Third edition of the WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater in Agriculture and Aquaculture

Guidance note for Programme Managers and Engineers

THE CONCEPT OF EXPOSURE REDUCTION IN THE USE OF EXCRETA AND GREYWATER IN AGRICULTURE[1].

INTRODUCTION

Volume 4 of the Guidelines primarily aims to maximize public health protection while at the same time optimizing beneficial use of the nutrient resources in excreta and the nutrient and water resources in greywater for agricultural production. The adverse health impacts of excreta and greywater use are offset by these benefits, which come to expression in food security and nutritional status. In the Guidelines this is essentially done through good management practice within a full system approach.

The Guidelines provide an integrated preventive management framework. They propose cumulative safety measures for application from the point of household excreta and greywater generation to the consumption of products grown either with treated excreta applied as fertilizers or treated greywater used for irrigation purposes. The resulting risk reduction relates to the potential exposure at different steps in the handling chain.

A health-impact target is provided in the Guidelines, which in turn relates to this exposure. This target is a globally acceptable level of health protection and is based on the additional disease burden arising from the exposure (for example, from direct contact with treated excreta or greywater, or from consuming crops fertilised with these products). The risk target is set not to exceed a loss of 10^{-6} disability-adjusted life years (DALYs) per person per year, which is the same level of protection set for drinking-water. Neither the minimum good practices nor the health-based targets are mandatory limits. Rather, they provide a guiding principle for health and system assessment, and for monitoring. The approaches adopted by national or local authorities towards implementation of the Guidelines, including health-based targets, may, therefore, vary depending on local social, cultural, environmental and economic conditions. They will be a function of available knowledge of routes of exposure, the nature and severity of hazards (e.g. prevalence of different excreta-related diseases) and the effectiveness of health protection measures available.

The objective of this guidance note is not to go through the calculation exercises of the numerical background values for the risk assessment, with reference to the health based target. For the numerical approaches, reference is made to *"The Numerical Guide to the Guidelines"* a guidance note prepared by Professor Duncan Mara for wastewater use in agriculture. Those numerical approaches equally apply to excreta and greywater use. Rather, this guidance note aims to provide programme managers and technical

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professionals who are responsible for small-scale excreta and greywater treatment, for assessing the risks posed by their use in agriculture and for designing realistic interventions with a short guide how the Guidelines' approach can be used in practice.

Volume 4 of the Guidelines includes a comprehensive summary of microbial risk management and system assessment approaches with their policy, institutional, social, environmental and economic dimensions. Several concepts, however, including predictive quantitative microbial risk analysis and disability-adjusted life, years are topics managers and engineering staff may be less familiar with. The core sections are chapter 5 (health protection measures including exposure control) and chapter 6 (system assessment including different levels of monitoring). Both refer to the concept of health-based targets proposed in chapter 4 of the guidelines. A simplified readers' guide is presented below.

CONSIDERATIONS FOR PLANNING AND IMPLEMENTATION

Deploying an implementation, monitoring and surveillance strategy for the use of excreta and/or greywater in agriculture requires a multidisciplinary and multi-sectoral team. Such a team, operating at either the national level or the local or project level may start its work by considering the general recommendations made in Chapter 11 of volume 4. The focus on the assessment is based on the needs of the user of sanitary facilities, the end users of the treated excreta and greywater and the service providers. In an integrated approach issues related to other sectors than the public health sector need to be addressed. These include:

- *Integration of aspects of safe use into the assessment of the current sanitary situation and into all the planning activities and conceptual work*
- *Integration of aspects related to water supply*
- *Integration of aspects of urban planning*
- *Integration of aspects of solid waste management*
- *Consideration of a much wider variety of sanitation systems*
- *Application of new and wider-ranging decision-making and evaluation criteria for water supply and sanitation services*
- *Provision of stakeholders with the relevant information, enabling them to make an "informed choice"*

By preference, sanitation planning should be focused on the household. With the household as the key stakeholder, women are provided with a strong voice in the planning process, and the government's role changes from that of a provider to that of an enabler. Furthermore, a circular system of resource management should be applied, emphasizing the conservation, recycling and reuse of resources, following the Bellagio Principles. These principles stand in contrast to the current linear sanitation service system.

