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HUMAN HEALTH RISKS IN WASTEWATER – IRRIGATED AGRICULTURE

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Abstract: To mitigate the effects of water scarcity in arid areas and to meet the increasing need of water in arid and non–arid areas, wastewater reuse for irrigation became a usual practice. Raw wastewater contains excreted organisms and pathogens (bacteria, viruses, fecal coliforms and intestinal helminthes) which can be inactivated or removed by disinfection. In developing countries lacking sanitation systems, wastewater is rarely treated for safe reuse, so farm workers, crop handlers and consumers are exposed to diseases. Women are particularly exposed to skin irritations and infections by H. Pylori, E. coli, Salmonella and rotavirus, as they do more work to produce vegetables and prepare meals. Typhoid fever, cholera and diarrheal disease are transmitted by consumption of fresh vegetables contaminated by wastewater. Between 6–8% of children and 2% of immunosuppressed adults are infected with *Giardia* and *Cryptopsporidium*, which cause them diarrheal disease, the second leading cause of 800,000 deaths of young children/year in developing countries. This paper reviews the primary routes of exposure to health risks associated with wastewater reuse in agriculture, highlighting the role of excreted microorganisms in disease occurrence in people coming in direct contact with wastewater and in consumers of crops irrigated with untreated wastewater.
Keywords: wastewater, irrigation, health, pathogens, diseases

INTRODUCTION

Nowadays, the growing scarcity of freshwater resources is one of the most limiting factors for crop production, food and energy security. The potential of irrigation to increase both agricultural productivity and living standards, especially in rural areas, is unanimously recognized.

Wastewater is increasingly accepted as a resource, because it is available in large quantities, does not depend on seasonal variability and is rich in organic nutrients. Wastewater recovery and reuse is not a new concept, but a practice encountered a few centuries ago. The reuse of treated wastewater mainly for irrigation of crops is an increasingly common practice, encouraged by governments and official bodies around the world, and it accounts for 70% of total agricultural water consumption (Zhang and Shen, 2017; Ungureanu et al., 2020). Large quantities of wastewater used in agriculture have led to a change in agricultural patterns, from seasonal cultivation to agriculture throughout the year, allowing farmers to have more harvests per year and thus increase their incomes. In addition, nutrient–rich wastewater is particularly important for farmers, as in most cases the need for chemical fertilizers decreases or is eliminated.

In developing countries, wastewater irrigation has become a planned and integral part of the economy, as urban dwellers are engaged in agriculture not only for subsistence but also for income generation from gardening. Irrigation with treated wastewater is already practiced in high–income countries with semi–arid lands: France, Italy, Spain, Cyprus, Malta, Israel, Jordan and the USA. In countries with moderate climates (eg Poland, Germany) this agricultural practice has not yet been implemented (Chojnacka et al., 2020). Volumes of reused wastewater have increased by 10–29% per year in Europe, the United States, China, and respectively by up to 41% in Australia (Zhang and Shen, 2017). To control the current water deficit in Europe, the reuse of treated municipal wastewater and wastewater from animal farms should increase more than twice in 2025 compared to 2000 (Lavrnić et al., 2017).

The reuse of wastewater in underdeveloped countries poses special problems. Indirect use of wastewater occurs when domestic wastewater, agro–zootechnical wastewater and in some cases industrial wastewater are discharged directly into urban watercourses without prior treatment. Direct use of wastewater occurs mainly in underdeveloped countries, when farmers deliberately collects wastewater in–house or enter the sewer lines and extract the wastewater. Thus, in conditions of water scarcity and deficient planning, irrigation of agricultural crops with wastewater has prospered as an unplanned or spontaneous activity.

The safety of reuse of wastewater for crop irrigation is an important issue worldwide. If wastewater is not treated properly before being used for irrigation, it can cause serious problems related to soil health (salinization, toxicity due to sodium ions, chloride and boron, structural degradation, reduced aeration and clogging of pores due to suspended solids in wastewater, reducing the hydraulic conductivity of the soil), agricultural crops (accumulation of heavy metals, microbial loading, delayed or irregular maturation of plants due to excess nutrients), groundwater (by leaching excess nitrates), but also to the health of farmers who apply these waters to consumers of irrigated crops (Ungureanu et al., 2020 a).

