2
Human wastes as a resource

Human wastes are regarded as a resource in many parts of the world, and they are widely used for a large variety of purposes (see Table 2.1). These Guidelines emphasize the following three reuse practices, since these are the most common:

- wastewater use in agriculture (crop irrigation);
- excreta use in agriculture (soil fertilization); and
- wastewater and excreta use in aquaculture (fish culture, aquatic macrophyte production).

2.1 Wastewater use in agriculture

With the introduction of the water-carriage system for domestic wastewater in the middle of the nineteenth century, many European and North American cities adopted crop irrigation as their means of wastewater disposal. Sewage farms, as they were called, were established in the United Kingdom as early as 1865, the United States in 1871, France in 1872, Germany in 1876, India in 1877, Australia in 1893 and Mexico in 1904. In most of these countries the impetus for sewage farming was to prevent river pollution rather than to enhance crop production; in the United Kingdom the dictum was "sewage to the land, rain to the rivers". However, as cities grew and the proportion of their population connected to sewer systems increased, the land area required for sewage farming became too great. The practice became less popular and, with the development of modern wastewater treatment processes such as biofiltration and activated sludge during the first two decades of this century, it disappeared completely in many countries soon after the First World War, since wastewaters could be readily discharged to surface waters without causing significant pollution. The sewage farms at Werribee (Melbourne, Australia) and Mexico City were notable exceptions to this trend, and they are still in operation some 80–90 years after their

Table 2.1 Examples of human wastes reuse practices

Reuse practice	Responsible social unit	Examples
Soil fertilization with untreated stored nightsoil	Family or community	China, India, Japan, Thailand
Nightsoil collected and composted for use in agriculture	Community or local authority	China, India
Nightsoil fed to animals	Family	Africa, Melanesia
Use of compost latrines	Family	Guatemala, United Republic of Tanzania, Viet Nam
Biogas production	Family or community	China, India
Fish pond fertilization with treated or untreated nightsoil	Family or community	China, Indonesia, Malaysia
Fish farming in stabilization ponds	Family (illegal) or commercial farmer	India, Israel, Kenya
Aquatic weed production in ponds	Family, community or local authority	S.E. Asia, Viet Nam
Agricultural application of wastewater	Local authority or commercial farmer	See Table 2.2
Agricultural application of wastewater sludges	Local authority or commercial farmer	Kenya, United Kingdom, United States of America
Irrigation with stabilization pond effluents	Local authority or commercial farmer	India, Israel, Peru
Algal production in stabilization ponds	Local authority	Israel, Japan, Mexico

Source: Strauss (1985)

inception. However, indirect reuse—the use of water from rivers receiving wastewater effluents—occurs throughout the world, and is currently the most common process of using effluents not only for irrigation but also, after appropriate treatment, for potable supplies.

In the past two decades there has been a great increase in the use of wastewater for crop irrigation (see Table 2.2), especially in semiarid

Table 2.2 Global data on wastewater irrigation

Country and city	Irrigated area (ha)
Argentina, Mendoza	3 700
Australia, Melbourne	10 000
Bahrain, Tubli	800
Chile, Santiago	16 000
China, all cities	1 330 000
Federal Republic of Germany, Braunschweig	3 000
Other cities	25 000
India, Calcutta	12 500
All cities	73 000
Israel, several cities	8 800
Kuwait, several cities[a]	12 000
Mexico, Mexico City	90 000
All cities[a]	250 000
Peru, Lima[a]	6 800
Saudi Arabia, Riyadh	2 850
South Africa, Johannesburg	1 800
Sudan, Khartoum	2 800
Tunisia, Tunis[a]	4 450
Other cities[a]	2 900
United States of America, Chandler, Arizona	2 800
Bakersfield, California	2 250
Fresno, California	1 625
Santa Rosa, California	1 600
Lubbock, Texas	3 000
Muskegon, Michigan	2 200

