BENEFITS AND RISKS OF WASTEWATER USE IN AGRICULTURE

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ABSTRACT

Wastewater use in agriculture has substantial benefits, but can also pose substantial risks to public health especially when untreated wastewater is used for crop irrigation. Farmers often have no alternative but to use untreated wastewater because there is no wastewater treatment and freshwater is either unavailable or too expensive. The major risks to public health are microbial and chemical. Wastewater use in agriculture can also create environmental risks in the form of soil and groundwater pollution. However, if properly planned, implemented and managed, wastewater irrigation can have several benefits for the environment, as well as for agriculture and water resources management. Given these risks and benefits, countries seeking to improve wastewater use in agriculture must reduce the risks, in particular to public health, and maximize the benefits.

KeyWords : WasteWater ,Agriculture , Benefit , Risk

1 . INTRODUCTION

Wastewater use is a growing practice worldwide. As freshwater sources become scarcer, wastewater use has become an attractive option for conserving and expanding available watersupplies. Wastewater use can have many types of applications, including irrigation of agricultural land, aquaculture, landscape irrigation, urban and industrial uses, recreational and environmental uses, and artificial groundwater recharge (Asano et al., 2007). Principally,

wastewater can be used for all purposes for which freshwater is used, given appropriate treatment. With a few exceptions worldwide, wastewater use applications are restricted to nonpotable uses, or at most to indirect potable uses.

Wastewater use in agriculture is by far the most established application, and the one with thelongest tradition. In most cases the irrigated lands are located in or near the urban areas where the wastewater is generated. Estimates on wastewater use worldwide indicate thatabout 20 million hectares or agricultural land is irrigated with (treated and untreated) wastewater (Jiménez and Asano, 2008). Especially in lower income countries and in arid and semi-arid high-income countries, wastewater irrigation is the most prominent and also the most rapidly expanding wastewater use. Besides increasing water stress, drivers for the expansion include increasing urbanization, growing urban wastewater flows due to the expansion of water supply and sewerage services, and more urban households engaged in agricultural activities that could be intensified with additional sources of irrigation water.

The problem with this growing trend toward more agricultural wastewater use is that in lowincome countries, but also many middle-income countries, the practice either involves the direct use of untreated wastewater or the indirect use of polluted waters from rivers and streams. With freshwater either unavailable or too expensive, and wastewater treatment not keeping up with urban growth, urban farmers often have no alternative but to use highly polluted water. Many of them belong to the urban poor who depend on agricultural activities as a source of income and employment generation as well as food security (UNDP, 1996;World Bank, 2000).

Especially when untreated wastewater is used for crop irrigation, it poses substantial risks to public health, not only to the farmers, but also the surrounding communities and the consumers of the crops. The biggest risk to health is microbial risk which arises due to pathogens , i.e. disease-causing organisms, that are usually present in untreated or partially treated (and to some level also in treated) wastewater (Feachem et al., 1983). Many excretarelated diseases can be spread by wastewater use in agriculture to those working in the wastewater-irrigated fields and those consuming wastewater-irrigated foods, especially when eaten uncooked. However, the consumption of wastewater-irrigated foods is only one possible route of transmission, and this route may or may not be of local public health importance.

2.Benesits of WasteWater use in Agriculture

2.1.Benefits For Agriculture

- Reliable, and possibly less costly irrigation water supply .
- Increased crop yields, often with larger increases than with freshwater due to the wastewater's nutrient content .
- More secure and higher urban agricultural production, and contribution to food security .
- Income and employment generation in urban areas
- Improved livelihoods for urban agriculturalists, many of whom are poor subsistence farmers, including a large share of women .

2.2.Benefits for water resources management

- Additional drought-proof water supply, often with lower cost than expanding supplies through storage, transfers, or desalinization
- More local sourcing of water
- Inclusion of wastewater in the broader water resources management context
- More integrated urban water resources management

2.3. Environmental benefits

If wastewater use schemes are managed well, they can have several environmental benefits (Mara and Cairncross, 1989):

- Avoidance of surface water pollution, which would occur if the wastewater were not used but discharged into rivers or lakes. Major environmental pollution problems, such as dissolved oxygen depletion, eutrophication, foaming, and fish kills, can thereby be avoided.
- Conservation or more rational use of freshwater resources, especially in arid and semi-arid areas—i.e. fresh water for urban demand, wastewater for agricultural use.
- Reduced requirements for artificial fertilizers, with a concomitant reduction in energy expenditure and industrial pollution elsewhere.
- Soil conservation through humus build-up and through the prevention of land erosion.
- Desertification control and desert reclamation, through irrigation and fertilization of tree belts.

