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Design of Water Treatment Plant in Ipara-Remo Community, Remo North Local Government Area, Ogun State, Nigeria

EGOP, Samuel Ezekiel[1] & OSILE, Oluwapelumi David[2]

ABSTRACT

This study assessed the physicochemical characteristics of groundwater from Ipara-Remo Community, Remo North Local Government Area, Ogun State, Nigeria, determined its Water Quality Index (WQI), and developed a treatment-plant design based on the identified water-quality conditions using BioWIN Simulator software. Groundwater samples were subjected to physicochemical assessment involving temperature, pH, total dissolved solids (TDS), chloride, biochemical oxygen demand (BOD), dissolved oxygen (DO), electrical conductivity (EC), oxidation-reduction potential (ORP) and salinity. The measured parameters were evaluated against the adopted reference standards, while the weighted arithmetic Water Quality Index method was used to determine the overall quality status of the groundwater. The study further applied engineering design principles to develop the major components of a proposed water treatment system. The results showed that the groundwater had a temperature of 28.4°C, pH of 4.63, TDS of 20 mg/L, Chloride concentration of 260 mg/L, BOD of 15 mg/L, DO of 3.1 mg/L, EC of 44 µS/cm, ORP of 276 mV, and salinity of 17 mg/L. Several parameters were within or close to the adopted reference conditions, but the low pH, elevated chloride, extremely high BOD and relatively low DO indicated important water-quality concerns. The calculated WQI was 219.28, placing the groundwater in Category E, classified as unsuitable water quality. The proposed treatment system comprised a biological reactor, ideal clarifier and disinfection unit. The bioreactor was designed for an influent flow of 290.4 m^3/day, with a volume of 2,000 m^3 and a detention time of 7 days. The clarifier had a proposed surface area of 500 m^2, while the disinfection tank was designed with a volume of approximately 9.044 m^3, using a chlorine dosage of 3 mg/L and a contact time of 45 minutes. The study concludes that the sampled

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groundwater is unsuitable for direct domestic consumption in its untreated condition and requires an appropriate treatment process before use. It is recommended that the proposed treatment system be subjected to detailed pilot testing and that regular physicochemical and microbiological monitoring be instituted to ensure sustained water quality and treatment efficiency.

KEYWORDS: *Water Treatment Plant, Physicochemecal Characteristics, Biological Characteristics, Water quality Index, BioWIN Simulator*

INTRODUCTION

Water is the most fundamental resource for life, public health, and socioeconomic development. Despite covering approximately 71% of the Earth's surface, only 2.5% of total water is fresh, and less than 1% is readily accessible for human use (WHO, 2022). As global population grows and industrial activities intensify the quality of available freshwater continues to deteriorate, making the development of robust water treatment infrastructure an engineering and public health imperative. In many sub-Saharan African communities, a substantial proportion of the population still relies on untreated or inadequately treated water from rivers, boreholes, and open wells. The World Health Organization (WHO, 2022) estimates that at least 2 billion people globally use contaminated drinking water sources, contributing to over 485,000 diarrheal deaths annually, in addition to the burden of waterborne diseases such as typhoid fever, cholera, hepatitis A, and dysentery.

A Water Treatment Plant is a centralized facility engineered to process raw water through a series of physical, chemical, and biological unit operations to produce potable water that conforms to established quality standards. The proper design of a WTP demands a multidisciplinary approach, incorporating hydrology, environmental engineering, public health, structural design, and process engineering (Crittenden *et al*., 2012). For rural communities in developing countries, the challenge is not merely the absence of water treatment infrastructure but the lack of appropriate, affordable, and maintainable solutions. Large-scale conventional treatment plants designed for urban centers are often unsuitable for rural setting due to high capital costs, energy demands, and technical complexity (Massoud *et al*., 2019; Yeo *et al*., 2025). Therefore, there is a pressing need for small-scale, low-cost, and robust water treatment systems tailored to the specific conditions of rural Nigerian communities such as Ipara-Remo in Remo North LGA, Ogun State.

