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Temporal Variations in Environmental Quality in Kokori-Erhoike Flow Station, Kokori Community, Delta State. Nigeria

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Abstract

The Niger Delta region of Nigeria, characterized by extensive oil and gas activities, frequently experiences gas flaring, a significant environmental concern. This study aims to investigate the temporal variations in environmental quality near the Kokori-Erhoike Flow Station in Kokori Community, Delta State, with a focus on assessing pollution levels in air, water, and soil. Samples were collected from various strategic locations around the flow station, including air, water, and soil samples. Samples were analyzed for a range of parameters including Total Petroleum Hydrocarbons (TPH), heavy metals (such as zinc, chromium, cadmium, lead, and copper), and physicochemical properties like pH, temperature, dissolved oxygen (DO), and electrical conductivity. The analytical methods employed included Atomic Absorption Spectrophotometry (AAS) for heavy metal analysis, Gas Chromatography-Mass Spectometry (GC-MS) for TPH. Significant findings revealed elevated levels of PM_{10}, and $PM_{2.5}$ in the air, particularly during the June period, with $PM_{2.5}$ concentrations exceeding WHO limits. Water sample analysis indicated high concentrations of TPH, especially in the June period, with levels rising from 1.67 mg/L to 2.91 mg/L at specific locations. Heavy metal contamination in water samples showed concentrations of lead (Pb) up to 0.54 mg/L and cadmium (Cd) up to 1.42 mg/L, surpassing WHO guidelines. Soil samples also exhibited high levels of heavy metals, with cadmium (Cd) concentrations up to 1.72 mg/kg and lead (Pb) concentrations up to 10.46 mg/kg. Pearson's correlation analysis highlighted strong positive correlations, such as between cadmium (Cd) and lead (Pb) ($r = 0.876$, $p < 0.01$), and zinc (Zn) and chromium (Cr) ($r = 0.821$, $p < 0.01$), suggesting common pollution sources, such as industrial discharges and agricultural runoff. The findings of this study indicate significant environmental degradation in the vicinity of the Kokori-Erhioke Flow Station due to gas flaring activities.

Keywords: Gas Flaring, Environmental Pollution, Total Petroleum Hydrocarbons (TPH), Heavy Metals, Niger Delta Environmental Quality.

1.0 INTRODUCTION

Gas flaring is a global environmental issue that has persisted for decades, primarily in regions abundant in oil and gas reserves (Udok and Akpan, 2017, Merem *et al*., 2017; Shahab-Deljoo *et al*., 2023). The practice involves the burning of natural gas associated with oil extraction, leading to significant emissions of carbon dioxide, methane, and other pollutants into the atmosphere (Mac Kinnon *et al*., 2018). Globally, gas flaring contributes to greenhouse gas emissions, exacerbating climate change and environmental degradation (Krane, 2020; Awulu, 2021; Harris, 2021; Ohen *et al*., 2022). The phenomenon is particularly prevalent in oil-rich regions such as the Middle East, Russia, and Africa, where infrastructural and economic challenges hinder the capture and utilization of associated gas (Graham and Ovadia, 2019). In Africa, Nigeria stands out as one of the largest culprits of gas flaring, with the Niger Delta being a significant hotspot for this activity (Akinwumiju *et al*., 2020; Mai-Bornu and Mai-Bornu, 2020). Despite global efforts to reduce gas flaring through initiatives like the World Bank's Global Gas Flaring Reduction Partnership (Cutler *et al*., 2018), the practice continues to pose severe environmental and health risks, particularly in developing regions where regulatory frameworks and enforcement are often weak (Tangcharoensathien *et al*., 2017).

The health and environmental impacts of gas flaring are profound and long-lasting (Webb *et al*., 2018; Wollin *et al*., 2020). Prolonged exposure to flared gases has been linked to respiratory diseases, cancer, and other serious health conditions among local populations living near flaring sites (Akuirene *et al*., 2019; Obi *et al*., 2021; Nwosisi *et al*., 2021). Furthermore, the release of pollutants like sulfur dioxide and volatile organic compounds contributes to acid rain, soil degradation, and water contamination, which, in turn, affect agriculture and biodiversity (Dutta and Singh, 2021). From a climate change perspective, gas flaring significantly contributes to global warming through the emission of carbon dioxide and methane, potent greenhouse gases that trap heat in the atmosphere (Al Muhyi and Aleedani, 2021). These effects show the urgent need for research focused on understanding and mitigating the impacts of gas flaring, particularly in regions like the Niger Delta, where communities are disproportionately affected (Echendu *et al*., 2022).

Research on gas flaring and its environmental impacts has been conducted in various parts of the world, with significant findings that highlight the gravity of the issue (Rana *et al*., 2017; Adeola *et al*., 2022; Wen *et al*., 2023). In regions such as the United States and Canada, studies have shown that gas flaring contributes to elevated levels of air pollutants, leading to increased respiratory problems among affected populations (Chen *et al*., 2022; Blundell and Kokoza, 2022). In Nigeria, several studies have documented the extensive environmental degradation in the Niger Delta, where gas flaring has led to the contamination of air, water, and soil, resulting in significant health risks to local communities (Adekola *et al*., 2017; Nnaemeka, 2020; Abayomi, 2021). These studies provide a critical foundation for understanding the environmental and health implications of gas flaring, but there remains a need for more localized research that addresses the specific conditions and impacts within different regions (Aigbe *et al*., 2023).

The aim of this research is to assess the environmental impacts of gas flaring in the Kokori-Erhioke area. The findings from this research will not only enhance our understanding of the specific environmental challenges faced by communities in the Niger Delta but will also inform the development of targeted mitigation strategies. The outcomes of this research are expected to contribute to the broader discourse on sustainable development and environmental justice in Nigeria and beyond.

2.0 RESEARCH METHODOLOGY

2.1 Study Area

The study area is located at the Kokori-Erhoike Flow Station within the Kokori-Erhoike community in Delta State, Nigeria (coordinates: 5°51'N, 6°06'E). Nestled amidst lush vegetation and fertile lands, Kokori-Erhoike is predominantly rural, with agriculture forming the backbone of the community alongside oil-related activities. The area is home to a diverse population, including indigenous residents and migrant workers attracted by employment opportunities in the oil industry. The Kokori-Erhoike community faces various environmental and socio-economic challenges associated with gas flaring and oil extraction activities, such as air and water pollution, health hazards, land degradation, and disruptions to traditional livelihoods.

