Climate Change on the Availability, Accessibility, and Quality of Water, Sanitation, and Hygiene (Wash) Services Within the Kolokuma/Opokuma Local Government Area

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Abstract
This study examines the influence of climate change on the availability, accessibility, and quality of Water, Sanitation, and Hygiene (WASH) services in Kolokuma/Opokuma Local Government Area (LGA) of Bayelsa State, Nigeria. Utilizing a quantitative research design, the study assessed the current state of WASH services and investigated the impacts of climate variability on water supply. Primary data was collected through structured questionnaires distributed among 384 residents, and analyzed using statistical tools including correlation, regression, and chi-square tests. Findings revealed widespread dissatisfaction with water quality, with over 43% of respondents expressing dissatisfaction. Climate change was perceived to have significantly affected water availability and quality, with the most reported effects being reduced availability (30.2%) and changes in quality (28.4%). However, there was no statistically significant relationship between educational level and perception of climate change impacts. The study concludes that climate change poses significant risks to WASH services in the LGA, calling for urgent investment in climate-resilient infrastructure, local water management, and community education initiatives. These findings underscore the importance of incorporating climate resilience into WASH planning to safeguard public health and promote sustainable development in vulnerable communities.

***Keywords**: Climate Change, WASH Services, Water Availability, Sanitation, Hygiene.*

Introduction

Climate change, as assessed by the Intergovernmental Panel on Climate Change (IPCC), presents an unequivocal global challenge with significant local and regional consequences (IPCC, 2021). The Kolokuma/Opokuma Local Government Area (LGA) in Bayelsa State, Nigeria, is not exempt from these impacts and bears unique vulnerabilities.

The IPCC has underscored the growing frequency and intensity of climate-related extreme events, such as floods and storms, which can disrupt ecosystems, infrastructure, and livelihoods (IPCC, 2021). Kolokuma/Opokuma LGA's low-lying topography and coastal orientation make its deltaic area particularly vulnerable to these extreme events. Rising sea levels and more erratic rainfall have helped low-lying areas flood, riverbanks to erode, and saltwater intrusion into freshwater sources (Ologundudu et al., 2020). These components aggravate the problems the residents deal with even more.

Kolokuma/Opokuma LGA's dependence on natural resources—including agriculture, fishing, and forestry—that define its economy exposes the area's vulnerability (Opuene et al., 2016). Direct consequences of the disturbance of these livelihoods by climate change events include effects on the food security and community's economic stability. Moreover, the people's reliance on subsistence farming makes them rather sensitive to changes in temperature and strong storms (Adesina et al., 2017).

Maintaining public health especially in an area prone to climate-induced waterborne diseases depends critically on water, sanitation, and hygiene (WASH) services (World Health Organization, 2019). Climate change can affect the availability and quality of water sources (IPCC, 2021) including effects for access to safe drinking water and sanitation facilities. By raising demand, urbanization and population growth in Kolokuma/Opokuma LGA aggravate already stressed infrastructure (Alalibo, 2018).

The Sustainable Development Goals (SDGs) provide a global framework for addressing water and sanitation challenges. SDG 6 aims to ensure everyone's availability of sanitation and water as well as their sustainable management. However, in places like Kolokuma/Opokuma the complicated interaction among public health, water resource management, and climate change limits SDG 6's accomplishment (United Nations, 2015).

One cannot underline the need of addressing climate change consequences on WASH services in Kolokuma/Opokuma LGA. This thesis intends to assess the specific shortcomings and challenges the area experiences in maintaining appropriate WASH services in a context of changing climate. By analyzing the intricate relationship between climate change and WASH services, this research aims to offer insights and policy recommendations that can help the local authorities, policymakers, and communities build resilience and adapt to the challenges posed by climate variability and uncertainty.

Problem Statement

The impacts of climate change on Water, Sanitation, and Hygiene (WASH) services pose a significant challenge for Kolokuma/Opokuma Local Government Area (LGA) in Bayelsa State, Nigeria. As highlighted by the Intergovernmental Panel on Climate Change (IPCC), the area is increasingly experiencing extreme events such as floods and storms due to rising climate variability (IPCC, 2021). These climatic disruptions adversely impact public health, livelihoods, and community well-being, thus jeopardizing the sustainability and accessibility of WASH services.

Kolokuma/Opokuma LGA’s vulnerability stems from multiple factors. Primarily, the low topography and closeness to the coast heighten the area's susceptibility to water-level rise and storm rage (Ologundudu et al., 2020). Such events threaten existing water supplies and can lead to saltwater contamination of freshwater resources, rendering them unfit for household use. Together, these challenges exacerbate community vulnerability.

Additionally, the local economy’s heavy reliance on natural resources, including fishing and agriculture, intensifies the population’s susceptibility to the unpredictable effects of climate change. Fluctuations in crop yields and disruptions to fishing caused by climate variability threaten food security and economic stability.

Moreover, population growth and urbanization in Kolokuma/Opokuma LGA place further strain on the existing WASH infrastructure. Insufficient sanitation facilities and inadequate hygiene practices, especially during extreme weather, pose significant health risks to the community (Alalibo, 2018).

Despite the evident challenges, limited research has been conducted to thoroughly examine the effects of climate change on WASH services in Kolokuma/Opokuma LGA. Understanding the specific vulnerabilities, risks, and coping strategies within this community is essential for developing effective adaptation and mitigation strategies.

Addressing these issues highlights the purpose of this study. Given Kolokuma/Opokuma LGA's vulnerability, implementing informed policies and strategies is crucial to enhancing resilience against climate change (UNDP, 2019). This thesis aims to bridge the knowledge gap by conducting an in-depth analysis of the link between WASH services and climate change in the area, offering valuable insights and policy recommendations to support local authorities, decision-makers, and communities in safeguarding WASH services and public health amidst the escalating climate threat.

