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Review

Soil-transmitted helminth infections associated with wastewater and sludge reuse: a review of current evidence

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Abstract

OBJECTIVE To review current evidence on infections related to the concentration of soil-transmitted helminth (STH) eggs in wastewater, sludge and vegetables irrigated with wastewater or grown on sludge-amended soils.

METHOD Search of Web of Science, Science Direct, PubMed and Google Scholar databases for publications reporting on STH egg concentration in wastewater, sludge and vegetables and for epidemiological studies on wastewater/sludge reuse and STH infections.

RESULTS STH egg concentrations were variable but high in wastewater and sludge especially in developing countries. They ranged from 6 to 16 000 eggs/L in wastewater and from 0 to 23 000 eggs/g in sludge and far exceed limits set in the WHO guideline for wastewater/sludge reuse. Numbers of STH eggs on vegetables ranged from 0 to 100 eggs/g. The concentration of STH eggs in wastewater, sludge and vegetables therefore relates to risks of infection through different exposure routes.

CONCLUSION Epidemiological evidence reveals an increased prevalence of STH infections associated with direct exposure to wastewater or sludge (farmers) and consumption of vegetables grown on soil treated with it. This calls for increased efforts to reduce the adverse health impact of wastewater and sludge reuse in line with the WHO multi-barrier approach.

keywords soil-transmitted helminths, wastewater reuse, sludge reuse, *Ascaris* spp, hookworm, *Toxocara* spp

Introduction

Wastewater and sludge reuse in agriculture have been promoted as a concept of sustainable development [1]. Wastewater may be used for irrigation either directly, or indirectly through the use of wastewater-contaminated surface water. Contamination of surface water with wastewater may occur due to poor infrastructure, such as non-treated effluents, leaky sewage pipes and faulty wastewater treatment plants [2]. The increase in the use of wastewater and sludge globally is driven by rapid urbanisation, growing water shortage and the benefits associated with the practice as irrigation water [1–4]. With approximately 330 km^3 of municipal wastewater produced per year [5], it is a reliable alternative water source for irrigation. Wastewater and sludge reuse is most predominant in developing and arid countries, but has also been documented in Northern America, Europe and Australia [2, 6–8]. Globally, wastewater-irrigated farms are estimated to cover 5–20 million hectares, with higher proportions in China [9] and Mexico [10]. When also accounting for wastewater-contaminated surface water, the total land area irrigated with wastewater is substantially higher [11]. The use of sludge is encouraged due to its high nutrient and organic material contents [12]. It is mostly applied as a soil amendment [13] to improve water retention of soil [14, 15]. Sludge may also be used to rehabilitate degraded, exhausted and burnt soil [16, 17].

Despite the many benefits of wastewater and sludge use in agriculture, these practices can have adverse impacts on human health [18, 19]. Wastewater may contain contaminants that are harmful to health, such as metalloids/metals [20, 21], excess nutrients, hormones [22–24], organic compounds such as pesticides, components of consumer products, pharmaceuticals and personal care products [25–27] and, most importantly, pathogenic microorganisms [28–32].

Among the microbial pathogens, soil-transmitted helminths (STHs) are of the most important health concern in wastewater and sludge reuse [19] especially in endemic regions, mainly due to their persistence in the environment and the low infectious dose [33–37]. Concentration of STH eggs in wastewater/sludge is an indication of the health hazard of its application [38, 39]. Despite the adoption of the WHO wastewater/sludge reuse guidelines and the development of local guidelines, where the suitability of these (wastewater and sludge) for reuse is covered, increased STH infections for different populations due to wastewater/sludge reuse continue to be reported. This review therefore presents the current evidence in relation to concentration of STH eggs in wastewater and sludge and reported adverse health effects (STH infections).

Methods

Search strategy

This review was based on a literature search of Web of Science, Science Direct, PubMed and Google Scholar databases. The keywords and word strings used were soil-transmitted helminths OR intestinal parasites OR *Ascaris* spp OR hookworm OR *Trichuris* spp OR *Toxocara* spp OR *Taenia* spp AND wastewater reuse OR sludge reuse. The organism search strings were repeated with AND compost OR vegetables OR crops OR plants; as well as with AND soil OR urine diversion (UD) toilet waste OR biosolids. Although *Taenia* spp is not a STH it was added to the review due to the similarity in survival characteristics in the environment, its epidemiology and transmission route with STHs [40].

Original articles reporting on STH egg concentrations in wastewater, sludge, compost and crops or vegetables were considered. Only peer-reviewed papers published in English were included. There were no restrictions on publication year or geographic location.

Article titles and abstracts were assessed to determine their suitability for inclusion in this review. Studies included can be categorised into publications on the concentration of STH eggs in wastewater and sludge reused in agriculture; publications that reported the concentration of these eggs on vegetables grown with wastewater or sludge; and publications that directly measured the impact of wastewater/sludge reuse on STH infections using epidemiological methods. Studies that reported infections other than STHs and *Taenia* spp were not included.

Data extraction and analysis

The following information was collected from each article considered for this review: (1) geographic location of the study; (2) concentration of STH eggs in samples studied; (3) type of STH reported; (4) target population studied; (5) infection levels reported in each exposed population.

STH egg concentrations in wastewater, sludge and on vegetables from articles and reports were collated and captured in tables for easy representation. Measured impacts of wastewater/sludge reuse on STH infections were also collated and the reported odds of infection, odds ratios or prevalence of infection from exposure captured in tables.

Results

The search yielded 175 articles, 150 from the search strings used and 25 from manual search. Of this number, 59 were included in this review. Figure 1 shows the process followed in arriving at the final number of articles reviewed. Of the 59 articles reviewed, 25 reported on the concentration of STH eggs in wastewater and sludge, 19 on STH contamination of vegetables irrigated with wastewater or grown on sludge-amended soils and 15 reported on the direct epidemiological link between wastewater/sludge reuse and STH infections.

Concentration of STH eggs in wastewater and sludge

STH eggs are a major group of pathogens of concern with concentrations in wastewater and sludge that vary between locations due to differences in infection prevalence or intensity in the connected population. An estimated 3000 eggs/L may be found in wastewater from endemic regions [41, 42]. Table 1 summarises reported concentrations of STH eggs found in wastewater and sludge. STH egg concentrations in developing countries are generally higher than in developed countries.

