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Roton Wastewater Stabilization Pond Effluent Quality Evaluation for Levels of Organic Matter and E. Coli

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Abstract: *Wastewater Stabilization Ponds(WSPs) are large human-made basins for sewage or fecal sludge treatment. These ponds usually connected in a series of three or more with effluent discharged from the anaerobic pond to the facultative and finally to the aerobic pond. Bacteria in the wastewater decompose the raw organic matter in the wastewater flow. WSPs focus on removal of suspended and floatable material, biodegradable organic matter and elimination of pathogenic organisms. WSPs requires many days for sewage treatment and large land area. However, its low capital and operation and maintenance cost is an advantage. Wastewater samples were collected and analyzed in Addis Ababa, Ethiopia for BOD and E. Coli, with the subsequent analysis done in Juba South Sudan for COD and E. Coli. The average percentage removal of BOD and COD were -2.1% and -22.8% respectively. Over the two laboratory analysis, there was no coli forming unit (cfu) growth seen due to disinfection of wastewater that destroyed microorganisms in the sewage. Therefore, Roton WSP is inefficient in removal of organic matter.*

Keywords: *Wastewater, Stabilization Ponds, Organic Matter, Effluent, E. Coli*

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I. Introduction

1.1Background

Wastewater stabilization ponds are large human-made basins in which grey water or faecal sludge can be treated to an effluent of relatively high quality and which may be reused in agriculture (irrigation) or aquaculture (macrophyte or fish ponds). For the most effective treatment, WSPs (wastewater stabilization ponds) should be connected in a series of three or more with effluent being discharged from the anaerobic pond to the facultative pond and, finally, to the aerobic pond. The anaerobic pond is the primary treatment process and reduces the quantity of organic matter in the wastewater. The entire depth of this basin is anaerobic, where anaerobic bacteria act on the organic material present. Solids and BOD (Biological Oxygen Demand) removal occurs by sedimentation and through subsequent anaerobic digestion inside the accumulated sludge. Anaerobic bacteria transform organic carbon in the wastewater into methane and through this process, remove up to 60% of the BOD.

The effluent from the anaerobic pond is discharged into the facultative pond, where further removal of BOD takes place. The upper layer of the facultative pond receives oxygen from the atmosphere through diffusion, wind action and algae photosynthesis. The bottom layer is deficient of oxygen and becomes anoxic or anaerobic. Settleable solids collect at the bottom and are decomposed by anaerobic bacteria. The aerobic and anaerobic bacteria collectively work together to achieve BOD reduction of up to 75%.

Aerobic or maturation or polishing ponds are essentially designed forpathogen removal and retaining suspended stabilized solids (Mara et al., 1992; SASSE, 1998; Tilley et al., 2008). The size and number of maturation ponds depends on the required bacteriological quality of the final effluent.

Microorganisms in the biological treatment processes decompose the raw organic material in the waste flow. As they do this, they use oxygen as part of the respiration process. Instead of directly measuring the strength of the organic load as milligrams of sugars and proteins, we determine the amount of oxygen that the microorganisms use as they digest the raw organic matter in the wastewater. This is known as the Biochemical Oxygen Demand or BOD. Wastewater generated by commercial, industrial and institutional facilities is typically referred to as high strength compared to domestic wastewater. For instance, BOD of 110mg/l, 190mg/l and 350mg/l are low, medium and high strength respectively whereas COD of 250mg/l, 430mg/l and 800mg/l are low, medium and high strength respectively (Metcalf and Eddy, Inc., 2003). However, WHO recommends effluent quality for BOD ranges between 10-30mg/l.

COD is one of the most widely used parameters indicating organic pollution, applied to both wastewater and water. Being an alternative to BOD, the measurement of COD may be used todetermine the size of wastewater treatment facilities, the strength of sewage and efficiency of some treatment plant(Jain, 2014). COD is an imperative parameter in analyzing the quality of water parameter, since it gives an index to assess the impact of discharge on the receiving water body. The more the COD level the higher the oxidation in an organic compound in the sample, which will eventually reduce the dissolved oxygen (DO) levels. The subsequent reduction in DO can further lead to anaerobic condition, which is harmful to aquatic life(Jain, 2014).

Coliform bacteria are enteric bacteria. This means that they are found in the intestinal tract of warm-blooded animals, including humans. These bacteria, known as fecal coliform in humans, do not cause disease and are necessary for digestion of food. The waterborne pathogens are also enteric bacteria and are part of the coliform family. Therefore, if fecal coliform bacteria are present, pathogens may also be present. The coliform bacteria live longer in water and are easier to detect in the laboratory. This is the reason the coliform group has been chosen as the indicator organism for waterborne pathogens. If coliform bacteria are not present it is assumed there are no pathogens present either.

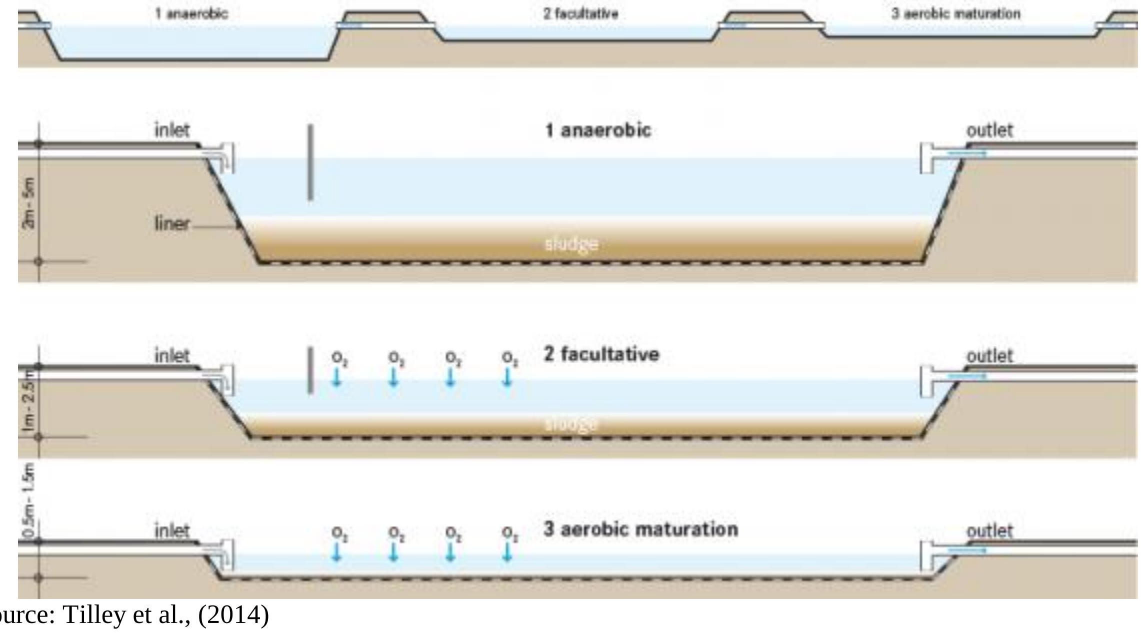
The removal of pathogens in WSPs takes place progressively along the pond series, with the highest removal efficiency occurring in the aerobic ponds (Mara et al., 1992).

