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Research Article

Assessing the efficiency of drinking water treatment plant and the impact of broken distribution systems on water quality of Wukari-Ibi plant

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ABSTRACT

Water treatment is essential in the provision of potable drinking water to communities. However, studies have shown that many local conventional drinking water treatment plants in Nigeria are ineffective in removing contaminants. This study evaluated the efficiency of drinking water from Wukari-Ibi plant by assessing water samples before and after treatment and comparing results to national and international drinking water standards. Forty water samples were collected and selected physical and biological parameters were determined according to standard laboratory procedures. The results indicated that after treatment, turbidity (6.74 NTU) and coliform count (17 cfu/100 mL) were still significantly greater than standard guidelines, which suggest that the treatment plant is unable to reduce the concentration of these contaminants to a safe level for consumption. Furthermore, assessing water at consumer taps indicated that broken distribution system is likely serving as a potential pathway for contamination. The plant removal efficiency of colour, turbidity, Total Dissolved Solids, hardness, and coliform count was computed as 74.7%, 66.57%, 32.58%, 30.11%, and 59.88% respectively. Overall, the removal efficiency was 52.77% which is considered unacceptable for the supply of potable drinking water. The study concludes that cost and poor skilled personnel are the major factors in the inefficient treatment and therefore we suggest a low-cost treatment using activated carbon from locally sourced plants to be incorporated for effective removal of contaminants. There is also a need for government to invest in infrastructure and equipment so as to upgrade the treatment plant.

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INTRODUCTION

Next to oxygen, water is considered one of the most precious commodities for human survival. Therefore, without water, it is safe to say that the existence of life is impossible [1]. Despite the fact that around 70% of the earth is covered by water, it has not been available when and where it is needed, and when it does, it is always not of sufficient quantity and quality for consumption [2–4]. This is particularly due to the unprecedented increase in population, accompanied by the increase in agricultural and industrial activities, which gives rise to waste generation and indiscriminate disposal

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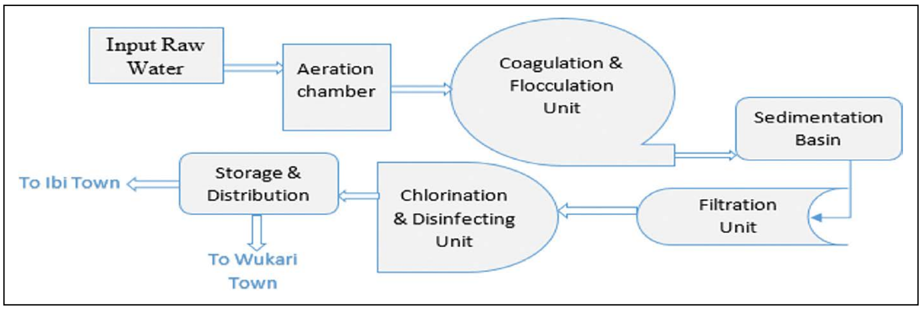

Figure 1. Schematic diagram of the treatment plant showing the various section.

into water bodies and the environment. Consequently, this has increased the rate and types of contaminants that are now identified in the environment [5–7]. These contaminants have been found in surface and groundwater and pose serious health concerns especially to rural people and areas where there are no water treatment facilities [8–11] or where the treatment facilities have either broken-down or are ineffective in removing contaminants.

Although pure water does not exist in its natural state due to the presence of gasses, dissolved and suspended solids, anthropogenic activities is now considered the biggest source of surface and groundwater pollution in many developing countries. Water quality has been identified as one of the key environmental indicators especially in areas susceptible to water contamination. Therefore, drinking water must be free from impurities and other hazardous chemicals and microorganisms that may adversely impact human health [7, 12–15]. This has led to the development of water treatment facilities across many communities for the provision of potable drinking water [12, 16]. However, even though the provision of safe, accessible, affordable, and sufficient drinking water is considered a fundamental human right [17], many communities still lack the facilities and infrastructure necessary for the treatment and distribution of adequate, safe, and sufficient water for all [3, 18, 19]. These communities are often in rural to semi-urban areas where there are engaged in large scale agricultural activities which contributes significantly to the high levels of nutrients, hormones, metals, and other chemicals found in drinking water [9, 20].

