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Chapter

Natural Wastewater Treatment Systems for Prevention and Control of Soil-Transmitted Helminths

Abdallah Zacharia, Anne H. Outwater and Rob Van Deun

Abstract

Wastewater reuse has been considered as an alternative way of overcoming water scarcity in many parts of the world. However, exposures to wastewater are associated with higher prevalence of soil-transmitted helminths (STHs). Globally, about two billion people are infected with at least one species of STHs with those having heavy infections presenting considerable morbidities. The most serious STH species infecting humans include roundworm (*Ascaris lumbricoides*), whipworm (*Trichuris trichiura*), and hookworms (*Necator americanus* and *Ancylostoma duodenale*). Despite ongoing control campaigns using preventive chemotherapy, wastewater in endemic countries still contains concentrations of STH eggs that put exposed populations at risk of infection. According to the World Health Organization, we can achieve sustainable control of STH by using improved sanitation systems. Since natural wastewater treatment systems (waste stabilization ponds and constructed wetlands) require low maintenance and operational costs, have low mechanical technology and energy consumption, they are ideal for sustainable sanitation services. In addition, natural wastewater treatment systems are reported to efficiently remove various pathogenic organisms from wastewater. This chapter explains the role of natural wastewater treatment systems as sustainable sanitation facilities in removing STH from wastewater and therefore preventing disease transmission.

Keywords: *Ascaris lumbricoides*, constructed wetlands, hookworms, soil-transmitted helminths, *Trichuris trichiura*, wastewater reuse, waste stabilization ponds

1. Introduction

Population growth significantly contributes to water shortages in about 100 countries worldwide. It is estimated that by the year 2025, two-thirds of all people will be experiencing moderate to severe fresh water shortage [1]. Wastewater reuse has been considered as an alternative way of overcoming water scarcity in various parts of the world [2]. Treated and untreated wastewaters have been applied to economic and domestic activities including industry (applied in cooling and cleaning); recreation (swimming pools, irrigation of parks, and golf courses); and agriculture (irrigation) [3]. Globally more than 20 million hectares of agricultural

land is irrigated with either treated or untreated wastewater [4]. In addition to the direct uses, about 80% of all wastewater is discharged to the world's water bodies such as rivers, lakes, swamps, and streams [5].

Whether it is used directly or indirectly, an important consideration in wastewater reuse is its quality in terms of pollutant types and content. Wastewater reuse or discharge to surface water poses risks of disease transmission from animal and/or human-excreted waterborne pathogenic organisms to exposed communities [6, 7]. Transmissions of pathogenic bacteria are frequently a public health concern; however, the most important public health problem is parasite transmission [8]. Among the pathogenic parasites identified in wastewater, soil-transmitted helminths (STHs) are the most common. The problem of STH predominance in wastewater is measured in terms of how frequently the parasites are identified and their level of concentration [9]. The predominance of STHs in wastewater has been associated with the ability of their eggs to resist different types of environmental conditions compared to other organisms [10, 11].

In many countries, exposure to wastewater has been associated with high prevalence of STH transmission [12–14]. In addition, STHs are more prevalent in low- and middle-income countries where more than 72% of generated wastewater is discharged without being treated [15, 16]. To prevent the spread of helminthic diseases such as those caused by STH (e.g., ascariasis, trichuriasis, and hookworm), several measures to protect health have been practiced in wastewater reuse. These measures include wastewater treatment, crop restrictions, control of wastewater application, control of human exposure, and promotion of personal hygiene. Of these measures, wastewater treatment is the most commonly adopted approach in many controlled wastewater reuse schemes [17]. **Figure 1** presents an estimation of wastewater treatment capacities in 2015 in countries classified by level of income and their expected achievement by 2030. The estimation in 2015 shows that the capacity of wastewater treatment is 70% of all wastewater generated in high-income countries and 8% of all wastewater generated in low-income countries [5].

Compared to conventional treatment systems such as activated sludge and trickling filters, natural wastewater treatment systems have been reported to be more efficient at removing STH eggs from wastewater [18]. The potential of two types of natural wastewater treatment systems (waste stabilization ponds and constructed wetlands) for prevention of STH infections is discussed in this chapter.

