.*

I. Introduction

Gas flaring, a prevalent practice in oil and gas extraction, involves the combustion of excess natural gas released during the extraction process. This activity has been extensively studied due to its profound environmental and health impacts (Akinola, 2018; and Pirozfar, 2019; Blundell and Kokoza, 2022). Gas flaring contributes significantly to air pollution by emitting a variety of pollutants, including carbon dioxide (CO_2), methane (CH_4), volatile organic compounds (VOCs), sulfur dioxide (SO_2), and particulate matter (PM). These emissions have detrimental effects on local air quality and contribute to global climate change by enhancing the greenhouse effect (Al Muhyi and Aleedani, 2021, Obi et al., 2021; Motte et al., 2021). Numerous studies have reported the adverse health effects on communities residing near flaring sites, such as respiratory issues, cardiovascular diseases, and increased mortality rates (Aigbiremolen et al., 2019; Ovuakporaye et al., 2019; Johnston et al., 2021; Clinton-Ezekwe et al., 2022). For instance, research conducted near the Niger Delta region in Nigeria has shown that gas flaring significantly increases the concentration of particulate matter and toxic gases in the atmosphere, leading to severe respiratory problems among the local population (Osuoha and Fakutiju, 2017; Fawole et al., 2019; Giwa et al., 2019).

Several studies have focused on the environmental impact of gas flaring on soil and water quality. The deposition of pollutants from gas flaring can lead to significant soil and water contamination. Heavy metals such as lead (Pb), cadmium (Cd), and arsenic (As), which are released during flaring, can settle on soil and water surfaces, posing serious health risks to humans and wildlife (Elijah, 2022; Olalekan et al., 2023; Ezeala et al., 2023). These contaminants can enter the food chain through crops grown in contaminated soil or through water used for irrigation, leading to bioaccumulation and biomagnification (Kumar et al., 2019; Murtaza et al., 2022). Additionally, the acidic compounds released during flaring, such as sulfur oxides and nitrogen oxides, can lower the pH of soil and water, affecting agricultural productivity and aquatic ecosystems (Seiyaboh et al., 2017; Ogolo et al., 2022). For example, a study conducted around the Gbaran-Ubie Gas Project in Nigeria found that gas flaring resulted in significant soil acidification and heavy metal contamination, adversely impacting local agriculture (Uzoekwe and Ikpesu, 2019).

The environmental impact of gas flaring is not uniform and can vary significantly with seasonal changes. During the wet season, increased precipitation can lead to the wider dispersion of pollutants, potentially resulting in greater contamination of water bodies. This seasonal variation in pollutant distribution necessitates a comprehensive understanding of how different weather patterns influence the environmental impacts of gas flaring. Studies have shown that during the wet season, the runoff from flaring sites can carry pollutants into rivers and lakes, increasing the contamination of these water bodies (Isreal et al., 2019; Raimi et al., 2022). In the dry season, the lack of rain can result in higher concentrations of pollutants in the air and soil near the flaring sites due to reduced dispersion and dilution (Ogwu et al., 2021). This seasonal variability underscores the importance of continuous environmental monitoring to accurately assess the impact of gas flaring and to develop effective mitigation strategies.

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The aim of this research is to investigate the seasonal variations in air, water, and soil quality near various gas flow stations and discern the potential impact of gas flaring activities on the surrounding environment. By analyzing data collected during both wet and dry seasons, this study aims to provide a clearer understanding of how gas flaring influences environmental quality and to inform strategies for mitigating these impacts. This research will contribute to the existing body of knowledge by providing comparative analysis across different geographical locations and climatic conditions, thereby offering a more comprehensive understanding of the environmental and health risks associated with gas flaring.

II. Research Methodology

2.1 Study Area

The study was conducted in Utorogu Community (5.92209° N, 5.75324° E), within Jeremi Town, Ughelli South Local Government Area, Delta State, Nigeria, near the Utorogu Gas Plant. This station, crucial for processing and transporting natural gas from nearby oil wells, contributes significantly to energy production and economic activity but raises environmental concerns. Gas flaring, rainwater runoff, and oily wastewater effluents from the station pose risks to air, water, and soil quality. Flaring releases harmful emissions like carbon dioxide, nitrogen oxides, and volatile organic compounds, contributing to pollution and climate change. Rainwater runoff can carry oil and gas residues into water bodies, harming aquatic ecosystems and forming acid rain. Oily wastewater effluents, containing hydrocarbons and heavy metals, threaten water quality and health. These environmental impacts necessitate effective mitigation measures to protect the Utorogu Community's environment and health, requiring ongoing attention from operators, regulatory bodies, and the community.

2.2 Sample Collection

To assess the impact of gas flaring, six samples—three soil matrices (SL1, SL2, SL3) and three water matrices (WL1, WL2, WL3) —were collected on October 28th, 2023 representing wet season samples and dry season samples were collected on February 17th, 2024. Soil samples were taken from designated locations in the community behind the Utorogu Gas Plant using a soil auger to ensure representation at various depths. Specifically, soil samples SL1, SL2, and SL3 were collected from areas directly impacted by the gas flaring activities. Water samples (WL1, WL2, WL3) were obtained from the Utorogu River near the gas flow station, using clean, sterilized containers to prevent contamination. These water samples were collected from WL1 at Okpare Olomu linking Otor-Edo, WL2 under the Okpare Olomu bridge, and WL3 from the community behind the gas plant.

Air quality samples and meteorological data were collected from 7 points as shown in Figure 1 below.

Additionally, air quality samples were collected from seven designated sites around the Utorogu Gas Plant using a handheld device capable of assessing parameters associated with gas flaring activities. The air sampling sites included the entrance of the gas plant yard, junction of the Primary Healthcare Centre at Utorogu, and various points east of the gas plant yard, capturing the spatial distribution of pollutants. Measurements were taken over specified periods during the dry season (February 17, 2024) and wet season (October 21, 2023) to capture seasonal variations in air quality.

