Helminth Management

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Contributor: Andy Ball

Understanding and managing the risk posed by helminth eggs (HE) is a key concern for wastewater engineers and public health regulators. The treatment processes that produce recycled water from sewage at wastewater treatment plants (WWTPs) rely on achieving a defined log10 reduction value (LRV) in HE concentration during the production of recycled water from sewage to achieve the guideline concentration of ≤1.0 HE/L.

Helminth Infection Management

1. Helminth Infection

In developed countries, the WHO recommends an upper limit of 10^{-6} disability-adjusted life years (DALY) per person per year (pppy) as a tolerable limit for the burden of the disease [1]. However, this is not achieved in many developing countries, where helminth infections are still endemic and the morbidity and sequelae they cause are higher due to the lack of prevention and treatment [2].

Since many helminths are transmitted via a fecal-oral route, high rates of exposure in developing countries due to limited sanitation present a public health challenge [3]. In such countries, high exposure rates are caused by factors, such as poverty, poor hygiene, limited treatment of sewage, higher prevalence of helminth eggs, and the lack of use of personal protective equipment when working with partially treated sewage [4][5].

A major source of infection for humans can be via exposure to sewage, and inadequately treated recycled water or biosolids allowing the completion of the helminth's life cycle. The number of HE in sewage has been reported to be as high as 5730 HE/L in some developing regions (**Table 1**). Wastewater treatment plant workers and farmers applying recycled water and biosolids for agriculture and aquaculture are particularly at risk as they may be directly exposed to HE present in the recycled water and biosolids during their work [6]. Large portions of the community can also be indirectly exposed to HE via handling and consuming products that are grown on farms that utilize recycled water and biosolids without adequate treatment.

Table 1. Reported concentrations of helminth eggs of human health significance in sewage from developing and developed nations.

Country	Economic Status [A]	Helminth Eggs in Sewage (HE/L)	References
Australia	Developed	≤1.0	[7]
France		9	[5]

Country	Economic Status [A]	Helminth Eggs in Sewage (HE/L)	References
UK		<1	[8]
USA		1–8	[8]
Bolivia		306–3006	[9]
Brazil		166–202	[9]
Jordan		300	[5]
Mexico	Developing	6–330	[5]
Morocco		840	[5]
Ukraine		60	[10]
Vietnam		5730	[11]

Helminth egg loads in sewage usually arise from the general population (although other sources, e.g., abattoirs, may be a source in some sewer catchments) and without sanitation, the life cycle of the helminth perpetuates. Where improvements to sanitation are difficult, there are large programs of mass drug administration designed to lower the helminth disease burden in endemic countries until sanitation can be improved. In non-endemic countries, the HE loads in the sewage system are reduced due to the lower disease burden in the population from good sanitation and access to medication. However, as the migration and movement of humans increases across the world, this could be reflected in variations in HE loads in sewage systems.

Zoonotic HE can also enter the sewer via licensed wastewater discharges from animal facilities (e.g., stock sale yards, abattoirs, boarding kennels, etc.) or via household disposal of fecal matter from domestic animals into the sewer. Stormwater from such facilities and urban areas can also be a source where it is connected to the sewer. This is particularly the case in jurisdictions with combined sewage and stormwater drainage systems.

For animal health, the helminth species of concern depends on the animal species in the catchment, the species exposed to the recycled water, and the helminth species endemic to the area. Because of these specificities, animal only helminths are not discussed in detail in this review, but they are important to consider for specific sites recognizing their potential sources discussed above.

The helminth taxa of most concern for sewage and protection of human health are typically *Ascaris lumbricoides* (human roundworm), *Trichuris trichiura* (human whipworm), *Ancylostoma duodenale* (human hookworm), *Necator americanus* (Human hookworm), *Taenia solium* (pork tapeworm) and *T. saginata* (beef tapeworm). Note that *Strongyloides stercoralis* (human roundworm) is excreted in feces as the larvae and therefore, readily removed by the WWTP.

