Design and Construction of a Prototype Household Water Purifier System

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Abstract

It is the general practice in Ogbomoso township, Oyo State, Nigeria, to construct hand-dug wells in residential plots of land to serve as reliable source of water supply. Most of these wells, due to constraints imposed by the size of the plots, are sited adjacent to septic tanks and soak-away pits inside or outside the compounds. The implication of this is that a sizable percentage of the indigent residents exposed to contaminated water are largely responsible for the prevalence of water-borne diseases in the township. To stem this menace on the short run, a simple and affordable preliminary Household Water Purifier System (HWPS) was designed and constructed. This purification system consists of composite filters (containing: sand, gravel and activated carbon), cartridges, as well as Ultra-Violet (UV) Lamp. Raw water samples (well water) were pumped into the system through Polyvinyl Chloride (PVC) pipes. Water samples from both the source and the outlet (purified water) were collected and then taken to the laboratory for physical, chemical and bacteriological analyses. The results from the tests were compared to Nigerian Industrial Standards (NIS) drinking water guidelines. It was observed that the HWPS was able to reduce to permissible levels physical contaminants, as well as most of the regularly checked chemical and bacteriological contaminants. It was observed that the HWPS filter media (aggregates, anthracite etc.) turned to a culture medium for bacteria growth when left for few weeks of inactivity. Conclusively, a number of challenges were identified, and the need for further research work on the HWPS was discovered.

Keywords: Household Water Purifier System (HWPS), Ultra-Violet (UV) Radiation, Polyvinyl Chloride (PVC) Pipes, Contaminants

Introduction

Human survival is dependent on water because it forms a fundamental part of life, which no person can live without. This has made water to be ranked by experts as second only to oxygen, for life to exist. An average adult body is made up of about 55% - 75% water, and two-third of every person's body weight is made up of about 40 - 50 quarts (37 - 47 liters) of water. A human embryo contains more than 80% water, and a new born baby contains about 74% water.

From the statistical data just disclosed, it is obvious that water is the largest component of the human body. It can also be deduced from the same data, that water is involved in all human body functions. Besides aiding in metabolism, water is used for body temperature regulation, and for the removal of toxins and body wastes. This "body-water" also cushions joints, and protects tissues and organs from shock and damage. Due to all these functions, each person needs to drink about half of their body weight in water daily i.e. a 70 kg man needs to drink about 35 kg (35 liters) of water daily to maintain good health. The World Health Organization (W. H. O) therefore recommends that every person needs to use a minimum of 150 liters of water per day, to satisfy their body, and environmental needs.

In addition to drinking water, people also use it for their everyday industrial, agricultural, sports, and transport activities. Some of the domestic (household) uses of water include: cooking, washing, bathing, etc. All other activities, events, machines, or processes in the daily lives of every human being, is centered on water, as it is present in all things around us.

The aim of the project work was to provide indigent families having potable water supply problems, with easy access to clean water, through the use of an efficient purification system.

The design and construction of an HWPS in Ogbomoso township, Oyo State, Nigeria, has become very essential, in view of the high cost of drilling, and running bore-hole water system. In Nigeria, only the rich can afford to spend large sums of money for drilling bore-hole water systems, thereby leaving more than 85% of the poor/ average income earners, with little or no access to potable water.

This project is limited to the hydraulic design, construction, and testing of an HWPS. Design criteria such as size, capacity, corrosion resistance, durability, availability, and cost, were considered for the selection of construction materials. The system components include: an Ultraviolet (U.V) lamp, one-horsepower (1 hp) pump, water pipes, slow sand filters, activated carbon filters, and electrical cables.

Water to be supplied for public use must be potable, i.e. satisfactory for drinking purposes from the standpoint of its chemical, physical and biological characteristics. Drinking water should be obtained from a source free from pollution.

