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Research article

Evaluation of contaminants removal by waste stabilization ponds: A case study of Siloam WSPs in Vhembe District, South Africa

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ABSTRACT

Waste stabilization ponds (WSPs) are widely used for wastewater management owing to the simplicity of their design, low cost and the use of low-skilled operators. This study was carried out to assess the efficiency of a WSP system in reducing the levels of contaminants in hospital wastewater in a rural area of South Africa and to evaluate the current management of the WSP system. Sampling was conducted monthly from January to June 2014. Physicochemical and microbiological parameters were monitored using standard methods. The microbiological parameters (*Escherichia coli* and enterococci) in the effluent were higher than those in the influent in some sampling months. Also, low pathogen removal efficiency (<1 log reduction) was recorded. The chemical oxygen demand (COD) in the effluent (82–200 mg/L) exceeded the South African Department of Water Affairs for wastewater discharge guideline value of 75 mg/L although reduction efficiencies of 7.7%, 49.1% and 31.1% were observed for the months of February, April and June, respectively. The WSP system did not show a general trend of contaminant reduction except for Zn (5.5–94.8%). The Siloam WSP is not functioning properly and is releasing effluent of poor quality into the receiving river. It is recommended that the WSP system be expanded to cater for the extra load of wastewater it receives, also desludging should be performed as recommended for such systems. Continuous monitoring of the system for compliance to regulatory guideline should be routinely performed.

1. Introduction

There is shortage of freshwater resources globally and this problem is exacerbated in arid and semi-arid countries. This is partly due to population growth, increased water contamination from anthropogenic sources and variability in weather and climate conditions (Edokpayi et al., 2020a; Ahmed et al., 2020). The use of such contaminated water for drinking, washing of clothes, swimming and irrigation are common in most rural areas of developing countries due to lack of sustainable access to clean and safe water (Olasoji et al., 2019; Edokpayi et al., 2018a). Surface water will continually be exploited for domestic purposes because as at 2017, the World Health Organization (WHO) estimated that 785 million people still lack a basic drinking water infrastructure with 144 million people depending on surface water for their basic water needs (WHO, 2019) while others depend on groundwater sources and water delivery through water tankers. The use of such unprotected water source has been implicated for the death of millions of underage children (Enitan-Folami et al., 2019). A major health concern is the microbiological and physico-chemical quality of surface water which is often plagued by a number of contaminants due to several anthropogenic activities (Bessong et al., 2009).

One of the major point sources of surface water pollution is the discharge of raw and poorly treated wastewater (Edokpayi et al., 2020b). Many countries have devised ways to treat wastewater before they are released into watercourses or reused. Wastewater management is a major challenge in developing countries as a result of low level of awareness, population growth, urbanization, industrialization and inadequate expertise (Edokpayi et al., 2018b; Cosgrove and Loucks, 2015; Beddow, 2010). Unfortunately, high generation of wastewater is often not accompanied by the expansion of wastewater treatment infrastructure (Olukanni and Ducost, 2011; Beddow, 2010). Inadequate treatment of wastewater often results in environmental deterioration and a disease burden to humans. Adequate treatment of wastewater is crucial to

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prevent the contamination of surface and groundwater resources (Edokpayi et al., 2016; Jhansi et al., 2013; Arth, 2012).

The major concerns of inadequately treated wastewater is high nutrient load and the presence of pathogenic organisms (Naidoo and Olaniran, 2014). Nitrates and phosphates, although useful to plants as macro nutrients, can lead to eutrophication if present in high levels, consequently promoting the overgrowth of algae which results in depletion of dissolved oxygen in surface water (Bahri, 2009; Edokpayi et al., 2017). This consequently imparts offensive odour to the water, affects aesthetic value and can lead to death of fish and other benthic organisms, which may also lead to loss of biodiversity (Edokpayi et al., 2015a; Osuolale and Okoh, 2015; Bahri, 2009). Similarly, high levels of microorganisms in water have been linked to several diseases including cholera, diarrhoea, schistosomiasis, giardiasis, typhoid fever, malaria, poliomyelitis, stomach ulcers, dysentery, guinea worm and ring worm infections (WHO, 2019; Singh et al., 2019; Haseena and Malik 2017; Okafor, 2011).

Wastewater management is crucial for the prevention of environmental degradation and public health problems. However, the cost involved in designing and building a wastewater treatment plant is very high and the operation requires highly skilled personnel. Most of the developing countries cannot afford the cost involved. A suitable alternative for treatment of wastewater without using the conventional wastewater treatment plant is the wastewater stabilization ponds (WSPs) which provide an effective and low cost means of handling domestic and industrial wastewater.

WSP systems are attractive in that: (i) they are simple to design, operate and maintain, (ii) require low technical manpower, (iii) low capital cost compared to other wastewater treatment systems and (iv) treatment does not depend on mechanised or expensive equipment (de Souza and Jack, 2010; Phuntsho et al., 2008). However, some disadvantages have been linked to the pond system of wastewater treatment which include large land and specific soil requirements, limited control of effluent quality and potential breeding sites for mosquitoes (Mara et al., 1992).

In South Africa, WSP systems are recommended for communities with populations less than 5000 (de Souza and Jack, 2010). If properly designed and operated, these systems are capable of yielding high quality effluent which pose no threat to the receiving watercourse and can be used for irrigation. However, some flaws in the design and management such as inadequate estimation of hydraulic retention time, short-circuiting of wastewater in the pond and overloading of the pond systems beyond its design capacity can yield low-quality effluents (Ho et al., 2017). Irrespective of good pond design, inadequate management of the system can adversely affect the treatment efficiency.

Edokpayi et al. (2017) stated that in most developing countries, the effluents from WSP systems rarely meet the acceptable discharge standards. Bateman (2008) reported that most of the South Africa's wastewater treatment facilities are either dysfunctional or non-functional, with millions of litres of sewage illegally discharged daily into rivers by small-town municipalities. Also, 85% of the South African sewage system infrastructure is dilapidated due to outright neglect and incompetent management (Bateman, 2010). The study conducted by Jagals et al. (2006) in Free State Province of South Africa revealed that 100% of the 60 WSP systems studied produced effluent which are not compliant to the recommended standards with respect to faecal indicator organisms.

