Investigating the Effectiveness of Ultraviolet (UV) Water Purification as Replacement of Chlorine Disinfection in Domestic Water Supply

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Abstract: Domestic water supply to residential buildings through hand-dug wells has been widely accepted as a reliable substitute to government owned municipal water supply system in Nigeria. This Paper investigates the effectiveness of Ultraviolet (UV) Water Sterilizers as a suitable replacement of chlorine disinfection in the removal of microbiological contaminants in domestic water supply. Water from an established contaminated well in Ogbomoso, Nigeria, were subjected, simultaneously and in parallel, to chlorine dosing and contact with UV light, over a period of seven (7) days without pre-filtration, and additional seven (7) days with pre-filtration. Pre-filtration was accomplished by the use of a calibrated pressure filter. Effluent water samples were taken daily for the two (2) scenarios to the laboratory for physical, chemical and biological analyses. The results indicated that UV water purification method was more effective only when pre-filtration of raw water was introduced. With monitored prefiltration prior to ultraviolet purification, the colony count, MPN Coliform Organisms and MPN E. Coli Organisms recorded seven day-average values of 1, 0 and 0, respectively. In both scenarios, it was confirmed that UV method produced no bi-products and did not alter the taste, pH or other properties of water, in contradistiction to chlorine disinfection method

Keywords: Microbiological Contaminants, Chlorine Disinfection, Ultraviolet Sterilizers, Efficiency, Bi-products, Pre-filtration.

1. Introduction

The continent of Africa is blessed with abundant natural water resources in large rivers, viz: Chad, Nile, Congo, Zambezi, Lake Victoria and Niger. In spite of this, millions of Africans still do not have access to potable water. In Nigeria, large conventional water supply schemes for domestic use, procured through World Bank loans and credit facilities obtained from multinational lending agencies, have proved largely to be unsustainable and inadequate to meet the needs of the ever increasing population. The reality today is that many communities in Nigeria do not have access to potable water supply for domestic use. A sizable percentage of the entire population have therefore resorted to alternative water supply through boreholes and hand-dug wells. It is amazing to note that almost every residential building, especially in high density areas, has a shallow well to meet its immediate water needs.

In most cases, water samples abstracted from these shallow wells have been found to be contaminated by leachates from septic tanks and soakaway pits located within the same residential compounds, or adjacent to it. This is confirmed by the prevalence of water borne diseases traceable to high density population areas. To stem the occurrence, residents have arbitrarily resorted to chlorine disinfection of their wells. The danger herein lies in the presence of poisonous excess residual chlorine in water meant for domestic use, which has been confirmed to produce harmful by-products called Trihalomethanes (THMs) linked to incidence of cancer.

Research over the years have identified Ultraviolet (UV) sterilizers as probably the most cost effective and efficient alternative technology available to home owners to eliminate a wide range of biological contaminants from their water supply. The advantages, according to research findings, lie in the fact that: it introduces no chemicals to the water, produces no bi-products and it does not alter the taste, pH, or other properties of the water.

Many researchers have carried out extensive work on the use of chlorine and ultraviolet sterilization lamps for the removal of microbiological contaminants from water meant for domestic use. Notable amongst such works are those published by [1-11].

This study investigated the effectiveness of Ultraviolet (UV) water purification as a suitable replacement for chlorine disinfection in domestic water supply.

2. Methodology

Water from an established contaminated well in Ogbomoso, Nigeria, was subjected, simultaneously and in parallel, to chlorine dosing and contact with UV light, over a period of seven (7) days without pre-filtration, and additional seven (7) days with pre-filtration. Pre-filtration was accomplished by the use of a calibrated pressure filter. Effluent water samples were taken weekly for the two (2) scenarios to the laboratory for physical, chemical and biological analyses.