Water is referred to as polluted when it is impaired by anthropogenic contaminants, and either does not support human use, such as for drinking; or undergoes a marked shift in its ability to support its constituent biotic community, such as fish. This has now become a major global problem. It has been suggested that polluted water is the leading worldwide cause of death and disease, and that it accounts for the death of more than 14, 000 people daily.

Many authors, amongst others, have worked on theoretical methods of water purification system, such as: Binnie et. al. (2002); Mallevaille et. al (1996) and Baker (2000). In addition to the acute problems of water pollution in developing countries, industrialized countries also continue to struggle with pollution problems as well. In the most recent national report on water quality in the United States, 45% of assessed streams, 47% of assessed lakes, and 32% of assessed bay and estuarine, were classified as polluted. This natural resource (water) is also becoming scarce in certain places, and its availability is now a major social and economic concern. Currently, about one billion people around the world routinely drink unhealthy water. This led to the decision of the G8 (2003) member countries to create the goal of reducing by half, the number of people worldwide, who do not have access to safe water and sanitation by year 2015. (W.H.O, 2008) also estimates that access to safe water can prevent the death of about 1.4 million children from diarrhea each year. However, since water is not a finite resource, it is always re-circulated as potable water in precipitation quantities of many degrees of higher magnitude than human consumption. Therefore, it is the relatively small quantity of water in the Earth's reserve (about 1% of our drinking water supply, which is replenished in water aquifers between 1 to 10 years), that is a non-renewable resource; and it is actually the distribution of potable and irrigation water which is scarce, rather than the actual amount of water that exists on earth.

Comparing the limited water sources with its daily high demand, as well as its high degree of pollution, it is obvious that urgent steps have to be taken to ensure that this highly demanded Earth resource is purified, and continues to be available in the quantity and quality for which it is needed. According to Yarn- Home & Industry Filters- South Africa (2011), water purification is the process by which every contaminant or micro-organism in a water sample is removed. The purification process has many steps. The steps that need to be followed depend on the type of impurities that are found in the water sample. This can differ for different types of water samples. Several water purification methods have been proposed, and implemented. Some of these are: collecting, water disinfection (majorly involving chlorine compounds), coagulation, settling, filtration, adsorption, aeration, fluoridation, neutralization, distribution, etc.

In Nigeria, only few of the water purification methods are currently being used, with water disinfection being the most widely used. Due to the usage of chemicals (especially chlorine) for the process, some side-effects come to place because of its use. The HWPS completely eliminates the usage of these chemicals, so that water can be cheaply purified and made available to residents, most of whom are economically impoverished. The Standards Organization of Nigeria has a section on its website where the Nigerian Standard for Drinking Water Quality (2007) is published.

Methodology

The HWPS was designed to work without chemicals, as it uses soft sand; coarse chippings aggregates; activated carbon; cartridge filters, and ultraviolet sterilizer to remove physical, chemical and biological contaminants. The three dimensional model of the HWPS is presented in Figure 1. The major component of the system is the two cylindrical composite filters, which are made of aluminum, and are 1.627 meters in height. Each filter also had a tripod footing on which it stood. The tripod footings of each filter were welded and bolted to its mobile support platform, which was made of angle steel bars. One of the platforms had a dimension of 1 m × 1 m × 0.05 m, and the other had a dimension of 0.8 m × 1 m × 0.05 m. The two filters were then connected to each other by PVC pipes, elbows, tees, male and female adaptors, union pipes, and ball valves.

