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Assessment of Water Quality Treatment and Costing: A Case Study of Sokoto State Water Board

[1]Nura Garba, [2]Abdullahi Adamu, [3]Ibrahim Abubakar Audu

[1]Department of Environmental and Resources Management,UsmanuDanfodiyo University, Sokoto, Nigeria
[2]Department of Environmental and Resources Management,UsmanuDanfodiyo University, Sokoto, Nigeria
[3]Department of Environmental and Resources Management,UsmanuDanfodiyo University, Sokoto, Nigeria
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ABSTRACT

Almost every organism both plants and animals need water either directly or indirectly for their survival. Over 70% of the earth's surface is covered with water. This is the reason why water is the most abundant naturally occurring substance found on the earth's crust. As such, this has brought the idea of using the g Sokoto State Water Board as a case study, to access how water quality standard can be improved and also meet the demand citizens in Sokoto metropolis. The quality of water can be determined by its physical, chemical and biological properties. As such, the water quality evaluation before its usage becomes necessary and the water quality parameters that are most likely to affect its quality for safe consumption must be assessed. The Sokoto State Water Board was established in 1963 with the first water treatment plant which was named "OLD WATER WORKS". It can produce six (6) million gallons, which is equivalent to 24 million liters per day. Its source (raw water) is from Bakalori Dam in Goronyo Local Government Area of Sokoto State. There are parameters which need to be taken into consideration in water quality analysis, such as temperature, conductivity, pH and turbidity. The laboratory analysis of raw water is done to determine the physicochemical and bacteriological parameters. The cost associated with each treatment method was determined to highlight the budgetary requirement for achieving portable water safe for consumption in the Sokoto metropolis.

Keywords: Sokoto, Alum, Lime, Water, Treatment, Plant

Introduction

Almost every organism both plants and animals need water either directly or indirectly for their survival. Over 70% of the earth`s surface is covered with water. This is the reason why water is the most abundant naturally occurring chemical substance found on the earth crust (Mathew & Krishnamurthy, 2017). From sources, 40% of the water for drinking comes from groundwater and around 30-40% of the water is used for agricultural purposes. Out of the total population of the world, around 97% of them depend on water for survival (Mathew & Krishnamurthy, 2017). As such, this has brought the idea of using the Sokoto State Water Board as the case study. Water has various purposes ranging from agriculture to industry, fisheries to domestic use. Water collects inorganic substances from the soil and organic substances together with microorganisms produced by human activities and the natural ecosystem (Magara, 2000). Food production heavily depends on water; such in the minimum standard of quality treatment is required. Impurities which occur in water include hazardous substances which are harmful to both plants and animals (Mathew & Krishnamurthy, 2017).

Water quality standard sets the level that is safe for consumption and domestic purposes, a realistic stand the one that which corresponds to the current scientific information. Hence, the quality standard of water should be scientifically evaluated periodically (Magara, 2000). Colourless, odourless, tasteless and neutral substance with the chemical formula (H_2O) and IUPAC name of dihydrogen monoxide. The water molecules have two hydrogen (H) atoms which are covalently bonded to a single oxygen (O) atom. And the molecular weight of water is 18.00g. Water occurs in all three states of matter namely; liquid-water, solid ice and gas vapor (Shah, 2017).

The quality of water can be determined by its physical, chemical and biological properties. As such, the water quality should be evaluated before its usage. All these water quality parameters that are most likely to affect the standard quality of water must be assessed (Shah, 2017).

Water quality is extremely associated with the general environmental status of any area. Application of different water quality improvement measures produces substantial costs, subsidies subsidy for agricultural production, implementation of new environmentally safe production methods, and building of wastewater treatment plants (Amic and Tadic, 2018). Subsequently, large rivers have metal and bacterial concentrations, as such, proper treatment is required before consumption for any other purposes (Amic and Tadic, 2018). Water is very an essential substance that has to be in continuous supply for both plants and animals to carry out their activities effectively. The human body needs water for metabolic activities. Safe drinking water is called portable water (Amic and Tadic, 2018).

