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MINI REVIEW

Possible scenarios of environmental transport, occurrence and fate of helminth eggs in light weight aggregate wastewater treatment systems

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Abstract This work discusses the potential routes of transport, possible occurrence and predicted fate of parasite eggs corresponding to human pathogens in on-site wastewater treatment systems with Light Weight Aggregates (LWA) media. The discussion is mainly based on scientific evidences supported by practical outcomes derived from a survey of helminth eggs in the specific LWA materials—typical filter media of constructed wetlands (CWs) treating domestic wastewater in Norway. The scientific evidences showed that the greatest reduction in the egg concentrations occurs in septic tanks. The eggs that could pass through the tank trap can be accumulated and effectively eliminated in the filter media of CWs. The practical outcomes did not show any accumulation and the consequent contamination of the LWA media with helminth eggs. Because the outcomes characterised a survey that was carried out for the first time ever on the above-specified filter media and was not replicated, the absence of parasite eggs in the CW filters cannot be definitely stated. However, it could be theoretically assumed that the possibility of finding human parasite eggs originated from domestic wastewater in the LWA filters should be negligible.

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1 Parasite egg contamination of wastewater

Parasite zoonoses (parasitic diseases transmitted between animals and humans) are complex water–food relations where faeces play the main role in the transmissible stages (spores, cysts, oocysts, ova, larval and encysted stages) of parasites. Although some spores and ova (eggs) may additionally contaminate the environment through urine (Nithiuthai et al. 2004; Slifko et al. 2000), the disposal of all animal and human faecal wastes remains a significant public health issue.

Among all pathogenic intestinal parasites, helminths cause the most number of parasitic infections in humans and animals, particularly in developing countries (Nithiuthai et al. 2004; Sidhu and Toze 2009; Strauss 2000; Venglovsky et al. 2006). These pathogens characterise parasitic warms of two phyla: Platyhelminthes, so called flatworms (e.g. cestodes and trematodes) and Nematoda, commonly called roundworms or nematodes (Tortora et al. 2002). They pose serious health risks due to the following: causing infections at lower levels than many bacteria, possessing high survival rates of the eggs and being resistant to common disinfectants (Buitrón and Galván 1998; references therein). The most persistent of all helminthic pathogens are *Ascaris* eggs and thus can be used as a parasite indicator when dealing with hygienisation of excreta (Strauss 2000). *Ascaris* (intestinal roundworms) can produce approximately 200,000 eggs per day, which when excreted into the soil become infectious within 2 weeks and might be viable for years (Bitton 1999).

Various numbers of helminth eggs have been found in raw wastewater, which might be related to the rates of transmission, population density, economical status of the society, geographical regions and climatic conditions. Stott et al. (1997) reported that the concentration of eggs of human intestinal helminths in raw wastewater in Egypt ranged from 6 to 42/l. Grimason et al. (1996) further noted that the numbers of *Ascaris* eggs in raw wastewater in Kenya varied from 17.5 to 133.3/l. In Morocco, the average number of helminth eggs in raw wastewater was 23/l (Kouraa et al. 2002); a similar average of 22.7/l was reported by Jimenez et al. (2000) in raw wastewater from Mexico City. High mean concentration of *Ascaris* eggs in untreated wastewater (150/l) was observed by Graham (1981) in Canada; however, the highest value (960/l) was reported by Ben Ayed et al. (2009) in Tunisia.

Venglovsky et al. (2006) reported that helminthic pathogens play a negligible role in industrialised countries. This could explain the very limited information and lack of published data on helminth concentrations in the wastewaters from highly developed and wealthy countries, such as Norway. Indeed, there was no massive outbreak of waterborne helminthiases noticed in Norway. However, a water/food-borne parasite contamination by protozoan cysts and oocysts was reported (Robertson and Gjerde 2001; Robertson et al. 2009).