3 . Risks of wastewater use in Agriculture

3. 1. Microbial risks

The pathogens present in wastewaters are the agents of excreta-related diseases and so comprise the viruses, bacteria, protozoa and helminths that cause these diseases . The diseases in the community caused by these pathogens may be endemic—i.e., the diseases are maintained within the community by continuous transmission between community members—or they may occur as epidemics—i.e., they are introduced to susceptible communities by persons from outside the community.

Many excreta-related diseases can be spread by wastewater use in agriculture to those working in wastewater-irrigated fields and/or those consuming wastewater-irrigated foods, especially when eaten uncooked (e.g., salad crops and some vegetables) (Table 1). However the consumption of wastewater-irrigated foods is only one possible route of transmission, and this route may or may not be of local public health importance.

Table 1 Environmental classification of excreta-related diseases important in wastewater-irrigated agriculture

Category	Environmental transmission featuresa	Major examples	Exposed groups and relative infection risksb,c
Non-bacterial feco-oral diseases	Non-latent Low to medium persistence Unable to multiply High infectivity	Viral diseases: Hepatitis A, E and F Diarrhea due to rotavirus, norovirus and adenovirus Protozoan diseases: Amebiasis Cryptosporidiosis Giardiasis Diarrhea due to Cyclo-spora cayetanensis, Enterocytozoon bienusi and Isopora belli	Fieldworkers: + Consumers: +++
Bacterial feco-oral diseases	Non-latent Medium to high persistence Able to multiply Medium to low infectivity	Campylobacteriosis Cholera Pathogenic Escherichia coli infections Salmonellosis Shigellosis	Fieldworkers: + Consumers: +++
Geohelminthiases	Latent Very high persistence Unable to multiply High infectivity	Ascariasis Hookworm infection Trichuriasis	Fieldworkers: +++ Consumers: +++

[a] Latency is the length of time required outside a human host for the pathogen to become infective, andpersistence is the length of time the pathogen can survive outside a human host.

[b] +++ = high risk, + = low risk. These risks refer to the use of untreated wastewater for crop irrigation; they canbe reduced by wastewater treatment and the use of the post-treatment health-protection control measures .

[c] Note that fieldworkers are often also consumers.

3 .1.1Transmission of microbial disease through wastewater

The available good-quality epidemiological evidence on the health risks due to wastewater use in agriculture was first reviewed by Shuval et al. (1986). The main findings from their study were:

- soil-transmitted helminthic infections represented the major actual and potential health risk to both those working in wastewater-irrigated fields and those consuming wastewater-irrigated foods uncooked when untreated wastewater was used for crop irrigation, but not when treated wastewater was used.
- bacterial feco-oral diseases, such as diarrhea and cholera, can be transmitted to those consuming wastewater-irrigated salad crops and raw vegetables.

There was less compelling evidence for the transmission of viral and protozoan diseases. Blumenthal and Peasey (2002) reviewed the epidemiological evidence reported after the study by Shuval et al. (1986). The main findings of their study were:

- Unrestricted irrigation: The use of untreated wastewater to irrigate vegetables led to increased helminth infection (mainly Ascaris lumbricoides infection), bacterial infections (typhoid, cholera, Helicobacter pylori infection), and symptomatic diarrheal disease in consumers. When wastewater was partially treated, there was evidence that the risk of bacterial and viral enteric infections was still significant when consumers ate some types of uncooked vegetables irrigated by water containing $\geq 10^5$ fecal coliforms per 100 mL .
- Restricted irrigation: Studies of the risks of viral and bacterial enteric infections related to use of treated wastewater suggested that when sprinkler irrigation was used and the population was exposed to wastewater aerosols, there was an increased risk of infection when the quality of the wastewater was 10^6 total coliforms per 100 mL, but no increased risk of infection when the quality of the wastewater was $10^3 - 10^4$ fecal coliforms per 100 mL. Studies of the risks of symptomatic diarrheal disease and enteric viral infections related to direct contact with treated wastewater through farm work (adults and children) or play suggested that, when flood or furrow irrigation occurs, there was an increased risk of infection in children when the quality of the wastewater was $>10^4$ fecal coliforms per 100 mL. For adults, the threshold level for symptomatic diarrheal disease was 10^5 fecal

coliforms per 100 mL, but the threshold level for transmission of a Mexican strain of norovirus was $<10^4$ fecal coliforms per 100 mL where high levels of contact occurred, even in a rural area where there were many other transmission routes for this virus.

