



Health implications of increasing reuse of wastewater as an adaptation to climate change

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Abstract

With climate change and a burgeoning future world population there will be an increased need to reuse treated wastewater for a variety of uses including domestic water supplies as a water conservation measure. While there are technologies for partial treatment for the reuse of wastewater, in some areas of the world there is presently unregulated reuse of wastewater for agricultural irrigation activities which poses severe public health risks. Current water treatment technologies are inadequate to safeguard communities against water-related diseases arising from reused wastewater. There is an urgent need to ensure up-to-date knowledge about implementation of basic practices based on appropriate policy frameworks to protect human health and the environment. The knowledge providing more equitable outcomes with the reuse of wastewater is an overwhelming issue. There is sufficient evidence to question the current approach measuring faecal indicator organisms or coliform counts to establish microbiological quality of water and further complications arise from the presence of heavy metals, chemicals, hormones and endocrine-disrupting chemicals. The risks associated with populations exposed to recycled wastewater are uncertain requiring much more research, technology transfer and strengthened regulatory frameworks.

Keywords: Water quality, reuse of wastewater, climate change, public health risks, water quality testing, environmental protection, water use

Introduction

Adaptation to climate change provides a myriad of complex challenges which have never been faced before by humankind [1]. Researchers have identified increased water shortages as an important issue which will be exacerbated by a rapidly growing world population. Already many parts of the world are facing changes in rainfall patterns, flood cycles, and droughts [2]. A key challenge is how to obtain more use with less water. The United Nations Environment Programme (UNEP) has acknowledged that water-related problems are one of the most immediate and serious environmental threats to humankind [2]. Furthermore, within the next 50 years 40% of the world's population will live in countries facing water stress [3].

Wastewater reuse is being widely used to address the global water resource crisis [4] and it is likely to increase in the next few decades as water shortages intensify [5]. Most collected wastewater is used for agriculture, food production, and other industrial processes and it is used for a wide variety of uses including groundwater recharge and drinking water production [6]. While water for agricultural and industrial purposes

does not need to be of potable quality, it should not be raw without any treatment.

Only about 1% of drinking water provided in a city is actually used for drinking, but with more used for cooking [7] and only 3% of water consumed in a city is used for drinking and cooking [8]. For centuries in some parts of the world, water for agricultural irrigation purposes has been in the form of untreated or partially treated human effluent without planning controls [9] with adverse health consequences [10]. Currently about 20% of the world's food is grown with the use of untreated wastewater [2] and the trend is increasing as a result of global water scarcity [11]. Most wastewater used for crop irrigation is untreated and it poses significant health problems [12].

How to obtain more use from less water

Over-extraction of freshwater systems for agricultural irrigation has led to significant degradation to rivers, streams and wetlands globally [4]. There is serious aquifer depletion in China, India, Pakistan, the western United States, North Africa and the Middle East, as well as several major rivers now being

completely used during dry months of the year in the western United States and Asia [13]. By reusing treated wastewater for applications such as agriculture, more freshwater can be allocated for uses that require higher quality, such as for drinking, and there will be less damage to the natural environment, with less demand on fresh water systems and with less wastewater being discharged into natural waterways [6] and the ground [14] leading to pollution of groundwater supplies and the break-down of ecosystems. A further adverse outcome in the over-use of aquifers is subsidence of ground, leading to potentially serious outcomes for cities and the built environment generally [4]. Reusing wastewater contributes to a more sustainable use of water. Wastewater reuse for agriculture represents a large reuse volume, and with increased water scarcity and an increase in applications, it is expected to increase considerably further, particularly in developing countries.

Treated wastewater has several uses, apart from agricultural irrigation, such as aquaculture, industrial processes, groundwater recharge, and even for potable water supply after extended treatment. There are membrane plants producing potable water in several countries including Japan and the US, and the UNEP was introducing the required technology to provide rural communities in southern Iraq with safe drinking water from waste water [2]. In Beijing, China, there were around 1,000 decentralized wastewater reuse systems in 2010 and their numbers are increasing, which are used mostly for spray irrigation [15].

The use of treated wastewater is implemented in Shinjuku, a suburb of Tokyo where a dual distribution system has been adopted. Sand-filtered water from the Ochiai Municipal Wastewater Treatment Plant is chlorinated and used as toilet-flushing water in 25 high-rise business premises. This has been operating since 1984 and it is supplying up to 8,000 m³ of water daily [2]. Treated wastewater is also being used as an environmental enhancement, augmenting natural/artificial streams, fountains, and ponds. The reuse of wastewater is an integral part of policy for Australia's water resource management with a scheme under consideration of infiltrating a potable aquifer with treated wastewater to secure Perth's drinking water supplies into the future [16]. Trials of drinking-water supply augmentation were carried out between 2010-2012 under the Australian National MAR Guidelines 2009 [17,18].

