Chapter 16

Public health risks associated with the reuse of wastewater for irrigation

Grigorios L. Kyriakopoulos[a], **Ioannis K. Kalavrouziotis**[b] and **Miltiadis G. Zamparas**[b]

[a] *School of Electrical and Computer Engineering, National Technical University of Athens, Zografou, Greece,* [b] *School of Science and Technology, Hellenic Open University, Patras, Greece*

16.1 Introduction

16.1.1 Regional context of an overview

In any wastewater recycling scheme, the protection of public health is of primary importance. In the Oceania continent the public health requirements applying to the treatment of recycled water are stringent (in Australia) (Owens et al., 2021). In the Oceania continent, they have been also reported earlier studies devoted to on-site wastewater treatment systems that are common (throughout Australia) with most systems located in the urban fringe and rural regions. The number of on-site treatment systems is increasing rapidly in the last two decades of analysis, as these areas undergo more intensive development. Consequently, there is a significant increase in environmental and public health risks associated with these systems. This fact has led to the recognition of the need for the articulation of treatment standards and criteria which are flexible and robust to satisfy specific public health and environmental requirements. Currently, these concepts are not being widely applied in the on-site treatment of wastewater. In response to this research, Carroll et al. (2004) projected the identification and assessment of the environmental, potential toxicological, and public health risks for public health of heavy metals in wheat crops irrigated with wastewater, being specifically associated with on-site wastewater treatment systems in an area within the Gold Coast region, Southeast Queensland, Australia (Carroll et al., 2004).

In the American continent, Soller et al. (2003) investigated the functionality of a wastewater treatment facility at the City of Stockton, CA, which discharges tertiary treated effluent during the summer and secondary treated effluent during the winter to the San Joaquin River. Investigations were carried out by

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Soller et al. (2003) during the period of 1996–2002, in which insights were provided regarding the potential public health benefit accumulated by year-round tertiary treatment (Soller et al., 2003).

In a similar research analysis of high regional interest, it was denoted that Northern America communities rely heavily on their local surroundings as a source of food, drinking water, and recreation, thus creating the possibility of human exposure to wastewater effluent (Daley et al., 2018). Human exposure to microbial hazards present in municipal wastewater can lead to acute gastrointestinal illness or more severe disease. In this context, it was stated that wastewater management in Canadian Arctic communities it is influenced by several geographical factors including climate, remoteness, population size, and local food-harvesting practices. Most communities use trucked collection services and basic treatment systems, being able of only low-level pathogen removal (Daley et al., 2018). Such systems have been proven to be typically reliant solely on natural environmental processes for treatment and making use of existing lagoons, wetlands, and bays. They are operated, as partially treated wastewater still containing potentially hazardous microorganisms is released into the terrestrial and aquatic environment at random times (Daley et al., 2018).

In the relevant literature production regarding public health risk assessment, it has been reported a wide diversification and research pluralism during the last decade of referencing. Such an analysis of the onsite wastewater treatment systems (OWTS) in the city of Port Harcourt, Nigeria, and its surrounding environments was carried out between the period of August 2012 and April 2013 (Cookey et al., 2016). This study showed how the public health risk assessment tool can be used to improve public policies on OWTS, by deploying an audit survey of 245 OWTS in the residential area of the city, a public policy survey of OWTS in Port Harcourt city, a public health risk assessment, field observations, and investigations (Cookey et al., 2016). It was revealed that there were no specific policies, legislative, and regulatory standards for the sustainability of OWTS practice and no risk assessment considerations in the current policy instruments. Besides, the public policy instruments of OWTS, including risk maps, were found to be inadequate for improved and standard system construction, installation, operations and maintenance, compliance, enforcement, and inspection, mainly due to widespread and dispersed risk in the use of OWTS (Cookey et al., 2016).

In the Asian context, the use of wastewater and excreta in agriculture is a common practice in Southeast Asia. Nevertheless, concerns remain about the potential public health risks of such a practice, thus, necessitating the examination of the extent, range, and theoretical-literature production, as well as a synthesis of the evidence for associations between wastewater and excreta management practices and public health risks in Southeast Asia (Lam et al., 2015).

In another research conducted in the Asian continent, Khan et al. (2013) studied the determination of the concentrations of mineral elements in wheat (*Triticum aestivum* L.) plants, in order to observe the level of elemental pollution in Sargodha, Punjab, Pakistan as well as the abilities of the wheat plants to accumulate heavy metals from the soil supplied with the sewage water. The experimental session was conducted to study the transfer of heavy metals to the grains of wheat cv. Milate-2011 was grown in soil without sewage-sludge treatment (control) and soil supplied with sewage-sludge. A number of heavy metals in soil and wheat grains were analyzed, showing that Cr, Cu, Ni, and Zn levels were below the maximum permissible limits for soil, while the reverse was true for other metals. A significant correlation was also observed between the concentrations of metals in the soil as well as their accumulation in grains, except Fe concentration. The bio-concentration factor of these heavy metals was higher in wheat grains, thus, domestic sewage water may lead to heavy metal toxicity in humans if used unprocessed for irrigation purposes (Khan et al., 2013).