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MATERIALS AND METHODS

Material

The following materials were used for the population survey of Ipara-Remo community:

- Structured household questionnaire (120 copies, representing approximately 10% of estimated 1,200 households)
- GPS-enabled smartphone for mapping the service area
- Secondary data: National Population Commission (NPC, 2006) census data for Remo North LGA and Ogun State RUWATSAN (2020) reports
- Microsoft Excel software for statistical calculations and data presentation
- Notebook, pens, and digital voice recorder for key informant interviews
- BioWIN Simulator

Methods

This section presents the methods adopted for data collection and the theoretical approach to the design.

Research Design

This study adopted a quantitative, design-based research approach. The research was conducted in two primary stages:

- The first stage is Population Survey and Water Demand Assessment which is to determine the population of Ipara-Remo and estimate the water demand for the design period.
- The second stage is Water Quality Characterization and Treatment Process Design which is to determine the characteristics of raw water through laboratory analysis and develop appropriate treatment units based on the identified water quality conditions and flow.

Water Quality Index

The Water Quality Index (WQI) was used to provide an overall assessment of the quality of the raw water based on the measured physicochemical parameters. The calculated WQI value was compared with the water quality classification. The classification criteria used to determine the status of the water quality are presented in Table 1.

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Table 1: Water Quality Index and Status of Water Quality

Category	Water Quality Index (%)	Water Quality Status
A	0-25	Excellent Water Quality
B	26-50	Good Water Quality
C	51-75	Poor Water Quality
D	76-100	Very Poor Water Quality
E	>100	Unsuitable Water Quality

(Source: Adewumi & Ibiwoye, 2023; Akinwumi et al., 2022; APHA, 2017; AWWA, 2011)

The classification provides a basis for interpreting the calculated WQI obtained from the laboratory results. According to the adopted classification, lower WQI values indicate better water quality, while values above 100 indicate unsuitable water quality. Influent design flow = 290.4 m^3/day; Effluent flow to disinfection = 289.4 m^3/day.

Treatment Process Selection

The treatment process was selected based on the characteristics of the raw water obtained from the laboratory analysis, the calculated water demand, and the need for a treatment system that is suitable for the conditions of Ipara-Remo. The selected treatment train consists of biological treatment in a bioreactor, clarification, and final disinfection. The proposed treatment sequence is:

Raw Water → Bioreactor → Ideal Clarifier → Disinfection Plant → Treated Water

The bioreactor provides biological treatment of the raw water, particularly in addressing the organic matter indicated by the elevated BOD value obtained from the laboratory analysis. The clarifier provides subsequent separation of suspended and settleable materials, while the disinfection tank provides final microbial control through chlorination. The selected treatment arrangement provides a sequential approach for improving the quality of the raw water before final use.

RESULTS AND DISCUSSION

Physiochemical Characteristics of Water Source

The physiochemical characteristics of the raw water sample collected from Ipara-Remo were determined through laboratory analysis. The parameters analyzed and their corresponding measured values are shown in Table 2.

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Table 2: Physiochemical Characteristics of Water Source

S/N	Parameter	Test Value	WHO Standard
1	Temperature (oC)	28.4	25
2	pH	4.63	6.5-8.5
3	TDS (mg/l)	20	500
4	Chloride (mg/l)	260	250
5	BOD (mg/l)	15	5.0
6	DO (mg/l)	3.1	6.5
7	EC (µS/cm)	44	400
8	ORP (mV)	276	650-790
9	Salinity (mg/l)	17	200
10	Specific Gravity	1.00	NA

The results show variations in the physiochemical characteristics of the raw water sample, with measured values obtained for temperature, pH, TDS, chloride, BOD, DO, EC. ORP, salinity and specific gravity. These results provide an overview of the existing quality of the water source and form the basis for the subsequent discussion and water treatment design.

