

Reuse of wastewater in Urban Agriculture

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1. The practice of reuse of urban waste water and human excreta in urban agriculture and aquaculture

All around the world, people both in rural and urban areas have been using human excreta for centuries to fertilise fields and fishponds and to maintain the soil organic fraction. Use of faecal sludge – these are sludges which are collected from septic tanks and unsewered family and public toilets – in both agriculture and aquaculture continues to be common in China and Southeast Asia as well as in various places in Africa (Cross 1985; Timmer and Visker 1998; Visker 1998; Timmer 1999; Strauss et al. 2000). Where water-borne excreta disposal (sewerage) was put in place, the use of the wastewater in agriculture became rapidly established, particularly so in urban and periurban areas of arid and seasonally arid zones. Wastewater is used as a source of irrigation water as well as a source of plant nutrients, allowing farmers to reduce or even eliminate the purchase of chemical fertiliser. Recent wastewater use practices range from the piped distribution of secondarily treated wastewater (i.e. mechanical and biological treatment) to periurban citrus fruit farms (e.g. City of Tunis) to farmers illegally accessing and breaking up buried trunk sewers from which raw wastewater is diverted to vegetable fields (e.g. City of Lima; Strauss and Blumenthal 1990). Agricultural reuse of wastewater is practised throughout South America and in Mexico and is also widespread in Northern Africa, Southern Europe, Western Asia, on the Arabian Peninsular, in South Asia and in the United States (Shuval et al. 1986; Strauss and Blumenthal 1990; Asano et al., eds. 1998; Bahri 1998; Niang 1999; Owusu-Bennoah 1993; Khouri et al. 1994).

Vegetable, fodder and non-food crops as well as green belt areas and golf courses are being irrigated. In a few countries (such as the United States and Saudi Arabia), wastewater is subjected to advanced treatment (secondary treatment, filtration and disinfection) prior to use. Table 1 lists selected examples of wastewater reuse.

It has been estimated that in the order of 10 % of the world's wastewater is currently being used for irrigation. 100 % of the wastewater from the cities of Santiago (Chile) and Mexico City is used for irrigation, constituting some 70 and 80 %, respectively, of the irrigation waters used in the surrounding agricultural zones during the dry season. In South Africa, in the order of 15-20 % of the wastewater is reused in agriculture (Khouri et al. 1994). Morocco was using about 16 % of its wastewater in 1990, constituting some 0.5 % of the entire irrigation waters used (Benchekroun 1991). Farmers have been utilising wastewater for a long time, whether untreated or treated, in a legal or illegal manner, to compensate for scarce or costly freshwater resources. In contrast to this, planners and decision makers have only more recently become aware of the need to make wastewater reuse part of urban strategic sanitation and infrastructure planning.

Table 1: Selected Examples of Wastewater Reuse in Agriculture

Americas		Asia	
Mexico	- Cereals, vegetables, fodder, parks	Kuwait	- Cereals, fruit trees, fodder
Peru	- Vegetables, fodder, cotton	Jordan (indirect)	- Vegetables, crops consumed processed
Chile	- Vegetables, grapes	Israel	- Cotton
Argentina	- Vegetables, fodder	Saudi Arabia	- Cereals, fodder
U.S.A. (Calif.)	- Vegetables, cereals, fodder	India	- Cereals, vegetables
Europe		North Africa	
Germany	- Cereals, sugar beet, potatoes	Tunisia	- Citrus, fodder
S. Europe	- Non-food crops, parks	Morocco	- Vegetables, fodder

Production of fish and to some extent of water vegetables (macrophytes) in ponds fertilised by human excreta or wastewater has long been, and continues to be, practiced in many countries in South and SE Asia (e.g. India, Thailand, Indonesia, Vietnam, Taiwan, China), in Western Asia (Israel) and in Africa (Edwards 1992). Many of these schemes and practices may be designated as urban or periurban as they make use of faecal sludges and wastewater collected in urban areas. Fish production rates of 1-6 tons/ha/year are achieved, depending on the type of fish raised, pond operations and temperature. Until after World War II there was also a practice of sewage-fed fishponds in Germany. The Calcutta Wetlands, consisting of some 30 km² of fishponds is the world's largest sewage-fed fish production site. The wastewater from East Calcutta, composed of domestic and industrial effluents, is batch-fed to the ponds by fishermen who have developed the skills over many generations. Tilapia and carp are the two main types of fish raised. The Wetlands reportedly cover some 10-15 % of the fish consumption in Calcutta.