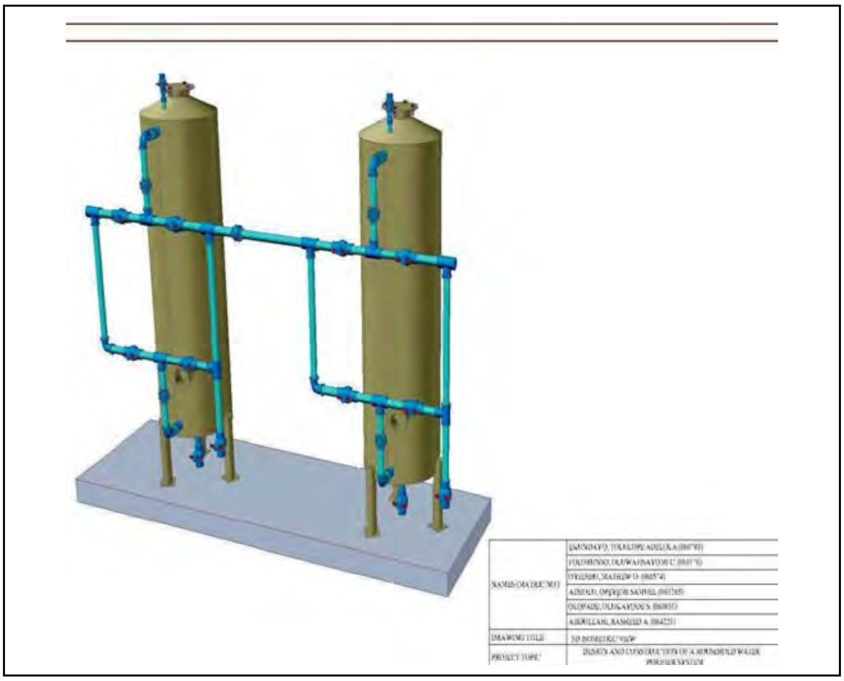

Figure 1: The Three Dimensional Model of the HWPS

A cylindrical pipe of 71 mm diameter perpendicularly intersects each filter central axis at 190 mm from its base. There is also a 32 mm diameter opening at the top and base of each filter, for the inflow and outflow of water through the filter; and there is a short pipe opening of 20 mm diameter at the frustum top section of each filter, which serves as an air valve. A top central opening of 71 mm diameter on each filter served as inlet for pouring the filtering media into the filter cylinder. This inlet is secured to each filter cylinder by three circular plates of 170 mm diameter.

Tee-pipes enable the simultaneous flow of water in three directions. As shown in Figure 2, the tee-pipe is made up of two short intersecting cylindrical pipes. The top opening of the tee-pipe has a 3 mm thickness, with an outer diameter of 38 mm, while the intersecting cylindrical pipe has a thickness of 5.5 mm, and an outer diameter of 43 mm. The height of the tee-pipe used is 70 mm, and its length is 77 mm.

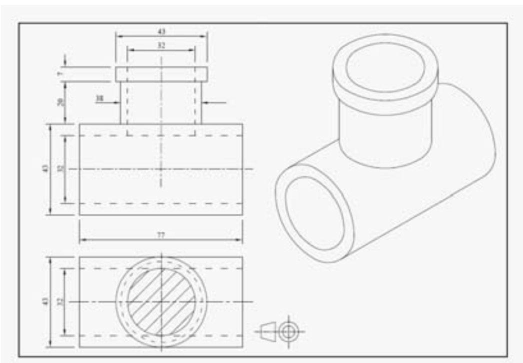

Figure 2: Tee Pipe

Male and female adapters were used as starting points for the connection of pipes to the front view openings. The adapters have two openings, and are threaded at the centre. They are of two basic types: 12.7 mm ($\frac{1}{2}$ inch) and 25.4 mm (1 inch) adapters. The 12.7mm ($\frac{1}{2}$ inch) adaptor shown in Figure 3, has a height of 36.5 mm, an inlet diameter of 28 mm with 4.5 mm thickness, and a 28 mm outlet diameter with 4 mm thickness.