Unlike developed countries where considerable attention is given to wastewater collection and treatment, the reuse of raw wastewater is a common practice in many developing countries. This is especially so for agriculture, with about 20% of the world's food being produced through this practice [2]. Pakistan is such a country where there is mostly unregulated reuse of untreated waste water in agriculture [19]. This reuse of untreated wastewater should be discontinued for public health reasons. Jordan relies heavily on the reuse of wastewater for agricultural irrigation and while it has sound regulations

for its use, there is a lack of coordination between agencies to ensure that the public is properly protected from poor quality reused wastewater [20]. There is an urgent need to ensure that there is up-to-date knowledge about and implementation of basic practices, based on appropriate policy frameworks to protect human health and the environment [2].

This is particularly so given the burgeoning population growth in some of these countries, which will place further pressure on water as a resource. Unfortunately, many developing countries lack appropriate capacity and resources to enforce strict standards for the treatment and reuse of wastewater. Due to this reuse of poorly or untreated wastewater being a common practice, farmers and consumers of those agricultural products face substantial health risks, an issue being considered by the World Health Organization (WHO) [2]. The knowledge transfer to provide more equitable outcomes with the reuse of wastewater is a pressing issue. "Wastewater treatment plants in most cities in developing countries are non-existent or function inadequately" [10]. There is little or no wastewater treatment in most cities in developing countries [21] or at least the reuse of poorly treated or untreated wastewater for irrigation is very common [5]. A review by Hamilton et al., 2007 [5] found that approximately one-third of wastewater collected by sewerage systems in Europe is not subject to treatment [5], without specifically stating whether the untreated wastewater is used for irrigation or is simply discharged into waterways to be disposed of.

In many developing countries there is a lack of risk-assessment methods, data for risk quantification and information on the effect of available mitigation measures in terms of safety, risk-reduction potential and economic and cultural acceptability [22]. There are no statutory regulations governing the reuse of wastewater [23]. There is a lack of national institutions responsible for urban and rural sanitation in 10% of countries in Asia, Africa and the Americas. The UNEP has suggested the necessity of reviewing relevant existing institutions in order to undertake wastewater reclamation projects in those countries [2]. There is large-scale water pollution and informal use of wastewater in sub-Saharan Africa exposing many people to serious health risks and the way forward requires a paradigm shift [24]. One of the biggest challenges ahead for those countries whose wastewater reuse practices are lagging is to ensure that highly trained engineers and technologists are used and are able to influence public policy to provide the best environmental and public health outcomes [25]. Social, cultural and religious factors also need to be considered in the Middle East and North Africa [14]. Wastewater reuse practices need to be an integral part of Integrated Urban Water Management (IUWM), a coherent framework of all water management, to assist in establishing standards for water quality and monitoring for public health purposes [26,27].

While wastewater reuse is well established in parts of Asia, especially China, waste-fed aquaculture occurs mostly in parts

of Asia. The intentional use of wastewater in aquaculture is declining due to urbanization, which reduces the amount of land available for ponds, and the switch to high-input aquaculture, which is not compatible with traditional waste-fed practices. The unintentional use of wastewater, excreta and greywater in aquaculture is probably increasing, because surface waters used for aquaculture are increasingly polluted with human waste, and overall aquacultural production is growing [9].

Even in Beijing where there are more than 1,000 policy-driven decentralized wastewater reuse systems in operation, and where it is said that there are adequate technologies to produce water of any quality from wastewater, it is suggested that these systems may “have negative impacts on human health” [15].

Apart from the (direct) use of untreated wastewater for irrigation of crops, there is an unquantifiable indirect use of diluted wastewater that pollutes streams and other waterways which are then used as sources of agricultural irrigation. This occurs in low income countries and fast-growing economies including China, Brazil, Lebanon, Palestine, some countries of North Africa, Spain, Italy, Portugal and Turkey. In Vietnam wastewater is pumped into irrigation canals to supplement irrigation water [10].

It appears that one of the difficulties in increasing the standard of practice with the reuse of wastewater may stem from the rationale of practice between developing countries and developed countries. In the former group of countries their main driver is livelihood dependence and food security, but in developed countries, the main focus is on good environmental practice [5]. We suggest, however, that in the future with water shortages that are expected generally around the world, developed countries will also increasingly consider wastewater reuse as necessary for livelihood and food security reasons. The fertilizing capacity of wastewater is also an attractive reason for its use in irrigation [5] and human excreta has been used as a fertilizer for centuries in many parts of Asia [13].

The public require greater information in relation to rationale for methodology employed and outcomes of health effects research when dealing with recycled wastewater [28]. There are potential adverse health and environmental effects of wastewater reuse which need further investigation [29].