In many developing countries, wastewater is not always completely treated. Wastewater contains high levels of excreted pathogens, such as bacteria, viruses, protozoa, helminthes, intestinal worms, whose usual limits are shown in Table 1. In many countries, the legislation on microbial parameters for wastewater reuse is affected by different interpretations of the concept of microbiological risk; thus, legislation is often an inadequate simplification to exploit the full potential of wastewater reuse in agriculture.

Table 1. Usual limits of some organisms excreted in raw (untreated) wastewater (Ungureanu et al., 2020 b)

Excreted organism	Number / liter of wastewater	Excreted organism	Number / liter of wastewater
Thermotolerant coliform	$10^8 - 10^{10}$	*Cryptosporidium parvum*	$1 - 10^4$
Salmonella sp.	$1 - 10^5$	*Entamoeba histolytica*	$1 - 10^2$
Shigella sp.	$10 - 10^4$	*Giarida intestinalis*	$10^2 - 10^5$
Vibrio cholerae	$10^2 - 10^5$	*Ascaris lumbricoides*	$1 - 10^3$
Enteric viruses	$10^5 - 10^6$	*Ancylostoma / Necator*	$1 - 10^3$
Rotavirus	$10^2 - 10^5$	*Trichuris trichiura*	$1 - 10^2$

Globally, bacterial pathogens (*Salmonella* sp., *Shigella* sp., *Legionella* sp., *Escherichia coli* and *Vibrio cholerae*), intestinal worms (*Ascaris* and *Tenia* sp.), and intestinal protozoa (*Giardia* and *Crysptospridium parvum*) are of great interest to public health. Waterborne viruses including HAV, HEV, adenovirus and rotavirus have the highest risk of transmission through wastewater reuse (WHO, 2006). The profile of pathogens and the concentrations of specific pathogens in raw wastewater depend on both the epidemiological status of individuals producing wastewater and the state of sewage systems and technological possibilities for wastewater treatment.

Table 2 presents data on the survival of excreted pathogens in soil and plants (here, the value in parentheses is the usual survival period). Under favorable conditions, viruses can survive for several months in the soil and 2–3 weeks in crops. Pathogenic protozoa are particularly sensitive to high temperatures and are less persistent in the environment, and their survival for more than 2 weeks is unusual. Fecal bacteria generally have a limited survival in water, but they can persist for months in moist organic soils.

Table 2. Survival of pathogens excreted at 20–30°C (NGESTP, Annex 8)

The type of pathogen	Survival period (days)			
	In faeces and sewage sludge	In freshwater and sewage	In the soil	On agricultural crops
Viruses				
Enterovirusuri	<100 (<20)	<120 (<50)	<100 (<20)	<60 (<15)
Bacteria				
Fecal coliforms	<90 (<50)	<60 (<30)	<70 (<20)	<30 (<15)
Salmonella sp.	<60 (<30)	<60 (<30)	<70 (<20)	<30 (<15)
Shigella sp.	<30 (<10)	<30 (<10)	–	<10 (<5)
Vibrio cholera	<30 (<5)	<30 (<10)	<20 (<10)	<5 (<2)
Protozoa				
Entamoebahistolytica cysts	<30 (<15)	<30 (<15)	<20 (<10)	<10 (<2)
Intestinal worms				
Ascarislunbricoides eggs	Many months	Many months	Many months	<60 (<30)

The risk of developing a bacterial, protozoan or fungal infection due to exposure to wastewater is much lower than that of developing an infection with pathogenic worm eggs, because the survival time of these pathogens in the environment is shorter and there is a higher immunity of the host. The lowest risk is for viral infections, mainly due to the high immunity of the host for virus infections (Cossio et al., 2019). It should also be noted that the presence of pathogenic microorganisms in treated or untreated wastewater does not mean that they will necessarily pose a threat to human health after watering the plants. The survival of these pathogens is affected by many factors, including UV radiation and high temperatures in dry areas. Other factors, such as low moisture, the presence of consortia of soil microorganisms and the type of crops have an important role in determining the viability of pathogens (Farhadkhani et al., 2018) and hence their transmission to humans via the food chain. Inactivation of pathogens on crops is faster in hot and sunny weather than in cool, cloudy or rainy weather. Worldwide, a limited number of field tests provided an approximate estimate of 0.5–2.0 log pathogen reduction units per day, with a higher amount of pathogens expected in dry and hot conditions. A suggested change of this measure is the use of uncontaminated irrigation water in the last days before harvest. However, prolonged periods of irrigation cessation can negatively affect vegetable productivity and freshness. Applying irrigation shutdowns before harvest, as a health protection measure, can be difficult for leafy vegetable crops that need to be harvested at the peak of freshness. Discontinuation of irrigation before harvest is not effective in reducing contamination during the wet season, because precipitation causes recontamination of vegetables by spraying with soil particles, and humid conditions generally favor the survival of the pathogen. Disposal of outer leaves that are in longer contact with contaminated soils and less exposed to direct sunlight can also help reduce contamination of vegetables with fecal coliforms (Keraita et al., 2007).