Concentration of STH eggs on vegetables irrigated with wastewater or grown on sludge-amended soil

Contamination of vegetables with STH eggs due to wastewater and sludge reuse occurs when these are used for irrigation or fertilisation. Local factors such as impact of UV light, rain pattern and withholding time between irrigation/fertilisation and harvest determine the concentrations and risk. The impact of these factors on STH egg levels on vegetables has rarely been addressed [43–45]. Concentrations of STH eggs ranged from 0.027 eggs/100 g [43] to 10 eggs/100 g [44] (Table 2). It is noteworthy that some of these did not report concentration of STH eggs but rather the prevalence of contamination in a particular region. Also, contamination may not always be

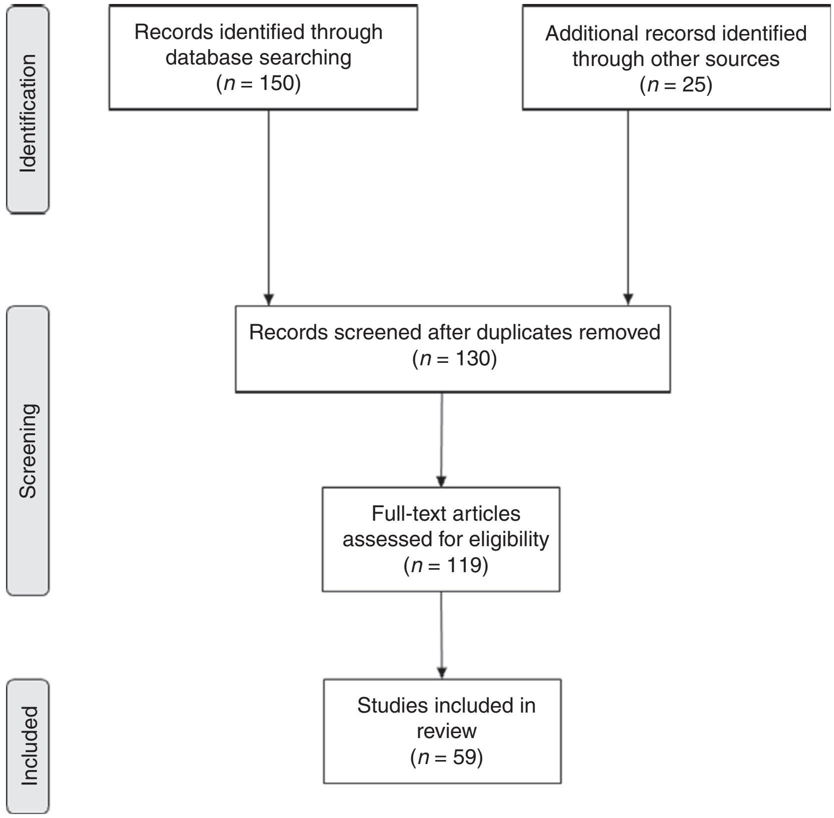

Figure 1 Number of articles obtained through the search process and the studies reviewed based on eligibility criteria.

Table 1 Concentration of STH eggs in wastewater and sludge from different locations

Country	Wastewater (eggs/L)	Sludge (eggs/g)	References
Egypt	6–42	Mean: 67; Maximum: 735	[84]
Ghana	12.9–15.1	13–94	[55, 85, 86]
Morocco	840	3.3–13.3	[87, 88]
South Africa	772	25–185	[89–91]
Tunisia	15–30	0–4	[87, 92–94]
Brazil	166–202	75	[85, 95]
United States	1–16	2–776	[85, 96–98]
Mexico	6–98	73–177	[85, 99]
Peru	115–273	60–260	[87, 100]
Japan	80	1–51	[87]
China	840	2300	[87]
Syria	800		[87]
Vietnam	450–16000		[101]
Pakistan	142–558		[102]
Ukraine	60	No data	[87]
France	9	5–7	[85, 103]
Germany	No data	<1	[85]
Great Britain	No data	<6	[85]
Spain	0–1	867	[104–107]

from wastewater or sludge reuse but in some cases may have been from post-harvest handling of the produce.

Evidence of STH infections associated with wastewater and sludge reuse

Direct exposure to wastewater or sludge during their application may result in STH infections, and consumption of the farm produce may result in infections due to the contamination. Several epidemiological studies established the association between wastewater/sludge reuse and STH infections (Table 3).

Discussion

STH eggs in wastewater and sludge pose a threat to human health upon direct or indirect exposure. Concentration of these eggs in faecal materials varies greatly depending on the infection levels within the connected populations [46, 47]. Infected individuals can excrete 10^2–10^4 eggs/g daily, contributing to high concentrations in wastewater and sludge [48]. Human faecal matter is

Table 2 Prevalence and concentration of STH and other helminth eggs contamination on vegetables

Type Of STH	Concentration	Location	References
Ascaris spp.	0.018 eggs/100 g 0.027 eggs/100 g 0.27 eggs/100 g (Coriander) 0.46 eggs/100 g (Mint) 0.07 eggs/100 g (Carrots) 0.16 eggs/100 g (Radish)	Morocco	[43]
Ascaris spp.	1–3 eggs/100 g (Lettuce) 0–3 eggs/100 g (Parsley) 0–2 eggs/100 g (Spinach)	Turkey	[108]
All helminth eggs	10 eggs/100 g (water spinach)	Cambodia	[44]
All helminth eggs	2.3 eggs/100 g (Lettuce)	Ghana	[109]
Ascaris lumbricoides, Hookworm, *Enterobius vermicularis, Trichuris trichiura, Taenia* and *Strongyloides* larvae	0.8–3.7 eggs/100 g (lettuce)	Ethiopia	[110]
Taenia spp, *Ascaris* spp, *Toxocara* spp and *Strongyloides* eggs.	8.4 eggs/100 g (mint, coriander, alfalfa).	Morocco	[45]
All STHs	32.6% (of 304) (a variety of vegetables)	Iran	[111]
Ascaris spp	2% (of 141)*	Iran	[112]
Ascaris spp, *Trichuris trichiura* and Hookworm	44.2% (of 172) (a variety of vegetables)	India	[113]
All STHs	57.8% (of 199) (a variety of vegetables)	Nigeria	[114]
Ascaris spp *Toxocara* spp *Taenia* spp	19–96% (of 126) 3–48% (of 126) 6–30% (of 126) (A variety of vegetables)	Libya	[115]
Ascaris spp., Hookworm, *Trichuris* spp., *Taenia/Echinococcus* spp., and *Strongyloides stercoralis*	8.2% (of 1130 for lettuce) 2.0% (of 1130 for cabbage) 1.0% (of 1130 for eggplant) 1.3% (of 1130 for carrot) 2.3% (of 1130 for cucumber)	Nigeria	[63]
All helminths	6.3% (of 111) (A variety of vegetables)	Turkey	[64]
All helminths	36.9% (of 118) (A variety of vegetables)	Palestine	[116]
Intestinal parasites	61% (of 168) (lettuce) 18% (of 168) (tomato)	Ghana	[117]
Intestinal parasites	13.5% (of 260)*	Sudan	[118]
All STHs	16.2% (of 270)*	Saudi Arabia	[65]
Intestinal parasites	8.4% (of 383)*	Iran	[119]
Intestinal parasites	14.6% (of 383)*	Iran	[120]

*Not specified.

the main concern, but impact from animals such as dogs and cats is also important where their faeces may contain eggs of *Toxocara* spp, which could lead to zoonotic infection. These eggs (*Toxocara* spp) are predominantly found in investigations of soil and playgrounds in developed countries, especially where pets are allowed [49, 50], while their abundance may be more generally occurring in many developing countries. The generally high concentration of STH eggs in wastewater and sludge is reflected by the infection prevalence and is of concern especially in reuse scenarios. Reuse of the wastewater and sludge is one major route through which exposure to the eggs may occur and affect exposed farmers directly, while indirectly impacting broader groups such as community members and consumers of crops. Infection risks are based on a single STH egg dose. The concentrations of STH eggs reported in wastewater and sludge as presented in Table 1 reflect the risks based on their further deposit or reuse linked to human direct or indirect exposure. Exposure is mainly through the oral route for most STHs and additionally through skin penetration for hookworms. The concentrations found in the majority of the reported investigations (Table 1) exceed the WHO guideline values for wastewater/sludge reuse and result in infections far above the health target of $\leq 10^{-6}$ disability adjusted life years (DALYs) [19]. Direct exposure to wastewater or sludge during application is the main route of exposure for farmers. The informal nature of wastewater or sludge reuse in many countries makes regulation difficult and also hinders implementation of effective public health awareness campaigns to reduce the impact of the practice on the health of farmers and the general population.