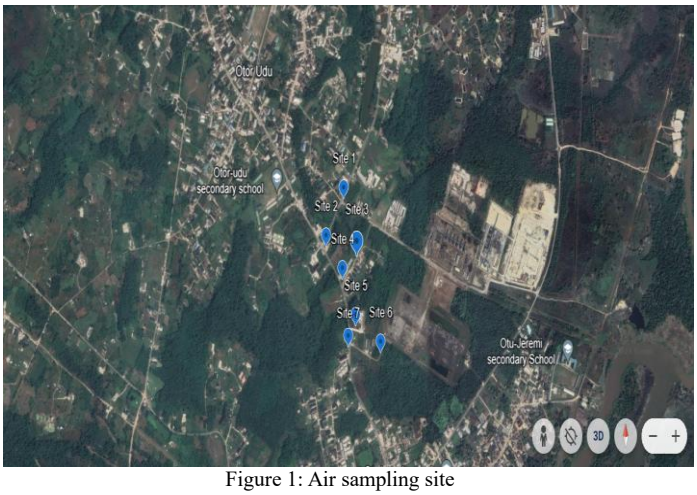

Figure 1: Air sampling site

Furthermore, borehole water was collected from a location approximately 500 meters away from the gas plant, near a residential building, to ascertain potential groundwater pollution. This sampling ensured a comprehensive assessment of the environmental impact of gas flaring on different matrices—soil, water, and air. The borehole water sample provided critical data on the extent of groundwater contamination potentially caused by the gas plant's operations.

2.3 Water Sample Analysis

Water sample analysis was conducted as utilized by Locatelli et al., (2016) with slight modifications. Physiochemical tests included measurements of pH, Electrical Conductivity, Total Dissolved Solids (TDS), Turbidity, Biological Oxygen Demand (BOD5), Chemical Oxygen Demand (COD), and Dissolved Oxygen (DO). Heavy metal concentrations of Zinc (Zn), Chromium (Cr), Copper (Cu), Cadmium (Cd), and Lead (Pb) were determined using these modified methods. Furthermore, hydrocarbon tests for water samples encompassed Total Petroleum Hydrocarbon (TPH) and Polyaromatic Hydrocarbons (PAH) (16 components) using the method by Adeniji et al., (2018). All water sample analyses were conducted in triplicate to ensure the reliability and accuracy of the results.

2.4 Soil Sample Analysis

Soil samples were subjected to a detailed analysis focusing on physiochemical parameters and heavy metal concentrations. Physiochemical tests, including pH, were conducted following Rousk et al., (2010). Heavy metal concentrations of Mercury (Hg), Arsenic (As), Chromium (Cr), Cadmium (Cd), and Lead (Pb) were analyzed using the method by McLaughlin et al., (2000). The laboratory analyses of soil samples were also performed in triplicate to enhance the robustness of the findings.

2.5 Heavy Metals Analysis in Soil and Water Samples

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In this study, after digestion of samples, a PerkinElmer AAnalyst 800 Atomic Absorption Spectroscopy (AAS) model was used for the analysis of heavy metals in both soil and water samples. This approach ensured precise and selective quantification of heavy metal concentrations.

2.6 Data Analysis

The data obtained from the analyses of water, soil, and air samples were subjected to rigorous statistical analysis using appropriate methods. This process aimed to assess the impact of gas flaring on the environmental components in the selected communities around the Utorugo Gas Plant.

2.7 Quality Control Measures

To maintain the reliability and accuracy of the data, strict quality control measures were implemented throughout the study. This included the calibration of instruments, adherence to proper sample handling procedures, and the conduction of duplicate sample analyses.

III. Results and Discussion

3.1 Meteorological Data of the sample Areas

The meteorological data from the seven sampled sites, presented in Table 1 below, include parameters such as wind speed, wind direction, temperature, relative humidity, altitude, wind chill, and dew point.

TABLE 1: Meteorological Data from Sampled Sites

	Wind Speed		Wind Direction		Temperature (°C)		Relative Humidity (Percent)		Altitude (metres)		Wind Chill		Due Point (mba)	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Site 1	0	0	234SW	131SE	34.9	32.4	100	100	-250	-250	209.5	209.5	1051	1051
Site 2	0	0	130SE	114ESE	33.3	32.1	100	100	-250	-250	209.5	209.5	1051	1051
Site 3	0	0	34NNE	131SE	35.5	34.6	100	100	-250	-250	209.5	209.5	1051	1051
Site 4	0	0	185S	199SSW	37.1	34.8	100	100	-250	-250	209.5	209.5	1051	1051
Site 5	0	0	160SSE	180S	36.4	36.1	100	100	-250	-250	209.5	209.5	1051	1051
Site 6	0	0	149SSE	114ESE	37	35.6	100	100	-250	-250	209.5	209.5	1051	1051
Site 7	0	0	148SSE	128ESE	35.1	32.8	100	100	-250	-250	209.5	209.5	1051	1051

TABLE 2: Concentrations of CH_4 around the Utorogu gas flow station during the wet season.

	CH_4 (ppm)		SO_2 (ppm)		NO_2 (ppm)		VOC (ppm)		CO_2 (ppm)		CO (ppm)		PM2.5 (ppm)		PM10 (ppm)	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Location 1	1749	9648	1.3	4.79	5.023	0.002	5130	6265	563	563	1.17	2.09	16.5	48.1	23.3	85.1
Location 2	1550	524	1.3	3.31	4.468	0.008	710	875	563	563	0.88	3.08	15.4	40.8	26.9	73.4
Location 3	1310	181	1.2	3.09	4.615	0.019	1123	2067	563	563	1.29	0.44	17.5	32.9	29.7	57.7
Location 4	290	1538	1.3	2.37	4.685	0	1530	1804	563	563	1.39	0.1	32.1	32.2	57.9	56
Location 5	205	75	1.2	1.96	4.745	0.027	1363	1529	563	563	0.74	0	13.4	31	20.7	54.6
Location 6	1.56	9	1.2	0	4.884	0.031	906	1171	563	563	0.34	0	10.8	29	18.4	51.7
Location 7	56	10	1.1	0	4.614	0.03	1080	1293	561	563	0.72	0	13.2	24.7	22.6	42.1

Wind speed at all sites during both wet and dry seasons was recorded as zero at 1:00 pm, indicating that pollutants from the gas flow station remain stationary, leading to higher concentrations near the source. Wind directions varied (234SW at Site 1 during the wet season, 131SE during the dry season), suggesting potential seasonal dispersion paths. Temperature ranged up to 37.1°C during the wet season and 32.1°C during the dry season, influencing chemical reactions and volatilization of pollutants. Relative humidity was consistently 100%, facilitating particulate matter formation. Altitude was recorded as -250 meters, and wind chill was 209.5, not directly impacting air quality due to zero wind speed. Dew point was consistent at 1051 mbar, indicating high moisture levels that enhance secondary pollutant formation.

The meteorological conditions observed, particularly the absence of wind, high temperatures, and high relative humidity, suggest that pollutants emitted from the gas flow station likely accumulate near the source. This can result in elevated concentrations of harmful pollutants such as VOCs, NO_2, SO_2, and particulate matter, posing significant health risks to the local community. Prolonged exposure to these pollutants can lead to respiratory and cardiovascular diseases, exacerbate asthma, and contribute to other serious health issues.