Results and discussion

Measuring faecal indicator organisms and the current state of knowledge in relation to wastewater

Increased use of wastewater needs to be underpinned by sound evidence-based technology, but we suggest that some present approaches are questionable. There is sufficient evidence to question the current approach of water testing of measuring faecal indicator organisms or coliform counts. The evidence suggests that tests carried out in waters for faecal indicator organisms may give an under-representation of the actual water contamination owing to the fact that such organ-

isms are believed to die off at a much more rapid rate than other pathogenic micro-organisms [30] especially relating to viruses [31]. In addition, our concerns relate to a general lack of cognisance of fungi as a potentially pathogenic component of human effluent, as discussed below.

In order to benchmark the state of knowledge relating to wastewater, which will assist in future strategies for its reuse, we have carried out a limited literature search in relation to the composition of human effluent, present indicator organisms and some aspects of die-off rates and survival times of some microbes which are prevalent in human effluent.

Human viral pathogens can be found in water with acceptably low coliform counts [31,32]. Benarde 1982 [33] questioned the reliability of using sample testing for particular bacteria to indicate that viruses were also not present. Some of the reasons he mentioned include that viruses can survive longer than indicator bacteria in the aquatic environment; much smaller quantities of viruses may be necessary to infect a susceptible host compared with bacteria; and water treatment systems are less efficient at removing viruses than bacteria, which is concurred by Okoh et al., 2010 [31].

The Department of Health 1992 [34] advised that faecal coliforms are less effective as indicators of excreted viruses, and of very limited use for protozoa and helminths for which no reliable indicators exist. They also advised that bacteria indicators are not adequate indicators of viral pollution [34]. McBride et al., 1992 [35] advised that “an increasing number of studies are showing the presence of pathogens in waters and shellfish when (faecal) coliforms are either absent or present in low numbers”. They felt that there is a greater die-off of coliforms relative to pathogens under certain circumstances and that disease risk may sometimes be under-estimated by (faecal) coliform densities [35]. Furthermore, Alvarez et al., 1995 [36] cautioned that not all organisms capable of inducing adverse health effects are necessarily able to be detected and cultured under laboratory conditions [36]. El-Abagy et al., 1998 [37] reported that just because a water body may be coliform-free, it is not necessarily pathogen-free [37]. It is suggested that the scientific community has “always been aware that detection and quantification of *E. coli* is not sufficient to define the whole quality of water” [6].

Thus in the spray irrigation of wastewater, coliform bacteria are not ideal indicator organisms in the monitoring of water quality. The following are better indicators: *Salmonella*, *Klebsiella*, *Alcaligenes faecalis*, *Streptococcus*, coliphages [38]. Table 1 lists some commentators who do not include fungi as a pathogen in effluent (not necessarily a comprehensive list), although this is acknowledged by Straub et al., 1993 [39] and found to be the case by us [30].

There are also several types of fungi in wastewater, including *Penicillium* spp., *Paecilomyces*-Thermophilic, *Cladosporium*/*Alternaria*, yeast, and *Aspergillus fumigatus* [30], although Salgot & Huertas 2006 [47] reported that few cases of fungi have been detected and that *E. coli* comprises a small component

Table 1. Descriptions of effluent microbes without inclusion of fungi.

References	Description
[40,41]	The most common types of bacteria in sewage are Enterobacteriaceae (this includes <i>E. coli</i>) and a range of other bacteria.
[42]	<i>Escherichia coli</i> has a better correlation with illness in populations than faecal coliforms for fresh waters but not marine environments
[43]	Domestic wastewater contains a variety of disease-causing bacteria, viruses, protozoa and helminths.
[44]	The survival times in days were considered for bacteria, protozoa, helminths and viruses.
[9]	Pathogenic organisms in excreta include bacteria, helminths, trematodes, protozoa and viruses.
[9]	Water quality monitoring parameters for the use of wastewater in agriculture and aquaculture are based on acceptable levels of <i>E. coli</i> .
[2]	The pathogens in human effluent are bacteria, protozoa, helminths and viruses.
[2,45]	Faecal coliforms are a good indicator of water that is unsafe to drink.
[45]	But faecal coliforms "are less effective as indicators of excreted viruses, and of very limited use for protozoa and helminths for which no reliable indicators exist".
[31]	Many types of viruses.
[46]	"Waterborne infections are caused by infectious agents belonging to three broad groups: bacteria, parasites (protozoa and helminths) and viruses".
[20]	There are two groups of wastewater-related diseases: (1) Viral (rotavirus), bacterial (<i>Campylobacter</i>), protozoa (amoeba, <i>Cryptosporidium</i>) and (2) diseases caused by Helminths' eggs (eg <i>Ascaris</i>).

of the total content of the human bowel [48].

It is apparent from these contradictions that more research is needed to confirm the most accurate basis for establishing water quality, especially with an increasing trend of reusing wastewater.