Waste stabilisation ponds have come into increasing use to treat wastewater in tropical areas. It is rather common that nearby dwellers make informal or illegal use of the ponds, notably the less contaminated of the 2-4 ponds operated in series to raise fish, both for consumption within the family and for sale on local markets.

Duckweed production in excreta or sewage-fed ponds has found increasing attention in recent years. In the cities of Tainan and Chia in Taiwan, wastewater-fed production of duckweed to be used as fish and duck feed was practised on a large scale for 30-40 years until the late nineties, when the duckweed ponds had to give way, partly at least, to growing urbanisation (Iqbal 1999). Duckweed production based on fertilisation by faecal sludges was investigated in the seventies and eighties at AIT in Bangkok (Edwards et al. 1987). The pilot field research revealed that duckweed production for fish feeding might become economically viable as a part of an integrated urban excreta reuse system but less so at village level. PRISM Bangladesh has set up, with external support, integrated excreta and wastewater-fertilised duckweed-fish production projects in three towns in Bangladesh from 1989 onwards. The economic viability of such systems is uncertain yet, although one of the systems produced net financial gains during a four-year period. The labour intensive and skill requiring operations of duckweed ponds appear to be a major cost factor. Institutional settings, entrepreneurial organisation and operating cost, might be the major factors which have prevented a larger-scale spreading of excreta/wastewater based duckweed systems to date.

2. The resource potential of wastewater: irrigation water, nutrients and organic matter

Excreta are a rich source of inorganic plant nutrients such as nitrogen, phosphorus and potassium, and of organic matter. Table 2 shows that the fertilising equivalent of excreta is nearly sufficient for a person to grow his own food (Drangert 1998). Excreta are not only fertilisers. The organic matter content, which serves as a soil conditioner and humus replenisher – an asset not shared by chemical fertilisers – is of equal importance. The traditional practices of recycling faecal sludges to agriculture or aquaculture (e.g. in Southeast Asia) have made use of this resource for centuries.

Table 2: The Fertiliser Equivalent of Human Excreta (Drangert 1998)

Nutrient	Nutrient in kg			
	In urine (500 l/year)	In faeces (50 l/year)	Total	Required for 250 kg of cereals
N Nitrogen	4.0	0.5	4.5	5.6
P Phosphorus	0.4	0.2	0.6	0.7
K Potassium	0.9	0.3	1.2	1.2

For

the same reason, urban farmers in arid or semi-arid zones or during dry seasons, in addition to procuring water for irrigation, are endeavouring to get access to wastewater, raw or treated. This allows them to renounce or minimize the purchase of chemical fertiliser. It is now being postulated that sanitation systems should, whenever feasible, be conceived and managed such as to enable and maximise the recycling of organic matter and nutrients contained in human excreta (Winblad 1997; Esrey et al. 1998).

A change in the sanitation management paradigm from flush-and-discharge to recycling of urine and faeces is gaining ground in Europe (Larsen and Guyer 1996; Otterpohl et al. 1997 and 1999; Otterpohl 2000). As a consequence, treatment strategies and technological options for faecal sludges and wastewater will have to be developed which allow the optimum recycling of nutrients and organic matter to periurban agriculture, while being adapted to the local situation and needs (see also Chapter 6 below).

In arid and semi-arid areas or in seasonally dry zones, irrigation requirements make up 80-90 % of the entire demand on natural water resources. The water required for urban water supply is thus small in relative terms. Hence, recycling urban wastewater to urban agricultural soils may bring about a saving in the national water budget of some 10-20 % at most. However, reusing urban wastewater within the urban agricultural perimeter may very well cover a substantial portion if not 100 % of the local water demand of urban agriculture, and thus contribute to farm-based income generation, socio-economic equity and urban food security (Shaht 1998). Hence, in dry areas and seasons, wastewater reuse is being practiced all over the world whether officially regulated or not (Scot et al 1999; Strauss and Blumenthal 1990; Nunan 2000).