Wastewater treatment to ensure pathogen removal and reduce health risks is the most recommended method of mitigating public health risks for both farmers and consumers of wastewater irrigated crops. Sophisticated tertiary treatment systems and disinfection systems require energy, infrastructure, maintenance and skilled labor, making them unfeasible for low–income countries. In many cities in developing countries, most wastewater is not treated and remains an easily accessible and inexpensive source of water for many urban farmers.

When planning the projects for wastewater reuse, training and awareness–raising activities for farmers must be taken into account, so that they can develop skills and knowledge about the use of recovered water, so that all groups at risk can be protected. In addition to health and environmental issues, training programs should also focus on technical aspects of wastewater and effluent reuse, such as the introduction of micro–irrigation techniques to reduce farmers' exposure to reclaimed water. Political efforts should be aimed at updating the knowledge, skills and an attitude of agricultural producers, through frequent training and workshops, so that farmers who use untreated wastewater for irrigation of crops can better appreciate the health risks posed by wastewater irrigation and knows how to adopt risk reduction strategies

(Valipour and Singh, 2016). Awareness and educational training programs should be extended to be included in school curricula. Furthermore, promoting improved hygiene and safe food preparation remain crucial even when irrigation water seems safe.

2. MATERIALS AND METHODS

Wastewater–related diseases are transmitted when an infected person excretes pathogens into the environment; pathogens are then transported by a suitable agent (eg food or water) and ingested by a susceptible human host. In general, most wastewater carries several of these pathogens, which have been excreted by infected individuals.

Wastewater irrigation is often seen as a way of reintroducing pathogens into the community (Shah et al., 2019), forming an integral element of the WASH (Water, Sanitation and Hygiene) nexus. Thus, wastewater irrigation is often seen as a source of vulnerability parallel to the absence of sanitation, carrying fecal pathogens through water, hands, farm, environment, and food into the community and resulting in adverse effects on the human health (Figure 1).

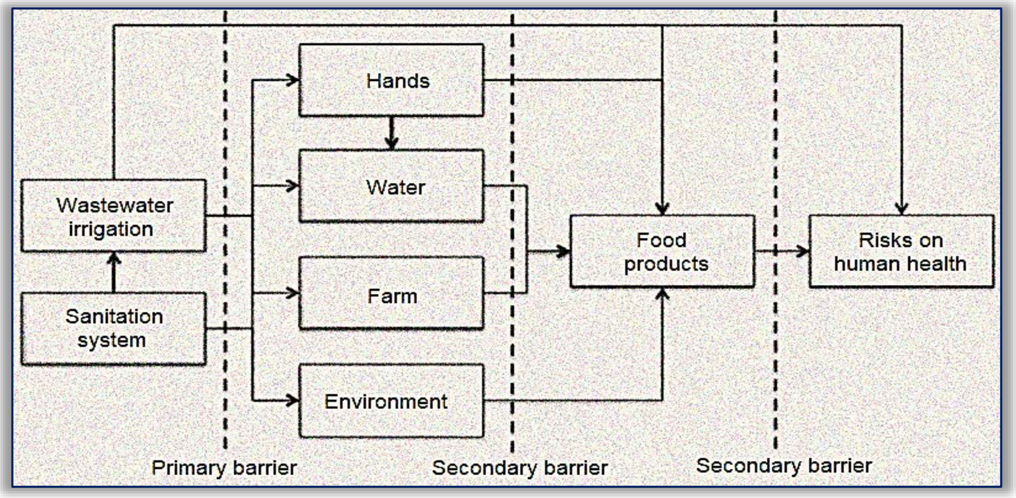

Figure 1 – Faecal–oral transmission routes for pathogens (Falkenberg et al., 2018) – (boxes are variables in the transmission process, arrows are the transmission pathways of faecal–oral pathogens, and dotted lines are primary and secondary barriers)

