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Pathogens Removal from Wastewater Using Sustainable Treatment Wetlands in Tanzania: A Review

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Abstract Municipal and domestic wastewater contains various pathogenic micro-organisms which, depending on their concentration pose a risk to human health. Therefore their presence must be reduced or eliminated before treated wastewater is reused or released into the environment. Studies conducted by researchers suggest that treatment wetlands are the best systems in removing pathogens from wastewater. Further, the literature reveals that some of the treatment wetland systems achieved up to 2 – 4 $\log_{10}$ removal efficiencies. Effective removal of pathogens in treatment wetland systems calls for an understanding of the processes responsible for pathogen removal. One way of understanding these processes is through the use of mathematical model equation. However, in the case of Horizontal Subsurface Flow (HSSF) constructed wetlands, there is no apparent mathematical model equation explaining pathogens removal processes. On the other hand, treatment wetland systems in Tanzania fail to remove pathogens as intended by designers probably and partly due to improper operation and poor maintenance. This article presents the review of treatment wetland performances in removing pathogens in Tanzania conducted in prior studies. It is also geared toward understanding the removal mechanisms responsible for pathogens removal in these treatment systems.

Keywords Design equation, Horizontal Subsurface Flow Constructed Wetland, Pathogens, Removal mechanisms, Treatment wetland, Waste stabilization pond

1. Introduction

Treatment wetlands have been established in Tanzania in the past two decades to treat both industrial and municipal wastewater [1]. Constructed Wetlands (CW) researches in Tanzania begin in 1998 at the University of Dar es Salaam, in which the first system was installed to treat wastewater effluents from Waste Stabilization Ponds (WSP) of the University of Dar es Salaam [2], [1]. Over 14 years of successful studies (1998 – 2012), fifteen CWs were established in Tanzania by the “WSP and CW Research group” of the University of Dar es Salaam [3]. In other hand Waste Stabilization Ponds were established in Tanzania in the early 1960’s to deal with problems exacerbated with sewage effluents from industries [4]. WSPs are wastewater treatment options recommended by the government of Tanzania [4]. The effluents from these treatment systems (WSPs and CWs) are used by the locals for irrigation farming, fish farming and sometimes domestic animal feeding due to inaccessibility of fresh water [5], [6], [7]. However reuse of inadequately treated wastewater can cause adverse health risks to humans because of the excreted pathogens it contains [8]. The recommended threshold limit for microbiological effluent quality to protect public health from wastewater exposure, is less than 1 nematode egg/L and less than 1000 cfu/100 mL.

[9]. Therefore without appropriate means of removing pathogens from wastewater, more cases of cholera outbreaks and other waterborne diseases are more likely to persist in Tanzania. It is known that controlling frequent outbreak of infectious diseases is more expensive [4].

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2. Performance of Wastewater Treatment Systems in Removing Pathogens in Tanzania

Constructed Wetlands and Waste Stabilization Ponds have been reported with good performance in treating wastewater worldwide [10]. Although these systems are being good in dealing with wastewater pollutants, some of prior studies carried out in Tanzania show inefficiencies of these systems in eradication of pathogens to the desired levels prescribed by WHO for wastewater reuse. This is elaborated in Table 1.

Table 1. Pathogens in Influent and Effluents of Wastewater Treatment Systems in Tanzania