Assuming a yearly rate of irrigation of 500 mm and a per-capita sewage production of 100 l/cap/day, a city of 1,000,000 people would produce enough wastewater to irrigate an area of 7,000 ha (70 km²!!), using efficient irrigation methods. The nutrient load of this wastewater would comprise about 1,800,000 kg of nitrogen, 360,000 kg of phosphorus and 540,000 kg of potassium (after Khouri et al. 1994). This may or may not fully satisfy the plant requirements, depending on the type of plants and the cultivation regime adopted.

3. The stakeholders in reuse of urban waste water and human excreta

It appears that only few investigations have been made to date which have attempted to assess who the stakeholders and actors are, what drives their activities, what constraints they face, and how they apply the wastes – faecal sludge or wastewater – to the fields or fish ponds.

Allison et al. (1998), Furedy (1988), Strauss and Blumenthal (1990), and Baumgartner (2000) have addressed the issue. Farmers cultivating empty plots within urban centres or nearcentre zones, in many localities, belong to the group of smallholders not availing of tenure over the land they are cultivating using human wastes. They themselves or members of their families may pursue other jobs and thereby contribute to the household's income. The basis of their cultivating activities is insecure. They are little organised and therefore barely have a political voice. The land they make use of is prone to be used for urban expansion eventually. In contrast to this, agricultural land bordering cities and being farmed by the legal owners of the land provides a much more stable basis of living. The size of holdings may range from small (in the order of 1,000 m² or less) to large land areas (> 1 ha).

In some places, farmers have set up farmers' organisations; e.g., those sharing water delivered through a common irrigation canal system (Strauss and Blumenthal 1990). On larger land holdings, notably so in Latin America, which are irrigated by untreated or treated urban wastewater, the land is owned by landlords and cultivated by employed agricultural workers. Many of these live in rather poor conditions and may not have access to health services. In the Calcutta Wetlands (see Chapter 1), part of the fishponds are owned by "pond" lords living in the city and managed by fishing families who may have been living in the Wetland area for many generations already. Other ponds are owned and operated by fishing co-operatives, which have developed their own social infrastructure such as schools and health facilities (Strauss and Blumenthal 1990).

Other important actors are the "deliverers", i.e. those in charge of faecal sludge or wastewater collection, treatment where existing, and disposal (Harris et al. 1998; Strauss and Blumenthal 1990). Responsibility for waste collection and delivery usually rests with the municipal or provincial authorities in charge of sanitation services (technical and/or health departments). In some cities or countries (e.g. Mexico, Tunisia), regional agricultural or irrigation authorities are in charge of wastewater distribution and of enforcing the regulations restricting crop irrigation with wastewater (Strauss and Blumenthal 1990). Usually, in such situations, the wastewater distributed through canals or pressure lines has to be requested and paid for by the farmers. While, notably in larger cities, municipal authorities are responsible for faecal sludge collection and disposal, the actual "business" of farm side delivery might, in most cases be dealt with directly by the sludge collectors (usually suction truck drivers) and the farmers. In many Asian cities, faecal sludges are collected by small entrepreneurs and sold to farmers at the urban fringe without the involvement of public authorities. Where faecal sludges are treated prior to use, intermediary, private entrepreneurs may play a role in selling treated products to farmers. There are, moreover, examples of smaller towns where microentrepreneurs do the house-to-house collection of septic tank or latrine sludges and sell these to periurban farmers (Montangero and Strauss 1999). In still other places, farmers may themselves have arrangements with urban households for collecting faecal sludge from their private pit latrine or septic tank.

The above shows clearly that different modes of stakeholder interactions and collaboration for the use of human waste in the urban and periurban environment have been established which differ according to the local administrative socio-cultural and economic setting and the type of human waste being used. It is of utmost importance to carefully evaluate these interactions when attempting to bring about changes or proposed improvements in human waste use patterns, including treatment, in order to not disrupt or jeopardise the beneficial recycling of excreta and wastewater.

4. Planning and Economic Aspects

Planning for the securing, improving or introducing of reuse of waste water and human waste in urban agriculture encompasses a wide range of aspects and activities. These comprise, among others, stakeholders involvement (concepts and operational patterns); strategic water resources planning; institutional coordination; pricing of treated wastes; technical support to enable sustainable waste collection and treatment; health protection; enforcement of treatment and use regulations; strategic sanitation planning; marketing of treated faecal sludges and wastewater; re-thinking the policy of fertiliser subsidy; training of professionals on sound alternatives for sanitation and recycling. These subjects have been touched upon to various levels of detail and comprehensiveness by Mara and Cairncross (1989), Khouri et al. (1994), Allison et al. (1998) and Furedy et al. (1999).

