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Construction and Testing of a Treatment System for Raw Water

Ahanmisi E. Onuoha S. N. Atanda E. O. Ajayi A. S.
Department of Agricultural and Bio-Environmental Engineering Technology, Auchi Polytechnic Auchi

Abstract
Water is a wonder of Nature. One among the major problems confronting the world today is access to clean and safe water. The objective of the study was to assemble an affordable water treatment unit for domestic use. This study was carried out in Auchi, which is located between latitude 70 10' and 70 20' North of the equator and longitude 60 16' and 60 36' east of the Greenwich Meridian with an altitude of 207m. The components of the treatment system are raw water tank, coagulation tank, sedimentation tank, filtration chamber, micro filters, ultraviolent light and treated water storage tank. Sample of the raw water collected from River Orhle in Auchi was kept at a constant temperature in a refrigerator. The raw and treated water sample was collected in a four litres jerican for laboratory analysis to test for Turbidity, pH, Appearance, Taste, Colour, Electrical conductivity, total dissolved solid (TDS), Nitrates, iron content, total hardness etc. The results met the desired specifications and standards set by WHO and NAFDAC for potable water usage.
Keywords: Potable water, raw water, water treatment, slow sand filter, ultraviolent light, water quality

INTRODUCTION

Water is a wonder of the Nature. "No life without water'' is a common saying depending upon the fact that water is one of the naturally occurring essential requirements of all life-supporting activities. Any change in the natural quality may disturb the equilibrium system and it would become unfit for designated uses. The availability of water through surface and groundwater resources has become critical today. Only 1% is available on land for drinking, agriculture, domestic power generation, industrial consummation, transportation and waste disposal (Punmia *et al.,* 2004). The WHO (2004), estimates that 94% of diarrheal cases are preventable through modifications of the environment, including access to potable water. Simple techniques for treating water at home, such as chlorination, filtration, solar disinfection, and storing it in safe containers could save a huge number of lives each year.

Impurities in water are classified as; suspended, dissolved and colloidal. Suspended impurities are microscopic and normally remain in suspension, making the water turbid. Dissolved impurities are not visible, but cause bad taste, hardness and alkalinity. Colloidal impurities are electrically charged particles, usually very small in size that remain in constant motion and do not settle. One of the simplest ways to remove the small-sized particles is by filtration.

The common sources of water are; rain water, surface water, groundwater, and water obtained from reclamation. Flanagan(1992) reported that the usual physical and chemical parameters of groundwater include: Temperature (T), pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), total alkalinity (TA), total hardness (TH), calcium (Ca2+), magnesium (Mg2+), sodium (Na+),potassium (K+), chloride (Cl-), fluoride (F-), nitrate (NO3-), sulphate (SO42-) and chemical oxygen demand (COD), odor, taste, color, turbidity, pathogenic organisms, and salinity . The quality parameters of importance as far as domestic water is concerned are its physical, chemical and bacteriological properties. Haas (1999) argued that irrespective of water sources, some soluble salts are always dissolved in it. Among the soluble constituents of prime importance in determining the quality of water and its suitability for domestic use are calcium, magnesium, sodium, chloride and sulphate. All surface waters and some groundwater require treatment prior to consumption to ensure that they do not constitute health risk to the users.

Quality and quantity of water to be produced are two criteria issues that are considered in the construction of water treatment unit (Linsley and Franzini, 1979). It is necessary to consider the population of the area under study, the daily consumption rate and expansion because of population growth rate.

The treatment unit to be constructed utilizes the principle of slow sand filtration system. A slow sand filter (SSF) is a type of water treatment system suitable for domestic use or in small rural communities. It removes sediment and pathogenic organisms from contaminated water in a single treatment process. The advantages of SSF include (1) it can be constructed by local people, it does not require high technical skill (2) it can be built with local available material (3) it can be operated and maintained manually, it does not require machinery (4) It produces a microbiologically clean water which does not require disinfection.

According to Thames Water and University of Surrey (2005), the purpose of filtration is to remove the particulates suspended in water by passing the water through a layer of porous media. Basically, filtration process is a combination of physical (filtration, sedimentation, and adsorption) biochemical and biological processes. A number of complex forces (transport, attachment, and purification) contribute to each of these stages. SSF is more suitable to treat raw water with low to moderate turbidity and moderate to high dissolved oxygen concentration. Some transport mechanisms involved include laminar/turbulent flow, interception, straining, sedimentation, gravity, inertial and centrifugal forces, diffusion, mass attraction, advection, motility, hydrodynamic forces, and electro-static and electro-kinetic forces .