Site	System type	Faecal bacteria (cfu/100ml or MPN/100 ml)		Parasites (Helminths (eggs/L) and Protozoa ((oo)cysts/L))		Source of Data
		Mean Influent	Mean Effluent	Max. Influent	Max. Effluent	
Moshi	WSP	7700 to MP	1100	-	-	[12]
		-	1000	-	-	[6]
	CW	7248.75	4626.87	-	-	[6]
		7700	4633	-	-	[12]
Mafisa, Morogoro	WSP	13.183×10^6	447	-	-	[13]
		4.2×10^6	3.6×10^3	-	-	[14]
		-	-	20 eggs/L, 2 oocyts/L	7 eggs/L	[15]
	CW	153,330	890	8 eggs/L	5 eggs/L	[15]
Mzumbe, Morogoro	WSP	12.0226×10^6	355	-	-	[13]
University of Dar es Salaam	WSP	3.04×10^6	653	-	-	[16]
	CW	55,125	22,762.5	-	-	[2]
		$60.4\pm14.2\times10^3$	$3.51\pm0.68\times10^3$	-	-	[10]
University College of Lands and Architectural Studies (UCLAS), "**experimental**"	CW (A)	$12.5x10^6$	$6.5x10^6$	-	-	[17]
	CW (B)	$12.5x10^6$	$7.5x10^6$	-	-	
	CW (C)	$12.5x10^6$	$4x10^6$	-	-	

Source: compiled by author from indicated sources. "-" means particular data were not part of the study. Max. = maximum

In assessing WSP and CW performance data collected in Table 1, Waste Stabilization Ponds seems to have higher performance in removing faecal bacteria. This is due to higher surface area and high retention time of the WSP over CW as described by Garcia et al. [11] in comparing them.

The major challenge of the established CWs in Tanzania is the operational and maintenance problem (such as clogging and flooding). The survey conducted by the University of Dar es Salaam Research group in 2010 indicated that 86% of the surveyed CW systems experienced such operational problems. Combination of clogging and flooding constituted 57.1%. While other operation problems like seepage through the walls and stormwater run-off especially after rainfall event contributed 28.6% [3].

These operational problems lead to the insufficient removal of pathogens from wastewater. In presence of flooding, clogging, stormwater run-off or seepage, wastewater tends to bypass the effective part of the treatment system resulting in to poor performance.

3. Mechanisms for Pathogens Removal

WSPs and CWs systems remove pollutants from wastewater by mimicking processes found in natural wetlands [18]. In most cases both systems are designed to remove organic matter, Nitrogen and Phosphorus. However pathogens removal from wastewater are also partly considered in the design [8], [18], [19]. In WSPs, systems are configured in such a way that the maturation pond is intentionally designed for removing pathogens [19], [20], [21]. In CW systems, pathogens are mainly removed by filtration, natural die-off, sedimentation, exposure to biocides excreted by wetland plants, and UV irradiation [18], [22]. But in case of horizontal subsurface flow constructed wetland (HSSF) solar intensity is insignificant in removing pathogens [23].

Both WSP and CW systems should be improved so that they may efficiently remove the pathogens especially bacteria indicator organisms, helminth eggs, and protozoa cysts. Many studies conducted have concentrated on modelling the systems for the removal of faecal bacteria and helminths in the WSPs. Little information is available in the case of CW for the pathogens removal from design to implementation. Several treatment wetland systems have been constructed and implemented in different countries, but less microbial information is available [24]. To achieve 100% removal of helminth eggs, it is suggested to use Horizontal Subsurface Flow constructed wetland with up to 25 m bed length [8]. Removal of pathogens is influenced by different associated mechanisms in the wetland system.

3.1. Bacteria and Viruses Removal Mechanisms

Removal mechanisms of bacteria indicator organisms are the most commonly studied in the previous research less information is discussed for specific viruses, bacteria, protozoan cysts and helminths [25], [26]. The mechanisms on the die-off of viruses in WSP are not well understood. Their removal are considered being enhanced mainly by sedimentation followed by adsorption onto solids that results from algae die-off and other bio solids [27]. Oragui et al. [28] investigated faecal coliform and rotavirus in several WSP series in northern Brazil. Each series was comprised of anaerobic, facultative and three maturation ponds, with an overall retention time of 10 – 25 days. Faecal coliforms were reduced from 3×10^7 cfu/100 ml to ~50 cfu/100 ml, achieving the removal efficiency of 99.9%; number of rotavirus was reduced from 1×10^4/L of raw wastewater to < 2 viruses/L of effluent, achieving removal efficiency of 99.9%. These results show better performance of WSP in dealing with faecal bacteria due to system associated factors.