Aerosols are a form of contamination of wastewater to people and plants [6]. During spray irrigation of wastewater "live bacteria and virus concentrations are reduced almost immediately by mortality from the shock of aerosolisation and by dilution during downwind travel, as well as from dessication and exposure to solar radiation". Slightly conflicting advice is that "a high proportion of aerosols generated from spray irrigation are in the potentially respirable size range of one to five microns" [45]. Vigneswaran and Sundaravadivel 2004 [44] suggested that the "US has not been implicated as the cause of any infectious disease outbreaks", and that there is no evidence of viral or microbial diseases as a result of exposure to effluent aerosols from spray irrigation with reclaimed water [44].

These views are in contrast to earlier findings of Teltsch et al., 1980 [49] who reported on the sprinkler application of wastewater where the aerosols formed had enteric microorganisms 100 times more concentrated than that of the source bulk liquid [49]. This concurs with Blanchard and Syzdek 1982 [50] who found enrichment factors of up to 100 in film drops [50]. The factors involved here are also referred to in the findings of Moore et al., 1988 [51]. Although spray irrigation is an alternative to advanced wastewater treatment, there is the important question of the disposal of pathogenic organisms, especially through downwind travel of aerosols [52]. Of the potential dangers, Bausum et al., 1983 [52] advised that "approximately 75% of the bacteria-bearing aerosol particles at

21 to 30 m. downwind were within the range of pulmonary deposition (1 to 5 μm)". Pathogens, if present, would have ready access to the lower respiratory tract [52]. The risk of inhalation of aerosol-borne viruses by people exposed to spray irrigation with treated sewage necessitates a minimum exposure distance (buffer zone) between sources and people [34,53].

There have been higher viral infection rates amongst study population members who had been exposed to effluent spray aerosols from irrigation projects [51] and there have been hepatitis A outbreaks in Israel communes where spray irrigation of crops with effluent is carried out [54].

The import of contaminated vegetables has led to disease outbreaks in recipient countries as pathogens can be (re) introduced into communities that have no natural immunity to them, resulting in important disease outbreaks [9].

The incidence of infectious disease is two to four times higher in communities practising wastewater irrigation compared with communities which were not [55]. The pathogen level decrease was only minimal when the effluent had been partially treated in oxidation ponds over three to seven days without disinfection. There was a higher increase in cases of influenza from sewage treatment plant workers and the detection of enteric bacteria of sewage origin up to 1200 metres from a trickling filter plant site [55].

Diseases can be spread by the spray irrigation of wastewater [38,49,56]. In samples of air and corresponding wastewater samples at fields where spray irrigation of wastewater took place there were high numbers of salmonella and viruses compared with coliforms, the latter may not be a suitable indicator of airborne contamination in this case [38].

It is apparent from the evidence presented that the survival time of bacteria generally may not be long enough to pose a

danger in the wider context of aerosol transfer. However, the findings have not been consistent, and they have tended to focus on bacteria, especially *E. coli*. This seems to be a problem, as many other harmful bacteria survive longer than *E. coli*, and little account has been taken of other forms of microorganisms, such as viruses, helminths, protozoa and fungi. Fungi, in particular, appear to be prevalent in sewage wastewater, and they are relatively easy to culture and incubate [30]. Diseases related to helminths are most effectively transmitted by irrigation with untreated wastewater because they persist in the environment for relatively long periods [57].

The 2006 WHO guidelines are more performance-based than the 1989 guidelines, as the latter is more focused on health outcomes, using new data from epidemiological studies, although they are “not straightforward for policymakers or practicing engineers to translate them into numerical values that are easy to implement” [58]. The adequacy of the WHO guidelines to protect farmer health has been questioned by Ensink et al., 2008 [11]. An Italian study found contamination by enteric bacteria (*Enterococcus Faecalis*) to varying levels in reused wastewater in Sicily, but this is not considered in the 2006 WHO guidelines [59]. The WHO Guidelines have not considered the limitations in methods in testing of water and this is significant with greater trade in food between countries where reused wastewater has been used for irrigation of the crops, as the guidelines are unlikely to provide equal protection to all populations [43]. Monitoring of treated drinking water (without considering wastewater as a source) has several limitations and it is not adequate in protecting against exposure of consumers to pathogens [60,61]. “Existing surveillance systems are designed for early warning purposes and not to detect low levels of disease in a community”. When dealing with recycled water specific health assessment investigations are required to overcome the inadequacies in existing surveillance systems [28]. Generally epidemiological studies are too insensitive as a means for studying health effects of recycled wastewater which has led to quantitative microbial risk assessment (QMRA) modeling to provide estimates for low level risks of enteric and other diseases [46].

There is a risk of contamination of enteric viruses in treated wastewater, with increased health concerns from the reuse of wastewater for agricultural irrigation [43,62]. There will always be a risk from human pathogens, particularly, viruses, which cannot always be detected [31,63].

