Potential links between irrigation water quality and microbiological quality of food in subsistence farming in KwaZulu-Natal, South Africa

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To lead a healthy lifestyle, it is essential to have a diet that includes fresh and minimally processed fruit and vegetables. A large proportion of the South African population exhibits suppressed immune systems, largely due to the HIV/AIDS epidemic. It is therefore imperative that minimally processed foods are not contaminated with potentially pathogenic microorganisms. As a result of local fresh water scarcity, many farmers resort to using surface water for irrigation. Due to a large number of informal settlements located near river systems lacking adequate sanitation, South Africa's rivers are prone to microbial pollution. A selected river in KwaZulu-Natal (South Africa), as well as fresh vegetables irrigated with this water, were therefore analysed to verify whether a transfer of potential pathogens onto produce might take place. The river selected was the Baynespruit, which is used to irrigate a local market garden. Microbiological analysis (for example detection of faecal coliforms) of river water and fresh produce was conducted using standard procedures. Both irrigation water and fresh produce samples showed the presence of faecal coliforms and *E. coli* with the microbial load of river water typically several times higher than the values recommended by WHO guidelines for safe use of wastewater. This demonstrates that the transfer of river bound microorganisms via irrigation water to fresh produce can take place and might therefore lead to fresh produce contamination at unacceptable levels.

Keywords Irrigation water; microbial water quality; greywater; wastewater; pathogens; food safety; PCR; minimally processed foods; water treatment.

1. Shortages of potable water and its implications

1.1 Shortages of potable water

Water is important in the production, preparation and processing of many foods thereby making it important for the purity and safety of the end product [1]. Worldwide infectious diseases continue to be one of the leading causes of mortality [2]. Wastewater - or the so called greywater which is usually referring to domestic wastewater - has always been used for the irrigation of agricultural crops. The nutrients present in the wastewater were regarded to be beneficial to the growth of the crops [3]. Wastewater is defined by Huibers and Van Lier [4] as water containing chemicals, organic material or pathogens as a result of domestic or industrial processes. Due to rapid population growth, urban development and climate change, the availability and quality of water sources are diminishing [5] and therefore, risks might be involved with using untreated wastewater. Urbanisation leads to an increase in water use, thereby increasing wastewater flows. At the same time the increase in population results in an increasing demand on the agricultural sector to produce sufficiently which in turn is causing farmers to become very reliant on wastewater use [4]. Indeed, the agricultural sector is experiencing rising pressure to meet the steadily growing food demands both globally [5] as well as in Africa [6].

With regards to informal farming or market gardening (that is small scale cultivation of crops for sale to the local market) [7], the use of potable water is expensive and there are difficulties in conveying it to crops due to the lack of infrastructure. Therefore, albeit potable water might be available, its use can nevertheless be restricted. The alternative option is the use of adjacent surface water such as from streams and lakes as well as including wastewater for irrigation. However, the use of these alternative water sources poses potential risks due to the presence of microbial pathogens that have entered the environment via the faeces of infected livestock or human hosts [4].

1.2 Quality of alternative water sources

Alternative water sources for crop irrigation are treated or untreated wastewater, including the so called greywater, as well as surface water collected from rivers and streams. Low income countries such as Ghana use irrigation water heavily polluted with untreated wastewater [3]. This is mainly due to poor sanitation in urban areas [8]. Amoah *et al.* [9] found that some irrigation water used on urban vegetable farms in Ghana had high levels of microbial contamination that exceeded World Health Organization (WHO) recommendations for unrestricted irrigation [10-13]. As overhead irrigation is common in Ghana and some vegetables grown can be eaten raw, a high level of microbial contamination in the water used for this type of irrigation is therefore raising concerns with regards to public health [14]. Another more attractive option for irrigation is through the use of low cost plastic water tanks to collect rainwater run-off during the rainy season [6]. However, there are risks involved with this method as animal faecal contamination (such as from birds) can still occur and it does require sufficient rainfall.