16.1.2 Human health risk overview

The health risk is defined as the likelihood that a negative health outcome will occur in a person or group of people that is exposed to a particular amount-dose of a hazardous agent. This implies that without exposure, there is no risk. The risk associated with the use of untreated wastewater and/or wastewater-contaminated water in agriculture can result from occupational and recreational activities, and diet. Recreational exposure is mainly associated with children as they engage in normal playing activities in areas that are polluted by contaminated irrigation water, which, in some countries, is not separated from agricultural fields. In some countries, parents work in agricultural fields with babies on their backs or around the fields, with some children providing help (Tongesayi & Tongesayi, 2015). As a result, occupational exposure can occur to both children and adults during normal agricultural activities, via direct contact with the contaminated water-wastewater, and wastewater-contaminated soils, as well as the inhalation of gases from the wastewater, and the inhalation and ingestion of dust from contaminated agricultural soils. Children can routinely, purposefully, or accidentally, swallow the wastewater and wastewater-contaminated soils while playing (Tongesayi & Tongesayi, 2015). Wastewater can further and inadvertently get into the mouths of adults during irrigation, being ingested. Direct contact with the wastewater and the wastewater-contaminated soils can result in certain pollutants, chemical or pathogenic, entering the human body through dermal penetration (Tongesayi & Tongesayi, 2015).

The oral route remains one of the major routes of human exposure to environmental pollutants. Dietary exposure occurs to everyone, but unlike occupational and recreational exposures, it can be both local and global. Dietary exposure emanates from the consumption of contaminated foodstuffs. At the local level, food can be further contaminated by washing or processing it with wastewater-contaminated natural water. Unlike the farmers involved and maybe a few locals, most consumers may not know the precise origin and, therefore, the safety of foods in their local supermarkets. Subsequently, the consumers cannot make informed choices that are based on the safety of the food, but their choices will obviously be based on visual quality, diversity, and advertisements, among other factors, and may get poisoned in the process (Tongesayi & Tongesayi, 2015).

Principal reasons why agricultural food contamination has become such a huge global challenge are the lack of consumer awareness, the widespread and ongoing use of untreated wastewater in agriculture, and the fact that locally produced food can be marketed globally. In the past there were researchers who attempted to assess safety, that is, the probability that harm can occur under specified conditions, and risk assessment, which are the probability that a person's health will be adversely affected under a particular set of conditions, of contaminated water and its use in agriculture mostly focused on dietary exposure while ignoring risks from occupational and recreational exposures, and in the process, significantly underestimated the risk that is associated with the use of wastewater or contaminated water in agriculture (Tongesayi & Tongesayi, 2015). There is overwhelming and undeniable literature data available about both chemical and biological contaminants from wastewater and contaminated freshwater getting into the food chain via irrigation and people getting sick through the eating of contaminated food, as well as through agriculturally related occupational activities and recreational activities around contaminated soils and water. Through research it was shown that exposure to environmental contaminants accounts for 85% of all, particularly chronic, diseases such as obesity, diabetes, heart disease, and cancer, while at least half of hospital beds globally are occupied by people with waterborne diseases, making the risk associated with the use of contaminated water in agriculture quite significant (Tongesayi & Tongesayi, 2015).

In a more detailed basis of analysis the following facts become evident from the foregoing discussions (Tongesayi & Tongesayi, 2015): (1) wastewater, broadly defined, can contain a wide variety of harmful contaminants; (2) wastewater is the principal anthropogenic polluter of freshwater in most countries; (3) untreated wastewater and wastewater-contaminated freshwater are routinely being used to irrigate crops in a large number of countries, some of which are the major producers of the world food reserves; (4) contact with wastewater and wastewater-contaminated water and soils during normal recreational and agricultural activities is causing people to get sick; (5) the contaminants from contaminated irrigation water are getting transferred into food in levels that are not safe and human illnesses have been reported as a result; (6) the use of contaminated water in agriculture is widespread and continuing unabated; (7) farmers have little to no knowledge of the hazards involved; (8) agricultural food products can be marketed globally; and (9) consumers are mostly unaware of the precise origins of the food and cannot make choices based on the safety of the food regardless of their knowledge about the potential dangers of consuming food grown using untreated wastewater or contaminated water. These facts combined, show that the risk associated with the use of contaminated water in agriculture is real, significant, and cannot be overemphasized. Drastic, at both national and international levels, measures and policies have to happen to preserve public health as well as ecological integrity, in terms of literature-based evaluation of risks associated with the different classes of irrigation water contaminants (Tongesayi & Tongesayi, 2015).

