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# Assessment of Water Quality and Pollution Load Capacity of the Mmubete Stream in Nigeria

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**Abstract:** The continuous discharge of waste with high organic content into water bodies causes water pollution. This study evaluates the level of pollution in the Mmubete Stream by focusing on monitoring and evaluating water pollution. The stream is useful for fishing and domestic activities. Water and effluent samples were collected every two months for one year at 12 sampling points covering a total of 1 km stretch of the stream. Seventy-two water samples were collected during the wet and dry seasons covering January, March, May, July, September, and November 2020. Twelve samples were collected in each sampling month and analyzed for twenty parameters: dissolved oxygen, turbidity, total dissolved solids, total suspended solids, biochemical oxygen demand, pH, temperature, electrical conductivity, phosphate, nitrate, copper, lead, iron, manganese, chloride, salinity, nickel, and chemical oxygen demand. The pollution status was evaluated using the modified Water Pollution Index and the National Sanitation Foundation Water Quality Index (NSFWQI) method. The results revealed that Mmubete stream is moderately polluted with water pollution indices for wet and dry seasons as 1.037 and 1.329 respectively and water quality index of 55.87 and 53.22 for dry and wet seasons respectively.

**Key words:** Stream, waste discharge, water pollution, water quality, wastewater.

# Nijerya'daki Mmubete Deresi'nin Su Kalitesi ve Kirlilik Yük Kapasitesinin Değerlendirilmesi

**Öz:** Su kütlelerine yüksek organik içerikli atıkların sürekli deşarjı su kirliliğine neden olur. Bu çalışma, su kirliliğinin izlenmesi ve değerlendirilmesine odaklanarak Mmubete Deresi'ndeki kirlilik seviyesini değerlendirmektedir. Dere, balıkçılık ve evsel faaliyetler için faydalıdır. Su ve atık su örnekleri, derenin toplam 1 km'lik bölümünü kapsayan 12 örnekleme noktasından bir yıl boyunca her iki ayda bir toplandı. Ocak, Mart, Mayıs, Temmuz, Eylül ve Kasım 2020'yi kapsayan yağışlı ve kurak mevsimlerde yetmiş iki su örneği toplandı. Her örnekleme ayında on iki örnek toplandı ve yirmi parametre açısından analiz edildi: çözünmüş oksijen, bulanıklık, toplam çözünmüş katılar, toplam askıda katılar, biyokimyasal oksijen ihtiyacı, pH, sıcaklık, elektriksel iletkenlik, fosfat, nitrat, bakır, kurşun, demir, manganez, klorür, tuzluluk, nikel ve kimyasal oksijen ihtiyacı. Kirlilik durumu, değiştirilmiş Su Kirliliği Endeksi ve Ulusal Sanitasyon Vakfı Su Kalitesi Endeksi (NSFWQI) yöntemi kullanılarak değerlendirildi. Sonuçlar, Mmubete Deresi'nin orta düzeyde kirli olduğunu, yağışlı ve kurak mevsimlerdeki su kirliliği indekslerinin sırasıyla 1,037 ve 1,329, kurak ve yağışlı mevsimlerdeki su kalitesi indekslerinin ise sırasıyla 55,87 ve 53,22 olduğunu ortaya koymuştur.

**Anahtar kelimeler:** Akarsu, atık deşarjı, su kirliliği, su kalitesi, atık su.

## 1. Introduction

The environment has been affected negatively since the creation of the world because of human activities. The negative impact or pollution issues were not a major issue in the early days when population, industrial activities, and technological advancement were minimal. This was so because the effects of human activities were naturally absorbed by the environment without serious negative impact [1]. Pollution of the natural environment became a threat during the era of the Industrial Revolution in Europe and America. Also, population explosion and industrial activities in Africa and other developing countries caused pollution to pose a serious threat to the natural environment [2][3]. In developing countries like Nigeria, there is a growing consciousness of the environmental impact of wastes and wastewater generated from industrial, commercial, agricultural, or domestic activities. In a quest to tackle the menace, several methods have been used to dispose of waste and wastewater

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generated from these activities. One of the means of disposing of the wastes or wastewater in Nigeria is by discharging them into surface water bodies such as streams, lakes, rivers, seas, oceans, etc. Rivers and streams are consistently used as the principal route to dispose of wastewater, be it industrial commercial, agricultural, or domestic waste [4]. This may continue for a long time, mostly in developing nations. This is a result of a poor attitude towards environmental sustainability and protection.

Water pollution can be caused by a variety of factors, including the discharge of effluent or solid waste (from commercial and industrial activities), runoff (from agricultural land), untreated waste and sewage from residential areas, chemical contaminants, and other sources into surface waters [5-6]. Most of the freshwater resources that are now available come from surface water (rivers and streams). Unfortunately, rivers and streams are being polluted because of crude oil leakage, discharge of untreated sewage and industrial waste, and several other types of waste that deteriorate water quality [5]. There has been an excessive release of industrial, agricultural, and commercial pollutants into the aquatic environment, which has harmed aquatic lives and people who use the water [7-8].

The quantity of effluent and solid waste that is dumped into streams is so enormous that the reduction of pathogens by natural mechanisms is low to preserve the public's health. In addition, industrial waste changes the pH of the water and makes it easier for bacteria to grow in water bodies by providing an abundance of nutrients. This makes it more difficult for natural systems to rid the water of harmful pathogens [9][10]. The discharge of sewage waste into bodies of water raises the level of biological oxygen demands to a point where it may cause a depletion of dissolved oxygen in the water; consequently, fishes, animals that live at the bottom of the food chain, marine plants, and even humans may be negatively impacted [7-8, 11]. Most Nigeria's fresh water supplies, notably in the Niger Delta region, are polluted, which has resulted in a serious epidemic of diseases that are transmitted through water and those that are associated with water. The chief contributors to stream pollution in the Niger Delta include oil exploration and extraction, industry, economic operations, agricultural activities, and urbanization. According to research, most of the sources of fresh water in Nigeria are polluted, which has led to a rise in waterborne diseases and water-related diseases.