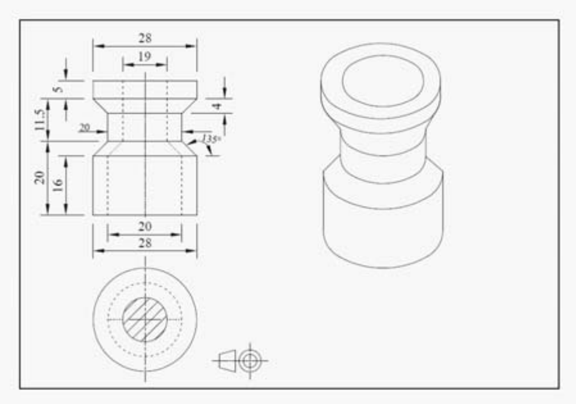

Figure 3: Half Inch Male & Female (M & F) Adapter

The 1 inch adapter shown in Figure 4, has a threaded inlet with 41.5 mm diameter, a thickness of 5.5 mm, and a outlet of 38 mm diameter with the same thickness.

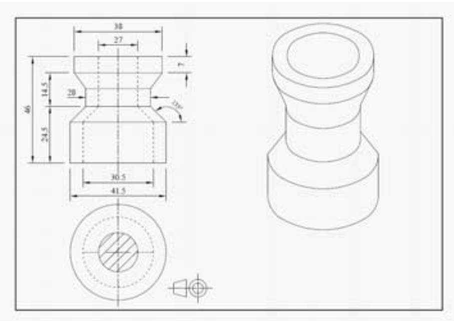

Figure 4: One Inch Male and Female (M and F) Adapter

Union pipes were also used to provide pipe connections at intervals where the HWPS could be disassembled when necessary. As shown in Figure 5, the pipe has its inlet and outlet threaded, with a diameter of 38 mm and 3 mm thickness, while its central union is of 55 mm diameter.

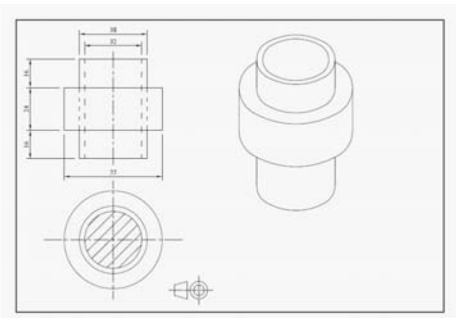

Figure 5: Union Pipe

An inlet pipe draws water from a non-potable water source (storage tank). This was done through a one horsepower (1 hp) electric pump. The inlet pipe was connected to a ball valve that allowed the water to flow through to the filters. When the pump was switched on, its delay element allowed the ultraviolet water sterilizer to "warm up" to full power in the ultraviolet chamber. This released an ultraviolet radiation that destroyed bacteria as water flowed through the chamber. An approximate ten second delay ensured that the water contained in the chamber was thoroughly purified by the ultraviolet radiation. Afterward, the water flows into filter F1, which is called the rapid sand filter. This filter removes particles with sizes as small as five microns, and it also removes any present water borne cysts.

The pressurized water then exits filter F1 and enters filter F2, which is called the activated carbon filter. This filter polishes the water to a crystal clear state, and also sweetens the water, thereby making it taste better. The F2 effluent water then enters a third stage, which comprises of three cartridge filters (with filtering sizes of 5, 1, and 0.5 microns). The water flowed through each filter in turn; beginning with the 5 micron cartridge filter, exiting at the final 0.5 microns cartridge filter. Stage-three cleaned most of the turbidity or dirt, and anything else that may have gotten past stage filters F1 & F2. The water then flows to the fourth stage, which is in the ultraviolet (UV) chamber. The UV chamber emits ultraviolet rays which kills all living organisms in the water, through their DNA exposure. After leaving stage-four, the initial non-potable water had been made potable for humans. In order to maintain its effectiveness, the rapid deep bed filter was back-washed (cleaned) about 10 to 20 minutes every day, after it was used.