16.1.3 Irrigation of agricultural land and health risk overview

The use of raw wastewater to irrigate crops across mid- to low-income countries in Africa, Asia, and Latin America is significantly contaminating natural freshwater sources and agricultural soils with chemicals, chiefly among them are the toxic heavy metalloids that eventually getting into crops in levels and at most cases, they are way above safe limits (Tongesayi & Tongesayi, 2015). In some crops, the uptake of certain heavy metals and metalloids can affect crop development and yields, with the accumulation being type and variety dependent in some cases. It has been argued that rice has proven an effective accumulator of As and other toxic heavy metalloids compared to other food crops, being able to accumulate As in the grain to unsafe levels from irrigation water containing the metalloid in levels that are considered safe for irrigation water (Tongesayi & Tongesayi, 2015). Arsenic accumulation in rice can further interfere with the uptake and accumulation of essential micro-nutrients like selenium (Se) and zinc (Zn) in the rice grain. Considering that rice is the staple food for more than half of the world population its research and findings are especially significant. Besides, the accumulation of As in vegetable species irrigated with As-contaminated water proved that spinach presents a more direct risk to human health based on the As levels, it accumulated in the edible parts while confirming the species-dependent enrichment and distribution of the metalloid within the plants. Despite the differences in the accumulation rates of metals and metalloids by crops and crop varieties, the overall enrichment levels remain a realistic and pronounced threat to public health (Tongesayi & Tongesayi, 2015).

16.1.3.1 Africa

Across Africa, untreated wastewater is extensively used in UPA, while millions of people are being exposed to the risk of heavy metal and metal(loid) toxicity in addition to other associated hazards. In Egypt, it was reported that wastewater irrigation causes the accumulation of heavy metals and metalloids in food to unsafe levels, while levels of Cd and Pb exceeded permissible levels in the soils as a direct result of the perennial use of wastewater in agriculture (Tongesayi & Tongesayi, 2015). In Ethiopia significant enrichment of heavy metalloids in the edible parts of food crops regarding the impact of the use of untreated wastewater in agriculture, while in Nigeria the levels of trace heavy metals that included Pb and Cd in sewage water samples from the Kubanni river drainage basin that is used as a source of irrigation water in Zaria City, they were detected as beyond irrigation water standards established by the US EPA and FAO (Tongesayi & Tongesayi, 2015).

Another hygiene issue is that irrigation sewage water from the drainage basin is potentially contaminating food. The national economy in Zimbabwe is largely agro-based, revealing that raw wastewater can be routinely utilized to irrigate crops in and around some of its major cities (Tongesayi & Tongesayi, 2015). Such research conducted in Zimbabwe showed severe contamination of freshwater sources, soil, and crops from the practice. At a similar context analysis levels of Cd, copper (Cu), Pb, and Zn in maize and tsunga (a green vegetable) as well as in other foods such as beans, pepper, and sugarcane they were under wastewater irrigation at a farm close to the nation's capital, whereas reported levels were several times higher than the European Union safe limits (Tongesayi & Tongesayi, 2015).

16.1.3.2 Asia

In Asia, where on average 87.6% of freshwater drawings are directed to agriculture, a large number of countries on the continent rely on wastewater in agriculture to ease the pressure on the water demands. Unlike, in Africa a lot of work has been done on the impacts of wastewater, focusing largely on contamination by As and its uptake by rice. This may be because rice is the major staple food in the region while As is one of the major chemical pollutants in the region as well. In particular, it was reported a substantial buildup of As in some Bangladesh soils from the use of As-contaminated irrigation water, and significant enrichment of the metalloid in the rice grain, which also resulted in a reduction in yield (Tongesayi & Tongesayi, 2015).

In the Bangladeshi agricultural sector, the literature showed that the concentration of As in irrigation water does not have to be higher than the recommended limits in irrigation water for the metalloid to accumulate to unsafe levels in the rice grain, concluding that the eating of contaminated rice constituted the major route of As exposure to humans compared to water in that region (Tongesayi & Tongesayi, 2015). This finding is quite remarkable because, in other regions where there is a risk of As exposure, drinking water is usually the major source. In fact, other studies in the same country considered the contamination of irrigation water as the major constraint to the country's agriculture because of the impacts of As in terrestrial systems (Tongesayi & Tongesayi, 2015).