Within local project planning, specific considerations should be given to:

- *Participatory approaches*
- *Treatment* (further consult chapter 5)
- *Crop selection (and restrictions) and application* (Background information on excreta as fertiliser in Chapter 1)
- *Human exposure control* (further information in Chapter 5 with background information on health risks in Chapter 3 and 4)
- *Supporting service and the need for training*

Detailed planning for excreta and greywater use schemes follows the national procedures for project planning, supplemented by procedures specific to the nature of the project (excreta and/or greywater use and for the required health protection measures). A checklist of relevant information for decisions is presented in Box 1.

Planners in need of further background information for developing a national policy framework to facilitate the safe use of excreta as fertilizer should consult Chapter 10. National approaches for adequate sanitation based on the WHO Guidelines will protect public health optimally when they are integrated into comprehensive public health programmes. Such programmes should include other sanitary measures, such as health and hygiene promotion and improving access to safe drinking-water. Chapter 10 has a section on different factors that influence stakeholders' attitudes towards the adaptation of safe use systems.

BOX 1. Technical information to be included in a project plan

- Current and projected generation rates of the wastes (excreta, sludge or greywater)
- Existing and required treatment facilities; pathogen removal efficiencies; physico-chemical quality
- Existing and required land areas: size, location and soil types
- Energy requirements and/or energy generating potential of excreta/greywater (possibly in combination with organic waste)
- Evaporation (need to make up for water lost through evaporation)
- Conveyance of treated material (collection of treated excreta and sludge by farmers or delivery by the treatment authority)
- Storage requirements for excreta (faeces and urine or combined) and greywater
- Excreta (faeces and urine or combined) and/or greywater application rates and methods
- Types of crops and their requirements for excreta or greywater quality and supplementary nutrients
- Estimated crop yields per hectare per year
- Strategy for health protection (with a specific focus on exposure control)

(adapted from Volume 4, Chapter 11, Box 11.3)

SYSTEM RISK MANAGEMENT CONSTITUTES THE CORE OF THE GUIDELINES

System risk management is addressed in Chapter 6 of volume 4. Planners and programme managers are advised to refer to this chapter after reading Chapter 11. The essential steps in the development of a risk management plan essentially follow established procedures from the WHO Drinking-Water Quality Guidelines; the process is described in Chapter 6 of volume 4 of the Guidelines and the corresponding figure showing the steps can be found in the *"Fact Sheet for the Research Community"* included in this information kit.

Step 1. The first step is to form a multidisciplinary team of experts with a thorough understanding of different aspects of the system for recirculation of excreta or greywater as resources. Typically, such a team would include agriculture experts, engineers, environmental health specialists and public health authorities. Its composition and goals may vary, however, depending on the local project type and it should be especially strong and solid if it is a national (rather than a local) programme that is planned.

Step 2. Hazard assessment and risk characterization. Effective management of the excreta/greywater system requires a comprehensive understanding of the nature and magnitude of possible hazards, the determinants of the associated risk levels and the ability of existing processes, barriers and infrastructure to manage these risks. It also requires an assessment of capabilities to meet targets. In a system assessment, the first step is to develop a risk management plan including collection and evaluation of all available relevant information and consideration of what risks may arise during the entire process. All elements of the system should be considered concurrently, as well as the interactions and mutual influences between elements and their overall effect.

From a risk calculation point of view we further need to know something about the background level of disease in the excreted population (and for different disease – realising that the current health statistics normally grossly underestimate the prevalence in different developing countries). We further need flow/volume data of urine, greywater or volume of treated human excreta and relate this to the following exposure.