Water Quality Index

The Water Quality Index (WQI) was determined to provide an overall assessment of the quality of the raw water sample collected from Ipara-Remo. The calculated WQI was obtained from the individual water quality parameters using the adopted method, and the results are presented in Table 3.

Table 3: Water Quality Index Calculation

S/N	Parameter	Vi	Si	Vi0	1/Si	Wi=K/Si	Qi	WiQi
1	Temperature (°C)	28.4	25	0	0.040	0.074922556	113.6	8.511
2	pH	4.63	8	7	0.125	0.234132988	237	55.490
3	TDS (mg/l)	20	500	0	0.002	0.003746128	4	0.015
4	Chloride (mg/l)	260	250	0	0.004	0.007492256	104	0.779

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5	BOD (mg/l)	15	5	0	0.200	0.374612780	300	112.384
6	DO (mg/l)	3.1	6.5	14.6	0.154	0.288163677	141.9753086	40.912
7	EC (μS/cm)	44	400	0	0.003	0.004682660	11	0.052
8	ORP (mV)	276	650	790	0.002	0.002881637	367.1428571	1.058
9	Salinity (mg/l)	17	200	0	0.005	0.009365320	8.5	0.080
SUM =					**0.534**	**1.000000000**		**219.280**
			K=		**1.87306**		**WQI=**	**219.280**

The calculated Water Quality Index (WQI) for the raw water sample was 219.28. Based on the classification presented in Table 3.1, the obtained value falls within Category E, indicating unsuitable water quality. The result was obtained from the combined assessment of the physicochemical parameters analysed.

Bioreactor Design

The bioreactor was designed based on the flow rate and the adopted design criteria for the proposed water treatment system. The design parameters obtained include the dimensions, volume, detention, time, diffuser coverage, diffuser unit area, and number of diffusers required. The results of the bioreactor design are presented in Table 4.

Table 4: Bioreactor Design

Parameter	Value
Influent Flow (m^3/d)	290.4
Length (m)	111.11
Width (m)	4
Depth (m)	4.5
Volume (m^3)	2000
Detention time (d)	7

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Diffuser coverage (%)	10
Diffuser unit area (m2)	0.041
Number of diffusers	1084

The bioreactor design resulted in a total volume of 2,000 m^3, with a length of 111.11m, width of 4m, and depth of 4.5m. A detention time of 7 days was obtained, with a diffuser coverage of 10% and a total of 1,084 diffuser units required for the design.

Ideal Clarifier Design

The ideal clarifier was designed to provide adequate clarification of the water following the bioreactor treatment stage. The design was based on the influent flow and the required clarifier volume, depth, and surface area. The results obtained from the design calculations ae presented in Table 5.

Table 5: Ideal Clarifier Design

Parameter	Value
Influent Flow (m^3/d)	290.4
Volume (m^3)	2000
Depth (m)	4
Area (m^2)	500

The ideal clarifier design resulted in a volume of 2,000m^3, with a depth of 4m and a surface area of 500m^2, based on an influent flow of 290.4m^3/day.

Disinfection Tank Design

The disinfection tank was designed as the final treatment unit of the proposed water treatment system. The design considered the effluent flow, chlorine dosage, required contact time, tank volume, and dimensions. The results obtained from the design calculations are shown below.

Table 6: Disinfection Tank Design

Disinfection Tank Design	Value
Effluent Flow (m^3/d)	289.4

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Dosage of Chlorine (mg/l)	3
Contact time (min)	45
Volume of tank (m^3)	9.04375
Number of tanks	1
Width of tank (m)	2
Depth of tank (m)	2
Length of tank (m)	2.2609375

The disinfection tank design resulted in a volume of approximately 9.04m^3, based on an effluent flow of 289.4 m^3/day. A chlorine dosage of 3mg/L and a contact time of 45minutes were adopted, with one tank having a width of 2m, depth of 2m, and length of approximately 2.26m.