Certainly, the urban farmers – smallholders and larger property holders alike – should stand at the centre of efforts to support urban agriculture. In conceiving projects and programmes involving the use of human waste in urban agriculture, planners, decision makers, engineers and extension workers in local and national level authorities, NGOs and donor agencies, should focus on the needs and constraints of the urban farmer. In some places, though, the usefulness of urban farming and use of waste water and human wastes must first be promoted among decision-makers and higher-level planners who still too often consider this as something undesirable and inferior. There is, often, a need to raise awareness among politicians and planners that urban agriculture and the judicious use of human wastes contributes greatly to the securing of socio-economic balance, food procurement and

environmental integrity in a city.

6. Health aspects

Excreted Pathogens

In developing countries, excreta-related diseases are very common, and faecal sludges and wastewater contain correspondingly high concentrations of excreted pathogens - the bacteria, viruses, protozoa, and the helminths (worms) that cause gastro-intestinal infections (GI) in man. There are approximately thirty excreted infections of public health importance, and many of these are of specific importance in excreta and wastewater use schemes. The risks of transmission of excreted pathogens using human wastes in agriculture and aquaculture have been, and continue to be, widely studied and reported about. This may be interpreted as reflecting the growing importance of human waste and waste water use in urban sanitation programmes and, as a consequence, the increased need and interest of decision makers and planners to become informed of the risks involved in the local context and to obtain guidance on how best to protect public health.

The agricultural or aquacultural use of excreta and wastewater can **only** result in an actual risk to public health, if **all** of the following occur.

- (a) That either an infection dosage of an excreted pathogen reaches the field or pond, or the pathogen multiplies in the field or pond to form an infective dosage;
- (b) That this infective dosage reaches a human host;
- (c) That this host becomes infected; and
- (d) That this infection causes disease or further transmission.

a), (b) and (c) constitute the **potential risk** and (d) the **actual risk** to public health. If (d) does not occur, the risks to public health remain potential only.

A multitude of transmission paths exist for excreta-related infections including transmission via waste water, soil, crops and fish, as well as through person-to-person contact (for members of the farmers' families not directly involved in farming activities). Transmission via fish may encompass infections, which require fish as a compulsory host (e.g. Chinese liver flukes) or as a passive carrier (bacteria and viruses).

The actual risks to public health that occur through waste use can be divided into three broad categories: those affecting consumers of the crops grown with the waste (**consumer risk, people involved in food processing and marketing**), those affecting the agricultural and pond workers who are exposed to the waste (**workers', farmers' or fishermen's risk**), and those affecting populations living near to a waste reuse scheme (**nearby population risk**).

Where night soil use and wastewater irrigation are unrestricted, so that all types of edible crops can be grown, then both consumer risk and worker risk are of interest. If use is restricted to certain crops, such as crops eaten cooked or processed, then this prevents the risk to consumers; in this situation, only the worker risk needs to be considered.

The actual public health importance of an excreta or wastewater use practice can be assessed by an epidemiological study to determine whether or not it results in an incidence or prevalence of disease, or intensity of infection, that is measurably in excess of that which occurs in its absence. Such studies are methodologically difficult, and there have been only a few well-designed epidemiological studies on human wastes reuse (see above).

Most of the available epidemiological evidence concerns wastewater irrigation.

The results of earlier studies by (Blum and Feachem 1985), Shuval et al. (1986) and of more recent work synthesized by Blumenthal (2000) can be summarised as follows:

- Crop irrigation with **untreated** wastewater causes significant excess infection with intestinal nematodes in both consumers of the irrigated crop and those who work in the irrigated fields. The latter, especially if they work barefoot, are likely to have more intense infections, particularly of hookworms, than those not working in wastewater irrigated fields.
- Crop irrigation with adequately **treated** wastewater does not lead to excess intestinal nematode infection amongst field workers or consumers unless conditions (lower mean ambient temperature, wastewater application through surface irrigation) prevail which favour the prolonged survival of nematode eggs, which may still be contained in the irrigation water
- Cholera, and probably also typhoid, can be effectively transmitted by the irrigation of vegetables with untreated wastewater.
- Cattle grazing on pasture irrigated with raw wastewater may become infected with beef tapeworm, but there is little evidence of actual risks of human infection.