Objectives

The study aims to comprehensively assess the influence of climate change on the availability, accessibility, and quality of water, sanitation, and hygiene (WASH) services within the Kolokuma/Opokuma Local Government Area. The following are the specific objectives of the study:

1. To assess the current state of Water, Sanitation, and Hygiene (WASH) services in the study area.
2. To investigate the impact of climate change on the availability and quality of water supply services in the study area and its implications for WASH services.

Conceptual Review

Climate Change and its Impact

Today, climate change stands as one of the most pressing global challenges, affecting nearly every aspect of life, from our environment and economies to the fabric of our societies. Primarily caused by human activities, climate change refers to long-term shifts in temperature and weather patterns (IPCC, 2014). Recent studies indicate an alarming acceleration in Earth's warming, with an increased frequency and severity of natural disasters and notable shifts in ice melt at both poles. Sea levels are now rising at unprecedented rates.

Human-induced climate change is largely fueled by elevated atmospheric levels of greenhouse gases, notably carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Currently, CO_2 levels are around 410 parts per million—concentrations unseen for at least 800,000 years (Lüthi et al., 2008). Fossil fuels, central to energy production and transportation worldwide, contribute heavily to emissions. As Chancel and Piketty (2015) highlighted, fossil fuel consumption in industrialized countries alone accounted for almost half of global emissions. In recent research, Tong et al. (2019) observed that fossil fuel use in developing regions is accelerating at a rate incompatible with the 1.5°C target. Projections indicate that ongoing fossil fuel projects could release over 650 billion metric tons of CO_2, far exceeding the remaining carbon budget to limit warming to 1.5°C above pre-industrial levels.

Additionally, deforestation and land use changes compound global warming—not only by releasing carbon stored in biomass but also by reducing the Earth's CO_2 absorption capacity. Forests, which store roughly 250 billion tons of carbon, represent critical land carbon sinks. However, forest cover loss is intensifying; satellite data from 2014 to 2018 reveals an average annual reduction of 26 million hectares, with tropical forests facing significant threats. Urban expansion is accelerating deforestation in areas like the Brazilian Amazon, Western Indonesia, and parts of Central Africa.

Agriculture also contributes to climate change through various activities, such as methane emissions from rice paddies and livestock, and nitrous oxide from synthetic fertilizers (Havlík et al., 2011). Livestock, especially cattle, account for approximately 14.5 percent of global greenhouse gas emissions (Gerber et al., 2013). Agriculture's expansion, particularly in tropical regions, has led to a decline in natural carbon sinks. However, climate-smart agriculture shows potential in mitigating these impacts. Techniques like improved crop and livestock management, agroforestry, and soil carbon sequestration can help reduce emissions while enhancing food security (Lipper et al., 2014).

The manifestations of climate change are evident worldwide, disrupting both natural and human systems. Sea levels, for instance, have been rising at 3.6 mm per year from 2006 to 2015, nearly double the rate of the previous century (IPCC, 2019), mainly due to glacier melt, land-based ice sheet expansion, and thermal expansion of oceans. In high-emission scenarios, sea levels could rise by up to 2 meters by 2100, potentially displacing tens of millions in coastal and island areas (Oppenheimer et al., 2019).

Climate change is also associated with more frequent and intense extreme weather events, such as heatwaves, droughts, hurricanes, and heavy rainfall. Diffenbaugh et al. (2017) reported that over 80% of the globe now faces an increased probability of record-high temperatures due to human-induced climate change. The year 2017 marked the costliest year for global weather-related damages, with an estimated loss of $320 billion (Munich Re, 2018), underscoring the escalating economic toll of extreme events. As these events become more severe, they pose significant challenges for public health, infrastructure resilience, and disaster preparedness.

Furthermore, climate change is altering species distribution, ecosystem services, and biodiversity. A 2017 meta-analysis published in *Nature* confirmed that climate change is causing species to shift their ranges poleward and to higher altitudes in terrestrial, marine, and freshwater ecosystems. These shifts are reshaping ecological communities and ecosystem functions, with potential implications for human well-being. Climate change also threatens species with extinction and exacerbates other biodiversity threats, such as pollution and habitat destruction.

Awareness is growing that climate change poses serious obstacles to sustainable development and global equity. Particularly in developing countries, climate change exacerbates existing inequalities and threatens progress toward food security and poverty alleviation (Hallegatte et al., 2016). A recent World Bank report predicts that, without mitigation, climate change could push an additional 100 million people into extreme poverty by 2030 (Hallegatte et al., 2016). Acting as a threat multiplier, climate change is also linked to increased conflicts and mass migration (Abel et al., 2019).

Dealing with the climate crisis calls for quick and coordinated local, national, and worldwide response. Adopting a worldwide goal to limit warming well below 2°C above pre-industrial levels and to pursue efforts of limiting warming to 1.5°C, the Paris Agreement (2015) let nations join forces. Such an aim calls for quick and extensive changes in land use, energy, industrial systems (IPCC, 2018). While offering major co-benefits for biodiversity and human well-being, reforestation, wetland restoration, and other types of nature-based solutions have the potential to greatly help to mitigate climate change (Griscom et al., 2017). Likewise, innovations in the domains of renewable energy, energy storage, carbon capture and storage could also bring about radical changes to decarbonize most economic sectors (Jacobson et al., 2017). But the scope and urgency of the climate crisis call for a wide spectrum of radical changes in society values, consumption patterns, and government systems that would allow a fair and sustainable low-carbon future.