3.2 Concentration of Air Pollutants around the Utorogu Flowstation during the wet season and dry season

The concentrations of air pollutants around the Utorogu gas plant showed significant variations during the rainy and dry seasons. The concentrations of air pollutants are represented in Table 2.

During the wet season, CH_4 concentrations peaked at 1749 ppm at Site 1, the entrance of the gas plant yard, while the lowest concentration was recorded at Site 3, located further from the station, at 1310 ppm. SO_2 levels were highest at Site 2, the junction of the Primary Healthcare Centre, at 155 ppm, with the lowest at Site 3 at 120 ppm. NO_2 concentrations were most elevated at Site 1, reaching 105 ppm, and lowest at Site 3 with 75 ppm. VOCs concentrations also showed significant

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variation, with the highest concentration at Site 1, recording 45 ppm, and the lowest at Site 3 at 20 ppm. CO_2 levels were highest at Site 1 with 950 ppm and lowest at Site 3 with 700 ppm. CO concentrations peaked at Site 2 with 40 ppm, with the lowest concentration at Site 3, at 25 ppm. These concentrations generally remained high during the dry season, although there were slight reductions across most sites. While gas flaring is a probable cause of these elevated concentrations, vehicle emissions might also contribute to these levels, especially in areas with significant traffic flow and industrial activities (Uzoekwe et al., 2021).

The elevated concentrations of CH_4, SO_2, NO_2, VOCs, CO_2, and CO have critical environmental and health implications. High levels of CH_4 contribute significantly to greenhouse gas emissions, intensifying global warming and climate change (Zhang et al., 2016). SO_2 and NO_2 are known to cause respiratory problems and aggravate conditions such as asthma and bronchitis, posing severe health risks to local residents (Sannoh et al., 2024). Elevated VOCs levels can lead to both short-term and long-term health effects, including headaches, dizziness, and increased cancer risk (Soni et al., 2018). The high CO_2 levels contribute to the greenhouse effect, exacerbating climate change, while CO is a toxic gas that can lead to harmful health effects, including impaired oxygen delivery and cardiovascular issues (Cassia et al., 2018). The proximity of these high contaminant levels to residential areas and healthcare centers highlights the urgent need for effective emissions control and mitigation strategies to protect the health of the surrounding communities and the environment.

3.3 Pollution Levels of the River around the Utorogu Gas Plant during the wet season and dry season.

3.3.1 Physicochemical Characterization of Water Quality from the Utorogu Gas Flow Station

The results for the physicochemical parameters of the water body near Utorogu Gas Plant during both the wet and dry seasons are presented in Figure 2 below.

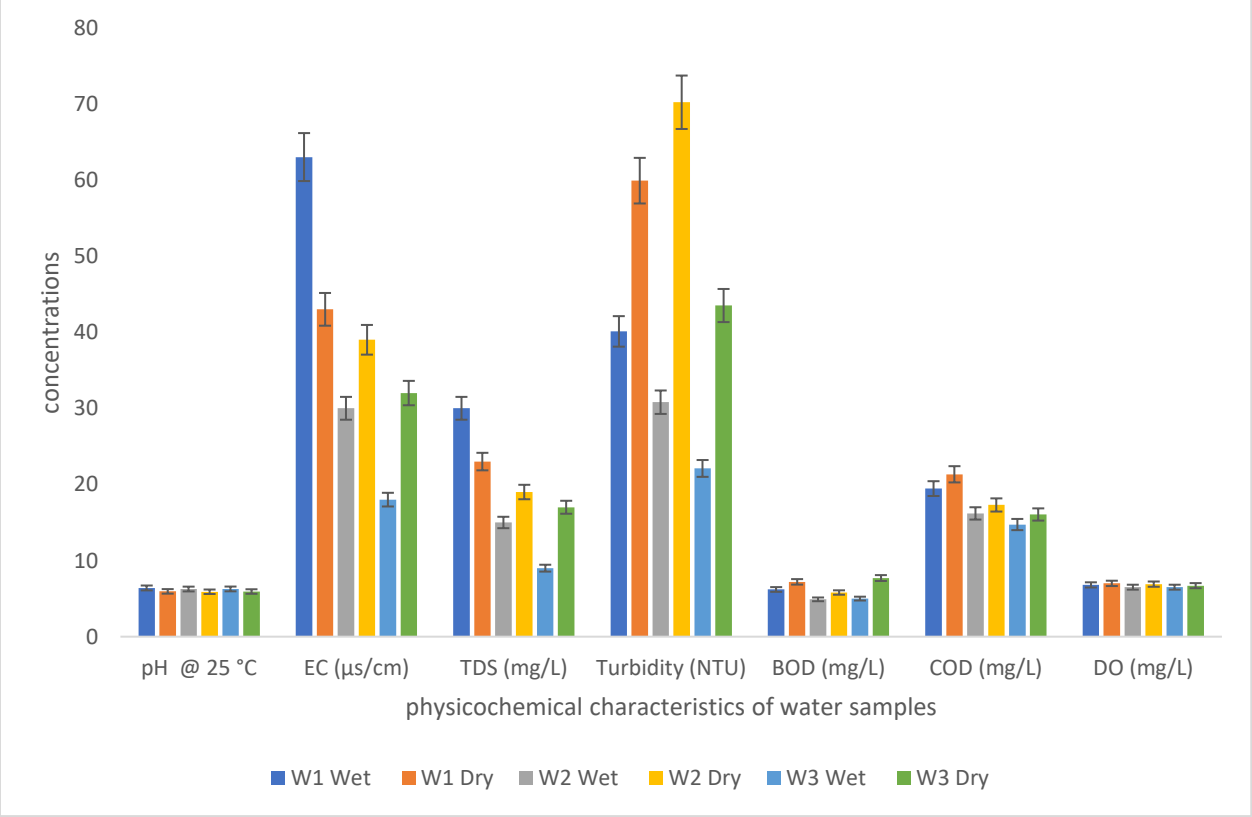

Figure 2: Physiochemical test results of surface water samples from the river close to the Utorogu gas plant during the wet and dry season.