In Pakistan, the use of contaminated sewage effluent to irrigate crops is reportedly an old tradition, necessitated by the acute shortages of irrigation water, even though the country's regulations prohibit the use of untreated wastewater in agriculture (Tongesayi & Tongesayi, 2015). A relevant Pakistan-focused study reported higher accumulation levels of toxic metals in the soils that were under raw sewage irrigation and the subsequent transfer of the metals to food, while another study investigated the health risks associated with the consumption of contaminated agricultural produce from the use of wastewater and reported Cd levels in the soil, as well as Cd, Pb, and Cr levels in the water and food crops that were higher than permissible limits. The accumulation factors for Mn and

Pb were determined as greater than one in food crops while the health risk index (HRI) for Pb was greater than one in all food crops that were irrigated with wastewater (Tongesayi & Tongesayi, 2015).

In Saudi Arabia the literature reported significant buildup of toxic heavy metalloids in soils from long-term impacts of the irrigation of agricultural soils with treated sewage effluent, suggesting that pretreatment may not offer long-term solution to the problem if contaminants are not completely removed (Tongesayi & Tongesayi, 2015). Similarly, in another study in Pakistan, it was concluded that human health risks associated with the irrigation of crops with untreated urban and industrial wastewater reported levels of Cr^{2+}, Pb^{2+}, and Cd^{2+} that were higher than EU permissible limits in vegetables. Similar studies in canal water, tube well water, and sewage water irrigation on vegetables collected from all the districts of Pakistan reported high levels of mercury that reached 130.6 ppb (Tongesayi & Tongesayi, 2015). Such levels of food contamination inferred that fish may no longer be the major source of mercury exposure to humans, at least in these regions. Some studies also reported declines in yields of crops other than rice due to the uptake of heavy metals from soils that were under wastewater irrigation, such as in the case of a decline in canola yields in Pakistan that was associated with the accumulation of heavy metals such as Pb, Cd, and Cr, denoting that the municipal sewage water containing high levels of metals was inhibiting canola growth and seed yield (Tongesayi & Tongesayi, 2015).

16.1.3.3 China

China is one of the leading countries where wastewater is routinely used in agricultural crops and one of the countries where there is widespread condemnation of the practice from researchers and the media. Similar studies have reported significant contamination of agricultural soils and crops with heavy metals and metalloids, with the levels in crops being positively correlated with levels in the soils. Specifically, it was reported the concentration of Pb in rice irrigated with sewage water, in Yinchuan, that was 10 times higher than the national safety standard for food, while in another study the levels of Hg, Cd, Pb, and As were determined in samples of irrigation water, sediment, soil, and groundwater from a field in Tianjin that was irrigated with wastewater, stressing out elevated levels in river sediments and wastewater-irrigated soils (Tongesayi & Tongesayi, 2015). In the Chinese context it was also reported that Cd levels exceeded the maximum acceptable limits set by the Ministry of Environmental Protection of China and the World Health Organization (WHO) in soils and vegetables irrigated with raw wastewater (Tongesayi & Tongesayi, 2015). Elevated levels of heavy metals and metalloids are commonly including Cd and Pd in soils and vegetables that were under sewage irrigation, implying that the risk posed by the consumption of the vegetables was not significant based on health risk calculations. However, the vegetables are usually part of a meal that may also be contaminated, and the effects of the entire meal will be accumulated. There is evidence of metalloids' accumulation with each application of sewage water and crops are accumulating the toxic chemicals in edible parts. These findings should be a matter of public concern (Tongesayi & Tongesayi, 2015).

16.1.3.4 India

India is reported to receive more than 70% of its annual rainfall during the 3 months of the monsoon, with most of it flooding out to sea with farmers lacking irrigation capabilities having to deal with water scarcity for about three-quarters of the year. Such water shortages resulted in the use of wastewater in some parts of the country to meet agricultural water needs. The practice reportedly led to levels of toxic heavy metals and metalloids in agricultural soils and foods that are largely beyond safe limits. Crops that were irrigated with uncontaminated water had much lower to undetectable levels of the heavy metals and metalloids showing, beyond reasonable doubt, that wastewater is one of the principal sources of food contamination in the country (Tongesayi & Tongesayi, 2015).

The long-term effects of the practice reported levels of Zn, Mn, Cu, Ni, Cr, Pb, and Cd in agricultural soil and crops that were higher than levels in control samples and also higher than the permissible limits, thus, arguing at proper management of irrigation water and periodic monitoring of soil and plant quality parameters towards accomplishing a successful, safe, long term wastewater irrigation (Tongesayi & Tongesayi, 2015). Such statements, together with the data on which they are based, are proven valuable only in case where opening new research paths and influencing public policy. Wastewater growing crops in the country reported levels of heavy metalloids in soils and vegetables that were higher than the limits set by FAO, with positive correlations between the levels in plants and the levels in sewage water and soils (Tongesayi & Tongesayi, 2015).