Water, Sanitation and Hygiene (WASH) Services

WASH services are a basic but essential part of public health. They are also a crucial component of environmental sustainability and human well-being. Reliable global water supplies will become increasingly difficult to predict as climate change brings more frequent and intense extremes, like droughts or floods. However, accurate forecasts of climate shifts can help ensure the reliability of WASH services. Predicted drought periods could trigger early interventions to secure water supplies and ensure ongoing maintenance of sanitation facilities to prevent waterborne disease outbreaks. As sanitation infrastructure becomes overwhelmed, heavy rainfall forecasts could guide efforts to protect water quality and prevent contamination. UNICEF and WHO (2019) note that incorporating climate forecasts into WASH planning is essential to building resilient WASH systems in the face of climate change (UNICEF & WHO, 2019). Several recent studies reflect these views, emphasising the need for climate-resilient WASH infrastructure in low-income regions most vulnerable to climate change impacts (Howard et al., 2016).

Importance of WASH Services

WASH services are the cornerstone of a healthy and thriving society. These services contribute to several critical aspects of well-being and development:

- **Public Health:** Perhaps the most evident and immediate impact of WASH services is on public health. Access to clean water and proper sanitation facilities significantly reduces the risk of waterborne diseases, which have long been major causes of morbidity and mortality worldwide (Bartram & Cairncross, 2010). The availability of clean water for drinking and cooking is vital to prevent the spread of diseases like cholera, dysentery, and diarrhea.
- **Hygiene Promotion:** Beyond the provision of infrastructure, WASH services involve hygiene education and behavior change programs. These initiatives teach individuals and communities the importance of handwashing, safe food preparation, and other hygienic practices. By promoting these behaviors, WASH services help reduce the transmission of diseases and safeguard public health (Curtis et al., 2000).
- **Dignity and Gender Equality:** Adequate sanitation facilities, especially for women and girls, promote dignity, safety, and gender equality. Access to private and secure sanitation can reduce the vulnerability of women and girls to gender-based violence, enhance their overall well-being, and support their empowerment (UNICEF & WHO, 2019).

Impact of WASH on Public Health

WASH services have a profound and far-reaching impact on public health:

- **Reducing Disease Burden:** Basic sanitation and access to clean drinking water substantially reduces the burden like cholera, dysentery and diarrhoea that are transmitted by contaminated water. The reduced prevalence of disease due to WASH services is a direct route to improved health (Wolf et al., 2018).
- **Child Survival:** Improved WASH services contribute to child survival. Diarrhoeal diseases, linked to contaminated water and poor sanitation, continue to be one of the leading causes of death for children under five years of age (in 2019, it was responsible for 11% of deaths among this age group) – and they can easily be prevented with access to clean water and sanitation.
- **Malnutrition:** Access to improved water and sanitation (and associated hygiene practices) is indirectly associated with improved nutrition. Reduced exposure to waterborne diseases

that can contribute to malnutrition, especially in children, can be a clear outcome of well-functioning WASH services (Clasen et al, 2014). Such relation shows how to bridge WASH-related issues with other more general public health and development efforts.

Challenges in Ensuring Universal Access

Despite the clear importance and impact of WASH services, several challenges impede universal access:

- **Infrastructure and Resources:** The building and maintenance of WASH infrastructure, ranging from water treatment plants and sewers to toilets, requires substantial financial resources and continuous investment, which can make this a tall order for countries with scarce financial resources (Hutton et al., 2015).
- **Climate Change:** Climate change can exacerbate water scarcity negatively impacting access to clean water and water quality, and making it even harder to meet water needs with the available clean water. Unprecedented and unpredictable weather patterns, droughts and extreme events can stress WASH assets and resources (UNICEF & WHO, 2019).
- **Inequality:** 'WASH access is disproportionately distributed, with the poorest, most marginalised and vulnerable populations facing greater barriers to accessing clean water and sanitation facilities (Pearce-Oroz et al, 2016). An unequal distribution of resources, in addition to social, economic and geographical disparities, exacerbates all aspects of these inequalities in access.

Water, sanitation and hygiene (WASH) services are foundational to public health and environmental sustainability, recognising that they are also essential for human wellbeing as advocated by the 2002 World Health Organization/United Nations Children's Fund (WHO/UNICEF) Joint Monitoring Programme for Water Supply and Sanitation. WASH services are also central to human rights and dignity. Yet, in view of the continued high numbers of people without access to these services, a compelling need remains to address critical gaps in understanding and addressing the factors underlying the slow pace of progress to meet this global imperative.

Interconnection between Climate Change and WASH Services

Public health depends on water, sanitation, and hygienic practices (WASH), which are therefore quite closely related to climate change. A major issue is how climate change affects WASH services since changing hydrological cycles, extreme events, and shifting weather patterns profoundly affect the availability and quality of water resources and sanitation facilities.

Climate Change Effects on WASH Services

Climate change alters precipitation patterns, prolongs droughts, and increases evaporation rates, so influencing the availability of fresh water. In some areas, reduced rainfall aggravates water shortage, so making it difficult to satisfy demand for safe drinking water (Bates et al., 2008).

- **Water Quality:** Extreme events linked to climate, such floods and storm surges, can contaminate water supplies and so compromise their quality. Strong rain and flooding can bring toxins and bacteria into water supplies, so endangering public health (Fewtrell et al., 2007).
- **Sanitation Infrastructure:** Rising sea levels and more coastal flooding brought on by climate change compromise the infrastructure supporting sanitation. Severe weather events

can compromise sewage systems, which results in untreated wastewater output and possible water source contamination (Adelekan et al., 2015).

- **Health Impacts:** Clearly seen in health results is the interaction between WASH services and climate change. Particularly among vulnerable populations, climate-induced water scarcity and waterborne diseases brought on by compromised sanitation and hygiene can cause more burden of water-related diseases (WHO, 2019).

Water Quality

Water is a vital resource essential for all forms of life on Earth. Since it directly affects human health, ecosystems, and the sustainability of our planet, water quality is absolutely vital. Water quality is the biological, chemical, and physical properties of water that define its fit for different purposes.