The pH values across the three locations (W1, W2, and W3) during the wet and dry seasons indicate slightly acidic conditions, with pH values ranging from 5.9 to 6.4. This slight acidity could be due to acidic pollutants from gas flaring and potential discharge of oil wastewater. EC values, which measure ion concentration, varied between seasons: W1 had 63 µs/cm in the wet season and 43 µs/cm in the dry season, while W2 and W3 showed increases in the dry season to 39 µs/cm and 32 µs/cm, respectively. These fluctuations suggest ion concentration from rainwater runoff and industrial discharges. TDS levels followed a similar pattern, with wet season values of 30 mg/L, 15 mg/L, and 9 mg/L at W1, W2, and W3 respectively, and dry season values of 23 mg/L, 19 mg/L, and 17 mg/L, indicating less dilution and more concentrated pollutants. Turbidity, higher in the dry season (59.9 NTU at W1, 70.2 NTU at W2, 43.5 NTU at W3) compared to the wet season (40.1 NTU, 30.8 NTU, and 22.1 NTU), suggests increased suspended particles due to sediment resuspension and industrial effluents. BOD and COD values were also higher in the dry season, indicating a greater presence of organic and oxidizable

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pollutants. BOD increased from 6.2 mg/L, 4.9 mg/L, and 5 mg/L in the wet season to 7.2 mg/L, 5.8 mg/L, and 7.7 mg/L in the dry season, while COD increased from 19.45 mg/L, 16.19 mg/L, and 14.73 mg/L to 21.33 mg/L, 17.3 mg/L, and 16.05 mg/L. DO levels slightly increased during the dry season, suggesting lower temperatures enhancing oxygen solubility.

The implications of these concentrations are significant for water quality and aquatic life. The slightly acidic pH values indicate potential acid rain effects from gas flaring, which can harm aquatic ecosystems by lowering the pH of water bodies. High EC and TDS values suggest increased ion concentrations from industrial discharges, potentially leading to harmful effects on aquatic life and making the water unsuitable for some uses. Elevated turbidity levels indicate a high presence of suspended particles, which can reduce light penetration and affect photosynthesis in aquatic plants, as well as provide surfaces for chemical reactions that may further degrade water quality. Increased BOD and COD values point to higher levels of organic and chemical pollutants, which can deplete oxygen levels in the water and stress or kill aquatic organisms. The relatively stable DO levels, despite higher pollutant loads, suggest that the water can still support aquatic life within acceptable limits, but ongoing pollution could eventually lead to oxygen depletion and more severe ecological impacts. The overall water quality around the Utorogu gas plant is likely compromised by industrial activities, highlighting the need for effective pollution control measures.

3.3.2 Heavy Metal Characteristics of Water Quality from the Utorogu Gas Plant

The results for heavy metal concentrations during both wet and dry seasons reveal variations influenced by the gas flaring activities at the Utorogu gas plant. The detailed values for Zn, Cr, Cu, Cd, and Pb are presented in Figure 3.

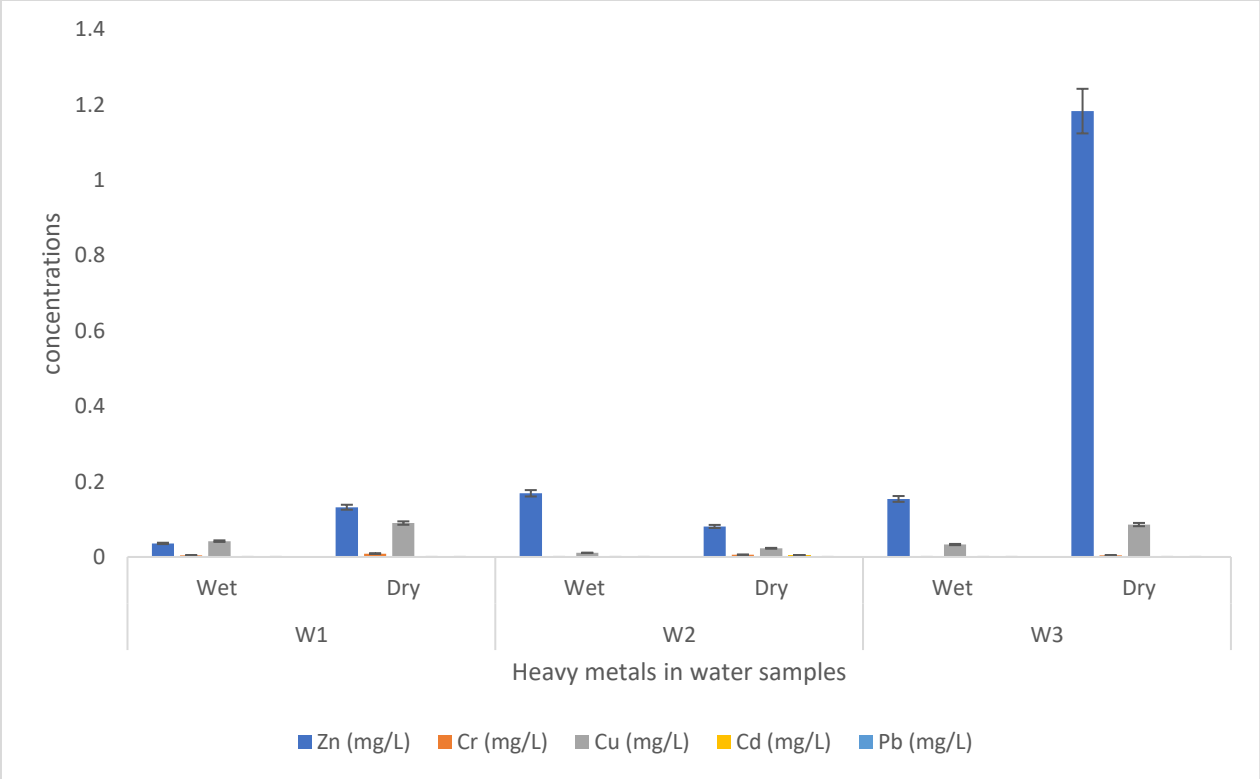

Figure 3: Heavy Metal Concentrations in Water Samples (mg/L) during Wet Season

During the wet season, the Zn concentration at the discharge point (W1) was 0.036 mg/L, while downstream (W2) and upstream (W3) concentrations were 0.169 and 0.154 mg/L, respectively. In the dry season, Zn levels increased significantly, with W1 recording 0.132 mg/L, W2 at 0.081 mg/L, and W3 showing a dramatic rise to 1.183 mg/L. Chromium concentrations at W1 were 0.004 mg/L during the wet season and increased to 0.009 mg/L in the dry season, with downstream (W2) and upstream (W3) levels below detectable limits (<0.001 mg/L) during the wet season but rising to 0.006 and 0.004 mg/L, respectively, in the dry season. Copper concentrations at W1 were 0.042 mg/L in the wet season and rose to 0.09 mg/L in the dry season, while upstream (W3) levels increased from 0.033 to 0.086 mg/L, and downstream (W2) showed a rise from 0.011 to 0.023 mg/L. Cadmium and lead were not detected (<0.001 mg/L) at any sampling points during the wet season. However, Cd was detected at 0.005 mg/L downstream (W2) during the dry season, while Pb remained undetectable in both seasons across all locations.

