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Research Article

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Assessment of Physicochemical and Bacteriological Parameters of Borehole Water: A Case Study from Lekki, Lagos, Nigeria

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Abstract

Access to clean and wholesome water is one of the fundamental human rights, despite billions of people around the world still lacking access to this basic necessity. In this study, a comprehensive analysis of the physicochemical and bacteriological parameters of borehole eater was carried out, using Lekki in Lagos state as a case study area. The city is a fast growing where a significant proportion of the populace rely on borehole water supply. The study assessed the quality of the raw water samples and the effectiveness of the conventional treatment methods employed by most residents in the study area. The findings indicate that there are significant deviations in the various parameters of the raw water samples from the approved levels of the World Health Organization (WHO) and the Nigeria Standards for Drinking Water Quality (NSDWQ), showing the need for improved water treatment techniques. The use of Hypochlorite, Soda ash, Alum, and a three-stage filtration system was proposed and tested, yielding significant improvements in both the physicochemical and bacteriological parameters of the water samples when compared with the control standards. The research contributes to the growing body of knowledge targeted at improving water quality, especially in regions that depend heavily on borehole water supply. The findings emphasize the benefits of implementing comprehensive and efficient water treatment methos, including the need for continuous optimization and monitoring of these techniques. This is important for promoting public access to safe and wholesome potable water, thereby contributing to the achievement of Sustainable Development Goal 6 (Clean Water and Sanitation). Further research is recommended to explore the scalability and cost-effectiveness of the improved treatment method for wider application.

Keywords: Borehole Water, Physicochemical Parameters, Bacteriological Parameters, Water Treatment Methods, Sustainable Development Goals (Clean Water and Sanitation).

1. Introduction

Access to clean and wholesome water is a fundamental human right vital for the maintenance of public health and overall socioeconomic development. Despite this, the World Health Organization (WHO) reported that billions of people worldwide continue to lack access to clean and wholesome water. Most developing countries worldwide still face serious challenges in providing the population with reliable access to potable water [1,2]. In the coastal city of Lekki, often referred to as "Lekki Peninsula in Nigeria, a large percentage of the population depends solely on borehole water supplies, which presents serious quality concerns.

Borehole water, which is often obtained by drilling deeply into the ground to access natural underground aquifers is the common source of potable water in most regions that lacks access to municipal water supply system [3,4]. Although borehole water provides a viable solution to the challenges of water scarcity, the quality of water from this source can vary depending on several factors.Local geological conditions, geographical locations, potential sources of contamination, lifestyle of users, and type of treatment method can affect the quality of borehole water [5,6].

Generally, the quality of groundwater varies depending on geographical location; it could also depend on seasonal changes, soil types, rocks, and the surfaces by which water is transported. Naturally occurring contaminants have also been found in rocks and sediments.As groundwater flows through these sediments, metals such as manganese and iron are dissolved and may become highly concentrated in water.Moreover, human activities can alter the composition of groundwater from its natural state. This occurs through the dissemination or deposition of microbial or chemical matter into the soil or through the disposal of waste directly into natural groundwater.Industrial waste, urban activities, groundwater plumage, and agricultural activities can impair the quality of groundwater in industrial areas.These human activities accumulate and impair the physicochemical and microbial qualities of the groundwater [7,8,9].

Annually, more than 1.2 million deaths are recorded because of water-related diseases.These data continue to increase, and it is estimated that over 135 million people will die in the near future from water-related diseases if no positive actions are taken. Diseases that could be attributed to poor water quality include diarrhea, intestinal helminth, schistosomiasis, trachoma, and poliomyelitis.In 2000, the World Health Organization (WHO recorded over 2.2 million deaths attributed to diarrhea (a water-borne disease).The United Nations Development Program (UNDP) recorded over five million deaths in 2002.While many studies have proven useful in identifying risks of poor water sources and creating awareness useful for water treatment regulations, there is need to delve deeper into the study to create more awareness, and recommend in fact cheaper and more accessible solutions to the challenge of poor water quality, especially in deprived urban areas [10,11,12].

This study aims to comprehensively assess the physicochemical and bacteriological characteristics of borehole water using Lekki, a fast-growing city in Lagos, Nigeria as a case study location. The objective is to examine the potability of borehole water and the effectiveness of the conventional method of treatment employed by residents. Furthermore, an improved system can be used immediately to solve the challenges in the neighborhood, as well as areas with similar situations. A comprehensive examination of borehole water quality will be provided by examining water parameters, such as temperature, pH, hardness, total dissolved solids (TDS), and the presence of heavy metals [13,14]. In addition, the key bacteriological parameters will be analyzed, which include coliform count. This is to determine the level of faecal contamination, to assess the risk of waterborne disease contamination in the water [15,16,17].

The significance of this study goes beyond academic interest, the findings will be useful for policy makers, environmental scientists, public health officials, to enable them to make informed decisions for improving water treatment and improving public health in general. Additionally, through understanding of possible threat to water quality, this research will provide practical guide to local communities, especially with similar conditions to improve their water treatment strategies and ensure access to potable water.

In a broader perspective, this study contributes to the sustainable development goal (SDG) number 6. The SDG-6- Clean water and sanitation explains the importance of having affordable and safe drinking water by the year 2030 [18]. The findings in this study will improve the growing body of knowledge that contributes to strategies to achieving this goal, particularly areas that concern borehole water supply.

2. Methodology

Description of Study Location

The study was conducted in Lekki phase 1, a naturally formed peninsula located in Lagos, Nigeria. The area is bounded by Ikoyi and Victoria Islandto its west, the Lekki lagoon to its east, the Atlantic Ocean to its south, and the Lagos lagoon to its north. Lekki has geographical coordinates of6°26'08.9"N 3°27'19.9"E, covering an estimated area of 30km2 and has a population of over120,000 people. Lekki phase 1 is typical for various estates, business districts,agricultural farmlands, and gated residential developments. The Lagos state land use master plan proposes the location as future "Blue-Green Environment City" [19,20,21].

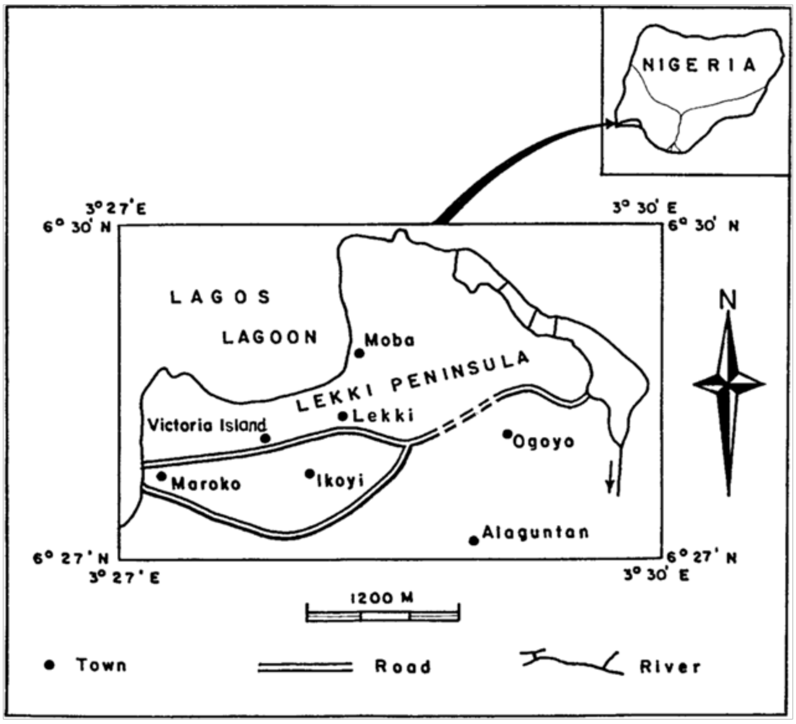

Figure 1: Map of the Study Area[22].