There are four basic components of slow sand filter system: (1) Raw (supernatant) water reservoir – to make maintain a constant head of water above the filter medium, the head provides the pressure that carries the water through the filter . (2) A bed of filter medium (sand) upon which various purification processes take place. (3) Under-drainage system which serves the purpose of supporting the filter medium and presenting minimum obstruction to the treated water as it emerges from the filter bed. (4) Control valves to regulate the velocity of flow through the bed to prevent the level in the raw water reservoir from dropping to minimum during operation.

One among the major problems confronting the world today is access to clean and safe water (Holiday, 2007). Apart from the variable rainfall in Auchi, Edo state, the only reliable source of water to certain extent is surface (river) waters. The potential hazards of pollutions are always higher when there is rainfall. The question now is whether these surface (rivers) waters are of quality standards for domestic purposes bearing in mind the poor sanitary condition and proximity of these waters to highly polluted environment, especially as these residents dispose their waste directly into the rivers. There are also boreholes and few wells in the study area but the quality of the water from all these sources are yet to be properly ascertained. The problem above forms the rationale behind the construction of a portable water treatment unit for domestic usage. The objectives of this study are to construct an affordable water treatment unit for domestic use. To produce water of high level of purity that will conform to the acceptable standards from the unit constructed and to eliminate the use of chlorine as its excess results to harmful by-products.

MATERIALS AND METHODS

Study area

Auchi is one of the fastest growing urban areas in Edo State. It is located between latitude 70 10' and 70 20' north of the equator and longitude 60 16' and 60 36' east of the Greenwich Meridian with an altitude of 207m. This area is made up of several quarters; they are Abotse, Ibie, Afedokhai, Usogun, Egereso, Akpekpe, Iyekhei, Igbe, Iyetse and Afobomhe. This area experiences the humid tropical climate, which is characterized by wet and dry seasons.

Components of the potable water treatment unit

Raw water/ Coagulation tank

The raw water/coagulation tank is a cylindrical plastic container measuring 0.90 m deep. The top and bottom diameters are 0.50 m and 0.4 m respectively. Also incorporated on the tank will be a coarse cylindrical strainer to help reduce algal and plankton effect and to trap undesirable particles from entering the sedimentary tank.

Sedimentation tank

The sedimentation tank consists of cylindrical plastic container with equal dimensions as that of raw water tank. Here, the raw water is allowed to settle for some minutes. The sedimentation tank was built to allow the upward flow of the settled water.

Plate 1: Raw water sedimentation tanks

Filtration chamber (slow sand filter)

This consists of plastic container, filter media (sand and gravel) and under drain pipe. Gravel materials were meant to provided support for the sand bed, and act as filter which prevents sand particles from blocking the under drain system (outlet) . It was first introduced into the container to a depth of 15 cm (0.15 m) as recommended by Stevenson (1994) that filters used in water filtration for domestic purposes should range from 0.15 m to 0.30 m in thickness. Then, the fine and coarse aggregates (sand) followed up as the first and middle layers of the media at a depth of 30 cm (0.30 m) and 10 cm (0.10 m) respectively (VanDijk and Oomen, 1978). The sand was light brown in colour and comprises of different grain sizes. It is completely free from clay, loam and organic matter. The material is common and abundant in the locality.

Plate 2: Slow sand filters

Micro filters

Microfiltration membranes (adsorbent) have pore sizes that vary from 0.5 to 5 microns. This is to separate suspended solids, bacteria, cysts and many other parasites whose diameter are larger than the pore size of the membrane. The adsorbent materials used were activated carbon because of its availability and affordability. According to Agunwamba (2001), adsorption is a process in which molecules leave the solution and are held in a surface by chemical and physical bonding. The absorbed material is called the adsorbate while the absorbing face is the adsorbent. The bonding is physical if it is reversible and chemical if it is irreversible. Adsorbent usually have large surface areas inside the particles (e.g. silica gel and activated carbon). Adsorption removes organics, taste, colour, turbidity etc.

Plate 3: Micro filters

Ultraviolet light (UVL)
The ultraviolet light chamber is used to generate ultraviolet wavelength with the desired germicidal properties and for delivery of the light to microbial pathogens, which is used for disinfecting the water. When properly connected and powered with electricity, it generates wavelengths of 200 – 300 nm, which inactivates most microorganisms, with the greatest amount of inactivation occurring around 260 nm.