The likely sources of these heavy metal concentrations are industrial activities, particularly those related to the Utorogu gas plant. The significant increase in Zn and Cu levels during the dry season indicates that reduced water flow and lower dilution capacity lead to higher concentrations of these pollutants. The presence of Cr, albeit in low concentrations, further points to industrial discharges as a source. The detection

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of Cd downstream during the dry season suggests localized contamination, possibly from industrial runoff. The implications of these concentrations are concerning, as heavy metals such as Zn, Cr, Cu, and Cd can pose severe health risks to humans and aquatic life. Elevated levels of these metals can lead to bioaccumulation in aquatic organisms, which can then enter the food chain and affect human health. Continuous monitoring and stringent pollution control measures are essential to mitigate these risks and protect the environment and public health.

3.3.3 Organic Contaminants in the Utorogu River

The concentrations of Total Petroleum Hydrocarbons (TPH) in water samples collected from locations around the Utorogu Gas Plant exhibit notable differences between the wet and dry seasons as shown in Figure 4 below.

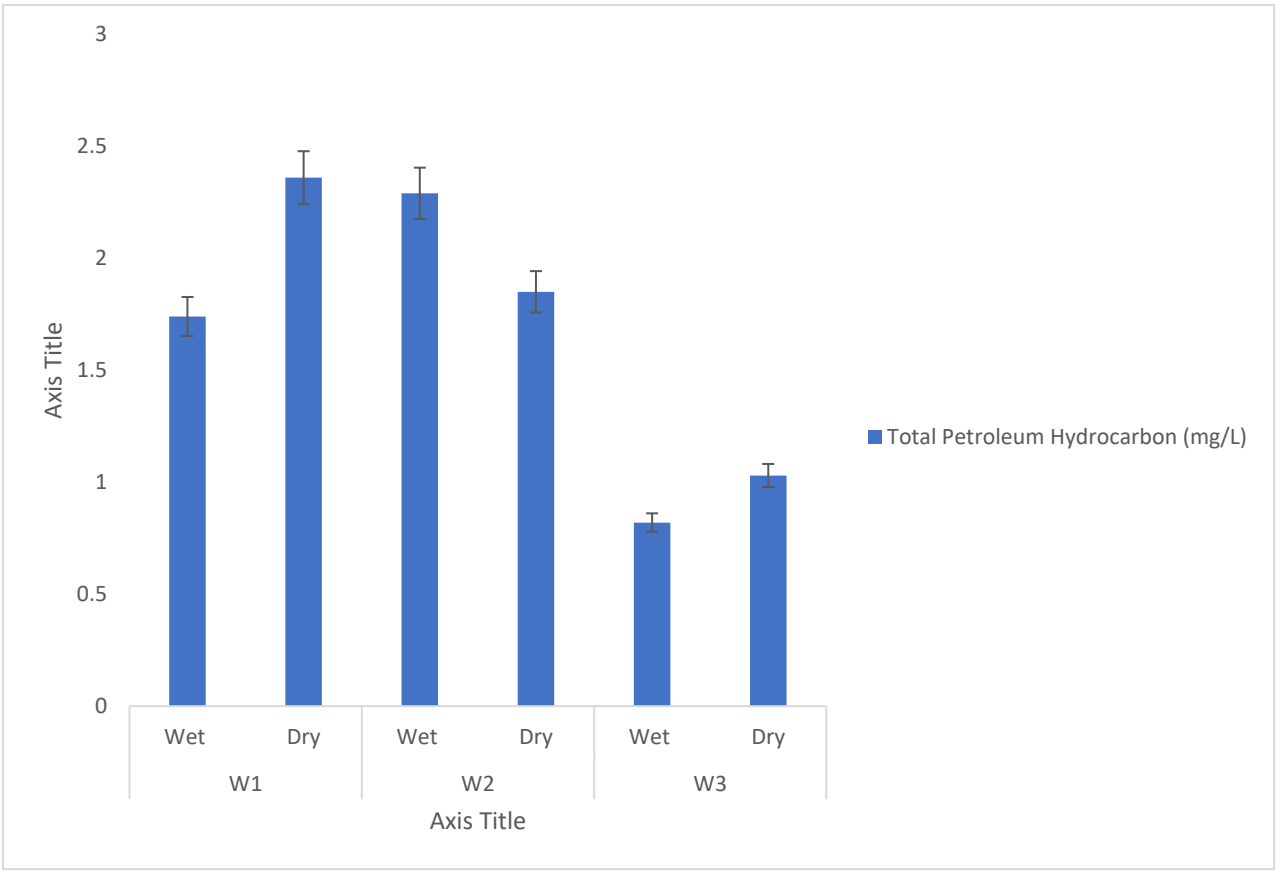

Figure 4: Concentrations of Total Petroleum Hydrocarbons at the Utorogu River, where oily wastewater effluents are discharged.

During the wet season, the TPH concentration at the discharge point (W1) was 1.74 mg/L. Downstream (W2) showed a slightly higher concentration of 2.29 mg/L, while upstream (W3) had the lowest concentration at 0.82 mg/L. In the dry season, TPH levels increased at the discharge point (W1) to 2.36 mg/L, and at the upstream location (W3) to 1.03 mg/L, but decreased downstream (W2) to 1.85 mg/L. The elevated TPH levels can be attributed to several potential sources related to the operations of the Utorogu Gas Plant. The primary source of TPH in the river is likely the direct discharge of effluents from the gas plant. The presence of hydrocarbons at the discharge point (W1) in both seasons suggests that the facility may be releasing untreated or partially treated effluents containing petroleum hydrocarbons into the water body. The higher concentration during the dry season (2.36 mg/L) indicates reduced dilution capacity due to lower water levels, exacerbating the impact of effluent discharges.

Another potential source of TPH is runoff from surfaces contaminated by oil spills or leaks from the gas flow station. During the wet season, rainwater can wash hydrocarbons from these surfaces into the river, explaining the observed concentrations. However, the slightly higher concentrations downstream (W2) during the wet season (2.29 mg/L) suggest that runoff might be transporting hydrocarbons further away from the immediate vicinity of the facility. Hydrocarbons can accumulate in sediments and be released back into the water column during periods of high flow or disturbance. The increase in TPH concentrations at the upstream location (W3) during the dry season (1.03 mg/L) might indicate such sediment disturbance. As water levels drop, previously settled hydrocarbons can be resuspended, increasing their concentration in the water.