EXPOSURE

The Guidelines are based on the Quantitative Microbial Risk Assessment (QMRA) approach, including a structured Hazard Assessment and Exposure Assessment. General knowledge of the exposure points, major exposure routes and groups at risks is the critical starting point for the detailed analysis. An overview is presented in the table below:

TABLE 1. Major exposure points for the reuse of excreta and greywater (from WHO 2006)

Risk activity[a]	Major exposure route	Groups at risk	Risk management considerations
Emptying the collection chamber/vessel (1–4)	Contact	Entrepreneurs Residents Local communities	Provision of protective clothing and suitable equipment for persons involved Training Facility should optimize on-site treatment Design of facility and selection of technology to facilitate safe emptying Avoid spillage
Transportation (1–5)	Contact Secondary spread through equipment	Entrepreneurs Local communities	Avoid spillage Equipment not used for other purposes without proper disinfection/cleaning
Off-site secondary treatment facility (1–3) Ponds (5)	Contact (all) Vectors	Workers Nearby communities	Ensure treatment efficiency Protective clothing Facility should be fenced off Ensure no access for children Consider and minimize vector propagation Exclude recreational activity and consider vectors (5)
Application (1–3, 5)	Contact Inhalation	Entrepreneurs Farmers Local communities	Use "close to the ground application," work the material into the soil directly and cover Reduced access should be ensured if quality is not guaranteed; in such cases, applications to parks, football fields or where the public have access should be avoided Protective clothing for workers Minimum one month between application and harvest
Crops Harvest Processing Sale (1–5)	Consumption Handling	Consumers Workers Vendors	Crops eaten raw pose the most risk; industrial crops, biofuels or crops eaten only after cooking pose less risk Adequate protective clothing (gloves, shoes) Provide safe water in markets for washing and refreshing vegetables
Consumption (1–5)	Consumption	Consumers	Practising good personal, domestic and food hygiene Cooking food thoroughly

[a] (1) Dry collection; (2) Faecal sludge; (3) Wet systems; (4) Urine; (5) Greywater.

The outputs of the hazard and exposure assessments are further related to dose-response information, mainly based on literature data. These are combined in the risk characterization and expressed either as “risk per exposure” or yearly numbers of infections. Comparisons are often made with the endemic background level of disease. To assess the exposure and give input data for the QMRA the following questions needs to be addressed, either as estimates or assumptions:

“What is the volume that individual are exposed to?” (This may vary – for example, the volume during maintenance, emptying or transport may be in the range of 0.1 –1 (g or ml), while the volume related to consumption of crops fertilised with excreta may be in the range of 100 g. Furthermore, the volume of soil or urine in contact with 1 gram of crop may be in the range of 0.01-0.05 g/ml).

“What is the likely frequency of exposure?” (This may relate to consumption – i.e. the number of days that crops fertilised with wastewater, greywater, treated faeces or urine are used for consumption (for example 100 days per year), or the number of days that x individuals are exposed during emptying, transport or handling) or the number of days that an individual may be exposed during farming activities or, if the wastewater or solid are affecting a surface or ground water source – the corresponding days.

“How many people (individuals) are exposed (directly; indirectly)”? (This may be the number of plumbers or maintenance personnel exposed (probably in the range of 1-10), it may be the number of people consuming crops fertilised with treated excreta, biosolids or urine (in the range of 100 and upwards) or the people indirectly exposed due to contamination of surface/ground water due to swimming/ personal hygiene or using the water as a drinking water source.

“Probability of exposure”? For a risk calculation we need some measurement of the likelihood of exposure. Does it occur every time (= 1)? Or, does it occur one out of hundred times (= 0.01)?

A quantitative assessment, estimate or “guesstimate” gives input data for the exposure risk analysis, which in turn is an input in the Quantitative Microbial Risk Assessment, and for the DALY calculations.

This risk calculation can be applied in a structured assessment of the full handling chain from exposure at the time of excreta, greywater or wastewater treatment, through exposure in outlet areas or in areas of reuse like agriculture. These points of exposure, with their inter-related, assumed or calculated, risks are also the focus of the risk management. The exposure assessment and its links to risk calculation and the health-based targets are as applicable in a stepwise approach for a source of generation, like open defecation, pit latrines, source-separating systems or wastewater treatment plants. The local incidence of different diseases is accounted for in the calculations as well as the treatment variability. Control measures can be defined for the different exposures within the risk management framework and, where applied, will further lower the risks. The management strategies focus on reduction of health risks (including treatment of wastes, crop restrictions, waste application methods and control of human exposure.