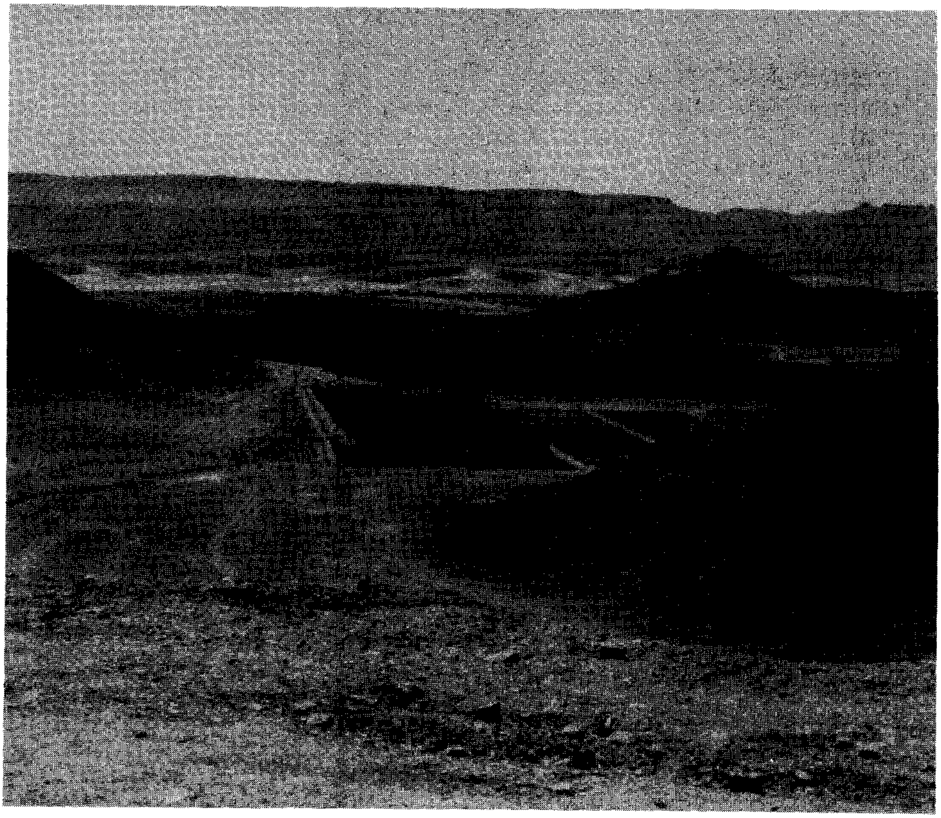
[a] Includes planned expansion of existing reuse

Source: Bartone & Arlosoroff (1987)

areas of both developed and developing countries (see Figure 2.1). This has occurred as a result of several factors:

- the scarcity of alternative waters for irrigation;
- the high cost of artificial fertilizers;
- the demonstration that health risks and soil damage are minimal if the necessary precautions are taken;
- the high cost of advanced wastewater treatment plants;
- the sociocultural acceptance of the practice; and

Figure 2.1 Irrigation with treated wastewater in Saudi Arabia
The irrigated fields are in stark contrast to the natural arid terrain.



- the recognition by water resource planners of the value of the practice.

Domestic wastewater is produced by households that have an in-house multiple-tap water supply service and flush-toilets connected to a sewer system into which all other household wastewater (sullage) is discharged. In the developing world as a whole, few households produce sewage, because sewerage is too expensive a sanitation technology; the majority produce excreta (nightsoil) and sullage separately. In many urban areas, however, sufficient households are connected to a sewer system to make the agricultural use of sewage an attractive economic proposition: crops are both irrigated and fertilized by the water and nutrients in sewage. At the same time the wasteful disposal of these scarce resources, which often leads to gross environmental pollution, is avoided. With proper management, crop

Box 2.1 Wastewater irrigation increases crop yields

There are many reports from all over the world that crop yields are significantly increased by irrigation with wastewater. In India, for example, long-term field experiments at the National Environmental Engineering Research Institute in Nagpur have shown that medium intensity irrigation with wastewater produces higher yields than irrigation with freshwater supplemented with standard doses of nitrogen, phosphorus and potassium (NPK), as shown in the table below.

Irrigation water	Crop yields (tonnes per hectare per year)				
	Wheat (8)[a]	Moong beans (5)	Rice (7)	Potato (4)	Cotton (3)
Raw wastewater	3.34	0.90	2.97	23.11	2.56
Settled wastewater	3.45	0.87	2.94	20.78	2.30
Stabilization pond effluent	3.45	0.78	2.98	22.31	2.41
Fresh water + NPK	2.70	0.72	2.03	17.16	1.70

[a] Years of harvest used to calculate average yield

Source: Shende (1985).

yields are increased (see Box 2.1) and no adverse health effects are induced. In current practice wastewater irrigation of crops sometimes does lead to an excess of excreta-related disease among farm labourers and crop consumers, but this is entirely due to the use of inappropriate techniques. It is now possible to design and implement wastewater use schemes that avoid the transmission of excreta-related infections, and thus potential health risks, which are now wholly avoidable (see Section 4), should no longer be considered sufficient reason not to continue and develop this otherwise very beneficial practice.