Shuval et al. (1986) showed that, when untreated wastewater was used for irrigation, there was an excess prevalence (and also an excess intensity of infection) of ascariasis and hookworm disease in fieldworkers compared with a control group (Figure 1), but not when treated wastewater was used. Blumenthal and Peasey (2002) confirmed this for both geohelminthic and bacterial diseases.

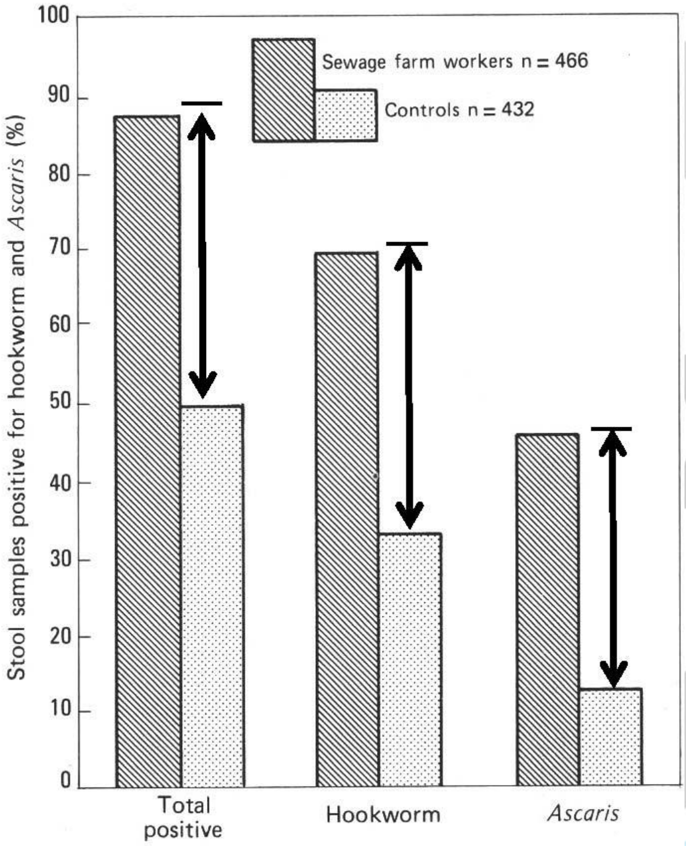

Figure 1 Prevalence of ascariasis and hookworm disease in 'sewage farm' workers in India using untreated wastewater for irrigation compared with a control group

3. 2 . Chemical risks

3 .2.1 . *Chemical risks to human health*

Health risks from chemicals are caused by heavy metals (e.g., cadmium, lead, and mercury) and many organic compounds (e.g., pesticides). These mostly derive from industrial wastewaters and, if these are discharged to public sewers, they are present in municipal wastewaters. The health effects of prolonged exposure to many of these chemicals is well known (e.g., cancers). There is an emerging class of chemical contaminants, the so-called ‘anthropogenic’ compounds, which include pharmaceuticals, hormones and endrocrine disruptors, antimicrobials and antibiotics, and personal care products, the long-term health effects of which are less clearly understood (Bhandari et al., 2009).

Chang et al. (2002) reviewed the principal chemical risks to human health resulting from the consumption of wastewater-irrigated foods. They found that:

- Land application has been a popular option for disposing of municipal wastewater and sewage sludge worldwide for more than a century. While most of the operations appear to be successful, reports from countries such as China suggested that large-scale irrigation of crops with mostly untreated municipal and industrial wastewaters could be harmful to crops and cause injuries to humans because of poorly controlled discharge of toxic and hazardous constituents in the wastes.

- Concentrations of potentially hazardous pollutants in the municipal wastewater and the resulting sewage sludge varied considerably from location to location and, for the same community, were subject to temporal variations due primarily to point-source discharges from industries. The frequency of detection for inorganic pollutants, such as the trace elements in the wastewater, usually ranges from 50 to 100 percent and they are invariably concentrated into the sewage sludge in the course of wastewater treatment. The frequency of detection for organic pollutants was considerably lower. They range usually from 5 to 10 percent and their concentrations, when found, were low. Community-wide industrial wastewater pretreatment provisions to prevent the discharge of pollutants by industries have been effective in reducing the pollutant concentrations in wastewater and sewage sludge.