The HE load from humans in sewage will be determined by the prevalence of helminth infections in the population and the presence of (a) mass drug administration (MDA) in endemic countries, and (b) population migration and movement between endemic and non-endemic countries. These two components are discussed below.

2.1. Mass Drug Administration

Mass HE loads in developing countries are expected to decrease due to preventive chemotherapy in the form of recent MDA programs where populations or sub-populations are offered treatment without an individual diagnosis [12]. The 2012 London declaration [13] committed to sustaining, expanding and extending drug access programs to ensure the necessary supply of drugs and other interventions to help control STHs by 2020. This declaration has seen many countries in Africa and Asia roll out MDA, especially among pre-school and school-aged children [14][15][16][17]. The WHO recommends MDA annually when the infection prevalence is between 20 and 50% and biannually when the prevalence exceeds 50% [18]. This approach is based on the current lack of sanitation systems and high reinfection rates in developing countries and is focused on these regions. For example, in a study conducted in India during 2001–2010, the cumulative impact of seven rounds of MDAs (especially albendazole and diethyl carbamazine) on STH infections in school children led to a decline in the prevalence of helminth infections from 60.4% to 12.5% [19].

2.2. Population Migration and Movement

The LRV and associated minimum lagoon HRT of 18 days was considered conservative for Australian conditions and likely to protect against outbreaks of helminthiasis from current baseloads in the country [7]. However, immigration and movement of people from endemic areas that are potentially infected pose a risk to these assumptions if HE loads in sewage are not monitored. It is most likely that imported cases of helminthiasis occur in most developed countries due to immigration from endemic regions [14] and business and tourist travelers returning from such regions.

Where there are large numbers of people moving from countries that are endemic with helminths to countries not endemic with helminths, there is a risk that the helminth loads to sewage systems in the non-endemic countries will increase. For example, in Australia, the population is projected to increase 61% from 23.3 million in 2020 to 37.6 million by 2050 with 60% of the new immigrants expected to be from endemic STH regions [20]. In limited cases, infections in immigrants in non-endemic areas have been detected more than 20 years after migration from an endemic area [21]. Maintaining modern sanitation and administration of anti-helminthic drugs to migrants and refugees in developed countries represent readily available options to limit the prevalence of helminth infections [22].

Other factors to consider are the presence of helminths in specific regions as climate change may have an impact on the spread of the pathogens as climates change across regions [21]. This could be related to shifting populations (hosts) or the life cycle of the helminth which may be temperature or moisture sensitive.

3. Controlling HE Movement into Non-Endemic Regions

Screening individuals returning to their country of origin from areas with endemic helminth infection could be used to control HE infection rates and thus HE loads to sewage. For example, in Australia people seeking residence as asylum seekers undergo health assessment on arrival at immigration detention facilities. However, screening focuses on the detection of diseases, such as acquired immunodeficiency syndrome (AIDS), and tuberculosis [21]. Since the diseases caused by STHs are not notifiable, there is a possibility that infections among Australians and travelers who enter Australia are neither identified nor reported. Surveys conducted among long-term immigrants from East Africa, Laos and Cambodia to Australia between 1997 and 2002 reveal that despite living in Australia for many years and having been subjected to immigration screening, there was a high prevalence of STH diseases among them [23][24]. Although the infections were generally asymptomatic, severe complications, such as eosinophilic pneumonia and malnutrition can occur [21]. Nevertheless, immigration screening for helminths and protozoa is not conducted upon entry into Australia [25], although refugees from refugee camps may be administered the anti-helminthic medicine albendazole as part of the predeparture medical assessment conducted on behalf of the Australian Government [26]. Since the migrant and refugee population in Australia is increasing, screening for helminth infections upon entry or within one month of arrival would appear appropriate.

Travelers returning home from overseas, particularly STH endemic areas may have also incidentally been infected with helminths. The only protection for this cohort is when the helminthiasis is identified, and medication is provided to treat the infection. Medication is generally considered effective [27].

One of the major sources for helminth infections in Australia is from returned service personnel, especially army veterans who have served in countries, such as Vietnam, Cambodia and other endemic regions of the world [28]. Since adult worms can persist for many years, there have been cases of long-term Australian residents who still test positive for STH infections [29].