Importance of Water Quality

Maintaining public health depends much on the quality of water. Contaminated water seriously compromises human well-being and can spread infections. A basic human right is access to safe, clean drinking water; absence of this can lead to waterborne diseases including dysentery and cholera. Millions of people die from these diseases globally, especially in underdeveloped countries lacking modern sanitation and water treatment systems (UN, 2010).

Moreover, for ecosystems water quality is essential. For their survival and good health, aquatic ecosystems depend on fresh water. Contaminated water upsets the equilibrium of ecosystems, which reduces biodiversity and, occasionally causes aquatic communities to entirely collapse (Carpenter et al., 1998). Water pollution can have far-reaching effects on terrestrial ecosystems as well as aquatic life, so affecting human societies.

Assessment of Water Quality

Assessing water quality involves monitoring various parameters that help determine its suitability for specific purposes. Some of the key indicators used to assess water quality include physical, chemical, and biological characteristics:

- **Physical Characteristics:** These include temperature, turbidity, color, and odor. Temperature affects the solubility of gases and the metabolic rates of aquatic organisms. High turbidity and unusual color or odor can indicate pollution.
- **Chemical Characteristics:** Key chemical parameters are pH, dissolved oxygen, nutrients (nitrogen and phosphorous), heavy metals, and organic pollutants. While dissolved oxygen is vital for aquatic life, pH levels can affect the toxicity of some drugs. Eutrophication brought on by nutrient pollution may produce algal blooms and oxygen depletion (Smith, 2003). For aquatic life, heavy metals and organic pollutants can be harmful; for humans, they have long-term health effects.
- **Biological Characteristics:** Water quality can be deduced from biological markers including the existence of indicator species or the variety of aquatic life. While great biodiversity points to a healthy ecosystem, the absence or decline of particular species may signal pollution (Allan, 2004).

Factors Influencing Water Quality

The fundamental factors responsible for water pollution are point-source pollution, non-point-source pollution, natural geological processes, and climate impacts. Pollutant discharges from discrete sites, such as pipes or ships, are point sources of pollution. These sites release pollutants directly into the water. According to the EPA (2021), these contaminants include oil, sewage, toxic chemicals, and radioactive materials. Early detection can easily separate these contaminants from the water. Non-point-source pollution occurs when rainfall moves over and through the ground. Because this type of pollution is not easily identified, it is difficult to control. Non-point-source pollution also includes run-off from agricultural lands and urban areas. Natural geological processes also have a significant impact on water quality. Various natural disasters, such as earthquakes and volcanic eruptions, can create pollutants that affect the quality of water. Climate-related impacts can lead to extreme weather events. This can result in surface water contamination. Hurricanes can cause saltwater intrusion, as well as storm surges that push saltwater into the freshwater supply.

Point-source pollution is perhaps the most visible and still a major challenge in water quality management. This is pollution from a definite and discrete source: pipe discharges from industrial effluents, sewage treatment plants, and so on. Despite the highly effective regulation of discharges, recent studies have shown that point-source pollution is still a major challenge. As expected, the problem can be particularly acute in developing countries, where regulatory enforcement may be less robust (Schwarzenbach et al., 2010). For example, a detailed study of discharges from industrial sites in China found that a large proportion of these sites exceeded local standards (Ma et al., 2020).

In contrast, non-point-source pollution is more diffuse and difficult to address. This is the pollution that originates from multiple, dispersed sources, often associated with land use such as agriculture, urban development, and transport. In many places, the most important source of non-point-source pollution is agricultural runoff, with its load of fertilisers, pesticides, and sediment. One recent assessment of global agricultural watersheds found that, compared with natural conditions, intensive agricultural practices could cause substantially higher nitrogen and phosphorus loads in adjacent waters (Bol et al., 2018). Urban stormwater runoff is also important, containing a diverse cocktail of pollutants from roads, parking lots, and other impervious surfaces and being introduced directly into the water system (Goonetilleke et al., 2017).

Pre-existing natural processes can have a profound impact on water quality and, in many cases, serve as a baseline for the chemical composition of water bodies. The interactions of water with the rocks and soils it currently resides in also shape its chemical fingerprints. Chemical weathering of rocks can introduce minerals and elements that alter water chemistry. For instance, a national geological survey of the United States found that naturally weathered arsenic-rich minerals in some rock formations are responsible for the elevated arsenic concentrations in groundwater that frequently exceed drinking water standards (Smedley and Kinniburgh 2002). Being able to identify these natural backgrounds is essential to understanding anthropogenic impacts and setting realistic water quality goals.

Climate change is driving water quality. It affects the quantity and quality of water. Changes in patterns of precipitation, temperature regimes, and extreme weather events have impacts on water resources. A literature review on the effects of climate change on water quality predicts that many regions will experience an increase in surface-water nutrient loading due to runoff patterns and increased soil erosion (Delpla et al., 2009). They project that higher water temperatures will increase algal blooms and further reduce dissolved oxygen levels. This can lead to widespread ecological changes in aquatic systems (Whitehead et al., 2009).

Responsibilities for water quality – from the individual to the global level – run the gamut from community-based water quality monitoring to international governance bodies. At the community level, community-based water quality monitoring programmes have been effective in the early detection of pollution events as well as launching programmes to inspire local stewardship of water resources. (Jollymore et al., 2017) Governments are responsible for setting and enforcing water quality standards, investing in infrastructure and policies that reduce pollution sources. Recent policy assessments have shown that countries with intersectoral approaches to water resource management tend to have better water quality outcomes, stressing the importance of integrated and cooperative governance structures. (UN Water, 2018) While monitoring and assessing water quality parameters will always be integral to water resource management, advances in technology are now enabling new ways to track water quality at exceedingly high spatiotemporal scales. Studies using satellite imagery and algorithms can now monitor several water quality parameters in lakes and rivers over large areas with increasing levels of accuracy.