Bundschuh et al. (2011) lamented on the impacts of wastewater; that concerns have largely been associated with the presence of microorganisms, while chemical parameters have been overlooked or inadequately considered. This could be due to the immediate impact of microbial contaminated water on human health. Most WSP systems were designed to remove faecal indicator organisms and not metals, although considerable metals' removal has been reported in WSP system (Edokpayi, 2016; Mwakaboko et al., 2014; Üstün, 2009). Trace metal removal from wastewater streams is of interest due to their persistence, bio-accumulative tendencies and toxicities both to humans and aquatic lives (Edokpayi et al., 2017; Osuolale and Okoh, 2015). There is currently an increasing concern for pharmaceuticals and personal care products in various freshwater systems due to the discharge of partially treated wastewater (Martin et al., 2012).

This study was carried out to determine the removal efficiency of chemical and microbiological contaminants from the Siloam WSP across a six months' period of dry and wet seasons with conditions typical for WSP system in rural areas of South Africa and to evaluate the current management of the WSP system. The Siloam WSP receive majorly hospital wastewater. The effluent is continuously discharged into the Mutangwi River which is a tributary of the Nzhelele River which is used for domestic, recreational and agricultural purposes.

2. Materials and methods

2.1. Description of waste stabilization ponds and the study area

The Siloam WSP system is located between latitudes 22°53′15.8″ S and 22°54′5″ S and longitudes 30°11′10.2″ E and 30°11′23.5″ E in the Limpopo Province of South Africa (Figure 1). The waste stabilization system is composed of two primary maturation ponds (P1 and P2) and 5 secondary maturation ponds (CSIR, 1983). Other details relating to the area and depth are presented in Table 1. The ponds were initially designed to treat 2000 cubic meters per day (m^3d^{-1}) of wastewater but have been treating more than 5000 m^3d^{-1} (DWA, 2012). There is no flow meter to record the inflow of water into the ponds. Chlorine is added (as solid sodium hypochlorite) to the effluent as the water leaves the last pond before entering the river, to further aid the reduction of microbes that could have escaped the effect of the pond system and to protect the receiving water from unnecessary microbial load. No laboratory is present onsite for compliance studies. The effluent from the WSP system is channelled into the Mutangwi River which flows into the Nzhelele River. Major land uses include formal and informal settlements and subsistence agriculture.

2.2. Meteorological data

The temperature, humidity and rainfall data of the study area is presented in Figure 2. The area is semi-arid and characterised with seasonal rainfall events. Daily temperature in the catchment varies between 20-40 °C (wet and summer season) and 12–22 °C (dry and winter season), respectively (Edokpayi et al., 2018a). The region is characterised by a warm wet season which is associated with high temperatures up to 40 °C usually between October and March (with peak precipitation in January–March) and cold dry season (April–September). The average precipitation pattern for the period of study varied between 0.5-258.82 mm/month.

2.3. Sampling

Triplicate samples were collected from different points in the seven ponds, with additional two samples (in triplicate), one from the influent and the other from the effluent (after disinfection) making a total of twenty-seven samples. The sampling was performed once monthly (the same day) from January-June, 2014. A total of 1 L was collected from each point using polyethylene bottles. Sterile containers were used for microbial sample collection. Three millilitres of concentrated nitric acid was used to preserve a set of the samples for trace metal analysis. The samples were transported on ice to the laboratory for further analyses. The meteorological data (temperature, humidity and rainfall) of Siloam village was obtained from the South African Weather Service.

2.4. Measurements of some physico-chemical parameters

Field measurements of pH and electrical conductivity (EC) were performed in triplicates using a Thermoscientific Orion 5 Star pH and EC multimeter. Turbidity measures the light scattering ability of water due