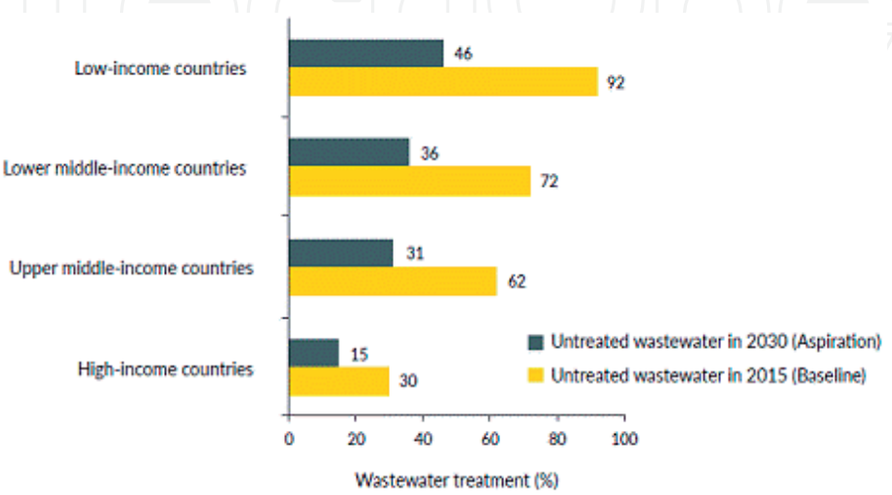


Figure 1.
Wastewater treatment in countries as classified based on the level of income. Figure from [16].

2. Soil-transmitted helminths in human and wastewater

2.1 Soil-transmitted helminths in humans

STHs, are also known as geohelminths, are multicellular intestinal nematodes. Part of their life cycle depends on soil for maturation and they are transmitted through contaminated soil. The important STH species infecting humans include roundworm (*Ascaris lumbricoides*), whipworm (*Trichuris trichiura*), and hookworms (*Necator americanus and Ancylostoma duodenale).* These helminths are distributed throughout the world. Globally, about two billion people are infected with at least one species of STHs with those having heavy infections presenting considerable morbidities including malnutrition, allergy, and respiratory difficulties including asthma and Löffler's syndrome, diarrhea, intestinal obstruction, rectal prolapse, anemia, and cognitive development problems [19]. With limited access to clean and safe water often leading to poor hygiene and insufficient sanitation services, frequency of helminthiasis is higher in low- and middle-income countries than in high-income countries [15].

2.2 Life cycles of soil-transmitted helminths

Transmission of STH occurs through the fecal-oral route by ingesting viable eggs of *Ascaris lumbricoides* and *Trichuris trichiura* from contaminated soil or food or, through skin penetration by third-stage hookworm larvae (filariform larvae). Based on the passage of young-stage worms (larvae), the STHs are divided into three groups. *Trichuris trichiura* undergoes a direct life cycle whereby the ingested eggs directly develop to adult worms inside human intestines. *Ascaris lumbricoides* undergoes a so-called modified direct life cycle whereby ingested eggs hatch to release larvae in the human intestine. The released larvae penetrate intestinal mucosa to the blood stream where they migrate to the liver, heart, lung, upper respiratory track, then return to the intestines where they develop into adults. Unlike *Ascaris lumbricoides* and *Trichuris trichiura,* eggs of hookworms hatch in the soil where they develop to the infective stage-three larvae (filariform larvae). The filariform larvae penetrate unbroken skin of human beings to the blood, and migrate to the liver, heart, lung, upper respiratory tract to the intestine where they mature to adults (**Figure 2**). In very rare cases, hookworm transmission occurs via the fecal-oral route. In the intestine, the sexually mature male and female adults mate and the female lays fertile eggs. In all these helminth species, eggs are excreted with feces to the environment. When they reach the soil, they mature and become infective (*Ascaris lumbricoides* and *Trichuris trichiura*), or hatch to rhabditiform larvae, which then develop into the infective filariform larvae (hookworms). STHs do not multiply in the host. Therefore, each one that is found in the intestine is the result of a single infection event [20].

2.3 Soil-transmitted helminth treatment and control

The drugs of choice for treatment of STHs are albendazole (400 mg) and mebendazole (500 mg). Measures used to control STH involve periodic deworming of at-risk groups to eliminate infective worms, health education to prevent infection and reinfection, and improved sanitation to reduce soil contamination with infective eggs.

In 2011, the World Health Organization (WHO) opted for the use of periodic mass treatment with albendazole for at-risk people in STH endemic areas.