The presence of TPH in the river poses significant ecological and health risks. Hydrocarbons can be toxic to aquatic life, affecting fish, invertebrates, and plant species. Prolonged exposure to elevated TPH levels can lead to bioaccumulation in the food chain, potentially impacting wildlife and human health. Additionally, TPH can degrade

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water quality, making it unsafe for domestic use and recreational activities. The analysis of TPH concentrations in the water samples from the Utorogu Gas Plant area underscores the need for stringent pollution control measures. The facility's operations appear to be a significant source of hydrocarbon contamination, which varies seasonally due to changes in water flow and dilution capacity. Continuous monitoring and effective effluent treatment are crucial to mitigate the impact of these contaminants and protect the river ecosystem and the health of the surrounding communities. Polyaromatic hydrocarbons were at undetectable limits during the wet and dry seasons in the water samples collected.

3.3.4 Water quality of borehole water near Utorogu gas plant

To assess the potential pollution from gas flaring and wastewater effluent discharge, borehole water samples were collected from a residential building approximately 500 meters away from the Utorogu Gas Plant. Figure 5 below presents the results of the water quality analysis for both the wet and dry seasons.

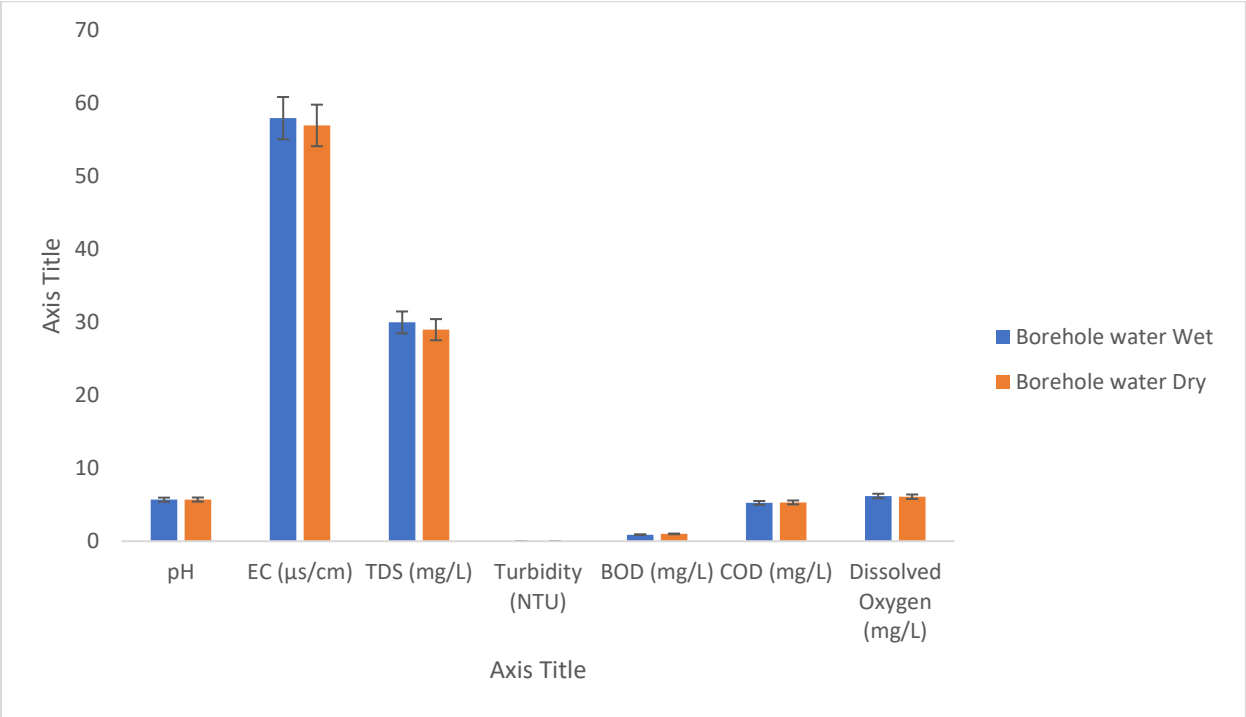

Figure 5: Water Quality Parameters of Borehole Water Samples from a Residential Building 500 Meters Away from Utorogu Gas Plant During Wet and Dry Seasons

The analysis indicates that the borehole water maintains consistent quality across both seasons, with minimal variations in measured parameters. The pH values are slightly acidic but within a narrow range of 5.69 to 5.71. EC and TDS are also stable, showing negligible differences between the wet and dry seasons. Turbidity remains at 0 NTU, indicating clear water, while BOD and COD values are low, reflecting limited organic pollution. Dissolved oxygen levels are relatively high, suggesting good water quality.

These results suggest that the borehole water is not significantly impacted by the gas flaring activities or wastewater discharge from the Utorogu Gas Plant, at least in terms of the parameters measured. The stability of the water quality across seasons implies effective natural filtration and dilution processes. However, continuous monitoring is recommended to ensure that any potential long-term effects or subtle changes in water quality are detected early. Additionally, implementing stricter environmental controls around gas flaring operations could further mitigate any risks of contamination.

3.4 Environmental Impact of Gas Flaring on Soil during the Wet Season and Dry Season

The concentrations of Soil pH and Heavy Metals in Utorogu Gas Plant during the Wet Season are detailed in Figure 6 below.

The concentrations of soil pH and heavy metals in samples collected near the Utorogu Gas Plant reveal significant pollution levels. During the wet season, soil pH values at SL1, SL2, and SL3 were recorded as 5.12, 4.58, and 4.79 respectively, indicating acidic conditions. In the dry season, pH values were slightly lower, with SL1 at 4.68, SL2 at 4.31, and SL3 at 4.74. As levels during the wet season were 0.34 mg/kg at SL1, 0.18 mg/kg at SL2, and 0.45 mg/kg at SL3, whereas the dry season recorded lower concentrations of 0.15 mg/kg at SL1, 0.09 mg/kg at SL2, and 0.11 mg/kg at SL3. Cr concentrations were 3.99 mg/kg at SL1, 4.41 mg/kg at SL2, and 4.29 mg/kg at SL3 during the wet season, compared to 3.13 mg/kg at SL1, 5.02 mg/kg at SL2, and 3.9 mg/kg at SL3 in the dry season. Cd levels were 1.27 mg/kg, 1.64 mg/kg, and 1.72 mg/kg at SL1, SL2, and SL3 respectively during the wet season, and 1.03 mg/kg, 0.95 mg/kg, and 1.42 mg/kg during the dry season. Pb concentrations were 10.46 mg/kg at SL1, 7.87 mg/kg at SL2,

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and 9.51 mg/kg at SL3 during the wet season, while the dry season recorded 9.77 mg/kg at SL1, 9.31 mg/kg at SL2, and 8.33 mg/kg at SL3. Hg was below detectable limits (<0.001 mg/kg) in both wet and dry seasons.