16.1.3.5 Japan

In the relevant literature, there are studies that have directly linked some heavy metalloids to specific diseases from the use of wastewater in agriculture. It is noteworthy that an extensive survey by the government of Toyama prefecture of Japan that was prompted by an outbreak of Cd-induced Itai-Itai disease was able to link the outbreak to the use of irrigation water that was contaminated by Cd (Tongesayi & Tongesayi, 2015). After the outbreak of the disease, analysis of Cd levels in rice and soils of paddy fields that were irrigated with the contaminated water over five decades revealed severe contamination of both soils and rice, while recommending that the upper soil layer of a total of 1500 ha of paddy fields be replaced. The replacement of the topsoil together with discontinuing the use of the contaminated water significantly can improve the quality of the soils and the whole agricultural production (Tongesayi & Tongesayi, 2015).

16.2 Methods and analyses

Among the earliest research approaches investigating the public health risks generated and managed by wastewater treatment, a hydraulic model of the San Joaquin River, CA, and a dynamic disease transmission model, they integrated a wide array of disparate data to estimate the level of viral gastroenteritis in the population under two treatment scenarios. The research results suggested that the risk of viral gastroenteritis attributable to the treatment facility under the existing treatment scheme was several orders of magnitude below the 8–14 illnesses per 1000 recreation events considered tolerable by the US EPA, and winter tertiary treatment would further reduce the existing risk by approximately 15–50%. The employed methodologies were proven applicable to other watersheds where additional water treatment is being considered to address public health concerns from recreation in receiving waters (Soller et al., 2003).

In addressing the key challenge of translating the results of monitoring of microorganisms in recycled water into a quantitative public health metric Owens et al. (2021) developed the novel method of disability-adjusted life year (DALY) metric, being a set level of negligible public health risk. The target maximum risk of 10-6 DALY per person per year was adopted in Australian water recycling guidelines in 2006. A key benefit of the DALY approach was its ability to standardize the understanding of risk across disparate areas of public health. This method was proven to an integrated approach, Fig. 16.1, where microbial surrogate organisms indigenous to wastewater were used to measure

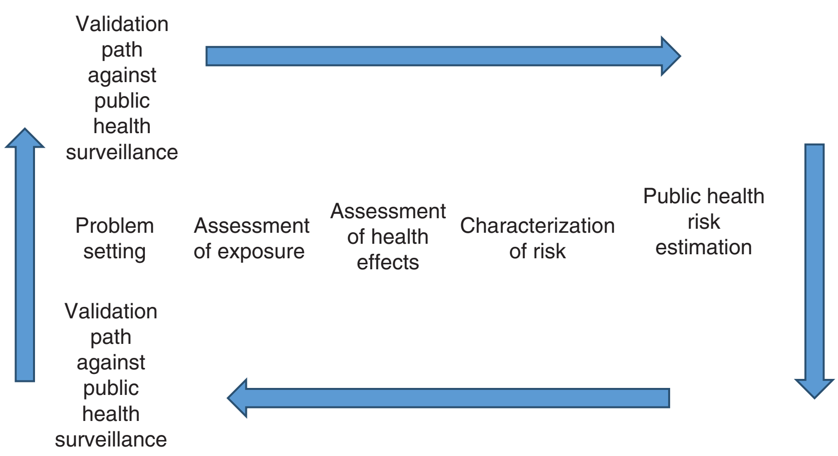

FIGURE 16.1 Looped process of microbial risk assessment. (*Source: Modified from Owens et al. [2021].*)

the efficiency of water recycling treatment processes and estimate public health risk, as in the case of implementation in the Greater Sydney region of Australia (Owens et al., 2021).

Another research stressed that climate change, increase in population, and scarcity of freshwater have led to global demand for wastewater reuse in irrigation, thus, wastewater has to be treated in order to minimize the presence of pathogens, such as the ova of soil-transmitted helminths (STHs) (Ravindran et al., 2019). These authors focused their analysis on limiting the transmission via the removal of STH ova, by recommending the accurate assessment of risks and minimizing the exposure to the public. The WHO guideline specified a limit of lower than 1 ova/L for safe wastewater reuse. Additionally, the Australian Guidelines for Water Recycling (AGWR) recommended a hydraulic retention time of over 25 days in a lagoon or stabilization pond to ensure a 4-log reduction value of helminth ova and to mitigate soil-transmitted helminths associated risks to humans (Ravindran et al., 2019).

