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Efficiency of Wastewater Treatment System and Its Use for Irrigation - A Case Study of a private University in Ghana

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Abstract

The reuse or utilization of treated wastewater for irrigation is conventionally considered as a means of mitigating water shortage or abating water pollution. Wastewater treatment plants designed for reuse in irrigation are more appropriate for developing countries striving to enhance access to improved sanitation. It is well known that successive stages of treatment of sewage effluent reduces the quantity of suspended solids, organic matter and nutrient load, bacteria population as well as biological oxygen demand to the extent that the final treated effluent contains virtually a small fraction compared to the influent sewage. A short-term assessment of the decentralised reuse-oriented effluent system of a private University (in Ghana) was carried out to determine its effluent quality for the purpose of irrigating its landscape. The investigation showed that Total Coliform, *E. coli* and *Vibrio spp.* were significantly reduced, through the treatment stages, but not to within Internationally accepted guideline values. *Salmonella spp.* was not significantly reduced. Physical parameters, nutrients as well as biological oxygen demand did not show any variation along the treatment stages. Suspended solids, optimum temperature and pH were identified as contributing to treatment inefficiency of the plant. It is therefore recommended the treated wastewater, prior to disinfection, should be filtered to reduce suspended solids. This will enhance effective chlorination and by extension, significantly reduce bacteria population. Furthermore Regular monitoring and laboratory analysis of the recycled effluent from the plant should be carried out by the EPA or other professional organisation to ensure compliance.

Keywords: Reuse, Wastewater, Irrigation, Chlorination

1. INTRODUCTION

Many environmental issues, particularly with water pollution and wastewater management have been reported in recent years within many developing countries. Similarly, the provision of good liquid waste treatment facilities have also become matters of growing concern in developing regions of the world. Rapid population increase and urbanization without adequate waste management has led to the pollution of both aquatic and terrestrial environment (Bosque-Hamilton, 1999).

In addition, untreated wastewater usually contains numerous pathogenic or disease causing microorganisms that dwell in the human intestinal tract. Wastewater also contains nutrients, which can stimulate the growth of aquatic plants leading to eutrophication and dissolved oxygen (DO) depletion. For these reasons, the immediate and nuisance-free removal of wastewater from its sources of generation, followed by treatment and disposal is not only desirable but also necessary in a modern society (Tchobanoglous *et al.,* 1991).

In many parts of the world, wastewater re-use is already an important element in water resource planning. The ultimate goal in wastewater treatment is its management in a manner in which the environment is protected, and also commensurate with public health, economic and social concerns (Tchobanoglous *et al.,* 1991).

In Ghana, many of the existing sanitation facilities are in disrepair and only 10 % of the approximately 70 wastewater and faecal sludge treatment plant function efficiently. Much of the failure is traced to limited institutional and financial capacity which has resulted in insufficient support for their operation and maintenance (Murray et *al.,* 2010).

Uncontrolled discharge of septic and faecal sludge has polluted the beaches, rivers and other water bodies leading to the main cause of cholera and typhoid. Currently, huge volume of raw faeces is dumped into water resources and the sea at Korle-Gonno in Accra thereby threatening human health, ecosystems and biodiversity (Bosque-Hamilton, 1999; Daily Graphic, 2013).

The disposal of wastewater is a major problem faced by municipalities, particularly in the case of large metropolitan areas, with limited space for land based treatment and disposal. On the other hand, wastewater is also a resource that can be applied for productive uses since wastewater contains nutrients that have the potential for use in agriculture, aquaculture, and other activities.

In both developed and developing countries, the most prevalent practice is the application of municipal wastewater (both treated and untreated) to land. In developing countries, though standards are set, these are not always strictly adhered to. Wastewater, in its untreated form, is widely used for agriculture and aquaculture and has been the practice for centuries in countries such as China, India and Mexico (Hussain *et al.,* 2002).

Reuse-oriented waste management systems on the other hand are able to deliver public and environmental health benefits associated with adequate sanitation, while also reduce significantly, capital and operational cost of wastewater and sludge treatment (Murray *et al.,* 2010).

Composition of Wastewater

Though the actual composition of wastewater may differ from community to community, all municipal wastewater contains the following broad groupings of constituents:

- Organic matter
- Nutrients (Nitrogen, Phosphorus, Potassium)
- Inorganic matter (dissolved minerals)
- Toxic chemicals
- Pathogens

A brief overview of the wastewater constituents, parameters, and possible impacts are given in table 1.

Table 1. Pollutants and contaminants in wastewater and their potential impacts through agricultural use.

Pollutants	Contaminants	Potential impact
Plant food nutrients	N, P, K, etc.	- Excess N: potential to cause nitrogen injury, excessive vegetative growth, delayed growing season and maturity and potential to cause economic loss to farmer - Excessive amounts of N, and P can cause excessive growth of undesirable aquatic species. (eutrophication) - nitrogen leaching causes groundwater pollution with adverse health and environmental impacts
Suspended solids	Volatile compounds, settleable, suspended and colloidal impurities	- Development of sludge deposits causing anaerobic conditions. - plugging of irrigation equipment and systems such as sprinklers
Pathogens	Viruses, bacteria, helminth eggs, fecal coliforms etc.	- can cause communicable diseases (discussed in detail later)
Biodegradable organics	BOD, COD	- depletion of dissolved oxygen in surface water - development of septic conditions - unsuitable habitat and environment - can inhibit pond-breeding amphibians - fish mortality - humus build-up
Stable organics	Phenols, pesticides, chlorinated hydrocarbons	- persist in the environment for long periods - toxic to environment - - may make wastewater unsuitable for irrigation
Dissolved inorganic substances	TDS, EC, Na, Ca, Mg, Cl, and B	- cause salinity and associated adverse impacts - phytotoxicity - affect permeability and soil structure
Heavy metals	Cd, Pb, Ni, Zn, As, Hg, etc	- bio accumulate in aquatic organisms (fish and planktons) - accumulate in irrigated soils and the environment - toxic to plants and animals - systemic uptake by plants - subsequent ingestion by humans or animals - possible health impacts - may make wastewater unsuitable for irrigation
Hydrogen ion concentrations	pH	- especially of concern in industrial wastewater - possible adverse impact on plant growth due to acidity or alkalinity - impact sometimes beneficial on soil flora and fauna
Residual chlorine in tertiary treated wastewater	Both free and combined chlorine	- leaf-tip burn - groundwater, surface water contamination (carcinogenic effects from organochlorides - formed when chlorine combines with residual organic compounds - greenhouse effect

Source: Partly adapted and updated from Asano *et al.,* (1985).