1.3 Advantages of wastewater use

The use of wastewater does, however, have advantages. First of all, it has the potential to satisfy the fast growing water demands, thereby conserving potable water. It can also contribute to reducing the application rate of fertilizer by farmers as wastewater may contain sufficiently high concentrations of organic and inorganic nutrients [15, 16]. In the case of improved fertilization via the use of wastewater, poorer communities farming at subsistence level can improve their nutritional status by potentially increasing their food supply and quality given that the microbiological quality of the wastewater used is sufficient [3]. Communities lacking access to potable water may not have an alternative to using wastewater as it constitutes the only feasible way ensuring crop output. In some semi-arid countries such as Pakistan, rural farmers have been granted approval by their local municipality to use untreated sewage on their farmlands. In addition, these farmers apparently prefer to use untreated wastewater (as opposed to treated) as it has a higher nutrient value, that way saving on fertilizer costs [3, 17]. Wastewater using farmers have been seen to make a higher income than non-wastewater using farmers as they save on fertilizer inputs. In addition, they can cultivate non-indigenous vegetables [18] and are able to plant all year round (unaffected by droughts) thereby increasing their profits through multiple cultivation cycles [3, 17]. In Pakistan for example, the gross margin of wastewater using farmers compared to clean canal water using farmers was considerably higher [17]. Therefore, the use of wastewater allows, in principle, for increased productivity, income and improved livelihoods [3]. In addition, Haruvy [19] stated that wastewater irrigation has the potential to reduce treatment costs as soil and crops can serve as biofilters and would therefore contribute to reducing the amount of wastewater to be treated in wastewater treatment plants (WWTPs).

This shows the importance of wastewater in agriculture and how banning its use would impact on urban food supply and productivity of small scale farmers. If its use were to be prohibited due to health concerns, alternatives would need to be supplied to farmers that use wastewater as its use provides the community better access to food and a reliable source of income [3].

1.4 Deteriorating quality of water sources

Unfortunately, given the positive factors associated with the use of wastewater, public health risks remain a concern for both the farming community and consumers [3, 13, 15, 20, 21].

South Africa's (as well as Africa's) rate of urbanisation and population growth has resulted in an increasing demand for water, placing strain on existing resources [3]. The escalating population growth, urbanisation and industrialisation resulted in mostly inadequate sanitation in the urban and sub-urban areas, leading to water sources becoming polluted with untreated wastewater [22, 23]. South Africa, like many countries in West Africa, has a large proportion of its population living in informal settlements and low cost housing, people who rely on subsistence farming and market gardening as their livelihood [7]. The lack or unreliability of the supply of potable water available to many of these residents, forces them to become reliant on other water sources [22]. Hence, rivers are used as a source of water both for crop irrigation as well as for domestic personal use such as washing, drinking and cooking without prior treatment [3]. Because of the lack of infrastructure in these settlements, the residents are forced to settle along river banks, and without sufficient sanitation this further contributes to the diminishing water quality. Unfortunately, those areas that do have water treatment facilities are finding renewed problems as the infrastructure used for storage and treatment of the wastewater is deteriorating. It appears that too much emphasis has been placed on supplying communities with potable water while at the same time the essential maintenance of the existing wastewater treatment infrastructure was neglected [24].

1.5 International significance

The irrigation water quality is of international importance because products exposed to microbiologically contaminated water may put consumers at risk both locally and internationally. As the international trade of agricultural products is growing, the export of fresh produce that is contaminated could assist in spreading potential pathogens and strains with new virulence characteristics into areas where previously such pathogens were not present, or were at least absent for a number of years [25].

2. Links between water quality and food safety

On August 15, 2006, a deadly outbreak of *Escherichia coli* O157:H7 (a so called enterohaemorrhagic strain of *E. coli* (i.e. EHEC)) was linked in California (USA) to spinach harvest [26, 27]. The outbreak led to three deaths and 205 illnesses (including haemolytic uremic syndrome); many of these illnesses were severe. Officials concluded that the contamination was caused by either the mixing of groundwater with contaminated surface water or via vectoring of wildlife, most likely feral pigs [27, 28]. Outbreaks of food borne infections associated with the consumption of raw vegetables or fruits are frequently reported [29-31], probably because consumers increasingly consume fresh and minimally processed produce. The presence of potential pathogens on a large variety of fruits and vegetables is indeed well established [32]. Pathogenic organisms are one of the main health risks when wastewater is used for irrigation [21].