## 2. Methodology

The Mmubete stream is in Aleto, Eleme Local Government Area of Rivers State, Nigeria. The stream is found on the Atlantic coast in the Southern part of Nigeria. It ends at the Imo River entrance. The stream crosses the East-West Road and is adjacent to the Petrochemical Company within the study location. The stream is freshwater and is located at the coordinates between Latitude 5° 50' 06" N and Longitude 7° 6' 11" E. The stream was selected as the focus of this research due to its significant role as a primary water source for surrounding communities and its vulnerability to anthropogenic activities such as domestic, agricultural, and industrial discharges. The stream is a critical component of the local ecosystem and serves as a key resource for drinking water, irrigation, and fishing, making its water quality a pressing concern for the sustainability and health of the dependent population. Despite its importance, limited studies have comprehensively assessed its pollution load capacity, leaving a gap in data needed for effective water resource management and environmental protection strategies. The map of Eleme LGA showing the stream is presented in Figure 1.

The timing of the sampling was strategically planned to account for seasonal variations in water quality, particularly in a region like Nigeria where the hydrological cycle is heavily influenced by distinct wet and dry seasons. Sampling during both seasons ensures a robust dataset, capturing the fluctuations in pollutant levels caused by rainfall patterns, runoff, and streamflow changes. The wet season typically introduces higher pollution loads due to surface runoff, while the dry season reflects baseline water quality conditions with minimal external inputs. This temporal approach provides a more accurate understanding of the stream's pollution dynamics. The frequency of sampling was chosen to balance logistical feasibility and the need for a detailed temporal resolution of water quality data. Regular sampling over a specified period allows for the detection of short-term variations and trends in water quality, enabling a comprehensive assessment of the stream's pollution load capacity. This systematic approach ensures that the data accurately reflect both natural variations and human-induced impacts, thereby supporting the development of targeted management interventions to mitigate water pollution and protect the stream's ecological integrity.

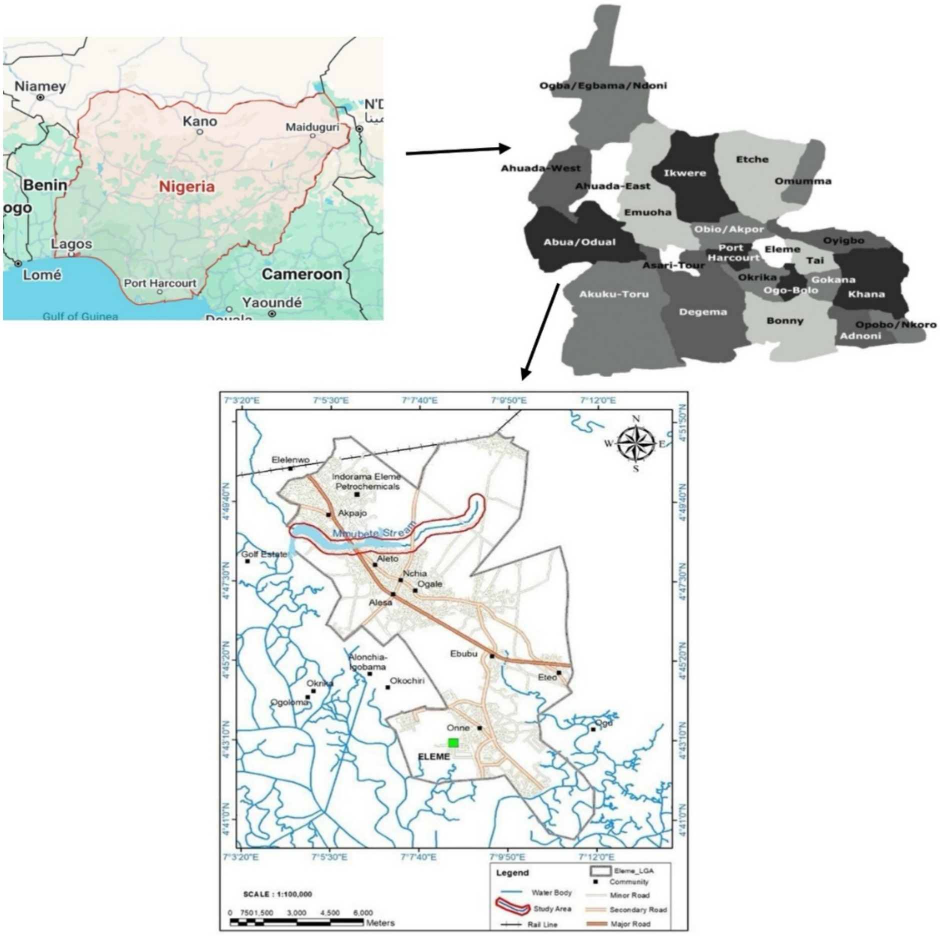


**Figure 1.** Map of Eleme LGA showing the study stream.

Twelve (12) sampling stations were established for data collection along the stream and pollution sources, including effluent, upstream samples, point of entry samples, and samples collected downstream up to a distance (stretch) of 1000m (1 km). The sampling points were purposively and strategically located to capture potential pollution sources from a petrochemical company, dredging sites and sand mining sites along the stream. The choice of 100m intervals between sampling points was for even distribution of sampling points along the section of the study stream which was 1000m. To achieve the above and accuracy of collection points, wooden pegs painted red were used as location markers and pinned at the locations presented in Figure 2.

The decision to sample every 100 meters along the Mmubete stream is informed by the need to capture spatial variability in water quality and pollution load. Dense sampling ensures that localised pollution hotspots or abrupt changes in water quality caused by point sources such as sewage outlets, industrial discharges, or agricultural runoffs are identified. While some information gathered through dense sampling may appear repetitive, this approach is crucial for a detailed spatial analysis, especially in a stream where pollution sources vary significantly over short distances. The repetition of observations at 100-meter intervals is necessary to ensure that subtle spatial variations in pollutant concentrations are not overlooked. Streams can exhibit significant heterogeneity in water quality due to natural factors like changes in flow dynamics, sediment deposition, and mixing patterns, as well as human activities that vary in intensity and location. Seasonal monitoring is often the most feasible and cost-effective approach for studies focused on capturing the influence of seasonal changes on water quality and pollution dynamics. For the stream, this means sampling during the peak of the wet season, the dry season, and transitional periods between them. This ensures that the dataset reflects the full range of hydrological and pollutant-loading conditions.