The incidence of community-acquired methicillin-resistant *Staphylococcus aureus* (CA-MRSA) infections is increasing in the US, which is believed to be linked to those who are exposed to reclaimed wastewater [64].

Heavy metals, chemicals, hormones and endocrine disrupting chemicals

Apart from the difficulties that many microbiological contaminants pose in relation to assessing the safety of water there are also an increasing number of heavy metals [65]

and endocrine-disrupting chemicals (EDCs) contaminating human effluent [25]. Epidemiological studies show that environmental exposures to low doses of EDCs are associated with human disease and disability [4,10,65,67].

Vandenberg et al., 2012 [67] list 28 EDCs with reported low-dose effects in animals or humans. A US Federal study found 112 toxic materials from everyday life are reaching the Columbia River after having passed through wastewater treatment plants, including flame retardants, pharmaceuticals, pesticides, personal care products, mercury and cleaning products [67].

All human sewage waste-water contains many of these “low-dose” compounds of concern. There is no known sustainable, septic or sewage treatment system, existing or in concept, that can reliably neutralize (or even identify) these compounds. There is a need for changes in chemical testing and safety determination in order to protect human health [67]. This need becomes paramount with an increasing reuse of wastewater as potable water.

Carcinogenic, hormonal, heavy metal and radiological effects must be considered for treatment of recycled water for drinking purposes [28,46] but chronic effects to low levels of chemicals is not well understood requiring further research [46].

Conclusions

The risks associated with populations exposed to recycled wastewater are uncertain and more research is needed before the public will have greater confidence in its use, particularly when used in the irrigation of vegetable crops [43].

With climate change and a burgeoning future world population there will be an increased need to reuse wastewater for a variety of uses including as potable water. Some of the highest population growth rates in the world occur in water-scarce areas of Africa and the Near East [13]. With significant present reuse of wastewater from partial treatment to no treatment at all, there is evidence of disease in some exposed populations.

We suggest that the present methods of testing water quality should be reviewed in relation to indicator organisms, survival times and the potential for fungi as pathogens which are presently not well acknowledged as a component of human waste. In addition, there is a need to improve testing for chemicals, hormones and EDCs. Furthermore, there are no recognised international standards to deal with the many different types of reuse of wastewater and in many jurisdictions there are not the political, governance, cultural and regulatory structures in place to monitor and control. Often the practice has arisen spontaneously and without planning, with different environmental impacts [9]. Regulatory frameworks need to be strengthened to ensure the safe use of new water sources [68]. Risk assessment should pay greater attention to degradation of water supplies and subsequent increasing use of wastewater [69].

Technology transfer is needed to ensure that the most appropriate engineering is implemented, the influence of which

reaches public policy to provide the best environmental and public health outcomes.

The countries with the most rudimentary approach to the reuse of wastewater, such as in the irrigation of crops, are generally under-developed countries with large populations, which comprise a large proportion of countries which will face increasing pressure to further intensify the reuse of wastewater. They generally have less developed political, governance, cultural and regulatory structures in place to monitor and control the process in order to protect public health.

We advocate, as have others, further research in relation to indicator organisms, especially in relation to fungi presence in wastewater, also including chemicals, hormones and EDCs and the potential for disease in a climate change/water shortage/burgeoning world population regime of the future [46]. The research needs to include evaluation of volume of contaminants to which workers may be exposed by inhalation and ingestion of aerosols [46].

Competing interests

The author declares that he has no competing interests.