Table 3 Studies reporting on the association between wastewater/sludge use in agriculture and STH infections

Author/Year	Target group	Practice	Health risk and conclusions
Pham-Duc *et al.* [121]	Farming households	Wastewater and excreta	Contact with wastewater was a significant risk factor for helminth infection (OR = 1.5, 95% CI 1.1–2.2) in general and also specifically for *Ascaris lumbricoides* infection (OR = 2.1, 95% CI 1.4–3.2). Significant risk factors for *Trichuris trichiura* infection include the use of human excreta (OR = 1.5, 95% CI 1.0–2.3)
Yajima *et al.* [57]	Community members	Human excreta only	Consumption of vegetables fertilised with human excreta resulted in high helminth infection rate
Trang *et al.* [74]	Farming households	Wastewater	No significant association was found between wastewater exposure and helminth infections
Trang *et al.* [122]	Adults and children	Wastewater and human excreta	Wastewater exposure did not pose a significant risk for helminth infection
Nguyen *et al.* [73]	Women	Excreta	The use of untreated faeces as fertiliser was significantly associated with infection with *A. lumbricoides* (OR = 1.2, 95% CI 1.0–1.6)
Van der-Hoek *et al.* [1]	Community members	Human excreta only	The use of human excreta as fertiliser was a significant risk factor for hookworm infection, especially among adult women
Gumbo *et al.* [123]	Male farmers	Wastewater	Farmers using wastewater for irrigation had a prevalence ratio of 1.50 for hookworm infections
Habbari *et al.* [61]	Children	Wastewater	Significant increase in prevalence of ascariasis for exposed children
Bouhoum and Schwartzbrod [124]	Children	Wastewater	Higher prevalence among exposed of any helminth infection (73% exposed *vs.* 30% unexposed), *Ascaris* infection (33% *vs.* 2%), and *Trichuris* infection (17% *vs.* 2%)
Blumenthal *et al.* [61]	Agricultural workers and their family members	Wastewater	Higher prevalence of *Ascaris* infection among exposed compared to unexposed for children. Children under 5 years had higher odds of infection (OR = 18.0) than children above 5 years (13.5)
Cifuentes *et al.* [125]	Agricultural workers and their family members	Wastewater	Higher prevalence of diarrheal disease (30% *vs.* 23%) and *Ascaris* infection (15% *vs.* 3%) for exposed children
Amoah *et al.* [54]	Agricultural workers and their family members	Wastewater	Increased odds of infection for farmers for both *Ascaris* spp and hookworm for farmers and family members as compared to unexposed populations, especially in the raining season
Pham-Duc *et al.* [18]	Farming households	Wastewater	People having close contact with wastewater polluted surface water had a higher risk of helminth infections compared with those without contact
Fuhrimann *et al.* [72]	Community members	Wastewater	High prevalence of intestinal parasite infections for peri-urban farmers, using wastewater for irrigation, as compared to other groups

Exposure to soil containing STH eggs may also result in increased infections. Due to the importance of soil in the transmission of these infections, several studies have focused on the prevalence and concentration of STH eggs in public parks, beaches, backyards and farmlands [51]. The prevalence and concentration of these eggs in soil varies greatly from 1.1 eggs/g [52] to 454.5 eggs/g [53]. Accumulation of STH eggs in farm soil occurs due to multiple applications of wastewater and sludge to the same parcel of land [51, 54]. As this accumulation persists over time, the risk of infection is not diminished due to the latency period. Coupled with the persistence of these eggs in the environment of 10–12 months [55], STH egg concentrations on farm soil could be higher than concentrations in the wastewater or sludge resulting in higher infection risks [54, 56]. For instance, Amoah *et al.* [54] reported an average concentration of 3.70 (±0.23) eggs/g for *Ascaris* spp and 2.01 (±0.23) eggs/g for hookworm on farms in Ghana. Fixed time periods for survival may be difficult to give as conditions may vary greatly. Due to the low infection dose (essentially a male and female worm for multiplication in the body), a conservative approach has been taken with an essentially low occurrence of eggs in environmental samples.

Direct exposure to wastewater and sludge has been reported as the main route of infection with STHs associated with reuse. However, Yajima *et al.* [57] reported an increased risk of STHs infections from consumption of vegetables fertilised with sludge rather than through direct exposure to sludge. The contamination of vegetables with STH eggs due to wastewater reuse is mainly dependent on the quality of the wastewater, the irrigation method used and the type of crops. WHO wastewater reuse guidelines relate the risk to the likelihood of contact, where for example the use of drip irrigation for high crops is given a reduction in the likelihood of infection risks of 4 log units of pathogens. A comparative value of 2 log units for low crops applies. A higher reduction in pathogens could be achieved with the use of subsurface irrigation, with 6 log units [19]. If instead sprinkler irrigation is used, this results in a higher risk due to the contact between potential STH eggs in water droplets and the crops, causing higher contamination of the vegetables. High ejection sprinkler irrigation may also result in exposure risks for communities residing close to the irrigation sites due to aerosols as reported in several earlier studies [58–60]. Furrow or flood irrigation may also increase the possibility of direct contact with the wastewater by farmers, increasing risks of infections [61, 62].

Contamination of vegetables with STH eggs from wastewater-irrigated fields has been reported extensively [63–68] (Table 2). The relative impact of contamination from other activities or routes parallel to wastewater/sludge reuse has not been demonstrated clearly. Contamination levels of STH eggs on vegetables are largely dependent on the quality of the wastewater/sludge as well as the irrigation method. Post-harvest practices such as hygiene of market women and even cleanliness of the markets during retail and transportation may result in additional contamination of the vegetables with STH eggs [69]. Uga *et al.* [70], reported that a high contamination of vegetables from markets occurred with both animal and human parasites. This could be attributed to both contaminations during cultivation and handling and storage practices at the various markets. Shuval *et al.* [71] reported that eggs of common STHs could survive on crops 4–12 months. These findings were instrumental in the development of the first WHO wastewater reuse guidelines.

Despite the established estimated risk levels of STH infections from wastewater/sludge reuse through QMRA, only a small number of studies have applied epidemiological assessments and methods to accurately measure the contribution of wastewater/sludge reuse to STH infections (Table 3).