Chang et al. (2002) developed the following two principles to minimize chemical risks to human health:

- Prevent pollutant accumulation in waste-receiving soils: In land application, if the pollutant input equals the pollutant output, there will not be a net accumulation of pollutants in the receiving soil. Consequently, the pollutant contents of the soil will remain at the background level and the soil's ecological and chemical integrity are preserved. When this requirement is met, the capacity of the soil to sustain any future land uses is guaranteed and the transfer of pollutants up the food chain is kept to a minimum. Numerical limits, therefore, are set to prevent the pollutant concentration of the soil from rising during the course of land application. Guidelines derived from this approach will have stringent upper limits for pollutants and are universally applicable. The cost of implementation will be high, however, as wastewater treatment plants need to employ advanced wastewater treatment technologies to minimize the pollutant levels in the reclaimed wastewater and sewage sludge.

- Take maximum advantage of the soil's capacity to assimilate, attenuate, and detoxify pollutants: Soils possess natural abilities to assimilate, attenuate, and detoxify pollutants. In land applications, this capacity should be fully utilized. In this manner, the agronomic benefits of applying wastewater and sewage sludge may be realized and, when managed properly, accumulation of pollutants in soil can be controlled so that they will not reach levels harmful to human health. Land application guidelines based on this approach set the maximum permissible pollutant loading and provide users the flexibility to develop suitable management practices for using wastewater and sewage sludge within the boundary. However, under this scenario, pollutant levels in the soil will rise eventually to levels considerably higher than the background levels, and future land uses may be restricted. Furthermore, the technical data needed to define the pollutant transfer parameters of the exposure pathways are not always available.

Chang et al. (2002) also derived tentative health protection guidelines for common inorganic and organic pollutants by considering the food-chain transfer of pollutants (i.e., wastewater → soil → plants → people) from the consumption of grains, vegetables, root/tuber crops, and fruit (which, together, account for about 75 percent of the daily global average adult diet) (Table 2). The exposure scenario used assumed that (1) most exposed individuals were adult residents with a 60-kg body weight; (2) their entire consumption of grains, vegetables, root/tuber crops, and fruit were produced in wastewater-irrigated fields; and (3) their daily intake of pollutants from consumption of grain, vegetable, root/tuber, and fruit foods accounted for 50 percent of the acceptable daily intake (ADI), with the remaining 50 percent of the ADI being credited to background exposure.

Chang et al. (2002, iv) note that where there are “effective industrial wastewater pretreatment programs, the pollutant discharge into the wastewater collection and treatment systems is effectively regulated and pollutants incompatible with land application may be screened out. The reclaimed wastewater from these communities may be used for crop irrigation without undue restrictions, provided the [microbiological] quality of the water is acceptable and the volume of water applied does not exceed the normal water requirement for a successful crop harvest. In this manner, the pollutant input to the receiving soil, realistically, may be balanced by the outputs through plant absorption when the reclaimed wastewater is used for irrigation.”

However, effective industrial wastewater pretreatment programs are not the norm in developing countries and therefore special attention has to be paid to chemical risks in such circumstances. Even if they do exist there is always the additional problem of household chemicals, such as soap and detergent residues, cleaning fluids, personal care products (e.g., deodorants), and pharmaceutical residues, all of which are discharged as part of the graywater into the household wastewater.

Table 2 Tentative guideline values for the maximum permissible concentrations of selected inorganic and organic pollutants in wastewater-irrigated soils

Maximum permissible concentrations (mg per kg soil)					
Inorganic compounds					
Antimony	36	Arsenic	8	Barium	302
Beryllium	0.2	Boron	1.7	Cadmium	4
Fluorine	635	Lead	84	Mercury	7
Molybdenum	0.6	Nickel	107	Selenium	6
Silver	3	Thallium	0.3	Vanadium	47
Organic compounds					
Aldrin	0.48	Benzene	0.14	PAHa	16
Chlorodane	3	Chlorobenzene	211	Chloroform	0.47
Dichlorobenzene	15	2,4−D	0.25	DDT	1.54
Dieldrin	0.17	Dioxins	1.2×10^{-4}	Heptachlor	0.18
Hexachlorobenzene	1.4	Lindane	12	Methoylchlor	4.27
Pentachlorophenol	14	PCBs	0.89	Pyrene	41
Tetrachloroethane	1.25	Toluene	12	Toxophene	0.0013
2,4,5−T	3.82	Trichloroethane	0.68	Phthalate	13,733
Styrene	0.68				

[a] As benzo(a)pyrene.