Water is perhaps the most precious natural resource after the air. Though the surface of the earth mostly consists of water, only a small part of it is usable, which makes this resource very limited. This precious and limited resource must be used with prudence. As water is required for different purposes, its suitability of it must be checked before use. Also, sources of water must be monitored regularly to determine whether they are in sound health or not. The poor condition of water bodies is not only an indicator of environmental degradation; it is also a threat to the ecosystem. In industries, improper quality of water may cause hazards and severe economic loss. Thus, the quality of water is very important in both environmental and economic aspects. Water quality analysis is of extremely necessary and essential for using it in any sector. After years of research, water quality analysis is now a public health concern (especially for drinking water) and therefore, consists of some standard protocols (Shah, 2017). This study examines the water treatment procedure in Sokoto and determines the cost of treating water for safe consumption.

The Sokoto State Water Board was established in 1963 by Sir Ahmadu Bello (Sardauna of Sokoto), who approved the construction of the first treatment plant which was named “OLD WATER WORKS”. It can produce six (6) million gallons, which is equivalent to 24 million liters per day. Its source (raw water) is from Bakalori Dam in Goronyo Local Government, Sokoto State (SSWB Manual, 2015).

An ever-increase in population growth has necessitated the establishment of another treatment plant named “BI-WATER WORKS”, which was constructed in 1981 by Sokoto State, Ministry of Water Resources during the regime of Shehu Muhammad Kangiwa. It has the capacity of producing 12 million gallons which is equivalent to 48 million liters per day. The source of the water (raw water) is River Rima (SSWB Manual, 2015). Another water treatment plant was created in 1987 during the regime of Yahaya Abdulkarim (The First Civilian Governor) named “NEW EXTENSION TREATMENT PLANT” and it has the capacity of producing 23 million gallons which for equivalent to 92 million liters per day (SSWB Manual 2015).

But, there is an extremely high demand for adequate quality water in some areas approved in the rural areas of Sokoto State. This made the Sokoto State Ministry of Water Resources approve the construction of another water treatment plant sourced during the regime of Governor Aliyu MagatakardaWamako and which was named “ASARE WATER PROJECT”. Its source (raw water) is underground water and has the capacity of producing 20 million gallons which is equivalent to 80 million liters per day. These are to date and still taking care of the demand for water in Sokoto State (SSWB Manual, 2015).

Methodology

Study Area

Sokoto metropolis is the capital of Sokoto State, situated between longitudes 5.136040 E to 5.302310 E and latitudes 12.956610 N to 13.083790 N. The normal annual rainfall is about 640mm, with the raining season lasting between May and October, the dry season extents between November and April. Temperature is as high as 43°C around March/April (middle of the dry season) and as low as 23°C in December/January (middle of the cold season).The area is drained by the westward flowing Sokoto-Rima River system which is responsible for rich alluvial soil fit for multiplicity of crops. The valley has a usual altitude of 240 meters above sea level, representing the lowest level in the study area. The highest part of the study area has an altitude of about 321 meters above sea level, giving an altitudinal difference of 81 meters. The metropolis has an estimated population of 685000 persons spread over a geographical area of 31041 km² (National Population Commission, 2022).

Water Treatment Plant

A water treatment plant is a place where raw water (wastewater) is processed or stabilized through physical and chemical for equipment portability before consumption (Environmental Protection Agency, 2013). The equipment which are used in the water treatment plant which includes:

i. Reservoirs
ii. Laboratory apparatus such as beakers and conical flasks
iii. Filters
iv. Coagulation tanks with stirrers each with a volume of around $20m^3$.
v. Clarifiers each with a volume of around $25000m^3$

Water Treatment Process

Efforts were made in the early 1800s to control pollution and other waste from drinking water (Environmental Protection Agency, 2013). To provide safe water, the hygienic condition is necessary for protecting human health during any disease outbreak or pandemic, especially those associated with water (WHO, 2020). Raw water from different natural sources contains suspended and dissolves particles and other impurities such as leaves, sand particles, particulate matter, dissolve salt and other results of different human activities (WHO, 2020).

