8

ENVIRONMENTAL ASPECTS

The use of excreta and greywater in agriculture has the potential for both positive and negative environmental impacts. The resource value of excreta and greywater has been largely described in chapter 1. The present chapter reviews the potential environmental impacts associated with the use of urine, faeces and greywater, which will differ depending on local conditions.

It is important to minimize the environmental impact associated with the direct use of excreta and greywater in agriculture in both the local and global context. For large-scale implementation, environmental impact assessment is a useful tool for the analysis. A procedure for measuring the environmental impacts of different sanitation approaches involves the analysis of material flows (see case study in Box 8.1) or a life cycle analysis for the production of different crops, which may also lead to a better understanding of the environmental impacts of different agricultural practices (see case study in Box 8.2).

Box 8.1 Example of environmental assessment through material flow analysis

A case study conducted in Viet Tri, Viet Nam, allowed an estimation of nitrogen flows related to excreta and organic solid waste management in Viet Tri by applying the method of material flow analysis (Montangero, Nguyen & Belevi, 2004). The results indicate that 60% of the nitrogen delivered to the households in the form of food is finally discharged with the excreta in surface water, in fish ponds or on the soil, resulting in water pollution. The impact of potential control measures — including increasing the proportion of households using urine diversion latrines from 5% to 25%, treating 25% of the effluent from on-site sanitation systems in duckweed ponds and treating 25% of the sludge from on-site systems in constructed wetlands — was quantified. The proposed measures led to a 30% reduction of the nitrogen load into soil and surface water.

Box 8.2 Life cycle analysis of wheat production using human urine as fertilizer

Life cycle analysis is another tool for monitoring environmental sustainability. The environmental consequences of introducing urine as a fertilizer for cereals were studied by Tidåker (2003). Conventional production of spring barley with a chemical fertilizer was compared with the same production using urine as fertilizer. If the collection system and handling were optimized and well functioning, the energy use decreased by 27% when urine was used as fertilizer. Eutrophication of surface waters was substantially lowered due to lower discharge of nitrogen and phosphorus, but a higher release of ammonia to the atmosphere occurred. The environmental impact depended on decisions made at the farm level, highlighting the need for monitoring the reuse system from the toilet all the way to the field.

The environmental impact of different sanitation systems can be measured in terms of the use of natural resources, discharges to water bodies, air emissions and impacts on soils. Table 8.1 summarizes the types of impacts that may be considered in an environmental impact assessment (Kvarnström et al., 2004). Most relevant in relation to the use of excreta and greywater are the potential environmental impacts on soil and water bodies.

8.1 Impacts on soil

Relevant substances to consider in terms of environmental impacts on soil are salts, heavy metals, persistent organic compounds, hormones and nutrients.

8.1.1 Metals

The content of heavy metals in excreta is generally low or very low, compared with other sources with potential impacts on soil, and depends on the amounts present in consumed food products. The contents of urine reflect metabolism, and the levels of heavy metals in urine are very low (Jönsson et al., 1999; Vinnerås, 2002; Palmquist, 2004). Concentrations of heavy metals are relatively higher in faeces than in urine, but the concentrations are lower than in chemical fertilizers (e.g. cadmium) and farmyard manure (e.g. chromium and lead). The main proportion of the micronutrients and other heavy metals passes through the intestine unaffected (Fraústo da Silva & Williams, 1997). Of all the liquid household effluents, greywater may have the highest heavy metal content.

Table 8.1 Criteria for measuring environmental impacts of sanitation systems

Criteria	Unit
Use of natural resources, construction, operation and maintenance	
Land	m²/person
Energy	MJ/person
Construction materials	Type and volume
Chemicals	Type and volume
Fresh water	m³/person per year
Discharge to water bodies	
BOD/COD	g/person per year
Impact on eutrophication	g/person per year of nitrogen and phosphorus
Hazardous substances: heavy metals, persistent organic compounds, pharmaceutical residues, hormones, pathogens	mg/person per year; number/unit
Air emissions	
Contribution to global warming	kg of carbon dioxide equivalents
Resources recovered	
Nutrients	% into the system
Energy	% consumption within the system
Organic materials	% into the system
Water	% into the system
Quality of recycled product released to soil	
Hazardous substances: heavy metals, persistent organic compounds, pharmaceutical residues, hormones, pathogens	mg/unit; number/unit

Source: Kvarnström et al. (2004).

Regardless of the metal content of the excreta and greywater, a metal will not impact plant uptake unless it first reaches a threshold concentration in the soil and the metal is in a mobile phase (i.e. dissolved in the soil solution and not adsorbed to soil particles). Metals are bound to soils at a pH above 6.5 and/or with high organic matter content. If the pH is below this value, organic matter is consumed or all feasible soil adsorption sites are saturated, metals become mobile and can be absorbed by crops and contaminate water bodies. The plant roots act as an efficient barrier against uptake of non-essential metals. Therefore, impacts on soils from heavy metals are usually noted on soil microbiology before they are observed in plants or ultimately humans (or animals). Impacts of heavy metals on crops are complex, because there humans (or animals). Impacts of heavy metals on crops are complex, because there may be antagonistic interactions that affect their uptake by plants (Drakatos et al., 2002).