When irrigating with wastewater, the risks to human health are classified into three categories, depending on the potential of the pathogens to transmit the diseases through wastewater (Kilelu C.W., 2004):

≡ high risk (high incidence of excess infection): intestinal worms (*Ancylostoma, Ascaris, Trichuris* and *Taenia*);
≡ medium risk (average incidence of excess infection): bacterial infections (*Cholera vibrio, Salmonella typhosa, Shigella* and possibly others) and protozoan infections;
≡ low risk (low incidence of excess infection): viral infections.

The assessment and management of health risk associated with exposure to microbial hazards through wastewater meets special challenges (Campos C., 2008):

≡ not all microbial risks (pathogens) are recognized and can be easily listed or studied;
≡ adverse health effects may occur after a single exposure, however water quality varies greatly and rapidly;
≡ management actions are rarely effective, and their outcome can be difficult to predict;
≡ when water use is unsafe, conventional testing indicates this only after exposure of people to risks has taken place, ie too late to help prevent disease.

Although the risks to human health when irrigating with wastewater cannot be accurately estimated, they cannot be ignored. Human and animal pathogens, phytopathogens and antibiotic–resistant bacteria and their genes are important biological contaminants that can be transported by wastewater and / or enriched in soil. Also, the mixture of many chemical contaminants, including xenobiotics, pharmaceuticals with traces of metals, can have unpredictable consequences for both environmental and human health (Becerra–Castro et al., 2015). Another common routes of exposure to health risks associated with wastewater irrigation is presented in Fig. 2.

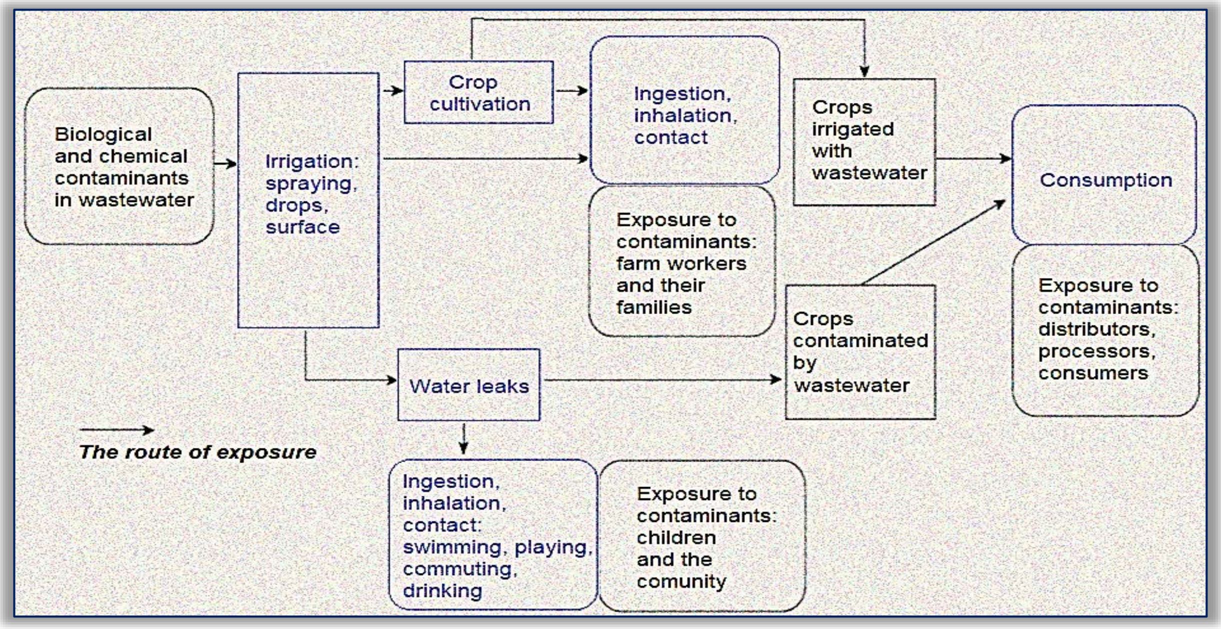

Figure 2 – Exposure routes associated with wastewater irrigation for consumers, agricultural workers and their families and communities living nearby (Dickin et al., 2016)