Plate 4: Ultraviolet light

Storage tank
This stores the treated clean water which is ready for human consumption. It is well covered to avoid recontamination of the water.

Assemble of the water treatment unit
The four plastic containers which served as a separate chamber (tank) for raw water/coagulation, sedimentation, slow sand filter and storage processes respectively were fitted with PVC pipes to the outlets interconnecting them. They were connected through the orifices that were drilled on each tank. The area of contact between each pipe and each container was sealed with sealing material (PVC glue) to prevent leakages. The entire system was arranged in varying elevations to allow free flow by gravity. The slow sand filter media was linked to the four micro filters to further improve the quality of the filtrate. The micro filters were connected to the ultraviolet light chamber using 2.54 cm PVC pipe to ensure that the filtrate was sterilized. The ultra violet light was connected to the storage tank. The orthographic and isometric view of the complete set up is shown in the Appendices.

Collection and treatment of mineral river materials
The mineral river materials will be scooped from the bottom of Orhle River. The sand (fine and coarse) and the gravel materials will be separately washed manually with water repeatedly. The washed sand and gravel materials were disinfected by soaking in a solution of chlorine and concentrated hydrochloric acid for 24 h to unbind the organisms attached to them. The sand and gravel materials were later washed in distilled water, to reduce their pH.

Plate 5: Raw water sample collection from River Orhle Auchi

Operation of the treatment plant
The raw water flows from the raw water/coagulation tank into the sedimentation tank and from there it enters slowly into the slow sand filter chamber. The filtrate is passed through micro-filters for more filtration process and then through ultraviolet (UV) light chamber for sterilization. After the UV light the filtrate (clean water)

enters the storage tank. Each stage or process is connected to the other with a valve to regulate the movement of water. With the slow sand filter, water is passed slowly downwards through a bed of sand, where it is treated by a combination of biological, physical and chemical processes. The water passes through the three layers of the slow sand filter media (fine sand, coarse sand, and gravel). Fine particles in the water are filtered out by the sand, while a population of microorganisms grow on top of the sand filter and feed on bacteria, viruses and organic matter in the water. The rate of downward movement of water is kept so small that laminar flow conditions may be assumed to prevail throughout the filter bed.

The four micro filters (membrane filtration), operate on the principle of particle separation, based on pore size and pore size distribution. The micro filters further filter the water eliminating colour and odour problems. The first micro filter membrane was incorporated with a 5 microns activated carbon micro filter to trap suspended solids larger than 5 microns, absorb chlorine and many other contaminants and also to improve taste of the filtrate . The second, third and fourth micro filtration membranes had pore sizes of 5 microns, 1 micron and 0.5 micron respectively which trap suspended solids greater than their respective pore sizes . The filtrate then flows into the ultraviolet light chamber. The pathogens in the filtrate were inactivated or sterilized to produce a desired water quality ready for usage, which eliminates the use of chlorine. The stages of operation are as shown in Figure 3.1.

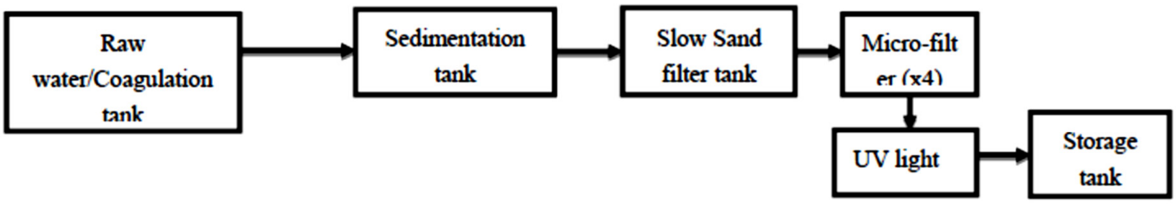

Figure 1: Flow chat of water treatment process

Water Sampling

Raw water samples were collected at a depth of 15 cm from OrhleRiver Auchi, in one-litre sterilized containers, kept in darkness at 4ºC until microbiological processing are completed . The samples will be collected in three replications across the width of the river (the two banks and the centre) by using a small canoe. It was collected in the morning hours (8.00 am) and transported under cold storage to the laboratory for analysis of the water quality.

Treated water samples were collected in one-litre sterilized containers in three replications and transported under cold storage to the laboratory for analysis. The essence of the cold storage was to keep the samples in stable condition.