Some pathogens that can affect human health such as viruses, bacteria and protozoans are commonly found in water. As a result of this, the raw water must be treated before distribution, especially he households (WHO, 2020). Water treatment is a process where raw water passes through potable physical, chemical and biological treatment to make the water potable for consumption and other industrial purposes. Another was aimed at eliminating and reducing the concentration of harmful chemical substances and eliminating pathogens in the raw water (WHO, 2020). The main raw materials and chemicals used for water treatment are:

i. Aluminum sulphate $Al_2(SO_4)_3$ (Alum)

ii. Calcium hydroxide (Lime) $Ca(OH)_2$

iii. Chlorine Cl_2 (in powdered form)

Stages of Water Treatment

1. Screening from the Source: These are precautionary methods taken to disallow big floating objects (wood, plant leaves and dead bodies) from passing through the pipes thereby blocking them. The process is carried out using barbed wires and nets (Environmental Protection Agency, 2019).

2. Grit Removal Chamber: This is a place where smaller particles are removed from the raw water. This is done with the machine in the treatment plant (Environmental Protection Agency, 2019).

3. Aeration Chamber: This process is carried out either naturally or artificially. It is the introduction of air to water. It is the process of removing odour and also oxidizing metal and nonmetal ions such as;

Fe^{2+}, Mg^{2+} etc.

Example: $4Fe^{2+} + 3O_2$ $2Fe_2O_3$ $\longrightarrow$

$2Fe(OH)$ $Fe^{3+} + 3OH^-$ $\longrightarrow$

$Mn^{2+} + O_2$ MnO_2 $\longrightarrow$

4. Flash Mixing Unit: This is a place where the addition of chemicals to the raw water takes place. Mostly, the chemicals added are aluminium sulphate Al2(SO4)3, calcium hydroxide Ca (OH)2 and chlorine (Cl2). These chemicals are added in a series of steps (Environmental Protection Agency, 2019).

First Stage: Alum will be added to raw water as a coagulant to initiate the coagulation process between the suspended particles in the raw water. It removes the particulates and non-settle solids which include colloidal materials that exhibit slightly negative charges repelling one another thereby staying in suspension (Mukashev, 2010).

$Al_2(SO_4)_3 + 6h_2O_{(l)} \longrightarrow 2Al(OH)_{3(aq)} + 3H_2SO_{4(aq)}$

The $Al(OH)_3$ is a stable and complex precipitate that plays a vital role in the flocculation process.

Second Stage: Calcium hydroxide Ca $(OH)_2$ would be added to stabilize the pH of the water (to the optimum level of 6.8 – 7.2 which is required for an effective coagulation process) thereby neutralizing the acidity caused by the alum $Al_2(SO_4)_3$ (Mukashe, 2010).

Third Stage: Chlorine (Cl_2) is added to the water in two phases: In the first step is called the pre-chlorination and chlorination stage to disinfect the micro-organisms (Mukashev, 2010). $Cl_{2(S)} + H_2O_{(l)} \longrightarrow HCl_{(aq)} + HOCl_{(aq)}$

1. Clarification/Sedimentation Unit: This component involves stationary tanks called Clarifiers where the flocks settle down and are separated from the treated water. The flocks are discharged as slugs back to the source or recycled through the treatment process (Environmental Protection Agency, 2019).