2.1 Sample Collection

The water samples used in this study were obtained from four distinct boreholes within the Lekki phase 1 residential areas. Each of the samples was collected in a pre-cleaned polyethylene bottle with capacity of 1.5 liters [23]. These samples were identified as A, B, C, D as presented in Table 1. Furthermore, in-situ measurements of pH and temperature of samples were performed to avoid potential contamination due to storage [24]. Raw borehole water samples (control samples) were collected before any treatment at all. After which, they were treated using the conventional water treatment methods adopted by most of the residents (chlorine, alum, and lime (this was ascertained from unpublished survey data used for this research purpose). The conventional treatment method common in the study area is further presented in figure10.Other samples were also collected after treatment with chlorine, alum, and lime (post-treatment), using the treatment process presented in figure10. The latter samples being labeled as A2, B2, C2, D2. Borehole depth and size were not considered for this study. In addition, a test was conducted on a specifically designed treatment plant (improved water treatment plant (IT)) based on the collected laboratory data.

2.2 Sample Preservation

Upon collecting the samples, certain physical parameters were analyzedon the site. The temperature of each sample was measured using a calibrated thermometer graded in degree Celsius, and the odor and taste were noted. The samples were then transported to the laboratory for further analysis. The samples were then stored in a refrigerator to maintain their quality before laboratory analysis. Standard analytical methods were used to evaluate various physicochemical parameters. Each measurement was taken in triplicate and the mean values were recorded.

2.3 Parameters Tested

This section describes the methodological approach taken to assess the physicochemicalproperties of the borehole water, this includes the determination of temperature, total dissolved solids (TDS) pH value, total solid, total hardness, suspended solids, sulphate, chloride, total phosphate, magnesium hardness, calcium, magnesium, calcium hardness, Iron, Chromium, Lead, Zinc, Cadmium, Nickel, and Copper.

A variety of testing tools were used in this assessment, this includes clinical thermometer, conductivity meter, glass electrode pH meter, multi-parameters test meter, and an atomic absorption spectroscopy (AAS) machine for the analysis of heavy metals.

2.4 Bacteriological Characteristics of Borehole Water

Further to the physical and chemical analysis of the water samples, the study also covered bacteriological parameters. The water samples were assessed for coliform count and colony count (pour-plate count) using multiple tube techniques.

The results obtained from the laboratory analyses were compared with WHO Standards for drinking water quality and NSDWQ [25,26,27]. They were also compared with the water standard of the local community's water treatment plant.

Collection of water samples was necessary to determine the physicochemical parameters including temperature, color, odor, appearance, turbidity, TDS, hardness, alkalinity, and others previously described. Bacteriological assessment of the water samples was also necessary to identify potential indicators of faecal pollutants, including streptococcus, Escherichia coli (E. coli), total heterotrophic bacteria, and clostridium perfringens. Finally, it was necessary to review secondary data from published and unpublished sources to corroborate the findings from the field study.

2.5 Data Analysis

The collected data were categorized under three headingsas presented in table 1 for comprehensive analysis:

• Raw Water/Control Samples (A, B, C, and D): These were raw water samples directly collected from each borehole. Their analysis was aimed to uncover the intrinsic physical, chemical, and biological quality of borehole water.

• Treated Water Samples (A2, B2, C2, and D2): These samples represented water post-treatment with Hydrated lime, Alum, and Chlorine – a conventional treatment method employed by most residents in the study area (more detail of the treatment process is further presented in figure10). The objective was to evaluate the effectiveness of these commonly used treatment methods.

• Improved Treated Sample (IT): This served as a standard or control for comparison, representing a water source treated with an optimal method for achieving potable water quality. The exact treatment used in this case comprised primarily HTH, Alum, and Soda Ash, including a designed system further described in figure 11.

These distinct categories allowed for a detailed understanding of the initial water quality, the impact of current treatment practices, and the potential for improved water treatment strategies, with the goal of ensuring safe and wholesome water for the humans.

	Raw Water Sample (Control)	Treated Water Sample (Lime, Chlorine, Alum)	Improved Treated Sample (HTH, Alum, Soda Ash)
1	Sample A	Sample A2	Improved Treated Sample (IT)
2	Sample B	Sample B2	
3	Sample C	Sample C2	
4	Sample D	Sample D2	

Table 1: Categorization of Water Samples

3. Results and Discussion

3.1.1Results of the Raw and Treated Samples

Samples were analyzed for physicochemical and bacteriological parameters. Samples were taken before treatment (Raw water) and after treatment with chlorine, alum, and lime (treated water). Results were obtained and further compared with sample from the test well results to ascertain if the recommendation is adequate. All results were compared with the Nigeria Standards for Drinking Water Quality and WHO standards [26,28].

The results of the assessment of the physical parameters of the raw and treated water samples are presented in Table 2. The physical parameter study yielded interesting findings about the quality of the raw water samples. The range of temperature values (28 – 29oC) were within the permissible ranges specified by both the NSDWQ and the WHO (22 – 30oC). In contrast to the specified standard of a clean and colorless appearance, the ocular assessment showed the presence of color and turbidity in all samples (A-D). Likewise, disagreeable taste and odor were observed in all samples, departing from the recommendations' specified unobjectionable features (Table 2). Turbidity levels in nephelometric turbidity units (NTU) exceeded the NSDWQ's maximum recommended limit. The conductivity levels were higher than the WHO limits, indicating that the water samples had a higher mineral content. Salinity data lacked defined guideline values but revealed excessive levels. Total dissolved solids (TDS) exceeded the maximum recommended amount as well, which is evidence that there is presence of diverse dissolved elements.

The result of the assessment of physical parameters in treated water samples (Table 3) indicated that the recommended standards were satisfied in general. Temperature values were within the permitted ranges specified by both the NSDWQ and the WHO, which is also similar to the raw samples. Visual inspection revealed that most of the samples were clear and colorless, except for Sample C2, which had minor coloring. Color measurements in Hazen units revealed values of 7.5, 9, and 8.5 for A2, B2, and C2, respectively, indicating low color presence. These readings were significantly below the recommendations' maximum limit of 15 Hazen units by the NSDWQ. While disagreeable taste and odor were observed for all samples, these findings could be said to meet the NSDWQ and WHO standards. Turbidity levels in the samples (0 – 3.5 NTU) were within permissible limits (5 NTU), indicating that suspended particles were effectively removed throughout the treatment process. Although conductivity levels were marginally different in some samples (A2 – C2), only D2 did not surpass the WHO's recommended range. There were no guideline values for salinity measurements, however all samples showed levels within safe limits.