2.2 Sample Collection

For this research, water samples were collected from two points along the river in the Kokori-Erhoike community, spaced 500 meters apart, and from a river in Ughelli where no oil and gas operations were present to serve as control points. Air quality assessment involved using a handheld device to measure concentrations of methane (CH_4), sulfur dioxide (SO_2), nitrogen oxides (NO_2), volatile organic compounds (VOCs), carbon monoxide (CO), and particulate matter ($PM_{2.5}$, PM_{10}) at specified locations within the community and near the flare stack as shown in Figure 1 below.

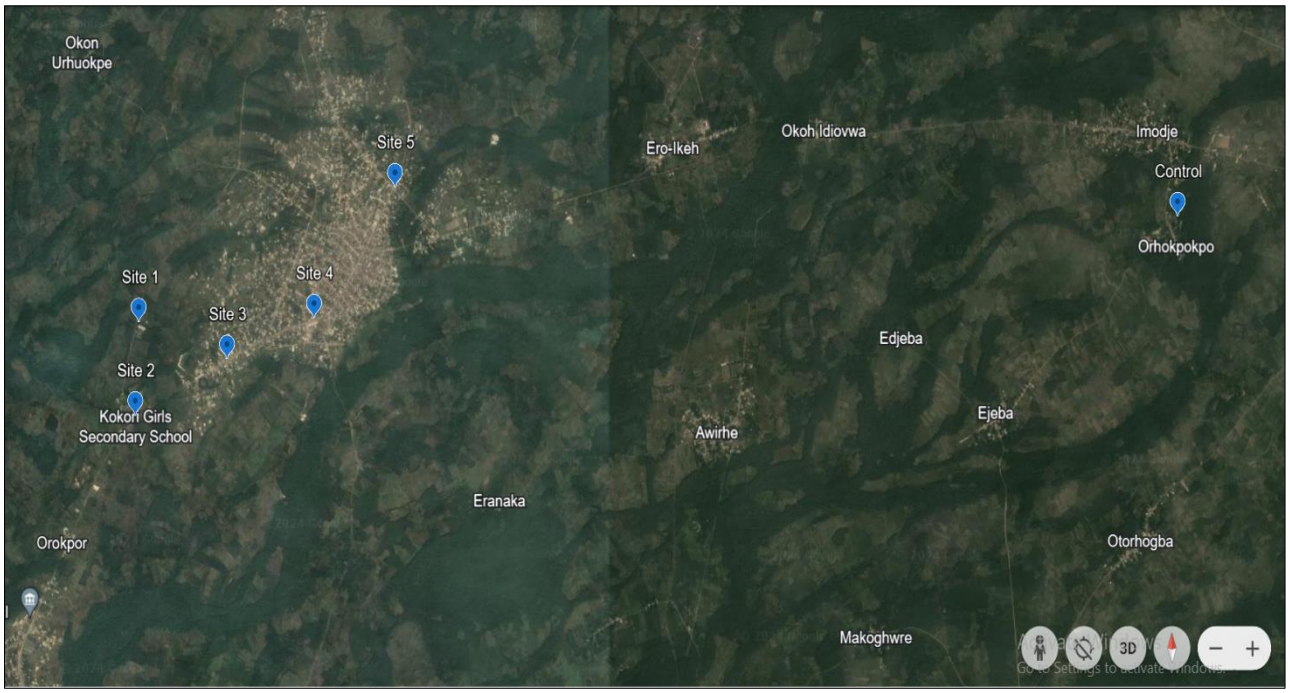

Figure 1: Air quality sample areas

Measurements were conducted at six (6) selected points both in the community and close to the flare area, following standardized procedures, and were taken in triplicates to ensure reliability. Soil samples were collected using a soil auger from four locations, including a control point. Samples were taken at a distance of 500 meters from the flow station, with subsequent samples spaced similarly. The control sample was collected in Odovie, a neighboring community, to provide a baseline for comparison.

2.3 Analysis of Soil and Water Samples

Water sample analysis encompassed the measurement of physicochemical parameters and heavy metal concentrations. Physicochemical tests conducted included pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Turbidity, Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), and Dissolved Oxygen (DO), conducted using handheld devices. Additionally, heavy metal concentrations of Zinc (Zn), Chromium (Cr), Copper (Cu), Cadmium (Cd), and Lead (Pb) were determined. Hydrocarbon tests for the water samples included assessments of Total Petroleum Hydrocarbon (TPH) and Polyaromatic Hydrocarbons (PAH). The analysis of TPH and PAH in water samples was conducted using a Thermo Scientific Trace 1300 Gas Chromatography-Mass Spectrometry (GC-MS) system. Following the method by Hu *et al*., (2018) with slight modifications, the analysis was conducted by extracting water samples using liquid-liquid extraction with a solvent mixture of 80% dichloromethane (DCM) and 20% methanol. The extracts were then concentrated and analyzed using GC-MS to determine the concentrations of TPH and PAH. This approach ensures the accurate assessment of hydrocarbon contamination in water samples, providing essential data for environmental monitoring.

Soil samples were subjected to detailed analysis focusing on physicochemical parameters and heavy metal concentrations, including soil pH and concentrations of Mercury (Hg), Arsenic (As), Chromium (Cr), Cadmium (Cd), and Lead (Pb). Laboratory analyses of soil samples were performed in triplicate to enhance the robustness of the findings. The analysis of TPH and PAH in soil samples was also performed using a Thermo Scientific Trace 1300 Gas Chromatography-Mass Spectrometry (GC-MS) system. Following the method by Sajid *et al*., (2022) with slight modifications, soil samples were subjected to solvent extraction using an ultrasonic bath with a solvent mixture of 70% hexane and 30% acetone. The extracts were then purified using silica gel columns to remove interfering substances before analysis. The processed samples were analyzed by GC-MS to measure the concentrations of TPH and PAH. Both soil and water samples were prepared for digestion using an acid digestion procedure, ensuring accurate and efficient analysis of the target contaminants. Heavy metal analysis in both soil and water samples was conducted using a PerkinElmer AAnalyst 800 Atomic Absorption Spectroscopy (AAS) system, providing precise quantification of heavy metal concentrations and ensuring reliable results for environmental assessment.

2.4 Data Analysis

The results from the analysis of water, soil, and air samples were thoroughly examined using rigorous statistical methods. This analysis was designed to evaluate the effects of gas flaring on environmental

factors in the communities surrounding the Kokori-Erhoike Gas Flow Station.