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References

- McMichael AJ and Lindgren E. **Climate change: present and future risks to health, and necessary responses.** *J Intern Med.* 2011; **270**:401-13. | [Article](#) | [PubMed](#)
- UNEP. **Water and Wastewater reuse: An Environmentally Sound Approach for Sustainable Urban Water Management.** 2005. | [Pdf](#)
- Fürhacker M. **Challenges and solutions for waste and waste water reuse.** *University of Natural Resources and Applied Life Sciences.* | [Pdf](#)
- Hamilton AJ, Versace VL, Stagnitti F, Li P, Yin W, Maher P, Hermon K, Premier RR and Ierodiaconou D. **Balancing environmental impacts and benefits of wastewater reuse.** *WSEAS Transactions on Environment and Development.* World Scientific and Engineering Academy and Society (WSEAS). 2006; **71**:80 | [Pdf](#)
- Hamilton AJ, Stagnitti F, Xiong X, Kreidl SL, Benke KK and Maher P. **Wastewater irrigation: The state of play.** *Vadose Zone J.* 2007; **6**:823-840. | [Article](#)
- Huertas E, Salgot M, Hollender J, Weber S, Dott W, Khan S, Schäfer A, Messalem R, Bis B, Aharoni A and Chikurel H. **Key objectives for water reuse concepts.** *Desalination.* 2008; **218**:120-131. | [Article](#)
- Australian Government. **Water made clear.** A consumer guide to accompany the Australian Drinking Water Guidelines 2004. | [Pdf](#)
- NewScientist. **The city with a brain—Kidneys.** 2010. | [Website](#)
- UNEP. **WHO guidelines for the safe use of wastewater, excreta and greywater.** *World Health Organization.* 2006. | [Website](#)
- Drechsel P, Scott CA, Raschid-Sally L, Redwood M and Bahri A. (eds). **Wastewater irrigation and health – Assessing and mitigating risk in low-income countries.** International Water Management Institute. 2010. Earthscan, the International Development Research Centre (IDRC) and the International Water Management Institute (IWMI). 433. | [Pdf](#)
- Ensink JH, Blumenthal UJ and Brooker S. **Wastewater quality and the risk of intestinal nematode infection in sewage farming families in Hyderabad, India.** *Am J Trop Med Hyg.* 2008; **79**:561-7. | [Article](#) | [PubMed Abstract](#) | [PubMed Full Text](#)
- Owaygen M. **Reflections on financial incentives and their relevance for a safe use of wastewater in agriculture.** *World Water Week.* 2010.
- Moe CL and Rheingans RD. **Global challenges in water, sanitation and health.** *J Water Health.* 2006; **4 Suppl 1**:41-57. | [Pdf](#) | [PubMed](#)
- McNeill LS, Almasri MN and Mizyed N. **A sustainable approach for reusing treated wastewater in agricultural irrigation in the West Bank - Palestine.** *Desalination.* 2008; **251**:315-321. | [Article](#)
- Liang X and van Dijk MP. **Financial and economic feasibility of decentralized wastewater reuse systems in Beijing.** *Water Sci Technol.* 2010; **61**:1965-73. | [Article](#) | [PubMed](#)
- Browne A, Leviston Z, Greenhill MP, Nancarrow BE, Tucker DI and Porter NB. **Structuring dimensions of risk. Technical and community perceptions of risk in the reuse of wastewater for irrigation and indirect potable supply.** *National Research Flagships, CSIRO, Australia.* 2007. | [Pdf](#)
- Australian National MAR Guidelines 2009. **Australian Guidelines 24 for water recycling: Managing health and environmental risks (phase 2) – Managed aquifer recharge.** *National Water Quality Management Strategy.* 2009. | [Website](#)
- Sustainable Water Integrated Management 2014. **Study on the legislative framework regulating the recharge of aquifers with adequately treated wastewater.** *Activity 1.3.4.3. European Union.* 2014. | [Pdf](#)
- Ensink JH and van der Hoek W. **Implementation of the WHO guidelines for the safe use of wastewater in Pakistan: balancing risks and benefits.** *J Water Health.* 2009; **7**:464-8. | [Article](#) | [PubMed](#)
- Seder N and Abdel-Jabbar S. **Safe use of treated wastewater in agriculture – Jordan case study.** *Arab Countries Water Utilities Association (ACWUA).* 2011. | [Pdf](#)
- Qadir M and Wichelms D et al. **Agricultural use of marginal-quality water-opportunities and challenges.** In D. Molden (ed). *Water for food, water for life: A comprehensive assessment of water management in agriculture.* 2007; 425-57. | [Pdf](#)
- Scott C, Drechsel P, Raschid-Sally L, Bahri A, Mara D, Redwood M and Jiménez B. **Wastewater irrigation and health: Challenges and outlook for mitigating risks in low-income countries.** 2015. | [Pdf](#)
- Chen C. **A framework for graywater recycling of household wastewater.** *Polish J. of Environ. Stud.* 2007; **16**:23-33. | [Pdf](#)
- Bahri A, Drechsel P and Brissaud F. **Water reuse in Africa: challenges and opportunities.** 2015. | [Pdf](#)
- Rydin Y, Bleahu A, Davies M, Davila JD, Friel S, De Grandis G, Groce N, Hallal PC, Hamilton I, Howden-Chapman P, Lai KM, Lim CJ, Martins J, Osrin D, Ridley I, Scott I, Taylor M, Wilkinson P and Wilson J. **Shaping cities for health: complexity and the planning of urban environments in the 21st century.** *Lancet.* 2012; **379**:2079-108. | [Article](#) | [PubMed Abstract](#) | [PubMed Full Text](#)
- Bahri A. **Towards Integrated Urban Water Management.** *Perspectives Paper,* Global Water Partnership, Sweden. 2011. | [Website](#)
- Bahri A. **Integrated urban water management.** *TEC Background Paper 16.* Global water Partnership, Sweden. 2012. | [Pdf](#)
- O'Toole J, Leder K and Sinclair M. **Recycled water and human health effects.** *Aust Fam Physician.* 2007; **36**:998-1000. | [Pdf](#) | [PubMed](#)
- Bambrick HJ, Capon AG, Barnett GB, Beatty RM and Burton AJ. **Climate change and health in the urban environment: adaptation opportunities in Australian cities.** *Asia Pac J Public Health.* 2011; **23**:675-79. | [Article](#) | [PubMed](#)
- Walls KL. **Microbiological aerosols in drainage systems.** PhD thesis, The University of Auckland, New Zealand. 1999. | [Article](#)
- Okoh AI, Sibanda T and Gusha SS. **Inadequately treated wastewater as a source of human enteric viruses in the environment.** *Int J Environ Res Public Health.* 2010; **7**:2620-37. | [Article](#) | [PubMed Abstract](#) | [PubMed Full Text](#)
- Croxson, in an appeal under the Water and Soil Conservation Act 1967.** Taylor v Northland Regional Council (1989) BCL. 1699.
- Benarde M. **Indicators and Health Effects, in Bacterial Indicators of Pollution.** Wesley O Pipes (ed.) CRC Press Inc, Florida. 1982.