Pathogenic parasites are resistant to common disinfectants and, in some cases, can also survive ultraviolet irradiation (Liberti et al. 2002; Mun et al. 2009; Murray et al. 2009). It is therefore essential to implement sufficient treatment methods that will not only provide hygienic and safe end products, but will also reduce the risk of environmental contamination by parasitic pathogens. In this aspect, it was of immense interest to survey the presence of infective parasite eggs in filter media of on-site domestic wastewater treatment systems. Paruch et al. (2005) was the first who conducted such survey in constructed wetlands (CWs) filled with the specific filter media (Light Weight Aggregates—LWA), developed in Norway for use in different water and wastewater treatment systems. The purpose of that initial study was not to directly determine the treatment efficiency of the LWA–CWs but to demonstrate the status of parasite contamination in the LWA filter media that could be reused (after completion of appropriate treatments) in agriculture (Paruch 2007; Paruch et al. 2005). The Norwegian survey (Paruch et al. 2005) focused on parasitic helminth eggs (mainly nematodes represented by *Ascaris*), because they are the most persistent of enteric pathogens and their eggs have the highest survival rate under different moisture conditions (Cofie et al. 2006; Slifko et al. 2000). For example, *Ascaris* eggs survive several years in soils, but extremes in moisture content (very high or low) may cause a decrease of the survival rate (Venglovsky et al. 2006; references therein).

2 Status of helminth egg contamination in light weight aggregate wastewater treatment systems

On-site domestic wastewater treatment systems with LWA–CWs have been developed, implemented and broadly used in Norway. They operate well under Scandinavian conditions and show high and stable treatment efficiency with reference to organic matter, phosphorus, nitrogen and pathogens (Jenssen et al. 2005; Mæhlum and Jenssen 2002). In general, such systems in Norway consist of three fundamental elements: a septic tank, a prefilter and a wetland filter/bed (Fig. 1).

The LWA are typical materials used in Norwegian CWs and, among them, Light Expanded Clay Aggregates (LECA) and Filtralite® are the most frequently used (Søvik and Kløve 2005). Some systems, however, are also constructed with sand filters, such as the first pioneering Norwegian wetland constructed in 1991—Haugstein (Table 1). Samples of these media (LWA and sand), collected from four CWs treating domestic wastewater in southeast Norway, were surveyed for the first time for helminth egg contamination (Paruch et al. 2005). The samples, 36 in number, were collected from each investigated CW. The collection was conducted in 9 sampling points (three points each at the inlet, in the middle and at the outlet section) and in 4 deep layers (10, 30, 50 and

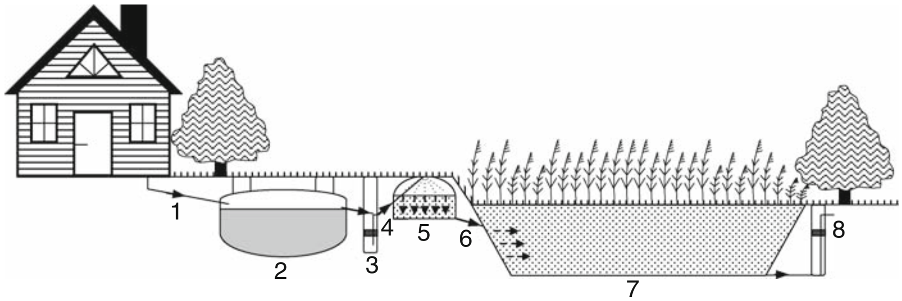

Fig. 1 General layout of LWA–CW system treating domestic wastewater in Norway: *1* inlet (domestic wastewater), *2* septic tank, *3* pump well, *4* effluent from the septic tank, *5* aerobic prefilter (biofilter), *6* effluent from the biofilter, *7* wetland filter, *8* outlet (effluent from the entire system)

80 cm) of the wetland bed (Paruch et al. 2005). Examination of the eggs in the collected samples was carried out in a specialised laboratory at the Norwegian School of Veterinary Sciences. According to the procedure for isolation of helminth eggs, the samples were incubated at 27°C for 4 weeks. After incubation, from each 100 g sample, 10 sub-samples of 10 grams each were examined for the eggs under a microscope at 100× magnification. The method had a lower detection limit of 1 egg per 10 g sample. The procedure has been described in greater detail by Gjerde (in Pierzo et al. 2004) and reviewed elsewhere (Paulsrud et al. 2004, 2006).

Wastewater was not considered for the parasite test, since neither the treatment efficiency of the CWs nor the reduction of the egg concentrations in the tested filter media was the initial intention of the Norwegian survey (Paruch et al. 2005).