2.5 Quality Control Measures

To ensure the accuracy and reliability of the data, comprehensive quality control procedures were followed throughout the study. This involved calibrating instruments, following proper sample handling protocols, and performing duplicate analysis of samples.

3.0 RESULTS AND DISCUSSION

3.1 Meteorological Data from Kokori-Erhoike Area during April and June Periods

The meteorological data collected from 5 sampling sites in the Kokori-Erhoike area during both the April and June periods is shown in Table 2 below.

Table 2: Meteorological Data from Kokori-Erhoike Area during April and June Periods

	Wind Speed (mph)		Compass		Temperature °C		Relative Humidity (%)		Altitude	
	April	June	April	June	April	June	April	June	April	June
Site 1	0.1	0	214NW	135NW	35.5	33	75.5	80.1	20	22
Site 2	1.1	1.5	99 N	125N	34	35.5	72.7	73.5	21	24
Site 3	2.9	2.3	75 EN	85 EN	34.6	33.4	72.1	69.9	20	18
Site 4	1.2	0.5	326 NW	214 NW	32.5	34.5	68.6	75.5	19	16
Site 5	0.2	0.4	166SW	145SW	36.8	35.3	75.7	80.9	15	11
Control	3.5	4.1	147	145	33.5	31.2	89.9	82.5	20	19

The meteorological data collected from Kokori-Erhoike during the April and June periods indicate significant variations in atmospheric conditions, which are crucial for understanding the dispersion of gases from gas flaring activities. During the April period, wind speeds range from 0.1 mph at Site 1 to 3.5 mph at the control site, while in the June period, wind speeds vary from 0 mph at Site 1 to 4.1 mph at the control site. Wind directions also differ, with notable shifts from northwest (NW) and north (N) directions predominantly in the April period to more varied northwest (NW) and southwest (SW) directions in the June period. Temperatures are slightly higher in the April period, with Site 1 recording the highest at 36.8 °C, and the control site the lowest at 33.5 °C. In the June period, temperatures are generally lower, with the highest being 35.5 °C at Site 2 and the lowest at 31.2 °C at the control site. Relative humidity shows a marked contrast between periods, being higher in the April period (75.5 to 89.9%) and somewhat lower in the June period (69.9 to 82.5%).

The differences in wind speed and direction between the April and June periods significantly influence the dispersion of gases from gas flaring. During the April period, lower wind speeds at most sites could lead to higher concentrations of pollutants near the ground, increasing exposure for local communities. Higher humidity levels could also enhance the formation of secondary pollutants like smog. In contrast, the higher wind speeds and slightly lower humidity in the June period might aid in the wider dispersion of pollutants, potentially reducing local concentrations but spreading contaminants over a broader area. These atmospheric conditions affect the health and well-being of the community by increasing the risk of respiratory and cardiovascular issues from prolonged exposure to harmful gases like sulfur dioxide (SO_2), nitrogen oxides (NO_2), and particulate matter (PM). Even though higher wind speeds in the June period may disperse pollutants more effectively, they can still pose health risks over a larger geographical area, potentially leading to long-term health implications for the community.

3.2 Concentration of Air Pollutants around Sampling Sites in the Kokori-Erhioke Flowstation Area during April and June Period

The concentration of various air pollutants measured around different sampling sites in the Kokori-Erhoike flowstation area during both April and June periods is shown in Figure 2 below. Understanding the levels of these pollutants and their temporal variations is essential for assessing the impact of gas flaring on air quality and the health of the local community.

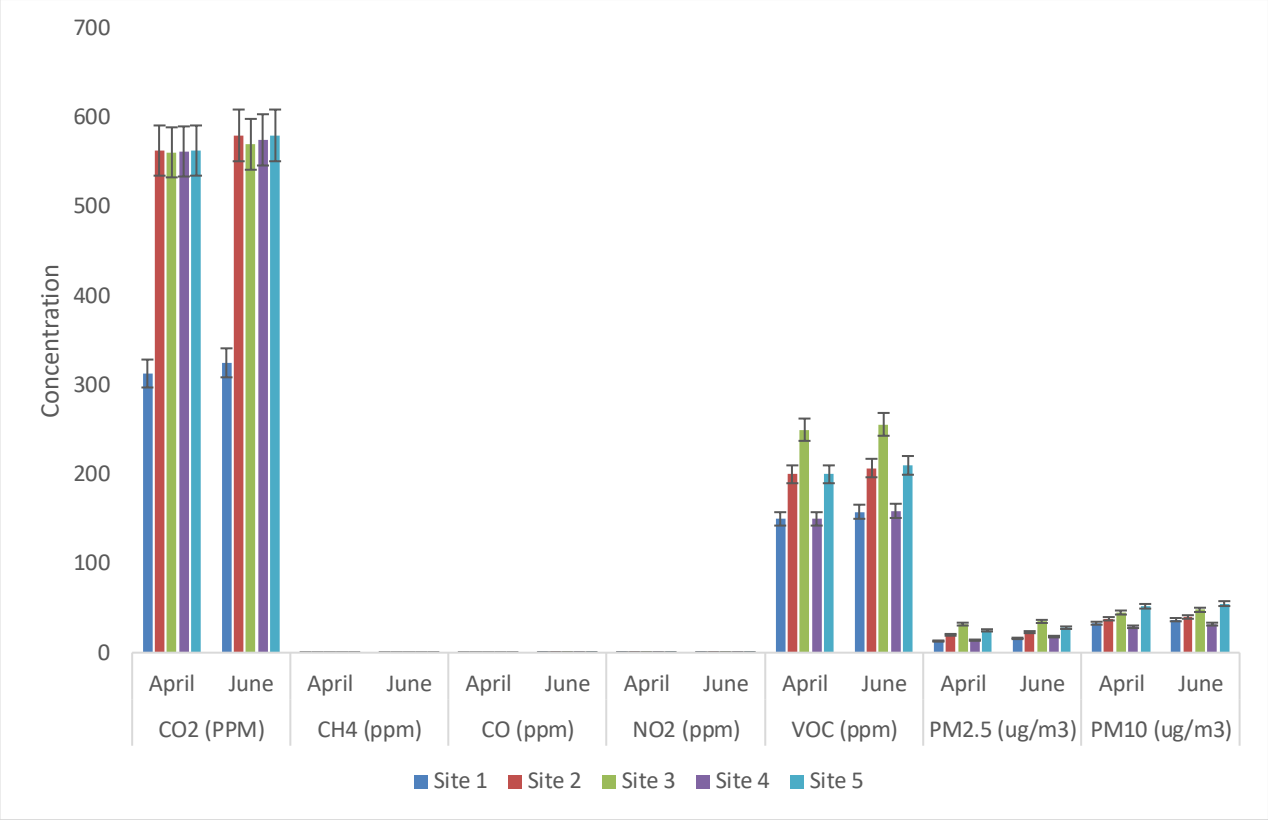

Figure 2: Concentration of Air Pollutants around Sampling Sites in the Kokori-Erhoike Flowstation Area during April and June Periods