For chlorine dosing, calcium hypochlorite, which was observed to be commonly used by home owners, was adopted for the study. A quantity of 5mg/l of calcium hypochlorite, in line with established literature, was applied to the raw water in the mixing chamber. A detention period of 24 hours was allowed to enable the chemical to penetrate through the cell wall of any pathogenic microorganism present in the water. It is confirmed that within the period, according to Paul and John (2005), chlorine will react through oxidation with organic matter and the pathogens in the water to kill them, react to form new chlorine compounds, or remain in the water as free residual chlorine.

Simultaneously, raw water from the same sampled well, was allowed, in the first instance without pre-filtration, and secondly, with filtration, to pass through a pipe into the attached ultraviolet (UV) inlet chamber. As water passes through the ultraviolet (UV) lamp, the pathogenic microorganisms in the water are exposed to ultraviolet (UV) radiation which inactivates organisms by absorption of the light which causes a photochemical reaction that alters molecular components essential to cell function. According to White (1992) and DeMars and Renner (1992), the energy released by the Ultraviolet (UV) rays reacts with nuclei acids and other vital cell components, resulting in injury or death of the exposed cells. Ultraviolet (UV) dosage, which is the most critical function of ultraviolet (UV) disinfection, was computed as afunction of the contact time. Contact time, which is the time the raw water is within the sterilization chamber, was defined by Clancy et al. (1997), as directly proportional to dosage. It is the amount of energy per unit area (calculated by dividing the output in watts by the surface area of the lamp), and thus the overall effectiveness of microbial destruction in the lamp. The product of intensity and time, known as the Dose, is expressed in microwatt seconds per square centimeter (uWsec/cm^2). With a contact time per litre of 4 seconds, cross-sectional area of ultraviolet lamp of 5.31cm^2, and a disinfected volume of 25 litres, the ultraviolet dosage was computed as: $\frac{4 \times 30}{5.31} = 22600 \mu wsec/cm^2$.

The mobile housing system for the study is depicted in Figure 1, while Figure 2 presents the schematic diagram of the photovoltaic system used to power the ultraviolet sterilizer. The maximum permiscible levels in drinking water of Physical and Organoleptic Parameters, Chemical Parameters and Biological Limits, outlined by the Nigerian Industrial Standard (NIS), are presented in Tables 1, 2 and 3, respectively.

3. Results and Discussion

The results of the averages over a seven day-period of physical, chemical and bacteriological analyses performed on samples taken from the contaminated well at the inlet and outlets, are presented in Tables 3 and 4. The outcome of the investigation is as outlined below:

1. **Appearance**
   Seven day-average of Contaminated Well Source Sample: Pale with brown particles
   Seven day-average of Ultraviolet Purification Method Sample: Clear with tiny particles
   Seven day-average of Chlorine Purification Method Sample: Pale with tiny particles
2. **Odour/Taste**
   Seven day-average of Contaminated Well Source Sample: Odourless
   Seven day-average of Ultraviolet Purification Method Sample: odourless
   Seven day-average of Chlorine Purification Method Sample: odourless
3. **Colour (TCU)**
   Seven day-average of Contaminated Well Source Sample: 20.00(unsatisfactory)
   Seven day-average of Ultraviolet Purification Method Sample: 5.00(satisfactory)
   Seven day-average of Chlorine Purification Method Sample: 30.00 (unsatisfactory)

The NIS requirements permit 15TCU for a good drinking water (Table 1).