One important heavy metal is cadmium, which is a non-essential element that can pass through the root barrier, due to its resemblance to zinc. Cadmium is toxic to humans and needs to be limited in the inflow to agricultural land. Heavy metal concentrations in excreta and greywater generated at the household or small community level will rarely be high enough, however, to threaten the environment.

Table 8.2 Concentrations of heavy metals in urine, faeces, wastewater and source-diverted kitchen waste, compared with farmyard manure

	Unit	Cu	Zn	Cr	Ni	Pb	Cd
Urine	µg/kg ww	67	30	7	5	1	0
Faeces	µg/kg ww	6 667	65 000	122	450	122	62
Blackwater	µg/kg ww	716	6 420	18	49	13	7
Kitchen waste	µg/kg ww	6 837	8 717	1 706	1 025	3 425	34
Cattle organic farmyard manure	µg/kg ww	5 220	26 640	684	630	184	23
Urine	mg/kg P	101	45	10	7	2	1
Faeces	mg/kg P	2 186	21 312	40	148	40	20
Blackwater	mg/kg P	797	7 146	20	54	15	7
Kitchen waste	mg/kg P	5 279	6 731	1 317	791	2 644	26
Sewage sludge	mg/kg P	13 360	19 793	1 072	617	1 108	46.9
Cattle organic farmyard manure	mg/kg P	3 537	18 049	463	427	124	16

ww: wet weight
Sources: Steineck et al. (1999); Vinnerås (2002).

8.1.2 Persistent organic compounds

Excreta and greywater normally have low contents of persistent organic compounds. However, depending on the household use, greywater may contain as many as 900 different organic compounds; nevertheless, most of these substances will be found at very low concentrations (Eriksson et al., 2002). Collected faecal sludge may also contain a range of different organic chemicals used in the household if they have been dumped in the toilet. Information to system users regarding the importance of correct handling of household chemicals is vital.

If excreta and greywater are treated prior to use in agriculture, the concentration of many of these compounds will be reduced by adsorption, volatilization and biodegradation. Absorption of these substances by plants through their root system is not likely to occur due to their usually large size and high molecular weight, which reduces their mobility in soil and water (Pahren et al., 1979). It is possible that these chemicals can be transferred to the edible surfaces of crops, but concentrations are likely to be low. These substances may be associated with soil that remains on the crops after harvest. Washing produce thoroughly prior to consumption will remove a large percentage of this contamination.

Synthetic organic compounds are adsorbed and biodegraded with time in soil. Cordy et al. (2003) studied the removal of 34 organic compounds that can be found in excreta and greywater and did not detect any of them after 3 m of infiltration through desert soils with a retention time of 21 days. Removal of endocrine disruptors such as steroidal hormones detected in treated and non-treated wastewater through infiltration in soils has been demonstrated (Mansell, Drewes & Rauch, 2004).

A variety of pharmaceutical residues or their metabolic by-products can be detected in excreta and sometimes greywater. Most of these substances are at the highest concentrations in urine. A number of biologically active pharmaceuticals and their metabolites have been identified in groundwater and drinking-water samples (Heberer, Schmidt-Bäumler & Stan, 1998; Heberer, 2002). The effects of these substances on the ecosystem and animals are not known, but negative effects on the quantity or quality of crops are assumed to be negligible. Furthermore, the amount of hormones in manure from domestic animals is far greater than the amount found in human urine or faeces. Thus, even though theoretical estimates based on effects on fish have indicated an ecotoxicological effect from estradiol, comparative assessments with manure strongly indicate that the risk is very limited (Hanselman, Graetz & Wilkie, 2003).

Urine and faecal fertilizers are mixed into the topsoil, where there is a high level of biological activity. Usually the substances are retained there for months. The dominant removal mechanism for these substances is adsorption. Removal efficiencies are greater in soils containing higher contents of silt, clay and organic matter. Some may be transported through the soil matrix to groundwater, and two drugs (carbamazepine and primidone) did not show significant reductions even after six years of passage through the soil aquifer treatment system (Drewes, Heberer & Reddersen, 2002). Additional attenuation, to below the detection limit, occurs by biodegradation, regardless of aerobic or anoxic conditions or the type of organic carbon matrix present (hydrophobic acids, hydrophilic carbon vs colloidal carbon). A variety of pharmaceutical residues or their metabolic by-products in low concentrations can be detected in wastewater, which may reflect either that they are excreted in urine and faeces or that they are flushed away in the toilet.

Endocrine disruptors (which interfere with hormone functions) have also been found in greywater and may not degrade quickly in the environment. Mansell, Drewes & Rauch (2004) found that 17-α-estradiol, estriol and testosterone are not sensitive to photodegradation (i.e. less than 10% destruction after 24-h exposure to ultraviolet light). Thus, these compounds could remain on the surface of crops irrigated with greywater that contains them. The concentrations of these compounds are usually extremely low, and to date only effects on animals in direct contact with polluted water have been demonstrated. Effects on humans have not been shown.