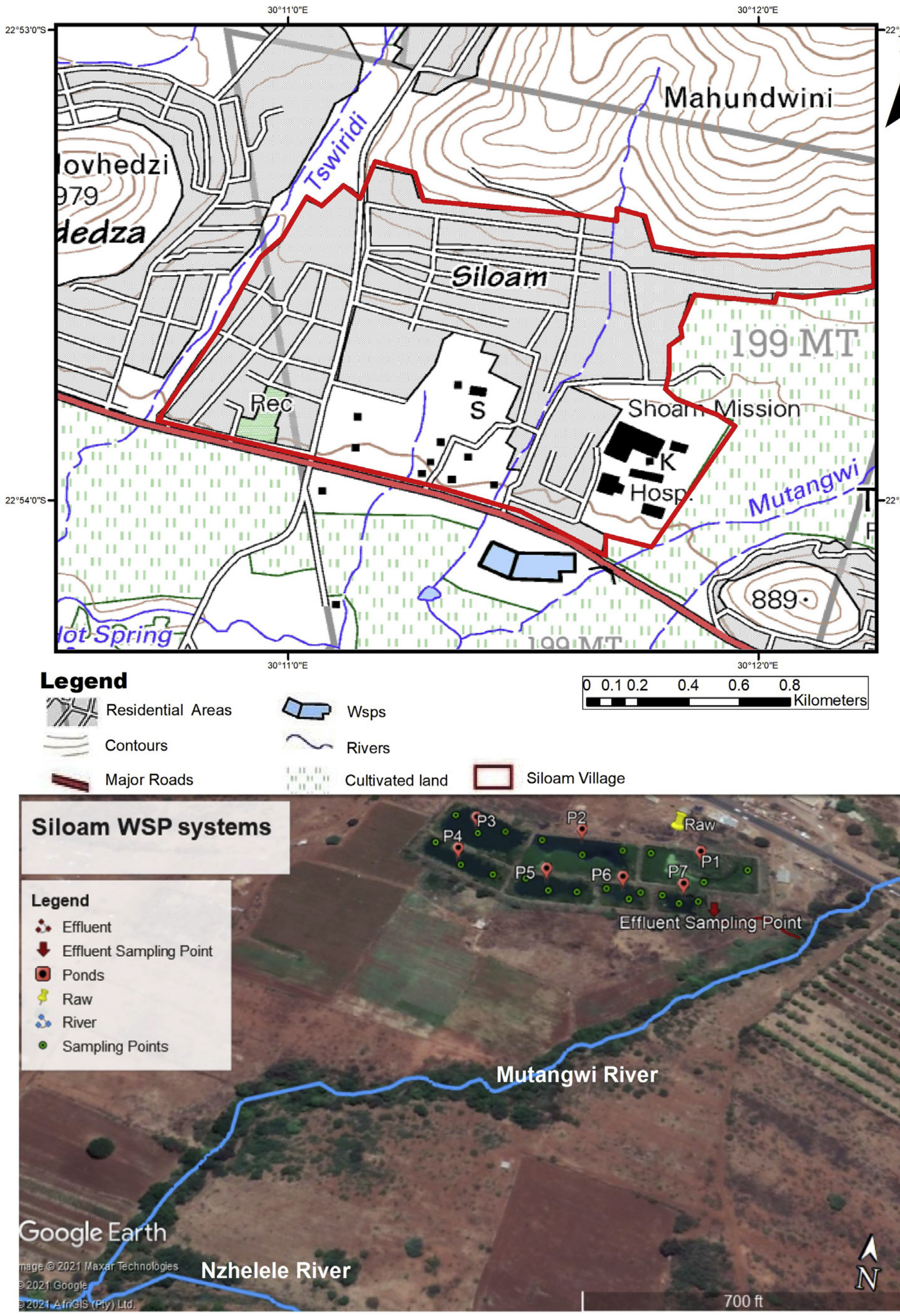

Figure 1. Map of Siloam Village (top) and map showing the configuration of the Siloam WSP systems (bottom).

to the presence of suspended materials like clays, silts and microorganisms. Turbidity measurement is directly related to total suspended solids in water and wastewater and is often preferred due to ease of measurement (Metcalf and Eddy, 2003). Turbidity was measured onsite using a turbidimeter (TB200, Orbeco Hellige). Briefly, the wastewater sample was collected with a clean bucket and transferred into a turbidity cell that was precleaned using de-ionized water with the aid of a clean conical flask. After calibration, the samples were analysed. Chemical oxygen demand (COD) gives an indirect measurement of the amount of organic pollutants in water and has been preferred over biochemical oxygen demand (BOD) as a routine measurement for chemical pollution in wastewater owing to its accuracy and rapid analysis (Abdalla and Hammam, 2014). In the laboratory, COD measurements were carried out using specialized COD test kits (Merck, Johannesburg, South Africa). The samples were digested at 148 °C in a thermoreactor (Spectroquant TR 620, Merck pty Ltd) for 2 h and were subsequently analysed after cooling by the Spectroquant Pharo 100 photometer (Merck Pty Ltd).

2.5. Sample pre-treatment and analysis

Faecal indicator organisms (*Escherichia coli* (*E. coli)* and enterococci) were enumerated in the wastewater samples following the protocol reported by the American Public Health Agency (APHA, 1999). A 100 mL of wastewater sample was filtered using a 0.45 μm pore size, 47 mm diameter Millipore filter membrane. *E. coli* and enterococci were enumerated on mFC and mEnterococcus (Acumedia, Pretoria, South Africa) agar plates after incubation at 37°C/24 h and 45°C/48 h respectively. The wastewater samples were diluted with sterile distilled de-ionised water in the ratio of 1:1000 before analysis. The samples were analyzed in duplicate and recorded as colony forming unit per 100 mL.

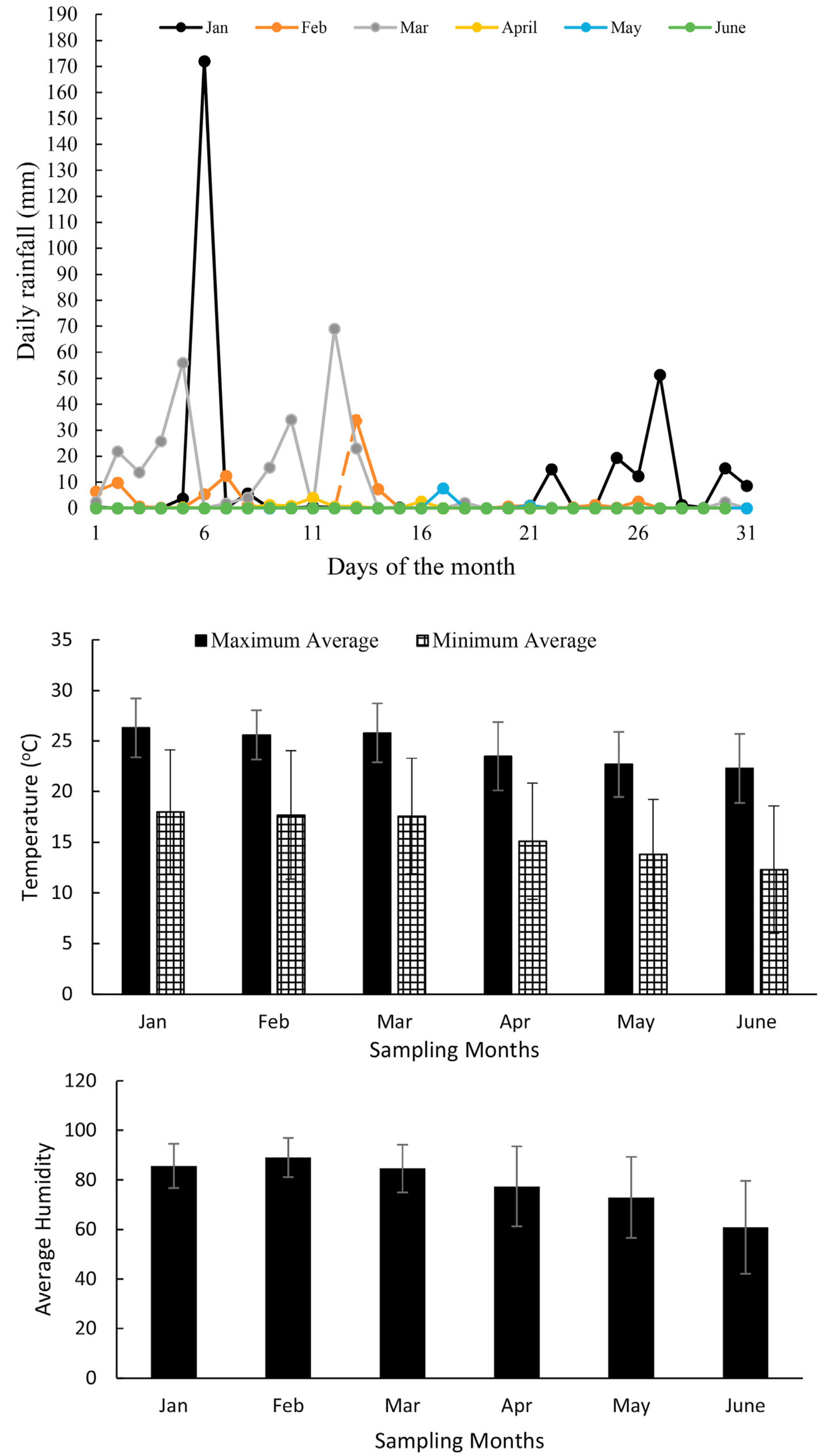

Figure 2. Meteorological data (2014) for Siloam area where the WSP system is situated. The error bar represents standard deviation.