Figure 1: Mobile Housing System Used for the Study

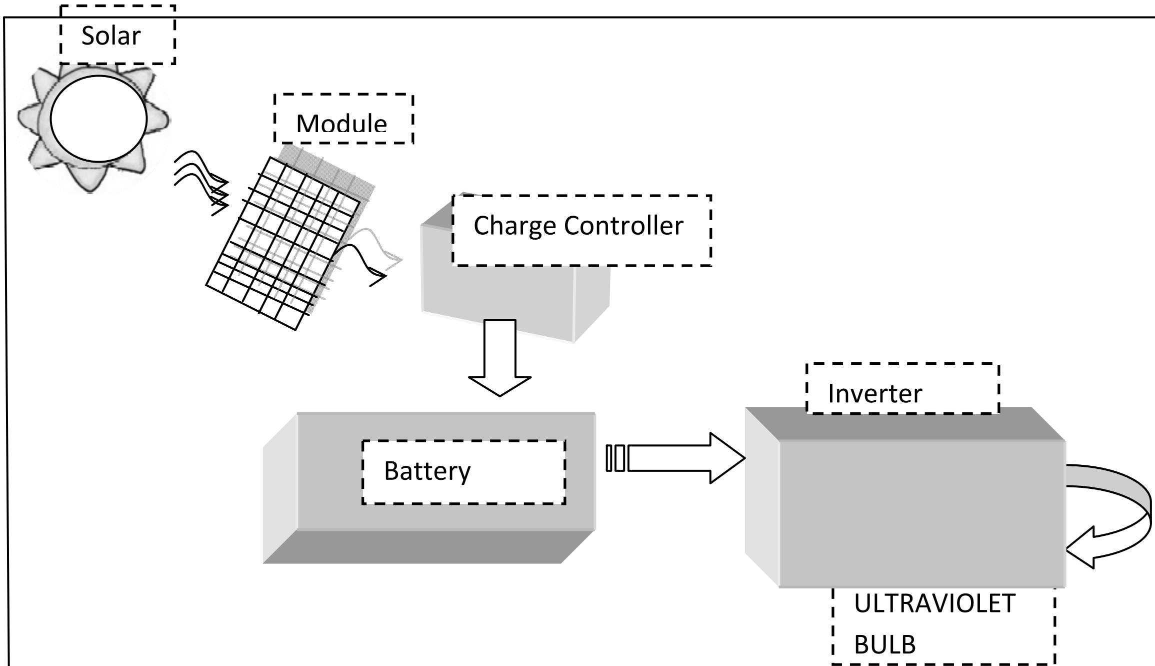

Figure 2: Schematic Diagram of a Photovoltaic System

Table 1: Physical / Organoleptic Parameters [12]

Parameter	Unit	Maximum Permitted Levels	Health Impact
Colour	TCU	15	None
Odour	-	Unobjectionable	None
Taste	-	Unobjectionable	None
Temperature	^{0} Celsius	Ambient	None
Turbidity	NTU	5	None

Table 2: Chemical Parameters (Inorganic) [12]

Constituents Parameter	**Unit**	**Maximum Permitted**	**Health Impact**
Aluminum (Al)	mg/L	0.2	Potential Neuro-degenerative disorders
Arsenic (As)	mg/L	0.01	Cancer,
Barium	mg/L	0.7	Hypertension
Cadmium (Cd)	mg/L	0.003	Toxic to the kidney
Chloride (Cl)	mg/L	250	None
Chromium (Cr6+)	mg/L	0.05	Cancer
Conductivity	µS/cm	1000	None
Copper (Cu+2)	mg/L	1	Gastrointestinal disorder,
Cyanide (CN-)	mg/L	0.01	Very toxic to the thyroid and the nervous system
Fluoride (F-)	mg/L	1.5	Fluorosis, Skeletal tissue (bones and teeth) morbidity
Hardness (as CaCO3)	mg/L	150	None
Hydrogen Sulphide (H2S)	mg/L	0.05	None
Iron (Fe+2)	mg/L	0.3	None
Lead (Pb)	mg/L	0.01	Cancer, interference with Vitamin D metabolism, affect mental development in infants, toxic to the central and peripheral nervous systems
Magnesium (Mg+2)	mg/L	0.20	Consumer acceptability
Manganese (Mn+2)	mg/L	0.2	Neurological disorder
Mercury (Hg)	mg/L	0.001	Affects the kidney and central nervous system
Nickel (Ni)	mg/L	0.02	Possible carcinogenic
Nitrate (NO3)	mg/L	50	Cyanosis, and asphyxia („blue-baby syndrome") in infants under 3 months syndrome") in infants under 3 months
Nitrite (NO2)	mg/L	0.2	Cyanosis, and asphyxia („blue-baby syndrome") in infants under 3 months
pH	-	6.5-8.5	None
Sodium (Na)	mg/L	200	None
Sulphate (SO4)	mg/L	100	None
Total Dissolved Solids	mg/L	500	None
Zinc (Zn)	mg/L	3	None