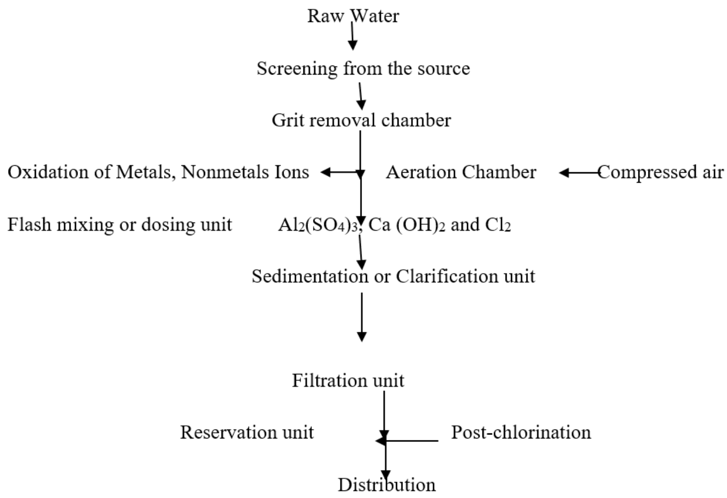
2. Filtration Unit: This is the place where the cleared water from the clarification unit is filtered. Filters are of two types; the sand filter and the carbon filter. It is in the filtration process that the residual suspended particles that are unable to sediment during coagulation are trapped on the surface of the sand filter bed. The filter bed consists of three layers; the gravel, the coarse sand and the fine sand. If the nozzles of the filter become dirt, the filtration process becomes slower and a backwash is required (WHO, 2020).

3. Back washing simply means washing the filters using water, air and a nozzle at high pressure to remove dirt and increase the rate of filtration. This is done via two stages; the first stage involves the upward introduction of air from the air blowers at high pressure to agitate the residue on the filter medium with water, then the second stage is the introduction of water from the bottom through the filter beds, after which the impurities are discharged from the top to evade spillage of fine sand (SSWB Manual, 2015).

4. Reservation: This is a place where the treated water is stored in a place called a reservoir underground or at the surface of the tank (Silva and Brunner, 2004).

5. Distribution: This is the final phase in the water treatment process. This is the stage where the treated water will be distributed to the general public through pipe networks. Post-chlorination should be carried out for the treated water before distribution (Silva and Brunner, 2004).

Summarized Flow Chart of the Water Treatment Process



Result and Discussion

There are parameters which need to be taken into consideration in carrying out water quality control analysis, such as temperature, conductivity, pH and turbidity. The laboratory analysis of raw water is done to determine the physicochemical and bacteriological parameters (Amic and Tadic, 2018).

Alum Jar Test

Aim: The aim of conducting a jar test is to determine the optimum alum dosage of alum needed to treat 1liter of raw water.

Apparatus: 1000cm^3 beakers, weighing balance, pipette, conical flask, measuring cylinder, turbidity meter, thermometer, pH value, flocculation machine.

Procedure: Before the start of the experiment, turbidity, pH and the temperature of the water were taken. 10g/L of alum solution was prepared (10g of alum was dissolved in 1000cm^3 of distilled water). Each 1.0ml of the stock solution is equal to 10mg/L when added to 1000cm^3 of the water was added to each of the four (4) beakers using a 1000cm^3 measuring cylinder which was followed by the addition of the alum sock solution.

Table 1: The dosage volume of alum stock solution in a water sample.

Beakers	Vol. of Aa lum Stock Solution Added (cm^3)	Vol. of Alum Dosage (mg/L)
1	9	90
2	10	100
3	11	110
4	12	120

Source: Author’s Analysis, 2022

From table 1, the four beakers were arranged in the flocculation machine and the stirrers were turned on. The stirrers were kept at high speed for 15mins and slow steady stirring for another 15mins. After which, the stirrers were turned off and flocks were allowed to settle and observed which beaker has the best clarity and result.

Table 2: The result of the experiment.

No. of Beakers	Quantity	Quqntity of Alum (mg/L)	pH Value	Turbidity
1	9	90	6.0	55.0
2	10	100	5.8	50.2
3	11	110	5.5	49.8
4	12	120	5.2	44.6

Source: Author’s Analysis, 2022

Observation: From table 2, there is not much feasible activity. The activity started from beakers 2 to 4 which shows rapid flocks formation and settlement. However, beaker 4 has the fastest rate of flocks formation and settlement with a pH of 5.2 and turbidity of 44.6 respectively.

Result: From the result of the above experiment carried out, it shows that the optimum dosage of alum for 1L of raw water is 12omg/L.

Alum/Lime Jar Test

Aim: This test is to determine the dosage of lime ($Ca(OH)_2$) that has neutralized the acidity caused by added aluminium sulphate (alum).