4. Helminth Egg Removal from Sewage

4.1. Removal of HE via Activated Sludge Plants and Lagoons

As noted, the resistance of HEs to disinfection via chlorine or UV makes it difficult to inactivate or destroy them via conventional disinfection processes. Consequently, in many countries, removal of HE in WWTPs is achieved through ASPs and waste stabilization ponds (referred to as lagoons hereafter).

The wastewater treatment processes of activated sludge and secondary sedimentation (ASP) should achieve 1 to <2 LRV for HEs [30]. Various studies suggest that the effectiveness of HE removal rates for ASPs range between 91 to 97% (i.e., around 1 to 2 LRV) [6][31][32][33].

If well designed, constructed and maintained, a series of maturation lagoons are an accepted method for the efficient settling of HEs from the sewage [34]. However, there is some evidence of lagoons not achieving the required <1.0 HE/L, perhaps due to the poor design or management (e.g., sludge build-up and hydraulic short-circuiting) [8].

In developed countries, WWTPs still utilize lagoon systems frequently as part of the treatment process and to achieve the required HE removal. The lagoons can be cost-effective to build and with appropriate design, operation and maintenance, the removal efficiency of HE can be maximized [7]. Appropriate design refers to appropriate inlet/outlet structures and baffling which minimize hydraulic short-circuiting, orientation in relation to the prevailing wind, width/length ratio, and depth.

4.2. Removal of HE via Sand Filtration

Early research reporting the removal of HE using sand filtration which suggested a possible 3 to 4 LRV has been moderated to a more widely accepted view [35][36][37][38] that sand filtration can achieve 1 to 2 LRV of HE, and 2 to 4 LRV of HE with coagulation. These LRVs depend on the process type and parameters used and require assessment of the sand filtration method for validation of the LRV achieved. However, validation is complicated where the HE concentration in sewage is <10 HE/L and the limit of detection is 1 HE/L (i.e., only 1 LRV can be validated).

One common and conservative solution to allocating an LRV to a filtration system in water recycling schemes using more advanced treatment systems than just ASPs and/or lagoons has been to adopt the LRV associated with protozoan parasites (usually *Cryptosporidium* oocysts) and simply assume that HE behave similarly [39]. Since HE are larger than *Cryptosporidium* oocysts and generally less numerous, they are less likely to be the limiting health risk compared to *Cryptosporidium* oocysts [40].

4.3. Other Filtration Approaches

Membrane filtration methods, such as microfiltration with pore sizes of filters ranging from 0.1 to 10 µm are effective in the removal of HE. The pathogens are removed by size exclusion where HE with sizes greater than the pore size are retained [41]. A study conducted using woven monofilament filter cloths (disc filter) of different pore sizes revealed that filter cloths with a pore size of 20 µm were not effective in the removal of *Trichuris trichiura* eggs (22 to 60 µm) and recommended the use of material with much smaller pore sizes [42]. In contrast, *A. lumbricoides* eggs were not detected in the filtrate following passage through a material with pore sizes ≤ 37 µm (fertile eggs range from 45 to 75 µm in length [43]).

Another filtration method is based on the use of HydroTech Discfilter with a pore size of 10 µm for the removal of HE as these filters are postulated to exhibit a high retention capacity. Others reported that these filters were able to retain all HE in the influent water in a Spanish WWTP resulting in an effluent devoid of HE [44]. Another study supports these findings [45]. However, despite being low maintenance, these filters are costly and may not be affordable for use in WWTPs in developing countries.

Other membrane filtration methods, such as nanofiltration and reverse osmosis (RO) that are highly effective in the removal of viruses and protozoan cysts may also be utilized for removing HE, especially in the production of high-quality recycled water for irrigation. RO can be expected to achieve a high LRV of >6 for HE [46][39][1].

Although membrane filtration methods have several advantages in the removal of HE, equipment costs can be high and adequate maintenance is required. Therefore, defining HE reductions via ASP and lagoons remains an important practical component of HE management.

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