The concentration of air pollutants across the sampling sites in the Kokori-Erhoike flowstation area varied between the April and June periods. For CO_2, Site 1 recorded 313 ppm in the April period and 325 ppm in the June period, while Site 2 had 563 ppm and 580 ppm, respectively. Site 3 had 561 ppm in the April period and 570 ppm in the June period, Site 4 had 562 ppm and 575 ppm, and Site 5 had 563 ppm and 580 ppm. CH_4 was undetectable at all sites during both periods. CO levels were negligible in the April period but were detected at 0.035 ppm in the June period at Sites 1, 2, and 5, and slightly lower at 0.034 ppm and 0.033 ppm at Sites 3 and 4, respectively. NO_3 levels were constant at 0.031 ppm across all sites and periods. VOCs ranged from 150 to 250 ppm during the April period and increased to 158 to 256 ppm in the June period, with the highest concentration at Site 3. $PM_{2.5}$ concentrations rose from 13–32 µg/m³ in the April period to 16–35 µg/m³ in the June period, while PM_{10} levels increased from 29–52 µg/m³ to 32–55 µg/m³, with the highest PM_{10} recorded at Site 5. The concentrations of air quality parameters around the Kokori-Erhoike flow station are consistent with the findings by Anyikwa *et al*., (2022), who conducted a study on air pollution at the Ohaji/Egbema flow station in Imo State, Nigeria. Their research measured concentrations of CO_2, CO, NOx, and SOx, and revealed a clear periodal variation in pollutant levels, with higher concentrations observed during the June period compared to the April period.

These concentrations indicate a significant periodal variation, particularly for CO_2, VOCs, $PM_{2.5}$, and PM_{10}, which were all higher during the June period. The meteorological results suggest that the lower atmospheric dispersion during the June period, due to reduced humidity and wind speed, contributed to these elevated pollutant levels. The increased concentrations of CO_2 and particulates, particularly $PM_{2.5}$ and PM_{10}, raise concerns for the health of local residents, as these pollutants can exacerbate respiratory conditions, cardiovascular diseases, and other health issues. These findings are consistent with other studies in gas-flaring regions, such as the Niger Delta, where similar periodal patterns and associated health risks have been reported.

3.3 Physicochemical Characteristics of Water Samples from Kokori-Erhoike during April and June Periods

The physicochemical characteristics of water samples from Kokori-Erhioke river during the April and June periods is shown in Figure 3 below.

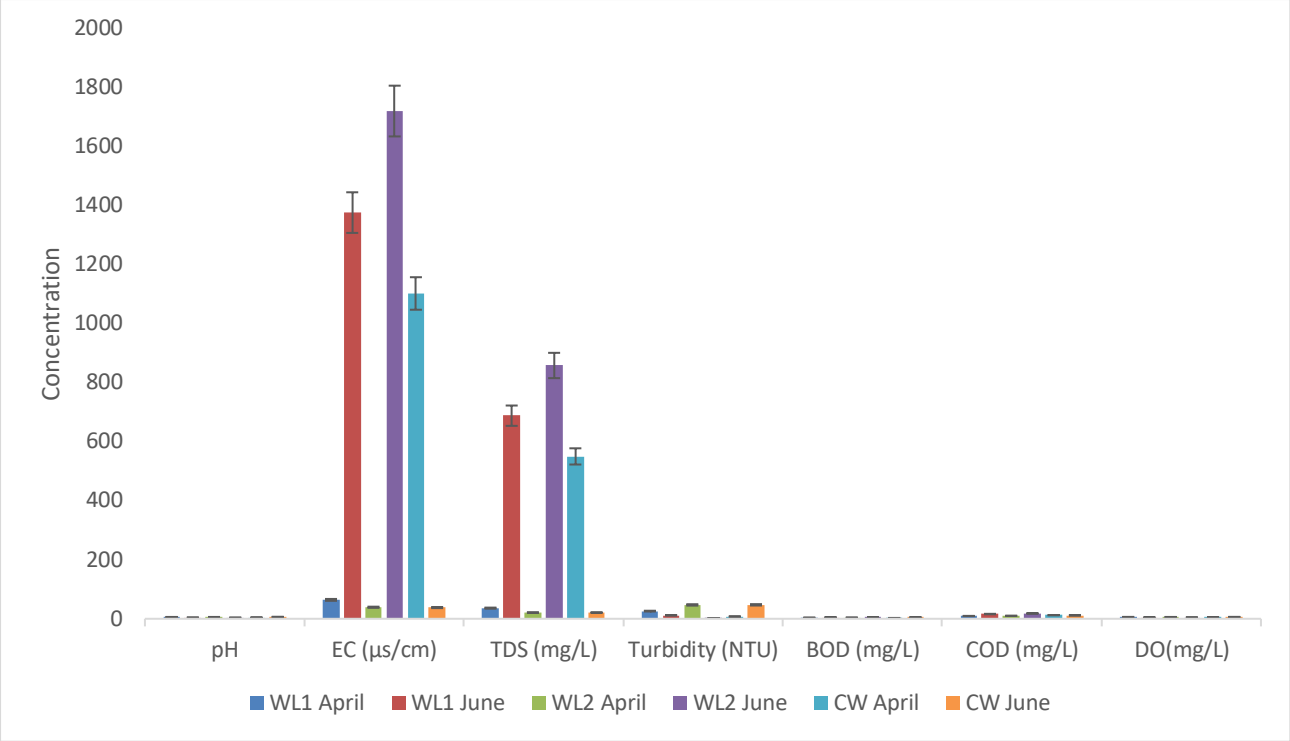

Figure 3: Physicochemical Characteristics of Water Samples from Kokori-Erhoike during April and June Periods