Table 3: Microbiological Limits [12]

Parameter	**Unit**	**Maximum Permitted Levels**	**Health Impact**
Total Coliform Count	cfu/mL	10	Indication of faecal contamination
Thermo Tolerant Coliform or E. Coli	cfu/100mL	0	Urinary track infections, bacteraemia, meningitis, diarrhea, (one of the main cause of morbidity and mortality among children), acute renal failure and haemolytic anaemia
Faecal streptococcus	cfu/100mL	0	Indication of recent faecal contamination
Clostridium Perfringens Spore	cfu/100mL	0	Index of intermittent faecal contamination

4. **Turbidity (N.T.U)**
   Seven day-average of Contaminated Well Source Sample: 14.6(unsatisfactory)
   Seven day-average of Ultraviolet Purification Method Sample: 3.00(satisfactory)
   Seven day-average of Chlorine Purification Method Sample: 18.00(unsatisfactory)

The NIS requirements permit 5N.T.U for a good drinking water (Table 1).

5. **Total Solids (mg/l)**
   Seven day-average of Contaminated Well Source Sample: 410(normal)
   Seven day-average of Ultraviolet Purification Method Sample: 322(normal)
   Seven day-average of Chlorine Purification Method Sample: 422(normal)

The NIS requirements permit 500mg/l for a good drinking water.

6. **Total Fil. Solids (mg/l)**
   Seven day-average of Contaminated Well Source Sample: 324(normal)
   Seven day-average of Ultraviolet Purification Method Sample: 222(normal)
   Seven day-average of Chlorine Purification Method Sample: 302(normal)

The NIS requirements permit 500mg/l for a good drinking water.

7. **Total Non-fil. Solids (mg/l)**
   Seven day-average of Contaminated Well Source Sample: 86(normal)
   Seven day-average of Ultraviolet Purification Method Sample: 100(normal)
   Seven day-average of Chlorine Purification Method Sample: 120(normal)

The NIS requirements permit 500mg/l for a good drinking water.

8. **Conductivity (μS/cm)**
   Seven day-average of Contaminated Well Source Sample: no conductivity
   Seven day-average of Ultraviolet Purification Method Sample: no conductivity
   Seven day-average of Chlorine Purification Method Sample: no conductivity

The NIS requirements permit 1000μS/cm for a good drinking water but it has no health impact.

9. **pH at Laboratory**
   Seven day-average of Contaminated Well Source Sample: 7.6(normal)
   Seven day-average of Ultraviolet Purification Method Sample: 7.5(normal)
   Seven day-average of Chlorine Purification Method Sample: 7.0(normal)

The NIS requirements permit between 6.5-8.5 for a good drinking water (Table 2).

10. **Dissolved Oxygen(mg/l)**
    Seven day-average of Contaminated Well Source Sample: 5.0(low)
    Seven day-average of Ultraviolet Purification Method Sample: 4.0(low)
    Seven day-average of Chlorine Purification Method Sample: 8.0(normal)
11. **Total Alkalinity(mg/l)**
    Seven day-average of Contaminated Well Source Sample: 98(satisfactory)
    Seven day-average of Ultraviolet Purification Method Sample: 92(satisfactory)
    Seven day-average of Chlorine Purification Method Sample: 108(satisfactory)
12. **Total Hardness(mg/l)**
    Seven day-average of Contaminated Well Source Sample: 178(satisfactory)
    Seven day-average of Ultraviolet Purification Method Sample: 138(satisfactory)
    Seven day-average of Chlorine Purification Method Sample: 188(satisfactory)
13. **Calcium Hardness(mg/l)**
    Seven day-average of Contaminated Well Source Sample: 70(satisfactory)
    Seven day-average of Ultraviolet Purification Method Sample: 66(satisfactory)
    Seven day-average of Chlorine Purification Method Sample: 78(satisfactory)

The NIS requirements permit 150mg/l for a good drinking water.