Procedure: 5g/L of lime ($Ca(OH)_2$) was prepared (2.5g of lime powder dissolved in 500cm^3 of distilled water). 10g/L of alum solution was also prepared. 1000cm^3 of the raw water was added to each of the four (4) beakers using a 1000cm^3 measuring cylinder, which was followed by the addition of 12cm^3 of the alum stock solution into each of the beakers and further with the addition of the lime solution.

Table 3: The dosage volume of alum and stock solution in the sample.

No. of beakers	Vol. of alum (cm^3)	Vol. of lime (cm^3)	Quantity of dosage lime (cm^3)
1	2	3	4
12	12	12	12
7	8	9	10
70	80	90	100

Source: Author's Analysis, 2022

From table 3, the four beakers were arranged in a flocculation machine and the stirrers were turned on. The stirrers were kept at high speed for 15mins and slow steady stirring for 15mins. After which, the stirrers were turned off and the flocks were allowed to settle and subsequently, the pH of each beaker was measured.

The pH of water is a measure of acidity or alkalinity. The pH is a logarithmic scale based on a measure of the free hydrogen ions in the water. The scale runs from 0 to 14, where 7 is considered neutral, 0 to 7 is acidic and 7 to 14 is alkaline. Because pH can be affected by dissolved minerals and chemicals, it is an important indicator of the change in water chemistry. According to the U.S. Environmental Protection Agency, drinking water with a pH between 6.0 and 9.5 generally is considered satisfactory. Several public water supplies have to maintain a pH above 9 to keep them in compliance with the Lead and Copper Rule of the Safe Drinking Water Act, which details how to prevent the leaching of these elements from piping systems. Water with a pH below 6 or above 9.5 can be corrosive to metal plumbing pipes and fixtures. The pH of water can affect the performance of pesticides, particularly herbicides.

Table 4: pH of the treated water.

No. of beakers	pH
1	6.0
2	6.1
3	6.4
4	7.2

Source: Author's Analysis, 2022

Observation: From table 4 above, it shows that beakers 1 and 3 were slightly acidic. But that of beaker 4 is neutral.

Result: Therefore, the above experiment, shows that 10cm^3 of lime would be enough to neutralize 12cm^3 of alum in the water treatment process.

Example: A jar test was conducted for a given sample of water and the result of the test is 110mg/L.

The capacity of the water tank is 2000L.

Calculation

110mg of alum will neutralize 1L

Xmg of alum will neutralize 200L

Xmg = 110 x 2000

X = 220a 00mg.

However, alum was measured and dissolved in water to make an alum solution. Then, the tank was half-filled to about 1000L; the solution was poured to the level mark of 2000L. This will help in the proper mixing of the alum solution and water in the water tank.

If a sample of water was tested and found to contain dissolved iron (Fe). There are two methods by which iron can be removed. These two methods are Free oxidation by air and Ion exchange resin (Silva and Brunner, 2004).

Free oxidation by air: In this method, the air is passed on the surface of the water that is moving continuously either artificially or naturally to oxidize Fe^{2+} to Fe^{3+} which is less harmful to human health. While in ion exchange resin, the ion exchanger is wrapped in cotton that serves as a carrier to disallow the washing away of the ion exchanger, the water is passed onto it and the resin will store the iron (Silva and Brunner, 2004).

The amount of chlorine to be added in 1L of a water sample is 0.2mg/L as residual chlorine. Active chlorine is the chlorine that is left in the water after all the bacteria are disinfected (Silver and Brunner, 2004).