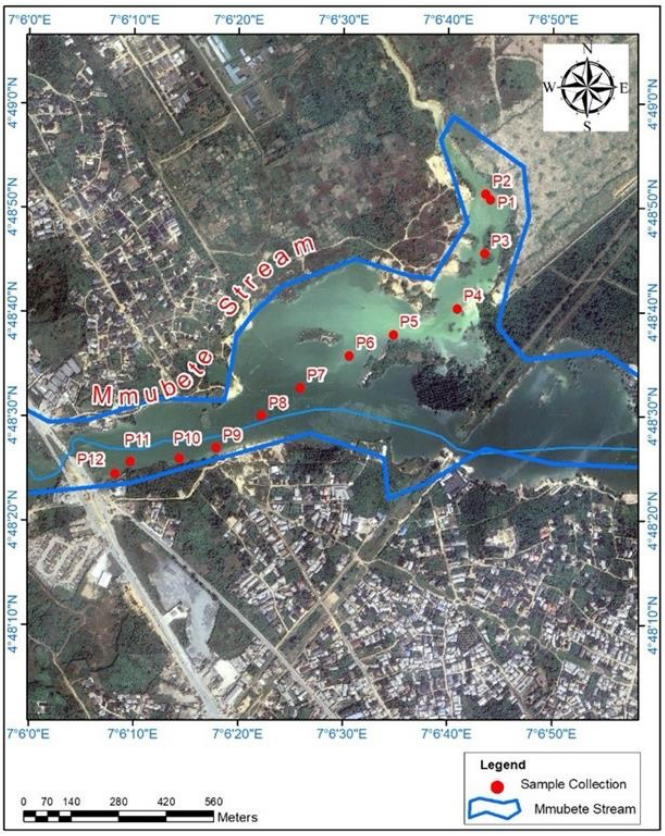


**Figure 2.** Sampled stations of Mmbute stream.

A denser network of sampling points provides a high-resolution dataset, which is critical for accurately mapping pollution gradients, validating predictive models, and designing targeted intervention strategies. A hand-held eTrex GPS unit was used to obtain the sampling point's coordinates with the sampling stations established every 100 meters. The coordinates are shown in Table 1. The samples were collected at every 100m to capture all other pollution sources (dredging points and sandmining points) along the section of the stream apart from the major pollution source (Petrochemical company).

**Table 1**. Co-ordinates of sampling stations.

| S/N | Easting | Northing | Point |
|---|---|---|---|
| 1 | 290646 | 532405 | P1 |
| 2 | 290632 | 532422 | P2 |
| 3 | 290628 | 532246 | P3 |
| 4 | 290547 | 532084 | P4 |
| 5 | 290359 | 532007 | P5 |
| 6 | 290229 | 531945 | P6 |
| 7 | 290085 | 531850 | P7 |
| 8 | 289971 | 531769 | P8 |
| 9 | 289837 | 531674 | P9 |
| 10 | 289728 | 531643 | P10 |
| 11 | 289584 | 531634 | P11 |
| 12 | 289539 | 531599 | P12 |

The study on the Mmubete stream considers the influence of land use changes and seasonal agricultural practices, recognising their critical roles in determining water quality dynamics. Over time, land use within the stream's catchment area has undergone significant transformations, including urban expansion, deforestation, and agricultural intensification. These changes have disrupted natural hydrological processes, increased surface runoff and introducing a variety of pollutants into the stream. Urban development, for instance, contributes contaminants such as heavy metals, hydrocarbons, and untreated domestic wastewater, while deforestation diminishes the natural filtration capacity of the watershed, leading to heightened turbidity and sedimentation. Seasonal agricultural practices within the watershed further exacerbate the water quality challenges faced by the Mmubete stream. During the wet season, heavy rainfall facilitates the transport of fertilisers, pesticides, and herbicides from agricultural fields into the stream, resulting in nutrient enrichment through elevated levels of nitrates and phosphates. This nutrient influx increases the potential for eutrophication and algal blooms. Additionally, the wet season's increased surface runoff and soil disturbance during planting or harvesting activities contribute to higher sediment loads in the water. In contrast, the dry season is characterised by reduced stream flow, which concentrates pollutants and amplifies their impact on water quality. The seasonal nature of these agricultural activities underscores the importance of monitoring water quality across different times of the year to understand the full extent of their effects. Through the analysis of the water quality data that was collected during both wet and dry seasons, the study identifies correlations between key parameters, such as nitrates, phosphates, and turbidity, and human activities within the watershed. Ultimately, the study aims to inform the development of targeted interventions to mitigate the impact of human activities on the stream's ecological balance and ensure the long-term sustainability of its water resources.

## 2.1 Measurement of water quality parameters

The water quality parameters were determined both in situ and in the laboratory. Temperature, total dissolved solids (TDS), dissolved oxygen (DO), pH, Electrical conductivity, and turbidity were measured in situ using various instruments for their determination. Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS), Total Petroleum Hydrocarbon (TPH), Nitrate, Nickel, Iron, Manganese, lead, and Phosphate were determined in the laboratory. The analyses were carried out using the following equipment and analytical methods as presented in Table 2.