Several factors that explain the die-off of faecal bacteria in WSP have been proposed, and they are grouped in a light-mediated process or a dark-mediated process [27]. The dark- mediated process includes sedimentation of bacteria adsorbed in to settleable solids, predation by protozoans and die-off due to senescence and starvation. External factors that aid dark- mediated process includes; pond depth (the deeper the pond, the greater darkness in deeper section), organic loading. The light-mediated factors include, temperature and time, high light intensity, high pH, and high dissolved oxygen. These factors are explained in detail in the following sections. Table 2 presents source of data used to create Figure 1, Figure 2, Figure 3, Figure 4, Figure 5 and Figure 6 developed by author.

Table 2. Studies done in Tanzania and their corresponding sources

Study	1 – 2	3 – 4	5 – 8	9 – 12	13-14	15-16	17-18
Source	[6]	[16]	[12]	[17]	[2]	[15]	[10]

3.1.1. Time and Temperature

Temperature is the result of the solar intensity on surface of the pond, the longer the pond is exposed to light-mediated factors the greater the faecal bacteria inactivation rate [19], [27]. From the data analysis of different WSPs (Figure 1) and CWs (Figure 2) studies carried out in Tanzania show that faecal bacteria concentration were not well correlated with temperature (r = 0.16 for WSP and 0.66) as compared to that reported by Liu et al. [29] (r = -0.50) this may be due to difference in weather conditions in which Liu et al. [29] study was conducted at high temperature range (-15 – 26°C).

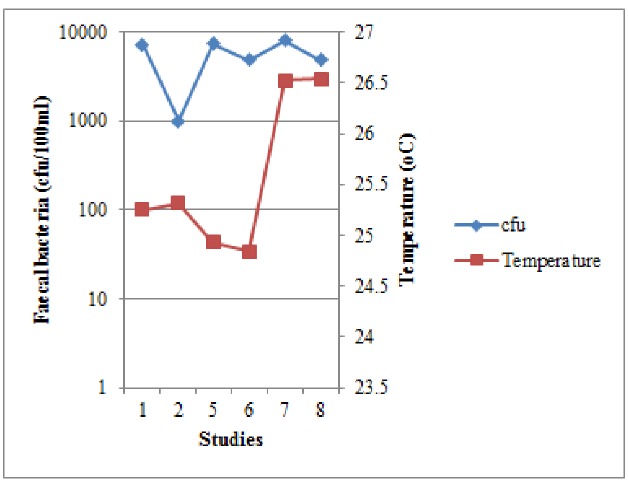

Figure 1. The relationship between faecal bacteria concentration and temperature in WSPs, from different studies in Tanzania

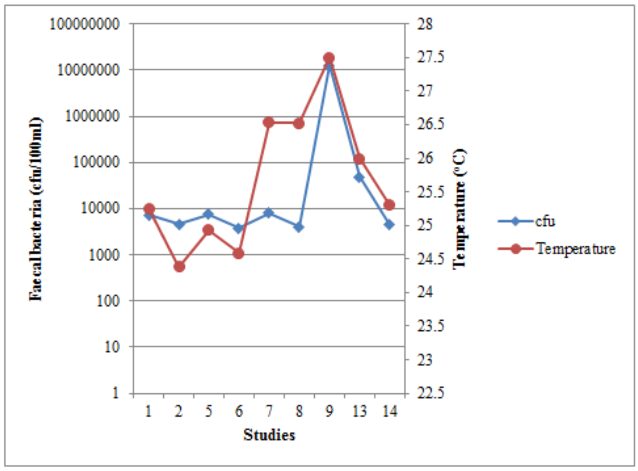

Figure 2. The relationship between faecal bacteria concentration and temperature in CWs from different studies in Tanzania