Recent studies have demonstrated the potential for water on a global scale. The authors used satellite-based remote-sensing techniques for deriving surface water indicators for nutrients, dissolved organic carbon and total suspended solids, which are important parameters for water quality assessment (Dörnhöfer & Oppelt, 2016). Together with traditional sampling techniques, new technologies and citizen science hold promise for tracking water quality in real time so that future generations can enjoy the benefits of healthy water.

Methodology

The study design is quantitative in nature. This is because it involves the use of statistical techniques to investigate how climate change leads to water, sanitation, and hygiene (WASH) in Kolokuma/Opokuma LGA. The quantitative methodology employs a technique that assigns measurements to variable quantities for objective analysis. A quantitative approach involves the collection and analysis of numerical data. It will be utilized to assess the current state of WASH services in the LGA and to quantify specific climate change-related variables. Structural questionnaire was distributed among residents of coomunities with the studied LGA, to collect primary data. This study examine the influence of climate change on WASH services in Kolokuma/Opokuma LGA using a more quantitative approach. Using specialised statistical software to guide our interpretation of our data, we will seek to provide clear, objective findings about the patterns and processes observed in our data. Using a suite of statistical tests – including correlation analyses, regression models and analysis of variance (ANOVA) – we will make precise inferences about how background climate variables translate into WASH services. Our commitment to quantitative methods aims to ensure that our results not only reflect reality, but are backed by solid data that provides a solid basis for future interventions.

Analysis And Results

<u>Physicochemical Analysis: Groundwater Physicochemical Analysis in Kolokuma/Opokuma LGA</u>

This section outlines the findings from the physicochemical analysis of groundwater samples taken from four boreholes, labeled BH1, BH2, BH3, and BH4, within the Kolokuma/Opokuma Local Government Area. The results are assessed against the World Health Organization (WHO) 2011 drinking water quality guidelines to determine their appropriateness for WASH services. Table 1 summarizes the physicochemical characteristics and heavy metal concentrations detected in the groundwater samples:

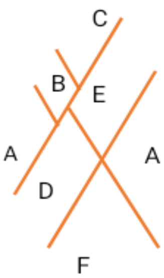
Table 4.1: Summary of Physicochemical and Heavy Metal Concentrations in Groundwater

Parameter	BH1	BH2	BH3	BH4	WHO Standards (2011)
pH	6.3	6.7	6.1	6.8	6.5 – 8.5
Turbidity (NTU)	7.5	4.4	3.8	5.2	≤ 5
Electrical Conductivity (µS/cm)	58.42	36.28	70.94	86.04	-
Total Dissolved Solids (mg/l)	29.21	18.14	35.47	43.02	≤ 1000
Sulphate ($SO4^{2}$-) (mg/l)	26.42	30.94	21.06	18.50	≤ 250
Chloride (Cl-) (mg/l)	17.54	23.08	19.50	16.72	≤ 250
Nitrate (NO3-) (mg/l)	0.16	0.35	0.18	0.24	≤ 3.0
Bicarbonate (HCO3-) (mg/l)	19.38	27.62	15.51	13.95	-
Dissolved Oxygen (DO) (mg/l)	3.6	7.1	6.6	4.8	6.5 – 8
Sodium (Na^{2}+) (mg/l)	24.13	19.92	25.65	21.80	-
Calcium (Ca^{2}+) (mg/l)	36.42	28.56	33.18	25.24	-
Magnesium (Mg^{2}+) (mg/l)	21.38	19.53	15.76	18.02	-
Iron (Fe^{2}+) (mg/l)	0.36	0.22	0.40	0.36	≤ 0.3
Copper (Cu^{2}+) (mg/l)	0.24	0.33	0.15	0.34	≤ 2
Lead (Pb^{2}+) (mg/l)	0.0056	0.0034	0.0048	0.0065	≤ 0.01
Zinc (Zn^{2}+) (mg/l)	0.73	0.85	0.63	0.58	≤ 5
Barium (Ba^{2}+) (mg/l)	0.86	0.75	0.49	0.62	≤ 0.7
Chromium (Cr^{2}+) (mg/l)	0.02	0.02	0.01	0.03	≤ 0.05

Note: To assess groundwater quality regarding health impacts and drinking suitability, these values are measured against WHO standards. This analysis helps identify any health risks associated with groundwater consumption and its use in WASH services.

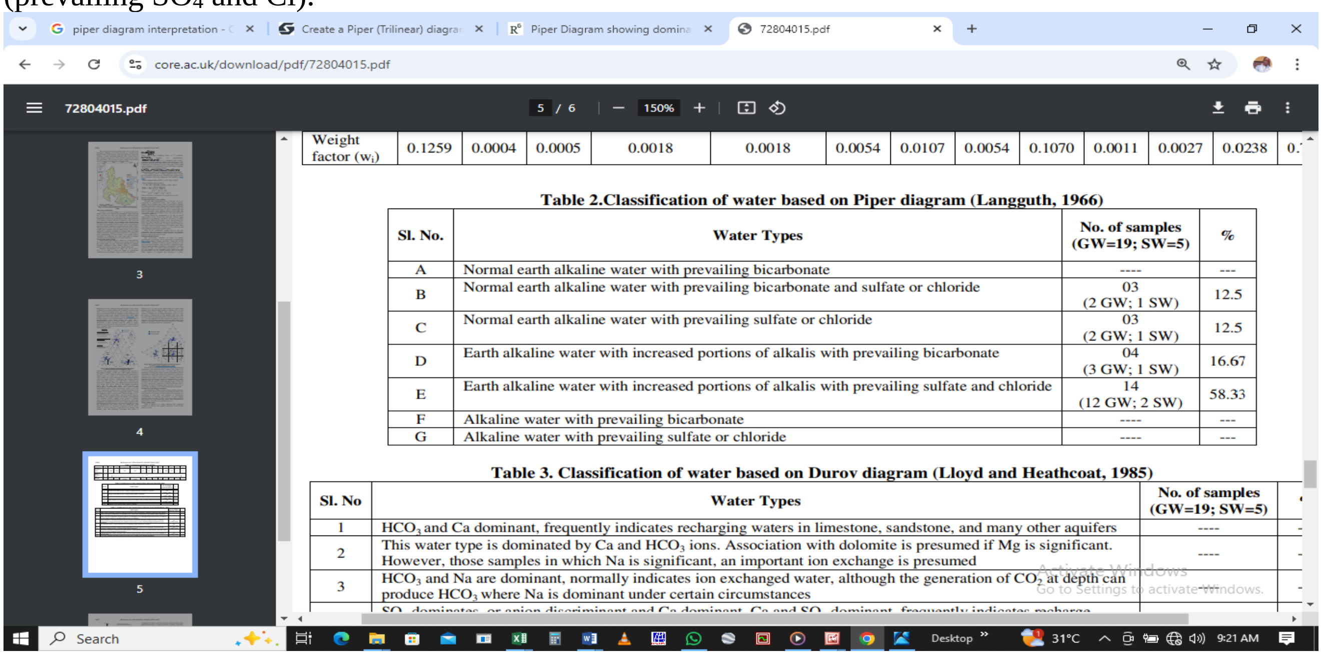
This data provides a basis for assessing groundwater quality in the study area, offering key insights into its suitability for water, sanitation, and hygiene needs. It also flags areas where treatment or corrective actions might be required due to non-compliance with recommended standards.
To analyze groundwater geochemistry in the study area, Piper and Durov diagrams (1948) are employed using Rockwork software. The Piper diagram displays percentage concentrations of primary cations and anions within two triangular fields, projected into a central diamond field. The