**Table 2.** Water quality parameters and analytical methods.

| **Parameter** | **Analytical method** |
|---|---|
| pH | Electrochemical method |
| Temperature | Thermometric method |
| Conductivity | Conductivity method |
| Turbidity | Nephelometric method |
| Total suspended solids | Gravimetric method (APHA 2540 D) |
| Chloride | Argentometric method (APHA4500-$Cl^-$ B) |
| Total dissolved solids | Conductivity method |
| Biochemical oxygen demand | Titrimetric method |
| Dissolved oxygen | Titrimetric method |
| Chemical oxygen demand | Closed Reflux Titrimetric method (APHA 5220 C) |
| Total petroleum hydrocarbon | Nonhalogenated organics method (USEPA 8015 C) |
| Salinity (Mg/l) | Conductivity method |
| Nitrate | Spectrophotometric method |
| Phosphate | Colorimetric method |
| Iron | Direct Air-Acetylene flame method (APHA 3111B) |
| Manganese | |
| Copper | |
| Lead | |
| Nickel | |
| Fecal coliform | Membrane filtration |

## 2.2 Sampling months

On account for seasonal variation, samples were collected and analysed for both the dry and rainy seasons. Sample collection was carried out every two months for a year. The sampling months and seasons are presented in Table 3.

**Table** Error! No text of specified style in document.**.** Sampling months for water samples collection.

| S/N | Sampling Month | Sampling Season | Number of Samples | Time of collection |
|---|---|---|---|---|
| 1 | January, 2023 | Dry | 12 | 12:00 – 2:00pm |
| 2 | March, 2023 | Dry | 12 | 12:00 – 2:00pm |
| 3 | May, 2023 | Wet | 12 | 12:00 – 2:00pm |
| 4 | July, 2023 | Wet | 12 | 12:00 – 2:00pm |
| 5 | September, 2023 | Wet | 12 | 12:00 – 2:00pm |
| 6 | November, 2023 | Dry | 12 | 12:00 – 2:00pm |

### 2.3 Determination of water quality and pollution index

Water quality is determined by assessing three classes of attributes: biological, chemical, and physical [12]. The water quality index for the study was determined using the National Sanitation Foundation Water Quality Index (NSFWQI). The NSFWQI technique makes provision for the following parameters to be used for water quality index computation: dissolved oxygen, fecal coliform, pH, BOD5, Temperature, phosphate, nitrate, turbidity, and total solid [13]. The NSFWQI is a 100-point scale index representing the results of nine parameters: BOD, DO, NO3, PO4, Temperature, Turbidity, TS, pH, and FC. NSFWQI presents water quality in general but does not account for water use capacities. Index parameters have exclusive importance, so a weighted average is crucial for calculating the index. The weight scores were obtained using expert judgement and Delphi method [14-16]. In assessing the water quality and pollution load capacity of the Mmubete stream, weightings are applied to different water quality parameters to reflect their relative significance. This ensures that more critical pollutants contribute more substantially to the overall assessment compared to those with lesser impacts. The process begins with the selection of relevant water quality parameters. These typically include physicochemical properties such as pH, temperature, dissolved oxygen (DO), turbidity, and total dissolved solids (TDS). Additionally, nutrient levels, including nitrate, phosphate, and ammonia, are considered, along with the presence of heavy metals such as lead, cadmium, mercury, and iron. Microbial indicators, such as fecal coliforms are also assessed, as they are crucial in determining the safety of the water for human and ecological use.

Once the parameters have been identified, weightings are assigned based on their importance to overall water quality [14]. This is done using expert judgment, regulatory guidelines from bodies such as the World Health Organization (WHO) and the Nigerian Environmental Standards and Regulations Enforcement Agency (NESREA), and statistical methods such as the Delphi technique. Parameters that pose greater risks, such as dissolved oxygen and heavy metal concentrations, are given higher weightings, while those with less severe effects, such as pH, receive moderate weightings.

Since different parameters have varying units of measurement, they must be normalised to a common scale before calculating an overall water quality index. Normalisation is achieved by converting each parameter's value into a standardized quality index using a formula that considers the minimum and maximum permissible limits. This ensures that the values can be meaningfully compared and aggregated. The final water quality index (WQI) is calculated by multiplying the quality index of each parameter by its assigned weight and summing the results for all parameters [13]. The resulting WQI value categorises the river's water quality into different levels, such as excellent, good, poor, very poor, or unfit for use. This classification helps in understanding the overall health of the Mmubete stream and whether it meets acceptable environmental standards.

The Delphi approach employed in this study is a structured and iterative method that gathered expert opinions to reach a consensus on complex issues. This method is valuable in determining the appropriate weightings for different water quality parameters. Since various factors influence water quality, and their impact can differ based on local environmental conditions, expert judgment is necessary to ensure a scientifically sound assessment. The process begins with the selection of a panel of experts with significant knowledge and experience related to water quality and environmental management. However, before the actual Delphi survey, a pilot assessment of the questionnaire was done with university researchers in civil engineering department of University of Benin and Ken Saro Wiwa Polytechnic to ensure the face validity of the research instrument. For the actual survey exercise, the panel of 3 hydrologists, 3 environmental scientists, 3 water resource engineers, 3 pollution control specialists, and 3 government regulators from the Nigerian Environmental Standards and Regulations Enforcement Agency (NESREA) were used.

Once the panel is established, the first round of consultation takes place. Each expert is provided with a structured questionnaire that asks them to assign weightings to various water quality parameters based on their perceived significance to the overall health of the Mmubete stream. These parameters include dissolved oxygen levels, heavy metal concentrations, microbial contaminants, nutrient levels, and physicochemical properties like pH and turbidity. Experts are required to rank these parameters based on how critically they affect the river's usability for drinking, agriculture, and aquatic life. To prevent any biases and ensure independent judgment, the responses are collected anonymously. The results from the first round are then statistically analysed to determine areas of agreement and disagreement among the experts. A summary of the findings often including the average weightings assigned, the range of values, and areas of divergence is then shared with the panel in a way that keeps individual responses confidential. In cases where there are significant variations in expert opinions, a second round is conducted. Experts are asked to review the summarised responses and consider revising their initial judgments considering the feedback from other experts. They were required to justify their positions or reconsider their weightings based on new insights provided by their peers. This iterative process continued to a third round, until a consensus is reached, meaning that the experts generally agree on the most appropriate weightings for each parameter. At the end of the Delphi process, a final set of agreed-upon weightings is established, which is then used in the computation of the Water Quality Index (WQI) for the Mmubete stream. These weightings help in objectively assessing the pollution level of the river and determining whether it meets regulatory standards. The outcome provides reliable guidance for policymakers, environmental managers, and local authorities in designing appropriate pollution mitigation strategies and ensuring sustainable management of the stream water resources.