34. Department of Health. **Public health guidelines for the safe use of sewage effluent and sewage sludge on land.** New Zealand. Department of Health, Wellington, New Zealand. 1992. | [Book](#)
35. McBride G, Cooper A and Till D. **Provisional Microbiological Water Quality Guidelines for Recreational and Shellfish-Gathering Waters in New Zealand.** Department of Health, Wellington. 1992. | [Pdf](#)
36. Alvarez AJ, Buttner MP and Stetzenbach LD. **PCR for bioaerosol monitoring: sensitivity and environmental interference.** *Appl Environ Microbiol.* 1995; **61**:3639-44. | [Article](#) | [PubMed Abstract](#) | [PubMed Full Text](#)
37. El-Abagy MM, Dutka BJ, Kamel M and el Zanfaly HT. **Incidence of coliphage in potable water supplies.** *Appl Environ Microbiol.* 1988; **54**:1632-3. | [Article](#) | [PubMed Abstract](#) | [PubMed Full Text](#)
38. Teltsch B, Kedmi S, Bonnet L, Borenstajn-Rotem Y and Katzenelson E. **Isolation and identification of pathogenic microorganisms at wastewater-irrigated fields: ratios in air and wastewater.** *Appl Environ Microbiol.* 1980; **39**:1183-90. | [Article](#) | [PubMed Abstract](#) | [PubMed Full Text](#)
39. Straub TM, Pepper IL and Gerba CP. **Hazards from pathogenic microorganisms in land-disposed sewage sludge.** *Rev Environ Contam Toxicol.* 1993; **132**:55-91. | [Article](#) | [PubMed](#)
40. Carpenter PL. **Microbiology.** WB Saunders & Co. Philadelphia. 1972.
41. Frobisher M, Hinsdill R, Crabtree K and Goodheart C. **Fundamentals of Microbiology.** 9th ed. W B Saunders Co, Philadelphia. 1974; 707-9.
42. Donnison A and Cooper R. **Enumeration of faecal coliforms and *Escherichia coli* in New Zealand receiving waters and effluents.** *Environmental Technology.* 1990; **11**:1123-27. | [Article](#)
43. Gerba C and Rose J. **International guidelines for water recycling: microbiological considerations.** *Water Science and Technology: Water Supply.* 2003; **3**:311-16. | [Pdf](#)
44. Vigneswaran S and Sundaravadivel M. **Recycle and reuse of domestic wastewater.** *Wastewater Recycle, Reuse and Reclamation.* UNESCO. 2004. | [Pdf](#)
45. Whitehouse L, Wang H and Tomer M. **Guidelines for utilisation of sewage effluent on land.** Part two: Issues for design and management. New Zealand Land Treatment Collective and Forest Research, New Zealand Land Treatment Collective and Forest Research, New Zealand. 2000. 180.
46. O'Toole J. **Identifying gaps and refining estimates of pathogen health risks for alternative water sources.** *Waterlines Report.* 50. Australian Government National Water Commission, Canberra. 2011. | [Pdf](#)
47. Salgot M and Huertas E. (eds). **Guideline for quality standard for water reuse in Europe.** Deliverable D15, AQUAREC-EVK1-CT-2002-00130. 2006.
48. Sussman M. (ed). **The Virulence of *Escherichia coli* - Reviews and Methods.** Society for General Microbiology. Academic Press, London. 1985. | [Book](#)
49. Teltsch B, Shuval HI and Tadmor J. **Die-away kinetics of aerosolized bacteria from sprinkler application of wastewater.** *Appl Environ Microbiol.* 1980; **39**:1191-7. | [Article](#) | [PubMed Abstract](#) | [PubMed Full Text](#)
50. Blanchard DC and Syzdek LD. **Water-to-Air Transfer and Enrichment of Bacteria in Drops from Bursting Bubbles.** *Appl Environ Microbiol.* 1982; **43**:1001-5. | [Article](#) | [PubMed Abstract](#) | [PubMed Full Text](#)
51. Moore B, Camann D, Turk C and Sorber C. **Microbial Characterization of Municipal Wastewater at a Spray Irrigation Site: The Lubbock Infection Surveillance Study.** *Journal (Water Pollution Control Federation).* 1988; **60**:1222-30. | [Article](#)