Public health risks dominate the negative attitude of the consumers and their decisions on the consumption of agricultural crops irrigated with wastewater, especially those irrigated with untreated wastewater and consumed raw. The additional issues posed by mad cow disease, bird flu, SARS and other pandemics such as cholera and diarrhea will further increase the risk associated with the consumption of wastewater irrigated crops. Additional risk factors may also be due to new regulations on wastewater or product marketing, restrictions on market access and lower prices for vegetables and fruits. Public policies to ensure product safety and to protect consumer health will emerge more noticeably in the future, but their integration with water policy and basic water programs will pose huge challenges (Hanjra et al., 2012).

Most developed countries where wastewater is reused have public health and environmental guidelines for wastewater treatment and reuse practices. These regulations as guidelines or code of practice are intended to protect the health of both consumers and workers, and can even prohibit the irrigation with wastewater at specific times before harvest, require appropriate clothing and ensure preventive care of workers. Wastewater reuse guidelines, although variable in different countries, are usually very strict due to water pollution control requirements.

3. RESULTS

Public health risks related to microbiological contaminants in wastewater used in irrigated agriculture relate to four broad categories of the population:

≡ Agricultural workers (farmers) who are directly exposed to wastewater in the fields.
≡ Wastewater crop traders, handlers and technical / operational staff.
≡ Consumers of crops grown with improperly treated wastewater.
≡ Populations living near farms that use wastewater, including children, elderly and immune–compromised people, who are most at risk.

The first two groups are mainly exposed at a professional level, due to direct contact with wastewater during application in irrigation and handling of products. Consumers are exposed directly to their diet, while residents near areas irrigated with sewage can be exposed to farm leaks, groundwater contamination and aerosols.

— Exposure of agricultural workers to health risks

Exposure of agricultural workers (farmers) and consequently their family members is significant due to the variability of possible routes, the frequency and duration of exposure. Depending on the level of mechanization of irrigation works in the farm, the dangers to human health are due to direct exposure to wastewater by planting and weeding operations (it is well known that farmers often work manually, without gloves and/or barefoot in the fields), variable exposure associated with different methods irrigation (for example, gravitational flow irrigation or manual irrigation with buckets), but also to accidental inhalation of sprayed aerosols, which is more common when using wastewater in high–income countries.

The danger posed by direct contact with wastewater during its application in agriculture depends to a large extent on the type of irrigation practiced and the individual behavior of agricultural workers. For example, although wastewater used in irrigation is more heavily contaminated than soil irrigated with these waters, the direct contact with soil is sometimes the determining factor in exposure to health risks when assessing the transmission of oral–fecal disease to farmers due to soil–to–mouth and hand–to–mouth events (Antwi–Agyei et al., 2016). The use of irrigation containers (e.g, boxes or buckets) to collect water for irrigation from ponds, as in the case in many developing countries where wastewater irrigation is a common practice, results in the highest exposure and therefore it involves a higher risk due to the lack of using personal protective equipment (nose masks, boots, gloves etc). Irrigation in furrows or by flooding the land increases the possibility of direct contact with wastewater, hence it increases the risk of infection outbreaks.

For agricultural workers, the health risks due to wastewater irrigation are mainly skin irritations (dermatitis, urticarial infections, itching and blisters on the hands and feet) and nail infections including koilonychias or spoon–formed nails (Drechsel et al., 2008) and fungal infections of the toes or nails (Vuong et al., 2007), diarrhea (Trang et al., 2007), helminth and intestinal worms infections (Pham–Duc et al., 2013; Amoah et al., 2016; Amoah et al., 2018), common cold caused by rhinoviruses and enteroviruses (Brisebois et al., 2018), and epilepsy (Lam et al., 2015). Most skin and intestinal infections occur among persons infected mainly via occupational exposure and ingestion of products contaminated by irrigation with partially treated or untreated wastewater (Adegoke et al., 2018).