The concentrations of the water quality parameters measured at three different locations during April and June periods are as follows: For WL1, the pH levels were 5.94 (April) and 3.91 (June), EC values were 64 µs/cm (April) and 1376 µs/cm (June), TDS values were 36 mg/L (April) and 688 mg/L (June), turbidity was 25.95 NTU (April) and 11.7 NTU (June), BOD values were 3.6 mg/L (April) and 4.7 mg/L (June), COD values were 9.34 mg/L (April) and 16 mg/L (June), and DO levels were 6.1 mg/L (April) and 4.4 mg/L (June). For WL2, the pH levels were 5.93 (April) and 3.69 (June), EC values were 39 µs/cm (April) and 1720 µs/cm (June), TDS values were 21 mg/L (April) and 858 mg/L (June), turbidity was 46.93 NTU (April) and 2.14 NTU (June), BOD values were 3.8 mg/L (April) and 5.1 mg/L (June), COD values were 10.06 mg/L (April) and 18.13 mg/L (June), and DO levels were 5.9 mg/L (April) and 4.2 mg/L (June). For CW, the pH levels were 4.07 (April) and 6.42 (June), EC values were 1102 µs/cm (April) and 38 µs/cm (June), TDS values were 550 mg/L (April) and 21 mg/L (June), turbidity was 7.45 NTU (April) and 47.25 NTU (June), BOD values were 2.7 mg/L (April) and 4.8 mg/L (June), COD values were 12.2 mg/L (April) and 11.53 mg/L (June), and DO levels were 5 mg/L (April) and 6.2 mg/L (June). The water quality in this study is similar to the study by Mokarram *et al*., (2020) who evaluated the quality of Kor River water located in southern Iran and identified the main sources of contamination as industrial effluent discharge.

The low pH values, particularly in WL1 and WL2 during the June period, indicate acidic conditions, which can be harmful to aquatic life and may pose health risks to humans if consumed. The high EC and TDS levels in WL1 and WL2 during the June period suggest elevated levels of dissolved salts, likely from industrial discharges or contaminated runoff. The elevated turbidity and BOD levels in WL2 during the April period also point to organic pollution, possibly from the discharge of oily wastewater effluent or gas flaring activities common in the area. The presence of high COD values further indicates the presence of oxidizable pollutants, likely hydrocarbons or other industrial wastes. The reduced DO levels, particularly during the June period, could lead to oxygen depletion in water bodies, threatening aquatic ecosystems and potentially leading to the death of fish and other aquatic organisms.

These pollutant concentrations have serious implications for water quality and public health. Consumption of such polluted water could lead to various health issues, including gastrointestinal diseases, skin irritation, and long-term effects like cancer due to the potential presence of toxic compounds (Ojha and Tiwary, 2021; Sarkar *et al*., 2022; Priyadarshanee *et al*., 2022). The acidic and high-salinity conditions may also corrode infrastructure, leading to further contamination. The possible sources of these pollutants, such as gas flaring or the discharge of oily wastewater effluents, are common in oil-producing areas.

3.4 Heavy Metal Concentrations in Water Samples from the River in Kokori-Erhoike Were Water Samples Were Collected From

The concentrations of heavy metals in water samples from sampling areas in Kokori-Erhoike is shown in Figure 4 below.