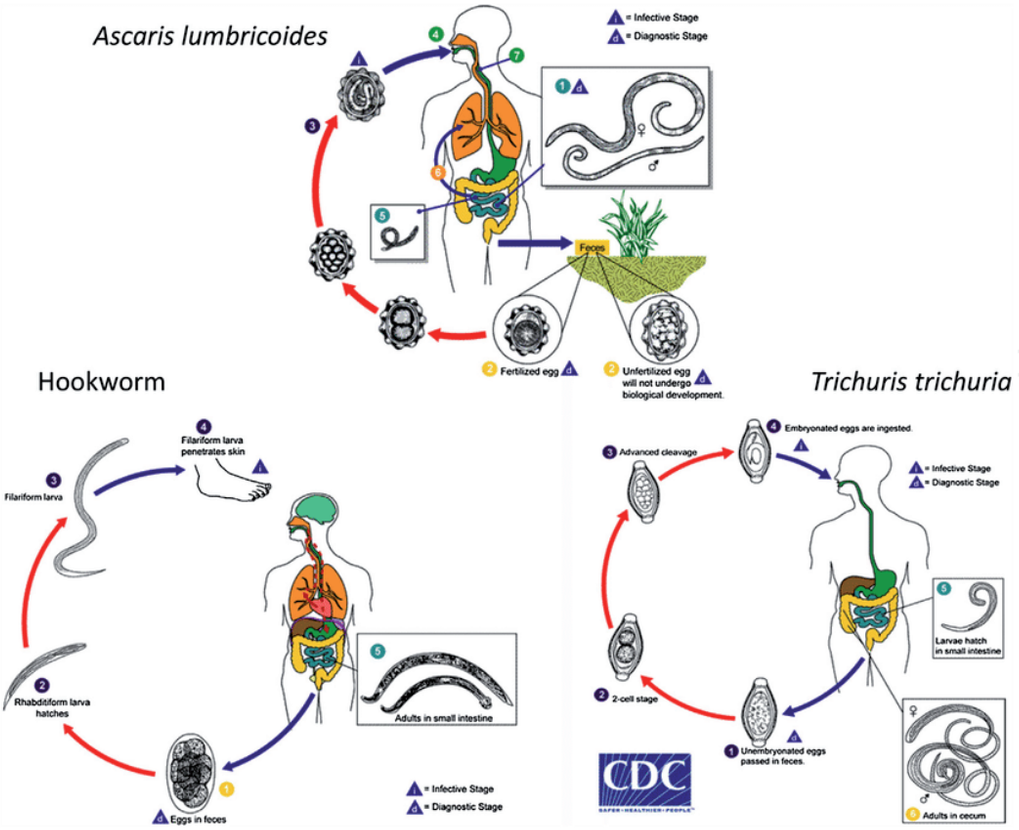


Figure 2.
Life cycles of three species of soil-transmitted helminths. Adapted from CDC, creative commons (Center for Disease Control and Prevention, 2015. Parasites [online]. Available at: http://www.cdc.gov/parasites/).

The objective was to control morbidity by reaching 75% coverage of preschool- and school-age children by the year 2020. Based on data collected in 2018, 68% of preschool-age children and 73% of school-age children in endemic countries who were in need of treatment received it during the 8 years of implementation (between 2010 and 2017). In spite of this achievement, transmission still continues.

In 2018, the WHO set six targeted for STH control programs in the period of 2020–2030. These targets include: achieving and sustaining elimination of STH morbidities in preschool- and school-age children by 2030, reducing the number of anthelminthic tablets required for preventive chemotherapy (PC), increasing financial support in endemic countries by their own governments for PC, establishing an efficient STH control program to women of reproductive age, establishing an efficient strongyloidiasis control program for school-age children, and ensuring universal access to at least basic sanitation and hygiene by 2030 in STH endemic areas [21].

2.4 Soil-transmitted helminths in wastewater

STHs are among the most frequently identified pathogens in wastewater. STHs may enter wastewater ways from both point and nonpoint sources. Domestic wastewater, by definition, is always contaminated with human and animal excreta. STHs are introduced into wastewater through direct discharge of human excreta (feces) containing eggs. STH can also enter wastewater through discharge of sewage to water ways and through water/rain runoff from contaminated soil (where humans practice open defecation) or agricultural lands using human and animal excreta as manure.

Commonly, STHs in wastewater occur in the form of eggs. Eggs are the most environmentally resistant stage of STH. They can persist outside of their host

bodies for up to 9 months [11]. STH eggs contain several shells, three to four layers depending on the genera. These shells are made up of lipoprotein and protein structures laminating the egg cell providing resistance against external physicochemical stresses. A thick outer layer gives the egg protection. The middle layer consists of several sub-layers and is important for prevention against physical destruction as well as giving the egg its shape. The inner layer is preventive against fatal chemicals such as strong acids, bases, oxidants and reducing agents, detergents, and proteolytic compounds. It also protects the egg from desiccation. Alongside the stated functions, these layers allow for gaseous exchange and water passage [22].