Performance test of the portable water treatment plant

Sample of the raw water collected from River Orhle in Auchi was kept at a constant temperature in a refrigerator. The treated sample was also collected in a four litres jerican for laboratory analysis to test for Turbidity, pH, Appearance, Taste, Colour, Electrical conductivity, total dissolved solid (TDS), Nitrates, iron content, total hardness etc.

The laboratory test was carried out following standard procedures at FCT Water Board, Usuma Dam Water Works, Bwari Road, Abuja. The results of the test are presented in the next chapter and their corresponding, WHO, NAFDAC and NWRI standards for portable water.

RESULTS AND DISCUSSION

Result of the Performance test of the treatment plant

The results of physical analysis are presented in Tables 4.2. These values were compared with the WHO (2004), NAFDAC (2004), NSDWQ (2013) and National Water Research Institute (NWRI, 2013) standards of potable water.

Table 1: Results of the Test

S/N	Parameters	Raw water	Treated water	WHO standards	NAFDAC standards	NWRI
1	Turbidity (mg/L)	39.00	4.50	5.00	-	5.00
2	pH	7.40	6.82	6.9 – 8.4	6.5 – 8.5	6.5 – 8.5
3	Appearance	Brownish	U	U	U	Clear
4	Taste	Objectionable	U	U	U	-
5	Colour	82.00	6.00	5.00	-	-
6	Electrical conductivity $\mu s/cm$	78.40	60.80	100	-	-
7	TDS mg/L	34.70	31.60	100	500	500
8	Nitrates	19.20	7.20	-	-	-
9	Iron content (Fe)	1.42	0.2	0.3 – 0.5	<0.2	0.3
10	Total hardness	100	80.00	200	200	100

*Note: KEY – U = Unobjectionable, NQRI: National Water Research Institute, WHO: World Health Organization, NAFDAC: National Agency for Food and Drug Administration and Control

Source: (Laboratory Department, Usuma Dam, FCT Abuja)

Discussion of the Result

There was a considerable reduction in the value of turbidity from 39 mg/L to 4.5 mg/L which is within the acceptable limit of WHO. Evidently, the filter media in conjunction with the micro filtration membranes had drastically reduced the turbidity of the raw water through filtration, implying high retention capacity of the filters. This shows the efficiency of the filter materials and their arrangement. That is gravel was laid in layers commencing with larger size at the bottom, and reducing in size progressively to the top followed by sand grains.

The pH value of the treated water (6.82) is within the range of WHO and NAFDAC's acceptable standard for drinking water, which is satisfactory for usage. This indicates that the coagulate dosage (16 mg/L) was okay.

The Colour of the raw water was 82 units, which was reduced to 6 units, hence corresponding to the WHO and NAFDAC acceptable standard for drinking/domestic water (5units) indicating that the colour of the treated water was clear and colourless. In addition, the filtrate sample was tasteless and had an unobjectionable smell. This made the water safe and palatable for its desired usage. The TDS of the raw water was 34.7mg/L and after treatment it reduced to 31.60mg/L, which was also within the range of WHO. Total hardness of the raw water sample, which was 100 units reduced considerably to 80 units after treatment. Other parameters also reduced at various proportions like electrical conductivity 78.40 to 60.80 µs/cm.

There was significant reduction in nitrates (NO3), iron (Fe) and total hardness. Excess of these chemical parameters have adverse effects. For example, Isikwue and Chikezie (2014), highlighted that excess amount of nitrates in water causes an increase in algal growth and if in drinking water can be toxic to humans. Sources of nitrates may include human and animal wastes, industrial pollutants and non-point source, runoff from heavily fertilized croplands and lawns. High levels of nitrates in drinking water have been linked to serious illness and even death in infants.

The quality of water delivered depends on (1) the quality of raw water (2) the climatic condition particularly (3) the filtration rate and (4) the composition of the filter medium. It was observed that, high flow velocities allowed the passage of water through the filter bed with least resistance and consequently results in low filtrate quality. Also the lower the flow rate the higher was the filtration efficiency - hence the more acceptable water quality. Flow rate and turbidity should be paramount in the design and need to be carefully controlled in the filtration process.

CONCLUSION

A potable water treatment unit was constructed and assembled with a capacity of about 100l/day. The filtrate and raw water samples were collected and analyzed. The results met the desired specifications and standards set by WHO and NAFDAC for potable water usage. Having achieved the stated objectives, the following recommendations are made: The treatment plant should be kept clean and safe, the filters should be changed regularly to avoid contamination of the water being treated.

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