Background information for the microbial calculations and its applications is given in chapters 2 and 3 of volume 4 of the Guidelines. A thorough documentation system for system assessment and exposure reduction is key to the entire approach and should be given special consideration by the team addressing the hazard assessment, risk characterisation and exposure control.

RELATIONSHIP TO HEALTH-BASED TARGETS

Health-based targets define a level of health protection that is contextually relevant. It relates to the different major group of organisms that are transmitted through excreta (bacteria, viruses and parasites). A health-based target is defined based on a standard metric of disease, such as a disability adjusted life year or DALY (i.e. 10^{-6} DALY). This relates to the probability of infection and can either be associated with a certain event of exposure or be annualised.

The health-based targets may be achieved through different treatment or handling barriers, or health protection measures that aim to either achieve a reduction in the number of different groups of pathogens or reduce the likelihood of exposure. Details are provided in Chapter 4 of volume 4. The barriers are checked by verification monitoring, mainly in large-scale systems for excreta and greywater. Verification monitoring is not applicable to urine. (Verification monitoring is further addressed both in Chapter 4 and 6 of the Guidelines).

TABLE 2. Guidelines values for verification monitoring in large-scale treatment systems of greywater, excreta and faecal sludge for use in agriculture

	Helminth eggs (number per gram total solids or per litre)	*E. coli* (number per 100 ml)
Treated faeces and faecal sludge	<1/g total solids	<1000 g/total solids
Greywater for use in:		
• Restricted irrigation	<1/litre	$<10^{5}$ [a]: relaxed to $<10^{6}$ when exposure is limited or re-growth is likely
• Unrestricted irrigation of crops eaten raw	<1/litre	$<10^{3}$: relaxed to $<10^{4}$ for high-growing leaf crops or drip irrigation

[a] These values are acceptable due to the high regrowth potential of *E. coli* and other faecal coliforms in greywater.

The health-based targets are also checked by operational monitoring, such as the outcome of storage (as an on-site treatment measure) or of further treatment off-site after collection. This relates to storage criteria for collected faeces and urine (or a mixture), which are further specified in Chapter 4 for different ambient temperature intervals, additions or crops. Other pre- and post-harvest health protection measures are defined with the collective aim of reducing the potential pathogen load by 8 logs if related to fresh faeces (A 1-log unit reduction is 90%, a 3-log reduction is 99.9%, and so on. Here, the 8-log reduction is 99.999999 %).

The different fractions can be dealt with based on the faecal load. Wastewater can by simplification be seen as excreta diluted around 100 times (requiring a 6-log reduction) and are dealt with as such. Excreted urine normally contains few pathogens (those found in urine include the *eggs of Schistosoma haematobium, Salmonella typhi/paratyphi* and some viruses), thus it is the faecal cross-contamination in source separation of urine that determines the need for treatment and the subsequent risk. Based on the likelihood of this cross-contamination, urine normally constitutes a 100 – 1000 times **less risk** than wastewater (A risk reduction strategy can therefore aim towards a 4-log reduction, but locally one may need to be observant of a higher faecal contamination load). Likewise, the risks related to greywater is determined by the faecal cross-contamination and is, like urine, less risky than wastewater (A primary strategy similar to urine may be taken). The problem from a risk monitoring point of view is a more rapid die-off of indicator bacteria in urine than pathogens, while a re-growth of indicator organisms may occur in greywater, due to the presence of easily degradable organic compounds. Therefore, a false positive risk level may be observed based on indicators in greywater. For those who want more background information about different pathogens in faeces, urine and greywater, further information can be found in Chapter 3 of the Guidelines.