3.1.2. pH

Wastewater pH ≥ 9.4 increases faecal bacteria die-off very rapidly [27]. High pH is the light mediated factor as it is enhanced by the pond algae. High pH values (above 9) in ponds are influenced by the rapid photosynthesis of pond algae which consumes CO_2 faster than it can be produced by heterotrophic bacteria during respiration [19]. The absence of dissolved CO_2 in the pond disturbs the equilibrium of CO_2 – bicarbonate – carbonate, and consequently bicarbonate and carbonate ions dissociate as shown in equation (1) and equation (2).

$$2HCO_3^- \rightarrow CO_3^{2-} + H_2O + CO_2 \qquad (1)$$

$$CO_3^{2-} + H_2O \rightarrow 2OH^- + CO_2 \qquad (2)$$

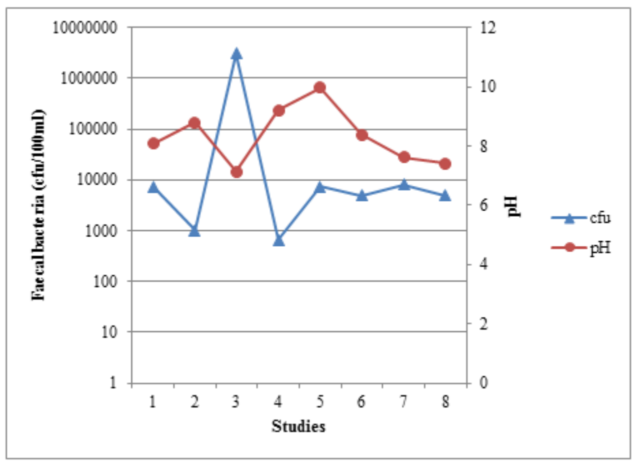

Figure 3. The relationship between faecal bacteria concentration and pH in WSPs from different studies in Tanzania

CO_2 that results from dissociation of bicarbonate is fixed by algae, and hydroxide ions (OH^-) accumulate in wastewater and raise the pH to values above 10, and this accelerates rapid faecal bacteria die-off. A high pH in wastewater kills faecal bacteria by causing them unable to maintain their optimal intracellular pH of 7.4 – 7.7 [27].

From different studies conducted in Tanzania show that the raise in pH enhanced gradual reduction in faecal bacteria in WSPs as shown in Figure 3. Faecal bacteria concentration were well correlated with pH values (r = -0.50) and indicating that at higher (pH >8) there is sharp decrease in faecal bacterial concentration levels.

Referring to Figure 4, the relationship of faecal bacteria concentration and pH were not well correlated in CW (r = -0.28) as that in WSP. This indicates that there are other possible mechanisms in subsurface flow CW that trigger the reduction process of faecal bacteria.

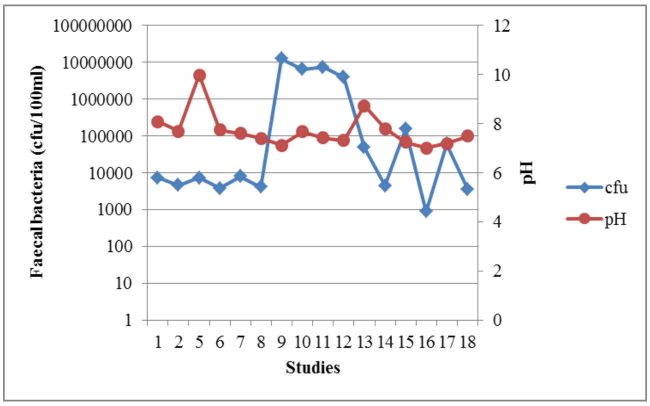

Figure 4. The relationship between faecal bacteria concentration and pH in CWs from different studies in Tanzania