Waste water treatment processes

Wastewater treatment processes include waste stabilisation ponds, wastewater storage and treatment reservoirs, and septic tanks, up flow anaerobic sludge beds (UASB's) and constructed wetlands. These require low amount of energy for operation. Energy intensive systems include aerated lagoons, activated sludge systems, bio filters, and rotating biological contactors. These are preceded by primary sedimentation and all are followed by secondary sedimentation, and if required, by disinfection, commonly through chlorination or maturation ponds (Jiménez et *al.,* 2010). The following are some of the treatment processes Waste stabilisation ponds (WSP'S), Waste storage and treatment reservoirs (WSTR'S), Constructed wetlands, Up flow anaerobic sludge bed / blanket (UASB's)

In Ghana, a private University, aware of scarcity of water due to its location and the possibility of waste water treatment and reuse, initiated a decentralised liquid waste treatment facility on its new campus on the hills of Akwapim overlooking Berekuso Township. Its main water sources are harvested rainfall and a borehole. To manage its scarce water resources, the institution recover, recycles and re-use water from its domestic sewage (both black and grey water) for the irrigation of its landscape and Biogas production.

This study is aimed at determination of the efficiency of the system by evaluating the physico-chemical parameters (Temperature, pH, Electrical conductivity, suspended solids (SS), biochemical oxygen demand (BOD), Chemical oxygen demand (COD), total dissolved solids (TDS), sulphate, phosphate, ammonia, nitrate) of the final effluent of waste water for the purposes of irrigation and to compare derived values of bacteriological and physico-chemical parameters to internationally accepted guideline values.

It is anticipated that information generated from the analysis of its wastewater treatment system will reveal the system's efficiency and reliability.

The private university uses a decentralised/on-site reuse-oriented wastewater treatment system

Decentralised/on-site reuse-oriented wastewater treatment system

Urban wastewater reuse is developing rapidly, particularly in large cities. Japan is the leader in urban wastewater reuse, with 8% of the total recycled water (about 2,113 mg/d or 8 million m³/year) used for urban purposes. The most common urban uses are for the irrigation of green areas (parks, golf courses and sports fields), road cleaning, car washing and fire fighting. Another major type of reuse is on-site water reuse within commercial and residential buildings. For example, Australia, Canada, Japan and the UK use treated domestic wastewater for toilet flushing. Golf course irrigation is reported as the most rapidly growing application of urban water reuse in Europe. (USEPA, 1999) Wastewater treatment and reuse may have a lower cost than developing new water supply sources, particularly for low quality reuse in toilet flushing and similar non potable urban uses. (USEPA, 1999)

Decentralised or on-site, reuse-oriented wastewater treatment system uses an innovative technology which can be easily operated and maintained. Unlike conventional central treatment plants, it does not require massive capital to operate.

Urban planners and sanitation experts now see the importance of introducing and adopting decentralised systems for urban wastewater and faecal sludge management that utilise the resource potential of human liquid waste in ways that have the greatest benefits. It shifts the goal of sanitation from being solely the safe disposal of wastewater to maximizing the extent to which embodied resources are safely captured and allocated (Murray et *al.,* 2010).

Decentralised liquid waste treatment system used by the University.

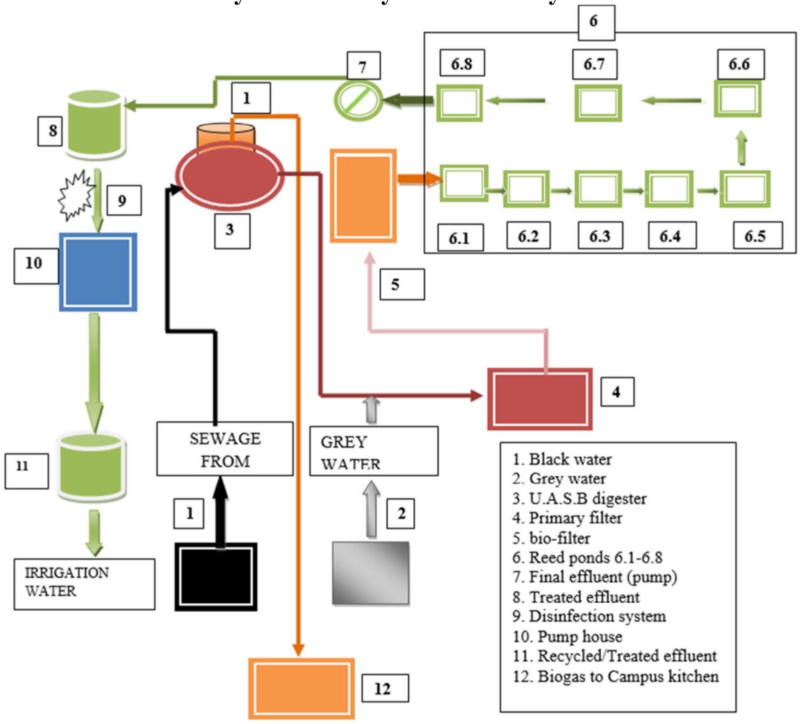

Figure 1: Decentralised liquid waste treatment system

Sewage from the University campus (i.e. faeces and urine) (1) is collected and transported into an Up flow Anaerobic Sludge Bed (UASB) (3) where the organic material is digested into a stabilised sludge. The effluent produced i.e. black water is channelled into a primary filter (4) where it is mixed with grey water from campus (2) (i.e. water from bathing, laundry and kitchen wastewater). The mixture is then filtered through an activated carbon in a bio-filter (5) from where it is routed through a series of eight constructed ponds/beds made up of Reed plant species (*Phragmites australis*) (6) used for phytoremediation in wastewater treatment. Bioremediation through bacterial action on the surface of roots and leaf litter removes some of the nutrients in biotransformation. The water finally flows into an effluent pump (7) from where it is pumped into Storage tank (8), through disinfection system (9), into a pump house (10). From here, the recycled/treated effluent is used for irrigation. Biogas produced from the UASB (11) is channelled to the campus kitchen (12) where it is used for culinary purposes.

Problems associated with decentralised liquid waste treatment systems

In spite of the numerous advantages associated with decentralised liquid waste treatment systems in developing countries, such as low investment, operational and maintenance costs, major constrains still exists. These are related to undefined and hazardous composition of the stabilised sludge and treated effluent, and the uncertainty of the design or applied technology which may not adequately handle all contaminants. Hodgson, 1998 reported the health risk associated with pathogens in treated effluents used for irrigation. Other general constraints relates to the fate of excess nutrients in the environment, fate of micro-pollutants, the fate of pathogens and problem related to soil salinization (Van Lier *et al.,1999*).

Etnier *et al.,* 2004 spoke about the little research done to establish the long term performance of decentralised wastewater treatment systems, with regard to their management, cost-effectiveness, reliability, maintenance and monitoring.