Durov plot represents milliequivalent percentages of cations and anions through ternary diagrams and a central rectangular box. These diagrams reveal patterns and differences across water samples, with similar samples clustering in specific directions (Todd, 2001). In the Piper diagram, or the central rectangular box in the case of Durov, water types are determined by plotting data across the diamond-shaped subdivisions.



Piper diagram showing the type of water (Langguth 1966)

From the piper diagram it is observed that the water samples are sulphate chloride water type (prevailing SO_4 and Cl).



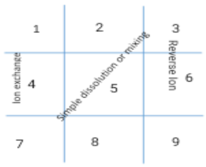
Weight factor (w_i)	0.1259	0.0004	0.0005	0.0018	0.0018	0.0054	0.0107	0.0054	0.1070	0.0011	0.0027	0.0238	0.[illegible]

Table 2.Classification of water based on Piper diagram (Langguth, 1966)

Sl. No.	Water Types	No. of samples (GW=19; SW=5)	%
A	Normal earth alkaline water with prevailing bicarbonate	----	---
B	Normal earth alkaline water with prevailing bicarbonate and sulfate or chloride	03 (2 GW; 1 SW)	12.5
C	Normal earth alkaline water with prevailing sulfate or chloride	03 (2 GW; 1 SW)	12.5
D	Earth alkaline water with increased portions of alkalis with prevailing bicarbonate	04 (3 GW; 1 SW)	16.67
E	Earth alkaline water with increased portions of alkalis with prevailing sulfate and chloride	14 (12 GW; 2 SW)	58.33
F	Alkaline water with prevailing bicarbonate	----	---
G	Alkaline water with prevailing sulfate or chloride	----	---

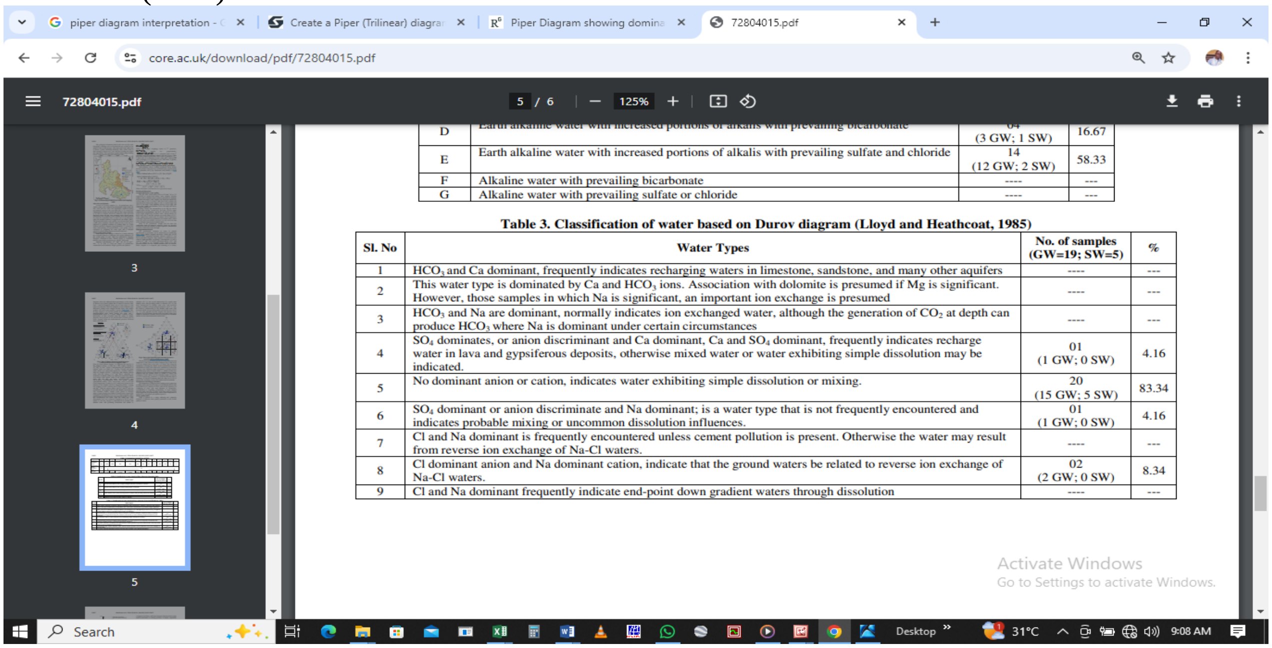
Table 3. Classification of water based on Durov diagram (Lloyd and Heathcoat, 1985)