Regarding excreta, some substances with endocrine disrupting properties, such as hormones (from humans, e.g. 7-ethinylestradiol, or from plants, e.g. 17-α-estradiol estriol) and pharmaceuticals, may be present in low concentrations, especially in diverted urine. It should be noted that animal manure also contains residues of pharmaceuticals used, in many cases preventive medication, resulting in high amounts of, especially, antibiotics. The soil system is generally better equipped than watercourses for degradation of the pharmaceutical residues present in the fertilizers.

8.1.3 Salinization

Salinity effects are, in general, of concern only in arid and semi-arid regions, where accumulated salts are not flushed regularly from the soil profile by rainfall. The use of urine and greywater can accelerate the process of soil salinization due to its higher salt content. However, fertilizers containing organic materials will help to buffer the negative effects of the salts in the soil profile.

There are four ways in which salinity affects soil productivity:

1) It changes the osmotic pressure at the root zone.
2) It provokes specific ion (sodium, boron or chloride) toxicity.
3) It may interfere with plant uptake of essential nutrients (e.g. potassium and nitrate) due to antagonism with sodium, chloride and sulfates.
4) It may destroy the soil structure by causing soil dispersion and clogging of pore spaces. This results in an increased lateral drainage, but may also affect the oxygenation. Both low-salinity waters and high sodium concentrations in the water in relation to calcium and magnesium concentrations in the soil exacerbate the effects.

Salinization is measured through a combination of parameters. Depending on the type of soils and the washing and drainage conditions, salinity problems can occur with conductivities of >3 mS/m, dissolved solids concentrations of >500 mg/l (being severe if >2000 mg/l) and sodium adsorption ratios of >3–9 (Ayers & Westcott, 1985). Soil salinization is also affected by inefficient drainage, climate and type of soil. Practices to limit salinization include soil washing and appropriate soil drainage.

8.2 Impacts on water bodies

Application of excreta and greywater to agricultural land will reduce the direct impacts on water bodies. However, as for any type of fertilizer, the nutrients may percolate to groundwater if applied in excess or be flushed into surface water after excessive rainfall. This impact will always be less compared with that of the direct use of water bodies as the primary recipient.

The impact of reuse of human excreta and greywater in agriculture on groundwater quality depends on factors such as agricultural application rate, the type of irrigation water, the soil type, aquifer vulnerability, the agricultural practices and the type of crops, as well as the recharge and groundwater use (Foster et al., 2004).

In order to avoid negative effects of using excreta and greywater as agricultural fertilizers, the following should be considered (Foster et al., 2004):

- improve agricultural practices;
- establish criteria to operate wells used to supply water for human consumption in the surroundings (establish safe distances to the agricultural site, depth of extraction and appropriate construction);
- routinely monitor groundwater.

Surface water bodies are affected by agricultural drainage and runoff. Impacts depend on the type of water body (rivers, agricultural channels, lakes or dams) and their use, as well as the hydraulic retention time and their function within the ecosystem.

A high organic load will, independently of the source, affect the dissolved oxygen levels, thus impacting aquatic organisms. Additionally, the nitrogen or phosphorus washed into water bodies will lead to eutrophication and subsequent oxygen depletion and will facilitate the growth of toxin-producing algae (Chorus & Bartram, 1999).

Organic chemicals originating from excreta and greywater will only minimally impact surface water bodies due to their adsorption to soil particles after application. The soil will act as a filter before the respective pollutants reach groundwater and surface waters.

Nitrogen can contaminate groundwater and surface water bodies by infiltration and agricultural runoff. The amount of nitrogen leached depends on crop demand, hydraulic load due to rain and agricultural water, soil permeability and nitrogen content in soils. Agricultural runoff containing phosphorus can cause eutrophication in surface water bodies (reservoirs and lakes). High concentrations of biodegradable organic matter in agricultural runoff water can lead to the consumption of dissolved oxygen in lakes and rivers.

Phosphorus is an essential element for plant growth, and mined phosphates are a common input into agricultural production in order to increase crop productivity. Soil phosphorus content varies with parent material, texture and management factors, such as rate of application, type of phosphorus applied and soil cultivation (Sharpley, 1995). It is usually present in soils in relatively important quantities. World supplies of accessible mined phosphate are diminishing. It is predicted that phosphate-carrying rocks/mineral reserves will run out in 60–130 years. The mining of phosphate causes environmental damage because it is often removed close to the surface in large open mines, leaving behind scarred land. Moreover, phosphate-carrying rocks/minerals also contain varying amounts of non-desired elements, such as cadmium. Approximately 25% of the mined phosphorus ends up in aquatic environments or buried in landfills or other sinks (Tiessen, 1995). The discharge into aquatic environments causes eutrophication of water bodies, leading to more environmental damage. To reduce the phenomenon of eutrophication, wastewater treatment plants require additional phosphorus removal treatment capacity, which adds to the costs and complexity of the treatment process.

Urine alone contains more than 50% of the phosphorus excreted by humans. Thus, the diversion of urine and its use in agriculture can aid crop production and reduce the need for costly, advanced wastewater treatment processes to remove phosphorus from the effluents (EcoSanRes, 2005).