In detecting and quantifying the evidence of interrelated occupational health risks of wastewater and excreta management practices, while three electronic databases—namely PubMed, CAB Direct, and Web of Science—were searched and a total of 27 relevant studies were evaluated. Such possible occupational health risks of wastewater and excreta management practices were evidenced, including diarrhea, skin infection, parasitic infection, bacterial infection, and epilepsy (Lam et al., 2015). Community members can be at risk for adverse health outcomes through consuming contaminated fish vegetables, or fruits, suggesting that practices of handling, treatment, and use of waste may be harmful to human health, particularly farmer's health. Literature limitations were also reported including lack of gender analyses, exposure assessment, and longitudinal study designs (Lam et al., 2015).

Among the most versatile and significant researches are those investigating the uncontrolled release of volatile organic compounds (VOCs) from wastewater treatment plants (WWTPs) and the adverse health effects on the public. In the study of Yang et al. (2014) a lab-scale bioreactor was constructed to analyze the mass distribution of three aromatic (benzene, toluene, and xylenes) and four chlorinated VOCs (chloroform, carbon tetrachloride, trichloroethylene, and tetrachloroethylene) among the air, water and sludge phases in wastewater treatment processes. The VOC distribution through a full-scale WWTP was located in northern China and it was further investigated with respect to the effects of seasonal temperature variations and treatment technologies, followed by the cancer risk assessment using a steady-state Gaussian plume model (industrial source complex) to simulate the atmospheric behaviors of the VOCs emitted from the WWTP (Yang et al., 2014). It was reported that three aromatic hydrocarbons, notably benzene, were more readily released from the wastewater into the atmosphere, whereas the chlorinated compounds except chloroform were mainly present in the water phase through the treatment processes. The primary clarifier was the technology releasing high levels of VOCs into the atmosphere from the wastewater. At the extent levels of volatilization or biodegradation, two important mechanisms to remove VOCs from wastewater were determined by the physicochemical characteristics of the compounds, as the influence of treatment technologies (e.g., aeration) and seasonal temperature variations were rather limited. Interestingly, the people living in areas even more than 4 km away from the WWTP were still potentially exposed to cancer risks exceeding the regulatory threshold limit (Yang et al., 2014).

Another ideal methodological approach is the risk assessment models that can separately consider variability and uncertainty, being also challenging to do so for food-safety risk assessment models. In this context, it has been literature-introduced a risk assessment model that incorporated and systematically characterized the variability and uncertainty in the data and assumptions for *Salmonella* contamination in alfalfa seeds, *Salmonella* growth and spread during sprout production, alfalfa sprout consumption patterns, as well as Salmonella dose–response relationship (Chen et al., 2018). In the relevant literature a risk assessment model introduced several parameters and refinements, including the use of *Salmonella* in seeds prevalence data relevant to U.S. sprout production operations, the vol/wt ratio of water to seed/in-process sprouts per irrigation cycle, in-process pathogen spread multiplier, and the extent of post-harvest pathogen spread, enabling the evaluation of the impact of these key factors on sprouts contamination and subsequent risk to the consumer (Chen et al., 2018).

This risk assessment utilized updated data to predict public health risk and the changes in public health risk by the various interventions of interest to risk managers, based on data and sprout practices relevant to the United States, being also applicable to address sprout food safety issues in other countries and regions with region-specific modifications, such as prevalence and levels of *Salmonella* in alfalfa seeds, sprout consumption, and any unique aspects in those sprout production operations, including the size of seed batch and control measures other than seed treatment and spent irrigation water (SIW) testing (Chen et al., 2018).

These authors denoted that a typical challenge in conducting such a microbial risk assessment has been the lack of baseline prevalence and enumeration data for food–hazard combinations of interest. Over the years, this situation has gradually prompted data calls by regulatory agencies and targeted data collection by collaborative government, academia, and industry efforts. Because of the lack of data on the contamination of *Salmonella* in seeds, past model-based studies either did not include prevalence data and treated prevalence as a user-input parameter or used data from other, than that of in-field application, countries. Subsequently, the prevalence data for seed samples used in the risk assessment model of Chen et al. (2018) were not known to be associated with reported outbreaks or sporadic cases of salmonellosis (Chen et al., 2018).

Application of seed treatment and/or SIW testing can reduce the number of cases of salmonellosis from the consumption of sprouts. The risk reduction can be estimated by 5- to 7-fold from a 1-$\log_{10}$ seed treatment alone, being comparable to that from SIW testing alone, and each additional 1-$\log_{10}$ seed treatment was predicted to provide a greater risk reduction than SIW testing.