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Wastewater treatment and reuse may have a lower cost than developing new water supply sources, particularly for low quality reuse in toilet flushing and similar non potable urban uses. (USEPA, 1999)

Decentralised or on-site, reuse-oriented wastewater treatment system uses an innovative technology which can be easily operated and maintained, unlike conventional central treatment plants.

2. MATERIALS AND METHODS

2.1 Study area

On August 2011,the institution inaugurated its new permanent campus, Log W(0° 13′ 35″ W) Lat(5° 45′ 25″ N) on the Akwapim Hills which is 1180 metres above sea level overlooking Berekuso Township. As at 2014, it had a population of 550 students and an administration staff of 100. Its main water supply is a borehole during the dry season and harvested rainwater during the rainy season. These two water supplies are treated and distributed to the entire campus for potable use. To maximise efficiency in its water usage, the University resorted to reclaim all its wastewater for the irrigation of its landscape. Main sources of its wastewater are greywater (generated from laundry, bathing and meal preparation etc) and black water (i.e. liquid waste effluent) from its biogas plant. These two wastewater sources are mixed in an underground reservoir of primary filters from where they are filtered through a series of eight reeds ponds/beds, disinfected by chlorination and used for irrigation purpose.

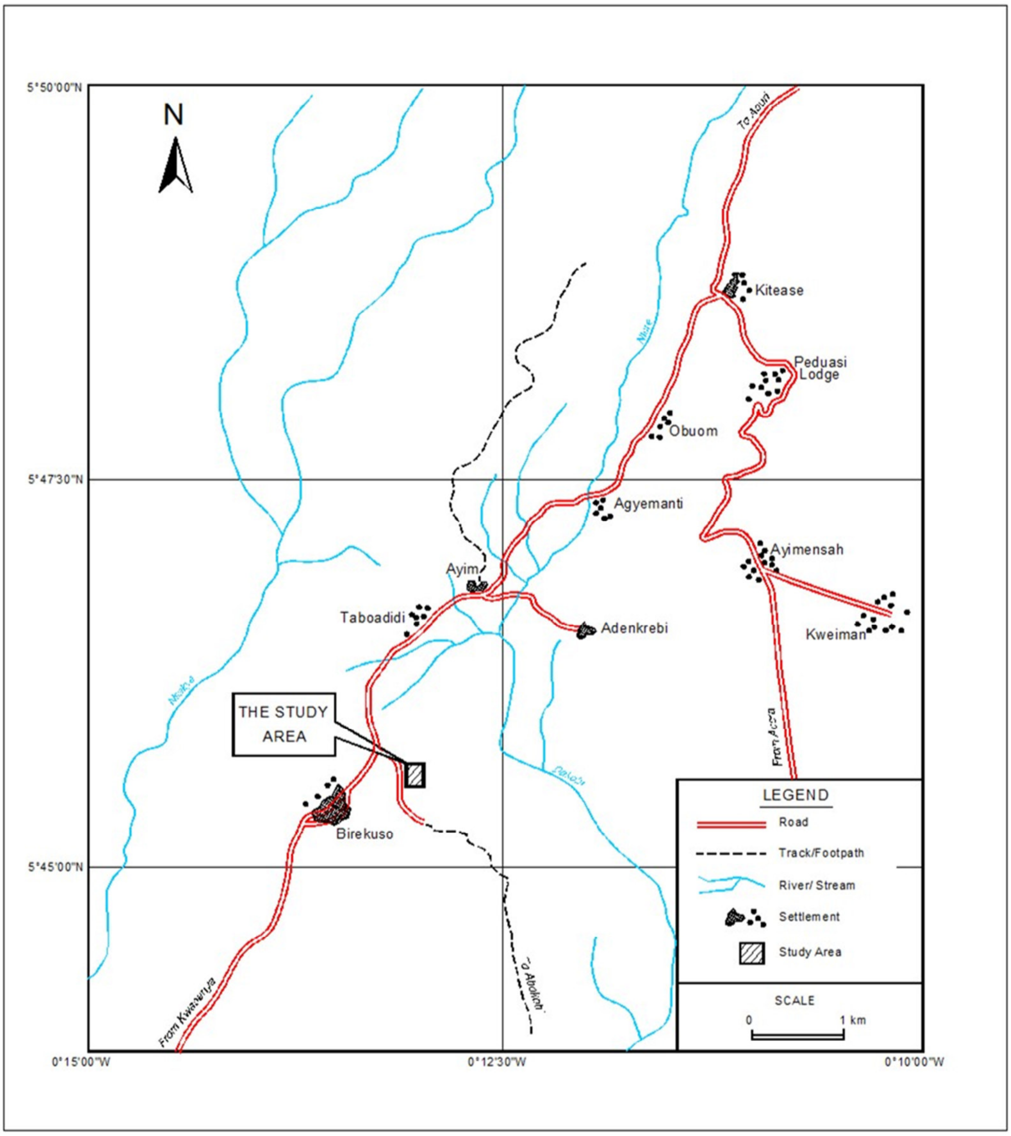

Figure 2: Study area

2.2 Sampling

Samples were taken from the primary filter, bio filter, Reed pond's (6.1), (6.3), (6.5) and (6.8) as well as final treated effluent i.e. irrigation water. Samples were taken at 11:00 am weekly within a three month period (March to the end of May).

Samples for Dissolved Oxygen (DO) were collected in narrow-mouth glass-stopper BOD bottles of 300 ml capacity with tapered and pointed ground glass stoppers. Sampling were carefully done to avoid entrapping atmospheric oxygen. DO was fixed on site using Winkler 1 and 2 solutions, (manganous sulphate monohydrate $MnSO_4.H_20$) and (alkali-iodide-azide solution) respectively. Fixed samples were transported to the laboratory under dark conditions. Samples for BOD were collected as done for DO but without fixing oxygen. Samples were stored near freezing temperatures and transported to the laboratory at 4°C. Samples for nutrients and other chemical parameters were done using clean sampling bottles of one litre volume.

Samplings for bacteriological parameters were done using a pre-sterilized bottle of 300ml volume. Bacteriological samples were stored temporary at 4°C. All samples were transported to the laboratory for analysis.

2.3 Analysis

Temperature and pH were taken in situ using mercury in glass thermometer and portable pH meter respectively. Other physicochemical parameters analysed were: Conductivity, Total Dissolved Solids (TDS) using gravimetric method, Total Suspended Solids (TSS) using gravimetric method, Dissolved Oxygen (DO) using Winkler method, Biochemical Oxygen Demand (BOD) using dilution method (winkler azide modification reagents), Chemical Oxygen Demand (COD) using closed reflux method, Ammonia-Nitrogen using direct nesslerization method, Nitrate using the hydrazine reduction method, Phosphate using stannous chloride method and Sulphate using turbidimetric method.