The weighted average is presented in Table 4. The water quality index was obtained following the Equation (1) by [17].

$$WQI = \sum_{i=1}^{n} Q_i W_i \tag{1}$$

where, $Q_i$ = sub-index for ith water quality parameter; $W_i$ = weight associated with ith water quality parameter; n = number of water quality parameters.

**Table 4.** Weight scores of the nine NSF-WQI parameters.

| Parameters | Weighted mean |
|---|---|
| DO, mg/L | 0.15 |
| CFU/100mL | 0.15 |
| pH | 0.12 |
| BOD, mg/L | 0.10 |
| Temperature, °C | 0.08 |
| $NO_3$, mg/L | 0.12 |
| $PO_4$, mg/L | 0.08 |
| Turbidity, NTU | 0.10 |
| TS, mg/L | 0.11 |

The guide for the classification of the water quality index is presented in Table 5.

**Table 5.** Water quality class and classification of the type of water resource usage.

| The index limit | Water quality | Classification of water resources and their usage |
|---|---|---|
| 90-100 | Excellent | No Need for treatment both for drinking water and other uses. It is good for rearing fish and water-resistant species. |
| 70-90 | Good | Conventional treatment is required, if usage is for provision of drinking water. It is appropriate for rearing fish and recreative purposes like swimming. |
| 50-70 | Moderate | Advanced treatment is required if usage is for provision of drinking water. Appropriate for fish farming and water-resistant plants and animals, and appropriate for domestic animals, as drinking water. |
| 25-50 | Bad | Appropriate for irrigation purposes |
| 0-25 | Very bad | Not appropriate for any of the above-mentioned uses, and it can support a limited number of aquatic animals. |
| **Source:** Authors' compilation, (Adapted from [15]) | | |

The Water Pollution Index (WPI) is a numerical value that indicates the level of pollution in water. It is often calculated using the concentrations of various pollutants. The water pollution index was determined using the modified water pollution index [15]. The WPI is determined by calculating the sum of the ratios of the observed yearly average value (Ai) and the standard threshold values (T) for each parameter and then dividing that total by the number of parameters (n) that were used. This is shown in Equation (2).

$$\text{WPI} = \sum_{i=1}^{n} \frac{Ai}{T} \times \frac{1}{n} \quad (2)$$

The guide for the classification of the water pollution index is presented in Table 6.

**Table 6.** Water quality class and water pollution index.

| Water Pollution Index Range | Water Quality Class | Description |
|---|---|---|
| 0–1 | Excellent | The water is very clean with no pollution |
| 1-2.5 | Good | Slightly polluted but generally clean |
| 2.5–5 | Moderate | Moderately polluted |
| 5-7.5 | Poor | Heavily polluted |
| 7.5-10 | Very Poor | Extremely polluted |
| >10 | Unsuitable for Drinking/Severe | Not fit for human consumption |

## 3. Results and discussion

**Table 7**. Mmubete water quality parameters during the wet and season.

| No | Parameters | Season | | | | | WHO Limit | NDW QS |
|---|---|---|---|---|---|---|---|---|
| | | Wet | | | | | | |
| | | Min | Max | Mean | S.D | Var | | |
| 1 | Temperature | 23.80 | 29.30 | 27.48 | 0.84 | 0.70 | 30 | 30 |
| 2 | pH | 6.25 | 6.75 | 6.54 | 0.09 | 0.008 | 6.5-8.5 | 8.5 |
| 3 | TDS (Mg/l) | 41.70 | 49.70 | 46.43 | 1.43 | 2.04 | 500 | 500 |
| 4 | TSS(Mg/l) | 10.10 | 23.90 | 18.75 | 2.07 | 4.30 | 30 | 30 |
| 5 | Chlorides (Mg/l) | 5.00 | 78.00 | 39.27 | 17.05 | 290.70 | 250 | 250 |
| 6 | Salinity (Mg/l) | 20.00 | 29.20 | 23.97 | 1.61 | 2.60 | 100 | 100 |
| 7 | DO (Mg/l) | 3.00 | 5.96 | 4.96 | 0.41 | 0.17 | 5.0 | 5 |
| 8 | EC (μs/cm) | 90.00 | 100.00 | 94.20 | 2.26 | 5.11 | 1000 | |
| 9 | COD (Mg/l) | 20.10 | 58.70 | 37.13 | 5.25 | 27.55 | 40 | 40 |
| 10 | BOD (Mg/l) | 12.60 | 37.40 | 24.56 | 3.65 | 13.32 | 4 | 4 |
| 11 | Turbidity (NTU) | 15.10 | 19.10 | 17.03 | 0.51 | 0.26 | 5 | 5 |
| 12 | Nitrate (Mg/l) | 10.10 | 17.80 | 13.01 | 1.96 | 3.85 | 50 | 50 |
| 13 | Copper (Mg/l) | 0.00 | 0.35 | 0.10 | 0.02 | 0.0003 | 1 | 1 |
| 14 | Lead (Pb) (Mg/l) | 0.01 | 0.03 | 0.02 | 0.002 | 0 | 0.05 | 0.005 |
| 15 | Nickel (Mg/l) | 0.10 | 0.34 | 0.14 | 0.05 | 0.002 | 0. | 0.03 |
| 16 | Phosphate (Mg/l) | 0.09 | 0.45 | 0.23 | 0.05 | 0.003 | | 0.1 |
| 17 | Iron (Mg/l) | 1.45 | 11.04 | 0.38 | 0.16 | 0.03 | 0.3 | 0.03 |
| 18 | Manganese (Mg/l) | 0.01 | 1.08 | 0.05 | 0.08 | 0.007 | 0.4 | 0.1 |
| No | Parameters | WHO Limit | NDW QS | Season | | | | |
| | | | | Dry | | | | |
| | | | | Min | Max | Mean | S.D | Var |
| 1 | Temperature | 30 | 30 | 25.40 | 29.80 | 27.99 | 0.70 | 0.49 |
| 2 | pH | 6.5-8.5 | 8.5 | 6.23 | 6.74 | 6.50 | 0.10 | 0.01 |
| 3 | TDS (Mg/l) | 500 | 500 | 40.00 | 53.00 | 46.55 | 2.23 | 4.98 |
| 4 | TSS(Mg/l) | 30 | 30 | 6.01 | 162.10 | 34.59 | 13.35 | 178.39 |
| 5 | Chlorides (Mg/l) | 250 | 250 | 5.47 | 215.00 | 37.89 | 30.92 | 955.91 |
| 6 | Salinity (Mg/l) | 100 | 100 | 20.10 | 30.30 | 24.38 | 1.60 | 2.56 |
| 7 | DO (Mg/l) | 5.0 | 5 | 4.00 | 10.20 | 6.15 | 0.68 | 0.46 |
| 8 | EC (μs/cm) | 1000 | | 89.00 | 101.00 | 94.70 | 2.65 | 7.02 |
| 9 | COD (Mg/l) | 40 | 40 | 6.30 | 38.40 | 18.52 | 2.96 | 8.74 |
| 10 | BOD (Mg/l) | 4 | 4 | 2.91 | 23.00 | 11.60 | 1.34 | 1.81 |
| 11 | Turbidity (NTU) | 5 | 5 | 10.40 | 20.10 | 16.18 | 0.54 | 0.29 |
| 12 | Nitrate (Mg/l) | 50 | 50 | 10.20 | 18.90 | 13.92 | 1.80 | 3.25 |
| 13 | Copper (Mg/l) | 1 | 1 | 0.00 | 0.32 | 0.10 | 0.01 | 0.0001 |
| 14 | Lead (Pb) (Mg/l) | 0.05 | 0.005 | 0.01 | 3.24 | 0.42 | 0.26 | 0.07 |
| 15 | Nickel (Mg/l) | 0. | 0.03 | 0.01 | 0.41 | 0.14 | 0.06 | 0.003 |
| 16 | Phosphate (Mg/l) | | 0.1 | 0.05 | 269.00 | 7.81 | 25.83 | 666.95 |
| 17 | Iron (Mg/l) | 0.3 | 0.03 | 2.23 | 13.51 | 0.26 | 0.05 | 0.003 |
| 18 | Manganese (Mg/l) | 0.4 | 0.1 | 0.04 | 0.82 | 0.06 | 0.005 | 0.0 |