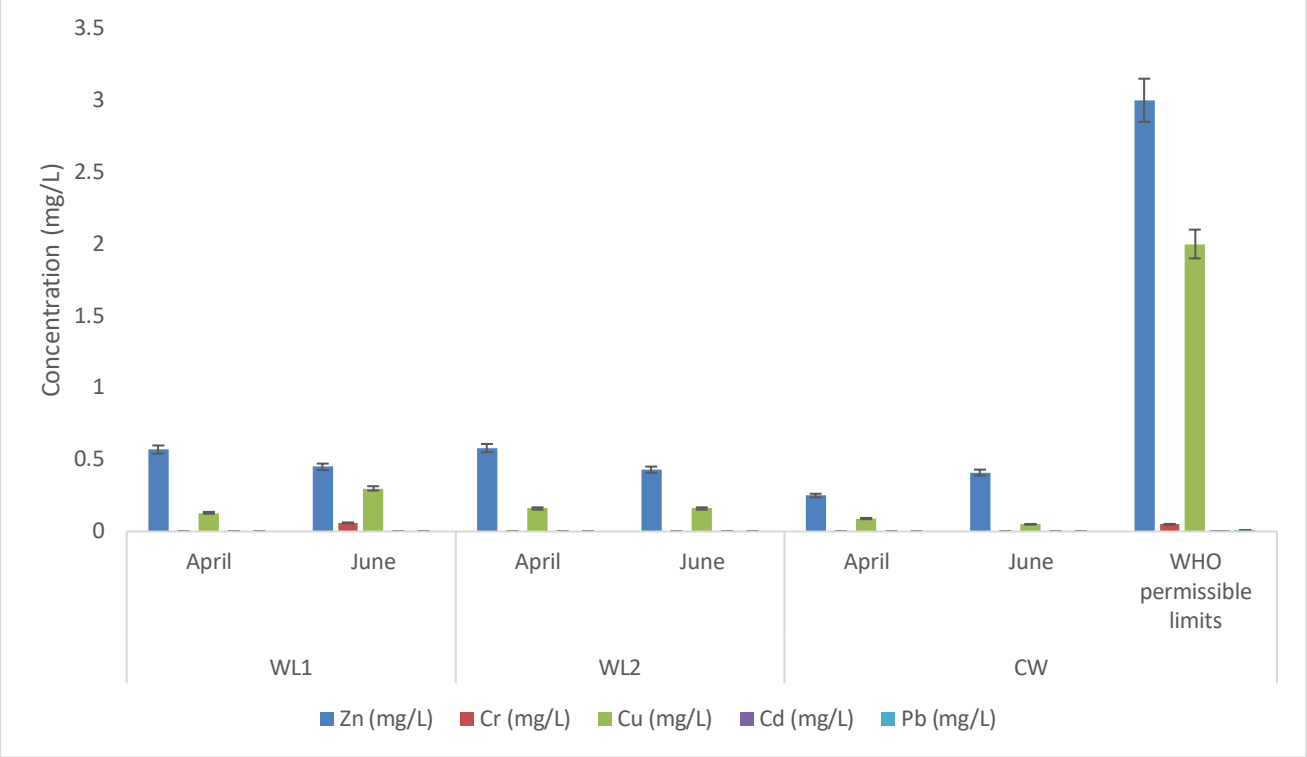

Figure 4: Heavy Metal Concentrations in Water Samples from Kokori-Erhoike

For Zn, WL1 exhibited concentrations of 0.57 mg/L in the April period, decreasing to 0.45 mg/L in the June period, while WL2 showed 0.58 mg/L and 0.43 mg/L for the April and June periods, respectively. The control site, CW, had lower concentrations of 0.25 mg/L during the April period, which increased to 0.41 mg/L in the June period. For Cr, concentrations were below detectable limits (<0.001 mg/L) during the April period across all sites, but WL1 had a noticeable increase to 0.06 mg/L in the June period, exceeding the WHO permissible limit of 0.05 mg/L. Cu levels in WL1 were 0.13 mg/L during the April period, rising to 0.3 mg/L in the June period, while WL2 remained at 0.16 mg/L for both periods. In CW, copper levels decreased from 0.09 mg/L in the April period to 0.05 mg/L in the June period. Cd and Pb were consistently below detectable limits (<0.001 mg/L) across all locations and periods, which are well below the WHO permissible limits of 0.003 mg/L for cadmium and 0.01 mg/L for lead.

The presence of these heavy metals, particularly the elevated chromium levels in WL1, suggests significant contamination likely originating from industrial activities such as gas flaring and the discharge of oily wastewater effluent. Gas flaring, a common practice in oil-producing regions, releases various pollutants, including heavy metals, into the environment, which can then accumulate in water bodies. The elevated levels of zinc and copper, although within WHO permissible limits, indicate potential ongoing pollution, likely exacerbated by industrial activities and temporal variations. These metals can bioaccumulate in aquatic organisms, disrupting ecosystems by affecting the growth and reproduction of fish and other wildlife. In humans, exposure to elevated levels of these metals, particularly chromium, poses serious health risks, including cancer, liver damage, and neurological disorders.

When comparing the heavy metals in water samples from around the river in Kokori-Erhioke community near the flow station to those found in similar studies, such as the one conducted by Ejike *et al*., (2017) in the Umuebulu oil-producing area of the Niger Delta, the concentrations were found to be similar. In the Kokori-Erhioke community, elevated levels of heavy metals like lead, arsenic, and cadmium were detected, mirroring the findings of the Niger Delta study where these metals were present in concentrations significantly exceeding the WHO's recommended maximum contaminant levels.

3.5 Organic Contaminants in Water Samples from Kokori-Erhoike during April and June Periods

The concentrations of Total Petroleum Hydrocarbon (TPH) in water samples from Kokori-Erhoike are shown in Figure 5 below. The analysis shows significant variations between the April and June periods across the three locations.

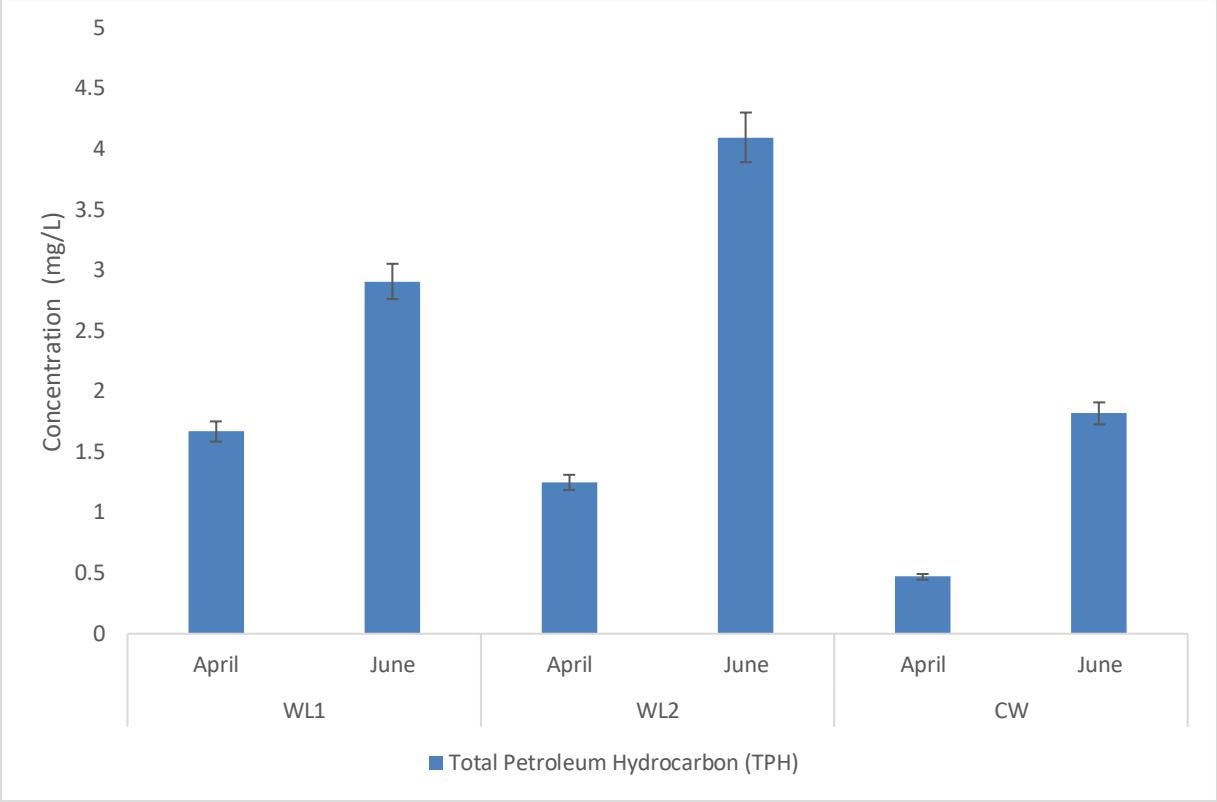

Figure 5: Total Petroleum Hydrocarbon (TPH) Concentrations (mg/L) in Water Samples from Kokori-Erhoike during April and June Periods

The concentrations of Total Petroleum Hydrocarbon (TPH) in water samples from Kokori-Erhoike varied significantly between the April and June periods across the three locations. In Kokori-Erhioke (WL1), TPH concentrations were recorded at 1.67 mg/L during the April period, increasing to 2.91 mg/L in the June period. Similarly, in Onwe (WL2), TPH levels rose from 1.25 mg/L in the April period to 4.1 mg/L in the June period. The control site in Ughelli (CW) exhibited the lowest TPH concentrations, with 0.47 mg/L in the April period and 1.82 mg/L during the June period. These results indicate a general trend of higher TPH concentrations during the June period across all locations. This increase could be attributed to the reduced water volume and dilution capacity during the June period, leading to the accumulation of hydrocarbons in the water.