Studies around the world suggest that awareness of health risks is not high among farmers (Hanjra et al., 2012). In many farms in developing countries where irrigation with wastewater is a commnon practice, farmers are not aware of the risks or possible consequences for their environment and health. Also, many agricultural workers cannot afford treatment for some of the health problems caused by exposure. Farmers' household members may be illiterate, or lack adequate information and resources, and have been exposed to poor sanitation for most of their lives. Therefore, many agricultural workers accept these health risks for the benefit of their occupation and, in the general context of their living conditions, contact with wastewater used in irrigation could be just one of the many health challenges (Qadir et al., 2010).

— Exposure of women to health risks

Women are a particularly important target group, not only because they are a vulnerable group but also because they often apply various methods to reduce the risks. In many countries, women provide much of the work needed to produce vegetables in their own gardens or on farms, and they carry out much of the weeding and transplanting of plants, which means they are exposed them to long–term contact with wastewater (Li et al., 2014). Women are generally responsible for preparing meals for their families, thus unintentionally creating the possibility of transferring pathogens to family members, unless of course, very good hygiene is maintained. In West Africa, where in 10 out of 13 countries, mainly men grow vegetables, women dominate the trade, especially in retail, of most vegetables; thus an important target group for the application of risk reduction measures are the markets (Drechsel et al., 2008).

— Exposure of children to health risks

Children are especially vulnerable to contaminants in wastewater. Irrigation with untreated wastewater leads to a higher prevalence of ascariasis and hookworm infections among children (Hanjra et al., 2012). Children in households exposed to contact with untreated wastewater used in irrigation have a 3 times higher risk of infection with *Ascaris lumbricoides* than those in households that do not irrigate with wastewater. Children can be exposed to wastewater by playing in contaminated areas, which increases the frequency and duration of exposure to this contaminated environment (*An et al., 2007*).

Children are less likely to practice sanitary behaviors such as hand washing and are often involved in agricultural work. A study by Melloul and Hassani (1999) in an area irrigated with wastewater from Marrakesh, reported that boys who helped with agricultural work had a higher risk of *Salmonella* infection than girls who stayed at home. However, all children in the irrigated wastewater area, especially those under the age of 10, had a higher prevalence of the disease compared to the control areas.

— Exposure of consumers to health risks

From the authorities' point of view, in the main risk group are the consumers of food from wastewater irrigated crops. Consumers are in the most sensitive group, but most of them are not aware of the source of the product they consume and the fact that these products come from wastewater irrigation containing various contaminants. Farmers should feel responsible for this group, manage and apply their wastewater according to the regulations in force in each country, so as to avoid contamination of crops.

Food consumption of agricultural crops is the most frequently studied way of contamination, and studies available in the literature include over 100 vegetables, fruits and cereals. Research in the world literature has focused primarily on food contamination, although a study by Farahat and Linderholm (2013) examined the contamination of crops used for medicinal products and supplements. Chary et al., (2008) and Yang et al., (2006) considered human contamination through milk and meat consumption, while several other studies examined forage crops. Contamination of green leafy plants can take place in several ways, for example through soil, manure, agricultural equipment, human handling, post–harvest cleaning processes and others, but irrigation water is considered the most important source of crop contamination. There have been a number of reported outbreaks globally that have been associated with the consumption of green leaves contaminated with pathogenic strains of Escherichia coli. When Escherichia coli infections are resistant to antibiotics (AR–E. Coli) and, in particular, resistant to multiple antibiotics, serious complications may occur in the treatment of infected patients (O'Flaherty et al., 2019).

— Exposure of nearby residents to irrigated areas with wastewater to health risks

Larger populations of water users downstream of wastewater areas will be exposed to uncertain health risks if wastewater is discharged into open water bodies. This applies especially in semi–arid and arid countries where the only open water bodies are irrigation canals and agricultural canals. In addition to agricultural use, these irrigation canals serve several domestic uses, such as washing, bathing and providing drinking water. Most studies of this group of people at risk have included poor living conditions, such as lack of access to safe drinking water and sanitation (Blumenthal et al., 2001; Ensink et al., 2008). In addition to occupational and food hazards, people living or commuting near agricutural fields or other type of lands irrigated land with wastewater may be exposed indirectly. For example, sports on cricket grounds near contaminated soil have been reported as possible sources of accidental ingestion (Ensink et al., 2006). Wastewater applied in irrigation in the form of aerosols (ie with sprayers or sprinklers) are sources of pathogen contamination of irrigators, but also of community members in the surrounding area (Ayuso–Gabella et al., 2011).