Sl. No	Water Types	No. of samples (GW=19; SW=5)	[illegible]
1	HCO_3 and Ca dominant, frequently indicates recharging waters in limestone, sandstone, and many other aquifers	----	-
2	This water type is dominated by Ca and HCO_3 ions. Association with dolomite is presumed if Mg is significant. However, those samples in which Na is significant, an important ion exchange is presumed	----	-
3	HCO_3 and Na are dominant, normally indicates ion exchanged water, although the generation of CO_2 at depth can produce HCO_3 where Na is dominant under certain circumstances	----	-



Durov diagram showing hydrochemical process.

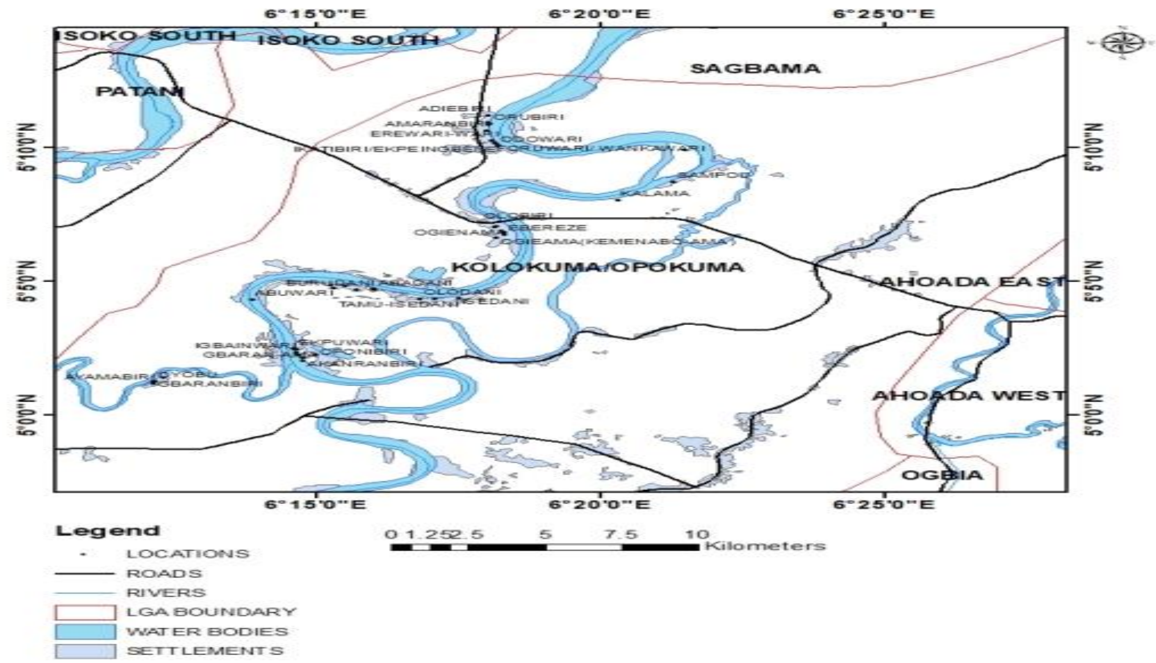
This analysis shows the prevalence of mixed water type in the study area, based on Lloyd and Heathcoat (1985) classification.



D	Earth alkaline water with increased portions of alkalis with prevailing bicarbonate	04 (3 GW; 1 SW)	16.67
E	Earth alkaline water with increased portions of alkalis with prevailing sulfate and chloride	14 (12 GW; 2 SW)	58.33
F	Alkaline water with prevailing bicarbonate	----	---
G	Alkaline water with prevailing sulfate or chloride	----	---

Table 3. Classification of water based on Durov diagram (Lloyd and Heathcoat, 1985)

Sl. No	Water Types	No. of samples (GW=19; SW=5)	%
1	HCO_3 and Ca dominant, frequently indicates recharging waters in limestone, sandstone, and many other aquifers	----	---
2	This water type is dominated by Ca and HCO_3 ions. Association with dolomite is presumed if Mg is significant. However, those samples in which Na is significant, an important ion exchange is presumed	----	---
3	HCO_3 and Na are dominant, normally indicates ion exchanged water, although the generation of CO_2 at depth can produce HCO_3 where Na is dominant under certain circumstances	----	---
4	SO_4 dominates, or anion discriminant and Ca dominant, Ca and SO_4 dominant, frequently indicates recharge water in lava and gypsiferous deposits, otherwise mixed water or water exhibiting simple dissolution may be indicated.	01 (1 GW; 0 SW)	4.16
5	No dominant anion or cation, indicates water exhibiting simple dissolution or mixing.	20 (15 GW; 5 SW)	83.34
6	SO_4 dominant or anion discriminate and Na dominant; is a water type that is not frequently encountered and indicates probable mixing or uncommon dissolution influences.	01 (1 GW; 0 SW)	4.16
7	Cl and Na dominant is frequently encountered unless cement pollution is present. Otherwise the water may result from reverse ion exchange of Na-Cl waters.	----	---
8	Cl dominant anion and Na dominant cation, indicate that the ground waters be related to reverse ion exchange of Na-Cl waters.	02 (2 GW; 0 SW)	8.34
9	Cl and Na dominant frequently indicate end-point down gradient waters through dissolution	----	---



In numerous countries, groundwater serves as the primary water source for domestic, agricultural, and industrial uses, and its contamination has emerged as a significant concern (Belkhiri et al., 2010). Groundwater quality is influenced by various factors beyond agricultural and industrial activities, such as bedrock composition, topography, geology, soil type, climate, atmospheric precipitation, and the quality of recharged water, in addition to human-induced pollution sources. Subsurface geochemical interactions—such as weathering, dissolution, precipitation, ion exchange, and biological processes—further shape groundwater quality (Todd, 1980; Sakram et al., 2013).