DISCUSSION

Physiochemical Characteristics of Water Source

The physicochemical characteristics of the raw water provide important information about the condition of the water source and the treatment requirements for the proposed water treatment plant at Ipara-Remo. Each parameter analysed has a particular influence on water quality and on the selection and effectiveness of the treatment processes.

Temperature: The recorded temperature of 28.4°C was slightly above the stated standard value of 25°C. Temperature affects the rate of biological and chemical reactions in water and can influence treatment efficiency. The measured temperature is therefore considered in understanding the conditions under which the proposed treatment processes will operate.

pH: The water sample recorded a pH of 4.63, which is below the recommended range of 6.5–8.5, indicating acidic water. pH is particularly important in water treatment because it influences chemical reactions and the effectiveness of treatment processes. The acidic condition of the raw water therefore needs to be considered in the treatment design to achieve a more suitable final water quality.

Total Dissolved Solids (TDS): The TDS value was 20mg/L, which is considerably below the stated limit of 500mg/L. TDS represents the concentration of dissolved substances in water.

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The relatively low value indicates that dissolved solids are not a major concern in the raw water and are therefore unlikely to constitute a significant treatment challenge.

Chloride: A chloride concentration of 260mg/L was recorded, slightly exceeding the stated limit of 250mg/L. Elevated chloride can affect the taste and acceptability of drinking water and may also contribute to corrosion under certain conditions. Its slightly elevated concentration indicates that chloride should be considered when assessing the overall quality of the water source.

Biochemical Oxygen Demand (BOD): The BOD value was 15mg/L, which is higher than the stated standard of 5mg/L. BOD indicates the amount of oxygen required by microorganisms to break down biodegradable organic matter in water. The relatively high value suggests the presence of organic matter and indicates a greater treatment requirement for reducing organic pollution before the water can be considered suitable for its intended use.

Dissolved Oxygen (DO): The measured DO was 3.1mg/L, below the stated value of 6.5mg/L. Dissolved oxygen is important for aquatic and biological processes and provides an indication of the oxygen condition of the water. The relatively low value, together with the elevated BOD, suggests that organic matter may be exerting an oxygen demand in the raw water.

Electrical Conductivity (EC): The EC value obtained was 44 µS/cm, which is below the stated limit of 400 µS/cm. Electrical conductivity indicates the ability of water to conduct electrical current and is related to the concentration of dissolved ions. The low value indicates that the water contains relatively low levels of ionized dissolved substances.

Oxidation-Reduction Potential (ORP): The measured ORP was 276mV, which was below the stated range of 650–790mV. ORP indicates the tendency of the water to undergo oxidation or reduction reactions. The result provides additional information about the chemical condition of the raw water and can be useful when considering treatment processes involving oxidation and disinfection.

Salinity: The salinity value of 17mg/L was well below the stated limit of 200mg/L. Salinity

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represents the concentration of dissolved salts in water. The low value indicates that excessive dissolved salts are not a significant concern for the proposed treatment system.

Specific Gravity: The specific gravity of the water sample was 1.00, which is approximately the expected value for water. This indicates that the density of the sample is close to that of pure water and does not present a significant concern for the proposed treatment process.

Overall, the physicochemical analysis shows that while several parameters, particularly TDS, EC, and salinity, were within the stated limits, the acidic pH, elevated chloride and BOD, and relatively low DO and ORP indicate that the raw water requires appropriate treatment. These characteristics are important in determining the treatment requirements and supporting the design of the proposed water treatment plant for Ipara-Remo.

Water Quality Index

The Water Quality Index (WQI) provides an overall assessment of the quality of the raw water by combining the individual water quality parameters into a single numerical value. The calculated WQI for the water sample from Ipara-Remo was 219.28.