The Ibi-Wukari treatment plant uses the conventional coagulation and filtration process to treat and distribute water to consumers. The conventional treatment process involves the collection of raw water (from surface water sources), which is aerated, coagulated, filtered, and disinfected before distributed to consumers for consumption (Fig. 1). These processes however have been questioned due to poor maintenance and lack of monitoring of the water treatment and its infrastructure [3, 19]. There have been reports from residents who are often dissatisfied with the water from the treatment plant and hence result to water vendors as an alternative means of water supply [21]. This necessitates the need to assess the efficiency of the treatment plant in removing the various contaminants, particularly those related to the aesthetics and biological properties of water.

MATERIALS AND METHODS

Water Quality Indicators

Physical and biological indicators were selected to assess how effective the treatment plant is in removing these parameters. The physical indicators assessed include pH, colour, turbidity, total dissolved solids (TDS), and total hardness while total coliform count was used to assess the removal of biological contaminants. These parameters were selected according to the Nigerian drinking water quality guidelines [22].

Sample Collection

Water samples were collected before treatment (raw water from the river source), after treatment (within the reservoir at the treatment plant), and at consumer taps within Wukari township. A total of 40 sampling sites (10, 15 & 15 sites before & after treatment and at consumer taps respectively) were randomly identified and water samples were subsequently collected. Water samples were collected in triplicates and the average was used to compute for both descriptive and inferential statistics. Water samples were collected in pre-treated 50cl bottle containers and pre-treatment was done by washing the bottle containers with 0.05M HCl and then rinsed with distilled water as specified by [23]. Furthermore, before collection, sample bottles were rinsed 3 times with the water samples before they were collected and subsequently transported to the laboratory in ice coolers under 4°C.

Sample Analysis

Temperature, pH and turbidity were measured using mercury thermometer, pre-calibrated digital electrode pH meter and turbid-meter respectively. Other physical and biological parameters comprising of colour, TDS, total hardness, and total coliform count were analysed in the laboratory according to standard laboratory procedures stipulated by [23, 24]. Colour was determined using the Hazen meth-

Table 1. Descriptive statistics of water samples before treatment

Parameters	NIS/WHO standards	Mean	St. Dev	SE mean	Range		P-values
					Min	Max	
Temperature (°C)	Ambient	20.276	0.335	0.0749	19.80	21.1	WR
pH	6.5–8.5	6.365	0.236	0.053	6.00	6.80	0.010***
Colour (TCU)	15	54.135	2.455	0.549	50.10	58.80	0.000***
Turbidity (NTU)	5	20.165	3.376	0.755	13.20	25.70	0.000***
TDS (mg/L)	500	633.38	25.27	5.65	588.70	684.20	0.000***
Hardness (mg/L)	150	212.81	16.30	3.65	182.50	241.00	0.000***
Total coliform (cfu/100 mL)	10	42.35	7.88	1.76	30	56.00	0.000***

Min: Minimum; Max: Maximum; St. Dev: Standard deviation; SE mean: Standard error mean; ***: Significantly exceeds WHO drinking water standard; *: Within WHO drinking water standard; WR-within stipulated range.

Table 2. Descriptive statistics of water samples after treatment

Parameters	NIS/WHO standards	Mean	St. Dev	SE mean	Range		P-values
					Min	Max	
Temperature (°C)	Ambient	21.93	0.50	0.113	21.00	22.8	WR
pH	6.5–8.5	7.5	0.18	0.041	7.10	7.8	*
Colour (TCU)	15	13.7	1.41	0.315	10.30	16.1	1.000*
Turbidity (NTU)	5	6.74	1.02	0.227	5.30	8.60	0.000***
TDS (mg/L)	500	427.02	13.95	3.12	400.10	448.8	1.000*
Hardness (mg/L)	150	148.73	5.38	1.20	140.00	158.2	0.847*
Total coliform (cfu/100 mL)	10	17	4.10	0.918	11.00	26.00	0.000***

Min: Minimum; Max: Maximum; St. Dev: Standard deviation; SE Mean: Standard error mean; ***: Significantly exceeds WHO drinking water standard; *: Within WHO drinking water standard; WR: Within stipulated range.

od, while TDS and total hardness were measured using the gravimetric methods and Winkler's titration method as described by [23, 24]. The total coliform count was determined using membrane filtration techniques with the aid of Eosin Methylene Blue Agar (oxoid), by incubating at 37°C since coliform bacteria is known to thrive well at 37°C [23].