Some governments have been understandably cautious in actively promoting wastewater use, especially as there has not, until recently, been either a realistic appraisal of the health risks involved, or sensible design guidelines for treatment of wastewater before use. However, no such caution is shown in practice by those who actually use the wastewater — farmers and market gardeners — and throughout the developing world untreated wastewater is commonly used to irrigate agricultural and horticultural produce. Indeed, in many areas wastewater is considered to be so valuable that sewers are broken into and the wastewater flow is diverted to the fields. Such a practice, which is by no means uncommon but of course is illegal and carries substantial health risks, clearly demonstrates the perceived advantage of wastewater use. It is doubtful whether such practices can ever be eliminated unless governments develop and promulgate national strategies for wastewater use. Proper measures to minimize health risks and ensure the equitable distribution of the wastewater for irrigation are the only means by which the potential economic advantage of wastewater use can be maximized, and its actual health risks eliminated.

Water

Wastewater is composed of 99.9% water and 0.1% other material (suspended, colloidal and dissolved solids). In arid and semi-arid areas water resources are so scarce that there is often a major conflict between urban (domestic and industrial) and agricultural demands for water. This conflict can usually be resolved only by the agricultural use of wastewater: the cities must use the fresh water first, and urban wastewater — after proper treatment (see Section 7) — is then used for crop irrigation. If such a sequence of water resource utilization is not followed, both urban and agricultural development may be seriously constrained, with consequent adverse effects on national economic development.

The rate of wastewater generation is usually between 80 and 200 litres per person per day, or some 30–70 m^3 per person per year. Thus in semi-arid areas with a water demand of, for example, 2 m per year (the range is commonly 1.5–3 m per year), one person's wastewater could be used to irrigate 15–35 m^2 of land. In other words, a city of one million people will produce enough wastewater to irrigate approximately 1500–3500 ha.

Nutrients

The suspended, colloidal and dissolved solids present in wastewater contain major plant nutrients (nitrogen, phosphorus and potassium) and also trace nutrients (such as copper, iron and zinc). Total nitrogen and phosphorus concentrations in raw wastewater are usually in the ranges 10–100 mg/litre and 5–25 mg/litre respectively, and potassium is in the range 10–40 mg/litre. Treated wastewaters will contain less nitrogen and phosphorus, but approximately the same amount of potassium, depending on the treatment process used. For the irrigation rate of 2 m per year commonly required in semi-arid climates, concentrations of 15 and 3 mg/litre of total nitrogen and total phosphorus respectively in well treated domestic wastewater (such as can be expected in the final effluent of a well designed series of waste stabilization ponds) correspond to annual nitrogen and phosphorus application rates of 300 and 60 kg/ha respectively. Supplementary fertilizer requirements can thus be reduced, or even eliminated, by wastewater irrigation.

Contaminants and toxins

In addition to beneficial nutrients wastewater also contains contaminants and toxins. The contaminants are the excreted pathogens—disease-causing viruses, bacteria, protozoa and helminths—which are present in variable numbers in all wastewaters. In Europe, for example, domestic wastewater often contains some 10^4 salmonella bacteria per litre; in developing countries pathogen numbers and diversity are much greater. The health risks posed by these pathogens are discussed in Section 4, and treatment processes for removing pathogens before irrigation are described in Section 7.

Wastewater, especially if it includes a significant proportion of industrial effluent, may contain compounds that are toxic to both humans and plants. Heavy metals are an obvious example, but boron (derived from synthetic detergents) is an important phytotoxin, especially of citrus crops. Provided that the quality of the wastewater conforms to that recommended by the Food and Agriculture Organization of the United Nations for irrigation water (Ayers & Westcot, 1984), it may be safely used for crop irrigation. Domestic and normal municipal wastewaters are usually of adequate physicochemical quality for crop irrigation, and only the boron sensitivity of the irrigated crop requires particular attention.

Application rate

The application rate of wastewater to crops is calculated in the same way as for irrigation with fresh water, with due regard to evapotranspiration demand, leaching requirements and salinity and sodicity control (Pettygrove & Asano, 1984).

2.2 Excreta use in agriculture

The application of excreta to the land to fertilize crops (Figure 2.2) is a common practice in China and Viet Nam, for example, and in the

Figure 2.2 Application of nightsoil to crops in China (Province of Taiwan)

recent past this was also true in Japan. It is the only agricultural use option in areas without a sewerage system and, since the majority of households lack such systems (a condition that is likely to persist for at least the foreseeable future), excreta use has greater agricultural potential than wastewater use. Emphasis should thus be directed towards the implementation of on-site sanitation technologies that readily permit the use of stored excreta—for example, alternating twin-pit or pour-flush latrines and compost toilets as used in such places as Guatemala and Viet Nam.