- There is limited evidence that the health of people living near fields irrigated with raw wastewater may be negatively affected either by direct contact with the soil, or indirectly through contact with farm labourers; in communities with high standards of personal hygiene such negative impacts are usually restricted to an excess incidence of benign gastroenteritis, often of viral aetiology, although there may also be an excess of bacterial infections.
- In wastewater reuse, the risks for farmers to contract gastro-intestinal infections (GI) are greatest when flood or furrow irrigation is practiced. The risks for consumers are greater, though, when the wastewater is applied by spray or sprinkler irrigation (aerosolised transmission of excreted viruses; however disease transmission is likely to be rare in practice since most people have high levels of immunity to viral disease endemic in their community).
- Children may become infected by nematodes by getting into contact through work or play with wastewater, which may not have been treated to a near-zero concentration of nematode eggs.

There is much less information about waste water and excreta use in aquaculture. Blum and Feachem (1985) came to the following conclusions:

- There is clear epidemiological evidence for the transmission of certain trematode diseases, principally *Chlonorchis* (oriental liver fluke) *Fasciolopsis* (giant intestinal fluke), and for *Schistosoma* (bilharzia) (Niu and Ling 1999)
- There is no conclusive evidence for disease transmission by passive transference of viruses, bacteria or protozoa by fish and aquatic vegetables, but there is a considerable potential risk, particularly through cross-contamination due to inadequate kitchen and personal hygiene.

Measures for Health Protection (pathogen risks)

It is possible to design, implement or upgrade waste water and human waste use schemes that do not pose any risk to public health, but this requires an understanding of the occurrence of excreted infections in the area of concern and an assessment of the epidemiological risks in relation to the actual use practice and exposure patterns.

On this basis sound and appropriate measures may be drawn up in a collaborative manner by the various stakeholders based on standards for the microbiological and parasitological quality of the excreta and wastewater intended for reuse or based on appropriate measures to be implemented at critical control points (e.g. waste treatment or crop restriction; see below).

There exist four basic options for health protection from excreted pathogen transmission:

- Faecal sludge and wastewater treatment
- Restriction of the crops grown
- Appropriate choice of methods of application of the waste water and human excreta to the soil or crops
- Control of human exposure, and improved personal and household hygiene

While full treatment stops excreted pathogens from even reaching the field or fishpond to which the wastes are applied, crop restriction and human exposure control act later in the pathway, preventing excreted pathogens from reaching the persons concerned, i.e. the crop consumers and the agricultural workers.

It will often be desirable to apply a combination of several methods. This will depend on the needs and conditions (technical, socio-economic, cultural, dietary and institutional) in any specific locality.

Non-Pathogenic Health Risks

Chemical contamination is another important potential risk associated with waste water reuse. Quite likely, this risk may turn out to be much more pronounced and relevant than the risk from pathogens in the long run. Chemical constituents, heavy metals in particular, but also refractory organics, accumulate in soils. This may curtail the prolonged use of waste water and hence put urban agriculture at risk.

The contamination of soils by chemicals, the potential but as yet uncertain extent of uptake by crops, which in turn may lead to chronic and long-term toxic effects in humans are discussed by Chang et al. (1995) and by Birley and Lock (1997). Contamination of plants might be caused by deposition of aerosol particles containing heavy metals, by soils, which have been loaded with toxic industrial waste, or by human wastes over long periods of time (Chang et al. 1995).

When intending to use faecal sludge or wastewater for irrigation or restoring soil fertility it is important to consider chemical constituents. A restriction in sludge application may become necessary to limit heavy metal accumulation in soils and crops through the repeated application of sludge.

It was found that faecal sludges (septage) collected in Bangkok and Manila quite surprisingly contained only non-negligible levels of heavy metals (Heinss et al. 1998).

Faecal sludges (FS) are usually “cleaner” than sewage treatment plant sludges, as they tend to contain less heavy metals or refractory organics. Exceptions may be found in places where septage is also collected from septic tanks serving cottage or small industrial enterprises. Heavy metal loads in municipal wastewater have been declining in a number of industrialised countries in recent years due to pre-treatment at the source of industrial wastewater discharged into the municipal sewerage systems, and due to water management and process improvements in industries.