Independently of that, a review of the scarce literature shows an overwhelming evidence of increased risks of STH infections due to wastewater/sludge reuse [1, 18, 54, 72, 73] even if some studies were unable to establish links. For instance, Trang *et al.* [74] found no increase in STH infections from exposure to wastewater in Vietnam. The interlinkages between different contamination sources and transmission routes are essential in these types of studies. Pham-Duc *et al.* [75] found that hygiene was the main pre-disposing factor to an increased risk of parasitic infections (mainly protozoan) rather than exposure to wastewater or sludge. The epidemiological studies highlight a high incidence of STH infections among farmers and consumers of vegetables irrigated with wastewater or on sludge amended soil. The epidemiological approach may be more accurate in determination of risks of STH infections associated with wastewater/sludge reuse than the QMRA, but is dependent on large enough sample sizes, a well-documented background level of disease and appropriate control groups. In these situations, the QMRA approach is simpler and can be interlinked with the epidemiological studies. QMRA therefore is a valuable predictive tool and has been used extensively in estimating the risks of STH infections from wastewater or sludge reuse [31, 56, 76–81]. The estimated risks are affected by several assumptions, which do not affect the epidemiological assessments to the same extent, like the dose of STH eggs ingested by exposed individuals (either assumed or calculated) and to a large extent the dose–response model used. These variations could result in under or over estimation of the associated risks. The use of different dose–response models to estimate infection risks from ingestion of the same dose would result in different risks estimates which creates a challenge for comparison. Despite the usefulness of the epidemiological methods as a golden standard, limitations also relate to the costs involved which is far higher than predictive estimates. These costs for epidemiological studies might be the driving force behind the increase use of the QMRA method in estimation of risks.

The use of either QMRA or epidemiological methods has established that wastewater or sludge reuse contributes significantly to increased STH infections. These risks are mainly due to the high concentration of STH eggs in the wastewater or sludge, which calls for the adoption of effective strategies for risks reduction and/or management. The WHO wastewater/sludge reuse guidelines suggested protective measures that will ensure a 6–7 log unit reduction in pathogen concentrations, thereby reducing risks of infections for both farmers and consumers. These measures, referred to as *the multiple barrier approach*, include the following:

- Wastewater/sludge treatment: The concentration of STH eggs after treatment varies depending on the treatment technology. For instance, the highest reduction in helminth eggs (1–3 log units) has been reported with low rate biological processes such as waste stabilisation ponds, wastewater storage and treatment reservoirs and constructed wetlands [19]. Therefore, reuse scenarios could be developed based on the type of treatment technology available or the treatment technology could be chosen based on the intended reuse. Background values like the ones summarised in Table 1 can then be applied in comparative assessments of the reduction efficiency and variability.
- Control of human exposure to the pathogens in the wastewater/sludge: This could be achieved through the use of protective gear such as boots, gloves, nose masks, etc. However, this is rare, especially in developing countries, where the practice is common, due to the financial constraints. In this context, both background information of contamination levels (Table 1) and follow-up epidemiological evidences (Table 3) are of importance and should be linked with risk-reduction strategies.
- Crop restriction: This measure helps ensure that the choice of crops irrigated or grown is dependent on the quality of wastewater/sludge so as to protect health. However, the WHO reuse guidelines acknowledge that this will not be possible in countries where a monitoring regime is not in place. Wastewater/sludge reuse in most countries is informal and driven by economic reasons; therefore, this barrier may not be effectively implemented. By a combination of information on incidence of STH infections in an area or region, risk assumptions may be reached, which combined with irrigation practices and potential occurrence (Tables 1 and 2) can give an indication for handling practices.
- Wastewater application technique: The type of irrigation technique plays a major role in contamination of crops with pathogens from wastewater. Different irrigation methods carry varying risks in relation to contamination of vegetables, exposure of farmers and communities living close to irrigation sites.
- Cessation of irrigation before harvest: Pathogens will naturally die depending on their survival ability; therefore, cessation of irrigation days before harvest has been suggested to result in reduction of contamination. However, this might not necessarily result in reduction of viable STH eggs due to their high persistence in the environment.
- Food preparation techniques: The pathogen reduction possible depends on the food preparation method, for instance washing in water and hypochlorite solution may result in 1–3 log units reduction, peeling of fruits and root vegetables 2 log reduction and cooking may result in 5–6 log unit reduction in pathogens. The food preparation method may therefore be instrumental in public health protection [19] where a higher and comparative assessment as related to the epidemiological outcomes (Table 3) would give a better decision base for the future.

The WHO wastewater/sludge reuse guideline also recommends a guideline value of ≤1 helminth egg per gram or litre of sludge or wastewater intended for unrestricted agriculture. Some researchers suggest the reduction of this guideline value to ≤0.1 helminth egg per gram or litre, especially in situations where children are exposed [82]. However, in resource-limited countries where prevalences of STH infections are high and causing high concentrations of eggs in the wastewater/sludge, this may not be achievable. In such situations, the use of the QMRA approach may provide an option to determine the least quality required for specific uses. This may result in the preparation of different application guidelines depending on the quality achievable with the treatment options available in such settings. The multiple barrier approach should always be advocated for in these situations.

The Sanitation Safety Plan (SSP) Manual prepared by WHO [83] makes it easier to implement these wastewater/sludge reuse guidelines by presenting a stepwise approach to incorporation of reuse scenarios to sanitation. This manual presents six modules for the planning of sanitation systems, from generation through to collection, transportation, to treatment and reuse. The SSP manual accounts for risks of reuse through the use of the QMRA approach which applies the principle of hazard analysis and critical control points (HACCP) based on the Stockholm framework for preventive risk assessment and management. The WHO wastewater/sludge reuse guidelines as well as the SSPs provide means for effective reuse of wastewater and sludge whiles protecting public health, but they must be adapted to the local context so as to ensure usefulness. In this context, better background information on occurrence, like presented in Tables 1 and 2, and a broader epidemiological evidence base

(Table 3) can be useful in decision-making and management of reuse schemes.

Conclusion

STH eggs in wastewater and sludge continue to pose serious risks for farmers and other farm workers, including consumers through contamination of vegetables with these eggs. From the scarce studies on epidemiological links between wastewater/sludge reuse and STH infections, it can be concluded that this practice contributes significantly to increased infections. Implementation of the WHO wastewater/sludge reuse guidelines and sanitation safety plans may be instrumental in reducing the risks associated with wastewater/sludge reuse. These guidelines present interventions that may provide additional layers of protection even in cases where the quality of wastewater or sludge being used is poor. The SSPs also provide steps that could be adapted to local contexts for safe reuse of wastewater and sludge. We suggest the adaptation of the WHO wastewater/sludge reuse guidelines and SSPs to local contexts by involving farmers, communities and policy makers to ensure their effective implementation.