The USEPA (1999) recommended method for the digestion of water samples was employed in this study. Briefly, concentrated nitric acid (3 mL) was added to 50 mL of the wastewater sample in a beaker covered with a ribbed watch glass. The solution was heated in a temperature-controlled hotplate until reflux action occurred. The heating continued until digestion was complete. The solution was allowed to cool after which 10 mL of 1:1 hydrochloric acid and 15 mL of de-ionized water was added. The resulting solution was heated for

15 min and allowed to cool. The walls of the beaker and watch glass were rinsed with de-ionized water and the solution filtered using a Whatman No 1 filter paper (with diameter of 90 mm). The filtrate was transferred to a 100 mL volumetric flask and made up to 100 mL with distilled water. Trace metals (Al, Cr, Cu, Fe, Mn, Pb and Zn) in the digested wastewater samples were analyzed using a Thermo scientific inductively coupled plasma optical emission spectrophotometer (ICP-OES (ICAP 6500 DUO) as described by Senila *et al.* (2011). Ion Chromatograph (Metrohm 850 Professional) were used for the analysis of nitrate in wastewater.

2.6. Validation of analytical methods

Calibration standards were prepared from a multi-element stock solution of all the metals of interest (1000 mg/L) supplied by Merck (pty), Ltd., Johannesburg, South Africa. Similarly, a calibration curve for nitrate was prepared using a multi-element solution for anions purchased from Merck. Linear calibration curves of trace metals and nitrate were obtained with correlation coefficients in the range of $R^2 = 0.98–0.99$. Recovery studies were also performed by adding known concentrations of the test analyte to the sample. The concentration of both the spiked and unspiked samples were determined and acceptable percentage recovery in the range of 90–110% was obtained. De-ionised water was used as a control for microbiological studies. U.S. EPA Method 200.7 (1994) was used to determine the detection limit of the analytical instrument (ICP-OES). The limit of detection for the metals varied between 0.1 and 0.8 μg/L.

2.7. Compliance study, statistical analyses and calculation of reduction efficiencies

The results obtained from this study were checked for compliance against the Department of Water Affairs (DWA) effluent standards for wastewater discharged onto natural water courses. The experimental data obtained were subjected to descriptive statistical analysis (95% confident limit) using SPSS version 26. Graphs were drawn using Microsoft Excel 2013. The percentage reduction efficiencies of the WSP for various parameters were calculated from the relation given below:

$$\%\ \text{Reduction efficiency} = \frac{\text{concentration in the influent} - \text{concentration in the effluent}}{\text{concentration in the influent}} \times 100$$

3. Results

3.1. Faecal indicator organisms

E. coli and enterococci concentrations varied both in the influent and effluent across the sampling months. The levels of *E. coli* in the influent and effluent varied between 3 x 10^3–1.0 x 10^5 cfu/100 mL and 2 x 10^3–7.7 x 10^5 cfu/100 mL while enterococci ranged from 5 x 10^3–6 x 10^4 and 2 x 10^3–7 x 10^4, respectively (Table 2). No uniform decreasing trend was determined for both faecal indicator organisms as the wastewater moves through one pond to another (P1–P7). The DWA guideline for faecal coliform in wastewater effluent is 1000 cfu/100 mL.

3.2. Physico-chemical parameters

The turbidity values of the influent were higher in the wet season (58.8–63.7 NTU) compared to the dry season (17.8–38.3 NTU) (Figure 3), while the effluent values ranged between 45-252.3 NTU and were also higher in the wet season.

The COD in the influent and the effluent varied from 70-169 mg/L and 82–200 mg/L, respectively (Figure 4). The COD of the effluent exceeded the DWA threshold value of 75 mg/L for wastewater discharge into surface water bodies (DWA, 2010).

The pH of the influent and effluent was found to be in the range of 7.4–8.1 and 7.2–9.1, respectively (Figure 5, Supplementary Table 1), being suitable for the precipitation of some metals in wastewater. Although there was variation in pH recorded, the effluent complied with the DWA guideline of 5.5–9.5 for wastewater discharge onto surface water bodies (DWA, 2010).

The Siloam WSP system recorded influent electrical conductivity (EC) values that ranged between 31.3 and 69.0 mS/m (Figure 5). The effluent

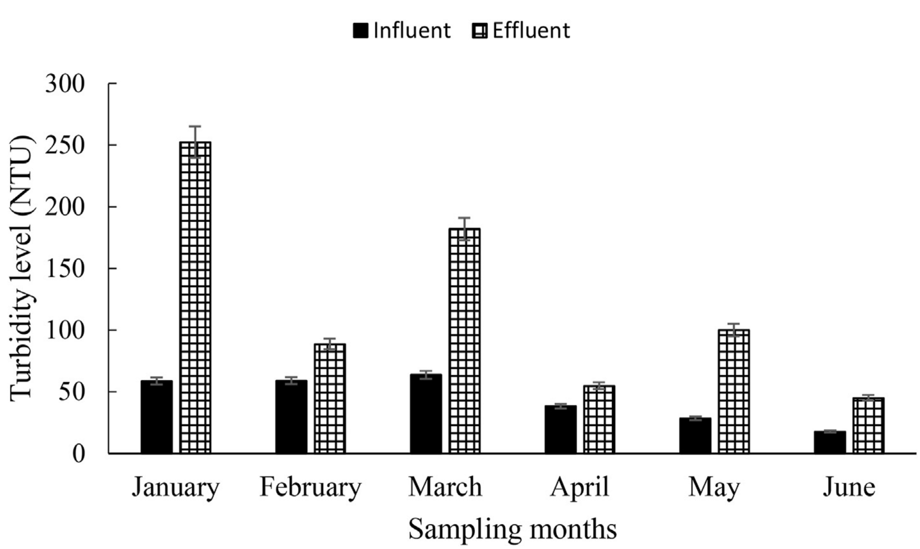

Figure 3. Turbidity levels in the influent and effluent of the Siloam WSP system. The error bar represents standard deviation.

