RESEARCH INTO UD/VIDP (URINE DIVERSION VENTILATED IMPROVED DOUBLE PIT) TOILETS: PHYSICAL AND HEALTH-RELATED CHARACTERISTICS OF UD/VIDP VAULT CONTENTS

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Water Research Commission

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OF UD/VIDP VAULT CONTENTS

Report to the
Water Research Commission

by

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on behalf of

Pollution Research Group
University of KwaZulu-Natal

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This report forms part of a series of two reports. The other report in this series is *Research into UD/VIDP (Urine diversion ventilated improved double pit) toilets: Prevalence and die-off of Ascaris ova in urine diversion waste* (WRC Report no TT 356/08).

EXECUTIVE SUMMARY

eThekwini Municipality is considered as one of the leading municipalities in South Africa in the provision of basic sanitation services. The municipality has selected **U**rine **D**iversion, **V**entilated **I**mproved **D**ouble **P**it (UD/VIDP) toilets as the preferred delivery mechanism for certain communities in their area of responsibility. The first units were installed in 2003 and there were 58 000 (UD/VIDP) toilets in communities outside the urban centre at the end of 2007, built according to a constantly improving design that was initially based on a number of guiding principles. It is planned to build 10 500 new units per year.

Urine Diversion (UD) systems have recently received a great deal of international attention in the context of "Ecological Sanitation" or "EcoSan". EcoSan refers to a cycle, or closed-loop system, which treats human excreta as a resource. In this system, excreta are processed on site until they are free of pathogenic (disease-causing) organisms. Thereafter the sanitized excreta are recycled by using them for agricultural purposes. Key features of ecosan are therefore:

- prevention of pollution and disease caused by human excreta;
- treatment of human excreta as a resource rather than as a waste product; and
- recovery and recycling of the nutrients.

An advantage of UD systems in EcoSan is that nutrients and pathogens are distributed differently between faeces and urine, and keeping them separate makes it easier to re-use nutrients while minimising disease transmission.

The eThekwini system is not a full EcoSan system, because it does not address the issue of recycling the nutrients in a systematic way. The eThekwini (UD/VIDP) toilets were installed because of the municipality's experience in the logistical difficulties and excessive cost associated with the emptying of Ventilated Improved Pit (VIP) toilets, which are recommended to be considered the minimum level of sanitation service that must be provided by a water services authority in South Africa.

The eThekwini UD/VIDP toilets have a number of unique features which were developed to suit local conditions. The basic design is a double vault dry toilet with urine diverted to a soak-away located near the unit. A pedestal is located above one pit, into which faeces, anal cleansing material and bulking agent are dropped. Once the first vault is full, the pedestal is moved to the hole above the second vault and the first is sealed and allowed to stand. Once the second vault is full, the first vault is opened via a back plate and manually emptied by the householder or a community based contractor. The emptied contents are buried on the householder's property and, ideally, the burial site marked by planting a tree over it. The pedestal is then returned to its position above the first vault and the second vault is closed and left to stand while the first refills. It is expected that each vault will take between 6 months to one year to fill, resulting in a range of vault contents age of between one to two years at the time at which they are removed from the vault.

The design was based on the following assumption concepts:

1. Biologically-mediated stabilisation and drying of organic material was expected to occur in the pit, rendering it less unpleasant to handle; and

2. Sufficient pathogen deactivation might occur during the standing phase to reduce the risk of disease transmission during manual emptying of the pit.

3. Urine, which is normally sterile, is diverted to a soak-away in the ground close to the toilet structure.

The motivation for a urine-diverting design is that the volume of material that requires handling should be substantially less than in a pit latrine which receives urine and often grey water as well as faeces and cleansing material. Thus a far smaller vault needs to be constructed. The smaller volume of the vault contents and their relative dryness means that the solids can be removed relatively easily by the householder with an appropriately sized rake or spade.

Despite the obvious benefits of the design, there are a number of unresolved scientific, technological, social and health-related questions about how the design works from a biological and mass transfer perspective, and what the real health and environmental risks are to the householder, community and any outsiders involved in the pit emptying process. In particular, the risk of infection by geohelminths such as *Ascaris* spp. has been identified as being an important factor in calculating the benefit of sanitation provision in terms of community health and quality of life. The infection cycle can be broken by a combination of hygiene education and practice, chemotherapy and improved sanitation. The fate of *Ascaris* spp. eggs in the urine diversion toilet is an important issue. Extended anaerobic conditions will result in the ultimate death of the eggs, thus burying the contents of a urine diversion toilet may be effective in breaking the infection cycle.