The expended media from the LWA–CWs might be considered for agricultural exploitation because some of them possess high phosphorus (P) sorption capacity and thus could be reused (after their lifetime of approximately 15 years) as complementary P fertilisers (Kvärnström et al. 2004) or as soil amendment agents and conditioners, as for example in sustainable agroecology (Paruch 2007). Therefore, the main focus of the Norwegian survey (Paruch et al. 2005) was on the LWA–Filtralite®P (0–4 mm) from the wetland bed (designed mainly for removal of P and pathogens); however, samples from other filter materials (the LWA–LECA 0.5–10 mm and iron rich sand 0–2 mm) were also investigated (Table 1).

The Norwegian survey (Paruch et al. 2005) did not reveal any egg accumulation and the consequent parasite contamination in the filter media of CWs. Thus, parasitic helminth eggs were detected neither in the LWA filters nor in the sand filter (Table 1). The survey, however, might not be fully representative of the overall Norwegian population and the LWA–CWs in general, as it was conducted only on four, randomly selected, systems treating domestic wastewater from a small number of people (7–40 persons, Table 1).

3 Scenarios for human parasite eggs during wastewater treatment in LWA filters

Outcomes from the Norwegian survey (although should be interpreted with some degree of caution)

Table 1 General characteristic of the LWA wastewater treatment systems and the status of helminth egg contamination in the filter media (data from Paruch et al. 2005)

System	Built year	No. of persons served	Filter				Helminth egg contamination
			Material	Area (m^2)	Depth (m)	Size fraction (mm)	
Haugstein	1991	7	Sand	60	0.8	0–2	Not detected
			LECA	40	0.9	0.5–10	Not detected
Tveter	1993	7	LECA	110	0.9	0.5–10	Not detected
Holt	1999	12	Filtralite®P	120	1.0	0–4	Not detected
Dal	2000	40	Filtralite®P	250	1.0	0–4	Not detected

could just verify the hypothesis that highly developed, wealthy and relatively healthy populations in Norway shall not have any disease outbreaks caused by pathogenic parasite eggs originating from human wastes. Indeed, any critical circumstances with parasitic egg contamination have not been reported until date. However, faecal wastes originating from humans represent a definite parasitical load, because the sludge from domestic wastewater produced in Norway contains pathogenic parasite eggs (Bergstrøm 1981; Paulsrud et al. 2004). Although the eggs may be contained in wastewater sludge, influents of the LWA–CWs do not have to be contaminated with the eggs. In this context, the question regarding the potential influent contamination and the exact location where parasite eggs are eliminated in the CW systems to the level that no egg is detected arises.

It appears that the first trap for the eggs is the septic tank. It represents an anaerobic treatment method that is the simplest, oldest and most common for on-site wastewater treatment (Jewell 1987; Ntengwe 2005). Processes occurring in the tank are initiated by the retention of solids transported along with the wastewater, followed by sedimentation of suspended solids and, finally, digestion of the organic matter settled at the bottom as sludge. Digestion is conducted by anaerobic bacteria and thus the septic tank may also function as a simple biological step in wastewater treatment. Although one of the main disadvantages of anaerobic treatment is the low removal rate of pathogens, it excludes helminth eggs that can be effectively captured in the sludge (Seghezzo et al. 1998). This phenomenon may be attributed to the fact that nematode eggs, and in general all helminth eggs, are bigger and heavier than some protozoan cysts and oocysts (Ben Ayed et al. 2009; Watson et al. 1983) and thus settle out more effectively because of their sedimentation speed: *Ascaris* eggs were estimated to settle at 65 cm/h compared to 1 cm/h for protozoa such as *Giardia* cysts (Amahmid et al. 2002; references therein). WHO (2006) recent guidelines on the reuse of wastewater, excreta and greywater cite a reduction of 90% for helminth eggs in full scale primary sedimentation units. Studies carried out by Zhang et al. (1996) showed a relatively high removal rate of helminth eggs (99.89%) in the septic tanks. The rate represented a reduction from 1,178 to 1.3 eggs/l. The studies also indicated that the concentration of parasite eggs follows a distribution and accumulation of the sludge from the inlet to the outlet part of the septic tank. In this aspect, the parameter of importance is the physical characteristic of density of helminth eggs, which results in a higher concentration of the eggs in the lower part of the sludge (Gaspard and Schwartzbrod 2003). In addition, nonviable eggs have a lower density than viable eggs and therefore take longer to settle out (Nelson et al. 2004).