Total hardness in water can be calculated using the formula below:

Total hardness in $CaCO_3$ mg/L = $\frac{A \times N \times C}{\text{Ml of the sample}}$

Where: A = Average volume (mol/dm)

C = Molar mass of $CaCO_3$ in mg

N = Normality of EDTA used (mol/dm)

ML = Mole of the sample (mol/dm)

If a test was carried out on a water sample and a prolonged test was found to be temporarily hard, then the hardness could be removed through prolonged heating of water or by the addition of lime to the water, which can form soluble bicarbonate that can be filtered out.

$$Ca(2HCO_3)_{(aq)} \longrightarrow CaCO_{3(s)} + H_2O_{(l)} + CO_{2(g)}$$

$$Ca(HCO_3)_{2(aq)} + Ca(OH)_{2aq} \longrightarrow 2CaCO_{3(s)} + 2H_2O_{(l)}$$

While the permanent hardness could be removed using caustic soda (NaOH) and washing soda ($Na_2CO_3.10H_2O$)

$$CaSO_{4(aq)} + Na_2CO_{3(aq)} \longrightarrow CaCO_{3(s)} + Na_2CO_{3(aq)}$$

$$CaSO_{4(aq)} + 2aOH_{(aq)} \longrightarrow Ca(OH)_{2(aq)} + Na_2SO_{4(aq)}$$

Costing

The high cost of producing and treating water for potable for consumption and other purposes has led to many private companies contemplating investing in water production. But for this case, the treatment of water for portable consumption lies in the hand of the Sokoto State Government. The Government provides all the materials for the production of safe and portable water such as land, chemicals, labour and machines.

Table 5: Cost of the chemicals consumed per day

Chemicals	Cost(N)	Demand	Daily cost
Alum ($Al_2(SO_4)_3$)	103,000	13tons/day	1,339,000
Lime ($Ca(OH)_2$)	78,000	2tons/day	156,000
Chlorine (Cl_2)	85,000	1tons/day	85,000
Total	266, 000	16tons/day	1,580,000

Source: Author's Analysis, 2022

Table 5 shows the cost of each chemical needed for treatment of certain liters per day. The cost of one ton of alum required for water treatment in Sokoto State Water Board is one hundred and three thousand naira and 13tons are required per day which will cost N1, 339,000. For the case of lime, each ton cost N78, 000 and the demand per day is 2tons. The daily cost of lime needed is N156, 000. For the chlorine which is used as a disinfectant to kill some bacteria and other microorganisms in raw water, 1ton is required daily and it is at the cost of N85,000. The total costs of the chemicals required for the treatment of raw water are 1,580,000 daily. The amount of money required monthly by the Sokoto State Government for the treatment of water is therefore 1,580,000 X 30= 47,400,000 monthly. Annually, the amount costing Sokoto state government is 47,400,000 x 12= 568,800,000. This amount shows the minimum yearly budgetary requirement for the effective treatment of water at the Sokoto State water board.

Conclusions and Recommendation

Assessing the costs of water treatment is one of the most crucial aspects in the feasibility and sustainability assessment of public water supply. Certainly, it is not always easy to either achieve a comprehensive knowledge of the costs associated with each treatment process or obtain comparable figures for various technologies. A detailed cost analysis by a process is therefore required to make useful cost predictions for operating plants, and for simulating new facilities.

The raw water must undergo a series of treatment processes before it can be considered safe and portable for drinking, domestic usage and other industrial purposes. There is no doubt that water plays a significant role in our life. The Sokoto State Government is putting more effort into providing clean and potable water to its citizen. This study highlighted the budgetary requirement for achieving safe, clean and potable water for Sokoto citizens. This cost analysis will inform policymakers on the need to ensure effective and sustainable funding to the state water board to guarantee a continued supply of clean water the residents.

In the light of the problems associated with water Quality treatment and costing in Sokoto metropolis as revealed in this study; it therefore recommends that; the government should provide new machines to replace the old ones in all the water treatment plants across the State. Government should increase the welfare of the staff especially those working in the chemical laboratories; hazard allowances should also be included in their salary with other incentives. Government should create more water treatment plants should be built across all other Local Governments; the State Government should also liaise with the Federal Government for the provision of chemicals for the treatment of water which will save some money for the State.

There is always required quality of water before its usage or consumption.it is therefore, recommended that Government should established water quality control laboratories across all the water treatment plants within the State. On the issue of cost of the water treatment, it is recommended that the Sokoto state water board should ensure the payment of water bills by residents through the use of technology such as metering the customers. This will help to augment the amount allocated to the board for treatment for the water and the shortfall in the amount needed for the provision of safe water for human consumption.

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