Therefore, the primary objective of wastewater treatment is to allow human and industrial effluents to be disposedof without threat to human health or unacceptable damage to the natural environment. Treatment systems focus on removal of suspended and floatable materials,treatment of biodegradable organics, and elimination of pathogenic organisms(Linsley, R.K., et al., 1992).

The major disadvantages of WSPs are long process of days to weeks (Mara & Pearson, 1998) and require a large land area far away from homes and public spaces for construction (DFID, 1998). However, because of the low capital and particularly low operation and maintenance (O&M) costs, it is a good option for wastewater treatment in developing countries. In addition, it is one of the few low-cost natural processes, which provides good treatment of pathogens

Pond systems are typically used for BOD and TSS (Total Suspended Solids) when limits are 30mg/L. However, when limits are more restrictive or include nutrient limits, mechanical treatment is necessary.In developed countries, industrial, institutional and commercial entities are required to improve the quality of their wastewater effluent discharges from time to time. However, population and production increases have increased water use, leading to rise in wastewater quantity and its corresponding low quality.This increased water use and wastewater generation requires more efficient removal of organic matter and pathogens that allows for effluent discharges with reasonable or established environmental regulatory limits.

Figure 1. Typical scheme of a was testabilization system: Ananaerobic, facultative and maturation pond in series.



Source: Tilley et al., (2014)

Roton wastewater stabilization ponds consist of a bay or receiving station where septic tank trucks discharge wastewater daily, a grit channel, anaerobic pond and a facultative pond. Wastewater once discharged in the bay pass through a covered channel to the anaerobic pond, but more removal of solids is done just before the discharge drains into the anaerobic pond. Wastewater flows to the facultative pond by gravity. According to the Director for Sanitation in the Ministry of Housing and Physical Infrastructure, wastewater remains in the ponds for a period of 30 to 45 days before exiting the ponds. From the facultative pond, effluent water is discharged into a long channel through a pipe. Downstream of the WSPs is a wetland. The discharged effluent gets into the wetland. The WSPs was constructed in 2009 to handle wastewater from Juba City, initially about 50 sewage tankers on average discharging wastewater into the plant daily. But currently, on average 100 sewage tankers of different volumes (volume range from 7,000 to 36,000 litres) discharge wastewater daily. Roton WSPs is the only functional wastewater treatment facility currently in Juba with the capacity of 34,000 gallons per day.

The objectives for establishing Roton Wastewater Stabilization Ponds are:

- To allow human and industrial effluents to be disposed of without causing hazard to human health or unacceptable damage to the natural environment.
- To produce quality effluent which can be safely discharged to the environment or reused.
- To avoid the contamination of water supply.

Figure 2. Different sections of Roton WSPs

a) Bay or receiving station where sewage tank trucks discharge raw wastewater, 20/3/2016
b) Inlet where influent (raw wastewater) is discharged into the anaerobic pond, 20/3/2016
c) Anaerobic pond discharges effluent into the facultative pond, 20/3/2016.
d) Effluent exits the facultative pond to a channel, 20/3/2016.
e) Effluent discharges through a pipe into a channel that drains to a wetland, 20/3/2016.
f) Anaerobic pond filled with sludge and weed, 30/10/2017.
Photos by author.

1.2Research Problem

The organic loading and volume of influent wastewater discharge into Roton wastewater stabilization ponds probably upset treatment capacity of the plant which leads to low effluent quality discharge into the environment. Wastewater for treatment in aerobic ponds should have BOD_5 content below 300 mg/l (SASSE, 1998). Facultative and anaerobic ponds may be charged with high-strength wastewater. However, bad odour cannot be avoided with high loading rates. WSPs are not appropriate for very dense or urban areas. WSPs are recommended for the treatment in order to reuse the effluent in agriculture and aquaculture, because of its effectiveness in removing nematodes (worms) and helminthes eggs (WHO 2006, Volume II), while preserving some nutrients. WHO recommends that effluent quality to be discharged range from 10-30 mg/l. If reuse is not possible, WSPs may not be appropriate for areas sensitive to eutrophication (UNEP 2004).

1.3Significance of the Problem

- Observation from the colour shows the effluent seems not adequately treated.
- The plant seems inadequate in terms of capacity to handle the daily volume of sewage ferried to the plant by hundreds of sewage tank trucks.
- The effluent is discharged into a wetland which increases the risk of water contamination and eutrophication.
- There are human settlements in the vicinity of the WWTP which suffer from odour problem.
- Land around the sewage plant is being used to produce vegetables especially during the dry season that are sold to the public that may lead to health hazards.
- Area of the wetland is also likely to expand due to the existence and continuous discharge of effluent from the treatment plant leading to degradation of this wetland ecosystem.
- As the discharged effluent flows, it may contaminate open dug wells.
- There is limited capacity for management of the treatment plant in terms of human resources and infrastructure that may result in operational malpractices in the facility.
- Although effluent quality needs to be monitored frequently for BOD, COD, pathogens, etc., this is not possible at present due to limited technical capacity.
- No any investigation of this kind has so far been carried to assess the performance efficiency of this WSP since its construction in 2009.