Septic tanks provide the most effective and undisturbed sedimentation of domestic wastewater. This process is unquestionably the main removal path of helminth eggs (Amahmid et al. 2002; Gaspard and Schwartzbrod 2003; Katsenovich et al. 2008; Liberti et al. 2002; Mandi et al. 1996; Maynard et al. 1999; Molleda et al. 2008). During sedimentation, the eggs are removed from the liquid phase of wastewater to the settled solids that are digested to sludge. Thus, it could be expected that the sludge, and not the effluent, from the septic tank is the most contaminated with pathogenic parasite eggs and therefore special attention is proposed to be paid to its treatment (Wen et al. 2009). Although helminth eggs may eventually die in the sludge (Ntengwe 2005), they still remain the most resistant form of parasite contamination found in the sludge (Gaspard and Schwartzbrod 2003; references therein). Cofie et al. (2006) reported, on the basis of available references, that the concentration of helminth eggs in the faecal sludge from on-site sanitation installations is normally higher by at least 10 times than in raw wastewater. Hence, the use of raw sludge for application in agriculture and other purposes involves a high risk of environmental contamination with parasitic pathogens. This is reflected in the findings reported by Ilsoe et al. (1990) that sludge from septic tanks applied directly in agriculture was the most frequent source of helminth infections of farm animals in Denmark. It could therefore be probable that Norwegian studies focused thus far more on sludge than on domestic wastewater contamination with parasitic pathogens (Bergstrøm 1981; Paulsrud et al. 2004). Bergstrøm (1981), for instance, reported a greater average number of *Ascaris* eggs in dewatered sludge from the septic tanks of domestic wastewater (6,928/100 g) than in the raw sludge from abattoirs (45/100 g). Moreover, these eggs predominated in the septic-tank sludge from housing estates with a majority of foreign residents, which could additionally indicate an overseas transfer of parasitic pathogens. Gaspard and Schwartzbrod (2003) noticed related observations showing that both travellers and the entire sector of tourism activities may have an important effect on sludge contamination by helminth eggs.

Although the effluents from the septic tanks contain a certain load of parasite eggs, it is relatively low (Zhang et al. 1996) and can be easily reduced during the subsequent treatment steps in CW systems. The reduction mainly involves accumulation of the eggs in the filter media. Since prefilters precede the filters of CWs (Fig. 1), it could be expected that the possibility of transport and occurrence of infective parasite eggs (if any) in the prefilter media was higher than that of finding them in the filter media.

The LWA Filtralite®P and LECA media have never been investigated before for parasite contamination; thus the outcomes from the Norwegian survey (Paruch et al. 2005) cannot be associated with any published data yet. Nevertheless, it has been broadly reported that sand filters can be very effective in the reduction of parasite egg contamination in wastewater. Gómez et al. (2006) found that sand filtration, which was introduced for pretreatment of urban wastewater and removal of parasite eggs, can produce effluents without pathogenic nematode eggs. Slifko et al. (2000) indicated that the filtration process can be an effective barrier to both helminth ova bigger than 20 μm and larger protozoan cysts. It therefore could provide an efficient removal of helminth eggs, having an approximate size of 10–100 μm (Asano 1998), and particularly *Ascaris* eggs, because their diameter is about 50 μm (Paulsrud et al. 2004; Quilès et al. 2006). Liberti et al. (2002) reported, on the basis of available references, that large and heavy parasites, such as nematode eggs, can be removed consistently by sand filtration. Shephard (in Buitrón and Galván 1998), referred to a significantly effective 100% removal of helminth eggs in slow sand filtration. Landa et al. (1997) showed that rapid sand filtration was also effective in removing helminth eggs and the best effluent with 0.1 egg/l was produced by a sand filter having effective size of 1.2 mm. Moreover, Jimenez et al. (2000) found that filtration in sand having an effective size of 1.2 mm was consistently able to remove helminth eggs and achieve levels of <1 egg/l. The same level was reported by Von Sperling and Chernicharo (2002) as being the consistently achieved effluent quality during sewage treatment by infiltration technologies combined with septic tanks. The above-cited studies focused mainly on the quality of effluents and did not consider the presence of helminth eggs in the filter media. What is therefore the fate of the accumulated eggs? Can they be eliminated to the level reported in the Norwegian survey (Paruch et al. 2005), where no egg can be found in the samples of sand and LWA filters (Table 1)?