Combining SIW testing with seed treatment can achieve approximately three times greater risk reduction compared to seed treatment alone at higher than 2-$\log_{10}$ reduction seed treatment. Evaluation of alternative scenarios with different assumptions for growth potential using this model can infer that growth potential is a key factor influencing the predicted number of cases, but it can weakly affect the predicted relative risk reduction. Given no seed treatment the likelihood of detecting a contaminated batch would increase with increasing initial *Salmonella* prevalence in seeds. When initial seed contamination is relatively high, e.g., if the contamination rate is 23.5% (instead of 2.35%) in the 6.8 kg seed batches, then SIW testing can be proven relatively effective in detecting the majority of the contaminated batches but would also lead to the removal of a large fraction (43.3%) of the sprout batches. When seed treatment is applied to reduce contamination before SIW testing is undertaken, a larger fraction of the sprout production batches would test negative (as it would be free from pathogen contamination) (Chen et al., 2018).

16.3 Discussion

The lack of fast and sensitive methods for assessing the concentration of pathogens in wastewater poses a considerable challenge for an accurate risk assessment. Consequently, it has been difficult to control pathogens despite effective mass drug administration. This limitation can be overcome with the advent of novel techniques for the detection of pathogens. Therefore, an assessment of the current detection methods has to be undertaken to detect the viable and soil-transmitted pathogens in wastewater (Ravindran et al., 2019).

Similarly to the aforementioned pathogens-related analysis, a detailed surface and groundwater investigation including nutrient and microbiological analysis and modeling studies were undertaken to identify and assess the risk of contamination from nutrients and pathogenic organisms discharged from on-site systems (Carroll et al., 2004). This analysis also included the assessment of the potential risks in relation to high densities of on-site systems. High levels of nutrients, in particular nitrate were found in an unconfined shallow aquifer within the study area, directly below high densities of systems. Similarly, high fecal coliforms were further observed in various locations throughout the area. Therefore, it was defined as crucial for the impact of high densities of on-site systems on shallow groundwater to be appropriately assessed in order to minimize the potential risks to the environment (Carroll et al., 2004).

Another significant argumentation is based on the fact that although estimating the actual disease burdens associated with wastewater exposures in some climatic zones of severe human-threatening conditions, such as those of Arctic communities, is a highly challenging endeavor, waterborne- and sanitation-related illness is believed to be comparatively higher than in other parts of the neighborhood countries, as that of Canada. Offering a conceptual framework and evaluation of current knowledge is crucial to enable the microbial risk assessment of exposure scenarios associated with food-harvesting and recreational activities in Arctic communities, where simplified wastewater systems are being operated (Daley et al., 2018).

A critical research finding in investigating the public health risks that are related to wastewater treatment processes is the complex nature and quantification of VOC emissions from WWTPs, inferring that the associated health impacts on the public near the WWTPs could be severely underestimated, whereas their treatment efficiencies by wastewater treatment technologies were overestimated (Yang et al., 2014). Instead of fully controlling the VOC release from WWTPs, the identification and abatement of important VOC species with regard to atmospheric emission and health concerns can be recommended as one possible alternative approach to effectively minimize the environmental and public health impacts by VOCs released from this particular source (Yang et al., 2014).

Comprehensively reviewing previously published studies on various seed treatments it showed that available chemical, physical, and other types of treatments are highly variable in their effectiveness in reducing *Salmonella* and other pathogens. These research findings demonstrated that such variability in the efficacy of seed treatment would affect the public health impact realized because that impact can be strongly dependent on the seed treatment $\log_{10}$ reduction level (Chen et al., 2018). The conduct of a risk model to predict changes in public health burden can predict changes in *Salmonella* contamination in the sprout supply from different levels of intervention. The model provides a means to quantitatively understand the magnitude of the relative risk reduction from seed treatment and SIW testing interventions. Expansion of the model to consider the impact on risk from other interventions (such as seed testing), other sprout varieties, or other pathogen contamination is possible, given sufficient data to inform the model inputs (Chen et al., 2018).

Faced with the increased demand for irrigation water to meet the increasing demand for food, the widespread contamination of traditional irrigation water sources leaves certainly farmers without options globally, but to use raw wastewater to irrigate their crops. Further pressure is put on farmers because they subsist on agriculture, and market incentives in cities can be hard to resist. Moreover, besides to poverty issues, freshwater scarcity, contamination of traditional sources of water, and lack of alternative water sources, against unprecedented demands, it was argued that some farmers prefer wastewater over traditional irrigation water citing reliability of wastewater and its nutrient content as the reasons for their choice. Unfortunately, all these reasons while make sense under certain circumstances, their consequences can be costly (Tongesayi & Tongesayi, 2015).