Statistical Analysis

Descriptive and inferential statistics were used to draw conclusions and inform the discussion of this paper. Minitab statistical software version 20.0 was used to analyse the data and the mean, standard deviation, minimum and maximum values were tabulated and presented. A 1-sample student T-test was used to compare the result to the WHO/NIS guidelines to identify samples that failed to conform to the stipulated standards while Analysis of Variance (ANOVA) was used to indicate differences between water samples before treatment, after treatment, and at consumer taps during distribution. In addition, a 2-Sample T-test was also used to assess the difference in water quality after treatment and at consumer taps. This was done in order to assess the impact of broken distribution systems (pipes) on water quality.

RESULTS AND DISCUSSION

Comparing Results to WHO & NIS Stipulated Standards

The descriptive statistics of the results is shown in Table 1, 2 and 3 respectively. The results shows that the samples had a mean temperature of 20.3°C, 21.9°C and 21.5°C before, and after treatment and at consumer taps respectively. The sample pH before treatment was slightly acidic (6.4) but appears to be adjusted after treatment (7.5) and at the consumer taps (7.4). Comparing pH of samples at the various stages indicates that the water samples before treatment appears to be below the stipulated guideline of 6.5–8.5. This suggests acidity and acidity in water can aid dissolution of minerals which can likely influence the total dissolved solids (TDS) and colour of water [25]. Water samples before treatment generally showed high levels of contaminants above the stipulated drinking water guidelines with colour (54.13TCU), turbidity 20.16 NTU), TDS (633.38 mg/L), total hardness (212.81 mg/L) and total coliform count (42.35 cfu/100mL) significantly exceeding the drinking water guidelines. This was consistent with findings from similar studies [3, 10, 26] and was expected because surface water particularly in close

Table 3. Descriptive statistics of distributed water samples

Parameters	NIS/WHO standards	Mean	St. Dev	SE mean	Range		P-values
					Min	Max	
Temperature (°C)	Ambient	21.49	0.49	0.111	20.60	22.20	WR
pH	6.5–8.5	7.4	0.23	0.052	7.0	7.8	WR
Colour (TCU)	15	14.93	1.35	0.302	12.10	17.30	0.590*
Turbidity (NTU)	5	7.80	1.51	0.338	5.30	10.80	0.000***
TDS (mg/L)	500	496.58	23.89	5.34	450.10	535.70	0.735*
Hardness (mg/L)	150	150.88	10.00	2.24	130.10	168.5	0.350*
Total coliform (cfu/100 mL)	10	23.55	7.43	1.66	9.00	37.00	0.000***

Min: Minimum; Max: Maximum; St. Dev: Standard deviation; SE Mean: Standard error mean; ***: Significantly exceeds WHO drinking water standard; *: Within WHO drinking water standard; WR: Within stipulated range.

Figure 2. Broken pipes indicating potential contamination pathways within the city.

proximity to agricultural and residential areas is highly susceptible to contamination. In addition, studies by [2, 9] showed similar findings along the upstream of the case study area which indicates that high concentrations of contaminants have been recorded along the river which feeds the treatment plant.

However, the result after treatment showed a significant reduction and removal of some of the contaminants (Table 2) when compared with the samples before treatment. Findings indicates that the pH was improved from 6.4 to around 7.5 after treatment. In addition, colour (13.9 TCU), TDS (427.02 mg/L), and total hardness (148.73 mg/L) have been reduced significantly and are now within the stipulated drinking water guidelines. Although, turbidity (6.74 NTU) and total coliform count (17 cfu/100 mL) were still above the stipulated standards even after treatment, they were significantly reduced during the treatment process. The removal indicates that the treatment plant is effective in reducing some of the contaminants but not to the desired level stipulated by the WHO and NIS drinking water guidelines.

Water samples at the consumer's taps shows that although some of the parameters were significantly removed, there appears to be an increase in some parameters. For instance, colour which was 13.7 TCU after treatment increased to 14.93 TCU at the consumers tap within Wukari township. The same was noticed with turbidity (from 6.74 to 7.8 NTU), TDS (from 427.01 to 496.58 mg/L), total hardness (from 148.73 to 150.88 mg/L) and coliform count (from 17 to 23.55 cfu/100mL). This suggests that there was a source of contamination either within the distribution system or at the consumers tap. However, a site visit revealed broken pipes (Fig. 2) which not only accounts for loss of water but serves as a medium for contamination flowing back into the pipes. This could likely be the cause of disparity between the water samples after treatment and at the consumers tap.