52. Bausum H, Schaub S, Bates R, McKim H, Schumacher P and Brockett B. **Microbiological aerosols from a field-source wastewater irrigation system.** *Journal of the Water Pollution Control Federation.* 1983; **55**:65-75. | [Article](#)
53. Adams AP and Spendlove JC. **Coliform aerosols emitted by sewage treatment plants.** *Science.* 1970; **169**:1218-20. | [Article](#) | [PubMed](#)
54. Gust I and Feinstone S. **Hepatitis A.** CRC Press, Florida. 1988.
55. Katzenelson E, Buim I and Shuval HI. **Risk of communicable disease infection associated with wastewater irrigation in agricultural settlements.** *Science.* 1976; **194**:944-6. | [Article](#) | [PubMed](#)
56. Teltsch B and Katzenelson E. **Airborne enteric bacteria and viruses from spray irrigation with wastewater.** *Appl Environ Microbiol.* 1978; **35**:290-6. | [Article](#) | [PubMed Abstract](#) | [PubMed Full Text](#)
57. Shuval H and Fattal B. **Control of pathogenic microorganisms in wastewater recycling and reuse in agriculture.** *The Handbook of Water and Wastewater Microbiology, Elsevier.* 2003. | [Pdf](#)
58. Mara DD and Kramer A. **The 2006 WHO guidelines for wastewater and greywater in agriculture: A practical interpretation.** In Al Baz I., Otterpohl I., Wendland C. (eds). *Efficient Management of Wastewater: Its Treatment and Reuse in Water Scarce Countries:* Springer, Heidelberg. 2008; 1-17. | [Pdf](#)
59. Aiello R, Cirelli GL, Consoli S, Licciardello F and Toscano A. **Risk assessment of treated municipal wastewater reuse in Sicily.** *Water Sci Technol.* 2013; **67**:89-98. | [Article](#) | [PubMed](#)
60. Rizak S, Cunliffe D, Sinclair M, Vulcano R, Howard J, Hruddy S and Callan P. **Drinking water quality management: a holistic approach.** *Water Sci Technol.* 2003; **47**:31-6. | [Article](#) | [PubMed](#)
61. Sinclair M and Rizak S. **Drinking-water quality management: the Australian framework.** *J Toxicol Environ Health A.* 2004; **67**:1567-79. | [Article](#) | [PubMed](#)
62. Campos C. **New perspectives on microbiological water control for wastewater reuse.** *Desalination.* 2008; **218**:34-42. | [Article](#)
63. Fane SA, Ashbolt NJ and White SB. **Decentralised urban water reuse: the implications of system scale for cost and pathogen risk.** *Water Sci Technol.* 2002; **46**:281-8. | [Pdf](#) | [PubMed](#)
64. Rosenberg Goldstein RE, Micallef SA, Gibbs SG, Davis JA, He X, George A, Kleinfelter LM, Schreiber NA, Mukherjee S, Sapkota A, Joseph SW and Sapkota AR. **Methicillin-resistant *Staphylococcus aureus* (MRSA) detected at four U.S. wastewater treatment plants.** *Environ Health Perspect.* 2012; **120**:1551-8. | [Article](#) | [PubMed Abstract](#) | [PubMed Full Text](#)
65. Toze S. **Reuse of effluent water-benefits and risks.** *Agric. Water Manage.* 2006; **80**:147-159. | [Article](#)
66. Helland J. **Endocrine disrupters as emerging contaminants in wastewater.** *Information Brief.* 651-296-5039. Minnesota House of Representatives Research Department. 2006. | [Pdf](#)
67. Vandenberg LN, Colborn T, Hayes TB, Heindel JJ, Jacobs DR, Jr., Lee DH, Shioda T, Soto AM, vom Saal FS, Welshons WV, Zoeller RT and Myers JP. **Hormones and endocrine-disrupting chemicals: low-dose effects and nonmonotonic dose responses.** *Endocr Rev.* 2012; **33**:378-455. | [Article](#) | [PubMed Abstract](#) | [PubMed Full Text](#)
68. Campbell-Lendrum D, Corvalan C and Neira M. **Global climate change: implications for international public health policy.** *Bull World Health Organ.* 2007; **85**. | [Article](#)
69. Campbell-Lendrum D, Bertollini R, Neira M, Ebi K and McMichael A. **Health and climate change: a roadmap for applied research.** *Lancet.* 2009; **373**:1663-5. | [Article](#) | [PubMed](#)

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