Salmonella spp and *Vibrio spp* were determination using the membrane filtration technique and were cultured using *Salmonella* agar 'öNöZ (HIMEDIA REF M 573)' and Thiosulphate-Citrate-Bile salt-Sucrose (TCBS) agar (Difco™) respectively. Also Total coliform bacteria and *E.coli* were determined using HiCromeTM Coliform Agar (Fluka)

3. RESULTS AND DISCUSSION

3.1 Physico-Chemical Parameters

The physical parameters used to assess the performance of the decentralised wastewater treatment system were temperature, pH, conductivity, total suspended solids as well as total dissolved solids; whiles the chemical parameters used are chemical oxygen demand, biochemical oxygen demand, phosphates, ammonia nitrogen, nitrate and sulphate. All results provided were mean values reported within the three months period of studies.

Table 2: Mean results from physicochemical analyses.

	PHYSICAL PARAMETERS					**CHEMICAL PARAMETER**					
SAMPLE ID	**TEMP.** °C	**pH**	**COND.** µS/cm	**TSS** mg/L	**TDS** mg/L	**COD** mg/L	**BOD** mg/L	**PO_4^{3-}** mg/L	**NH_3-N** mg/L	**NO_3-N** mg/L	**SO_4^{2-}** mg/L
PRIMARY FILTERED WATER	30.4	6.73	1609	105	704	327	158	1.51	6.84	0.245	54.6
BIOFILTER	30.5	6.73	1617	117	725	318	148	1.52	5.70	0.255	53.9
REED POND 6.1	30.3	6.72	1652	87	768	319	160	1.82	5.45	0.271	64.5
REED POND 6.3	30.4	6.78	1605	168	682	376	153	1.77	5.94	0.230	66.6
REED POND 6.5	30.4	6.80	1634	129	703	332	122	2.02	5.88	0.243	66.1
REED POND 6.8	30.5	6.73	1628	99	697	290	99	1.69	4.93	0.235	72.7
TREATED EFFLUENT	31.2	6.89	1677	54	740	266	98	1.11	4.79	0.231	65.6
RECYCLED/ TREATED EFFLENT	31.5	7.00	1787	66	721	181	80	0.96	4.30	0.172	70.9

3.1.1 Temperature

Mean temperature rose by 1.2ºC from 30.3ºC in the primary filter to 31.5ºC in the recycled effluent, a change which cannot impact on bacteria population. Figure 3 depicts the pattern of temperature variation along the treatment stages.

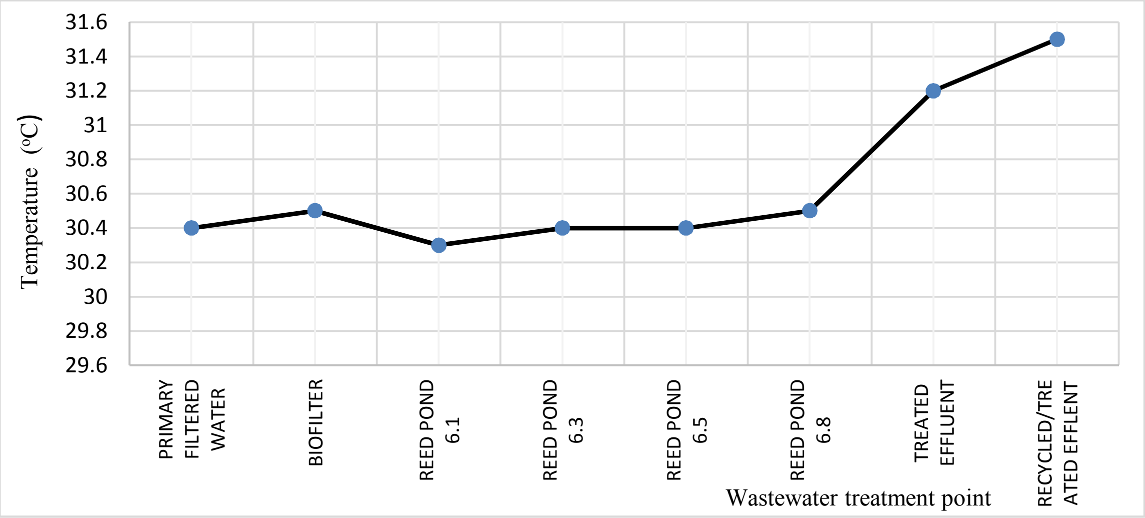

Figure 3 Mean values of Temperature along the treatment stage

The temperature of wastewater is commonly higher than that of freshwater because of the addition of warm water from household activities. It is a very important parameter because of its effect on chemical reactions, reaction rates, metabolic activities of bacterial population as well as the settling characteristics of suspended biological solids. In addition, chlorine evaporates quickly in warm water than in cold water rendering it ineffective in water treatment. Optimum temperature for bacterial activity is in the range from about 25ºC to 35ºC (Tchobanoglous *et al.*, 1991). The temperature recorded in the plant range from a minimum of 30.3 ºC in reed pond 6.1 to a maximum of 31.5 ºC in the recycled effluent. This means the temperature of the plant optimises bacteria growth.

There was no drastic change in temperature; from the ANOVA table ($p=0.056$) compared to $p< 0.05$ at 95% confidence limit, to influence a significant change in other parameters.

3.1.2 pH

Just as temperature, mean pH recorded at all the treatment stages did not show any significant change as depicted in the ANOVA table ($p=0.529$) compared to $p< 0.05$ at 95% confidence level. It was generally in the near neutral region which is ideal for bacteria growth, with the final recycled water recording a pH of 7.0. Figure 4 shows the pH variation pattern along the treatment stages.