Analysing Difference Before and After Treatment and at Consumer Taps

Analysing the differences in water quality before treatment, after treatment and at the distribution point showed that there were significant differences in the means of parameters which suggests that the treatment plant is removing

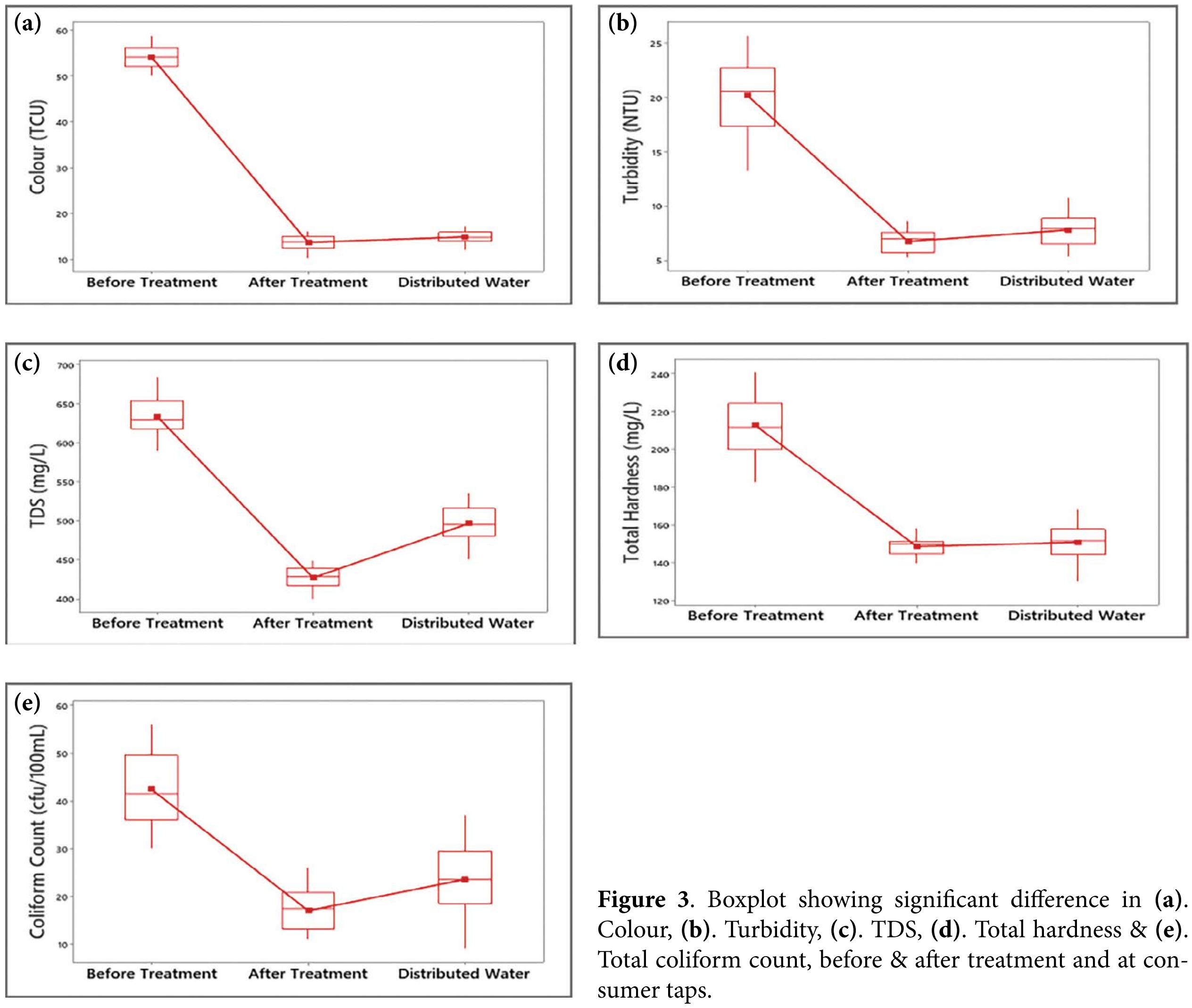

Figure 3. Boxplot showing significant difference in **(a)**. Colour, **(b)**. Turbidity, **(c)**. TDS, **(d)**. Total hardness & **(e)**. Total coliform count, before & after treatment and at consumer taps.