The analysis of chemical properties in both raw (raw) and treated water samples as presented in Table 3, also provided valuable insights into the composition and effectiveness of water treatment processes. Several chemical parameters of the raw water samples differ among the samples. The pH values vary between 6.8 to 7.0, indicating conditions that were slightly acidic to neutral. The failure to detect residual chlorine indicates that the raw water samples were not disinfected. The iron contents ranged from 0.5 mg/l to 0.8 mg/l, with sample B having the lowest and Sample D, on the other hand, having the highest. The total alkalinity ranged from 12 mg/l (Sample A) to 97 mg/l (Sample B), while the total hardness ranged from 537 mg/l (Sample B) to 586 mg/l (Sample A). The amounts of chloride varied between 95 mg/l to 117 mg/l, while nitrate levels ranged from 0 mg/l to 1.4 mg/l. No residual aluminum was found within any of the raw water samples.

The chemical parameters of the water samples improved noticeably after treatment (Table 4). The pH levels varied between 6.9 to 7.6, suggesting an increase in alkalinity. Residual chlorine was not found in any of the treated water samples, suggesting either the disinfection was effective or because of initial absence, the treatment system does not cater for chlorine removal. Iron levels dropped drastically, with levels ranging from 0.049 mg/l to 0.27 mg/l. The total alkalinity ranged from 89 to 98 mg/l, while the total hardness ranged from 400 to 442 mg/l. The total chloride concentrations in the treated samples ranged from 102 mg/l to 142 mg/l. Nitrate levels in treated water samples remained low, ranging from 0 mg/l to 1.4 mg/l. Only Sample D2 contained residual aluminum at a value of 0.1 mg/l.

The result of the microbial analysis of the water samples are presented in Table 5.It was found that the aerobic mesophilic were too numerous to count in the raw samples. This exceeds both the WHO and NSDWQ standard which was set to be less than 100 cfu/ml. The total coliform result of all the samples were observed to be greater than the minimum of 0 set by the WHO and NSDWQ (range of 99 – 115 MPN/100ml). In the treated samples (Table 5), it was observed that there was a significant reduction in aerobic mesophilic of sample A (sample A2 = 10 cfu/ml) and lower than the WHO and NSDWQ standards (100 cfu/ml). However, the reduction in other samples (B2-D2) ranged from 124 – 142 cfu/ml which is above the standards of comparison. The total coliforms in all samples reduced effectively to 0 MPN/100 ml in all the treated samples, indicating the effectiveness of the treatment technique.

Organoleptic Parameters	Sample A	Sample B	Sample C	Sample D	Sample A2	Sample B2	Sample C2	Sample D2	NSDWQ	WHO
Visual Inspection	Brownish	Turbid and Brownish	Turbid and Brownish	Turbid and Brownish	Clear	Clear/Colorless	Slight coloration	Clear	Clear/Colorless	Clear
Color (Hazen)	Brownish	48	53	46	Colorless	7.5	9	8.5	0-15	Colorless
Taste	Objectionable	Objectionable	Objectionable	Objectionable	Objectionable	Objectionable	Objectionable	Objectionable	Unobjectionable	Unobjectionable
Odor	Objectionable	Objectionable	Objectionable	Objectionable	Odorless	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable	Odorless
NOTE: *WHO: World Health Organization, NSDWQ: Nigeria Standard for Drinking Water Quality.*										

Table 2: Organoleptic Parameters of Raw (A-D) and Treated Water Sample (A2-D2)

	Sample A	Sample B	Sample C	Sample D	Sample A2	Sample B2	Sample C2	Sample D2	IT Sample	NSDWQ	WHO
Temperature of water (◦C)	28	28	29	29	28	28	28	27	28	22-30	22-30
Temperature of Air (◦C)	27	27	27	27	27	27	28	28	27	25-30	25-30
Turbidity (NTU)	12.4	13.71	12.3	11.9	0	2.31	3.5	3.15	2.75	5	
Conductivity (µS/cm)	1390	1362	1387	1387	202	1226	1274	1315	434	1500	900-1200
Salinity (mg/L)	652	681	630	612	612	613	610	622	217	No guideline values	---
Total Dissolved Solids (mg/L)	746	885	899	884	96.4	797	797	753	282	1200 (Maximum)	500

Table 3: Physical Properties of Raw (A-D), Treated (A2-D2)and Improved Treated (IT) Water Samples.

Chemical Properties of Raw Water Samples	Chemical Properties of Treated and Improved Treated Water Samples										
	Sample A	Sample B	Sample C	Sample D	Sample A2	Sample B2	Sample C2	Sample D2	IT Samples	NSDWQ	WHO
pH	6.9	6.8	6.9	7	7.5	7.3	6.9	7.6	7.4	6.8-8.5	6.8-8.5
Residual Cl(mg/L)	0	0	0	0	0	0	0	0	0	0.2-0.5	0.2
Iron (mg/L)	0.8	0.5	0.7	0.8	0.049	0.25	0.27	0.24	0.2	0.3	0.1-1.0
Total Alkalinity (mg/L)	12	97	94	94	12	94	98	89	20	No guideline value	30-500
Total Hardness (CaCO3mg/L)	586	537	584	564	ND	421	442	426	58	400	30-200
Calcium Hardness (CaCO3mg/L)	ND	372	390	395	ND	302	310	307	39	200	75-200
Mg Hardness (CaCO3mg/L)	ND	165	173	171	ND	119	111	117	19	50	
Chloride (mg/L)	95	117	108	102	40	102	121	142	13.5	250	200-600
Nitrate (mg/L)	1.4	0	0	0	1.4	0	0	0	0	0.1	5 to 30
Residual Aluminum (mg/L)	ND	0	0	0	ND	0	0	0.1	0	0.2	
NOTE: *ND: Not Determined, WHO: World Health Organization, NSDWQ: Nigeria Standard for Drinking Water Quality.*											

Table 4: Chemical Properties of Raw (A-D),Treated (A2-D2) and Improved Treated(IT) Water Samples

	Sample A	Sample B	Sample C	Sample D	Sample A2	Sample B2	Sample C2	Sample D2	IT Sample	NSDWQ	WHO
Aerobic Mesophilic (cfu/ml)	TNTC	TNTC	TNTC	TNTC	10	128	124	142	28	<100	100
Total Coliforms (MPN/100ml)	99	102	115	115	0	0	0	0	0	0	0
NOTE: *WHO: World Health Organization, NSDWQ: Nigeria Standard for Drinking Water Quality.*											

Table 5: Microbial Properties of Raw, Treated and Improved Treated Water Samples

3.1.2 Results of the Improved Treatment System Design

This study also attempted to build a treatment system that can be a better option for treating the water for safe drinking. Water sample was collected from borehole and treated as recommended in the improved treatment method. The treatments employed are Hypochlorite, Soda ash, Alum, media filter tank, activated carbon filter tank and Iron resin filter tank. The filter tanks were separated and increased to three for a more efficient treatment process. Figure 10 showed the common treatment system existing in the study area and figure 11 showed an improved treatment system design. The water quality result was presented in Table 4 and Table 5.The physical parameters such as temperature, visual inspection, color, turbidity, conductivity, salinity, and total dissolved solids, were found to be lower than the standard set by the NSDWQ. Similar lower values and within permissible range were obtained for the chemical and microbial parameters measured.