Historically the importance of excreta use in agriculture may be judged by the experience in China, where soil fertility has been maintained by this practice for thousands of years (see Box 2.2). In 1965, for example, approximately 90% of all human excreta produced in China was used as fertilizer, and this amounted to 22% of all plant nutrients used, including those derived from chemical fertilizers; a further 25% was derived from the use of animal manure (Chao, 1970). In addition to supplying nutrients, excreta are very valuable in increasing the humus content of the soil, which significantly improves the structure and water-retaining capacity of the soil. Notwithstanding the clear agricultural and horticultural advantages, there is in many societies a strong sociocultural aversion to the

Box 2.2 Agricultural utilization of excreta in Eastern Asia

One of the most remarkable agricultural practices adopted by any civilised people is the centuries-long and well-nigh universal conservation of all human waste in China, Korea and Japan .... The human manure saved and applied to the fields of Japan in 1908 amounted to 23 850 295 tons [21 636 988 tonnes], which is an average of 1.75 tons per acre [3.92 t/ha] of their 21 321 square miles [55 226 km^2] of cultivated land in the four main islands .... In Eastern Asia for more than thirty centuries, these wastes have been religiously saved, and today the 400 millions of adult population send back to their fields annually 150 000 tons [136 000 t] of phosphorus, 376 000 tons [341 000 t] of potassium and 1 158 000 tons [1 051 000 t] of nitrogen comprised in a gross weight exceeding 182 000 000 tons [165 000 000 t].

Source: King (1926)

agricultural and horticultural use of excreta (see Section 5), although the use of some excreta-derived products is common and socially acceptable. In the United Kingdom, for example, 47% of all wastewater sludge is applied to land (Water Authorities Association, 1985).

The agricultural and horticultural use of excreta has the potential to promote the transmission of excreta-related disease, especially if raw excreta are applied to the land. However, as in the case of wastewater use, it is now possible to design and operate excreta use schemes in which pathogen transfer via excreta-fertilized crops, even including salad crops eaten raw, is eliminated (see Section 7). It is thus no longer necessary to consider excreta use as a practice that automatically causes disease transmission, and attention can be shifted to its clear agricultural and horticultural advantages.

Excreta quality

Because of differences in diet and climatic factors, there is considerable variation in the quantity of excreta produced, but a typical value for urban areas of developing countries is 1.8 litres per person per day (Feachem et al., 1983). In this volume there are approximately 350 grams of dry solids which comprise around 90 grams of organic

Table 2.3 Approximate nutrient content of various natural fertilizers

Type of fertilizer	Nutrient content (% of dry weight)		
	Total N	P_2O_5	K_2O
Human faeces	5–7	3–5.4	1–2.5
Human urine	15–19	2.5–5	3–4.5
Fresh nightsoil[a]	10.4–13.1	2.7–5.1	2.1–3.5
Fresh cattle manure	0.3–1.9	0.1–0.7	0.3–1.2
Pig manure	4–6	3–4	2.5–3
Plant residues	1–11	0.5–2.8	1.1–11

[a] Faeces, urine and 0.35 litres of ablution water

Source: Strauss (1985)

matter and significant quantities of plant nutrients (see Table 2.3). Treatment of excreta, in addition to destroying pathogens, improves quality principally by stabilizing the organic matter so that it is a better soil conditioner and by converting the nutrients to forms more readily used by plants. The physicochemical and microbiological qualities of excreta-derived materials (for example sludge from latrines and septic tanks, composted nightsoil and wastewater sludges) depend on the degree of treatment given, and should be regularly monitored before application to crops.

Application rates

Excreta and excreta-derived materials are often applied to the land before crop planting, at an annual rate of approximately 5–30 t/ha depending on the available concentrations of nutrients and the crops being fertilized. These are not high rates of application—10 t/ha, for example, is equal to only 1 kg/m^2—and supplementary fertilization may be required to obtain maximal yields.

Urban nightsoil, if it contains small quantities of toilet flushwater in addition to excreta (such that its volume is some 5–10 litres per person per day), is often used, especially in Eastern Asia, for crop irrigation as well as fertilization. In such cases the application rate depends on the consumption demands of the crop, although supplementary irrigation may be advisable to prevent wastage of the nutrients present in the nightsoil.