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References

1. van der Hoek W, Hassan MUL, Ensink JHJ, Feenstra S, Raschid-Sally L, Munir S. Urban Wastewater: A Valuable Resource for Agriculture: a Case Study from Haroonabad, Pakistan’. Research Report 63, Colombo, Sri Lanka. International Water Management Institute, 2002. pp. 2–5.
2. Rutkowski T, Raschid-Sally L, Buechler S. Wastewater irrigation in the developing world—Two case studies from the Kathmandu Valley in Nepal. *Agric Water Manag* 2007: **88**: 83–91.
3. Amoah P, Keraita B, Akple M, Drechsel P, Abaidoo RC, Konradsen F. Low-cost Options for Reducing Consumer Health Risks from Farm to Fork where Crops Are Irrigated with Polluted Water in West Africa. International Water Management Institute. Research Report 141, pp, 2011.
4. Drechsel P, Graefe S, Sonou M, Cofie O. Informal irrigation in urban West Africa: An overview, Research Report 102, International Water Management Institute, Colombo, Sri Lanka, 2006.
5. Mateo-Sagasta J, Raschid-sally L, Thebo A. Global wastewater and sludge production, treatment and use. In: Drechsel P, Qadir M Wichelns D (eds). *Wastewater-Economic Asset in an Urbanizing World*. Springer, Dordrecht Heidelberg: New York; London, 2015, 15–38.
6. Angelakis AN, Marecos do Monte MH, Bontoux L, Asano T. The status of wastewater reuse practice in the Mediterranean basin. *Water Res* 1999: **33**(10): 2201–2217.
7. Crook J. Water reuse—an overview. Keynote Speech Presented at MED-REUNET 1 Project, International Seminar on Wastewater Reclamation and Reuse, Izmir, Turkey, 25–26 September 2003, 2003. Website: Mediterranean network on wastewater reclamation and reuse. www.med-reunet.com
8. Lallana C, Krinner W, Estrela T, Nixon S, Leonard J, Berland JM. Sustainable water use in Europe, Part 2: demand management. In: Environmental Issues. Report No. 19. European Environment Agency. Denmark, 2001.
9. Drechsel P, Evans AEV. Wastewater use in irrigated agriculture. *Irrigat Drain Syst* 2010: **24**(1): 1–3.
10. Peasey A, Blumenthal UJ, Mara DD, Ruiz-Palacois G. 2000. *A review of policy and standards for wastewater reuse in agriculture: A Latin American perspective*. Water Eng. Dev. Ctr., Loughborough, UK.
11. WWAP (United Nations World Water Assessment Programme). *The United Nations World Water Development Report 2017. Wastewater: The Untapped Resource*. UNESCO: Paris, 2017.
12. Pompeo R, Andreoli C, Alcântara de Castro E, Aisse M. Influence of long-term storage operating conditions on the reduction of viable *Ascaris* eggs in sewage sludge for agricultural reuse. *Water Air Soil Pollut* 2016: **227**(144): 1–14.
13. Julca-Otiniano A, Meneses-Florian L, Blas-Sevillano R, Bello-Amez S. Organic matter, importance and experience of its use in agriculture. *IDESIA* 2006: **24**(9): 49–61.
14. Almendro-Candel MB, Navarro-Pedreño J, Gómez Lucas I, Jordán Vidal MM, García Sánchez E, Mataix Solera J. Movement of Fe, Mn, Cu and Zn in a sewage sludge-treated soil. In: Almorza D, Brebbia CA, Sales D, Popov V (eds). *Waste Management and the Environment*. WIT Press: Barcelona, Spain, 2002. pp. 311–320.
15. Navarro-Pedreño J, Almendro-Candel MB, Jordán-Vidal MM, Mataix-Solera J, García-Sánchez E. Mobility of cadmium, chromium and nickel through the profile of a calcisol treated with sewage-sludge in the southeast of Spain. *Environ Geol* 2003: **44**(8): 545–553.
16. Guerrero C, Gómez I, Mataix-Solera J. El uso de enmiendas en la restauración de suelos quemados. In: Caja Mediterráneo (ed). *Incendios forestales, Suelos y Erosión hídrica*. CEMACAM: Alcoy, 2007, 119–154.
17. Jiménez R, Álvarez AM. *Control de la degradación de suelos*. Ed. Universidad Autónoma de Madrid: Madrid, 2005.

18. Pham-Duc P, Nguyen-Viet H, Hattendorf J *et al.* *Ascaris lumbricoides* and *Trichuris trichiura* infections associated with wastewater and human excreta use in agriculture in Vietnam. *Parasitol Int* 2013: **62**(2): 172–180.
19. WHO-World Health Organization. *Guidelines for the Safe Use of Wastewater, Excreta and Greywater—Volume 2: Wastewater Use in Agriculture*. WHO-World Health Organization: Geneva, Switzerland, 2006.
20. Castells XE. *Vías de tratamiento y valorización de fangos de depuradora: Reciclaje de residuos industriales*. Ed. Díaz de Santos: Madrid, 2012.
21. Lam S, Nguyen-Viet H, Tuyet-Hanh TT, Nguyen-Mai H, Harper S. Evidence for public health risks of wastewater and excreta management practices in Southeast Asia: a scoping review. *Int J Environ Res Public Health* 2015: **12** (10): 12863–12885.
22. Burkholder J, Libra B, Weyer P *et al.* Impacts of waste from concentrated animal feeding operations on water quality. *Environ Health Perspect* 2007: **115**(2): 308–312.
23. Dalsgaard A. Special issue: wastewater use—Food safety and health aspects. *Tropic Med Health* 2007: **12**(2): 1–90.
24. Arvaniti OS, Stasinakis AS. Review on the occurrence, fate and removal of perfluorinated compounds during wastewater treatment. *Sci Total Environ* 2015: **524–525**: 81–92.
25. Harrison EZ, Oakes SR, Hysell M, Hay A. Organic chemicals in sewage sludges. *Sci Total Environ* 2006: **367**(2–3): 481–497.
26. Semblante GU, Hai FI, Huang X, Ball AS, Price WE, Nghiem LD. Trace organic contaminants in biosolids: impact of conventional wastewater and sludge processing technologies and emerging alternatives. *J Hazard Mater* 2015: **300**(14): 1–17.
27. Yang S, Hai FI, Price WE, McDonald J, Khan SJ, Nghiem LD. Occurrence of trace organic contaminants in wastewater sludge and their removals by anaerobic digestion. *Biores Technol* 2016: **210**(8): 153–159.
28. Gerba CP, Smith JE Jr. Sources of pathogenic microorganisms and their fate during land application of wastes. *J Environ Qual* 2005: **34**(1): 42–48.
29. Jiménez B, Austin A, Cloete E, Plasha C, Beltran N. Biological risks to foods crops fertilized with Ecosan sludge. *Water Sci Technol* 2007: **55**(7): S21–S29.
30. Krzyzanowski F Jr, Lauretto MS, Nardocci AC, Sato MIZ, Razzolini MTP. Assessing the probability of infection by *Salmonella* due to sewage sludge use in agriculture under several exposure scenarios for crops and soil ingestion. *Sci Total Environ* 2016: **568**(12): 66–74.
31. Navarro I, Jiménez B, Lucario S, Cifuentes E. Application of helminth ova infection dose curve to estimate the risks associated with biosolid application on soil. *J Water Health* 2009: **7**(1): 31–44.
32. Pepper IL, Zerzghi H, Brooks JP, Gerba CP. Sustainability of land application of Class B biosoloids. *J Environ Qual* 2008: **37**: S58–S67.
33. Crompton DWT, Nesheim MC. Nutritional impact of intestinal helminthiasis during the human life cycle. *Annu Rev Nutr* 2002: **22**: 35–59.
34. Melvin DM, Brooke MM, Sadun EH. *Common Intestinal Helminths of Humans*. DHEW Publication No. (CDC) 80-8286, Atlanta, Georgia, USA, 2001.
35. Nelson KL, Darby JL. Inactivation of viable *Ascaris* eggs by reagents during enumeration. *Appl Environ Microbiol* 2001: **67**(12): 5453–5459.
36. Stephenson LS, Latham MC, Ottesen EA. Malnutrition and parasitic helminth infections. *Parasitology* 2000: **121** (Suppl): S23–S38.
37. Toze S. Reuse of effluent water—benefits and risks. *Agric Water Manag* 2006: **80**(57): 147–159.
38. Zdybel J, Cencek T, Karamon J, Kłapéc T. Effectiveness of selected stages of waste water treatment in elimination of eggs of intestinal parasites. *Bull Vet Inst Pulawy* 2015: **59** (1): 51–57.
39. Gaspard PG, Wiart J, Shwartzbrod J. Urban sludge reuse in agriculture: waste treatment and parasitological risk. *Biores Technol* 1995: **52**(1): 37–40.
40. Asha A, Okello A, Khamlome B, Inthavong P, Allen J, Thompson RCA. Controlling *Taenia solium* and soil transmitted helminths in a northern Lao PDR village: impact of a triple dose albendazole regime. *Acta Tropical* 2017: **174**: 171–178.
41. Kamizoulis G. Setting health based targets for water reuse (in agriculture). *Desalination* 2008: **218**(1–3): 154–163.
42. Mara D, Sleigh A. Estimation of *Ascaris* infection risks in children under 15 from the consumption of wastewater irrigated carrots. *J Water Health* 2010: **8**(1): 35–38.
43. Amahmid O, Asmama S, Bouhoum K. The effect of waste water reuse in irrigation on the contamination level of food crops by Giardia cysts and Ascaris eggs. *Int J Food Microbiol* 1999: **49**(1–2): 19–26.
44. Anh VT, Tram NT, Klank LT, Cam PD, Dalsgaard A. Faecal and protozoan parasite contamination of water spinach (*Ipomoea aquatica*) cultivated in urban wastewater in Phnom Penh, Cambodia. *Tropic Med Int Health* 2007: **12** (suppl. 2): 73–81.
45. Hajjami K, Ennaji MM, Fouad S, Oubrim N, Cohen N. Wastewater reuse for irrigation in morocco: helminth eggs contamination's level of irrigated crops and sanitary risk (a case study of Settat and Soualem Regions). *J Bacteriol Parasitol* 2013: **4**: 163. https://doi.org/10.4172/2155-9597.1000163.
46. Chan MS. The global burden of intestinal nematode infections-Fifty years on. *Parasitol Today* 1997: **13**: 438–443.
47. Mara D, Horan N. *Handbook of Water and Wastewater Microbiology*. Academic Press: London, 2003. ISBN 0-12-470100-0.
48. Smith H, Rose JB. Waterborne Cryptosporidiosis: current Status. *Parasitol Today* 1998: **14**: 14–22.
49. Kostopoulou D, Claerebout E, Arvanitis D *et al.* Abundance, zoonotic potential and risk factors of intestinal