the contaminants. However, the removal may not be to the desired level especially since there are still parameters that were not removed to conform to the stipulated drinking water standards. Analysis of variance (ANOVA) showed that the means of all parameters were significantly different (Table 4), particularly the means of samples before treatment and after treatment (Fig. 3). However, the means of samples after treatment and at consumer taps appears to be insignificant, a 2-sample test needs to be carried out to assess the difference in samples after treatment and during distribution at the consumer taps.

Table 4. ANOVA for difference in water before and after treatment and at consumer taps

Parameters	P-value	F-value	R-Sq (%)
Colour (TCU)	0.000	322.19	99.12
Turbidity (NTU)	0.000	227.03	88.85
TDS (mg/L)	0.000	471.09	94.30
Total Hardness (mg/L)	0.000	201.27	87.60
Total Coliform (cfu/100 mL)	0.000	77.43	73.09

Analysing Difference Between Water After Treatment and Water at Consumer Taps

The results from a 2-Sample T-test indicates that there were significant differences between colour after treatment and at consumer taps with a p-value of 0.008. Similarly, the results for turbidity (p=0.014), TDS (p=0.000), and coliform count (p=0.002) were also found to be significant (Fig. 4a–c, e). However, total hardness showed no significant difference (p=0.406) between water after treatment and at consumer taps (Fig. 4d). This analysis suggests that the rate of contamination of water during distribution is significant and can likely pose a serious health concern. Although the parameters that exceeded the standard after treatment, remained the same parameters that exceeded standard at the customer taps, the increase in concentration may like-