The table presents a comprehensive analysis of various water quality parameters measured in the Mmubete stream during both wet and dry seasons. As shown in Table 7, the data includes the minimum, maximum, mean values, standard deviation (S.D.), and variance (Var) for each parameter. These values are compared against the World Health Organization (WHO) limits and the Nigerian Drinking Water Quality Standards (NDWQS) to assess the water's suitability for consumption and other uses. The temperature during the wet season ranged from 23.80°C to 29.30°C, with a mean of 27.48°C. The standard deviation was 0.84, indicating relatively stable temperatures with minor fluctuations. The variance was 0.70. During the dry season, the temperature ranged from 25.40°C to 29.80°C, with a slightly higher mean of 27.99°C. The standard deviation and variance were lower at 0.70 and 0.49, respectively, suggesting even more stable temperatures. The temperature in both seasons remained below the WHO and NDWQS limits of 30°C, indicating that temperature is not a significant concern regarding water quality in this stream.

The pH ranged between 6.25 and 6.75, with a mean of 6.54, which is within the lower bound of the WHO guideline (6.5-8.5). The standard deviation was 0.09, with a variance of 0.008. The pH during the dry season was slightly more acidic, ranging from 6.23 to 6.74, with a mean of 6.50. The standard deviation was 0.10, and the variance was 0.01. The pH values indicate that the water is slightly acidic during both seasons, with the dry season showing a marginally lower pH, indicating increased acidity. However, the values are within acceptable limits, though require close monitoring. Total Dissolved Solids (TDS) ranged from 41.70 mg/L to 49.70 mg/L, with a mean of 46.43 mg/L during the wet seasons. The standard deviation was 1.43, with a variance of 2.04. TDS values in the dry season varied more, ranging from 40.00 mg/L to 53.00 mg/L, with a mean of 46.55 mg/L. The standard deviation was higher at 2.23, and the variance was 4.98. Both seasons recorded TDS levels far below the WHO and NDWQS limit of 500 mg/L, indicating good water quality concerning dissolved solids. However, the dry season shows a slight increase in TDS, suggesting potential evaporative concentration effects.

Total Suspended Solids (TSS) levels ranged from 10.10 mg/L to 23.90 mg/L, with a mean of 18.75 mg/L during the wet season with a standard deviation of 2.07, and a variance of 4.30. However, TSS levels during the dry season showed a dramatic increase, ranging from 6.01 mg/L to 162.10 mg/L, with a mean of 34.59 mg/L. The standard deviation and variance were much higher at 13.35 and 178.39, respectively. The significant increase in TSS during the dry season could be due to reduced water flow, which allows for the accumulation of suspended particles. Despite this, the mean TSS value during the wet season remains within acceptable limits, while the dry season shows potential concerns.

In the wet season, the Chloride levels ranged from 5.00 mg/L to 78.00 mg/L, with a mean of 39.27 mg/L. The standard deviation was 17.05, with a variance of 290.70. However, the Chloride levels varied more in the dry season, with a range of 5.47 mg/L to 215.00 mg/L and a mean of 37.89 mg/L. The standard deviation was 30.92, and the variance was 955.91. Both seasons recorded chloride levels below the WHO and NDWQS limit of 250 mg/L. However, the wide range and higher variance during the dry season suggest sporadic but significant chloride inputs, possibly from anthropogenic sources or natural mineral dissolution. As for the water Salinity, this ranged from 20.00 mg/L to 29.20 mg/L, with a mean of 23.97 mg/L in the wet season. The standard deviation was 1.61, with a variance of 2.60. During the dry season, salinity ranged from 20.10 mg/L to 30.30 mg/L, with a mean of 24.38 mg/L. The standard deviation was 1.60, and the variance was 2.56. Salinity levels remained consistent across both seasons and well within the acceptable limit of 100 mg/L, indicating that salinity is not a significant issue for the Mmubete stream.