parasitism amongst dog and cat populations: the scenario of Crete, Greece. *Parasites Vectors* 2017: **10**: 43–55.
50. Pereira A, Martins A, Brancal H *et al.* Parasitic zoonoses associated with dogs and cats: a survey of Portuguese pet owners' awareness and deworming practices. *Parasites Vectors* 2016: **9**: 245–254.
51. Blaszkowska J, Kurnatowski P, Damiecka P. Contamination of the soil by eggs of geohelminths in rural areas of Lodz district (Poland). *Helminthologia* 2011: **48**(2): 67–76.
52. Nooraldeen K. Contamination of public squares and parks with parasites in Erbil city, Iraq. *Ann Agric Environ Med* 2015: **22**: 418–420.
53. Horiuchi S, Paller VGV, Uga S. Soil contamination by parasite eggs in rural village in the Philippines. *Trop Biomed* 2013: **30**: 495–503.
54. Amoah ID, Abubakari A, Stenström TA, Abaidoo RC, Seidu R. Contribution of wastewater irrigation to soil transmitted Helminths infection among vegetable farmers in Kumasi, Ghana. *PLoS Neglect Tropic Dis* 2016: **10**(12): e0005161.
55. Kone′ D, Cofie O, Zurbrügg C *et al.* Helminth eggs inactivation efficiency by faecal sludge dewatering and co-composting in tropical climates. *Water Res* 2007: **41**(19): 4397–4402.
56. Seidu R, Drechsel P, Amoah P *et al.* Quantitative microbial risk assessment of wastewater and faecal sludge reuse in Ghana. 33rd WEDC International Conference, Accra, Ghana, 2008.
57. Yajima A, Jouquet P, Trung DD *et al.* High latrine coverage is not reducing the prevalence of soil-transmitted helminthiasis in Hoa Binh province, Vietnam. *Trans Royal Soc Tropic Med Hygiene* 2009: **103**(3): 237–241.
58. Fattal B, Bercovier H, Derai-Cochin M, Shuval HI. Wastewater reuse and exposure to Legionella organisms. *Water Resour* 1985: **19**: 693–696.
59. Fattal B, Margalith M, Shuval HI, Wax Y, Morag A. Viral antibodies in agricultural populations exposed to aerosols from wastewater irrigation during a viral disease outbreak. *Am J Epidemiol* 1987: **125**: 899–906.
60. Margalith M, Morag A, Fattal B. Antibodies to polioviruses in an Israeli population and overseas volunteers. *J Med Virol* 1990: **30**: 68–72.
61. Blumenthal UJ, Cifuentes E, Bennett S, Quigley M, Ruiz-Palacios G. The risk of enteric infections associated with wastewater reuse; the effect of season and degree of storage of wastewater. *Trans Royal Soc Tropic Med Hygiene* 2001: **95**(2): 131–137.
62. Habbari K, Tifnouti A, Bitton G, Mandil A. Geohelminthic infections associated with raw wastewater reuse for agricultural purposes in Beni-Mellal, Morocco. *Parasitol Int* 2000: **48**(3): 249–254.
63. Adamu NB, Adamu JY, Mohammed D. Prevalence of helminth parasites found on vegetables sold in Maiduguri, Northeastern Nigeria. *Food Control* 2012: **25**(1): 23–26.
64. Adanir R, Tasci F. Prevalence of helminth eggs in raw vegetables consumed in Burdur, Turkey. *Food Control* 2013: **31**: 482–484.
65. Al-Megrin WAI. Prevalence of intestinal parasites in leafy vegetables in Riyadh, Saudi Arabia. *Int J Zool Res* 2010: **5**: 20–23.
66. Fallah AA, Makhtumi Y, Pirali-Kheirabadi K. Seasonal study of parasitic contamination in fresh salad vegetables marketed in Shahrekord, Iran. *Food Control* 2016: **60**(4): 538–542.
67. Rostami A, Ebrahimi M, Mehravar S, Omrani VF, Fallahi S, Behniafar H. Contamination of commonly consumed raw vegetables with soil transmitted helminth eggs in Mazandaran province, Northern Iran. *Int J Food Microbiol* 2016: **225**(12): 54–58.
68. Said DS. Detection of parasites in commonly consumed raw vegetables. *Alexandria J Med* 2012: **48**: 345–352.
69. Beuchat LR, Ryu JH. Produce handling and processing practices. *Emerg Infect Dis* 1997: **3**(4): 5–7.
70. Uga S, Hoa NTV, Noda S *et al.* Parasite egg contamination of vegetables from a suburban market in Hanoi, Vietnam. *Nepal Med College J* 2009: **11**(2): 75–78.
71. Shuval HL, Adin A, Fattal B, Rawitz E, Yekutiel P. Wastewater Irrigation in Developing Countries: Health Effects and Technical Solutions. World Bank Technical Paper Number 51. Washington, D.C., 1986.
72. Fuhrimann S, Winkler MS, Kabatereine NB *et al.* Risk of intestinal parasitic infections in people with different exposures to wastewater and fecal sludge in Kampala, Uganda: a cross-sectional study. *PLoS Neglect Tropic Dis* 2016: **10**(3): e0004469. https://doi.org/10.1371/journal.pntd.0004469.
73. Nguyen PH, Nguyen KC, Nguyen TD *et al.* Intestinal helminth infections among reproductive age women in Vietnam: prevalence, co-infection and risk factors. *Southeast Asian J Trop Med Public Health* 2006: **37**(5): 865–874.
74. Trang DT, van der Hoek W, Cam PD. Low risk for helminth infection in wastewater-fed rice cultivation in Vietnam. *J Water Health* 2006: **4**: 321–331.
75. Pham Duc P, Nguyen-Viet H, Hattendorf J, Zinsstag J, Dac Cam P, Odermatt P. Risk factors for *Entamoeba histolytica* infection in an agricultural community in Hanam province, Vietnam. *Parasites Vectors* 2011: **4**: 102.
76. Cutolo SA, Piveli RP, Santos JG *et al.* Parasitological risk assessment from wastewater reuse for disposal in soil in developing countries. *Water Sci Technol* 2012: **65**(8): 1357–1367.
77. Kundu A, Poma HR, Jenkins MW, Rajal VB, Wuertz S. QMRA of intestinal nematode infection via multimedia exposure pathways. In: Ames DP, Quinn NWT, Rizzoli AE (Eds.), International Environmental Modelling and Software Society (iEMSs) 7th Intl. Congress on Env. Modelling and Software, San Diego, CA, USA, 2014.
78. Navarro I, Jiménez B, Cifuentes E, Lucario S. A quantitative microbial risk assessment of helminth ova in reusing