The procedure for constructing the HWPS is as follows:

1. A 0.225 m × 0.125 m net was placed inside both filter cylinders as packing, to cover their perforated base. The packing at bottom of each filter cylinder was screwed with thin circular aluminum discs to avoid leakages.
2. Rapid Sand Filter (F1)
   (a) Coarse aggregates (chippings) of sizes ranging from 8 mm to 20 mm were poured through the top of the rapid filter cylinder F1, to a depth of 0.30 m. Prior to this, the bottom side of the filter was properly secured with screws, to prevent fall out of the chippings.
   (b) Fine aggregates of sizes ranging from 500 μm to 5.6 mm were poured into F1 to a depth of 0.3 m, after which the more coarse aggregates of sizes between 8 μm to 5.6 mm were poured in to a depth of 0.2 m. Hence, the height left for water to occupy in F1 during operation, was 0.52 m.
3. Activated Carbon Filter Stand (F2)
   (a) 19.05 mm (¾ inch) of coarse aggregates (chippings) were poured in to a depth of 0.05 m. This firstly served as the bed layer for F2, and also helped increase the stability of the activated carbon that would be poured in later. Just as was done for F1, the bottom side of F2 was also properly secured with screws, thereby preventing fall out of the chippings.
   (b) Granular activated carbon was then poured through the top of F2, to a depth of 0.75 m.
4. The inlets (at the top) for both F1 and F2 were secured with packing materials, and were tightly screwed to prevent water leakage during operation.
5. Pipe Connections (refer to Figure 6).
   a) A 12.7 mm (½ inch) diameter M & F adapter was connected to a 12.7 mm (½ inch) diameter ball valves at the top of F1 and F2, to serve as air valves.
   b) Another 625.4 mm diameter M & F adapter was connected to a 25.4 mm (1 inch) diameter ball valve at the bottom of F1 and F2, for flushing.
   c) M & F 1 adapter was connected to filter F1 inlet, and on to a 0.0762 m length pipe, which was then connected to a 25.4 mm elbow pipe (E1), and later connected downward to a pipe of length 0.127 m, and on to union pipe (U1), which was connected to a pipe of length 0.127 m, and on to a tee pipe (T2). At the left of T2, a pipe of length 0.127 m was connected to a 25.4 mm diameter ball valve (P1), which was then connected to a pipe of length 0.127 m, and on to tee pipe (T1). T1 was then connected downward to a pipe of length 0.508 m, which was connected to elbow pipe (E2). A pipe of length 0.127 m was then connected to the right side of E2, and on to a 25.4 mm diameter ball valve (P3), which was connected to tee pipe (T4). Another pipe of length 0.127 m was also connected downward from T4, and on to a pipe length of 0.127 m, which was connected to a union pipe (U2), and on to a pipe of length 0.127 m, which was connected to elbow pipe (E3), and was finally connected to a 25.4 mm (1 inch) diameter M & F 1 adapter pipe, close to bottom of filter cylinder F1.
   d) To the right of T2, a pipe length 0.127 m was connected to a 25.4 mm (1 inch) ball valve (P2), which was connected to a pipe of length 0.127 m, and on to tee