More comprehensive representations of the data compared with the control standards are further presented in Figures 2 to 9. Figure 2 compares the temperature of all the samples with the improved treatment system. Figure 3 shows the comparison of the turbidity values of all the samples. Figure 4 shows the conductivity values of all the water samples. Figure 5 shows the comparison between the total dissolved solids of all the water samples. Figure 6 represents the pH values of all the water samples. Figure 7 shows the comparison total hardness of all the samples. Figure 8 compares the total alkalinity and Figure 9 compares the values of the concentration of chlorine for all the water samples.

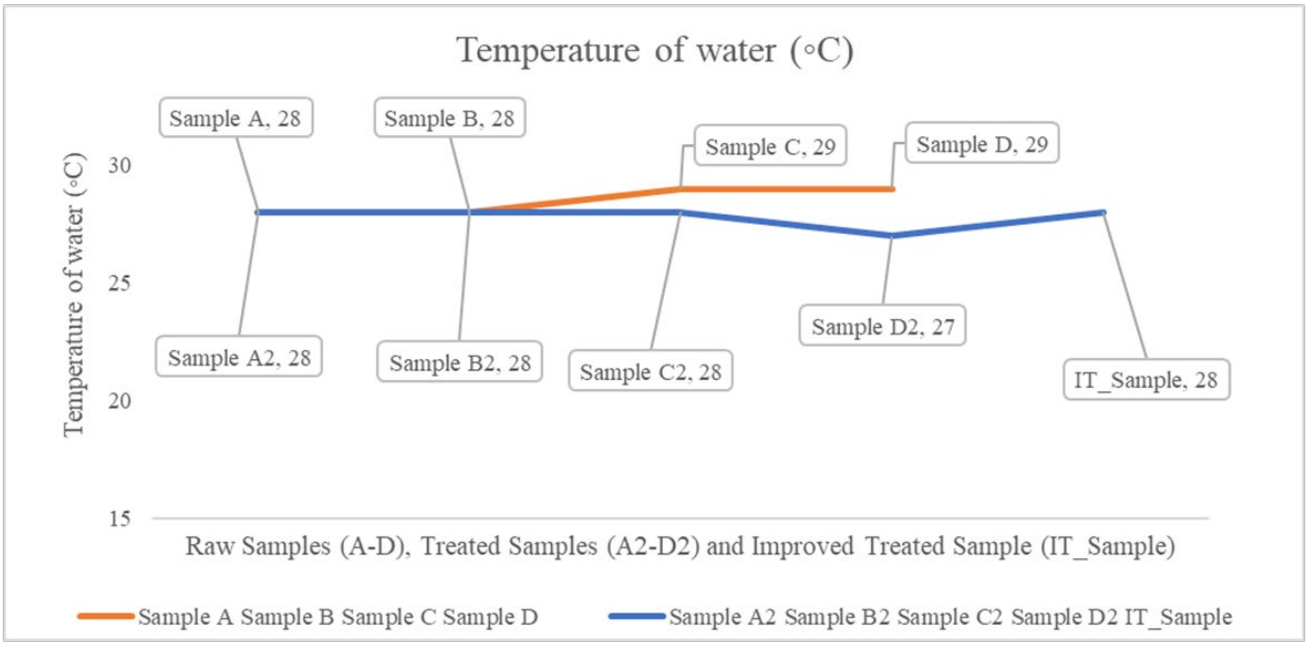

Figure 2: Temperature comparison of the raw water, treated water, and the improved treated water samples.

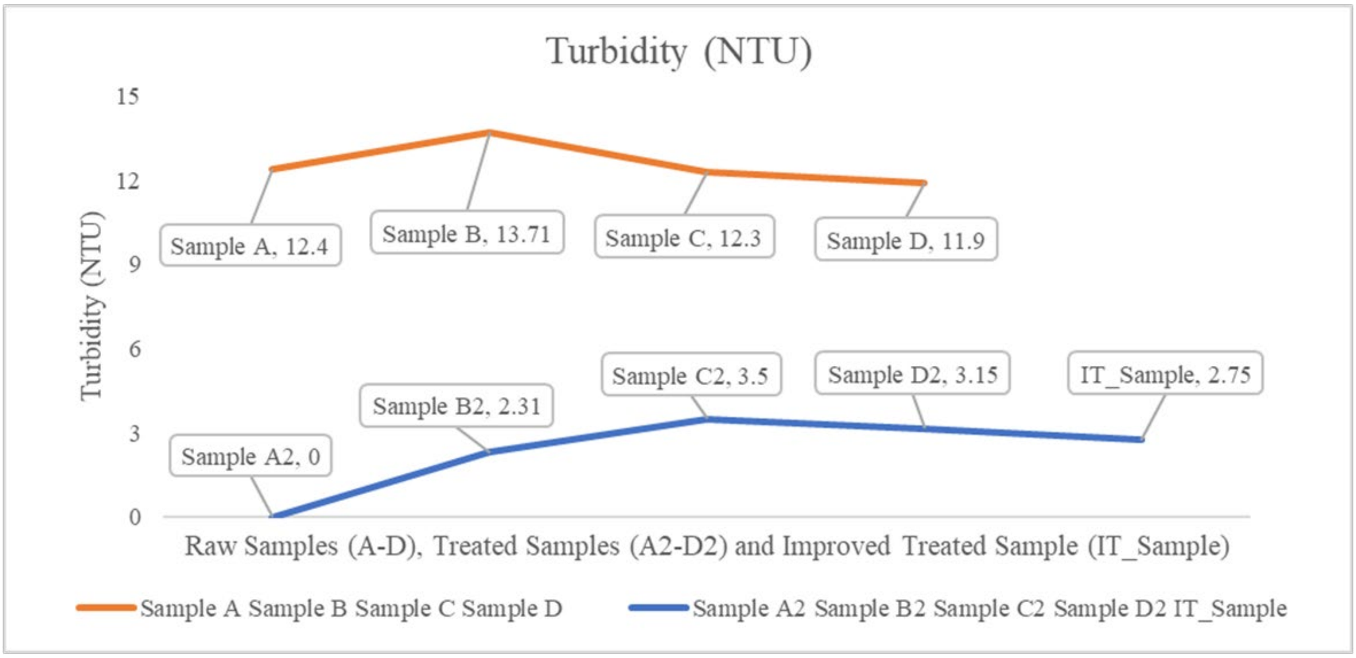

Figure 3: Turbidity (NTU) of the raw water, treated water, and the improved treated water samples.