The elevated TPH levels observed during the June period can be linked to several factors, including reduced rainfall, which limits the natural dilution and dispersion of hydrocarbons (Quiñonez-Plaza *et al*., 2017). In contrast, during the April period, rainwater helps to dilute and disperse TPH, resulting in lower concentrations. The possible sources of TPH in these areas likely include wastewater effluents from industrial activities, spills from oil and gas operations, and urban runoff (Vane *et al*., 2017). The presence of oil and gas exploration and production activities in Kokori-Erhioke and Onwe, as well as potential illegal dumping of petroleum products, are significant contributors to the TPH contamination.

The presence of TPH in water bodies poses considerable ecological and human health risks. Hydrocarbons can cause acute and chronic toxicity in aquatic organisms, disrupting food chains and degrading water quality. This can lead to long-term environmental impacts, including the loss of biodiversity and the impairment of ecosystem services (Addla *et al*., 2022; Ekka *et al*., 2023). For humans, exposure to high levels of TPH can result in adverse health effects, such as skin irritation, respiratory issues, and long-term damage to the liver and kidneys (Kuppusamy *et al*., 2020; Priyadarshanee *et al*., 2022). The undetectable levels of polyaromatic hydrocarbons (PAHs) in the water samples during both periods provide some relief but do not negate the risks posed by TPH. These findings indicate the importance of implementing stringent monitoring and regulation of industrial discharges and other potential sources of hydrocarbon pollution. Regular water quality assessments and proactive measures to mitigate pollution are essential to protect both the environment and the health of local communities.

3.6 Environmental Impact of Gas Flaring on Soil during the April Period and June Period

The concentration of Ph and heavy metals in soil samples from around Kokori-Erhioke gas flow station is shown in Figure 6 below.

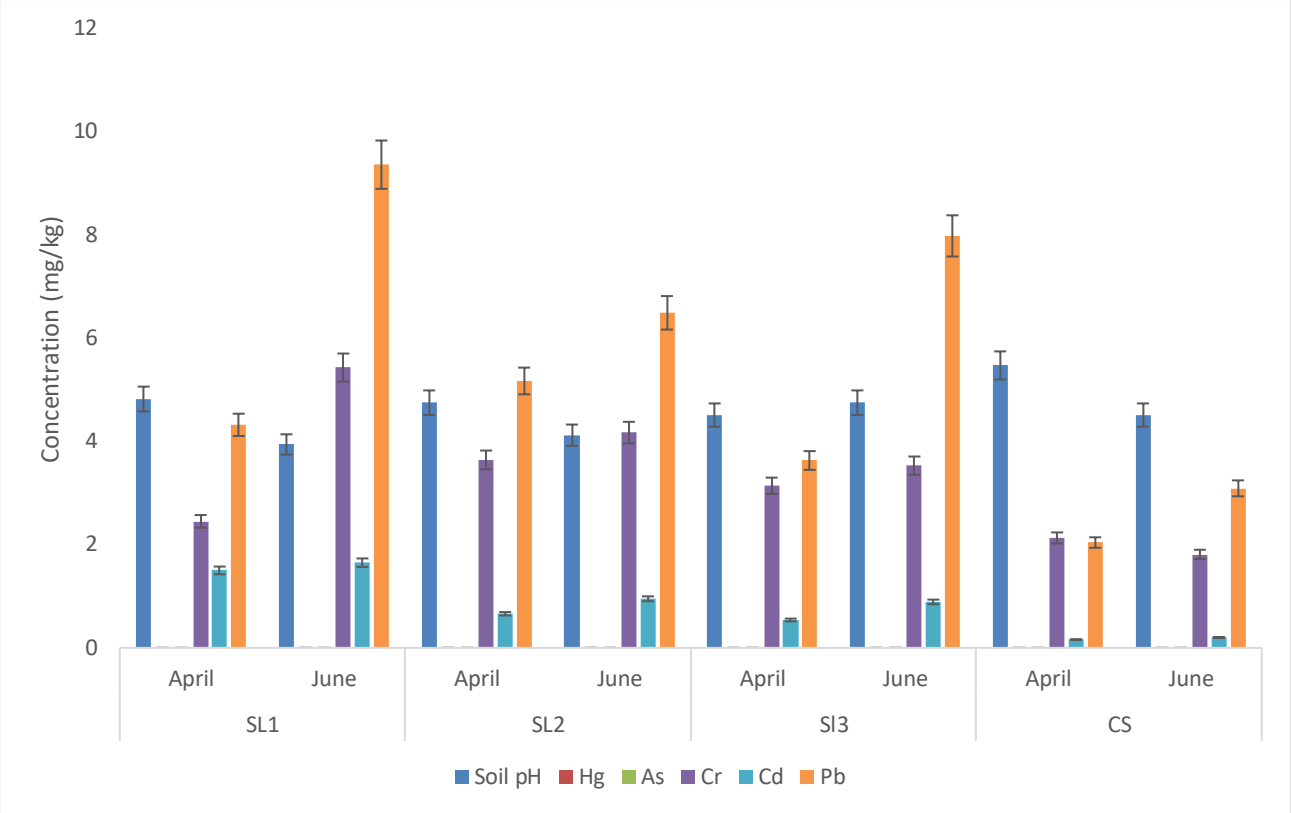

Figure 6: Soil pH and Heavy Metal Concentrations in Soil Samples from Kokori-Erhoike flowstation during April and June Periods

The soil pH and heavy metal concentrations in Kokori-Erhoike during the April and June periods reveal significant variations. Soil pH values ranged from 4.51 to 4.82 during the April period and decreased to 3.94 to 4.75 in the June period, indicating increased soil acidity in the June period. Heavy metal analysis showed that mercury (Hg) and arsenic (As) levels were consistently below detectable limits (<0.001 mg/kg) across all samples in both periods. Chromium (Cr) levels increased from 2.45 to 5.43 mg/kg (SL1), 3.64 to 4.17 mg/kg (SL2), and 3.14 to 3.53 mg/kg (SL3) from April to June periods, while the control soil (CS) showed a decrease from 2.13 to 1.81 mg/kg. Cadmium (Cd) concentrations also rose from 1.5 to 1.65 mg/kg (SL1), 0.66 to 0.95 mg/kg (SL2), and 0.54 to 0.89 mg/kg (SL3) from April to June periods, with the control showing a slight increase from 0.16 to 0.2 mg/kg. Lead (Pb) levels saw a significant rise, with SL1 increasing from 4.32 to 9.36 mg/kg, SL2 from 5.17 to 6.49 mg/kg, and SL3 from 3.63 to 7.98 mg/kg, while the control soil showed an increase from 2.04 to 3.09 mg/kg.