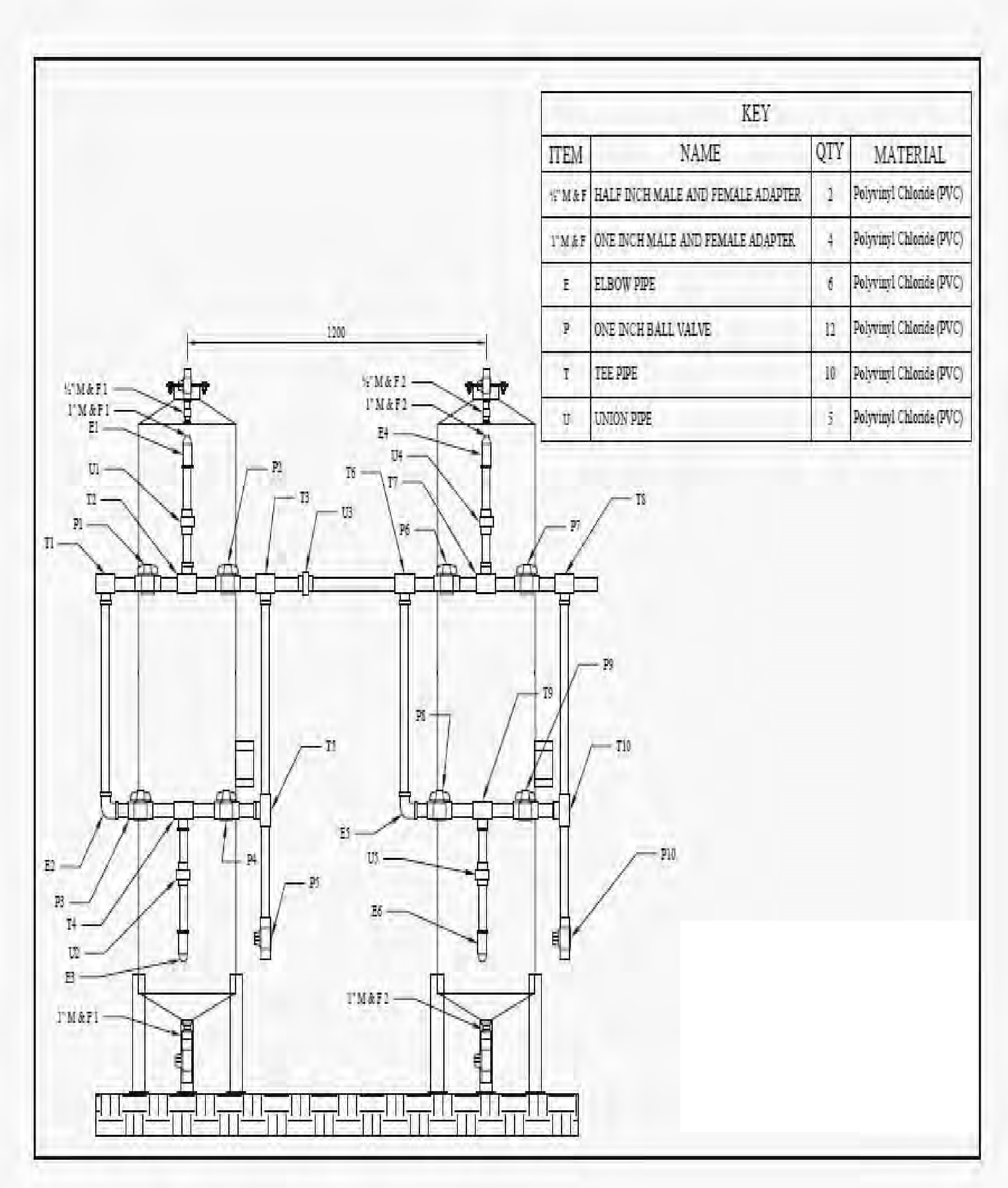

Figure 6: Schematic Diagram of the HWPS

e) pipe (T3). At the side of T3, a pipe of length 0.127 m was connected to union pipe (U3).
f) A pipe of length 0.508 m was connected downward from T3, to tee pipe (T5). From T5, another pipe of length 0.508 m was connected downward to a 25.4mm (1 inch) ball valve (P5).
g) At the left side of T5, a pipe length of 0. 254 m was connected to a ball valve (P4), which is to the right of T4. This makes the pipe network arrangement from (c) to (f) to form a closed loop. This completes the pipe network for filter F1.
h) For filter F2, the layout arrangement and size of the pipes are the same as that of F1.
i) A pipe of length 0.254 m was used to connect the two loops of F1 & F2 together. This pipe was connected to the right side of union pipe (U3).