3.1.3. Dissolved Oxygen (DO) and Light Intensity

Light of wavelength up to 700 nm can damage faecal bacteria [30]. However light of wavelength below 450 nm was not an important factor in WSP since it is completely absorbed in the first few mm in the pond downward [27]. The UV wavelengths that can be absorbed by microorganisms, and can effectively disinfect them, comprise the range of 240 – 280 nm [22]. However light of wavelength more than 450 nm can only damage faecal bacteria in the presence of both dissolved oxygen and dissolved sensitizer such as the humic substances. Both dissolved oxygen and humic substances are required for light induced damage of faecal bacteria (referred as photo-oxidation damage) [27], [29]. Photo-oxidation is the process whereby exogenous or endogenous sensitizer absorb light energy and transfer it to other molecules leading to the formation of reactive oxygen species (ROS). ROS react with pathogens and adversely cause cells damage [29]. Therefore an increase in DO concentration is considered to raise the effect of photo-oxidation. Dissolved Oxygen increase in the WSP is associated with algae photosynthesis process.

However, photo-oxidation induced disinfection is not only dependent on DO concentrations but also enhanced significantly by sunlight intensity. The light – oxygen – humic substance damage is influenced by intracellular pH values greater than 7.7. Therefore the algae in pond are essential for inactivation of faecal bacteria; since they raise oxygen levels in pond during photosynthesis process and induce high pH values in wastewater. The combination of high light intensity, high dissolved oxygen, high pH and humic substance inactivate bacteria as follows. Humic substance absorbs light and then forms oxygen radicals (e.g. H_2O_2) after reacting with oxygen by photo oxidation process. Resulting oxygen radicals damage the cell membrane causing the cell to die, and high pH enhances the cell damage in the same way [27].

The analysis of data from prior studies conducted in Tanzania (Figure 5) shows that, the DO increase in WSPs lead to sharp decrease in faecal bacterial concentration and they were well correlated by (r = -0.80). Also in CW (Figure 6) the DO concentrations and faecal bacterial concentrations were well correlated by, r = -0.74.

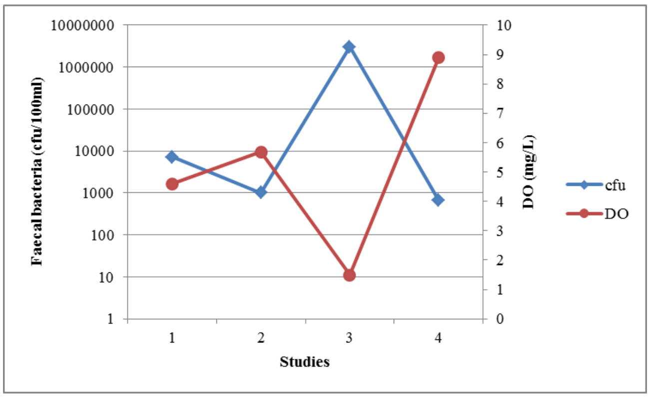

Figure 5. The relationship between faecal bacteria concentration and DO in WSPs from different studies in Tanzania

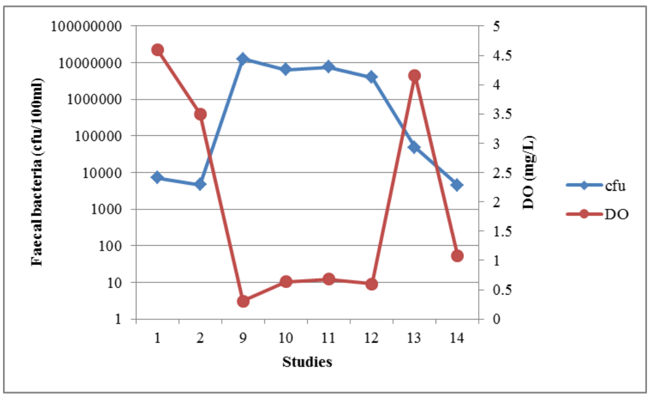

Figure 6. The relationship between faecal bacteria concentration and DO in CWs from different studies in Tanzania