1.4Objectives of the Study:

To evaluate the treatment performance of Roton WSPs and in so doing the study aims to:

1. Determine the organic matter (BOD_5/COD) removal efficiency of the WSPs.
2. Determine the E. Coli removal efficiency in the WSPs.

1.5Hypothesis

Probable treatment inefficiency of Roton WSPs may be due to:

1. High organic loading resulting in inefficient organic matter removal.
2. High hydraulic and flow rate that decreases HRT in the treatment processes, leading to inadequate organic matter and E. Coli removal.

1.6Scope of the Study

The study is meant to determine the efficiency of Roton WSPs in the removal of organic matter and E. Coli bacteriain the Wastewater and thereafter, recommend necessary action(s) in line with the study findings.

II. Literature Review

2.1 Wastewater stabilization ponds (WSPs)

Wastewater Stabilization Ponds (WSP) has been used world-wide for several decades for municipal and industrial wastewater treatment. This treatment system has been adopted and used to improve the physical, chemical or biological characteristics of wastewater. The WSP can be classified in regards to the type(s) of biological activity taking place in a pond. Three types of ponds may be distinguished: anaerobic ponds, facultative and aerobic ponds.

WSP method of wastewater treatment is well suited to countries in tropical and sub-tropical regions, because the abundance of sun light and higher temperaturescontributeto a more efficient removal of waste. WSPs have been used all around the world because of the efficiency to reduce waste through the application of microorganisms, although its effectiveness is affected by different climatic conditions in different locations.

WSPs are now regarded as the technology of preference for wastewater treatmentalmost all around the globe (Boutin et al., 1987; Bucksteeg, 1987). For example, in Europe, WSPs are mostly used for small communities (approximately a population of up to 2,000 people). However, larger systems are found in the Mediterranean region of France, Spain and Portugal (Boutin et al., 1987; Bucksteeg, 1987). The effluents of these ponds have several uses, like in agriculture, aquaculture, etc.

2.2 Wastewater stabilization ponds specification

Anaerobic ponds are built to a depth of 2 to 5 m and have a short retention time of 1 to 7 days. Facultative pondsare built to a depth of 1 to 2.5 m and have a retention time of between 5 to 30 days. Aerobic ponds are normally between 0.5 to 1.5 m deep with a retention time of 15 to 20 days. If used in combination with algae and/or fish harvesting, this type of pond is effective at removing the majority of nitrogen and phosphorus from the effluent. Ideally, several aerobic ponds can be constructed in series to provide a high level of pathogen removal. Pre-treatment is essential to prevent scum formation and to avoid excess solids and garbage from entering the ponds. To prevent leaching into the groundwater, the ponds should have a liner. The liner can be made from clay, asphalt, compacted earth, or any other impervious material. To protect the pond from runoff and erosion, a protective berm should be built around the pond. A fence should be provided to make sure that people and animals have no access to the area and that garbage does not enter the ponds.

The slightly polluted wastewater from the anaerobic pond may be discharged directly into primary facultative ponds. If requirement for the final effluent in terms of pathogen reduction is not so strict, only anaerobic and facultative ponds are necessary in some instances.

a) Anaerobic ponds (APs)

The main function of anaerobic ponds is BOD removal, which can be reduced 40 to 85 % (WSP, 2007). As a complete process, theanaerobic pondserves to:

- Settle undigested material and non-degradable solids as bottom sludge
- Dissolve organic material
- Break downbiodegradableorganic material

BOD removal inanaerobic ponds is attained by the same processes that take place in all otheranaerobicreactors (Mara et al., 1992) andanaerobic pondsdo not or only rarely contain algae. The process relies on the sedimentation of settable solids and subsequent anaerobic digestion in the resulting sludge layer. Duringanaerobic digestion, biogas is produced which could be collected by covering theanaerobic pond with a floating plastic membrane (Pena Varon, 2004;Wafler, 2008). The recovered biogas can be used for heating, cooking or, if sufficient amounts can be collected forenergyproduction.

The formation of odour and accumulation of residue has to do with the kind of waste that the pond is treating. This kind of concentration and volumetric load can be produced by sulphate (SO_4), whichis reduced to hydrogen sulphide (H_2S) under anaerobic conditions. The best solution for this case is to follow the recommendations of waste loadings. A small amount of sulphide is essential as it combines with the heavy metals to form insoluble metal sulphides (Mara et al., 1992).

b) Facultative ponds (FPs)

Facultative ponds are the simplest of all WSPs and consist ofaerobic zone close to the surface and a deeperanaerobic zone. They are designed for BOD removal and can treat water in the BOD range of 100 to 400 kg/ha/day, corresponding to 10 to 40 g/m^2/day at temperatures above 20°C (Mara and Pearson, 1998).

The algal production of oxygen occurs near the surface of aerobic ponds to the depth to which light can penetrate (i.e. typically up to 500 mm). Additional oxygen can be introduced by wind due to vertical mixing of the water. Oxygen is unable to be maintained at the lower layers if the pond is too deep, and the colour too dark to allow light to penetrate fully or if the BOD and COD in the lower layer is higher than the supply. As a result of the photosynthetic activities of the pond algae, there is a diurnal variation in the concentration ofdissolved oxygen. At peak sun radiation, the pond will be mostlyaerobic due to algal activity, while at sunrise the pond will be predominantly anaerobic (Ertas et al. 2005).

The facultative pondserves to:

- Further treat wastewater through sedimentation andaerobicoxidation of organic material
- Reduce odour
- Reduce some disease-causingmicroorganisms ifpH raises
- Store residues as bottom sludge

FPs looseammoniainto the air at highpH*;* and settle somenitrogenand phosphorus in thesludge. FPs can result in the removal of 80 to 95% ofBOD_5 (WSP, 2007) which means an overall removal of 95% over the two ponds *(*AP andFP*)*.Total nitrogen removal inWSPsystems can reach 80% or more, andammonia removal can be as high as 95%. To remove the algae fromaerobic pond, effluents*'* rockfiltration, grass plots, floatingmacrophytesand herbivorous fish can be used, but most commonly, theeffluent flows directly in a finalmaturation pond.