There is ample evidence indicating the presence of excreted pathogens on the surfaces of vegetables that were irrigated or fertilized with faecal products [21]. It was clearly demonstrated that pathogenic microorganisms (including bacteria, viruses and protozoa) and other organisms causing disease such as helminths, are highly abundant in raw and partially treated wastewater [21]. These authors also found that such microorganisms can survive for days, weeks or even months on crops that have been contaminated through the use of microbially polluted wastewater for irrigation. The survival of pathogens on plants is influenced largely by ecological factors such as weather conditions [32]; warmth, exposure to sunlight and low humidity are detrimental for pathogen survival. Survival times were therefore higher in areas of vegetables and salad crops protected from desiccation (such as leafy vegetables like lettuce or cabbage). Both field and laboratory studies conducted by Shuval *et al.* [21] demonstrated that pathogens present in raw wastewater can survive extended periods of time in soil and on crops, thereby allowing some of these pathogens to survive harvesting and subsequent processes such as packaging to finally reach the consumer. Staff working in the agricultural production and processing of fresh produce involving wastewater and wastewater irrigated soil and crops are exposed to potentially pathogenic microorganisms present. Whether people become infected or sick after consuming wastewater irrigated vegetables depends on a number of additional factors such as the minimal infectious dose for a particular microorganism, the level of immunity and simultaneous contamination through other routes [21]. The so called YOPI group comprising **y**oung, **o**ld, **p**regnant and **i**mmune compromised subjects is generally considered as being most vulnerable to pathogens present on fresh produce. Usually, it is assumed that bacteria are not able to actively penetrate undamaged vegetable skins. However, a recent study indicates that *Salmonella* spp. present on the surface of plants cannot only survive for extended periods [33], but might overcome the innate immune response of plants [34] and actively enter the plant via the stomata as was demonstrated for lettuce [35]. This means that if fresh produce were to be contaminated by irrigation using microbially polluted water, the microbes present on the plant surface might escape post harvest treatment procedures.

The World Health Organisation (WHO) published guidelines in 1989 and 2006 for the microbial quality of treated wastewater as well as excreta and greywater that can be safely used in agriculture [10-12]. According to these WHO guidelines, the number of faecal coliforms per 100 ml must not exceed 1000 [10-12]. Therefore a microbial analysis of irrigation water and fresh produce (irrigated with this water) was conducted over a period of 6 months targeting relevant water quality indicators suggested by the WHO. Samples were collected from the Baynespruit River in Sobantu, Pietermaritzburg (KwaZulu-Natal, South Africa). The analysis revealed the presence of *E. coli* in both the water and on produce samples. Table 1 shows the total coliform and faecal coliform counts obtained in January 2010 (month of high rainfall) and April 2010 (low rainfall) for river water and irrigated produce.

Table 1 Microbiological analysis of river water and fresh produce targeting relevant hygiene indicator bacteria. Both the water used for irrigation and the fresh produce irrigated using this water were sampled at the Baynespruit River in Sobantu, Pietermaritzburg (KwaZulu-Natal, South Africa).

	January 2010	**April 2010**
pH	8.40	7.67
Water temperature	22.40	20.2
Monthly rainfall (mm)*	136	7.8
Total coliforms		
Irrigation water (MPN per 100 ml)	>160 000	33 000
Parsley (MPN per gram)	>160 000	1100
Faecal coliforms		
Irrigation water (MPN per 100 ml)	35 000	7 000
Parsley (MPN per gram)	160 000	130
WHO recommendation (Faecal coliforms per 100 ml)	1 000	1 000
Presence of *E. coli*	Present**	Present**

* Personal communication, Steve Terry, Umgeni water, Pietermaritzburg.
** Confirmed using the method MFHPB-19 suggested by Health Canada [36] and a PCR based approach.

These data strongly indicate a possible transfer of microorganisms from wastewater to fresh produce. However, these findings are not sufficient evidence to imply that humans are becoming ill as a result of contaminated produce; these results merely confirm the risks involved with using microbially contaminated wastewater for irrigation.

In addition to the well established cultural method [36] we also confirmed the presence of *E. coli* in samples by targeting its DNA (i.e. the gadA gene which encodes glutamate decarboxylase A) using previously tested and published primers [37-39]. Samples showing gas formation in EC broth after incubation at 45°C, as well as typical coliform or *E. coli* colonies on EMB agar were directly analyzed by polymerase chain reaction (PCR) for the presence of *E. coli* by using 100 µl EC-broth from a positive tube and a typical colony.

Using a PCR based method to confirm the presence of *E. coli* either directly in EC-broth or by using typical MUG+/MUG- colonies suspected to be *E. coli* (for example on EMB plates) might improve the reliability of *E. coli* detection as it is known that phenotypic features such as the β-glucuronidase activity are sometimes repressed on carbohydrate rich media whilst the genotype can be detected [38, 40].