sludge for agricultural production in developing countries. *Risk Anal* 2008: **6**: 65–74.
79. O'Connor NA, Surapaneni A, Smith D, Stevens D. Occurrence and fate of *Ascaris lumbricoides* ova in biosolids in Victoria, Australia: a human health risk assessment of biosolids storage periods. *Water Sci Technol* 2017: **76**: 1332–1346.
80. Schönning C, Westrell T, Stenström TA *et al.* Microbial risk assessment of local handling and use of human faeces. *J Water Health* 2007: **5**: 117–128.
81. Seidu R, Heistad A, Amoah P, Drechsel P, Jenssen PD, Stenström TA. Quantification of the health risk associated with wastewater reuse in Accra, Ghana: a contribution toward local guidelines. *J Water Health* 2008a: **6**: 461–471.
82. Blumenthal UJ, Mara DD, Peasey A, Ruiz-Palcios G, Stott R. Guidelines for the microbiological quality of treated wastewater used in agriculture: recommendations for revising WHO guidelines. *Bull World Health Organ* 2000: **78** (9): 1104–1116.
83. WHO-World Health Organization. *Sanitation Safety Planning: Manual For Safe Use and Disposal of Wastewater, Greywater and Excreta*. WHO Press, World Health Organization: Geneva, Switzerland, 2016.
84. Stott R, May E, Mara DD. Parasite removal by natural wastewater treatment systems: Performance of waste stabilization ponds and constructed wetlands. Proceedings of the 5th IWA Waste Stabilization Ponds, 2-5 April. Auckland, New Zealand, 2002.
85. Jimenez B, Wang L. Sludge treatment and management, chapter 10. In: Ujang Z, Henze M (eds). *Municipal Wastewater Management in Developing Countries: Principles and Engineering*. International Water Association Publishing: London, UK, 2006. pp. 237–292.
86. Sengupta ME, Keraita B, Olsen A *et al.* Use of *Moringa oleifera* seed extracts to reduce helminth egg numbers and turbidity in irrigation water. *Water Res* 2011: **46**(11): 3646–3656.
87. Jimenez-Cisneros BE, Maya-Rendon C. Helminths and sanitation. In: Méndez-Vilas A (Ed.), *Communicating Current Research and Educational Topics and Trends in Applied Microbiology*. Formatex Research Center, Badajoz, Spain, 2007. pp. 60–71.
88. Moubarrad FZL, Assobhei O. Health risks of raw sewage with particular reference to *Ascaris* in the discharge zone of El Jadida (Morocco). *Desalination* 2007: **215**(1–3): 120–126.
89. Amoah ID, Reddy P, Seidu R, Stenström TA. Concentration of soil-transmitted Helminth eggs in sludge from South Africa and Senegal: a probabilistic estimation of infection risks associated with agricultural application. *J Environ Manage* 2018: **206**: 1020–1027.
90. Amoah ID, Seidu R, Reddy P, Stenström TA. Removal of soil-transmitted helminth egg in selected centralized and decentralized wastewater treatment plants in South Africa and Lesotho: health implications for direct and indirect exposure to the effluents (Under review). *Environ Sci Pollut Res* 2017: **17**: 1–13.
91. Pillay S, Foxon K, Rodda N, Smith M, Buckley C. The use of effluent from an anaerobic baffled reactor (ABR) for irrigation in a peri-urban community. In: Ecosan GTZ (ed.), *3rd International Ecological Sanitation Conference*. DFID, EcoSanRes, CSIR: Durban, South Africa, 2005. pp. 445–449.
92. Khouja LBA, Cama V, Xiao L. Parasitic contamination in wastewater and sludge samples in Tunisia using three different detection techniques. *Parasitol Res* 2010: **107**(1): 109–116.
93. Riahi K, Mammou AB, Thayer BB. Date-palm fibers media filters as a potential technology for tertiary domestic wastewater treatment. *J Hazard Mater* 2009: **161**(2–3): 608–613.
94. Saddoud A, Ellouze M, Dhouib A, Sayadi S. Anaerobic membrane bioreactor treatment of domestic wastewater in Tunisia. *Desalination* 2007: **207**(78): 205–215.
95. Bastos VK, Cutolo SA, Doria MCO, Razzolini MTP. Detection and quantification of viable *Ascaris* sp. and other helminth eggs in sewage sludge. *Int J Environ Health Res* 2013: **23**(4): 352–362.
96. Bowman DD, Little MD, Reimers RS. Precision and accuracy of an assay for detecting *Ascaris* eggs in various biosolid matrices. *Water Res* 2003: **37**(9): 2063–2072.
97. Engohang-Ndong J, Uribe RM, Gregory R, Gangoda M, Nickelsen MG, Loar P. Effect of electron beam irradiation on bacterial and Ascaris ova loads and volatile organic compounds in municipal sewage sludge. *Radiat Phys Chem* 2015: **112**: 6–12.
98. Rose JB, Dickson LJ, Farrah SR, Carnahan RP. Removal of pathogenic and indicator microorganisms by a full-scale water reclamation facility. *Water Res* 1996: **30**(11): 2785–2797.
99. Pecson BM, Barrios JA, Jimenez BE, Nelson KL. The effects of temperature, pH, and ammonia concentration on the inactivation of *Ascaris* eggs in sewage sludge. *Water Res* 2007: **41**(13): 2893–2902.
100. Yaya-Beas R, Cadillo-La-Torre E, Kujawa-Roeleveld K, van Lier JB, Zeeman G. Presence of helminth eggs in domestic wastewater and its removal at low temperature UASB reactors in Peruvian highlands. *Water Res* 2016: **90**: 286–293.
101. Yen-Phi VT, Rechenburg A, Vinneras B, Clemens J, Kistemann T. Pathogens in septage in Vietnam. *Sci Total Environ* 2010: **408**(9): 2050–2053.
102. Ensink JHJ, Mahmood T, Dalsgaard A. Wastewater-irrigated vegetables: market handling versus irrigation water quality. *Tropical Med Int Health* 2007: **12**(Suppl 2): 2–7.
103. Gantzer C, Gaspard P, Gálvez L, Huyard A, Dumouthier N, Schwartzbrod J. Monitoring of bacterial and parasitological contamination during various treatment of sludge. *Water Res* 2002: **35**(16): 3763–3770.
104. Abreu-Acosta N, Vera L. Occurrence and removal of parasites enteric bacteria and faecal contamination indicators in