The resistant nature of STH eggs allows them to remain viable in external environments such as wastewater. For example, *Ascaris lumbricoides* eggs have been found to be as viable in wastewater as in fresh stool samples. In addition, the eggs embryonate after being exposed to aerobic conditions. Hookworm eggs remain viable in anaerobic conditions for up to 2 weeks. They hatch when they are in an aerobic condition to release first-stage (rhabditiform) larva. However, the released larvae seem unable to develop to the infective stage-L3 (filariform) larva [11].

Table 1 presents concentrations of different species of STHs in raw wastewater or wastewater sludge reported in various STH endemic countries with preventive chemotherapy intervention campaigns. These findings are from research conducted a short time before the start of PC, within, or after a PC campaign (data collected between 2009 and 2018). Studies conducted between the year 2014 and 2018 in India, Lesotho, Malawi, South Africa, Tanzania, and Cameroon recorded high concentrations of STH eggs in either wastewater and/or sludge samples [24–28, 31, 33]. These countries had less than 5 years of PC implementation with coverage of more than 75% by the year 2017 [21]. Despite being in a group of few countries that have controlled moderate and heavy intensity of STH infection to less than 1% [21], a study conducted in Senegal in 2016 presented high concentration of STH eggs in sludge samples collected from wastewater treatment plants [30]. The presence of high concentrations of STH eggs in wastewater and sludge in countries with high coverage of PC implementation could be attributed to the fact that the campaign is selective for some at-risk groups (preschool- and school-age children) and leaves out others such as adults working in high-risk areas. These findings demonstrate that the risk of STH transmission still exists especially in communities exposed to wastewater, and wastewater-produced products such as vegetables. This solicits for the need of interventions that will prevent transmission and bring effects across all at-risk groups.

Concentrations of STH eggs in wastewater vary from one country to another. Variations also exist within different parts of the same country and even between sampling points (**Table 1**). Several reasons may account for the variation in concentration of STH eggs in wastewater. Factors include: endemicity of the area's source of wastewater, volume of wastewater sampled, and diagnostic methods used. In areas with high STH endemicity, the concentration of eggs in wastewater is expected to be higher compared to low endemicity areas. The sources of wastewater affect the concentration of eggs since wastewater collected directly from toilets, latrines, or septic tanks contains high concentrations of fecal matter compared to that collected from other sources such as wastewater treatment systems or contaminated rivers. When domestic wastewater is mixed with wastewater from other sources (industrial or rain runoff) in the treatment systems or rivers, dilution of fecal contents (including STH eggs) in domestic wastewater occurs and therefore lowers its concentration. This is clearly depicted in **Table 1**, whereby in many cases concentrations of STH eggs were higher in wastewater and sludge collected from latrines and trucks compared to that collected from influents of treatment systems. The volume and type of diagnostic method have an influence on the determined

Country	Source	STH species	Mean(s) eggs/L or g	Reference
Burkina Faso	Wastewater from WWTP	*A. lumbricoides*	7	[23]
		Hookworms	6	
		T. trichiura	1.40	
Cameroon	Wastewater from marshy areas	*A. lumbricoides*	77.75	[24]
		Hookworms	59	
		T. trichiura	115.67	
	Sludge from latrines	*A. lumbricoides*	16667[a]	[25]
		Hookworms	16611[a]	
		T. trichiura	13444[a]	
Ghana	Wastewater from farm	*A. lumbricoides*	2.72	[14]
		Hookworms	1.72	
Lesotho	Wastewater from WWTP	*A. lumbricoides*	87	[26]
		Hookworms	26	
		T. trichiura	12	
Malawi	Sludge from pit latrines	*A. lumbricoides*	0.4 and 4.7[*]	[27, 28]
		Hookworms	7.65 and 20.5[*]	
		T. trichiura	0.06[*]	
Nigeria	Wastewater from WWTP	*A. lumbricoides*	307	[29]
		Hookworms	135	
		T. trichiura	92	
Senegal	Sludge from WWTP	*A. lumbricoides*	1079[*]	[30]
		Hookworms	257[*]	
		T. trichiura	1647[*]	
South Africa	Wastewater from WWTP	*A. lumbricoides*	54	[26]
		Hookworms	31.33	
		T. trichiura	14.53	
	Sludge from WWTP	*A. lumbricoides*	722[*]	[30]
		Hookworms	334[*]	
		T. trichiura	154[*]	
Tanzania	Wastewater from WWTP	*A. lumbricoides*	13.67	[31]
		Hookworms	20.75	
		T. trichiura	20	
Uganda	Wastewater from channel	*A. lumbricoides*	4	[32]
		Hookworms	27	
India	Wastewater from shared toilet	*A. lumbricoides*	58	[33]
		Hookworms	25,174	
		T. trichiura	38	
Indonesia	Wastewater from trucks and farm	*A. lumbricoides*	18.24 and 119.44	[34, 35]
		Hookworms	51.29	