The relatively high WQI value is mainly associated with the parameters that showed considerable deviation from their respective standards. In particular, the pH, BOD, DO, and ORP contributed significantly to the overall water quality rating. The high BOD value indicates the presence of biodegradable organic matter, while the low pH and DO indicate that the raw water requires further treatment before use. Based on the WQI classification adopted for this study, a value of 219.28 indicates unsuitable water quality. This confirms that the raw water cannot be relied upon for direct consumption and supports the need for a properly designed treatment system. The WQI therefore provides an overall justification for the treatment processes proposed for the Ipara-Remo water supply scheme.

Bioreactor Design

The bioreactor was designed with an influent flow of 290.4m³/day and a total volume of 2,000m³. The resulting dimensions were 111.11m in length, 4m in width, and 4.5m in depth, with a detention time of 7 days. The detention time is important because it provides sufficient time for the intended biological treatment processes to occur within the reactor. The provision

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of 1,084 diffuser units, with a diffuser coverage of 10%, supports the required aeration within the bioreactor. Adequate aeration is important for maintaining the conditions required for biological treatment and for improving the breakdown of organic matter indicated by the relatively high BOD obtained from the raw water analysis. The bioreactor therefore provides an important treatment stage for addressing the organic pollution characteristics identified in the raw water sample. Its design parameters provide the required capacity to receive and treat the design flow before the water proceeds to the clarification stage.

Ideal Clarifier Design

The ideal clarifier was designed for an influent flow of 290.4m³/day, with a volume of 2,000m³, depth of 4m, and surface area of 500m². Clarification is an important stage in the treatment process because it allows suspended and settleable materials to be separated from the water after the preceding treatment process. The relatively large volume and surface area provided in the design allow adequate space for the settling process to occur. The clarifier therefore complements the bioreactor by providing a subsequent separation stage before the water enters the final disinfection unit. Its inclusion in the treatment system is particularly important in ensuring that remaining suspended materials do not interfere with the effectiveness of the disinfection process.

Disinfection Tank Design

The disinfection tank was designed to handle an effluent flow of 289.4m³/day, using a chlorine dosage of 3mg/L and a contact time of 45 minutes. The resulting tank volume was approximately 9.04m³, with dimensions of 2 m width, 2m depth, and approximately 2.26m length. Chlorination serves as the final treatment stage for reducing microorganisms that may remain in the water after the preceding treatment processes. The adopted contact time provides an adequate period for the chlorine to interact with the treated water before it leaves the disinfection unit. The provision of a dedicated disinfection tank is therefore important for improving the microbiological safety of the treated water. The design parameters obtained provide the required basis for the final treatment stage of the proposed water treatment plant.

Water Treatment Plant Flow Network

Figure 1 shows the flow diagram of the water treatment plant flow network.

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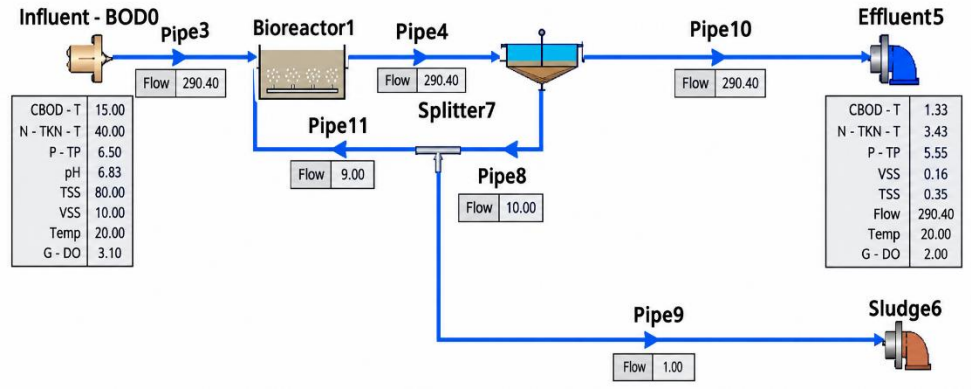