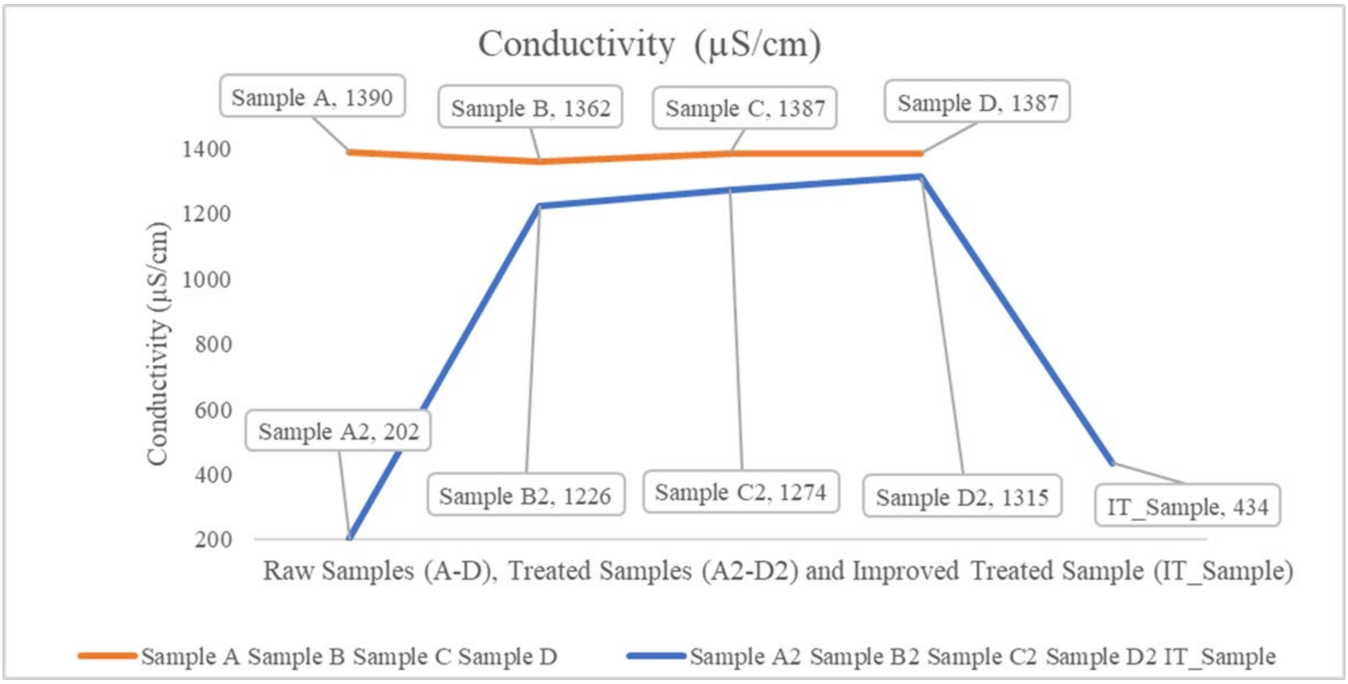

Figure 4: Conductivity of the raw water, treated water, and the improved treated water samples.

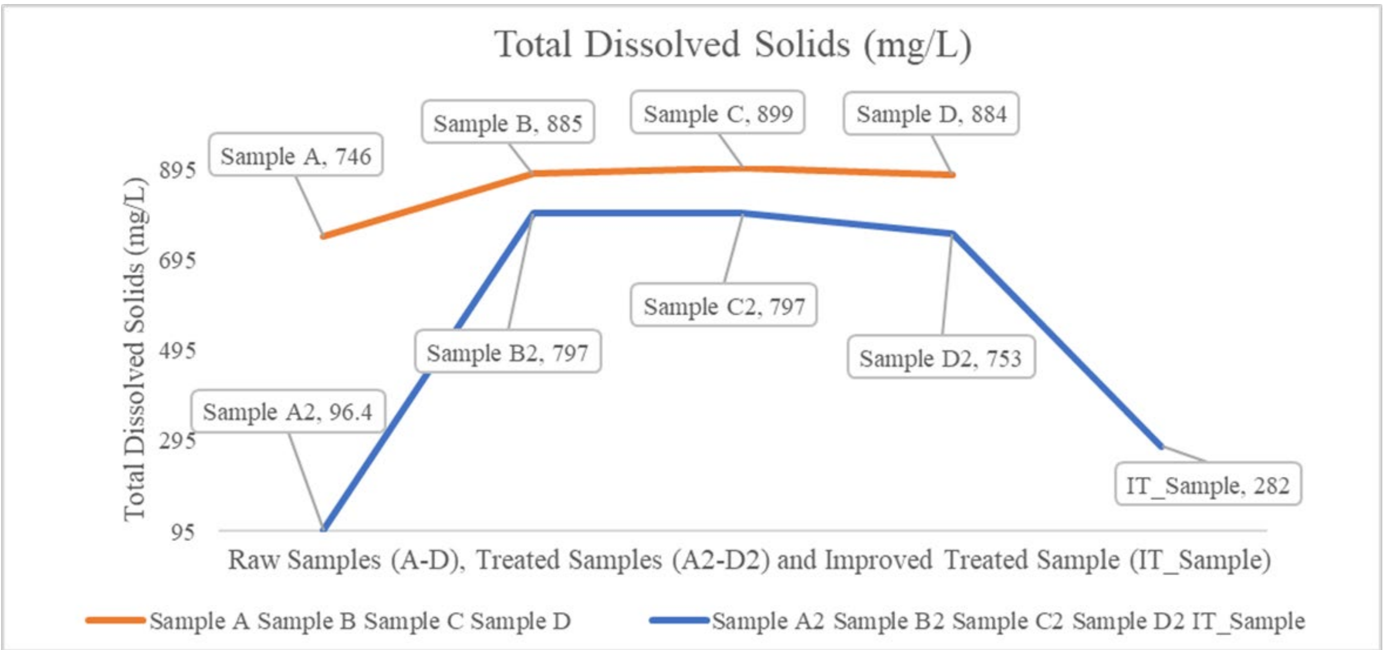

Figure 5: Total Dissolved Solids of the raw water, treated water, and the improved treated water samples.