RISK REDUCTION BY TREATMENT OR HANDLING STRATEGIES AND MONITORING

Validation is concerned with obtaining system evidence on the performance of control measures, both individually and collectively. It should ensure a system's capability of meeting specified microbial reduction targets and design criteria. Validation is used to test or prove these criteria. It should be conducted before a new risk management process is put into place (e.g. for greywater and excreta treatment, application and crop harvest), when system components are upgraded (e.g. a new toilet collection design) or when procedures (e.g. composting or pH elevation of excreta; irrigation regimes of greywater) are added. Validation of an on-site excreta treatment/storage system could provide data on die-off of different enteric pathogens under existing treatment conditions (e.g. temperature, moisture content, or after addition of lime) and can be conducted at the facility scale or on a test scale, starting with consideration of existing data on site, data from other utilities, the scientific literature, data from regulation and legislation departments and professional bodies, historical data and supplier knowledge. Validation is not intended for day-to-day management. Thus, a validation essentially serves to optimise the reduction of different steps in the system, and is linked directly to exposure control. This will include the effectiveness of different excreta and greywater treatment alternatives, strategies to reduce contact with insufficiently treated material, fertilization practises and methods of crop harvesting to optimise the pathogen die-off in the fields. Validation is of major concern for small-scale or individual system, where the verification monitoring is less practical to perform routinely.

Published evaluations on the reduction in different treatment system components or based on handling practises will function as baseline information for system design and implementation in addition to validation monitoring (and also as an input into risk calculation at the points of exposure, and, therefore, for the QMRA, probability of infection and DALY calculation). Examples of on-site and source-separation systems are given in Chapter 5, with indications of their reduction potential.

Example: In a double vault faecal collection chamber where no new material is added for at least one year the reduction of bacteria, viruses and parasitic protozoa will be in the range of up to 5-6 logs. An additional 2 to 3-log reduction will be achieved in the field, if the treated excreta is applied during planting, thus in theory fulfilling the set reduction target of 8 logs. The risk reduction may not be fully achieved during emptying practises of the stored faeces, thus focusing the exposure control on emptying and application in agriculture. The operational monitoring may focus, for example, on storage time and storage conditions.

Example: Urine is collected and stored for one month at ambient temperatures around or above 20 C. The faecal cross-contamination is minimal and a risk reduction target of 4 logs should be achieved. The storage will achieve this reduction for pathogenic bacteria and parasitic protozoa but not fully for viruses. However, the application of urine to the crop should be done during sowing or planting. A reduction of at least 3-4 logs will be achieved in one month, which is considered the shortest crop rotation cycle. Again, the risk reduction is in theory achieved in relation to the crops, but the handling practises during collection, transport and application may be part of an operational monitoring strategy.

Example: Small-scale greywater treatment is considered at a project site. The discussion on selection criteria focuses on either a subsurface flow wetland or an open drain system with a small pond before use at an agricultural site. The greywater is marginally contaminated by faecal material and a 4-log reduction is assumed to be sufficient. A sub-surface flow wetland with a root resorption bed will minimise all contact with the water and fulfil the risk criteria. The open drain/pond system may result in accidental contact by children playing in the area. The second alternative will lead to multiple potential exposures both due to accidental contact and in agriculture. The system may simply be upgraded based on exposure control, by covering the drain and changing the configuration of the receiving pond.

The most effective means of consistently ensuring safety in the agricultural use of excreta and greywater is through the use of the comprehensive risk assessment and risk management approach that encompasses al steps in the process from waste generation to treatment, use of excreta as fertilizers or use of greywater for irrigation purposes and product use or consumption. The validation monitoring is part of this assessment.

A further supplemented component is the operational monitoring, which includes the technical functions. It is, however, not restricted to such functions, but can also include, for example, health and hygiene promotion, wastewater application, withholding periods, product restrictions and intermediate host and vector control. Central questions to be decided within the local context both for this and for verification monitoring are the monitoring frequency as well as critical monitoring points within the system.

In part, verification monitoring centers on compliance with microbial guideline values. Verification monitoring basically uses *E. coli* numbers as a proxy for viral, bacterial and protozoan pathogen concentrations. Caution is needed in specific settings, where for example, an x-log unit pathogen reduction by treatment doesn't necessarily relate to the stated *E. coli* reduction. Helminth eggs counts are only valid in situations where intestinal worms occur in the human population.

In relation to the guideline values, it is important to decide on the frequency of sampling, as well as on actions in response to non-compliance. Similarly, product and handling practises are areas for consideration, action and approaches in relation to non-compliance. Additionally, special issues related to small-scale systems (and how these are defined) need to be decided on.

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