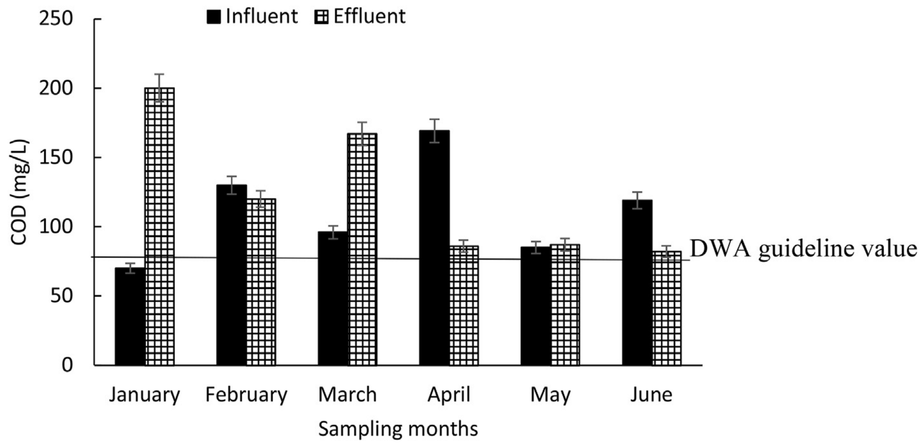

Figure 4. COD concentration in the influent and effluent of the Siloam WSP system. The error bar represents standard deviation.

EC values varied from 24.3 mS/m in January to 92.9 mS/m in June. There was a steady increase in EC levels from January (24.3 mS/m) to April (51.7 mS/m) then, a slight decrease in May (49.4 mS/m) and another increase in June (92.9 mS/m). The EC level of the effluent complied with the DWA guideline (150 mS/m) for wastewater discharge (DWA, 2010).

3.3. *Total nitrate (NO_3^- mg/L)*

The influent concentrations ranged from 1.27-17.32 mg/L. Sudden increases and decreases were observed as the wastewater flowed from one pond to the other (Supplementary Table 1). The effluent concentrations ranged between 0.48-13.24 mg/L (Figure 6).

3.4. *Trace metal concentrations*

Trace metals occurred at varying levels in the influent and effluent of Siloam WSP system (Table 3). Some reduction efficiencies were recorded in some sampling months for Al (31.4–82.9), Fe (17.7–63.5), Zn (5.5–94.8), Cr (12–30.8), Cu (13.1–77.1), Mn (23–80.6) and Pb (0–100). Despite the recorded reductions, some of the metals (e.g., Al, Cu and Fe) failed to comply with the DWA regulatory guideline for all the sampling months while Cr, Mn and Zn complied in some months. Pb complied during the entire period of the study. The results of each pond (Supplementary Table 2) did not show a uniform trend in the reduction of the trace metals.

4. Discussion of results

The faecal indicator bacteria levels were sometimes higher in the influent than the effluent (Table 2). The log reductions recorded were below one during the course of the study for both indicator organisms and did not comply with the recommended guideline of Department of Water Affairs (DWA) for wastewater discharge (1×10^3 cfu/100 mL) onto water bodies (DWA, 2010).

The release of such partially treated wastewater onto freshwater sources has both short- and long-term effects on humans and the environment. Human enteric bacteria and viruses have been reported in wastewater effluent by Osuolale and Okoh (2017). Several other authors have reported high levels of microorganisms in wastewater effluents (Osuolale and Okoh, 2015; Edokpayi et al., 2015b; Naidoo and Olaniran, 2014). There have been reports of cholera and diarrhea outbreak in South Africa and other developing countries after the consumption of faecal contaminated water by wastewater (Naidoo and Olaniran, 2014; Bateman, 2009, 2010; Bessong et al., 2009). It is therefore necessary to rid wastewater of pathogens to prevent cases of water borne diseases. Helminth eggs in concentrations above regulatory standards have been recorded in wastewater effluents of South Africa (Gumbo et al., 2010). The discharge of such effluent will not only affect the aesthetic property of the receiving water course but increase the risk of parasitic infection on anyone who swims in the water (Amoah et al., 2018; Gumbo et al., 2010).

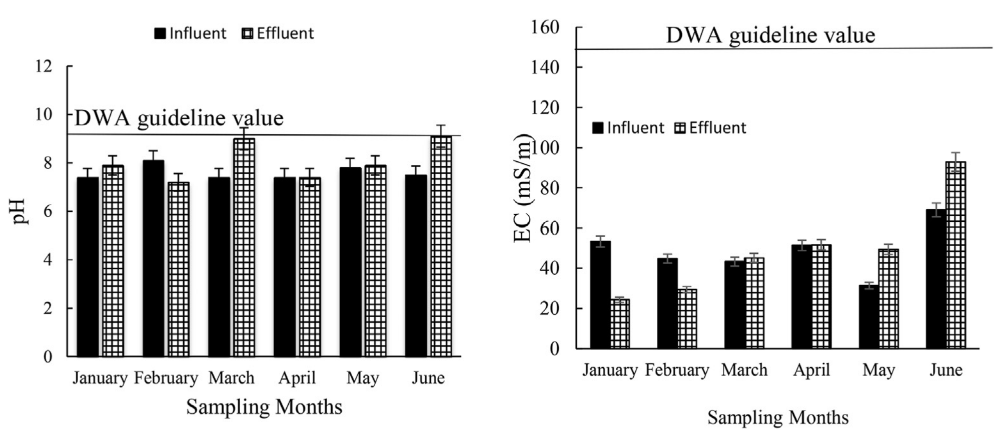

Figure 5. pH and EC levels in the influent and effluent of the Siloam WSP system. The error bar represents standard deviation.