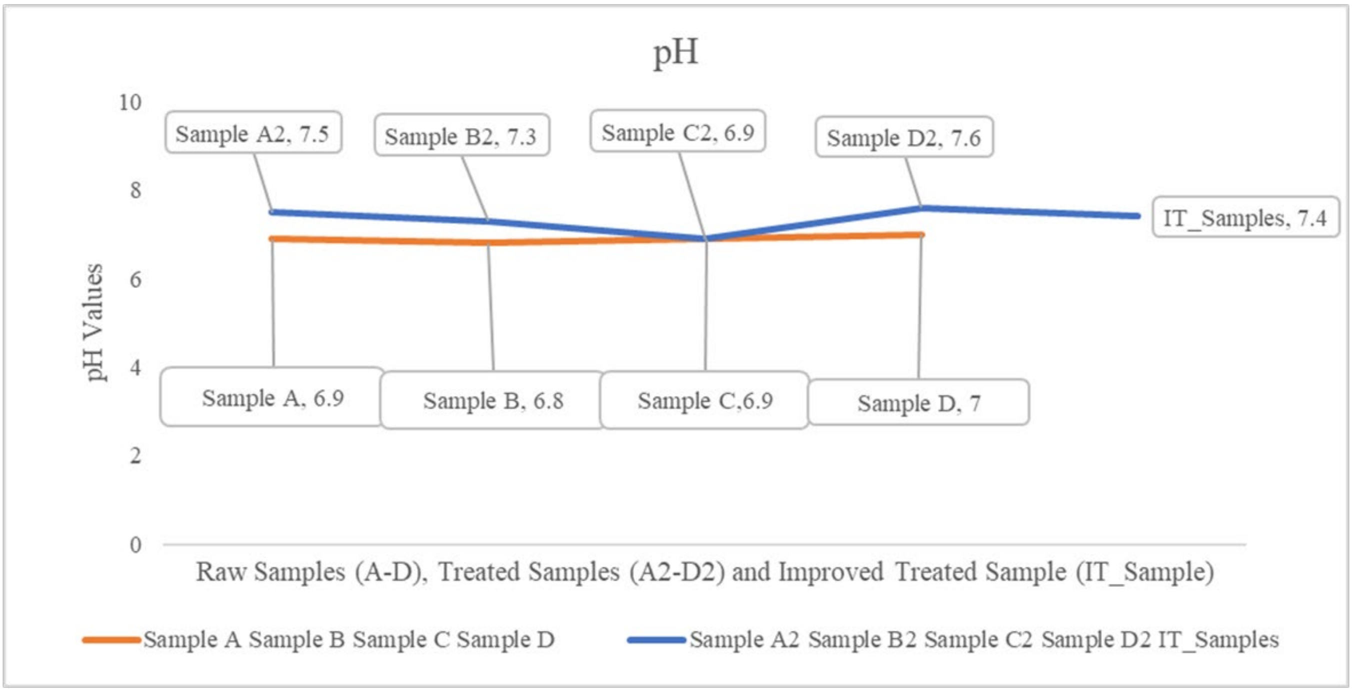

Figure 6: pH Values of the raw water, treated water, and the improved water samples.

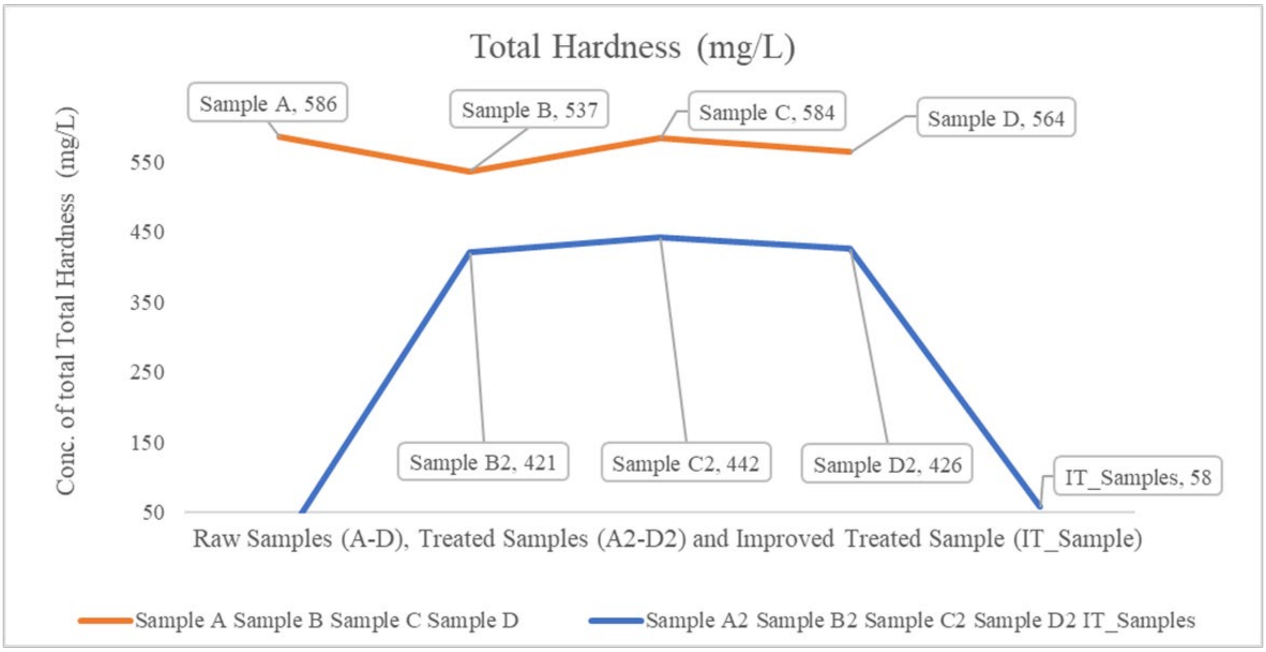

Figure 7: Concentration of Total Harness of the raw water, treated water, and the improved water samples.

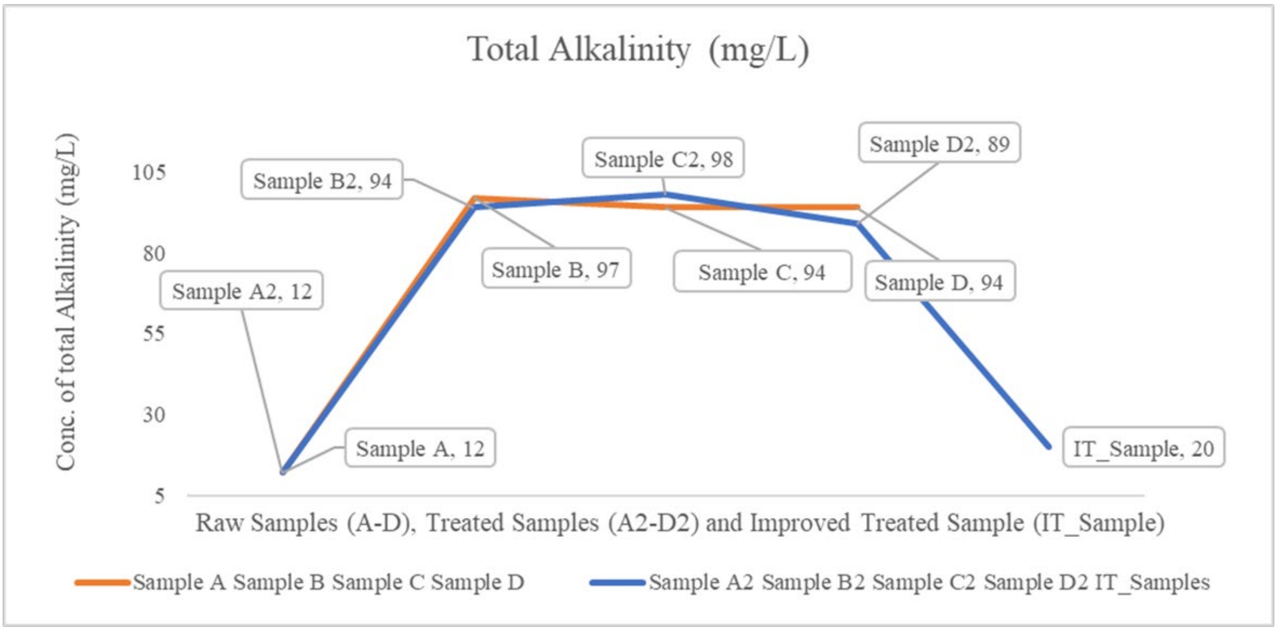

Figure 8: Concentration of Total Alkalinity of raw water, treated water, and improved water samples.