3. Treatment options

The treatment of wastewater implies its purification until its characteristics achieve a certain objective. This can be in terms of health, environmental or economic objectives. There are a number of well established treatment options available such as waste-stabilisation ponds (WSPs), aerobic systems (i.e. activated sludge) and anaerobic digesters [4]. According to Mara [41], WSPs can reduce wastewater irrigation risks significantly as they were shown to be particularly effective, compared to other treatment processes such as tertiary processes, in lowering *E. coli* counts. Mara [41] stated that a properly designed WSP can reduce the *E. coli* count from 10^7 per 100 ml to less than 10^3 per 100 ml, thereby meeting the WHO guideline for untreated irrigation via a 4 log unit removal. In addition, WSPs were seen to lower the total bacterial count by up to 6 log units and the viral count by 4 log units [41]. However, if no such stabilisation pond treatment is employed to reduce the number of pathogenic microorganisms present in wastewater or the reduction is not sufficient, additional tertiary treatments such as chemical disinfection (i.e. ozonation, chlorination), UV irradiation, activated carbon treatment, membrane filtration and reverse osmosis [42, 43] can be employed. In fact, water treatment can be classified into 3 processes: the preliminary and primary treatment eliminates course material and suspended solids through the use of physical processes (flotation and settling); the secondary treatment eliminates dissolved organic matter via the catabolic activity of microscopic organisms (i.e. mainly bacteria); and finally, the tertiary treatment is supposed to remove microorganisms including pathogens and remaining nutrients by chemical, photochemical and biological means [4].

The level of treatment for wastewater depends on the economic situation and infrastructure available for water collection and treatment, as well as on the farmer's needs and policies implemented by governments for the use of wastewater [4]. It is important that the wastewater is treated sufficiently to meet the WHO recommended levels [10-12] for safe irrigation (less than 1000 faecal coliforms per 100 ml) prior to use for irrigation. Otherwise the potential risks associated with the consumption of irrigated produce are unacceptable for susceptible consumers such as the YOPI group [44]. Therefore, farmers that use only partially treated or untreated wastewater may be legally bound to use only a limited range of crops. In addition, they might be forced to sell their produce at a lower price [4]. Farmers relying on small scale gardens, however, may not be aware of the implications of using potentially contaminated (i.e. microbially that is) wastewater in irrigation. As a consequence, they might place consumers at risk. As there is, unfortunately, a lack of adequate treatment facilities available in many parts of the world, this leads to an increased use of partially treated and untreated wastewater for irrigation [4]. Source treatment (i.e. on farmlands) of wastewater may not be feasible in the short term to reduce the potential risks associated with wastewater irrigation. Waste stabilisation ponds cannot be constructed on all farms given that, particularly on small plots, space might be limited. In sub-Saharan Africa, small-scale farming makes up 96 percent of the total farming community. Its population growth is faster than any other region in the world with estimates showing an increase by almost 400 million by 2025. Coupled with this, climate change could result in a loss of 247 million acres of farmland by 2050, placing further pressure on the environment for available arable land [6].

Ponds (usually less than 5 m in diameter and 1 m deep), are widely used for irrigation in Ghana's urban vegetable farms. They are generally used as storage reservoirs where surface run-off and wastewater is channelled for irrigation. Given that sufficient settling time is provided, the sedimentation of pathogens may take place, potentially making these on-farm sedimentation ponds a simple and cheap method of reducing pathogen levels in irrigation water. Keraita *et al.* [14] assessed the potential of using on-farm ponds to reduce microbial contamination in wastewater-contaminated irrigation water. However, for thermo-tolerant coliforms the duration required to achieve a relevant reduction was relatively long (at least six days) and a considerable reduction occurred only during the dry season. Unfortunately, it is difficult for farmers to leave water even to settle for three days over the dry season, due to water scarcity. The authors indicated that methods to enhance sedimentation and faecal coliform die-off (such as the addition of natural flocculants) would be useful. On the more positive side they demonstrated that an average of two-thirds of helminth eggs in on-farm ponds were present in sediments thereby indicating that these ponds, given careful collection of water without disturbing sediments, could reduce the number of helminth eggs present in irrigation water. The settlement of helminth eggs took place predominantly in one day, while three days of settlement reduced the number to less than 1 egg per litre [14], thereby meeting the relevant WHO guidelines [10-12]. On farm wastewater treatment has the potential to reduce helminth eggs sufficiently but potentially pathogenic microorganisms only to a lesser extent given short settling periods.

Hence measures such as safer irrigation practices would need to be implemented alongside on-farm sedimentation ponds for increased food safety [14].

4. Conclusion

The use of wastewater for irrigation has numerous benefits, especially as water shortages are becoming a growing problem. There are, however, factors that need to be taken into account when using wastewater in agriculture. The main reason for concern is the presence of pathogens as they have the potential to cause disease in susceptible consumers. This potential risk can be minimized through the proper use of water, proper produce treatment as well as through effective agricultural processes. Clearly more research needs to be conducted to develop cheap but more effective methods for small scale farmers to lower microbial loads in wastewater used for irrigation.

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