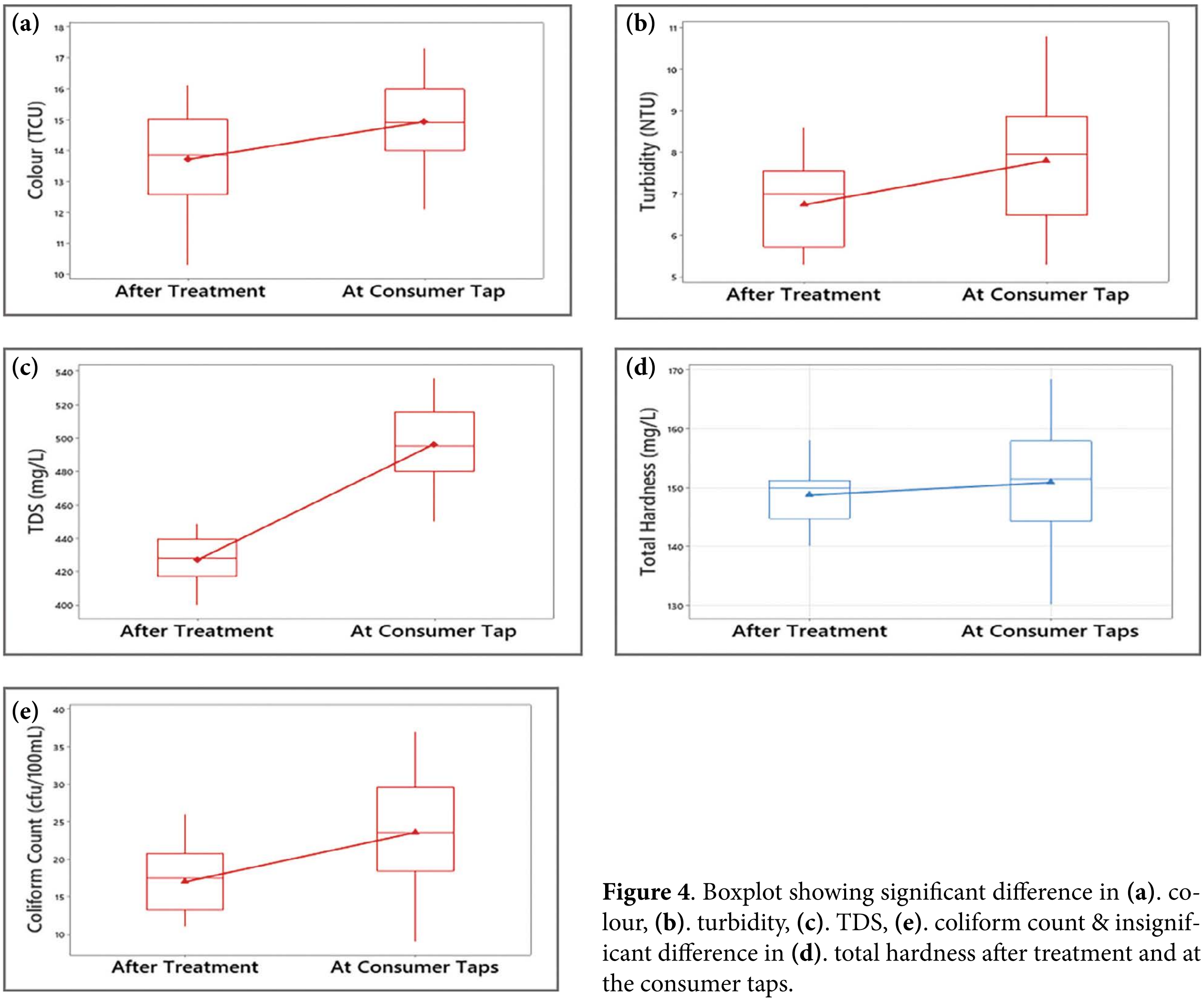

Figure 4. Boxplot showing significant difference in **(a)**. colour, **(b)**. turbidity, **(c)**. TDS, **(e)**. coliform count & insignificant difference in **(d)**. total hardness after treatment and at the consumer taps.

ly impact vulnerable children, elderly people and visitors who have not been exposed to such level of contaminants. The difference may likely be due to broken pipes (Fig. 2) at various point in the distribution system. The findings of the study corroborate with findings from [19] which indicates that leakages from pipes can severely impact water quality.

Implication of Broken Pipes on Water Quality

Historically, the provision of piped water within homes have been associated with improve sanitation and hygiene and a significant decrease in water related diseases [19, 20]. However, with continuous stress, poor maintenance and ageing of water infrastructure, water distribution systems are likely to become vulnerable to contamination. The loss of water along the distribution system accounts for a substantial volume of water and energy annually, and although the water pipe system in the study area is not metered, and therefore water loss cannot be accounted for (Fig. 5), but however, the risk to water contamination through these leaking pipes has been identified. Materials used in water distribution systems (including pipes) have different life span and therefore require monitoring to ensure that they do not deteriorate to the point that they pose severe risk to the quality of water that is being distributed [19].

Efficiency of the Treatment Plant

The efficiency of the treatment plant was computed based on the removal efficiency (RE) of each of the parameters assessed. The efficiency is computed and expressed as a percentage using the formula:

$$Removal\ efficency = \frac{influent - effluent}{influent} X\ 100 \qquad (1)$$

The RE was computed and tabulated in Table 5. The computation indicates that colour had a removal efficiency of 74.69%, turbidity (66.57%), TDS (32.58%), total hardness (30.11%), and coliform form count (59.88%). The study result is in conformity to findings from [10, 11, 13]. This suggests that the treatment plant is indeed removing the

Figure 5. Water loss during pumping due to broken pipes within the city.

Table 5. Removal efficiency of the treatment plant

Parameters	Influent	Effluent	R.E (%)
Colour (TCU)	54.14	13.7	74.69
Turbidity (NTU)	20.17	6.74	66.57
TDS (mg/L)	633.38	427.02	32.58
Total Hardness (mg/L)	212.81	148.73	30.11
Coliform count (cfu/100 mL)	42.35	17	59.88

R.E: Removal efficiency expressed as percentage.

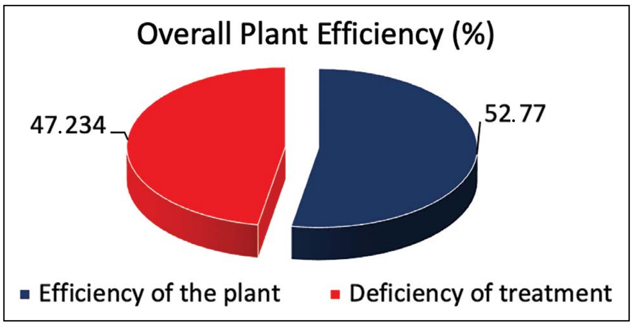

Figure 6. Overall treatment plant efficiency and deficiency (%).

contaminants but however not to the desired level. For instance, in a study by [27], the removal of colour should be at least around 86% to ensure water is aesthetically acceptable by most consumers. This however indicates that all though colour in our study was removed to conform to drinking water standards, the RE was not adequate.