In hydrologic systems, water's diagnostic chemical traits are represented by the concept of hydrochemical facies, reflecting the intricate hydrochemical reactions occurring below ground (Sajil Kumar, 2013) between lithologic formations and groundwater. This approach allows for the examination of groundwater chemistry and its spatial variation in terms of hydrochemical evolution. The Durov diagram is particularly useful compared to the Piper diagram in revealing certain geochemical processes that might influence groundwater origins, while the Piper trilinear diagram (Piper, 1944) evaluates river water evolution and the relationship between rock types and water composition.

The groundwater analysis indicates that water quality in the study area is generally favorable, with slightly acidic to neutral pH, low total dissolved solids (TDS), and varying electrical conductivity (EC) levels. This suggests that the groundwater is predominantly fresh, though external influences such as industrial emissions and climate variations may impact it. The presence of key ions—sodium, calcium, magnesium, chloride, and bicarbonate—indicates a blend of water types, potentially due to seasonal changes in aquifer recharge. Findings from the Piper and Durov

diagrams support these conclusions, pointing to potential mixing processes and the influence of external factors on groundwater composition.
Additionally, the study highlights groundwater quality's sensitivity to climatic conditions, especially rising temperatures and altered rainfall patterns. These changes may lead to increased TDS and ion concentrations due to evaporation and diminished dilution. This underscores the urgent need for ongoing groundwater monitoring to detect early changes and to ensure sustainable water management practices.

Objective 1
To assess the current state of Water, Sanitation, and Hygiene (WASH) services in the study area.
Here are the tabulated distributions for the current state of Water, Sanitation, and Hygiene (WASH) services in Kolokuma/Opokuma LGA, based on a sample size of 384 respondents:

Table 2. Water Quality Satisfaction Distribution

Water Quality Satisfaction	Percentage (%)
Very dissatisfied	22.14
Dissatisfied	21.61
Satisfied	21.09
Very satisfied	18.75
Neutral	16.41

Figure 1: Water Quality Satisfaction

Water Quality Satisfaction: The majority of the community is not satisfied with their water quality, with over 43% reporting dissatisfaction. This is in line with Okoro and Onyejekwe (2020) who mentioned the fact that the deteriorating climatic conditions will cause an increased dissatisfaction on the quality of water in an area. This highlight concerns over water safety and suitability for daily use, necessitating immediate attention to improve water treatment and management practices.

Objective 2

To investigate the impact of climate change on the availability and quality of water supply services in the study area and its implications for WASH services.

Here are the tabulated results for perceptions of climate change impact and the specific effects reported:

Table 3: Specific Effects of Climate Change

Effect	Percentage (%)
Reduced water availability	30.2
Changes in water quality	28.4
Contaminated water sources	19.8
Increased reliance on unsafe water sources	10.4
Not sure	6.3
No effect	5.0

Nearly half of the respondents believe that climate change has impacted their water supply, emphasizing the perception of climate change as a significant factor affecting water resources.

The most reported effects — reduced water availability and changes in water quality — suggest that climate change is perceived to affect both the quantity and the safety of water, which could have severe implications for hygiene and sanitation practices in line with observations of Okoro & Onyejekwe (2020) and UNICEF & WHO (2019) who made similar findings that climatic change have severe impact on the quality and availabilty of water in a region.

Chi-Square Test Results:

Test Outcome:

- Chi-Square Statistic: $x^2 = 4.256$
- Degrees of Freedom: 6
- P-value: 0.642

Table 4.6. Crosstab of 'Climate Change Impact on Water Supply' and 'Education Level':

		No Formal	Primary	Secondary	Tertiary
No		30	35	32	24
Not sure		13	22	21	20
Yes		51	44	50	42

Table 4.7. Expected Frequencies:

	No Formal	Primary	Secondary	Tertiary
No	29.62	31.83	32.46	27.10
Not sure	18.60	19.99	20.39	17.02
Yes	45.78	49.18	50.16	41.88

The P-value (0.642) is greater than the typical alpha level of 0.05, which means there is no statistically significant association between the respondents' education level and their perceptions of climate change impacts on water supply. The variations observed in the crosstab are likely due to chance rather than any meaningful relationship.

The distribution of responses across different education levels is relatively close to what would be expected if there were no association between these variables (as shown in the expected frequencies).

The perception of climate change impacts on water supply does not significantly vary with education level among respondents in this study. This suggests that educational background does not strongly influence how residents of Kolokuma/Opokuma LGA perceive the effects of climate change on their water services.

Conclusion

The analysis revealed that a significant portion of the population experiences intermittent water scarcity and dissatisfaction with water quality. The primary sources of drinking water varied, including river/stream, borehole, and piped water, which highlighted a diverse but potentially vulnerable water supply system.

A substantial number of respondents indicated that climate change has adversely affected their water supply, with reported effects including reduced water availability and deteriorated water quality. These changes have significant implications for community health and daily living conditions.

Recommendations

1. Invest in upgrading and building resilient WASH infrastructure that can withstand extreme weather conditions.
2. Develop community-led water management initiatives and support local governance structures to manage WASH services effectively.
3. Implement extensive community education programs to increase awareness about climate change impacts and promote sustainable WASH practices.

Implications to Study

The study's findings underscore the critical need for integrating climate resilience into WASH service planning and implementation. The direct impacts of climate change on water availability and sanitation infrastructure pose serious threats to public health and require immediate and sustained action. The implications extend beyond environmental concerns, touching on social justice and economic stability, particularly in climate-vulnerable communities like Kolokuma/Opokuma LGA.

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