Residents near farms should be fully informed about the location of all fields where wastewater is used. In this way, they can avoid entering these lands. In high–income countries, there are still risks to the health of communities near wastewater irrigated areas, where insufficiently treated wastewater is used to grow non–food crops. For example, contamination of groundwater and drinking water, as well as nearby areas (food fields) is related to the use of wastewater to irrigate energy crops used as biomass sources (Carlander et al., 2009). A study conducted by Ferrer et al. (2012) identified a range of exposures to contaminants through recreational activities such as swimming, bathing and fishing in channels contaminated with untreated domestic, livestock and industrial wastewater, in addition to exposures from vegetable cultivation. Increased urbanization and industrial development have increased levels of contamination in canals, so these multiple routes of exposure pose serious health risks. A key challenge for health risk assessment due to wastewater use is that people living near or in wastewater irrigated areas may face exposures from a number of sources, and the assessment of specific risk factors is more very difficult.

— Other categories of people exposed to health risks

Another category of people exposed to risks is the general public who use landscaped areas irrigated with wastewater, especially if children play on the irrigated lawn or other people come into direct contact with the lawn. If high concentrations of pathogens remain on the lawn at the time of application, the risks of human transmission are higher. However, agricultural workers are not responsible for this category of wastewater application. Although many studies have shown high levels of contamination of vegetables grown by irrigation with wastewater, which increase the risk of negative effects on public health for both farmers and consumers, other ways of contamination must be considered. Health risks due to the reproduction of mosquitoes, which are vectors of malaria transmission, in wastewater that are treated in stabilization ponds before recovery have also been identified (Mukhtar et al., 2006; Dickin et al., 2016).

If proper care has not been taken at the treatment stage and farmers irrigating wastewater do not use proper practices, pathogens may be present on crops in such concentrations as to contaminate the hands or clothing of workers handling or packaging the contaminated crops. The unhygienic distribution and handling of food in markets, including the washing of sewage products, are other sources of microbiological contamination, at levels even higher than those due to irrigation of wastewater on the farm.

4. DISEASES CAUSED BY PATHOGENS IN WASTEWATER

A summary of the pathogenic microorganisms in the wastewater and the diseases they cause is presented in Table 3.

— Infections with intestinal parasites

Dilution of wastewater with clean water leads to a decrease in the number of coliform eggs and worms, but in most cases they will remain too high according to the guidelines of the World Health Organization. Farmers who used mainly untreated wastewater had a higher rate of intestinal parasite infection compared to farmers who diluted wastewater with groundwater. Intestinal nematodes *Ascaris lumbricoides, Anclyostoma duodenale, Necator americanus* and *Trichuris* pose the highest health risks (Zhang and Shen, 2017; Contreras et al., 2017). In developed countries, 2% of adults and 6–8% of children are infected with *Giardia* protozoan cysts, causing virulent outbreaks (Plutzer et al., 2010).

Table 3. Some water–borne diseases related to wastewater (Jaramillo and Restrepo, 2017)

Disease	Pathogen agent
Typhoid fever	*Salmonella typhi*
Paratyphoid fever [2]	*Salmonella paratyphi*
Gastroenteritis [1]	*Salmonella typhimurium*
Gastroenteritis [2]	Enterovirus, parvovirus, rotavirus
Cholera	*Vibrio cholerae*
Bacillary dysentery [2]	*Shigella dysenteriae*
Amebiasis [2]	*Emntamoeba histolytica*
Giardiasis [1]	*Giardia duodenalis*
Cryptosporidiosis [1]	*Cryptosporidium*
Cyclosporiasis [2]	*Cyclospora cayetanesis*
Infectious hepatitis [1]	Hepatitis A
Infantile paralysis	Polyovirus
Leptospirosis [1]	*Leptospira icterohaemorrhagiae*
Ear infections	*Pseudomonas aeruginosa*
Scab	*Sarcoptes scabiei*
Trachoma	*Chlamydia trachomatis*
Schistosomiasis [2]	*Schistosoma*
Malaria	*Plasmodium*
Yellow fever	Flavivirus
Dengue	Flavivirus