This can be seen in our study results indicating colour with mean value of 13.7 TCU at a RE of 74.7%. A further increase in RE to the minimum 80% suggested by [27] will likely decrease colour to under 12TCU. Similarly, the removal of turbidity at 66.6% was not sufficient to reduce turbidity to conform to drinking water standard. More so, findings from [28] suggests a RE of over 90% to adequately reduce turbidity which will increase the removal of bacterial contaminants. Total hardness and TDS having a low RE indicating failure of the plant in effectively removing contaminants. Ineffective removal efficiency of dissolved solids can suggest poor removal of metals and other chemical contaminants in water. Consequently, there was a low RE of biological contaminants which also suggest risk to public health particularly because coliform count was significantly greater than the stipulated drinking water standards. The treatment plant showed an overall efficiency of 52.77% (Fig. 6) which is not sufficient especially to service two local government areas with large scale agricultural activities. The study outcome therefore suggests the need to assess each stage of the treatment plant process to understand how each stage performs.

A study by [19] showed that there could be improper dosage of coagulant and disinfectants during the treatment process. This can explain the inefficient removal of turbidity and bacteriological contaminants in water. A site visit indicates that the water treatment plant lacks a functional laboratory for testing and analysing water before and during every treatment stage. The addition of coagulating agents plays a key role in the removal of solids, colour and turbidity while disinfecting agents eliminates bacteriological parameters. Dosing these agents in the treatment plant requires adequate computation to ensure the right dosage is used at any given point. The findings suggests that these treatment agents are underutilised, probably because of poor funding or due to unqualified personals. There is therefore the need for adequate monitoring of water at every treatment stage to ensure that water leaving one stage for another is effectively treated before it gets to the final stage of disinfection and subsequent distribution.

Proposed Approach to Improve Water Treatment Using Low-cost Activated Carbon

Some of challenges confronting Ibi drinking water treatment plant is high treatment costs. Thus, there is dire need to explore alternatives ways to reduce costs without negatively affecting the quality of water delivery [21]. In this section, sustainable methods of improving drinking water properties using novel bio sorbent material developed from biomass waste as suggested by [29] is proposed. This will open a new way of water treatment in Ibi by using low-cost activated carbon made from locally available organic waste and at the same time expand waste management options for these readily available biomass materials. Ibi climatic condition are conducive for cultivation of a large variety of biomasses. Due to the richness of the minerals in the parent rock; these soils are generally well suited for rice, maize, guinea corn likewise arable farming and tree crops production. According to [30], utilizing local residual biomass as a raw material for removal of organic micropollutants in water treatment plants may be advantageous in terms of sustainability.

It has been observed that state government resources and interventions towards sustaining water supply in Ibi town and environs have been insufficient [21]. The result has been constant water crisis and shortages over the years. This study recommends a paradigm shift from the use of conventional and costly coal-derived activated carbon to activated developed from green sources. In the literature, green activated carbon materials have been used extensively in drinking water treatment in various roles, including removal of colour, turbidity and micro-pollutants [31]. New materials have also been discovered in the world of natural coagulants and adsorbents [32, 33] to improve drinking water properties. Granular activated carbon (GAC) media [34, 35] of various origins coal, coconut shell [36] and bovine bone) and providing a range of physical characteristics with reference to pore size, have been appraised with reference to their capacity for natural organic matter [37].

CONCLUSION

The water quality before and after treatment was assessed and compared with the stipulated drinking water standard. The study showed that the treatment was not effective in removing some parameters and hence require further assessment. The overall efficiency was below expectation which could potentially impact public health. Additionally, dilapidated water distribution infrastructure is now a potential source of contamination which needs to be addressed in order to supply potable drinking water to the inhabitants of Ibi and Wukari town. Furthermore, low-cost activated carbon was proposed to compliment the conventional treatment process for effective removal of contaminants. In addition, the government needs to invest in infrastructure, skilled personal and operational inputs such as diesel and water treatment chemicals.

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DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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