Discussion on elimination of helminth eggs in sand and LWA media can be related to the environmental impacts of persistence of parasite ova. It is due to the fact that CW filters containing these media can be associated with environmentally open and biologically active ecosystems. Mandi et al. (1996) and Reinoso et al. (2008) reported from available references that the accumulated eggs could be eliminated by many factors, such as temperature, pH, insolation and solar radiation, in addition to the presence of antagonistic organisms. Grønvold et al. (1996) described a possible method for the destruction of cestode eggs by ants, earthworms and beetles. Earthworms, for instance, consuming large volumes of soil and organic matter can also inevitably consume nematode eggs (Grønvold et al. 1996). Lysek (1963) found that some predators such as springtails and mites are capable of consuming *Ascaris suum* eggs. Miller (1961) observed that helminth eggs can be also directly destroyed by the mouth parts of feeding dung beetles. Rhizomes of reeds (common vegetation in CWs) can enhance these phenomena by barring the outflow of helminth eggs from the bed (El-Khateeb et al. 2009; references therein; Mandi et al. 1996) and thus allowing the antagonists to carry out their elimination processes (Reinoso et al. 2008; references therein). As a result, CWs can be very effective in removal of helminth eggs from wastewater showing a reduction rate of 99.9% (WHO 2006).

Following the above scenarios of transport and fate (reduction and elimination) of helminth eggs, it could be assumed that the possibility of finding eggs of human parasites in the LWA filters treating domestic wastewater should be negligible. However, the possibility of finding infective parasite eggs could not be dismissed completely because the filters constituted a part of the surrounding ecological environment. Therefore, the filters are exposed to environmental sources of contamination by parasitic pathogens, e.g. excreta from wild animals (birds, ruminants, foxes and rodents), which are hard to control (Edwards et al. 1997; references therein; Nithiuthai et al. 2004). In addition, helminth ova can be found in air, dust and soil (Peng et al. 2003; references therein; Slifko et al. 2000) and thus can be also easily transported to the open filters of CWs.

4 Conclusions

From the theoretical viewpoint, it could be assumed that the possibility of finding parasitic helminth eggs in the LWA filters treating domestic wastewater should be negligible. Absence of the eggs in CW filter media might be related to the fact that the key removal mechanisms occur in septic tanks. As the tanks are the major traps for the human parasite eggs, negligible contamination with the eggs can be found in the tank effluents. The eggs that could pass through the trap can be subsequently caught in the prefilters. If some of the eggs would be still further transported, they would be accumulated in the CW filters. These filters, performing amid the surrounding ecosystems, are exposed to varying environmental factors that may effectively eliminate the accumulated eggs. Although the assumption was derived more from scientific evidences, it was to some extent verified by practical results. The outcomes, however, should be interpreted with caution, because they characterised survey that was conducted for the first time ever on these specific LWA filter media and was never replicated. In addition, the survey was limited to just four LWA–CWs. Therefore, the outcomes might not be representative enough to precisely characterise the status of parasite egg contamination in LWA wastewater treatment systems, in general. Thus, further extension of the survey is necessary to demonstrate an updated status of parasite contamination in the LWA media. At this point, further studies aimed at determining helminth egg contamination in domestic wastewater and assessing treatment efficiency of the main components (septic tank, prefilter and wetland filter/bed) of the LWA–CWs in the removal of helminth eggs are also recommended.

On the basis of the above considerations, it can be stated that, theoretically, the LWA filter media shall not be contaminated with human parasitic helminth eggs originated from domestic wastewater; however, practically, the possibility of finding parasite eggs in the filters of on-site wastewater treatment systems cannot be entirely dismissed.

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