Liu et al. [29] Conducted a study on three environmental factors; temperature, pH and Dissolved Oxygen (DO) on inactivation efficiency of *E. coli* in WSP system. The pond system consisted of three facultative cells in series, operated in temperate climate region in eastern Ontario, Canada. In case of DO analysis showed that DO increase was not well correlated with *E. coli* inactivation as it was expected to raise the rate of photo-oxidation. This might be attributed by photo-oxidation induced disinfection, which do not only depend on DO concentrations, but also influenced significantly by sunlight intensity. In case of pH, it was observed that the number of *E. coli* concentration increased at pH below 8 while reduced rapidly at pH above 8. In case of Temperature, it was observed that the *E. coli* concentrations were well correlated with temperature, (r = -0.50), where negative correlation indicated that at lower temperatures the *E. coli* concentrations were higher than during the warmer seasons. In warmer season (April – September) the *E. coli* concentrations were found to be significantly higher than that in colder seasons (October – March). These findings indicate that temperature may play a vital role in survival of *E. coli.* In cold weather ($T < 5^{o}C$) *E. coli* survived better, possibly because algae lacked sunlight intensity that doomed their growth, hence resulting into decreased pH (pH ≤ 8) which is favourable to survival of *E. coli* [29].

3.2. Helminth Eggs and Protozoa Cysts Removal

Studies conducted by Ayres et al. [31] Revealed that helminth eggs and protozoa cysts are mainly removed by sedimentation in WSP. The sedimentation rate is highly influenced by the settling velocity of a specific parasite as indicated in Table 3. To have sufficient removal of helminth eggs and cysts there should be enough hydraulic retention time at a given length/width ratio of WSP system (at least hydraulic retention time of more than 9 days is required to achieve 99% removal) [31].

Table 3. Settling velocities for parasites eggs and cysts

Parasite	egg/cyst size (μm)	Relative density	Settling velocity (m/h)
Ascaris lumbricoides	55 x 40	1.11	0.65
Trichuris trichiura	22 x 50	1.15	1.53
Hookworms	60 x 40	1.06	0.39
Giardia lamblia	14	1.05	0.02
Cryptosporidiumparvum	6	1.08	0.004
Entamoeba histolytica	5	1.1	0.007
Schistosoma sp.	50 x 150	1.18	12.55

Source: [32]

In accessing seasonal particle size distribution dynamics (particles similar to helminth eggs) to understand settling dynamics in Buguruni WSPs, Tanzania, Izdori et al. [33] found that particles coming to the pond were mainly super colloidal by 52.9% and setleables by 45.6% in dry season and 48.9% and 49.9% respectively in wet season. In investigating further found that about 61.5% of particles with similar size to helminth eggs are suspended during dry season and about 45.2% remain suspended during the wet season. Therefore there is possibility of these particles to be carried out in the effluent.

Horizontal subsurface flow constructed wetlands (CW) are also considered being good in removing pathogens from wastewater. Stott et al. [8] investigated the removal of parasites from wastewater using gravel beds hydroponic Constructed Wetlands at Abu Attwa Ismailia, Egypt. The study resulted into significant reduction of parasites eggs by 100%, in which the inlet concentrations of parasites ranged between 6 to 38 eggs/litre and were significantly reduced and no eggs detected in the effluent. Stott et al. [8] concluded that the removal mechanisms were highly influenced by filter media and bed length. Apparently, vegetation were reported to have no effect on hygienic quality of treated wastewater. In contrast to that, samples were taken from the inlet and outlet of the treatment system for the beds of 50 m and 100 m and consideration was not given to the removal at every interval from the inlet to outlet that would have provided the perfect design relationship on the bed length and parasites retained.

4. Design Equations and Modelling of Pathogens Removal in WSP and CW

Design equations and models provides a better understanding on the mechanisms and factors that influence pathogens removal in WSP or CW. Majority of models developed concentrated on bacteria indicator organisms as representative to pathogens quality of wastewater effluents. However some studies treated them separately, in which parasites eggs were also considered in separate equation [31].