3.2.2 Chemical risks to plant health

Crop yields may be reduced if the physicochemical quality of the wastewater used for irrigation is unsuitable—for example by being too saline or having concentrations of boron, heavy metals and other industrial toxicants, nitrogen, and/or sodium which inhibit plant growth either directly in the case of toxicants or indirectly by reducing the plant’s ability to absorb nutrients. The principal (and still current) reference document on the physicochemical quality of water, including wastewater, used for crop irrigation is FAO’s Water Quality for Agriculture (Ayers and Westcot, 1985). This may be supplemented by two later FAO publications The Use of Saline Waters for Crop Production (Rhoades et al., 1992) and Quality Control of Wastewater for Irrigated Crop Production (Westcot, 1997), and the World Bank publication Salinity Management for Sustainable Irrigation: Integrating Science, Environment, and Economics (Hillel, 2000).

In general treated domestic wastewaters, or treated municipal wastewaters that contain little industrial effluent, present no problem; care has to be exercised as the proportion of industrial effluent in the wastewater increases. However, even for treated domestic wastewaters, there are five parameters that should be monitored during the irrigation season: 1) electrical conductivity (as a measure of total dissolved solids or “salinity hazard”), 2) the sodium adsorption ratio (as a measure of the ‘sodium hazard’), 3) the concentrations of boron, 4) the concentrations of total nitrogen, and 5) pH. These measurements are relatively easy to do in the case of large wastewater-use schemes, but at the smaller scale of urban/periurban agriculture they would not generally be possible. The environmental health departments of city and town councils should nonetheless be encouraged to conduct these five analyses reasonably regularly (for example, at least monthly) throughout the irrigation season.

3.3 . Environmental risks

Soil and groundwater pollution is clearly a potential disadvantage of using wastewater in agriculture. Under most conditions, wastewater irrigation does not present a microbiological threat to groundwater since it is a process similar to slow sand filtration: most of the pathogens are retained in the top few meters of the soil, and horizontal-travel distances in uniform soil conditions are normally less than 20 meters. However, in certain hydrogeological situations (for example in limestone formations) microbial pollutants can be transported for much greater distances, and careful investigation is required in such cases (BGS, 2001). Chemical pollutants, among which nitrates are of principal concern in the case of domestic wastes, can travel for greater distances, and there is the potential risk that drinking-water supplies in the vicinity of wastewater irrigation projects may be affected. In general, therefore, and unless a rigorous hydrogelogical appraisal indicates otherwise, water supplies should not be located within, or close to, wastewater-irrigated fields; conversely, wastewater irrigation should not take place in areas where the groundwater is used for drinking-water supplies.

As a result of increased rates of salinization and waterlogging, soil pollution can occur through wastewater irrigation if adequate attention is not paid to leaching and draining requirements. Saline drainage waters should be used to irrigate salt-tolerant crops where possible, and crop and field rotation will generally be necessary to avoid long-term damage to the soil structure. Adherence to good irrigation practice is essential to avoid adverse environmental effects (Ayers and Westcot, 1985; Rhoades et al., 1992; Hillel, 2000; Tanji and Kielen, 2002). Often a trade-off has to be made between agricultural production and environmental protection, and this must be carefully evaluated at the project planning stage. Many of these potential disadvantages of wastewater irrigation, together with such hazards as odor, vector development, and the effects of accidental discharges of toxic substances, can be avoided by the use of properly treated wastewater. This includes adequate control of non-biodegradable and toxic industrial wastewaters, which generally require separate treatment or at least pretreatment prior to discharge to public sewers .

4 . CONCLUSIONS

Faced with these risks and benefits, countries seeking to improve wastewater use in agriculture should pursue the following key objectives:

Objective 1: Minimize risk to public health

Objective 2: Minimize risk to the environment

Objective 3: Improve livelihoods for urban agriculturalists

Objective 4: Integrate wastewater into the broader water resources management context.

Depending on the level of economic development, a country may seek to achieve one or a combination of objectives. Given the strong association between a country's income and the way it handles wastewater, low-income countries are likely to put the highest priority on minimizing the risk to public health while improving the livelihoods of urban agriculturalists. High-income countries, on the other hand, are more likely to emphasize environmental risk reduction and, especially when they are water-stressed or water scarce, a fuller integration of wastewater into their water resources management system .

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