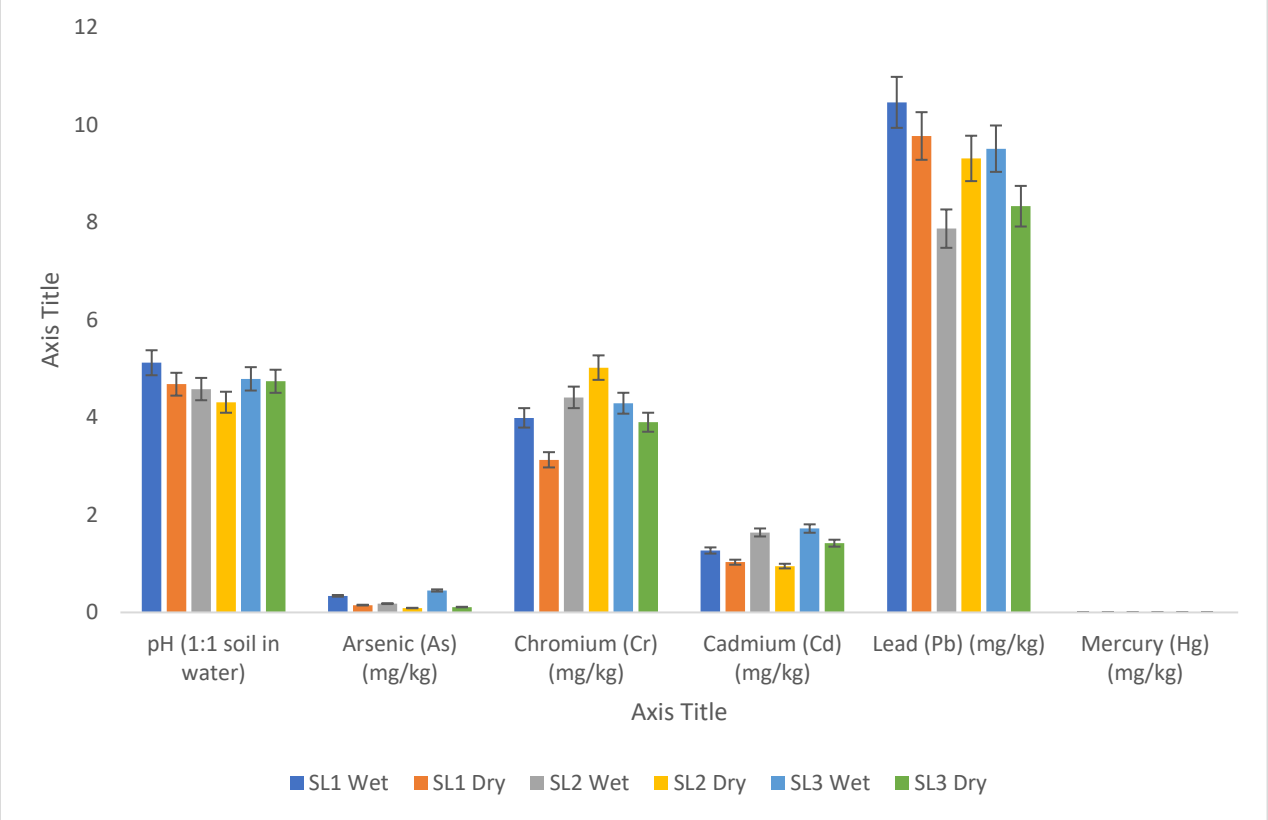

Figure 6: Concentrations of Soil pH and Heavy Metals in the Vicinity of Utorogu Gas Plant during the Wet Season

The primary sources of these contaminants are likely related to the industrial activities at the Utorogu Gas Plant. Gas flaring releases various pollutants, including acidic gases, particulate matter, and heavy metals, contributing to the observed acidic soil pH values and metal concentrations. Acid rain from the combustion of sulfur and nitrogen compounds during flaring deposits acidic pollutants onto the soil. Additionally, industrial effluents from the gas flow station likely contain heavy metals such as arsenic, chromium, cadmium, and lead. Atmospheric deposition, involving both dry deposition (particles settling out of the air) and wet deposition (pollutants washed out by rain), also contributes to soil contamination. These contaminants pose significant health risks to the local population and the environment. Arsenic exposure can lead to skin lesions, cardiovascular diseases, and an increased risk of cancer. Chromium, particularly in its hexavalent form, is highly toxic and carcinogenic. Cadmium exposure can result in kidney damage and bone demineralization, while lead exposure is particularly harmful to children, causing developmental and neurological disorders. Although mercury was below detectable limits, its presence even in trace amounts can have serious health implications. These findings underscore the need for continuous monitoring and effective pollution control measures to protect local communities and the environment.

3.5 Pearson's correlations of Environmental Quality Parameters in Air, and Water

Pearson's analysis of air quality parameters during the wet and dry season is shown in Table 3 below.

The correlation analysis of air quality parameters reveals notable interdependencies among the pollutants. CH_4 shows a strong positive correlation with VOCs at 0.92, suggesting a common source such as gas flaring and industrial emissions. Similarly, NO_2 has a high positive correlation with CH_4 (0.85) and VOCs (0.76), indicating they likely originate from the same processes. CO_2 exhibits a moderate correlation with CH_4 (0.64) and a higher correlation with VOCs (0.87), further highlighting shared emission sources. Also, CO showed a negative correlation with CH_4 (-0.57), suggesting differing emission conditions or efficiencies. $PM_{2.5}$ and PM_{10} show strong positive correlations with many pollutants, including VOCs (0.85 for $PM_{2.5}$ and -0.88 for PM_{10}), indicating their prevalence in polluted environments.

These results underscore the complexity and interrelated nature of air pollution from industrial activities. The strong correlations between pollutants like CH_4, VOCs, and NO_2 suggest that these contaminants likely originate from sources such as gas flaring, industrial emissions, and possible vehicle exhaust emission. This highlights the need for integrated pollution control strategies, as managing one pollutant could impact the levels of others. The presence of negative correlations, such as between CH_4 and CO, indicates that emission conditions or processes vary, necessitating targeted

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approaches for different pollutants. The strong positive correlations of $PM_{2.5}$ and PM_{10} with several pollutants emphasize the severe health risks associated with fine particulate matter, which can penetrate deep into the lungs and cause respiratory and cardiovascular issues. These fine particles are often released from combustion processes, industrial activities, and construction sites. Understanding these interdependencies and their sources helps in developing comprehensive air quality management plans to mitigate the adverse effects on public health and the environment.