Country	Source	STH species	Mean(s) eggs/L or g	Reference
Brazil	Wastewater from WWTP	*Ascaris species* and Hookworms	300	[36]
Bolivia	Wastewater from WWTP	*A. lumbricoides*	324.33	[37]
		Hookworms	5.13	
		T. trichiura	29.02	
Colombia	Wastewater from WWTP	*A. lumbricoides*	72	[38]
		T. trichiura	1.60	
Peru	Wastewater from WWTP	*A. lumbricoides*	142	[39]

STH—Soil-transmitted helminth; WWTP—Wastewater treatment plant.
[a]*Median.*
[*]*Concentrations in sludge in eggs per gram.*

Table 1.
Soil-transmitted helminth concentrations reported in wastewater and sludge in various endemic countries with Albendazole preventive chemotherapy intervention implementation campaign.

concentration of STH eggs in wastewater. The larger the volume of wastewater, the higher the chance of STH eggs recovery and concentration. Also when the diagnostic method used had high eggs recovery efficiency, the chance of STH recovery increased as along with concentration [11].

3. Natural wastewater treatment systems

Natural wastewater treatment systems are biological treatment systems that require no or very little electrical energy; instead, they rely on entirely natural factors such as sunlight, temperature, filtration, adsorption, sedimentation, biodegradation, etc., to treat wastewater or fecal sludge. They utilize naturally occurring physicochemical and ecological processes in removing pollutants from wastewater. The processes involve interactions of microorganisms, aquatic plants, substrates (media), solar energy (temperature and light), and wind. These processes are important for removal of both physicochemical pollutants and biological (pathogenic) pollutants. Natural wastewater treatment systems have low maintenance and operational costs, low energy consumption, and low mechanical technology and are therefore ideal for sustainable sanitation services, especially in low- and middle-income countries [40]. Waste stabilization ponds (WSPs) and constructed wetlands (CWs) are common natural wastewater treatment systems used for treating wastewater from both point and nonpoint sources. They can be applied as a single standing treatment system or coupled with other treatment system(s). When used as part of larger treatment plants, they may be applied as primary, secondary, or tertiary systems. These systems are capable of efficiently removing varieties of wastewater pollutants including organic matter, nutrients, harmful chemicals, as well as pathogens [41]. Since the main purpose of this chapter is to provide information on the role played by natural wastewater treatment systems on prevention of STH, the following discussion focuses on mechanisms for their removal by these systems.

3.1 Waste stabilization ponds

WSPs are human-made shallow basins comprised of a single or series of anaerobic, facultative, or maturation ponds (**Figure 3**). They are used in either centralized

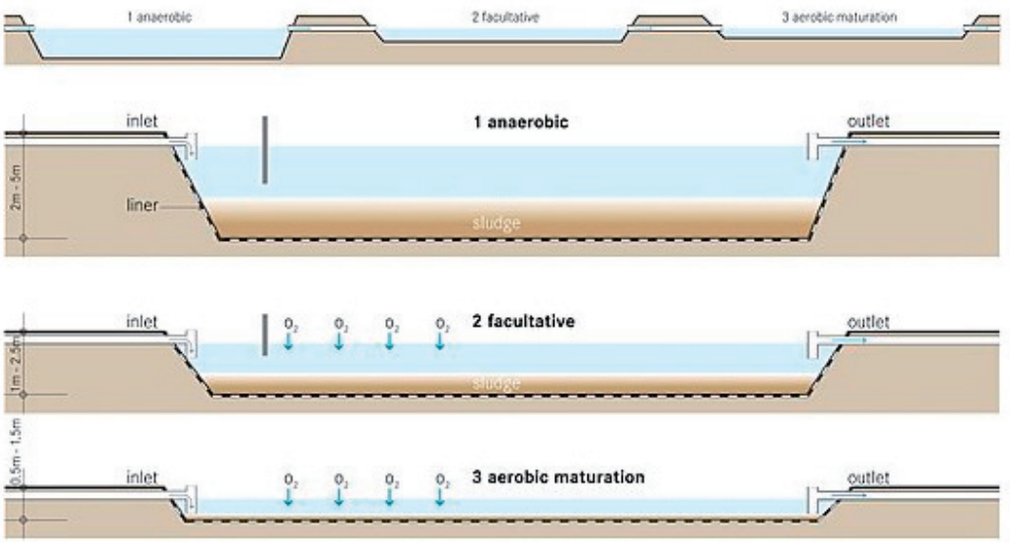


Figure 3.
Layout of typical waste stabilization pond system showing design of all three treatment stages.