Figure 1: Plant Flow Process

The overall treatment process diagram provides a visual representation of the movement of water through the proposed treatment system and shows the relationship between the major treatment units and the associated flow streams. The influent enters the system at a flow rate of 290.40 m³/day and is directed to the bioreactor, where biological treatment takes place. The treated flow subsequently proceeds to the clarification stage, where suspended materials and biological solids are separated from the water. The diagram also indicates the separation of flow into the different streams following clarification, including the treated effluent and the solids/sludge stream. The final effluent is shown leaving the treatment process at approximately 289.40 m³/day, while the remaining flow is associated with the solids and internal process streams. This illustrates the importance of accounting for flow losses, solids separation, and sludge production when assessing the overall performance of a treatment system. The process flow diagram therefore provides an overall representation of the proposed treatment scheme and complements the individual design calculations presented for the bioreactor, clarifier, and disinfection stage. It demonstrates how the different treatment components are hydraulically connected to provide a continuous treatment process from influent water to final effluent.

CONCLUSION AND RECOMMENDATION

Conclusion

Based on the findings of this study, it can be concluded that the raw water source assessed in Ipara-Remo requires adequate treatment before it can be considered suitable for its intended use. The physicochemical analysis carried out on the water sample revealed variations in the measured parameters, with some of the parameters requiring particular consideration in the selection and design of the treatment processes. The results therefore demonstrate that the

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existing quality of the raw water cannot be relied upon without appropriate treatment and monitoring. Furthermore, the calculated **Water Quality Index (WQI) of 219.28** places the water within **Category E, classified as unsuitable water quality**, according to the adopted WQI classification.

The findings of the study consequently established the need for a properly designed and appropriately operated water treatment system for Ipara-Remo. Based on the characteristics of the raw water and the requirements of the study, a treatment process consisting of **biological treatment in a bioreactor, clarification in an ideal clarifier, and final disinfection** was proposed. Each treatment stage serves a specific purpose in improving the quality of the raw water, with the bioreactor providing biological treatment, the ideal clarifier facilitating the removal of suspended and settleable materials, and the disinfection stage providing final treatment through chlorination.

The design of the selected treatment units provides the basic engineering parameters required for the further development and implementation of the proposed water treatment plant. The study therefore provides a practical basis for addressing the identified water quality concerns within the study area. With proper construction, effective operation, regular maintenance, and continuous monitoring of both the raw and treated water, the proposed treatment system can contribute significantly to improving the availability, reliability, and quality of treated water for the Ipara-Remo community.

Recommendation

Based on the findings and conclusions of the study, the following recommendations are made:

- Regular water quality monitoring should be carried out to identify changes in the characteristics of the raw water and ensure that the treatment process remains effective.
- Seasonal water sampling should be conducted to account for variations in water quality between wet and dry seasons.
- The proposed bioreactor, ideal clarifier, and disinfection tank should be properly operated and maintained in accordance with their design requirements.
- Chlorine dosage and contact time should be regularly monitored during operation to ensure effective disinfection without excessive chlorine application.

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- Periodic laboratory analysis of the treated water should be carried out to ensure that the final water quality complies with the applicable drinking-water standards.
- Further investigations should include microbiological and heavy-metal analyses, particularly where activities within or around the water catchment may introduce additional contaminants.
- Adequate training should be provided for personnel responsible for the operation and maintenance of the treatment plant to ensure efficient and sustainable operation.
- The treatment facilities should be subjected to routine inspection and preventive maintenance to reduce operational failures and extend the service life of the plant.
- Further studies may be undertaken to develop a detailed economic assessment, structural design, and operational framework for the full implementation of the proposed treatment plant.

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***Author for Correspondence**
EGOP, Samuel Ezekiel
E-mail: samuel.egop@ust.edu.ng

[1]Lecturer II, Department of Civil Engineering, Rivers State University, Port Harcourt, Rivers State, Nigeria
[2]Research Scholar, Department of Civil Engineering, Rivers State University, Port Harcourt, Rivers State, Nigeria

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