2.3 Excreta and wastewater use in aquaculture

Aquaculture means "water-farming", just as agriculture means "field-farming", and it refers to the ancient practices of fish culture, notably of carp and tilapia, and the growing of certain aquatic crops, such as water spinach (*Ipomoea aquatica*), water chestnut (*Eleocharis dulcis* and *E. tuberosa*), water hyacinth (*Eichhornia crassipes*), water calthrop (*Trapa* spp) and lotus (*Nelumbo nucifera*). The fertilization of aquaculture ponds with human wastes has been practised for thousands of years in Asia (Figure 2.3), and today at least two-thirds of the world yield of farmed fish is obtained from ponds fertilized with excreta and animal manure. Such fish represent the cheapest source of animal protein. The Chinese experience, especially their integration of aquaculture with agriculture (see Box 2.3), is an

Box 2.3 Integration of aquaculture and agriculture in China

"Aquaculture in China is a part of the overall agricultural farming system. It is either carried out as a primary farm occupation, or as a secondary or sideline activity depending on the extent and nature of land and water resources available. This integration of farming activities provides a vivid demonstration of how the full use of all raw materials available in the farm can be cycled into the production of food. Animal manures are used to fertilize the ponds and croplands; the land, in turn, produces food crops for animals, fish and man; the wastes of fish accumulated in the pond are recycled back to the soil where land crops are grown. This illustrates the practical reasons for integration and diversification of land and water farming.

"Integration of aquaculture with agriculture is carried out on only a limited scale in other countries, unlike the full integration that is found in China. A major reason for this is the difference in the control of the means of production, and in the ownership of resources used for production. Most countries have private land ownership systems where it is difficult to implement a unified development strategy. In China, land is state-owned and development programmes are centrally directed even though implementation is highly decentralized. This gives flexibility at the local level in undertaking their respective production activities, but at the same time maintains central control over the resources decisive for nationwide development. Local needs and experience are the basis of planning, which provides a strong motivation for rural production and development."

Source: Tapiador et al. (1977)

Figure 2.3 Application of nightsoil to fishponds in China

important example of waste-based aquaculture. China produces 60% of the world's farmed fish in only 27% of the world's area of fish-ponds (2.25 million tonnes per year from 7000 km² of ponds in China, compared with 1.5 million tonnes per year from 18 000 km² of ponds in the rest of the world). The mean yield in Chinese fish-ponds is 3200 kilograms per hectare per year, but in well managed intensive polyculture ponds the yield can be up to 7000 kilograms per hectare per year (Wohlfarth, 1978).

The use of untreated excreta to fertilize fish is becoming less common in many parts of the world, and in China excreta are now used only after storage for four weeks in closed containers (Tapiador et al., 1977). In addition to excreta, wastewater sludge, biogas slurry, septage and excreta-derived compost can all be used to fertilize fish-ponds (Polprasert et al., 1982; Huggins, 1985; Zandstra, 1986). More recent aquacultural developments have been the culture and harvesting of microalgae in high-rate algal ponds, and the raising of valuable crustaceans such as shrimps and crayfish.

Fish can be successfully raised in the maturation ponds of a series of waste stabilization ponds (Bartone, 1985; Payne, 1985), and annual yields of up to 3000 kilograms per hectare have been obtained. Care is needed to maintain aerobic conditions and to keep unionized ammonia levels low (<0.5 mg nitrogen/litre) in order to avoid fish kills (Bartone et al., 1985). The sale of harvested fish can be used to pay for improved operation and maintenance of municipal sewerage systems in developing countries (Meadows, 1983).

Application rates

Despite the very large number of reports describing the successful culture of fish and aquatic macrophytes in ponds fertilized with excreta and wastewater, there are almost no data on excreta and wastewater application rates. The fish-ponds at Munich, Federal Republic of Germany, which are fertilized with settled wastewater, receive an annual mean organic loading in the range 33–77 kilograms BOD (biochemical oxygen demand) per hectare per day (Edwards, 1985). On the basis of a design loading of 50 kilograms BOD per hectare per day and a per caput BOD contribution of 25 grams per day (for settled wastewater or raw nightsoil), this corresponds to 1 hectare of fish-pond for every 2000 people. In China, however, excreta and animal manures are applied to fish-ponds at an annual rate of up to 40 000 kg/ha, corresponding to approximately 1 hectare of pond for every 45 pigs or 115 people (Tapiador et al., 1977). Advice for small-scale fish farming operations is given by Edwards & Kaewpaitoon (1984), but clearly further work is needed to develop more rational guidelines for loading fish-ponds with human wastes.