Project aims

1. Provide a scientific basis for the design and operation of urine diversion toilets as used by eThekwini Municipality.

2. Evaluate the effectiveness of urine diversion toilets in improving the wellbeing of the user community.

3. Determine the fate of *Ascaris* spp. eggs from urine diversion toilets.

Products

The project contract specified the following products for this project:

1. An assessment of the health benefits of urine diversion toilets.

2. A qualitative model of the moisture balance and rate of stabilisation of the contents of a urine diversion toilet.

3. A risk assessment of the operation and maintenance of urine diversion toilets.

Methodology

This project involved a number of sub-projects, each of which followed its own particular methodology. The unifying principle was that each should contribute to the risk/benefit assessment of the Durban system as a whole, by providing scientific data to allow the evaluation of risks and benefits in the design and operation of the system. Some of the issues involved risks and benefits that were perceived at the start of the project, others were identified during the course of the investigations. Because of the wide scope of the investigations, where the risk involved in a topic appeared not to be critical, or the required data were available from elsewhere, the topic was not pursued.

In particular, the issue of the health benefits of providing UD toilets to communities was the subject of an extensive epidemiological investigation by the eThekwini Health Department and the University of KwaZulu-Natal Medical School, so that aspect was not investigated separately in this project. A brief summary of the findings of that investigation appears in this report.

The investigations undertaken in this project fell into three main groups:

1. physical and biological processes occurring in UD waste in the toilet vaults and after being removed from the vaults and buried;
2. the occurrence and survival of pathogens in UD waste;
3. the health risks associated with the process of vault emptying and burying the contents, as recommended by the eThekwini implementation of UD toilets.

The principal conclusion of the first and second groups of investigations was that greatest risk in the whole system was the spread of infection by geohelminths during the process of emptying the vaults and burying the contents, so the risk assessment focused on a quantitative estimate of this risk, and the measures required to minimise it.

A substantially part of the experimental effort was devoted to developing and evaluating experimental techniques for characterising UD waste. A significant new technique, the *AMBIC protocol*, was developed for detecting geohelminth ova in samples containing soil. The AMBIC protocol represents a major advance over previously accepted methods, which were shown to probably seriously underestimate the incidence of ova in samples containing soil particles. This discovery casts doubts on the validity of previous studies on the survival of these pathogens in the soil. The probable underestimation of *Ascaris* in soil/waste mixtures, arising from low recoveries of previous detection methods for *Ascaris* ova, and those of other geohelminths, in soil, is of particular concern.

The development of the AMBIC protocol is the subject of the separate WRC Report TT 356/08: *Prevalence and die-off of Ascaris Ova in UD/VIDP Toilets.*

Physical and chemical characterisation of UD waste

The processes of drying and biological degradation which take place in UD vaults were investigated, with a view to understanding the characteristics of the UD waste at the time that the vault is to be emptied.

Moisture content and drying

With a double vault latrine, one vault is used at a time. While it is filling, the contents of the idle vault are allowed to dry, hopefully to the point where they become safe and not unpleasant to handle. The vault can then be emptied in preparation for the next cycle of use. There are two obvious phases which need to be considered in analysing the drying problem, 1) while the vault is in use and gradually filling, and 2) when it is idle and its contents are undisturbed.

A mathematical analysis was carried out primarily to provide a framework for interpreting experimental results. This analysis used the simplest possible one-dimensional model of the solids, and a fully mixed model of the gas headspace.

It showed that the moisture content during the filling phase should remain approximately constant, if the material entering the vault is approximately constant. Assessing the moisture content of a vault during the filling phase is thus largely a matter of obtaining a sufficiently representative sample of the non-homogeneous material.

The analysis has also highlighted the importance of the air circulation rate for achieving good drying. The fact that the Durban system is to close off the vault during the standing phase is therefore an unsatisfactory feature of the system, since it means that very little drying will occur during the standing phase.

Physical and chemical characteristics

The process of degradation in a UD vault was thought to be anaerobic biodegradation, with some aerobic degradation occurring at the air interface at the top surface of the waste.