***c)* Aerobic / Maturation ponds (MPs)**

Whereasanaerobicand facultative ponds are designed for BOD removal, maturation or polishing ponds are essentially designed forpathogen removal and retaining suspended stabilized solids (Mara et al., 1992; SASSE, 1998; Tilley et al., 2008). The size and number of maturation ponds depends on the required bacteriological quality of the final effluent. The principal mechanisms for faecal bacterial removal in facultative and maturation ponds areHRT, temperature, high pH(> 9), and high light intensity.Virus andmicroorganisms get also removed. If used in combination with algae and/or fish harvesting, this type of pond is also effective at removing the majority of nitrogen andphosphorus from theeffluent(Tilley et al., 2008).

2.3 Cost of Wastewater stabilization ponds

According to the International Water and Sanitation Centre (IRC), stabilization ponds are the most cost-effective wastewater treatment technology for the reduction of disease causing microorganisms in wastewater. But this depends largely on the availability of land and its cost. Stabilization ponds also have the advantage of very low operating costs since they don't use energy compared to other wastewater treatment methods not mentioning the low-tech infrastructure used in WSPs. This makes WSPs suitable for underdeveloped countries where many conventional wastewater treatment plants have cease to operate because water and sewer utilities did not generate sufficient revenue to pay the electricity bill for the plant (IRC 2004).

However, expert design is still greatly required. Further, the ponds can be combined with aquaculture to produce animal feed (e.g. duckweed) or fish (e.g. fish pond).

2.4 Operation and maintenance (O&M)

Once the WSPs operate, it is necessary to carry out the maintenance work. The maintenance of WSPs is simple and easy to manage. According to Mara and Pearson, (1998):

Scum that collect on the surface of the pond should be removed. Aquatic plants that grow in the pond should be cleared because they may become breeding place for mosquitoes and even block light from penetrating the water body.

The anaerobic pond must be de-sludged approximately once every two to five years when the accumulated solids reach one third of the pond volume.Accumulated solids reduce the detention time of the pond, which can reduce treatment.Most solids will deposit within a certain radius of the influent pipe, causing a "volcano" type build-up effect. Sometimes solids may only need to be removed in the near vicinity of theinfluent sewage pipe to ensure solids do not affect the influent sewage flow rate. For facultative ponds, sludge removal is rare and aerobic ponds hardly require de-sludging. Sludge can be removed by using a raft-mounted sludge pump, a mechanical scraper at the bottom of the pond or by draining and dewatering the pond and remove the sludge with a front-end loader.The WHO (WHO, 2005; Morel and Diner, 2006) does not promote pond systems if appropriate mosquito control measures are not put in place.If the water is reused for irrigation, the salinity of the effluent should be controlled regularly so that it does not impact the soil adversely,

2.5Application of WSPs

Wastewater in maturation ponds should have BOD content below 300mg/l (SASSE, 1998). Facultative and anaerobic ponds may be charged with high-strength wastewater. But bad odour cannot be avoided especially with high loading rates. WSPs are among the most common and efficient methods of wastewater treatment around the world. They are especially well suited for rural communities that have large, open and abundant lands far from homes and public places and where it is possible to develop a local collection system. They are not suitable for urban areas. WSPs are suitable for tropical and sub-tropical countries because of the abundance of sunlight and elevated temperatures which are key factors for their efficiency (IRC, 2004). In cold climates, the HRT and loading may be adjusted. However, when mean temperatures fall below 12^{O}C during several months of the year, WSPs seem not to be appropriate (Arthur, 1983).

WSPs are also recommended for the treatment of wastewater in order to reuse the effluent in agriculture and aquaculture, because of their effectiveness in removing nematodes (worms) and helminthes eggs (WHO, 2006. Volume II), while preserving some nutrients. If reuse is not possible, WSPs may not be adequate for areas sensitive to eutrophication (UNEP, 2004)

2.6Advantages and disadvantages of WSPs

a) Advantages

- Resistant to organic and hydraulic shock loads
- High reduction of solids, BOD and pathogens
- High nutrient removal if combined with aquaculture
- Low operation cost
- Electrical energy not required
- No real problem with flies or odour if designed and maintained properly
- Can be built and repaired with locally available material
- Effluent can be reused in aquaculture or irrigation in agriculture

b) **Disadvantages of WSPs**

- Requires large land area
- High capital cost depending on the price of land
- Requires expert design and construction
- Sludge needs proper removal and treatment
- De-sludging, normally few years
- Mosquito control needed
- If the effluent is reused, salinity needs to be monitored
- WSPs are not appropriate for colder climates

2.7 Strength of wastewater

The strength of wastewater is determined by measuring the amount of suspended material in the water and the amount of organic material in the water. The organic strength of the wastewater is determined indirectly. The microorganisms in the biological treatment processes decompose the raw organic material in the waste flow. As they do this, they use oxygen as part of the respiration process. Instead of directly measuring the strength of the organic load as milligrams of sugars and proteins, we determine the amount of oxygen that the microorganisms use as they digest the raw organic matter in the wastewater. This is known as Biochemical Oxygen Demand or BOD. Wastewater generated by commercial, industrial and institutional facilities is typically referred to as high strength compared to domestic wastewater. For instance, BOD of 110mg/l, 190mg/l and 350mg/l are low, medium and high strength respectively whereas COD of 250mg/l, 430mg/l and 800mg/l are low, medium and high strength respectively(Metcalf and Eddy, Inc., 2003).However, WHO recommends effluent quality for BOD ranges between 10-30mg/l.

The removal of BOD which is an organic compound in raw wastewater requires oxygen so that bacteria can consume the organic compounds in the wastewater. The decomposition of these organic compounds release CO_2. Carbon-dioxide released by bacteria during respiration (decomposition) enables algae to perform photosynthesis that release excess oxygen for further decomposition of organic matter in the wastewater by bacteria. The warmer the climate, the more effective and faster this process will be, although other factors, especially pH, also impact this process.