Chang et al. (1995) citing others, report that the major portions of toxic chemicals contained in wastewater are removed from the liquid fraction during treatment, adsorbing on particulate matter and ending up in the sludge. Yet, at least traces of chemicals will always be retained in the wastewater. Studies are cited which reportedly indicated that the use of wastewater treated by so-called secondary and tertiary treatment is safe regarding the trace element contamination of food. It may, however, be speculated that the use of sewage sludge, unless it is of entirely domestic origin, would, in most cases lead to levels of chemical contaminants in the soil which may in turn lead to substantial crop uptake, endanger human health and possibly threaten or at least curtail the agricultural practice making use of such human wastes.

Chang et al. (1995) address the difficult epidemiology of toxic chemicals. In contrast to pathogen-related health risks, which are characterised by causing symptoms fairly rapidly, by well-known cause-effect and dose-response relationships, and by a fairly good knowledge of the possible routes of exposure, disorders caused or assumed to be caused by toxic chemicals are much more difficult to assess. Their prevalence and cause-effect relationship is not yet well known and documented. The difficulties rest in the fact that effects are usually long-term and may involve lifetime follow-up. Disorders are often influenced by synergetic effects from various chemicals.

7. Treatment for Use

There exists a large array of technological and process options to achieve pathogen attenuation in faecal sludges and wastewater. The simplest option relates to the storage pits or vaults of pit or vault latrines. Where double-pit or vault toilets are in use and properly operated in an alternating manner, the faecal sludge stored in the pit at rest is likely to become fully hygienised in tropical climate before its contents need to be removed from the pit. With ascariasis being highly prevalent in most developing countries, at least so in the rural and periurban areas, and with *Ascaris* eggs being the most persistent of all pathogens, *Ascaris* eggs can be used as a hygienic indicator of stored excreta. It takes in tropical climates from 6 months to one year for complete *Ascaris* egg die-off (Feachem et al. 1983, Strauss 1985; Phi et al. 1999). Faecal sludges which have undergone this period of storage may thus be safely used on land or in fish culture, not causing excess risk of infection to either farmers or consumers.

A review of mostly low-cost options to treat wastewater and faecal sludge has been made by Rose (1999). A compilation of waster treatments systems frequently used in developing countries has been published by Von Sperling (1996). Options for faecal sludge treatment have been discussed and presented by Strauss et al. (1997) and Montangero and Strauss (2000).

Grey water treatment has not received much attention to date and only scarce literature exists on it (Del Porto and Steinfeld 1999).

The various treatment options either in use or proposed achieve pathogen inactivation to a variable degree, hence health protection of farmers, consumers and populations living near application sites, is not provided to the same extent for all treatment options. Care must be exerted when comparing various treatment options as to their pathogen removal performance vs. land use and cost. Conclusive comparisons can only be made for options, which have been conceived and designed to achieve comparable levels of pathogens in the effluent or biosolids. A planted soil filter, e.g., requires less land than a waste stabilisation pond (WSP) scheme. But then, WSP, whether including maturation ponds or not, would normally produce higher removal efficiencies for bacteria and viruses due mainly to the longer system retention time (10-28 days in WSP schemes in warm climate vs. 1-2 days in a planted soil filter).

The choice of a particular treatment option depends on various factors, viz. the objective of treatment (reuse or discharge into the environment), hence, the desired or legally stipulated quality of liquid effluents and of biosolids produced by the process; the simplicity and

sturdiness of the plant and its operation; the financial and economic cost; the land requirements; the type of cultivation envisaged or being practiced; the market opportunities for the sale of treatment products; the farmers' ability to pay and lastly, the need or non-need to devise options which may be managed by rather unskilled persons on a decentralised, community-based scale.

A low-cost system proven to be most effective in removing pathogens in warm climates are waste stabilisation ponds Mara (Arthur 1983; Mara et al. 1992; Yanez 1993; Mara 1997; Mara and Pearson, 1998). They can be built and operated without much mechanical equipment, except if wastewater needs to be pumped for topographic reasons or if machinery is required to de-sludge ponds. Numerous small and large systems have been implemented throughout the world in the past decades, the effluents of which are largely used for irrigation. They may, if properly designed and operated, produce effluent meeting stringent hygienic quality standards. V

Variants of this option allow to produce effluent either for so-called restricted irrigation as well as for unrestricted irrigation, i.e. irrigation of crops eaten uncooked. Pond systems may also prove suitable to treat faecal sludges (FS) if particular precautions are taken with respect to solids separation and handling and to excessive ammonia levels in fresh, rather undigested FS (Heinss et al. 1998).