wastewater natural reclamation systems in Tenerife-Canary Islands, Spain. *Ecol Eng* 2011: **37**(3): 496–503.
105. Molleda P, Blanco I, Ansola G, de Luis E. Removal of wastewater pathogen indicators in a constructed wetland in Leon, Spain. *Ecol Eng* 2008: **33**: 252–257.
106. Reinoso R, Becares E. The occurrence of intestinal parasites in swine slurry and their removal in activated sludge plants. *Biores Technol* 2008: **99**(4): 6661–6665.
107. Reinoso R, Torres LA, Bécares E. Efficiency of natural systems for removal of bacteria and pathogenic parasites from wastewater. *Sci Total Environ* 2008: **395**(2–3): 80–86.
108. Erdoğrul Ö, Şener H. The contamination of various fruit and vegetable with *Enterobius vermicularis*, Ascaris eggs, *Entamoeba histolytica* cysts and *Giardia* cysts. *Food Control* 2005: **16**(6): 557–560.
109. Keraita B, Konradsen F, Drechsel P, Abaidoo RC. Effect of low-cost irrigation methods on microbial contamination of lettuce irrigated with untreated wastewater. *Tropical Med Int Health* 2007: **12**(2): 15–22.
110. Woldetsadik D, Drechsel P, Keraita B, Itanna F, Erko B, Gebrekidan H. Microbiological quality of lettuce (Lactuca sativa) irrigated with wastewater in Addis Ababa, Ethiopia and effect of green salads washing methods. *Int J Food* 2017: **4**: 3.
111. Fallah AA, Pirali-Kheirabadi K, Shirvani F, Saei-Dehkordi SS. Prevalence of parasitic contamination in vegetables used for raw consumption in Shahrekord, Iran: influence of season and washing procedure. *Food Control* 2012: **25**: 617–620.
112. Daryani A, Ettehad GH, Sharif M, Ghorbani L, Ziaei H. Prevalence of intestinal parasites in vegetables consumed in Ardabil, Iran. *Food Control* 2008: **19**: 790–794.
113. Gupta N, Khan DK, Santra SC. Prevalence of intestinal helminth eggs on vegetables grown in wastewater-irrigated areas of Titagarh West Bengal, India. *Food Control* 2009: **20**: 942–945.
114. Maikai B, Elisha I, Baba-Onoja E. Contamination of vegetables sold in markets with helminth eggs in Zaria metropolis, Kaduna State-Nigeria. *Food Control* 2012: **28**: 345–348.
115. Abougrain AK, Nahaisi MH, Madi NS, Saied MM, Ghenghesh KS. Parasitological contamination in salad vegetables in Tripoli-Libya. *Food Control* 2010: **21**: 760–762.
116. Al-Hindi AI, Elmanama AA, Khalaf S. Prevalence of intestinal parasites and microbial contamination in common edible vegetables used in Gaza Governorate, Palestine. *J Food Safety Hygiene* 2016: **2**(1–2): 21–25.
117. Duedu KO, Yarnie EA, Tetteh-Quarcoo PB, Attah SK, Donkor ES, Ayeh-Kumi PF. A comparative survey of the prevalence of human parasites found in fresh vegetables sold in supermarkets and open-aired markets in Accra, Ghana. *BMC Res Notes* 2014: **7**: 836.
118. Mohamed MA, Siddig EE, Elaagip AH, Edris AMM, Nasr AA. Parasitic contamination of fresh vegetables sold at central markets in Khartoum state, Sudan. *Ann Clin Microbiol Antimicrob* 2016: **15**: 17.
119. Matini M, Shamsi-Ehsan T, Maghsood AH. The parasitic contamination of farm vegetables in Asadabad City, West of Iran, in 2014. *Avicenna J Clin Microbiol Infect* 2017: **4**: e32474.
120. Rahmati K, Fallah M, Maghsood AH, Shamsi-Ehsan T, Matini M. The prevalence of parasitic contamination of vegetables consumed in Malayer City, West of Iran, in 2014. *Avicenna J Clin Microbiol Infect* 2017: **4**(2): e42380. https://doi.org/10.5812/ajcmi.42380.
121. Pham-Duc P, Nguyen-Viet H, Hattendorf J *et al.* Diarrhoeal diseases among adult population in an agricultural community Hanam province, Vietnam, with high wastewater and excreta reuse. *BMC Public Health* 2014: **14**: 978.
122. Trang DT, Mølbak K, Cam PD, Dalsgaard A. Helminth infections among people using wastewater and human excreta in peri-urban agriculture and aquaculture in Hanoi, Vietnam. *Tropical Med Int Health* 2007: **12**: 82–90.
123. Gumbo JR, Malaka EM, Odiyo JO, Nare L. The health implications of wastewater reuse in vegetable irrigation: a case study from Malamulele, South Africa. *Int J Environ Health Res* 2010: **20**(3): 201–211.
124. Bouhoum K, Schwartzbrod J. Epidemiological study of intestinal helminthiasis in a Marrakech raw sewage spreading zone. *Zentralblatt für Hygiene und Umweltmedizin* 1998: **200**: 553–561.
125. Cifuentes E, Blumenthal U, Ruiz-Palacios G, Bennett S, Peasey A. Epidemiologic setting of the agricultural use of sewage: Valle Del Mezquital, Mexico. *Salud Publica Mex* 1994: **36**(1): 3–9.
126. Jimenez-Cisneros BE. Helminth ova control in wastewater and sludge for agriculture reuse. *Water Health* 2006: **2**: 1–12.

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