or semi-centralized wastewater treatment plants serving connected households in towns and cities. Anaerobic ponds are used as pre-treatment. This part of the WSP system receives high organic loads of raw wastewater, often including septic tank sludge. The high organic loads produce anaerobic conditions throughout the pond. Anaerobic ponds are designed to remove particles (organic matter) through sedimentation or biological degradation. Facultative ponds are used as a secondary stage. Both aerobic and anaerobic processes occur in facultative ponds. Remaining biodegradable organic matter from anaerobic pond is removed in facultative pond, through the coordinated activity of algae and heterotrophic bacteria. Maturation pond is used as tertiary treatment before discharge to the outside environment. Their main function is the removal of pathogens. These ponds entirely use aerobic processes [42].

3.2 Constructed wetlands

Constructed wetlands (CWs) are human-made systems designed to utilize naturally occurring processes similar to those occurring in natural wetlands but in a controlled environment, for wastewater purification [43]. They consist of a bed of media (soil, gravel substrate) or liner and wetland plants (free floating, rooted emergent, or submerged). CWs are classified based on the position of the water surface (level) in relation to the surface of the soil or substrate; they can be surface flow (free water) or subsurface flow (**Figure 4**). In a surface flow, CW water level is positioned above the substrate and covered with wetland plants. This type of CW can be further classified based on the growth form of dominating vegetation as free floating, floating leafed, emergent, or submerged macrophytes. In a subsurface flow CW, wastewater is flowing through the porous media; the water level is positioned beneath the surface of the wetland media. This type of CW makes the use of emergent macrophytes only. The subsurface flow CW is further classified based on the predominant water flow direction in the system as horizontal or vertical. In horizontal subsurface flow CW, the predominant water flow direction is horizontal to the surface of the system while in vertical subsurface flow CW the predominant water flow direction is vertical to the surface of the system [42].

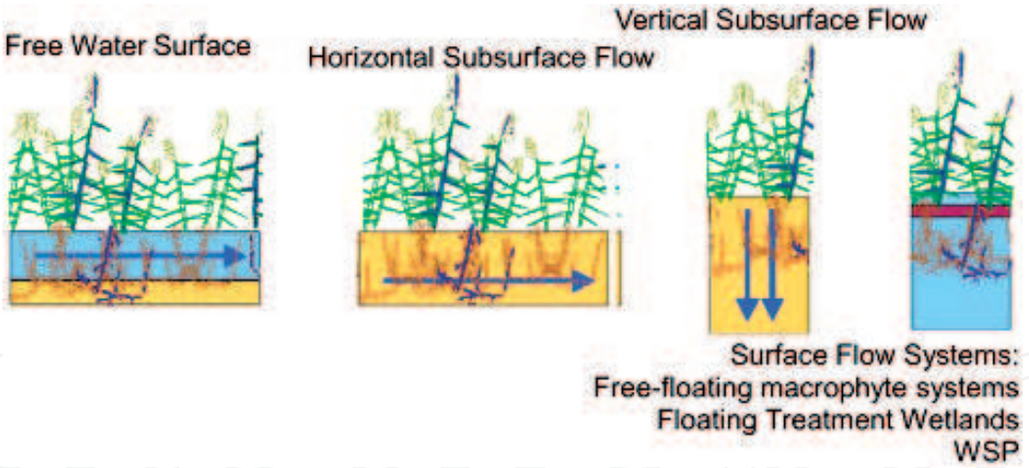


Figure 4.
Types of constructed wetlands systems. Picture from [42].