Table 1. Description of each pond in Siloam WSP system.

Pond	Area (m^2)	Depth (m)
P1	4700	0.60
P2	4347	0.75
P3	3106	0.90
P4	2570	0.47
P5	2254	0.63
P6	1223	0.55
P7	1023	0.80

Under optimal conditions, *E. coli* removal by WSP systems can be up to 6 log reduction but most WSP systems usually report about 2–3 log reductions of faecal coliforms (Zacharia et al., 2019; Verbyla et al., 2017; Olukami and Duscoste, 2011). Results from this study did not show notable log reductions of pathogens in the wastewater and this is a potential threat to the water quality of the receiving stream. The possible reason for the low pathogen removal recorded could be due to several factors which could be operational and management in nature. Siloam WSP system currently receives more wastewater than its original design capacity, therefore, the Hydraulic Retention Time (HRT) of the system has been compromised. The HRT is known to influence the rate of pathogen removal in WSP systems.

Ponds with accumulated sludge usually lowers the HRT, consequently leading to less pathogen removal efficiency (Verbyla et al., 2017). The volume occupied by accumulated sludge in a WSP system often reduces the effective volume of the pond and consequently its treatment efficiency (Shilton and Harrison, 2003). The sludge in Siloam WSP system has not be removed since its inception over three decades ago and there is a great likelihood of sludge accumulation. Coggins et al. (2017) reported that the accumulation of sludge in WSP systems can negatively affect the ponds' removal efficiency of contaminants. Therefore, the quality of treated effluent is affected when there is significant reduction of wastewater HRT in the treatment ponds as a result of sludge accumulation. Gopolang and Letshwenyo (2018) reported from their study that sludge accumulation in ponds reduced the designed HRT from 20 days to 7.1 days. Such accumulation of sludge adversely affected the efficiency of the system which failed to produce effluents with microbiological quality that complied to regulatory standards. Hence, the cost of sludge removal should be incorporated into operational cost of WSP system, because failure to do this will amount to the failure of the entire treatment system (Verbyla et al., 2016; Oakley et al., 2012).

Another major factor that also influences pathogen removal in WSP system include short circuiting of water in the ponds as noticed in this study. During rainfall, it was observed that wastewater from the first pond (P1) flows directly to the last pond (P7) without passing through the other ponds due to high volumes of water (i.e., combined wastewater from the hospital, surface runoff and rainwater) entering P1. In addition, the way the ponds are configured also creates the possibility of the short circuiting of wastewater therefore contributing to the poor log removal recorded. Such short circuiting reduces the ponds' pathogen removal efficiency. Shilton and Harrison (2003) stated that short circuiting of wastewater through a pond system often led to significant reduction of effluent quality due to reduced time of treatment. Apart from the proper design of a WSP system, proper maintenance of the system is vital to efficient removal of contaminants. Inadequate maintenance will consequently lead to the malfunction of the system (Verbyla et al., 2013, 2016).

Clarity of wastewater is another factor that also influences the rate of pathogen removal. In this study, the turbidity of the effluent was higher than the influent in all the sampling months. Although WSP systems are not designed to remove all the suspended solids in a wastewater stream, its reduction is important as it can aid the disinfection of the wastewater. Léziart et al. (2019) showed that the turbidity of water has a direct relationship with the efficacy of disinfection (chlorination). Chlorine demand is often influenced by the composition of the wastewater under treatment. The facility under study usually applies the same amount of sodium hypochlorite as a disinfectant irrespective of the turbidity of the wastewater.

Turbidity levels greater than 2 NTU can have a profound effect on chlorination as it reduces its efficiency partly by shielding faecal bacteria from inactivation (WHO 2017, Edokpayi et al., 2015a). Although disinfection can occur at high turbidity levels, these must be accompanied by higher chlorine dosage and contact time (Pal, 2017; Keegan et al., 2012). Discharge of turbid effluent into natural streams can have far-reaching negative effects. It can reduce the aesthetic value of the receiving river and can deplete dissolved oxygen leading to stress and death of some aquatic organisms (Aniyikaiye et al., 2019; Edokpayi et al., 2015b, 2017).

The COD levels recorded in this study for each month of sampling did not comply with the South African Department of Water Affairs standards of wastewater discharge onto watercourses. Similar results have been reported in several WSP systems in developing countries (Table 4). Although there have been reported cases of COD reductions up to 70%, the resulting effluents usually exceed the regulatory standards of most countries (50–75 mg/L). In this study, the main reason for this finding

Table 2. Influent and effluent concentrations and log reduction of *E. coli* and enterococci in the Siloam WSP system. DWA guideline for wastewater discharge is 1×10^3 cfu/100 mL.

E. coli (cfu/100 mL)			
Months	Influent	Effluent	Log Removal Value
January	1.5×10^4	5.1×10^4	-0.53
February	3.0×10^3	2.0×10^3	0.18
March	2.0×10^4	1.0×10^4	0.30
April	1.0×10^5	5.0×10^5	-0.70
May	1.5×10^4	2.0×10^5	-1.12
June	2.0×10^4	7.7×10^5	-1.59
Enterococci (cfu/100 mL)			
January	8.4×10^3	5.2×10^3	0.21
February	5.0×10^3	2.0×10^3	0.40
March	4.5×10^4	3.0×10^4	0.18
April	6.0×10^4	7.0×10^4	-0.07
May	1.2×10^4	2.0×10^4	-0.22
June	9.5×10^3	9.0×10^3	0.02