The Dissolved Oxygen (DO) levels in the wet season ranged from 3.00 mg/L to 5.96 mg/L, with a mean of 4.96 mg/L. The standard deviation was 0.41, with a variance of 0.17. In the dry season, DO levels increased, ranging from 4.00 mg/L to 10.20 mg/L, with a mean of 6.15 mg/L. The standard deviation was 0.68, and the variance was 0.46. DO levels are generally within acceptable limits, with the dry season showing higher oxygen levels, likely due to lower temperatures and reduced biological oxygen demand. The wet season's DO is slightly lower but still within acceptable limits for most aquatic life. The values of Electrical Conductivity (EC) in the wet season ranged from 90.00 µs/cm to 100.00 µs/cm, with a mean of 94.20 µs/cm. The standard deviation was 2.26, with a variance of 5.11. EC levels in the dry season ranged from 89.00 µs/cm to 101.00 µs/cm, with a mean of 94.70 µs/cm. The standard deviation was 2.65, and the variance was 7.02. Both seasons show EC levels well below the WHO guideline of 1000 µs/cm, indicating that the water has low mineral content and is unlikely to pose significant risks related to electrical conductivity.

The Chemical Oxygen Demand (COD) values during the wet season range from 20.10 mg/L to 58.70 mg/L, with a mean of 37.13 mg/L. The standard deviation was 5.25, with a variance of 27.55. During the dry season, COD levels dropped significantly, ranging from 6.30 mg/L to 38.40 mg/L, with a mean of 18.52 mg/L. The standard deviation was 2.96, and the variance was 8.74. COD values indicate organic pollution levels, with the wet season showing higher COD values, possibly due to increased organic matter from runoff. The dry season's lower COD suggests reduced organic loading, likely due to less runoff. The Biological Oxygen Demand (BOD) in the wet season ranges from 12.60 mg/L to 37.40 mg/L, with a mean of 24.56 mg/L. The standard deviation was 3.65, with a variance of 13.32. During the dry season, the BOD values were lower, ranging from 2.91 mg/L to 23.00 mg/L, with a mean of 11.60 mg/L. The standard deviation was 1.34, and the variance was 1.81. BOD levels were significantly higher during the wet season, indicating higher levels of biodegradable organic matter, which could lead to oxygen depletion. In contrast, the dry season recorded lower BOD values, reflecting reduced organic pollution.

The Turbidity values of the stream during the wet season ranged from 15.10 NTU to 19.10 NTU, with a mean of 17.03 NTU. The standard deviation was 0.51, with a variance of 0.26. Turbidity during the dry season ranged from 10.40 NTU to 20.10 NTU, with a mean of 16.18 NTU. The standard deviation was 0.54, and the variance was 0.29. Both seasons recorded turbidity levels above the WHO limit of 5 NTU, indicating that the water is quite murky, which could affect its suitability for drinking without adequate treatment. The slight reduction in turbidity during the dry season might be due to lower runoff, but it remains a concern. As for the Nitrate levels in the wet season, this ranges from 10.10 mg/L to 17.80 mg/L, with a mean of 13.01 mg/L. The standard deviation was 1.96, with a variance of 3.85. Nitrate values during the dry season ranged from 10.20 mg/L to 18.90 mg/L, with a mean of 13.92 mg/L. The standard deviation was 1.80, and the variance was 3.25. Nitrate levels in both seasons were well within the WHO and NDWQS limits of 50 mg/L, indicating that the stream is unlikely to suffer from eutrophication due to nitrate pollution.

The Copper levels in the Mmumbete Stream during the wet season ranged from 0.00 mg/L to 0.35 mg/L, with a mean of 0.10 mg/L. The standard deviation was 0.02, with a variance of 0.0003. During the dry season, copper levels were similar, ranging from 0.00 mg/L to 0.32 mg/L, with a mean of 0.10 mg/L. The standard deviation was 0.01, and the variance was 0.0001. Copper concentrations remained below the WHO and NDWQS limits of 1 mg/L in both seasons, indicating no significant contamination from copper. The Lead levels ranged from 0.01 mg/L to 0.03 mg/L, with a mean of 0.02 mg/L, the standard deviation was 0.002, with a variance of 0 during the wet season. However, the Lead levels increased significantly in the dry season, ranging from 0.01 mg/L to 3.24 mg/L, with a mean of 0.42 mg/L. The standard deviation was 0.26, and the variance was 0.07. Lead levels during the wet season were within safe limits, but the dry season showed a concerning spike, exceeding the WHO limit of 0.05 mg/L. This suggests potential contamination sources that may need to be investigated and mitigated.

In the wet season, Nickel levels ranged from 0.10 mg/L to 0.34 mg/L, with a mean of 0.14 mg/L. The standard deviation was 0.05, with a variance of 0.002. However, during the dry season, it ranged from 0.01 mg/L to 0.41 mg/L, with a mean of 0.14 mg/L. The standard deviation was 0.06, and the variance was 0.003. Nickel levels were generally low and within acceptable limits during both seasons, with no significant variations between wet and dry periods. The Phosphate levels in the wet season ranged from 0.09 mg/L to 0.45 mg/L, with a mean of 0.23 mg/L. The standard deviation was 0.05, with a variance of 0.003. During the dry season, phosphate levels showed a wide range from 0.05 mg/L to 269.00 mg/L, with a mean of 7.81 mg/L. The standard deviation was 25.83, and the variance was 666.95. The dramatic increase in phosphate levels during the dry season is concerning, as it could lead to eutrophication, especially since the maximum value far exceeds typically acceptable limits.