[1] Human and / or animal waste; [2] Human waste

— Diarrheal disease

Professional exposure to wastewater during agricultural activities contributes significantly to the risk of diarrhea in adults (Do et al., 2007; Ferrer et al., 2012), and the risk is much higher in combination with poor personal hygiene practices (Pham–Duc et al., 2014). Diarrheal disease threatens the health and proper development of young children, with 800,000 premature deaths being attributed to this disease each year. Diarrheal disease remains the second leading cause of death for young children in developing countries (UNICEF, 2012). *Cryptopsporidium* and *Giardia* are protozoan pathogens highly resistant to disinfection; they have an extremely low infectious dose and 10–30 cysts or oocysts can cause clinical infection (Campos C., 2008). *Cryptosporidium*, the second most common pathogen in wastewater worldwide, is responsible in 2% of all cases of diarrhea in developed countries, including 7% in children and 14% in AIDS patients (Kotloff et al., 2013). *Cyclospora cayetanensis* is another protozoan associated with relapsing diarrhea (Campos C., 2008).

There is an increase in the incidence of nonspecific diarrhea when more than 10^4 thermotolerant coliforms per 100 mL are found in water. A study conducted in Pakistan found higher incidences of diarrheal diseases and a high prevalence of roundworms in families who irrigated their crops with wastewater compared to those consuming products non–irrigated with wastewater (Feenstra and van der Hoek, 2000). An equivalent increase in fecal coliforms that cause contamination of water sources has a higher risk of diarrhea in infants than contamination of drinking water stored in households, as family members are likely to develop immunity to pathogens frequently found in the home (Hanjra et al. al., 2012). In recent years, global efforts have been initiated to reduce the risk of diarrheal disease, aiming to create safer and improved drinking water sources through the provision and proper treatment of drinking water, as well as ensuring access to improved drinking water and sanitation services. However, it should be noted that although improved water sources have lower chances of contamination compared to unimproved sources, it is estimated that a quarter of the improved sources are contaminated with fecal pathogens (Bain et al., 2014).

— Gastroenteriris

Outbreaks of enteric viral infections such as acute gastroenteritis have been reported due to the consumption of irrigated vegetables with wastewater (Toze S., 2006; Moazeni et al., 2017). Entericpathogens *Escherichia coli* and some *Campilobacter* species are considered to be a significant cause of acute gastroenteritis transmitted by contaminated water or by eating contaminated food. The infectious dose of *Campilobacter* is small, but its epidemiological incidence is similar to that of *Salmonella*. Only some strains of *Yersinia enterocolítica* are virulent factors and pathogens that are transmitted through water and the consumption of contaminated food, causing gastrointestinal infections (Campos et al., 2008).

— Other diseases

Untreated wastewater can be responsible for several diseases and conditions resulting from infection with pathogens. These diseases include malaria, typhoid fever (*Salmonella* sp.); dysentery or shigellosis epidemics (*Shigella* sp. and *Entamoeba hystolytica*); vomiting or malabsorption (adenovirus, rotavirus, *Cryptosporidium parvum*, *Giardia intestinalis* – formely known as *Giardia lambila*, *Trichuris trichiura, Taenia solium, Shistosoma* sp.); cholera (*Vibrio cholerae*); ascariasis (*Ascaris lumbricoides*); anemia (*Necator americanus*), as well as seropositive responses for *Helicobacter pylori*, the latter leading to chronic infections and even cancer (Aziz et al., 2015).

5. CONCLUSIONS

Wastewater is a widely available resource and its safe reuse can become a valuable strategy for managing water demand, as it can reduce the large amounts of freshwater needed for irrigation and meet the growing freshwater needs of cities in developing countries. On the other hand, in less developed countries, access to untreated wastewater and its reuse for agricultural purposes increases farmers' vulnerability to a number of health risks.

In agricultural areas where wastewater is used for crop irrigation, health education programs must be implemented to raise awareness and to promote a preventive behavior (i.e. personal hygiene, use of protective clothing, etc.) in order to reduce the occurrence of diseases and protect human health.

If investments in small–scale on–farm treatment systems and/or in municipal wastewater treatment plants are made, following mechanical–biological treatment coupled with a disinfection step, the effluent can be safely used in agriculture and can ensure a series of economic, social, agricultural and ecological benefits.

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