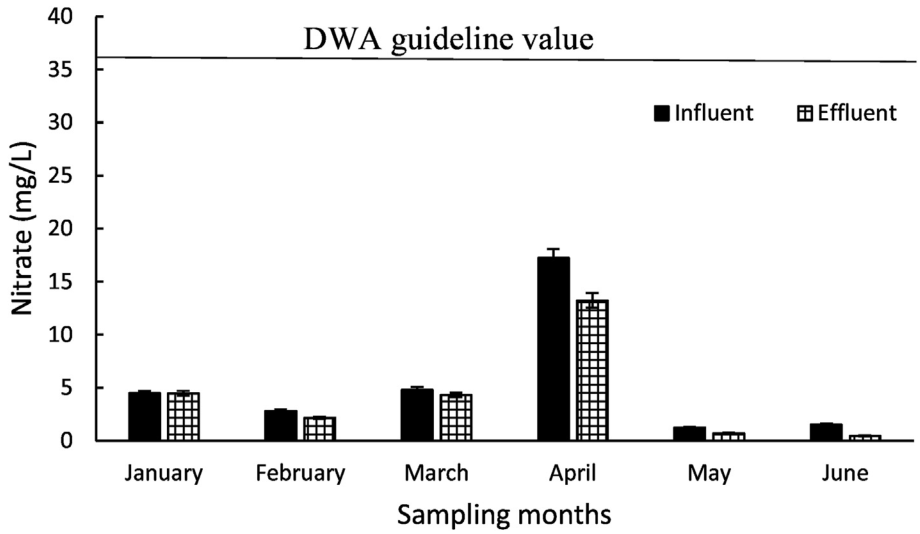

Figure 6. Nitrate concentrations in the influent and effluent of the Siloam WSP system. The error bar represents standard deviation.

could be due to the fact that the WSP facility has been overstretched beyond its design capacity and receives more than twice the wastewater it was designed to handle and treat. Another contributing factor could be due to the reduction of HRT.

The WSP system showed varying trend of EC levels across the sampling months. Generally, more EC levels were recorded in the effluent during the dry season which could be attributed to evaporating effects, thus leading to higher levels of ions. On the contrary, lower levels were determined in the effluent for January and February in the wet season. This could be due to dilution effects caused by the increased precipitation event. There is usually a breakdown of organic compounds and nutrients with the aid of microorganisms in WSP systems which could increase the levels of ionic compound in the ponds. However, some WSP systems have reported decrease in EC levels (Gopolang and Letshwenyo 2018; Levlin, 2010; Hodgson, 2007).

Nitrate is commonly found in wastewater and the discharge of effluent rich in nitrates can initiate algae blooms in the receiving watershed leading to depletion of dissolved oxygen which is injurious to aquatic organisms (Edokpayi, 2016). Nitrate concentrations that complied to the DWA (2010) guideline of 36 mg/L were recorded both in the influent and effluent during the study period (Figure 6). The levels could be higher if domestic wastewater and runoffs from agricultural lands were included in the raw water. But since the major source of wastewater in this system is from hospital, these levels are anticipated. A reduction efficiency in the range of 10.56–69% were recorded for February–June of the sampling months.

Trace metals are not routinely monitored in most wastewater treatment facilities, but their concentrations are important owing to their toxicities, persistence and bio-accumulative tendencies once released into the environment (Mihajlovic et al., 2014; Wang and Chen, 2009; Bailey et al., 1999). Several authors have reported that WSP systems do reduce the levels of metals in the raw water it receives (Mwakaboko et al., 2014; Üstün, 2009; Shpiner et al., 2009).

Due to the deleterious nature of most metals, it is important they are removed from wastewater stream before discharge into freshwater sources. Although dilution of the metals is possible during high river flow in the receiving stream, their presence will increase the background levels of metals in the stream and can induce physiological changes in benthic organisms. Also, metals can bio-accumulate in fish and other freshwater food that can easily be passed to man if consumed (Edokpayi et al., 2017). Non-essential metals and metalloid like Pb, Hg, Cd and As are known to bioaccumulate in fish tissues. Similarly, several other metals like Cr, Cu, Zn, Mn and a host of others which are essential to various fish species are also known to bioaccumulate in the fish tissues. The consumption of such metal rich fish provides a route of their introduction into human food chain thus constituting a potential risk to humans (Ali and Khan, 2018; Edokpayi et al., 2014). Apart from the human health risks WSPs pose by the discharge of metal rich effluent, trace metals in water are known to induce oxidative stress and cause fish deformities, alteration in their life cycle and death. Thus, the protection of the aquatic ecosystem is important both ecologically, environmentally and economically.

4.1. Implications and recommendations for managers of WSP systems in developing countries

To forestall the potential risk inadequate wastewater treatment would have on the environment and public health, it is imperative that WSP systems functions efficiently. The Siloam WSP system like many others in developing countries do not efficiently treat the wastewater they receive due to several reasons. This includes irregular monitoring and maintenance of the system. There are reports that in developing countries, most WSP system were efficient at the inception of the facility but as time goes by the system produces poor effluents that negatively impact on the receiving stream due to neglect, inadequate monitoring or lack of maintenance (Osuolale and Okoh, 2015; Libhaber and Orozco-Jaramillo, 2012; CSIR, 1983). Some signs of inefficient management include animal grazing within the facility, broken fence, broken cement embankments on the ponds, overgrowth of unwanted plants and weeds within and outside the ponds, overflowing of ponds, blocked screen in the inlet channel (Edokpayi, 2016; de Souza and Jack, 2010).

Another major problem associated with WSP systems in developing countries is the overloading of the facility. Siloam WSP like many others receive wastewater above their design capacity and this have an impact on the quality of effluent that will be produced. The overloading of the facility reduces the time the wastewater spends in the pond (Verbyla et al., 2017). Another major limitation to efficient wastewater treatment is sludge accumulation. Most WSP system do not have budget for desludging of the system. Some scholars have recommended that desludging of waste stabilization treatment systems should be done within every 3–5 years, this is to limit the chances of a dead zone within the pond that affects its effective volume (Verbyla et al., 2013; Oakley et al., 2012). Such reduction of volume would have a direct impact on the HRT of the pond thus producing poor quality effluent. Poor design of WSP system is another factor that can affect its treatment efficiency. If the required kind of pond are not made and there is a compromise in size and

Table 3. Influent and effluent concentration of metals in the Siloam WSP system.