Anaerobic ponds are designed to maximize BOD removal, but need to limit odour and maintain a pH high enough to continue decomposition. Acidic ponds generally need to be neutralized because a low pH affects decomposition. The lowering BOD is expressed as a percentage.

In Kenya, a higher than expected BOD removal rates of 82% was reported from an anaerobic pond at the Dandora, Nairobi WSP system, operated at $17^{O}C$ with a loading of $240gBOD/m^3d$. The over loaded WSP system at Nakuru was monitored for periods of one week at three different times in 1988-1989. The two anaerobic ponds had a depth of approximately 4m and were designed for a 1.2d retention time and a loading of $380gBOD/m^3d$. The loading in this period of time was 1.1 to 4.8 times higher; the hydraulic retention time was between 0.38 and 0.6 which was too small. The results on the influent had a higher proportion of industrial waste and a sulfide level of 350mg/l. The COD removal fluctuated between 15% and 46% (Pearson et al., 1998).

In Melbourne, Australia where some of the largest anaerobic ponds in the world can be found, has been reported to achieve a BOD removal of 62% with 10% temperature differences throughout the year. The anaerobic ponds were covered with a kind of membrane, producing $20{,}000m^3$ of biogas per day and a methane content of 80% (Hodgson and Paspaliaris, 1996).

2.8 Pathogens removal

Another issue that must be addressed in wastewater treatment is the removal of pathogenic bacteria that can cause water-borne diseases. Wastewater operators need to be mindful of the potential for contact with organisms that are responsible for typhoid, cholera, dysentery, and hepatitis. Blood-borne pathogens responsible for illnesses like HIV are also a concern in wastewater. Wastewater must be disinfected to kill these harmful organisms before it can be discharged. The effluent must be tested for coliform bacteria to confirm proper disinfection.

Coliform bacteria are enteric bacteria. This means that they are found in the intestinal tract of warm-blooded animals, including humans. These bacteria, known as fecal coliform in humans, do not cause disease and are necessary for digestion of food. The waterborne pathogens are also enteric bacteria and are part of the coliform family. Therefore, if fecal coliform bacteria are present, pathogens may also be present. The coliform bacteria live longer in water and are easier to detect in the laboratory. This is the reason the coliform group has been chosen as the indicator organism for waterborne pathogens. If coliform bacteria are not present it is assumed there are no pathogens present either.

The removal of pathogens in WSPs takes place progressively along the pond series, with the highest removal efficiency occurring in the aerobic ponds (Mara et al., 1992).

(Arridge et al., 1995) reported that when working on an experimental WSP complex in Northeast Brazil, they found a log unit removal of each of the following indicators: faecal Coliform, faecal streptococci and Clostridium perfringens. Salmonellae were reduced from 130 to 70 MPN/100ml and Vibrio cholera 01 was reduced from 40 to 10 MPN/l. Anaerobic ponds seem to be essential for high levels of cholera removal.

(Grimason et al., 1993) studied the occurrence and removal of Cryptosporidium spp, oocysts and Giardia spp. Cysts in eleven WSP systems located in towns across Kenya. Results from these studies showed a significantly higher concentration of Giardia cysts detected inraw wastewater compared to anaerobic pond effluent.

2.9 Effects of Temperature and pH on Biological Activity

Most biological activity occurs when the water temperature is between 10-29^{O}C. Some anaerobic digestion processes operate at temperatures of over 37.8^{O}C. Wastewater bugs become less active when temperature drops. A temperature drop of 10^{O}C will cause a 50 percent reduction in biological activity. This means that process adjustments must be made during the winter months to compensate for the drop in water temperature in the treatment processes.

All three types of wastewater treatment bacteria operate most efficiently at a pH of 6.8-7.2. When pH drops below 6.0 or rises above 8.5, activity drops off dramatically. Bioactivity in wastewater treatment processes tends to lower the pH. This happens because carbon dioxide that is released in the decomposition process reacts with water to create carbonic acid. Industrial wastes that create abrupt changes in pH can cause serious upsets of the secondary processes.

2.10 Daily Flow Fluctuations

The flow at the treatment plant will fluctuate with the changes in water usage by its domestic customers. At night water usage is low and so is the flow at the treatment plant. In the morning, usually between 6:00-8:00am, water usage increases and so does the flow to the plant. But it takes several hours for the wastewater to make its way through the collection system, so that peak flow usually hits the treatment plant between 9:00-10:30am.

This peak flow can be as much as two and a half times the daily average flow. The flow will spike again between 6:00-8:00pm, which corresponds with the evening peak water usage. Treatment process adjustments must be made to compensate for the high and low flows that will affect the hydraulic loading on the plant. A higher flow rate will result in decreased detention time in treatment processes and can adversely affect treatment by increasing the surface loading rate in the clarifiers.

2.11 Performance limiting factors

Floating mats (e.g. floating sludge, oil/grease, blue-green algae, etc) prevent sunlight from penetrating the ponds, slowing algae photosynthesis and reducing oxygen production leading to anaerobic conditions. Mats also prevent surface aeration by reducing wind turbulence that enables diffusion of oxygen in the surface water of the ponds. As a result, such mats need to be removed.

Pond short-circuiting is also another factor where uneven flow distribution of wastewater occurs in a pond. Wastewater flows through the pond faster in some parts of the pond than others. As a result, wastewater detention time is reduced with some wastewater getting poorer treatment than in other parts. If short-circuiting is severe, inadequate treatment and effluent violation can take place. However, mechanical mixers can be used in ponds to better distribute and improve the evenness of flow.

III. Material and Methods

4.1 Description of study area

Roton WSPs lies North of Juba International Airport (JIA). The distance between the plant and the Nile River is approximately three kilometers. Downstream of the ponds is a wetland. This wetland area is used for growing vegetables that are sold in the markets especially during the dry season. Goats can also be seen grazing in the wetland area which provides better grazing site during the dry season. Settlement and residential areas can be seen within 400 meters reach of the WSPs fence.