Other wastewater treatments systems which may prove suitable for effluent reuse are anaerobic filters (e.g. in combination with individual or communal septic tanks), upflow anaerobic sludge blanket (UASB) clarifiers; trickling filters, planted vertical-flow soil filters ("constructed wetlands"); and duckweed ponds. These require low to moderate construction and operating costs, but are effective in removing or inactivating pathogens to a lesser degree than waste stabilisation ponds schemes.

Otterpohl (2000) reported on a new, recycling-based system for excreta and grey water management under construction in Luebeck, Germany. Excreta are vacuum-collected from low-flush toilets and co-treated with organic kitchen residues by anaerobic digestion. The treated and hygienised slurry will be used in periurban agriculture for soil conditioning and fertilisation. Grey water will be treated by vertical-flow constructed wetlands and used for green space irrigation or allowed to infiltrate. Compared to conventional, centralised flushand-discharge systems, this innovative solution yields considerable savings of pollutant emissions (organic matter, nutrients) as well as energy and resource savings for fertiliser production. Rather sophisticated technology is required, though, rendering this type of excreta management system less feasible for the majority of developing countries.

Treatment options not achieving the effluent quality required for a specified use (e.g. irrigation of raw-eaten vegetables) may be complemented by suitable processes to meet the stipulated hygienic quality like polishing ponds, chlorinisation (but the latter technique is expensive and leading to the formation of chlorinated hydrocarbons, which are carcinogenic).

Biosolids produced in FS or wastewater treatment plants will under most circumstances constitute a precious agricultural resource for soil amendment and fertilisation, unless treatment plants receive toxic wastes at a regular basis and in high proportions. Biosolids produced during the treatment process contain high loads of viable pathogens. Hence biosolids need storage and sun drying for a prolonged period to achieve a sufficient die-off of pathogens, helminth (worm) eggs in particular. Desiccation to below 10 % of solids – in dry warm climates achievable within 2-4 months – will lead to complete inactivation of all worm eggs. Alternatively, the combined composting of biosolids with organic municipal waste or other organic residues may constitute an option to hygienise pathogen-loaded sludges (Shuval 1986; Obeng et al. 1995).

8. Guidelines and Standards

Excreted Pathogens

Following the recommendations by a WHO Scientific Group, WHO published guidelines for wastewater use in agriculture and aquaculture (WHO 1989). These replaced the previous guidelines (WHO 1973), which, in the light of then new evidence, were considered by WHO to be too strict with respect to the suggested quality parameter for pathogenic bacteria and nematode (roundworm) egg guidelines.

The purpose of the guidelines was to guide design engineers and planners in the choice of waste treatment technologies and waste management options.

Waste treatment is considered for use by category A, waste treatment and crop restriction for

category B and a choice of application measures and human exposure control for category C.
 Table 3: Recommended Microbiological Quality Guidelines for Wastewater Use in Agriculture (WHO 1989)

Category	Reuse conditions	Exposed group	Intestinal nematodes (/litre)	Faecal coliforms (/100ml)	Wastewater treatment expected to achieve required quality
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks	Workers, consumer s, public	≤ 1	≤ 1000	A series of stabilisation ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees	Workers	≤ 1	None set	Retention in stabilisation ponds for 8-10 days or equivalent helminth removal.
C	Localised irrigation of crops if category B exposure of workers and the public does not occur.	None	Not applicable	Not applicable	Pre-treatment as required by the irrigation technology, but not less than primary sedimentation.

Similar guidelines were developed for the use of excreta in agriculture and aquaculture (Mara and Cairncross 1989), and for the use of wastewater in aquaculture (WHO 1989). The WHO guidelines for agricultural use of wastewater have been adopted in several countries, either directly or in amended versions to suit local epidemiological, socio-economic conditions and health policies, viz. in Mexico, Tunisia and France.

Many countries, among them also developing countries, have adopted much stricter guidelines, based on a zero-risk principle, resulting in quality standards for wastewater used for irrigation of vegetable crops, which are very close to drinking water standards. Where such standards were enacted in developing countries, they were hardly ever enforced as compliance is economically unfeasible and enforcement institutionally impossible. Hence, wastewater reuse goes by uncontrolled, or may be entirely prohibited, as monitoring and control cannot be implemented. Achieving wastewater quality close to drinking water standards is economically unsustainable and epidemiologically unjustified in many places. That is why the WHO guidelines, are based on another principle: the objective that there should be no excess infection in the population attributable to wastewater reuse and that risks from reuse in a specific population must be assessed relative to risks of enteric infections from other transmission routes.