j) At the outlet of filter F2, a 25.4 mm diameter pipe of length 0.08 m was connected, and serves as flow path for the effluent water from both F2.
k) An elbow pipe of diameter 25.4 mm was then used to extend the outlet pipe of F2 to a length 0.195 m . The end of this pipe was then connected to another elbow of 25.4 mm diameter, which was then connected to a pipe of length 0.13 m, which enters directly into the cartridge filters. These filters were connected in series, with the 5 micron cartridge filter being the first to receive the effluent water, followed by the 1 micron filter, and then the 0.5 micron cartridge filter.
l) A pipe of length 0.06 m was connected to the outlet of the 0.5 micron cartridge filter. This pipe was then connected to a 25.4 mm diameter union pipe, that was connected to the inlet of the UV sterilizer.
m) A pipe of length 0.054 m was connected to the outlet of the UV chamber to a 25.4 mm elbow pipe, and on to another pipe of length 0.093 m, which was connected to a union pipe.
n) Another pipe length of 0.178 m connected both the 25.4 mm diameter union and elbow pipes together.
o) Finally, a pipe of length 0.922 m served as the final outlet pipe to the reservoir (Point of Use).
p) Visual inspection of the entire HWPS was carried out to check for leakages at every pipe connection points. The final entire setup of the HWPS is as shown in Figure 7.

Figure 7:.Setup of the HWPS

Results and Discussion

Point of Use (POU) samples of the HWPS were collected and taken the same day to the Laboratory for Water analyses from the source (hand-dug well) behind the Food Science Laboratory of Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, Nigeria. The samples were tested for Phsyco-chemical and bacteriological tests using standard procedures. The tests were restricted to most of the regularly checked parameters of Nigerian Industrial Standard (NIS). The test result is as shown in Table 1.

Comparing Table 1 with Nigerian Industrial Standards (1987), it was observed that some parameters conformed to the standards. The parameters are presented in Table 2. Based on the present study, Tables 3, 4 and 5 compared quality parameter values between the source, effluent, and N.I.S Standard.

Conclusions and Recommendation

Based on the present work, the following conclusions are made:

1. The capacity of the aggregates, sand, anthracite and Ultraviolet (UV) sterilizer in the purification process, based on laboratory analyses, is confirmed.
2. The media (aggregates, anthracite etc.) will turn to a culture medium for bacteria growth if left for too long without use. This inactivity will ultimately increase the micro-biological activities in the effluent.
3. From the results, the HWPS was able to reduce the physical and chemical impurities by 100% and 92% respectively.
4. It was observed that the longer the run time of HWPS, the more efficient it becomes in removing pathogenic micro-organisms.

It is recommended that the HWPS should be used regularly to avoid excessive biological activities in the filters. In future, further investigation should be carried out to explore the possibility of reducing the size of the individual components to a more compact size for household use, without jeopardizing the quality of the treated water.

Acknowledgement

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Table 1: Test Results of Quality of Source Water and Effluent Water

QUALITY PARAMETER	**LEVEL OF PARAMETER**	**LEVEL OF PARAMETER**
PHYSICAL PROPERTY	**SOURCE (S) SAMPLE**	**EFFLUENT (E) SAMPLE**
APPEARANCE	Pale with brown particles	Clear with tiny particles
ODOUR/ TASTE	Odorless	Odorless
COLOUR (H.U)	20.00	5.00
TURBIDITY (N.T.U)	14.6	3.00
TOTAL SOLIDS (mg/ l)	410.00	302.00
TOTAL FIL. SOLID (mg/ l)	324.00	222.00
TOTAL NON FIL. SOLID (mg/ l)	86.00	80.00
CHEMICAL PROPERTIES		
CONDUCTIVITY		
pH AT LABORATORY	7.6	6.9
DISSOLVED OXYGEN (mg/ l)	5.0	2.0
TOTAL ALKANITY (mg/ l)	98.00	62.00
TOTAL HARDNESS (mg/ l)	178.00	128.00
CALCIUM HARDNESS (mg/ l)	70.00	42.00
CALCIUM ION (mg/ l)	28.00	16.80
Mg HARDNESS (mg/ l)	108.00	86.00
Mg ION (mg/ l)	15.98	4.80
SULPHATE (mg/ l)	< 35.0	< 25.0
CHLORIDE (mg/ l)	40.00	50.00
IRON AS Fe^{2+} (mg/ l)	< 0.1	< 0.1
SILICA (mg/ l)	9.00	8.00
NITRATE ION (mg/ l)	< 10.00	< 10.00
NITRITE (mg/ l)	< 5.00	< 5.00
CHLORINE DEMAND (ppm)	2.020	4.090