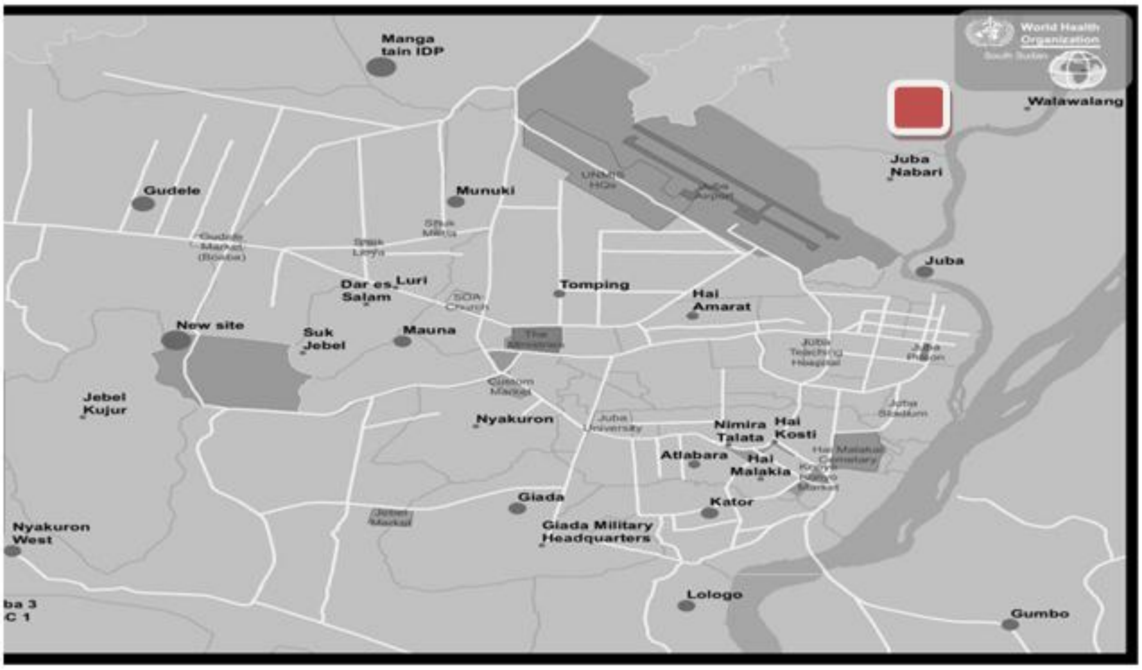


Figure 3. Map of Juba and the location of Roton WSP

Source: WHO, South Sudan

I. Climate

The climate of Juba is tropical, characterized by a rainy season of high humidity and large amount of rain, followed by a drier season. The most rainfall in Juba is between April and October and the average yearly total rainfall is approximately 953 mm, (South Sudan Meteorological Service, 2013).

II. Temperature

Average temperatures are always high, the warmest month is March (23-37 ^{O}C) and the coldest month is July (20-30^{O}C) (weather-and-climate.com**).**

III. Population

The population of Juba City was estimated to be 372,413; South Sudan Center for Census, Statistics and Evaluation (SSCCSE) 2008 census, with the density of 20.03 persons per Km^2. Japanese International Cooperation Agent (JICA) estimated the population of Juba city in 2010 to be 450,000. Whereas Global Water Intelligent in 2011 estimated the population of Juba city to be 500, 000 with growth rate of 4.23%. The population of Juba is ever growing with the influx of returnees, internal displaced people from other states and economic migrants from neighboring countries (Sudan, Ethiopia, Kenya, Uganda, and Congo DRC) and beyond.

4.2Material

- Note book for noting observations and interviews.
- Camera for acquisition of photos.
- Marker pen for labeling samples.
- Gloves, protective gear during sample collection.
- Three plastic bottles for sample collection.
- A sampler.
- 10% NHO_3 (Nitric Acid) for samples preservation on their way to Addis.
- Ice pack for sample storage and transportation.

4.3Methods

- Interviews were conducted with officials at the site.
- Field observation was done throughout the entire length of the WSPs with photos acquired to document the findings.
- Secondary data were retrieved from reliable documents pertaining to Roton WSP.
- Laboratory test on wastewater samples.

4.4Sample collection Procedure

- A total of three composite wastewater samples were collected on 18/04/2016 from 1:00 pm to 1:45pm, 500ml by volume each from different point.
- Sample (1) was collected from the influent point where raw wastewater discharges into the anaerobic pond after thorough mixing.
- Sample (2) was collected from the point where the anaerobic pond discharges its effluent into the facultative pond.
- Sample (3) was collected from the point where the facultative pond discharges effluent outside the system into a channel where the effluent drains to a wetland.
- On 25/10/2017, 30/10/2017 and 06/11/2017, three composite wastewater samples on each day were collected mostly from afternoon hours (11:45 to 1:40) with S1 from influent point, S2 from anaerobic pond and S3 from the facultative pond and all 3 samples were 100ml by volume each.

Figure 4. Sample collection sites

4.5Sample Preservation, storage and transportation

- NHO_3 was used to preserve the samples on their way to Addis Ababa, Ethiopia.
- Storage and transport was under ice in an ice pack.
- These samples were collected on 18/04/2016 at 1:00pm and transported to Addis Ababa on the same day where Laboratory analysis started on 19/04/2016 at 10:00am, within 24hours.
- The 25/10/2017, 30/10/2017 and 06/10/2017 samples were stored and transported under ice pack where Laboratory analysis started the same day from 2:00 pm each day in Juba.

4.6Laboratory analysis

1) APHA (1995) standard method for E. Coli bacteria test was used.

E. Coli Test Procedure

- Three samples 100ml each was collected from sites $S_{1,}$ S_2 and S_3.
- 1ml of each sample was diluted into 100ml distilled water each.
- This 100ml was filtered through 0.45M filter size and incubated at 44^OC for 24 hours in a lauryl Sulphate medium and the result obtained.

2) APHA (1995) standard method for BOD_5 measurement was followed during the BOD_5 test.