The enforcement of regulations is reportedly made difficult by lack of alternative sources of irrigation water. In some countries local authorities are supposed to be custodians of the regulations, they are forced by circumstances to supply untreated wastewater to farmers to meet their obligations to the farmers. It is particularly noted that in Pakistan untreated wastewater is usually auctioned for use in agriculture even though the national laws stipulate that untreated wastewater cannot be used in agriculture. In the case of Bangalore, local authorities are prone to distribute wastewater for use in agriculture, treated or untreated, while, in Nam Dinh, local authorities are reported to pump wastewater on a regular basis from the city drainage system directly into the irrigation system in times of scarcity. In India, the use of wastewater for irrigation is not encouraged but, in relevant literature, it is used regardless. In a general context, local authorities in all places—where untreated wastewater is used in agriculture—are aware of the potential hazards of the practice, but because they cannot provide their citizens with uncontaminated water, they pretend this as a good agricultural practice. However in practice, if regulations cannot be enforced then they are just as good as nonexistent and enforcing regulations on the use of wastewater without providing farmers with alternative means makes no sense at all. On the other hand, there are developed countries that realized the public health hazards of the use of wastewater in agriculture and they completely banned it (Tongesayi & Tongesayi, 2015). However, chemical measurements in the soils previously irrigated with sewage before the practice was stopped still show elevated levels of toxic chemicals, particularly heavy metals, and metalloids, that are a potential threat to human health. In such a practice it makes agricultural lands essentially hazardous sites that are needful of intensive remediation for food safety to be ensured. The longer wastewater is used on the soils, the more difficult and expensive it will likely be to remediate (Tongesayi & Tongesayi, 2015).

16.4 Conclusion

Future research perspectives can emerge state-of-the-art research and developments that have the potential to replace currently available conventional and polymerase chain reaction-based methods and achieve the guidelines of the WHO in order to allow the safe reuse of wastewater for non-potable applications, thereby minimizing public health risks (Ravindran et al., 2019). Another future field of appreciation and valuation resides in the benefits of wastewater use in agriculture that are truly insignificant when compared to the risks involved. However, in the absence of complete and accessible data and sound national and international policy to the contrary, those involved will continue using this practice (Tongesayi & Tongesayi, 2015). Risks will be manifesting, of course, but the cause may not be fully understood early enough for corrective measures to be implemented with economic viability. The loading of contaminants in the soil over a long period can essentially turn agricultural lands into hazardous waste sites, which will eventually need extensive remediation to make them usable for food production (Tongesayi & Tongesayi, 2015).

Future studies should focus on identifying, quantitatively assessing, and mitigating health risks, if sustainable benefits are to be obtained from wastewater and excreta reuse in agriculture especially among developing economies, such as that of Southeast Asia (Lam et al., 2015). However, it cannot be undermined the fact that even though information of mitigating health risks from wastewater treatment they may be available in the literature, it may be too fragmented to inform formal and feasible public policy (Tongesayi & Tongesayi, 2015). In this context media outlets in some countries attempted to publicize the potential hazards associated with the use of wastewater in agriculture in their respective countries. While this is commendable in the absence of coherent government policy and complete data on wastewater, it may cause panic and discontent because of potential inaccuracies (Tongesayi & Tongesayi, 2015). There is also a reality that many farmers in some countries choose to use wastewater instead of uncontaminated alternatives based on minor benefits that betray a lack of information. In fact, a clear lack of understanding of the types of infections and risks associated with the use of wastewater in agriculture among both consumers and farmers may be reported (Tongesayi & Tongesayi, 2015). The excuse of poverty every time of failure to meet public obligations to local citizens cannot be continued to be used. Especially among developing countries, while support should be sought from developed countries in terms of technological (and possibly paid) know-how, national resources must be carefully prioritized to make sure public health is sustainably preserved. After all, some of the countries that are using untreated wastewater in agriculture are not poor by any means, regardless that international organizations can help, as they have always tried to do, but they cannot and certainly should not replace national obligations (Tongesayi & Tongesayi, 2015).

Finally, it is noteworthy that:

- Modern approaches of public health risks are those of integrating and co-evaluating the effects of wastewater management on human health targeting at the benefits and risks of wastewater to water safety, soil quality, crop production, and food security. In particular, wastewater management in irrigation can benefited the improvement of soil quality, the provision of nutrients for plants, and the saving expenses of diverting freshwater for irrigation. Research limitations and severe adverse impacts on environment, society, and human beings, they cannot be undermined. These may bring contamination to groundwater, soils, and ecological environment, while adversely effecting directly or indirectly on human health. Subsequently, wastewater should be used rationally and scientifically to enlarge the benefits induced by wastewater reuse but reduce its risks (Yang et al., 2014).
- Health risks are always manifesting through time but the cause may not be fully understood early enough for corrective measures to be implemented with economic viability. The loading of contaminants in the soil over a long period can essentially turn agricultural lands into hazardous waste sites, which eventually need extensive remediation to make them usable for food production. Continuing the practice can affect not only the current generation but also the future generations (Tongesayi & Tongesayi, 2015).

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