The Iron levels of the stream in the wet season ranged from 1.45 mg/L to 11.04 mg/L, with a mean of 0.38 mg/L. The standard deviation was 0.16, with a variance of 0.03. But during the dry season ranged from 2.23 mg/L to 13.51 mg/L, with a mean of 0.26 mg/L. The standard deviation was 0.05, and the variance was 0.003. Iron levels exceeded the WHO and NDWQS limit of 0.3 mg/L during both seasons, with higher variability and maximum values observed in the dry season, indicating a potential issue with iron contamination in the stream. Manganese levels in the wet season ranged from 0.01 mg/L to 1.08 mg/L, with a mean of 0.05 mg/L. The standard deviation was 0.08, with a variance of 0.007. Manganese levels during the dry season ranged from 0.04 mg/L to 0.82 mg/L, with a mean of 0.06 mg/L. The standard deviation was 0.005, and the variance was 0. Manganese levels remained below the WHO and NDWQS limits of 0.4 mg/L in both seasons, with minimal variations observed.

### 3.1 Water Quality and Pollution Index

**Table 8.** Water quality index of Mmubete stream during the wet and dry season.

| S/N | Season | Water Index Value | | Remark |
|---|---|---|---|---|
| | | Quality | Pollution | |
| 1 | Wet | 53.22 | 1.037 | Moderate pollution |
| 2 | Dry | 55.87 | 1.329 | Moderate pollution |

The water quality index (WQI) values of the Mmubete Stream for both wet and dry seasons is presented in Table 8. The WQI is a critical indicator that helps in assessing the overall quality of water, integrating multiple parameters to give a singular value that reflects the water's suitability for various uses, such as drinking, agriculture, and recreation. The index values are accompanied by pollution index values, which further categorise the pollution levels in the stream. The data indicates that the stream experiences moderate pollution throughout the year, with minor seasonal variations. The water quality is slightly better during the wet season but worsens slightly during the dry season. This could be due to the balance between increased runoff during the wet season and the reduced dilution capacity of the stream during the dry season.

The WQI during the wet season is recorded as 53.22. This value falls within the range that generally signifies water of fair quality, bordering on good. According to most water quality standards, this index suggests that the water is moderately polluted but still usable for many purposes with basic treatment. The implication here is that the wet season introduces a variety of pollutants into the stream, likely due to runoff, which may carry agricultural chemicals, waste, and other contaminants into the water. During the dry season, the WQI slightly increases to 55.87. This marginal rise suggests a small improvement in water quality, but the stream remains within the category of moderate pollution. The improvement in WQI during the dry season may be attributed to a reduction in surface runoff, which is typically lower when there is less rain. However, despite the lower input of pollutants from runoff, the water quality does not drastically improve, possibly due to reduced flow and higher concentrations of pollutants that persist in the stream.

The practical consequences of the results of the water quality index are on human, environment and socio-economic activities. The environmental consequences include reduction of biodiversity in and around the stream [19], eutrophication risk [14] and alteration of ecosystem balance [12]. From the human health perspective, the stream is unsafe for drinking, hence requires treatment before using [19-20]. It posed recreational hazard and potential disease spread. The economic and social impacts of the WQI results include high cost of water treatment, reduced fisheries yield and declined tourism and recreation [21]

The pollution index during the wet season is 1.037. The value obtained indicates that while the water is not severely polluted, there is a notable presence of pollutants. The wet season typically sees an influx of pollutants from various sources due to higher rainfall and increased surface runoff. These sources can include agricultural runoff, untreated sewage, and other contaminants from urban and rural landscapes. The presence of such pollutants can adversely affect the water quality, resulting in moderate pollution levels as recorded. In the dry season, the pollution index rises to 1.329, indicating a slight increase in the level of pollution compared to the wet season. This increase might seem counterintuitive at first, considering the absence of heavy rainfall that could carry pollutants into the stream. However, during dry periods, the reduced water flow can lead to higher concentrations of existing pollutants, as there is less water to dilute contaminants.

Furthermore, human activities around the stream may continue to introduce pollutants, such as through the disposal of waste, leading to a consistent pollution load. Both seasons are classified as having "moderate pollution", according to the remarks in the Table 5. This classification is critical as it highlights that while the water is not severely polluted, it is still not of optimal quality. The stream's water during both seasons may require some level of treatment before it can be deemed safe for human consumption or other sensitive uses. The consistent classification across seasons suggests that while there are seasonal variations in water quality and pollution, these changes are not significant enough to alter the overall assessment of the stream's health. From an environmental management perspective, these results suggest that efforts to improve the water quality of Mmubete stream should be sustained year-round. During the wet season, controlling runoff and its associated pollutants could be critical, while during the dry season, maintaining flow rates and addressing point-source pollution could help mitigate the concentration of pollutants. Regular monitoring and specific interventions during each season could help in improving the overall water quality, thereby making the stream more suitable for diverse uses. While the water quality in Mmubete stream does not fall into a critical category, the moderate pollution status across both seasons indicates a need for ongoing attention to ensure the water remains usable and does not degrade further, especially in the face of environmental changes and human activities.

## 4. Conclusion

The Mmubete stream receives the effluent from the abattoir, petrochemical company, and sand dredging and mining activities within the state. Hence, the pollution status of the stream was assessed. The results of the physicochemical analysis revealed that BOD and turbidity of the stream are higher in the rainy season than in the dry season. This is because of the runoff and crude oil from oil spill sites entering the stream during the wet season. The high BOD and turbidity negatively affect the DO and COD. The low DO values, high BOD, and COD values are indications of pollution of the stream. The DO values fluctuate due to multiple sources of pollution including several points of dredging alongthe studied stretch of the stream and discharge from an abattoir. Also, the results of the water pollution index show that for wet and dry seasons, the values are 1.037 and 1.329 respectively. These indices imply that the stream water is moderately polluted in both the wet and dry seasons. The overall water quality index of the Mmubete stream during the wet and dry seasons are 53.22 and 55.87 respectively. Both the water pollution index and water quality index indicate that the Mmubete stream is moderately polluted. Therefore, regular monitoring of the stream is necessary to mitigate the degradation of water quality.

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