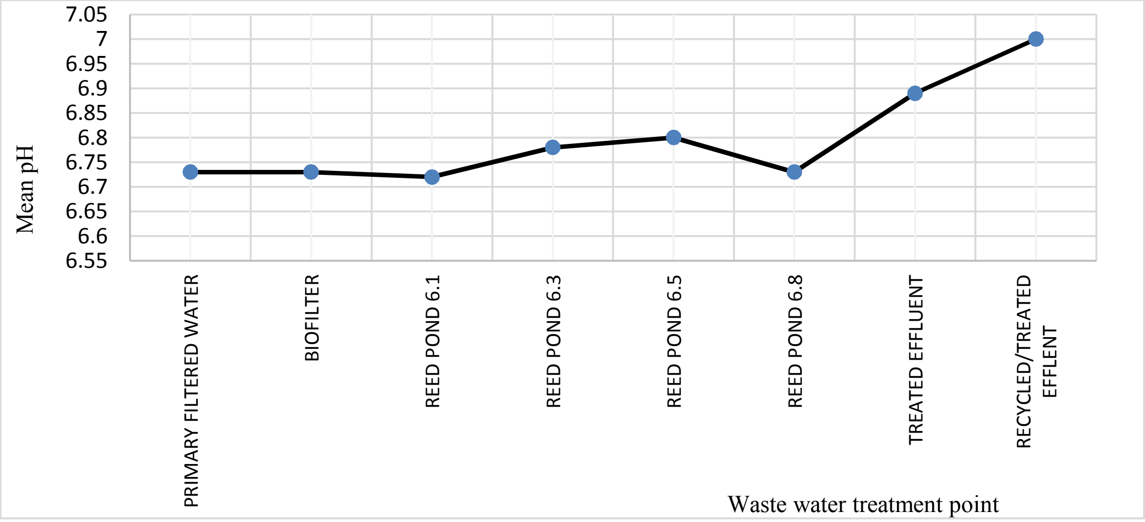

Figure 4: Mean values of pH along the treatment stage

3.1.3 Conductivity

Conductivity followed the same pattern as temperature and pH. It however correlated well with total dissolved solids (TDS). The ANOVA table shows ($p=0.821$) which depicts insignificant change when compared to $p< 0.05$ at 95% confidence limit. Figure 4 shows the pattern of conductivity changes along the treatment stages.

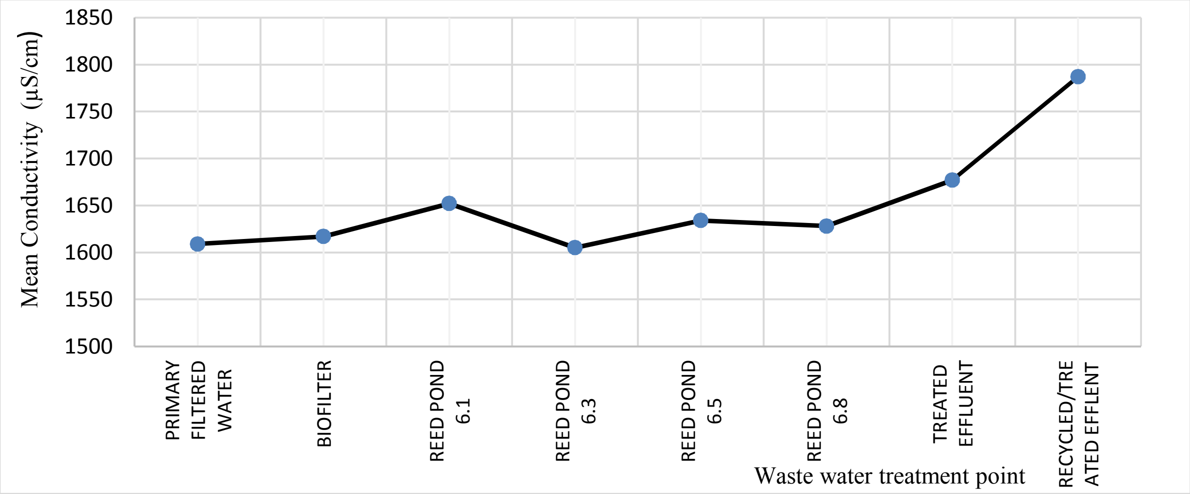

Figure 5: Mean values of Conductivity along the treatment stage

3.1.4 Total suspended solids (TSS and TDS)

Mean TSS value reduced from 105mg/L to 54mg/L at the treated effluent stage representing 48.6% reduction. It then rose by18.2% to 66mg/L in the final recycled effluent giving an overall reduction of 37.1%.

Mean TDS value increased steadily by 8.3% from the primary filter to reed pond 6.1. It then fell by 11.2% in reed pond 6.3; this pattern of rising and falling continued throughout the rest of the treatment stages to the final recycled effluent. TDS correlated very well with conductivity.

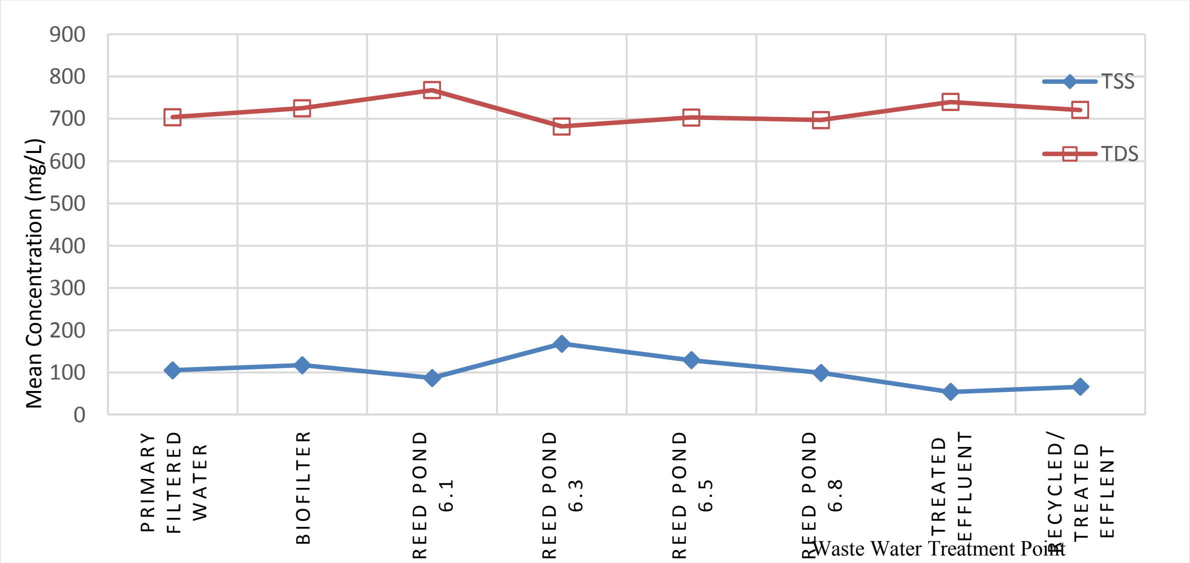

Figure 6: Mean values of TSS and TDS along the treatment stage.

Hodgson 1998, reported that effluents high in SS can cause sludge deposition and anaerobic conditions in receiving water body. SS can also cause havoc in irrigation systems where in the form of algae can block pipes, sprinklers and emitters (Fosu, 2009).

According to USEPA, 1999 Standard as well as WHO (2006) guideline for suspended solids in recycled wastewater, SS should range between (5-50) mg/L in secondary effluents. The USEPA however set a goal of (< 5-30) mg/L as treatment goal for recycled water. The final recycled effluent recorded 66 mg/L which was not satisfactory compared to both the USEPA Standard and WHO guideline. The ANOVA table also gave (p=0.580) which confirms the insignificant reduction of TSS when compared to $p < 0.05$ at 95% confidence limit.