FLOCCULATION (ppm)	60	40 with 1% lime sol
BACTERIOLOGICAL EXAMINATION		
CHLORINE RESIDUAL (mg/l)	-	-
COLONY COUNT	120	0
MPN COLIFORM ORGANISMS	120	0
MPN E.COLI ORGANISMS	15	0

Table 2: Comparison between Effluent Water and Potable Water Standards.

QUALITY PARAMETER	EFFLUENT			N.I.S (2007)
PHYSICAL PROPERTIES				
APPEARANCE	Clear with tiny particles			-
ODOUR	Odorless			Unobjectionable
TASTE				Unobjectionable
COLOUR (H.U)	5.00			15
TURBIDITY (N.T.U)	3.00			5
TOTAL SOLIDS (mg/ l)	302.00			-
TOTAL FIL. SOLID (mg/ l)	222.00			500
TOTAL NON FIL. SOLID (mg/ l)	80.00			-
CHEMICAL PROPERTIES				
CONDUCTIVITY (µS/cm)				1000
pH AT LABORATORY	6.9			6.5 – 8.5
DISSOLVED OXYGEN (mg/ l)	2.0			-
TOTAL ALKANITY (mg/ l)	62.00			-
TOTAL HARDNESS (mg/ l)	128.00			150
CALCIUM HARDNESS(mg/ l)	42.00			-
CALCIUM ION (mg/ l)	16.80			-
Mg HARDNESS (mg/ l)	86.00			-
Mg ION (mg/ l)	4.80			0.2
SULPHATE (mg/ l)	< 25.0			100
CHEMICAL PROPERTIES				
CHLORIDE (mg/ l)	50.00			250
IRON AS Fe^{2+} (mg/ l)	< 0.1			0.3
SILICA (mg/ l)	8.00			
NITRATE ION (mg/ l)	<10.00			50
NITRITE (mg/ l)	<5.00			0.2
CHLORINE DEMAND (ppm)	4.090			-
FLOCCULATION (ppm)	40 with 1% lime sol			-
BACTERIOLOGICAL EXAMINATION				
CHLORINE RESIDUAL (mg/l)	-			0.2 – 0.25
COLONY COUNT	0			0
MPN COLIFORM ORGANISMS (CFU/ ml)	0			10
MPN E.COLI ORGANISM	0			0

Table 3: Physical Parameters of Source, Effluent, and NIS Standard

	SOURCE	STANDARD	EFFLUENT
PHYSICAL PARAMETERS			
COLOUR	20	15	5
TURBIDITY (NTU)	14.6	5	3
TOTAL FILTRATE SOLID	324	500	222

Table 4: Chemical Parameters of Source, Effluent, and NIS Standard

	SOURCE	STANDARD	EFFLUENT
CHEMICAL PARAMETERS			
pH	7.6	7	6.9
TOTAL HARDNESS	178	150	128
Chloride	40	250	50

Table 5: Bacteriological Parameters of Source, Effluent, and Standard

	SOURCE	STANDARD	EFFLUENT
BACTERIOLOGICAL PARAMETERS			
COLONY COUNT	120	0	0
MPN COLIFORM ORGANISMS	120	10	0
MPN E.COLI ORGANISMS	15	0	0