4.1. Design Equation and Modelling Faecal Bacteria Removal

Faecal coliform is the most commonly used as indicator organism group to define the presence of pathogens in wastewater [22]. Their removal in Free Water Surface wetlands (FWS) and WSP was considered to follow the first order removal kinetics [19], [22], [27]. Equation (3) below, describes the first order removal kinetics of *E. coli* [27].

$$N_e = \frac{N_i}{(1+K_T\theta)} \tag{3}$$

Where N_e = faecal bacteria (cfu /100 mL) of effluent, N_i = faecal bacteria (cfu/100 mL) of influent, K_T = first order removal rate constant for faecal coliform (d^{-1}), θ = retention time (day).

The K_T value is highly dependent on temperature and it can be computed by using equation (4).

$$K_T = 2.6(1.19)^{(T-20)} \tag{4}$$

Where by T = temperature (^{o}C).

For series of anaerobic, facultative and maturation ponds equation (3) becomes as shown in equation (5) [27].

$$Ne = \frac{N_i}{[(1+K_T\theta_a)(1+K_T\theta_f)(1+K_T\theta_m)]} \tag{5}$$

Where subscript a, f and m refers to anaerobic, facultative and maturation ponds, and n is the number of maturation ponds. Equation 5 assumes that all maturation ponds are equally sized.

Since UV radiation is the potential factor in killing bacteria in FWS and WSP [22]. Equation (6) is an exponential equation (first order kinetic equation) used to describe the inactivation rate of bacteria.

$$N = N_o e^{(-k_i I\theta)} \quad (6)$$

Where by: I = Intensity of UV light in solution, J/m^2.d, k_i = inactivation rate coefficient, m^2/J, N = Surviving number of dispersed organisms, N_o = Initial number of dispersed organisms, θ = time, d.

From equation (6), the inactivation rate of faecal bacteria is highly dependent on the UV – intensity of the solar radiation and the time of exposure to sunlight. However the inactivation of faecal bacteria is reduced by poor penetration of light to the deeper section of the wetland system. Therefore the solar inactivation rate is inversely proportional with the pond depth [22]. The proportionality of solar inactivation rate coefficient and depth of the wetland system is described in equation (7)

$$k_s = \frac{k_s'}{k_L h} \quad (7)$$

Where by: h = water depth, (m), k_s = overall solar inactivation rate coefficient, m^2/J, k_s' = intrinsic solar inactivation rate coefficient, m^2/J, K_L = light attenuation coefficient (m^{-1}).

Mayo [34] studied the kinetics of faecal *streptococci* and faecal coliform mortality in the Free Water Surface wetland cell. The cell had the following dimensions; effective area 7.5m x 1.5m and 0.7m deep, half filled with 19 mm sized aggregates and remaining part filled with water. In assessing the performance of the system he developed bacteria removal rate constant (equation (8)), and finally an improved bacteria mortality rate equation (9). It was concluded that bacteria mortality rate constant was largely enhanced by sunlight intensity that contributed 72.6% of removal, while pH and dissolved oxygen each contributed 7%. Bacteria removal by sedimentation contributed only 0.44% of the total removal and other factors were less significant. The model efficiency was reported to be 0.80 (80%).

$$k_{predicted} = 0.00366 S_o^{0.762}(1-e^{-8H})(pH)^{0.329}(DO)^{0.088} + \frac{0.00905}{\mu_T} \quad (8)$$

$$N_e = N_i \exp[0.00366 S_o^{0.762}(1-e^{-8H})(pH)^{0.329}(DO)^{0.088} + \frac{0.00905}{\mu_T}] \quad (9)$$

Where by: N_e = effluent bacteria number per 100ml, N_i = influent bacteria number per 100ml, S_o = solar intensity (cal/cm^2/d), DO = Dissolved Oxygen (mg/l), μ = dynamic viscosity (Pa.S), H = height of water column in wetland (m) and $k_{predicted}$ = is the predicted bacteria mortality rate constant.