4. Soil-transmitted helminth removal in natural treatment systems

An actual risk of soil-transmitted helminthiasis to public health occurs when four conditions are present during wastewater reuse: (1) an infective dose of the helminths eggs reaches the field, (2) the infective dose reaches the human host, (3) the host becomes infected, and (4) the infection causes diseases or further transmission. If the first three conditions are present and the fourth is absent, the risk is just a potential risk. The WHO has set the health-based targets that can be used to reduce public health risk of helminths transmission. According to the WHO Guideline, helminth transmission among a wastewater-exposed population should not happen when wastewater quality is ≤1 helminth egg per liter. To achieve the set health-based target, a combination of health protection measures targeted at different areas of intervention should be implemented. The health protection measures include: (1) wastewater treatment or (2) a combination of wastewater treatment and thoroughly washing wastewater-irrigated produce to protect consumers, or (3) a combination of wastewater treatment and protection of workers by giving them personal protective equipment such as shoes and gloves. When children less than 15 years are part of an exposed population, extra measures are required. The extra measures include more stringent wastewater treatment in order to achieve wastewater quality of ≤0.1 helminth egg per liter, or providing PC with anthelminthic [44]. The above explanations show that wastewater treatments play a vital role in preventing STH transmission among exposed communities.

STH eggs cannot be inactivated by wastewater disinfection methods such as chlorine, ozone, temperature (unless above 40°C), or UV light applied in conventional systems because of their highly resistant nature caused by the three outer layers. Natural wastewater treatment systems are considered more effective at removing STH eggs from wastewater compared to conventional treatment systems such as activated sludge and trickling filters. Large sizes and high densities of most STH eggs allow them to be easily removed by mechanisms occurring in natural wastewater treatment systems (sedimentation, filtration, and adsorption). Natural wastewater treatment systems can remove 100% of helminth eggs from wastewater while conventional wastewater treatment processes can remove up to 90–99% of helminth eggs [45]. The higher efficiency of helminth egg removal by natural wastewater treatment systems prevents them from reaching the field or the exposed human hosts. Different types and designs of natural wastewater treatment systems have different helminth egg removal mechanisms and hence different efficiencies.

The commonly known natural wastewater treatment systems include WSP and CW. Studies conducted in different counties have shown that WSP systems are able to remove all STH eggs from wastewater. These systems have been shown to be efficient at removing helminth eggs in tropical countries like Burkina Faso, Honduras, Tanzania, Kenya, Bolivia, Brazil, and Colombia. They were also efficient in temperate countries as recorded in Iran, Morocco, Egypt, and Spain. However, sometimes WSP effluents have reported higher concentrations of STH eggs than that recommended by the WHO. Two out of five assessed WSP systems in Tunisia gave out effluents with more than one *Ascaris lumbricoides* eggs per liter [46], while one WSP in Tanzania and one WSP in Cayman Islands generated effluents with more than one hookworm eggs per liter [31, 47].

CW systems have also been shown to efficiently remove STH eggs from wastewater. The systems were observed to be more efficient when coupled with other treatment systems such as WSP [48]. Data collected from the few studies conducted to assess parasite removal efficiency of CW systems showed that, regardless of the influent concentration, this type of natural wastewater treatment could reduce the STH eggs to <1 per liter (**Table 2**).

Sedimentation is believed to be the primary removal mechanism in WSP and free water surface flow CW treatment systems. In subsurface flow CW, mechanical filtration and adsorption are the primary removal mechanisms for STH. Filtration and adsorption by biological films on the substrates and plant roots in subsurface flow CW occur by attachment of helminth eggs to the substrates, plant roots, or substrate-plant roots complex. Sedimentation, filtration, and adsorption do not involve either inactivation or destruction of the eggs, but they separate the eggs from wastewater. The separated eggs remain in the sludge of WSP and free water surface flow CW or attached to biofilms on substrate and plant roots of subsurface flow CW allowing the effluents to be free of helminth eggs. Other removal mechanisms that apply in both WSP and CW systems include natural die off, predation, and chemicals such as ammonia. However, these mechanisms have little contribution [64].

Water turbulence, the number of ponds in a series, hydraulic retention time, sludge accumulation, and hydraulic short-circuiting are the factors affecting helminth removal in WSP systems. These factors affect the rate of helminth egg sedimentation. Water turbulence and overturning caused by water flow, wind, rain, human disturbance, buoyed gas babbles from pond sludge or temperature interfere with the gravitational settling of helminth eggs [4]. Long hydraulic retention time of wastewater in the system provides time for helminth egg sedimentation, while excessive accumulation of sludge affects pond hydraulics, creating short-circuiting that may carry helminth eggs through to the outlet or re-suspend eggs that have been deposited in the pond sediments. Increasing the number of ponds in a series increases helminth egg removal efficiency [65].