3) COD Test Procedure

- Three samples of wastewater 100ml volume each was collected from Roton Wastewater Stabilization Pond.
- 2ml of each sample were put into COD digestion reagent (vials).
- The100ml sample each was homogenized for 30 seconds by shaking.
- The COD reactor was turned on and pre-heated to 150^OC.
- The cap of cool digestion vials for appropriate range (150 range reagent, i.e. low range) was removed. The vials were held at 45^O angle and the 2ml samples were poured into the vials after which the caps were tightly replaced and the outside of vials rinsed with deionized water and wiped.
- The vials were held by the cap and over a sink, inverted gently several times to mix the content and then placed in a pre-heated COD reactor.
- A blank was prepared by repeating the same steps, substituting 2ml deionized water for the samples.
- The vials were heated for 2 hours at 150^OC after which the reactor was turned off; the vials were left to cool for 20 minutes to 120^OC or less.
- The vials were then inverted each several times while still warm and then placed into a rack until vials cooled to 25^OC. Then the COD were measured in a 7100 Photometer, there was no FAS.

IV. Results and Discussion

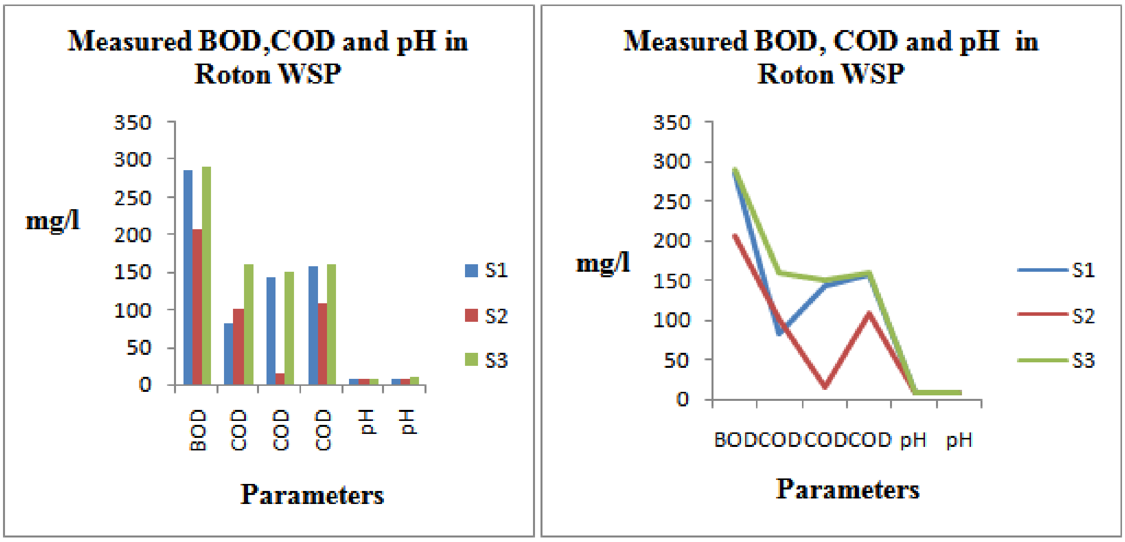
5.1 Results

Table 1. Parameters measured in Roton WSPs

Parameter	Sample date	Unit	S1	S2	S3	Lab facility
BOD_5	18/04/2016	mg/l	285	206.4	291	CESL, AAU, ET
COD	25/10/2017	mg/l	82	102	160	MWRDCL, SSD
COD	30/10/2017	mg/l	142	15	150	“
COD	06/11/2017	mg/l	158	108	160	“
E. Coli	18/04/2016	cfu	No growth	No growth	No growth	CESL, AAU, ET
E. Coli	25/10/2017	cfu	No growth	No growth	No growth	MWRDCL, SSD
E. Coli	30/10/2017	cfu	No growth	No growth	No growth	“
E. Coli	06/11/2017	cfu	No growth	No growth	No growth	“
pH	30/10/2017	-	8.1	8.2	8.2	“
pH	06/11/2017	-	8.4	8.2	8.7	“

1-CESL, AAU, ET(Center for Environmental Science Laboratory, Addis Ababa University, Ethiopia).
2-MWRDCL, SSD (Ministry of Water Resources and Dams,Central Water Quality Analysis Laboratory,SouthSudan).
3- cfu (Colony forming unit)

Figure 5. Measured levels of BOD, COD and pH in Roton WSP



Percentage Removal= {(Influent BOD-effluent BOD)/Influent BOD}*100
Therefore, % Removal BOD= {(285-291/285)} *100=-2.1%
% Removal COD1={(82-160/82)} *100= -95%
% Removal COD2 = {(142-150/142)} *100= -5.6%
% Removal COD3 = {(158-160/158)} *100= -1.3%

Table 2. The average removal efficiencies percent of parameters in RotonWSP

Parameter	Influent (mg/l)	Effluent (mg/l)	Removal efficiency %
BOD	285	291	-2.1
COD	127.3	156.3	-22.8

Table 3. Typical municipal wastewater characterization adopted from (Metcalf and Eddy Inc., 2003).

Parameter	High	Medium	Low
BOD	560	350	230
COD	1200	750	500
pH	8.0	7.5	7.0

Table 4. Indicative Values for Treated Sanitary Sewage discharges from (EHS Guidelines, 2007)

Parameter	Units	Guideline Value
pH	pH	6-9
BOD	mg/l	30
COD	mg/l	125
Total Coliform bacteria	MPN/100ml	400

V. Discussion

The results of the levels of BOD, COD and pH measured in water samples collected from Roton WSPs are summarized in Table.1 above. The BOD result from the influent and effluent points show a disturbing result, with the effluent wastewater slightly higher at 291mg/l compared to the influent wastewater at 285mg/l.

However, due to unreliable power and time factor, three subsequent tests for organic matter were carried out this time measuring the COD levels of wastewater from Roton WSP. The three COD test results also follow the same trend of the previous BOD result, with the effluent wastewater organic matter concentration higher than the influent wastewater as shown in table 1 above.