14. **Calcium Ion(mg/l)**
    Seven day-average of Contaminated Well Source Sample: 28.00(satisfactory)
    Seven day-average of Ultraviolet Purification Method Sample: 26.40(satisfactory)
    Chlorine: 31.20 (satisfactory)
15. **Magnesium Hardness(mg/l)**
    Seven day-average of Contaminated Well Source Sample: 108(satisfactory)
    Seven day-average of Ultraviolet Purification Method Sample: 72(satisfactory)
    Seven day-average of Chlorine Purification Method Sample: 110(satisfactory)

16. **Sulphate(mg/l)**
    Seven day-average of Contaminated Well Source Sample: <35(satisfactory)
    Seven day-average of Ultraviolet Purification Method Sample: <25(satisfactory)
    Seven day-average of Chlorine Purification Method Sample :< 25(satisfactory)

The NIS requirements permit100mg/l for a good drinking water.

17.Chlorine Residual(mg/l)

Seven day-average of Contaminated Well Source Sample: no chlorine residual
Seven day-average of Ultraviolet Purification Method Sample: no chlorine residual
Seven day-average of Chlorine Purification Method Sample: 0.25

18. Colony Count

Seven day-average of Contaminated Well Source Sample: 120
Seven day-average of Ultraviolet Purification Method Sample: 8
Seven day-average of Chlorine Purification Method Sample: no colony count.

19. MPN Coliform Organisms

Seven day-average of Contaminated Well Source Sample: 120
Seven day-average of Ultraviolet Purification Method Sample: 9
Seven day-average of Chlorine Purification Method Sample: no MPN Coliform Organisms.

The NIS requirements permit maximum total coliform count of not more than 10 for a good drinking water.

20. MPN E. Coli Organisms

Seven day-average of Contaminated Well Source Sample: 15
Seven day-average of Ultraviolet Purification Method Sample: 6
Seven day-average of Chlorine Purification Method Sample: no MPN E. Coli Organisms.

With monitored prefiltration prior to ultraviolet purification, the colony count, MPN Coliform Organisms and MPN E. Coli Organisms recorded seven day-average values of 1, 0 and 0, respectively. The other parameters were not monitored for this exercise as they do not have any significant influence on the investigation.

4. Conclusions and Recommendations

The following conclusions are drawn from the investigation:

(i) The ultraviolet disinfection should be applied cautiously as the UV dose required for the effective inactivation of pathogenic microorganisms is determined by site-specific data relating to the water quality. This observation is in agreement with [7-8].

(ii) Producing UV radiation requires electricity supply to power UV lamps. An independent photovoltaic system arrangement should be deployed in place of the unreliable and unsteady supply through Power Holding Corporation of Nigeria (PHCN).

(iii) UV disinfection system has its constraints since it is a physical process that requires a contact time to accomplish pathogen inactivation. It does not provide a residual to control pathogen proliferation and biofilm formation in the distribution system. It is recommended by [5] that some form of secondary chemical disinfection to maintain water quality within the distribution system. This will obviously negate the principal objective of this study.

(iv) Several factors, viz: chemical and biological films developing on surface of UV lamp, colour, turbidity and short-circuiting in water flowing through the UV sterilizer, could adversely affect the disinfection efficiency of UV, as observed during the investigation.

It is recommended that home owners in Nigeria be encouraged to substitute the affordable Ultraviolet (UV) Sterilizers as replacement to the arbitrary chlorine dosing in practice, in the removal (or reduction to acceptable limits) of microbiological contaminants from domestic water supply. Also, a form of pre-sedimentation (or pre-filtration) should be introduced prior to purification to achieve maximum efficiency of the process. The UV purification system can be deployed to inexpensively disinfect drinking water for poor communities in developing countries.

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