Total dissolved solids (TDS) increased from 704 mg/L in the primary filter to 721 mg/L in the final recycled effluent. This correlated very well with conductivity which showed a parallel increase from 1609 µS/cm in the primary filter to 1787 µS/cm in the recycled effluent respectively.

Systematic increase in sulphate concentration along the treatment stages may possibly indicate increased mineralization as wastewater move slowly through the reed ponds. Since wastewater move slowly, aerobic bacteria oxidises products of anaerobic digestion in the UASB such as phosphorus, ammonia, nitrogen as well as sulphur into phosphates, nitrates and sulphates respectively. This together with cations such as sodium and potassium from soaps and other salts used by students and staff on campus may explain the increase in concentration of dissolved solids. This may have resulted in the high sulphate and TDS concentration and by extension, the parallel high conductivity values recorded in the final treated effluent.

However just as conductivity, the ANOVA table gave ($p= 0.896$) showing insignificant reduction when compared to $p< 0.05$ at 95% confidence limit.

3.2 Chemical parameters

3.2.1 Biochemical oxygen demand (BOD) and Chemical oxygen demand (COD)

From 158mg/L to 80mg/L, mean value for BOD was reduced by 50.6% in the final treated effluent. Figure 7 below shows a steady reduction of the parameter except in reed pond 6.1; 160mg/L and reed pond 6.3; 153mg/L. The mean COD value reduced from 327mg/L to 181mg/L representing 44.6%. It initially reduced by 2.3 % from the primary filter to the bio filter. From here, it increased to 376mg/L in reed pond 6.3 from where it reduced steadily along the rest of the treatment stages to 181mg/L in the final recycled effluent.

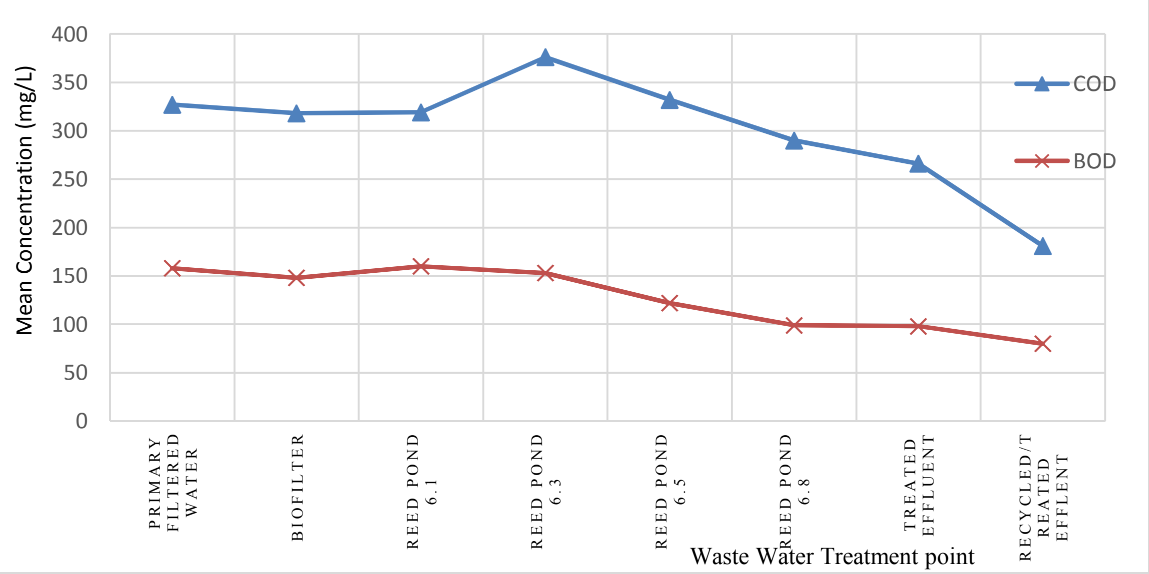

Figure 7: Mean values of BOD and COD along the treatment stage

Effluents high in BOD concentration can cause depletion of natural oxygen which may lead to the development of septic conditions (Hodgson, 1998). High BOD and COD concentration serves as substrate and can favour bacterial regrowth and fouling in distribution systems.

The USEPA maximum permissible limit for BOD is (10-30) mg/L and (50-150) mg/L for COD. The recycled effluent recorded 80 mg/L and 181 mg/L for BOD and COD respectively which is not satisfactory. The BOD level was higher than the Ghana Environmental Protection Agency (GEPA) value of <50mg/L BOD. The COD value however was within acceptable limits compared to GEPA value of <250 mg/L. High BOD and COD might have created the condition for bacteria regrowth.

The ANOVA table gave ($p=0.282$ and 0.668) respectively for BOD and COD, an indication that reduction is not significant when compared to $p< 0.05$ at 95% confidence limit.

3.2.2 Nitrate and Phosphates

Increase and decrease in Nitrate were observed along the various treatment stages except between the treated effluent and the final recycled water, where a sharp decline of the parameter was recorded. The overall reduction of Nitrate was 29.8 %.

Mean value for phosphates finally reduced to 0.96 mg/L in the recycled effluent from 1.51mg/l in the primary filter, representing 36.4%. The concentration rose gradually in the bio filter to reach a maximum concentration of 2.02 mg/L in reed pond 6.5 before falling steadily into the recycled effluent water. Refer to figure 8.