Microbial removal in a Horizontal Subsurface Flow constructed wetland is described by assuming it performs as an ideal plug flow reactor with first order kinetic decay constant, described in equation (10), [35].

$$\frac{C_1}{C_o} = \exp(-k\theta) \quad (10)$$

Where by: C_o and C_I are the influent and effluent microbial concentration (in FC/100 ml or SC/100 ml respectively, k is the first-order decay kinetics (in days^{-1}), and θ is the hydraulic retention time (HRT), (in days). Garcia et al. (2003) discussed the influence of HRT on microbial removal, but didn't consider other influencing factors like filtration, pH, Dissolved Oxygen within the wetlands.

Since removal mechanisms in HSSF are based on filtration, sedimentation, exposure to biocides excreted by wetland plants, etc. Those removal processes of pathogens cannot be described by kinetic models which are based on (bio)chemical reaction mechanisms (such as 1st order kinetic models). Therefore there is a need to develop a mathematical model that will consider those factors.

4.2. Design Equation and Modelling of Parasites Eggs Removal

Ayres et al. [31] developed the design equation for human intestinal nematode eggs removal in Waste Stabilisation Ponds. Equation (11) is the design equation developed, with lower confidence limit of 95% for the design of ponds to meet the WHO microbiological guidelines.

$$R = 100[1 - 0.41\exp(-0.49\theta + 0.0085\theta^2)] \quad (11)$$

Where by: R = Percentage (%) removal and θ = Hydraulic retention time (day).

Clearly, from equation (11), it can be seen that the removal of helminth eggs is highly influenced by the hydraulic retention time (Table 4). In other words, enough time is required for helminth eggs to settle down.

Table 4. Removal efficiency (%) at different hydraulic retention time

θ	R	θ	R	θ	R
1	74.6679	13	99.7047	25	99.9602
2	84.0801	14	99.7725	26	99.9624
3	89.8236	15	99.8216	27	99.9638
4	93.3835	16	99.8578	28	99.9646
5	95.6243	17	99.8847	29	99.9648
6	97.0566	18	99.9049	30	99.9644
7	97.9861	19	99.9202	31	99.9634
8	98.5985	20	99.9319	32	99.9617
9	99.0079	21	99.9409	33	99.9592
10	99.2857	22	99.9478	34	99.9559
11	99.4769	23	99.9531	35	99.9514
12	99.6103	24	99.9572	36	99.9455

Source: Developed by author by inserting data in equation (11)

According to this review no study was observed, reporting on developing separate modelling equation of parasites removal for the Horizontal Subsurface Flow constructed wetlands. Parasite removal mathematical model equation in HSSF should be quite different from those of FWS, largely because of the associated mechanisms in microbial removal which is the result of the nature of hydraulic characteristics between the two systems. In HSSF the removal mechanisms are excluded from sunlight inactivation. Fortunately, inactivation and removal of pathogens is influenced by mechanical filtration, temperature, adsorption to organic matters, adhesion to bio-film and exposure to biocides excreted by wetland plants [23].

In HSSF wastewater percolates through the porous media during the treatment process, and then the process is considered to follow the Darcy's equation. Therefore the discharge rate of wastewater through the porous media is highly dependent on the intrinsic permeability. As the process goes on, solid matters tend to accumulate in the pore spaces and clog the system that further accelerate parasites to bypass effective treatment path. Therefore regular maintenance on the HSSF is the crucial factor on its performance in removing pathogens.

5. Conclusions

From reviewed literature on the removal of pathogens from wastewater using sustainable treatment wetlands, it can be concluded that:

The study on mechanisms responsible for removing pathogens is still lacking, hence needs more investigations to speculate what might be promoting or hindering the removal process especially in Horizontal Subsurface Flow constructed wetlands.

In case of Horizontal Subsurface Flow, there is no apparent kinetic model for better understanding the removal processes. Therefore the model governing pathogens removal process in HSSF is required and should be developed by considering all factors with significant influence.

Finally this can be achieved through formal research by studying, the performance of the wetland systems, factors promoting pathogens inactivation and detention, configuration of the available systems, and manipulation of operational parameters in pilot scale model with improved configuration.

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