Months	Al (mg/L)		
	Influent	Effluent	% removal
January	1.90 ± 1.06	13.44 ± 4.06	-607
February	3.15 ± 1.12	0.54 ± 0.87	82.9
March	2.57 ± 0.76	0.84 ± 0.96	67.4
April	5.17 ± 2.06	2.14 ± 2.04	58.6
May	9.39 ± 4.00	2.82 ± 0.85	66.9
June	2.53 ± 0.78	1.73 ± 1.03	31.4
Detection limits (μg/L)	0.1		
DWA (2010)	0.03*		
	Fe (mg/L)		
January	0.94 ± 0.33	2.64 ± 0.86	-181
February	0.81 ± 0.20	0.53 ± 0.23	34.1
March	1.06 ± 0.06	1.09 ± 0.24	-2.83
April	0.96 ± 0.04	0.79 ± 0.06	17.7
May	3.49 ± 1.16	1.27 ± 0.44	63.5
June	0.40 ± 0.06	0.44 ± 0.05	-10
Detection limits (μg/L)	0.8		
DWA (2010)	0.3		
	Zn (mg/L)		
January	0.18 ± 0.02	0.17 ± 0.03	5.5
February	0.08 ± 0.02	0.05 ± 0.01	36.5
March	0.13 ± 0.04	0.07 ± 0.02	42.7
April	0.16 ± 0.05	0.12 ± 0.03	25.1
May	0.54 ± 0.10	0.08 ± 0.02	85.4
June	0.09 ± 0.01	0.01 ± 0.01	94.8
Detection limits (μg/L)	0.2		
DWA (2010)	0.1		
	Cr (mg/L)		
January	0.25 ± 0.08	0.46 ± 0.10	-84
February	0.31 ± 0.05	0.21 ± 0.09	30.8
March	0.35 ± 0.05	0.31 ± 0.05	12
April	0.02 ± 0.001	0.04 ± 0.001	-100
May	0.33 ± 0.06	0.22 ± 0.06	23.4
June	0.02 ± 0.001	0.02 ± 0.001	0
Detection limits (μg/L)	0.1		
DWA (2010)	0.05		
	Cu (mg/L)		
January	0.07 ± 0.002	0.16 ± 0.01	-129
February	0.03 ± 0.001	0.03 ± 0.001	0
March	0.02 ± 0.001	0.02 ± 0.001	13.1
April	0.06 ± 0.004	0.04 ± 0.003	23.9
May	0.13 ± 0.01	0.06 ± 0.002	56.4
June	0.09 ± 0.09	0.02 ± 0.001	77.1
Detection limits (μg/L)	0.1		
DWA (2010)	0.01		
	Mn (mg/L)		
January	0.05 ± 0.01	0.58 ± 0.12	-1060
February	0.20 ± 0.04	0.04 ± 0.01	80.6
March	0.17 ± 0.02	0.26 ± 0.04	-52.94
April	0.16 ± 0.03	0.19 ± 0.02	-18.75
May	0.29 ± 0.05	0.22 ± 0.04	23
June	0.11 ± 0.05	0.2 ± 0.06	-81.82
Detection limits (μg/L)	0.1		
DWA (2010)	0.1		
	Pb (mg/L)		
January	0.01 ± 0.001	0.01 ± 0.001	0
February	bdl	Bdl	NA
March	0.62 ± 0.201	Bdl	100

(*continued on next page*)

Table 3 (*continued*)

Months	Al (mg/L)		
	Influent	Effluent	% removal
April	0.06 ± 0.05	0.01 ± 0.001	77.1
May	0.05 ± 0.01	Bdl	93.7
June	0.01 ± 0.001	Bdl	100
Detection limits (μg/L)	0.1		
DWA (2010)	0.01		

Bdl: below detection limit, NA: not applicable. * represent a future guideline value.

Table 4. Average COD (mg/L) levels and percentage removal in WSP systems in some developing countries.

WSP system	COD influent	COD Effluent	% removal	Reference
Morogoro (Tanzania)	420	200	52.4	Zacharia et al., 2019
Mwanza (Tanzania)	575	215	63	Zacharia et al., 2019
Iringa (Tanzania)	815	235	71.2	Zacharia et al., 2019
Roton (South Sudan)	127.3	156.3	-22.8	Manya et al., 2019
Akosombo (Ghana)	263.0	64.9	75.0	Adu-Ofori et al., 2016
Kilombero (Tanzania)	301	112	62.8	Machibya and Mwanuzi, 2006
Arak (Iran)	524.9	150.7	71	Naddafi et al., 2009
Enugu (Nigeria)	151	189	-25.2	Nweze et al., 2014
Siloam (South Africa)	111.5	123.7	-10.94	This study

depth or a poor estimation of the pond capacity as well as the HRT will contribute to poor effluent generation (de Souza and Jack, 2010).

The recommendation to waste stabilization managers from this study include extension of the current system to prevent overloading of the facility. Unwanted vegetation which should be eliminated continuously. There is a need for a flow meter to determine the exact volume of wastewater entering the pond system and this can help to provide much needed data for possible extension. Provision should be made for routine testing of the effluent for microbiological and physicochemical compliance to regulatory standards. The maturation ponds alone cannot satisfactorily treat the wastewater, because they are often used to polish the wastewater after prior treatment either with the anaerobic or facultative ponds. The WSP system managers should either include an anaerobic and/or facultative ponds to the present set-up. The last pond should be re-configured to prevent short-circuiting of wastewater from the first pond. A better fence should be installed that can prohibit the entering of cows and other animals in the treatment vicinity.

5. Conclusion

From the experimental data obtained during the study period, Siloam WSP system is not performing properly and needs improved maintenance. The counts of faecal indicator organisms in the effluent exceeded the set guideline of 1 x 10^3 cfu/100 mL. The pond system is also not effective in reducing the levels of suspended solids in the wastewater. This is critical because these suspended particles can reduce the effectiveness of the disinfection process and negatively impact on the dissolved oxygen in the receiving stream. Hospital wastewater is usually characterised with the presence of organic compounds, which this study established by using COD levels as a proxy indicator. The WSP system fails to reduce the levels of organic contaminants to acceptable values. Currently, there is no flow meter that measures the quantity of the influent entering the ponds and there is no routine testing to ensure compliance with guidelines. The resulting effluent can be regarded as potentially harmful because it is currently discharged into a river used by people for various activities. This study has shown that the Siloam WSP system is typical of most WSP systems in developing countries; it is poorly maintained and lacks adequate monitoring assessment for compliance. It is recommended that the pond system be extended to deal with the extra load, and adequately maintained to treat the wastewater. This should include desludging and preventing short circuiting of wastewater during high rainfall.

Declarations

Author contribution statement

J.N. Edokpayi: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

J.O. Odiyo, E.O. Popoola and T.A.M. Msagati: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

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