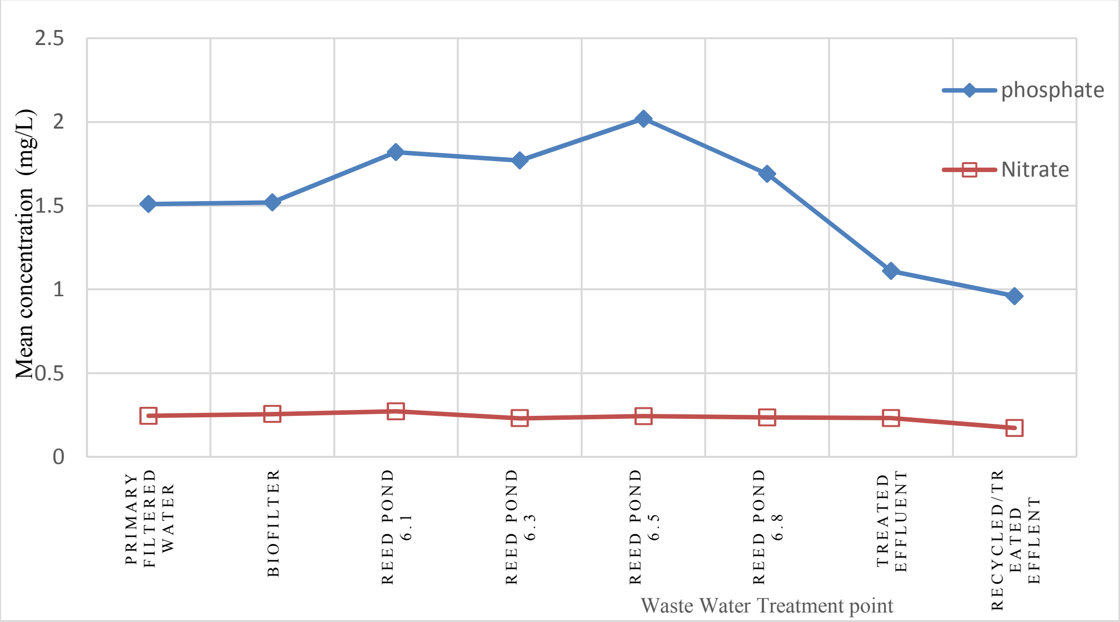

Figure 8: Mean values of Nitrate and Phosphate along the treatment stage

Nutrients such as nitrates and phosphates in wastewater serve as fertilizer for irrigation. They however can contribute to algal growth. Nitrogen in ammonia can cause corrosion in metal pipes and fittings through the process of nitrification while phosphorus in phosphates could cause scale formation. (Tchobanoglous *et al.*, 1991).

The recycled effluent recorded 0.172 mg/L and 0.96 mg/L for nitrate and phosphate respectively. The USEPA, 1999 gave a Standard of 1.0 mg/L for nitrate and 0.1 mg/L for phosphate. The plant therefore reduced nitrate efficiently but not phosphate. The presence of high phosphate may be attributed to the growth of algae and by extension, suspended solids.

The ANOVA table gave ($p= 0.940$ and $p = 0.690$) respectively for nitrate and Phosphate Respectively. An indication that the two compounds were insignificantly reduced when compared to $p< 0.05$ at 95% confidence limit.

3.2.3 Ammonia nitrogen and Sulphate

The mean value of Ammonia Nitrogen reduced by 29.2% to 4.84mg/L in the recycled effluent, from 6.84mg/L in the primary filter. The concentration of the parameter reduced steadily except in reed ponds 6.3 and 6.5 (5.94mg/L and 5.88mg/L resp.).

Mean sulphate concentration rose from 54.6mg/l in the primary filter to 70.9mg/l in the final treated effluent; representing a 22.9% increase. It is the only chemical parameter which increased in concentration in the final recycled effluent.

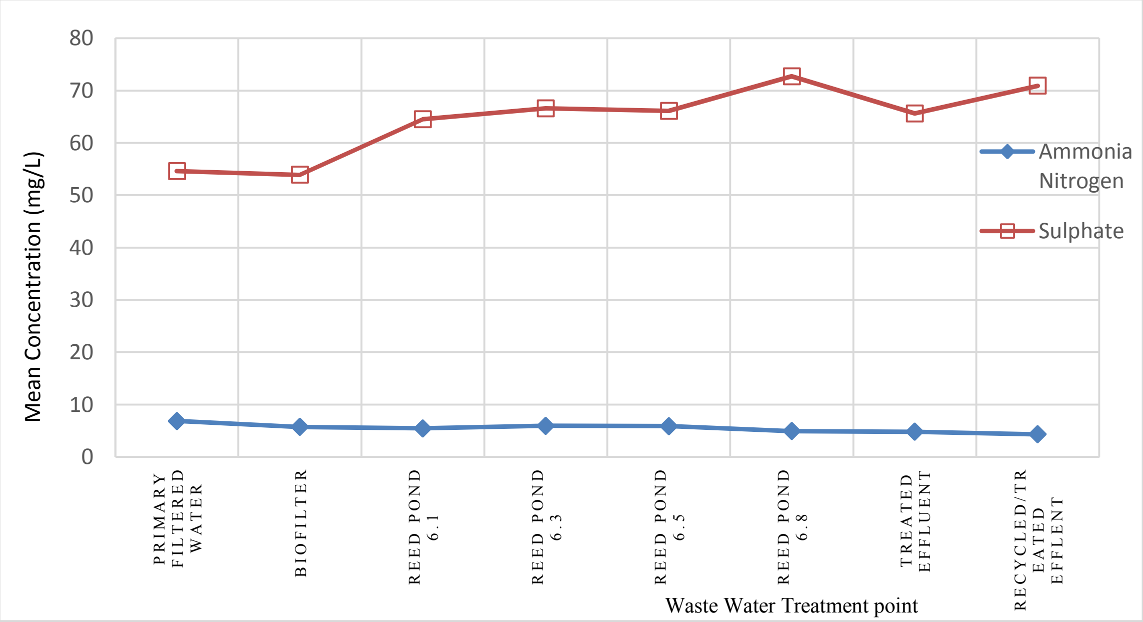

Figure 9: Mean values of Ammonical nitrogen and Sulphate along the treatment stage

Sulphates are components of soapless detergents and form a major part of the greywater which is mixed with black water at the treatment plant. Their chief sources are detergents used in laundry and in dish washing.

This is the only chemical parameter which increased from 54.6 mg/L in the primary filtered water to 70.9 mg/L in the final recycled effluent. This increase may be attributed to the breakdown of organic material originating from proteins in the anaerobic digester (UASB) releasing hydrogen sulphide. As the water flow slowly along the reed ponds, oxidation of this sulphur compound leads to its conversion to sulphite (SO_3^{2-}) which is further oxidised to sulphate (SO_4^{2-}) since the reed ponds operate under aerobic conditions.

Sulphate causes odour and sewer corrosion problems as a result of hydrogen sulphide being produced by bacteria reducing sulphates under anaerobic condition. Statistical analysis reveals that $p = 0.931$ and 0.744 respectively for Ammonical nitrogen and sulphate compared to $p<0.05$ at 95% confidence level.

3.3 Bacteriological parameters

Most pathogenic microorganisms remain in sewage sludge; however, some of them together with the resultant effluent can reach the environment. The quality of treatment method applied is thus of primary importance if the recycled water is to be used for irrigation. Recycled wastewater irrigation contributes to environmental sustainability by using the nutrients and water beneficially.

Major differences in bacteria population was observed in the final/recycled treated effluent. Mean removal efficiency of Total Coliforms, *E. coli, Salmonella spp. and Vibrio spp.* were 94.1%, 96.0%, 97.0%, and 96.9% respectively.