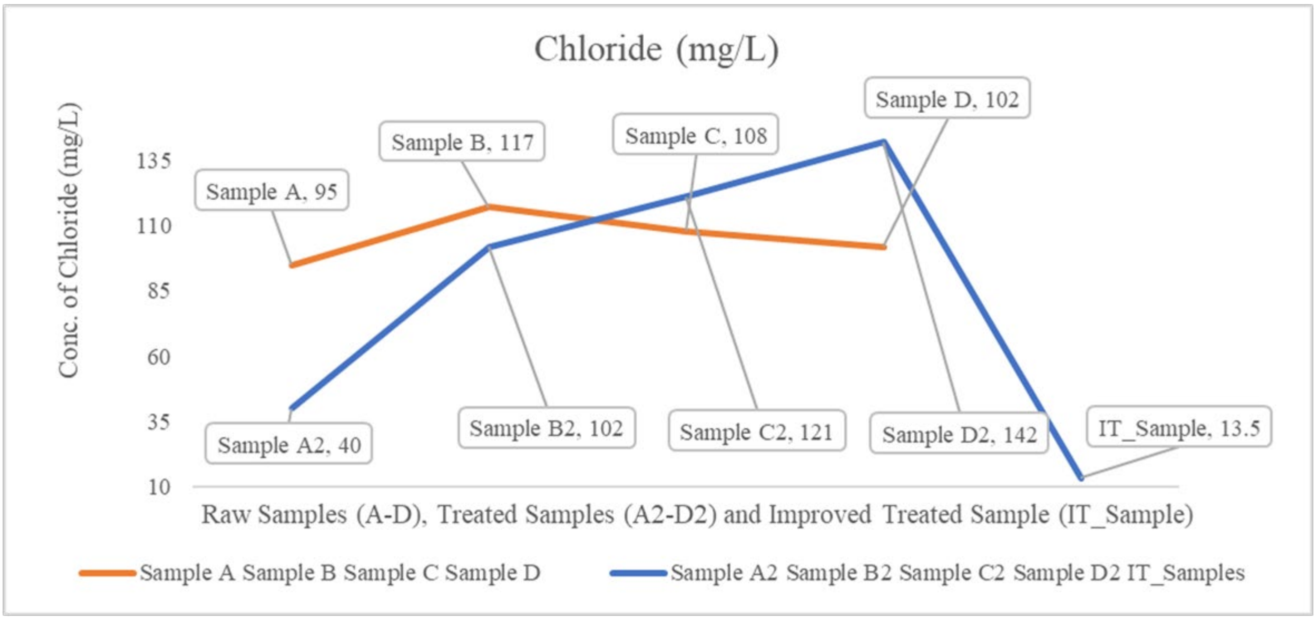

Figure 9: Concentration of Chlorine of the raw water, treated water, and improved water samples.

Figure 10: Example of treatment process used by most elite residents.

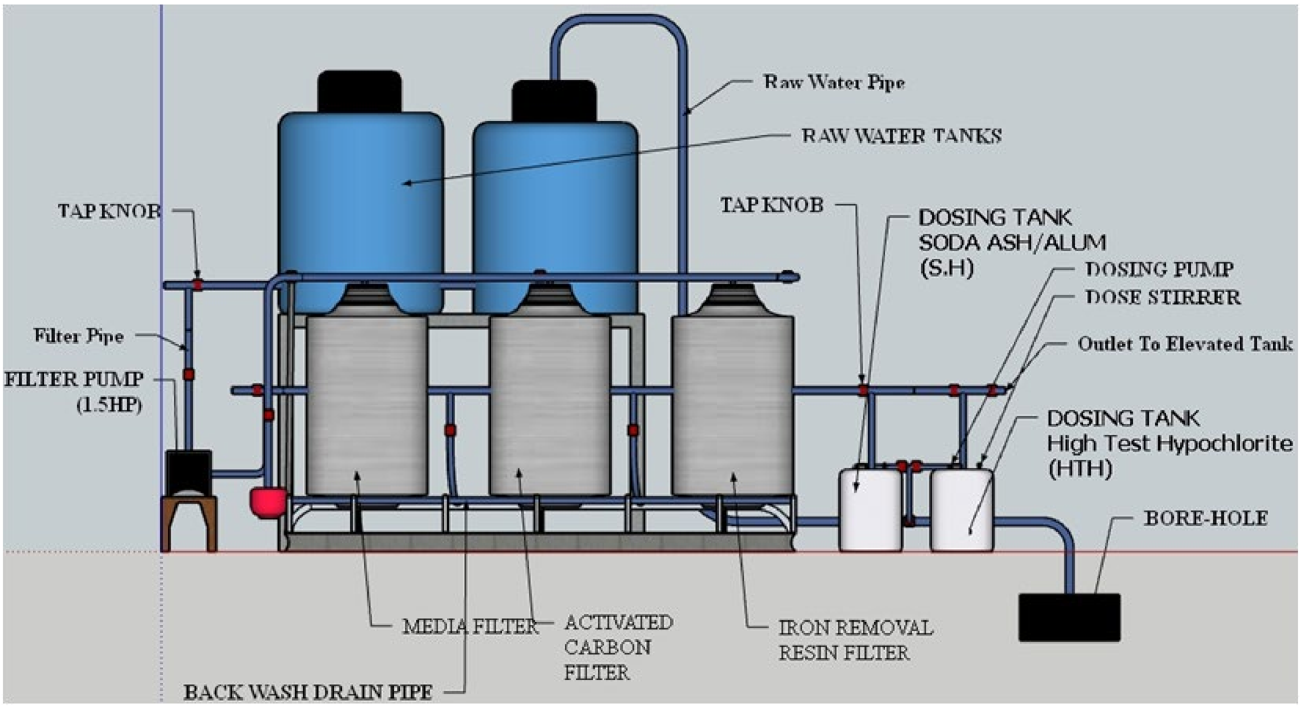

Figure 11: Improved Water Treatment Plant Design Recommended for Borehole Water Treatment

3.2 Discussion

Physical parameter measurement in both raw and treated water samples provide useful information into the efficacy of water treatment methods and their consequences for water quality. A comprehensive comparison of the findings reveals significant findings as well as potential implications for water resource management and public health.

Several metrics in the raw water samples deviated from the NSDWQ and WHO approved levels. Color, disagreeable taste and odor, increased turbidity, conductivity, salinity, and total dissolved solids all specify that there is a need for improvement in the currently existing treatment technology to guarantee compliance with water quality criteria. These findings highlight the need to establish efficient purification techniques to eliminate contaminants and improve the safety and usage of water supplies.

The pH values of less than 7.0 of the raw water samples indicate a slightly acidic condition. Deep groundwater sources like boreholes frequently have low pH levels in their groundwater. Due to the presence of CO2, which is produced in the soil by both aerobic and anaerobic microbial processes, as well as the fact that at such depths it is difficult for it to easily escape into the atmosphere, groundwater has a low pH [29].

The increase in the pH values observed in the treated samples emphasized the significance of pH control water quality management as posited by Li and Wu (2019) [30]. Hoko (2008) posited that water taste is influenced by pH, hence, there is a need for adequate treatment for pH in water situated for drinking [29]. Temperature has an impact on nature and degree of other parameters, such as conductivity. The temperature also influences bacterial activity. Warm temperatures lead to accelerated bacterial activity, which increases the potential for the development of odors through the oxygen-depleting oxidation of organic and nitrous compounds that may be present in water [29].