The influent BOD and COD levels according to Metcalf and Eddy, Inc., 2003, fall in the medium and low strength ranges respectively with the pH falling in the high range. However, indicative values for BOD and COD for treated sanitary sewage effluent fromEHS Guidelines, 2007 shown in (table 4) is relatively lower than the BOD and COD discharges at Roton WSP, with only pH values falling within the EHS Guidelines, 2007 ranges. But WHO recommends effluent quality for BOD range between 10-30mg/l. As a result, the effluent quality for BOD and COD in Roton are much higher compared to both the EHS Guidelines, 2007 and the WHO recommendations. But such pond systems worked well according to studies carried in 1988-1989in Dandora WWTP in Nairobi and Nakuru with anaerobic pond loading of 240gBOD/m^3d and 380gBOD/m^3d respectively (Pearson et. al, 1998)

However, the rise in the effluent wastewater strength might be due to operational and maintenance problems as well as performance limiting factors. In regards to operational and maintenance problems, the anaerobic pondhas not been desludged since Roton WSP was constructed in 2009. As a result, almost two thirds of the anaerobic pond volume is filled with sludge. The accumulation of sludge at such a level reduces the detention time of the ponds hence affecting treatment efficiency of the ponds. As per the performance limiting factors, pond short-circuiting must be another factor which courses uneven flow of wastewater in the ponds resulting in reduction of detention time leading to inadequate treatment in other parts of the ponds.

Therefore, with these operational and maintenance as well as performance limiting factors affecting Roton WSP, organic matter removal efficiency of the WSP in form of BOD and COD are negatively affected. This can be seen in(Table 2) above where BOD percentage removal efficiency is -2.1% and the average COD percentage removal efficiency is -22.8%. This means there is no net removal of organic matter, instead more organic matter is added to the effluent wastewater.

The flow rate in Roton WSP fluctuates daily as a result of wastewater discharge pattern. The sewage tankers ferry wastewater from 8:00 am to 5:00pm every day to the WSP, creating continuous flow during this time period. However, from 5:00pm to 7:00 am, no discharge of wastewater into the pond. This high and low flow rates will affect the hydraulic loading in the WSP with higher flow rate decreasing detention time in the treatment processes leading to increased surface loading rate in the ponds.

In the case of E. Coli bacteria, the results are zero colony forming unit (cfu), over the two laboratory tests carried in Ethiopia and South Sudan. These means there was no growth of microorganisms in the culture media during the two laboratory tests. However, these can be attributed to two factors.

Factor number one is that, the successive outbreak of cholera in Juba, South Sudan since 2006 up to 2017 must have encouraged disinfection of wastewater or sewage in Juba with chlorine or other disinfectants at the sources of these wastewaters. As a result, enteric bacteria and other microorganisms in this wastewater must have been killed by these chemicals, rendering the wastewater discharged in the WSP bacteria free.

Factor number two is that, according to the official in charge and workers at the WSP, a product called SanPit or Wastewater digester is applied in the bay wherewastewater is discharged from the sewage tankers where it drains through the channel to the anaerobic pond. 100kg of this sewage digester is applied every 15 days. However, after thorough examination of the labeling on the container of this product, no detailed information was provided about the ingredients of this product. The available information was: SANPIT(Sewage Digester). Blue Ring Products Ltd. P.O Box 56337, 00200, City Square Nairobi. Jageen Enterprises, mobile 0956099902/0912333408, Juba South Sudan.

In my opinion, such product could be a chemical that kill bacteria (microorganisms) or bactericide meant to disinfect the effluent discharged from the WSP, means for removal of pathogens. However, this renders the WSP not to achieve its objectives of reduction of organic matter in the ponds as well as in the effluent through the decomposition of such organic matter by bacteria. Such negative act on the function of the natural treatment processes have led to fast and rapid accumulation of sludge that can be seen in the anaerobic pond in Roton WSP.

VI. Conclusion and Recommendations

6.1 Conclusion

However, taking into consideration the two laboratory test results from Ethiopia and South Sudan, there is every reason to say Roton WSP is inefficient in the removal of organic matter as a result of poor operation and maintenance as well as performance limiting factors like pond short-circuiting, floating mats, etc.

Decreased hydraulic retention time (HRT) due to high hydraulic flow rate as a result of sludge accumulation in almost two thirds of the anaerobic pond has led to inadequate treatment process, therefore, very poor removal of organic matter in Roton WSP.

The successive cholera outbreaks in Juba from 2006-2017 gave rise to compulsory disinfection of sewage at their different sources, accompanied by the application of sewage digester in Roton WSP. Therefore, bacteria meant for the decomposition and reduction of organic matter concentration in the effluent wastewater are destroyed.

6.2 Recommendations

The following recommendations are crucial for the improvement of operational and maintenance as well as wastewater treatment efficiency in Roton WSP.

1. The operation and maintenance of Roton WSP should be consistent with the designer's operation and maintenance manual.
2. Wastewater strength and hydraulic loading and flow rate should be according to the design capacity.
3. Aerobic or maturation pond should be constructed in the present layout as a matter of urgency that will eliminate pathogens, with subsequent construction of anaerobic, facultative and aerobic ponds in parallel to the present layout to increase the capacity of Roton WSP to handle wastewater volume and strength, improve treatment efficiency and ensure smooth WSP functioning during alternate pond desludging.
4. Provision of simple laboratory facility and flow meter in the WSP to measure essential parameters where adjustments can be made to WSP operations.
5. Desludging of the anaerobic pond and evaluation of the facultative pond should be done as soon as possible which will eliminate pond short-circuiting.
6. Removal of floating mats, aquatic weeds, etc. which interfere with light penetration and oxygen diffusion at the pond surface is required.
7. Prohibition of use of chemicals in the ponds except in the effluent wastewater section.
8. Activated sludge should be introduced in the ponds to provide active bacteria that will decompose the organic matter in the wastewater reducing the volume of sludge in the ponds therefore, takes longer period to accumulate sludge.
9. Withhold money collected at Roton WSP in a special account to meet operational and maintenance cost of the WSP and acquire required tools and machineries for proper functioning of the WSP.
10. Training of Roton WSP facility employees in regards to pond management, operation and maintenance.

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