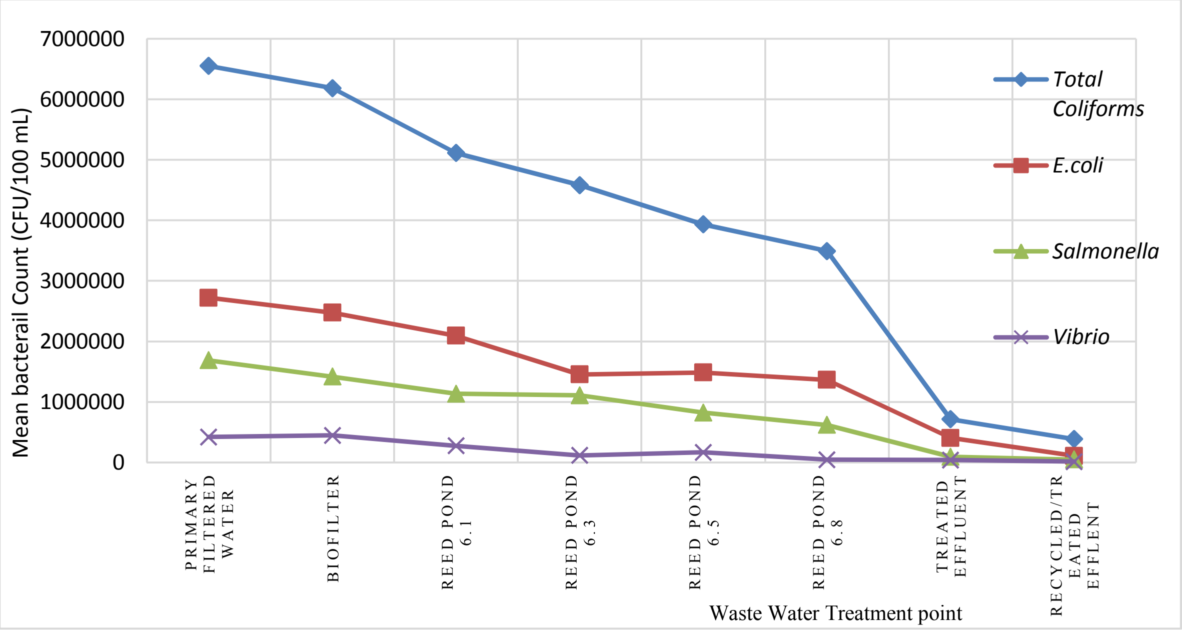

Figure 10: Mean Microbial concentration along the treatment stage

Total coliform bacteria (TC)

The overall reduction of total Coliform (TC) bacteria from the primary filter to the final treated effluent was 94.1 %. TC reduced steadily through the various treatment stages. Significant reduction of the bacteria (79.6%) occurred only between reed pond 6.8 and the treated effluent as depicted in Figure 13. The ANOVA table gave p=0.00 which shows there was significant reduction of TC as compared to $p<0.05$ at 95% confidence level. Figure 10 gives the overall trend of TC reduction.

E. coli

E. coli reduced steadily by 46.5% from the primary filter to reed pond 6.3. It however increased slightly by 2% between reed pond 6.3 and reed pond 6.5 before finally taking a sharp dive between reed pond 6.8 and the recycled effluent as depicted by Figure 10, giving a final percentage reduction of 96.0%.The ANOVA table gave p=0.00 indicating significant reduction compared to $p<0.05$ at 95% confidence limit.

***Salmonella* spp.**

97.0% overall reduction was achieved for *Salmonella spp.* between the primary filter and the final treated effluent. Reduction of the bacteria was steady throughout the treatment stages except between reed pond 6.1 and reed pond 6.3 where reduction was lowest (2.2%).It is the only bacteria parameter not significantly reduced as shown by the ANOVA table (p=0.607) when compared to $p<0.05$ at 95%confidence limit. Figure 15 depicts an overall reduction of *Salmonella spp.*

***Vibrio* spp.**

The overall percentage reduction of *Vibrio spp*. in the final treated effluent vis-á-vis the primary filter was 96.9%. On the whole, changes occurred as depicted by the ANOVA table (p= 0.002) when compared to p< 0.05 at 95% confidence limit, but not as significant as with the case of TC and E. coli. Figure 10 shows a sharp decline of Vibrio spp. population after initially rising slightly by 5.9% from the primary filter to the bio filter; from where the bacteria population declined sharply by 79.9% in reed pond 6.3. Population of the bacteria increased by 29.9% from reed pond 6.3 to reed pond 6.5 before it finally reduced by 62.2% at the recycled effluent.

Bacteria removal efficiency of the plant during this study may be attributed to adsorption or entrapment within the activated carbon used in the reed ponds to slow the flow rate of the wastewater. By this, an ideal condition is created for the settlement of suspended solids, removal of odour, reduction of excess nutrients and for the filtration of bacteria. The slow flow rate of wastewater in the reed ponds increases its retention time. This coupled with the exposure to UV rays from the sun contributed to bacteria death by providing a large surface area for effective bacteria-UV contact resulting in mortality (US EPA, 1999). This agrees with Fosu, 2009 who linked bacteria removal efficiency of sewage treatment plants to its flow rate and retention time.

Tchobanoglous *et al.,* 1991 reported that there is no uniform set of standards even in the USA for treated wastewater reuse. However, certain states in the US have developed reclaimed wastewater regulations for specific irrigation uses based on the expected degree of human contact and intended use. For example, the state of California requires that treated wastewater used for landscape irrigation with unlimited public access must be adequately oxidised, filtered and disinfected prior to use; with median TC count of not more than 2.2/100ml. The state of Florida requires no detectable faecal coliform per 100ml of recycled wastewater. Some Middle East countries, as reported by Beiruti *et al*., 2004 set a standard of ≤ 1000 faecal coliforms per 100ml of treated wastewater used for the irrigation of sports fields, public parks, tourist areas as well as hotel lawns. This standard conforms to WHO (2006) guidelines category A of ≤ 1000 fc/100ml and less than 1 helminth egg/L. In Jordan, as reported by Ulimat, 2012, compliance Standards for *E. coli* is set at 100c.f.u per 100ml while guideline value accepts the WHO (2006) guideline of 1000 c.f.u per 100ml. Exceeding this value must require that the end user must carry out scientific studies to verify the effect of that water on public health and the environment and means to prevent damage to either.

4. CONCLUSION

The mean bacteriological results of the recycled effluent indicated that the decentralised waste water treatment system performs below standard with regards to pathogenic bacteria removal. With the exception of *Salmonella spp.,* TC, *E. coli*, and *Vibrio spp.* were reduced significantly along the treatment stages as per ANOVA. Factors which might have contributed to the ineffective disinfection of bacteria at the treated effluent stage were (i) Suspended solids (TSS) which inhibits chlorine contact with bacteria thus rendering disinfection ineffective, (ii) Optimum temperature and pH for bacteria growth, and availability of nutrients such as nitrates and phosphates which encourage bacteria regrowth in storage tank.

The treatment plant was however not effective in reducing dissolved solids (TDS). This may be explained by the inability of the plant to reduce sulphate and possibly other dissolved solids resulting in the parallel increase in conductivity.

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