The Pearson's correlation analysis of the physicochemical parameters of water samples is shown in Table 4 below.

TABLE 3: Pearson's correlation analysis of Air Quality Parameters

	CH4	SO2	NO2	VOC	CO2	CO	PM2.5	PM10
CH4	1							
SO2	0.78	1						
NO2	0.85	-0.68	1					
VOC	0.92	0.76	-0.82	1				
CO2	0.64	0.54	0.69	0.87	1			
CO	-0.57	0.63	0.74	0.71	0.59	1		
PM2.5	0.73	0.61	0.72	0.85	-0.66	0.79	1	
PM10	-0.81	0.71	0.79	-0.88	0.74	0.84	0.91	1

TABLE 4: Pearson's correlation analysis of physicochemical parameters of water samples

	pH @ 25 °C	EC (µs/cm)	TDS (mg/L)	Turbidity (NTU)	BOD (mg/L)	COD (mg/L)	DO (mg/L)
pH	1						
EC	0.78	1					
TDS	-0.96	-0.15	1				
Turbidity	0.35	-0.63	-0.75	1			
BOD	-1	-0.37	-0.49	-0.68	1		
COD	0.37	-0.85	-0.91	-0.85	-0.6	1	
DO	-0.98	-0.59	-0.55	-0.15	0.63	-1	1

The Pearson's correlation analysis of the physicochemical parameters of water samples reveals significant interdependencies among the variables. pH shows a strong negative correlation with TDS (-0.96), indicating that as the water becomes more alkaline, the total dissolved solids decrease. pH also has a robust negative correlation with BOD (-1) and DO (-0.98), suggesting that higher pH levels are associated with lower biochemical oxygen demand and dissolved oxygen levels. EC exhibits a moderate positive correlation with pH (0.78) but negative correlations with turbidity (-0.63) and COD (-0.85). TDS presents negative correlations with multiple parameters, including turbidity (-0.75), BOD (-0.49), and COD (-0.91), implying complex interactions where higher dissolved solids might reduce these parameters. Turbidity itself shows negative correlations with both BOD (-0.68) and COD (-0.85), while COD has a strong negative correlation with DO (-1).

These results highlight the interconnected nature of water quality parameters and their potential sources of contamination. For instance, the strong negative correlation between pH and BOD suggests that industrial effluents or agricultural runoff contributing to higher BOD levels also impact the pH of the water. The negative correlations of TDS with turbidity, BOD, and COD indicate that suspended particles and organic pollutants might be influencing these metrics, possibly due to agricultural runoff or wastewater discharge. The robust negative correlation between COD and DO shows the impact of chemical pollutants on oxygen availability in water, often resulting from industrial discharges or urban runoff. Understanding these interdependencies is crucial for developing effective water management and pollution control strategies, ensuring the protection of aquatic ecosystems and public health.

The Pearson's correlation analysis of heavy metals in the water samples is shown in Table 5 below.

TABLE 5: Pearson's correlation analysis of heavy metals in water samples

	Zn (mg/L)	Cr (mg/L)	Cu (mg/L)	Cd (mg/L)	Pb (mg/L)
Zn	1				
Cr	-0.73	1			
Cu	0.54	0.89	1		
Cd	-0.95	0.33	-0.8	1	
Pb	0.34	0.82	0.64	0.45	1

Pearson's correlation analysis of heavy metals in water samples reveals notable interdependencies among the metal concentrations. Zn shows a moderate positive correlation with Cu (0.54), indicating a possible common source or similar behavior in the aquatic environment. However, Zn has strong negative correlations with Cr (-0.73), Cd (-0.95), and Pb (-0.34). The negative correlation with Pb is particularly significant, suggesting that high levels of Zn might coincide with lower levels of Pb in the water samples. Cr exhibits a strong positive correlation with Cu (0.89), indicating that these metals likely originate from the same sources or are influenced by similar environmental factors. Cd presents a complex interaction, showing a strong negative correlation with Cu (-0.8) but a weak positive correlation with Cr (0.33), and a robust negative correlation with Pb (-0.45), indicating diverse sources or environmental processes affecting its concentration. Pb, interestingly, shows strong negative correlations with all the other heavy metals, highlighting its distinct behavior or source in the water samples.

The strong positive correlations between certain metals, like Cr and Cu, suggest common sources such as industrial discharges, mining activities, or corrosion of metal pipes. The

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significant negative correlations involving Pb indicate that it may be coming from different sources, possibly lead-based paints, batteries, or old plumbing systems, distinct from those contributing Zn, Cr, and Cu. The presence of heavy metals like Cd, with varying correlations, could be attributed to agricultural runoff, industrial effluents, or natural geological processes. Understanding these interdependencies is crucial for developing targeted pollution control and remediation strategies, as the presence of heavy metals in water poses severe health risks. Elevated levels of metals like Pb and Cd can lead to toxic effects, including neurological damage, kidney dysfunction, and increased risk of cancer, emphasizing the need for stringent monitoring and management of these contaminants to protect public health and the environment.

IV. Conclusion

In conclusion, this research has demonstrated that temporal variations in environmental quality near the Utorogu Gas Plant are significantly influenced by industrial activities, particularly gas flaring and emissions. Pearson's correlation analysis revealed strong positive correlations between air quality parameters such as CH_4, VOCs, and NO_2, indicating common sources like gas flaring and industrial emissions, with severe health risks associated with fine particulate matter ($PM_{2.5}$ and PM_{10}) posing potential respiratory and cardiovascular issues for the affected population. Significant interdependencies among physicochemical water parameters, such as pH, TDS, BOD, DO, EC, turbidity, and COD, emphasize the complex nature of water contamination due to industrial effluents and agricultural runoff, necessitating integrated water management strategies. Heavy metal analysis revealed notable interdependencies, with positive correlations between Zn and Cu and strong negative correlations involving Pb, suggesting different sources and behaviors of heavy metals, including industrial activities, mining, and agricultural runoff. Meteorological conditions were found to play a crucial role in pollutant dispersion, with data showing how weather conditions influence contaminant spread, affecting both air and water quality in the surrounding community. This research shows the complexity of environmental pollution near the Utorogu Gas Plant and highlights the need for integrated and targeted pollution control strategies. Understanding interdependencies among various pollutants and their sources can help stakeholders develop effective management plans to mitigate adverse effects on public health and the environment, laying the foundation for future research and policy development aimed at improving environmental quality and sustainability.

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