These findings suggest that the increased soil acidity during the June period may enhance the mobility and bioavailability of heavy metals, leading to their higher concentrations in the soil. The elevated levels of chromium, cadmium, and lead during the June period can be linked to reduced leaching and runoff, allowing these metals to accumulate more readily in the soil (Oyewo *et al*., 2020). The absence of detectable mercury and arsenic in both periods indicates that gas flaring in the Kokori-Erhoike area does not significantly contribute to contamination by these metals. However, the observed increases in chromium, cadmium, and lead concentrations pose potential environmental and health risks, as these metals are known for their toxicity and adverse effects on both ecosystems and human health. Continued monitoring and mitigation efforts are necessary to manage the impact of gas flaring and prevent long-term soil degradation in the area.

3.7 Associations and Relationships

The correlation analysis of air quality parameters during the April and June period from the Kokori-Erhioke flowstation is shown in Table 3 below.

Table 3: ANOVA Analysis of Air Quality Parameters

	CH_4	SO_2	NO_2	VOCs	CO_2	CO	$PM_{2.5}$	PM_{10}
CH_4	1							
SO_2	0.69	1						
NO_2	0.92	0.88	1					
VOCs	-0.42	0.69	0.76	1				

	CH_4	**SO_2**	**NO_2**	**VOCs**	**CO_2**	**CO**	**$PM_{2.5}$**	**PM_{10}**
CO_2	0.73	-0.59	-0.87	0.72	1			
CO	-0.75	0.39	0.23	-0.25	0.84	1		
$PM_{2.5}$	0.23	0.52	0.69	0.75	-0.83	0.66	1	
PM_{10}	-0.68	0.18	0.12	-0.52	0.94	0.24	0.42	1

The ANOVA analysis of air quality parameters reveals notable interdependencies among the pollutants. CH_4 shows a positive correlation with CO_2 at 0.73, suggesting a common source such as gas flaring and industrial emissions. Similarly, NO_2 has a strong positive correlation with CH_4 (0.92) and VOCs (0.76), indicating they likely originate from the same processes. CO_2 exhibits moderate correlations with CH_4 (0.73) and VOCs (0.72), further highlighting shared emission sources. Additionally, CO displays a negative correlation with CH_4 (-0.75), suggesting differing emission conditions or efficiencies. $PM_{2.5}$ and PM_{10} show positive correlations with several pollutants, including $PM_{2.5}$ with VOCs (0.75) and PM_{10} with CO_2 (0.94), indicating their prevalence in polluted environments.

These results indicate 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 emissions. 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 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 ANOVA analysis of the physicochemical characteristics of water samples is shown in Table 4 below.

Table 4: ANOVA 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	0.62	1					
TDS	-0.82	-0.15	1				
Turbidity	0.53	-0.74	0.55	1			
BOD	-0.86	0.14	-0.74	-0.68	1		
COD	0.62	0.92	0.19	-0.82	-0.96	1	
DO	-0.83	-0.42	-0.75	-0.15	0.82	-0.98	1

The ANOVA analysis of the physicochemical parameters of water samples from Kokori-Erhioke reveals significant interdependencies among the variables. pH shows a strong negative correlation with TDS (-0.82), indicating that as the water becomes more alkaline, the total dissolved solids decrease. pH also has a robust negative correlation with BOD (-0.86) and DO (-0.83), suggesting that higher pH levels are associated with lower biochemical oxygen demand and dissolved oxygen levels. EC exhibits a moderate positive correlation with pH (0.62) but negative correlations with turbidity (-0.74) and COD (-0.92). TDS presents negative correlations with multiple parameters, including turbidity (0.55), BOD (-0.74), and COD (0.19), implying complex interactions where higher dissolved solids might reduce these parameters. Turbidity itself shows negative correlations with both BOD (-0.68) and COD (-0.82), while COD has a strong negative correlation with DO (-0.98).

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 ANOVA analysis of heavy metals in the water samples is shown in Table 5 below.

Table 5: ANOVA Analysis of Heavy Metals in Water Samples from Kokori-Erhoike

	Zn (mg/L)	Cr (mg/L)	Cu (mg/L)	Cd (mg/L)	Pb (mg/L)
Zn	1				
Cr	0.66	1			
Cu	0.63	0.45	1		
Cd	-0.14	0.21	-0.73	1	
Pb	0.71	0.74	0.38	0.65	1

The ANOVA analysis of heavy metals in water samples from Kokori-Erhoike reveals notable interdependencies among the metal concentrations. Zn shows a moderate positive correlation with Cr (0.66) and Cu (0.63), indicating a possible common source or similar behavior in the aquatic environment. However, Zn has a weak negative correlation with Cd (-0.14), suggesting diverse sources or environmental processes affecting its concentration. Cr exhibits a moderate positive correlation with Pb (0.74) and a weak positive correlation with Cu (0.45), 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 (-0.73) but a weak positive correlation with Cr (0.21) and a moderate positive correlation with Pb (0.65). Pb shows moderate to strong positive correlations with Zn (0.71), Cr (0.74), Cu (0.38), and Cd (0.65), highlighting its distinct behavior or source in the water samples.

These results underscore the complex nature of heavy metal contamination in water bodies and point towards potential sources of these contaminants. The strong positive correlations between certain metals, like Cr and Pb, suggest common sources such as industrial discharges, mining activities, or corrosion of metal pipes. The moderate positive 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.

4.0 CONCLUSION

The study reveals significant contamination levels in water samples, particularly in heavy metals such as Zn, Cr, Cd, Pb, and Cu, with concentrations exceeding WHO limits for safe drinking water. The findings highlight strong correlations between certain metals, pointing to common sources like industrial discharges and mining activities, as well as multiple contamination sources, including agricultural runoff. The complex nature of heavy metal pollution poses serious health risks and environmental degradation, emphasizing the need for regular monitoring, effective pollution control, public awareness, and remediation efforts. The study underscores the urgency of addressing these issues to safeguard the health and livelihoods of the local population and improve environmental quality in the region.

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