Blumenthal (2000) suggests to choose an approach for setting future guidelines or standards that is based more on epidemiological evidence for excess risks due to a specific reuse practice, and on calculations of risks from a particular practice and then comparing this to an acceptable risk definition as laid out by, for example, health authorities.

Food Hygienic Quality

ICMSF (1995) has issued quality recommendations for food. The limits stipulated for agricultural crops, applicable to raw-eaten vegetables, are 10^5 /100g fresh weight ("if – possible"-limit) and 10^3 faecal coliforms/100g fresh weight ("tolerable"-limit), respectively. These limits may appear lenient. They must, however, be viewed in the light of the fact that fresh, unprocessed and unpacked vegetables that have been grown on rain-fed or freshwater-irrigated fields and sold on markets or in food stores, may easily carry faecal indicator bacteria concentrations close to the indicated quality limits! This fact is often disregarded when evaluating the potential health risks associated with the use of faecal sludges or wastewater.

Chemical contaminants

Following the publication of pathogen-related guidelines by WHO in 1989, WHO mandated a team of researchers to assess the risks related to chemical contaminants and to viruses, respectively. Chang et al. (1995) suggested tentative guidelines for chemical pollutants, assuming, based on literature evidence, that transfer via the food chain is the primary route of exposure for humans. From this, the authors adopted a maximum daily intake and then derived the maximum concentration of the respective pollutants, which may be tolerated in the soil. This inevitably leads to a limitation in the use of untreated or partially treated wastewater and of biosolids, in which the contaminants are concentrated. They stipulate, on the other hand, based again on reported evidence, that adequately (secondary or tertiary) treated wastewater may be used for edible crop irrigation without restriction.

Standard Setting

In adopting standards, many countries tend to immediately adopt the strictest standards as used in industrialised countries. This may satisfy the legal requirements of the enacting authorities and provide the prestige of “also having standards”, but may often not be feasible in the local economic and institutional context. Instead of this, it would make much sense that countries would adopt a stepwise approach in setting standards, which would -if followed and enforced- already achieve a considerable advancement in terms of pollution abatement and risk prevention. Johnstone and Horan (1994 and 1996) and Von Sperling and Fattal (in press) have made sensible suggestions related to guideline setting and remind one that standard setting in industrialised countries has evolved gradually and based on scientific and economic advancement.

One should also be aware that where wastewater is now being used in an informal, de facto illegal manner, urban sanitation upgrading may lead to situations where treated human wastes might neither be affordable nor be accessible anymore by urban farmers.

9. Gaps-in-knowledge

Allison et al. (1998), Birley and Lock (1999) and Rose (1999) have identified gaps-in-knowledge relating to waste water reuse in urban agriculture and are suggesting action and field research to fill them. Below is a non-exhaustive listing of identified gaps:

- Assess the health impacts from chemical constituents contained in waste water and human wastes (heavy metals; persistent organics; pharmaceuticals) in the human waste – soil – crops – food –cycle and identify strategies to avoid (e.g. through source separation) the mixing of toxic chemicals and domestic wastewater and faecal sludges
- Development of appropriate, i.e. implementable and enforceable, quality standards for treated human wastes and waste water applied in urban agriculture and aquaculture
- Technical, economic/financial, institutional, cultural and agronomic aspects of noncentralised waste water treatment and reuse (“integrated urban waste management”) schemes based on domestic sources mainly, e.g. through case studies of existing schemes or components thereof or through pilot projects with stakeholder involvement
- Carbon (organic matter) and nutrient needs in urban agriculture vs. carbon and nutrient generation in the city; estimating the theoretical carbon and nutrient demand potential of urban farms; use of material flow analysis (MFA) as an assessment and planning tool
- To assess farmers’ needs and constraints; methods of cultivation; organisation; tenure as well as attitudes vis-à-vis human waste use; health problems; hygienic practices and behaviour determining exposure to wastes; financial conditions; use of inorganic fertiliser
- Cost-benefit evaluation of waste management schemes with and without reuse.