Furthermore, the lack of residual chlorine in raw water samples emphasizes the importance of good disinfection during treatment, as chlorine is a critical agent for pathogen elimination [31]. The turbidity values of the samples in the present study were found to be lower than the report of Palamuleni and Akoth (2015) study carried out in South Africa where a maximum of 40.9 NTU was discovered [5]. The result revealed a high level of turbidity in the raw water samples. The dissolved solids, high organic matter content, and B.O.D of the water samples could all contribute to the turbidity water samples [32]. More so, the present study reported turbidity values lower than report of Ighalo and Adeniyi (2018)carried out in Abuja, Nigeria [33]. This affirmed that there exist spatial differences in physical properties of borehole water within regions of the world [34,35]. Iron concentration changes indicate the existence of dissolved iron, which can lead to water coloring and perhaps alter taste and odor [36]. Total alkalinity and total hardness levels in raw water samples represent mineral content and can influence water suitability for household and industrial use. Chloride and nitrate in raw water samples may suggest anthropogenic contamination from agricultural runoff or industrial discharges [31]. The reduction in iron content in treated samples, combined with increase in alkalinity and total hardness, illustrates the treatment techniques' efficacy in eliminating dissolved minerals and improving water quality [37]. However, the presence of residual aluminum in Sample D2, while at a low quantity, shows that more research and modification of treatment procedures are needed to reduce the presence of this component in the final water product.

The improved treatment system is poised to perform better than existing treatment designs in the study area and have capability of reducing physical-chemical-microbial parameters to levels within permissible limits of WHO and NSDWQ.These findings emphasize the significance of comprehensive water treatment techniques that include disinfection, pH control, and pollutant removal. Continuous monitoring and optimization of treatment procedures based on the individual problems associated with different water sources are critical to ensuring the public's access to safe and compliant drinking water.

4. Conclusion

This study provided a comprehensive analysis of the physicochemical and bacteriological parameters of borehole water in Lekki, Lagos, Nigeria. The findings revealed significant deviations in several parameters of the raw water samples from the approved levels of the Nigeria Standards for Drinking Water Quality (NSDWQ) and the World Health Organization (WHO). These deviations underscore the necessity for improved water treatment methods to ensure the safety and effectiveness of borehole water supplies.

The study also assessed the effectiveness of the conventional treatment methods employed by most residents in the study area, which involved the use of chlorine, alum, and lime. While these methods were found to improve several parameters, they were not entirely effective in ensuring compliance with the control water quality standards. This highlights the need for continuous monitoring and optimization of water treatment procedures to address the unique challenges associated with different water sources.

Furthermore, the study introduced an improved treatment method involving the use of Hypochlorite, Soda ash, Alum, and a three-stage filtration system. The results from this method showed significant improvements in both the physicochemical and bacteriological parameters of the water samples, bringing them within the acceptable limits set by the WHO and NSDWQ. This suggests that the improved treatment method could be a viable solution for enhancing the quality of borehole water in the study area.

Finally, this study contributes to the growing body of knowledge aimed at improving water quality, particularly in regions that rely heavily on borehole water supply. The findings underscore the importance of implementing comprehensive and efficient water treatment techniques, as well as the need for continuous monitoring and optimization of these techniques. This is crucial for ensuring public access to safe and wholesome drinking water, thereby contributing to the achievement of Sustainable Development Goal 6 - Clean Water and Sanitation. Future research should focus on the scalability and cost-effectiveness of the improved treatment method for wider application.

5. Recommendations

Based on the findings of this study, the following recommendations are proposed:

- Improved Water Treatment Methods: The conventional water treatment methods employed by most residents in the study area were found to be inadequate in ensuring compliance with the control water quality standards. Therefore, it is pertinent to adopt improved water treatment methods, such as the one proposed in this study, which involves the use of Hypochlorite, Soda ash, Alum, and a three-stage filtration system.
- Continuous Monitoring and Optimization: Regular monitoring and optimization of water treatment procedures are important in ensuring the safety and effectiveness of borehole water supplies. This should involve routine testing of water quality parameters and adjusting treatment methods as necessary to accommodate any identified issues.
- Public Awareness and Education: It is necessary to increase public awareness and education on the importance of water quality and the potential health implications associated with consuming raw or ill-treated borehole water. This could be in the form of community workshops, distribution of informational materials, and other outreach activities.
- Policy and Regulation: It is recommended that policymakers should consider implementation of stringent regulations on borehole water quality and treatment methods. This could involve setting stricter water quality standards, requiring regular testing of borehole water supplies, and enforcing penalties for non-compliance.
- Further Research: Further research is needed to explore the scalability and cost-effectiveness of the improved treatment method proposed in this study. This could include pilot testing the technique in different regions and conducting cost-benefit analyses to evaluate its economic viability. Moreover, further research is needed to understand the time required to change or replace the chemicals in the improved water treatment design. This will help to optimize the treatment process and ensure the effectiveness and longevity of the system.
- Infrastructure Development: Investing in infrastructural development is important to make clean water more accessible. Activities such as construction and maintenance of water treatment plants, provision of improved water treatment techniques, and provision of government serviced water supply could improve access to clean and safe water.

Implementation of the recommendations would improve the quality of borehole water significantly, especially in areas where the water has impaired coloration. This will ensure the overall health and wellbeing of the population that relies on borehole eater supply for their daily needs.

Declaration of Competing Interest

The authors declare that there are no competing financial interests or personal relationships that could have influenced the works or data presented in this paper.

Author Contribution Statement

The authors declare that we have carried out the experiment and the conception or design of the work, or the acquisition, analysis, or interpretation of data for the work. We are responsible for all the important intellectual content and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Daniel Akerelewas responsible for the conception and design of the study, acquisition of data, and analysis. CallistusObunadike was responsible for the data analysis and interpretation of data. Finally, PelumiAbiodun was responsible for writing the manuscript and revising it critically for important intellectual content.

Data Availability

The datasets used and/or analyzed during the study are presented in this published article. Other raw data are available from the corresponding author on reasonable request.

Statement of Compliance with Ethical Standards

This research paper adheres to the highest ethical standards in conducting and reporting the study. The following statement outlines compliance with ethical considerations:

1) Animal Subjects: No animal subjects were involved in this research study.
2) Human Subject: No human subjects were involved in this research study.
3) Data Protection and Confidentiality: No personal information is shared in this research study.
4) Conflict of Interest: The authors declare that there are no conflicts of interest that could influence the objectivity or integrity of the research. Any potential conflicts of interest, financial or otherwise, have been fully disclosed.
5) Funding Disclosure: The author declares that there is no funding provided from any source for this research study. All costs for conducting this research were borne by the authors.
6) Plagiarism and Originality: The manuscript presents original work, and proper citations and references have been provided for all sources used. The authors attest that the content of this paper does not infringe upon the intellectual property rights or copyrights of others.
7) Compliance with Ethical Guidelines: Throughout the research process, including data collection, analysis, and reporting, relevant ethical guidelines and regulations have been followed as outlined by the University of Ibadan and other applicable professional bodies.

The authors are committed to upholding ethical practices in research and ensuring the integrity and validity of the findings presented in this paper.

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