Hydraulic retention time and hydraulic short-circuiting also effect helminth egg removal in CW systems. As in WSP, long hydraulic retention times provide more time for helminth eggs to be exposed to the removal mechanisms such as sedimentation in free water flow CW or filtration in subsurface flow CW systems. In CW systems, hydraulic retention time depends on wastewater flow rate, water depth, vegetation, and type of substrate used. Hydraulic short-circuiting as a result of clogging at the inlet or outlet of a CW system may reduce wastewater residence time, therefore lowering helminth egg removal efficiency. Other factors affecting helminth egg removal in CW systems include the design or type of CW (subsurface systems have higher efficiency than surface systems) and vegetation coverage [66].

Country	System	STH species	Mean/MR influent (eggs/L)	Mean/MR effluent (eggs/L)	Reference
Burkina Faso	WSP	*A. lumbricoides*	7	0	[23]
		Hookworm	6	0	
		T. trichiura	1.4	0	
Egypt	CWs	*A. lumbricoides*	1.59	0	[49]
		Hookworm	0.12	0	
		T. trichiura	0.09	0	
		All STH	2.3	0	[41]
	WSP	*A. lumbricoides*	4	0	[50]
Kenya	WSPs	*A. lumbricoides*	17.5–133.5	0	[51]
		All STH	158–398	0	[52]
Morocco	WSPs	*A. lumbricoides*	0.4	0.01	[53]
		A. lumbricoides	4	0	[54]
		T. trichiura	2.2	0	
Nigeria	WSP	*A. lumbricoides*	12.38	0.19	[29]
		A. lumbricoides	7.69	0.19	
		T. trichiura	4.12	0.31	
Tanzania	WSPs	*A. lumbricoides*	10–19	0	[31]
		Hookworm	9.5–32	0.2–7.5	
		T. trichiura	20	0	
Tunisia	WSPs	*A. lumbricoides*	413.5–731	0–111.5	[46]
	CWs	*A. lumbricoides T. trichiura and E. vermicularis*	3.8	0.1–0.8	[55, 56]
Iran	CWs	*A. lumbricoides*	30.43	0.08	[57, 58]
	WSPs	*A. lumbricoides*	30–38	0	[58]
		T. trichiura	2.5	0	
Brazil	WSPs	All STH	992.6–1740	0	[41, 59]
Bolivia	WSP	*A. lumbricoides*	306	0	[60]
Cayman Island	WSP	*A. lumbricoides*	32	0	[47]
		Hookworm	113–957	33–690	
		T. trichiura	273	0	
Colombia	WSP	*A. lumbricoides*	183	0	[61]
		T. trichiura	31	0	
Honduras	WSPs	All STH	9–744	0	[62]
Spain	WSP	*Ascaris* spp. and *T. trichiura*	1.8	0	[63]

STH—Soil-transmitted helminths, MR—Range of means reported from different treatment systems in a particular country, WSP—Waste stabilization pond, and CW—Constructed wetland.

Table 2.
Concentration of soil-transmitted helminth eggs in the influents and effluents of waste stabilization ponds and constructed wetlands systems in different countries.

Due to their cost-effectiveness, natural wastewater treatment systems are preferred wastewater treatment systems in many low- and middle income-countries. Adequate maintenance and operation are critical to the performance of natural wastewater treatment systems. However, all too often these systems become overloaded and receive inadequate maintenance. Most factors associated with poor performance of natural wastewater treatment systems are the result of lack of adequate maintenance and repair, abandonment of the systems, or poor design [67]. Inadequate maintenance such as desludging results in sludge accumulation in the systems, which will reduce hydraulic residence of wastewater and sometimes create hydraulic short-circuiting resulting in poor performance of the systems. In CW systems, accumulation of sludge may result in clogging of the system leading to the system malfunctioning.

Generally, natural wastewater treatment systems receive influent wastewater with high concentrations of STH eggs and are capable of producing effluents containing ≤0.01 egg per liter, which is suitable for use or discharge to the environment even when children aged less than 15 years are exposed. The main reason for inadequate maintenance of natural wastewater treatment systems in low-income countries is a decrease in governmental financial support as well as decrease in finance generated by the systems as they become older [37]. In addition to that, poor system design such as errors in system geometry (e.g., length-width ratio) or poor arrangements of inlet and outlet may lead to water turbulence and hydraulic short-circuiting resulting in low system performance [60, 67].

5. Conclusion

Countries implementing prophylactic chemotherapy for controlling helminthiasis report high concentrations of STH eggs in wastewater. For the wastewater to be safe for reuse and/or discharge, it requires further treatment. Natural wastewater treatment systems including sedimentation ponds and constructed wetlands work well in assisting STH control through interrupting transmission by removing eggs from wastewater.

Conflict of interest

The authors declare that there are no conflicts of interests.

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