Two student projects between them analysed samples from 11 different UD toilets. The main thrust of both projects was to characterise the process of biodegradation in the pits using the anaerobic *serum bottle test* (Remigi and Foxon, 2006). This technique collects and analyses the biogas evolved from a sample of material contained in a serum bottle. Unfortunately neither investigation was successful in terms of this objective, because the quantities of gas evolved were too low and erratic for meaningful conclusions to be drawn from them. However both carried out a battery of supporting tests on the samples, and re-analysis of these results has yielded a reasonably consistent characterisation of the contents of UD vaults, and offered a possible explanation of why the serum bottle tests results were inconclusive.

The following tests were carried out:

- Drying at 105°C to determine moisture and total solids content ;
- Ignition at 550°C to determine volatile solids and inorganic solids content ;
- Chemical oxygen demand (COD).

Analysis of the data suggested the following:

1. faecal material is combined erratically with sand as it enters the vault, forming a highly non-homogenous mixture;

2. while it remains in contact with air on the surface, some faecal material is removed by aerobic degradation, resulting in a decrease in both the volatile solids and moisture content;

3. once it becomes covered over and is removed from direct contact with air, both degradation and evaporation stop, or almost stop, so that the buried contents of a filling vault do not change significantly;

4. in the standing phase, slow aerobic degradation and evaporation continue at the surface of the heap, with little happening below the surface.

If this is correct, the degradation process proceeds in a remarkably similar way to the drying process described in the previous section. However, these mechanistic conclusions should be viewed with caution, as they are based on data from a set of experiments that were designed around the hypothesis that the degradation would chiefly be anaerobic. It now seems that the reason that the anaerobic tests were unsuccessful could be that conditions in the heaps are not conducive to anaerobic digestion.

Although the data are insufficient to provide a clear picture of the processes occurring in the vault, it does give a good idea of what will be encountered when emptying a vault that has been through a standing phase, as shown in the following table.

Property (% mass)	Range	Average
Moisture	7 - 31	14
Total solids	69 - 93	86
Inorganic solids	58- 92	82
Organic solids	1.5 – 11	3.7
COD (g/g)	0.006 – 0.28	0.07

Because of the way in which the faeces and sand are added to the vault, the mixture is very non-homogeneous, so the local composition has a wide range.

What is chiefly missing from this information is the proportion of the organic solids that is still biodegradable.

The 80% average inorganic (sand) content has an important implication for the rate at which vaults fill, and consequently how often they need to be emptied.

Microbiological characteristics

Although there are many pathogens associated with faecal wastes, helminth ova (particularly *Ascaris* and *Taenia*) are regarded as key hygienic quality indicators because of their persistence in the environment. Nearly one billion people worldwide are infected by hookworm, particularly in the moist tropics and subtropics. In this project there were further reasons to focus on helminths: the long period which the waste spends undisturbed in the vaults should allow less persistent pathogens to die off to a large extent, and ascariasis is a widespread and serious problem among the poorer communities in the eThekwini municipal area.

Ascaris is the largest of the common nematode parasites of man, and has a relatively simple lifecycle. Each female worm has the potential to produce over 200 000 eggs per day. Eggs are passed in the faeces in the unembryonated state and humans contract ascariasis by ingestion of embryonated eggs through faecal contamination. It has been reported that adult worms can survive for 1 to 2 years and female worms can generate eggs for a period of one year while some may continue as long as 20 months. Diagnosis of helminth infection is normally through the detection of the eggs in the faeces. These eggs are highly infectious, and very robust.

It has been estimated that 10^{14} eggs pass daily into the global environment and an egg, once infective, could remain viable for up to 15 years. In the context of agricultural wastewater reuse, it has been specified by the WHO that the recommended maximum permissible level of intestinal helminth egg load in sewage is 1 egg/L.

Health Benefits of providing UD toilets to communities

The Environmental Health Department and eThekwini Water and Sanitation Section (EWS) from eThekwini Municipality, in collaboration with the World Health Organisation (WHO-Geneva), Swedish Institute of Infectious Disease Control (Sweden, SMI), The Nelson R Mandela School of Medicine (UKZN, Durban) conducted an epidemiological study (observational, analytic, prospective cohort study) to evaluate the health outcomes of using UD toilets, together with provision of water and hygiene programmes, in Intervention Areas, and compared it to health outcomes in Control Areas of similar socio-economic and demographic stratification, but without UD toilets.

Using a multistage random sampling process, 659 households in three intervention areas and 678 households in three matched control areas were selected. One intervention area and one control area from each of the 3 eThekwini Health sub-districts were randomly selected to be included in the study. Hence the North, South and West sub-districts were represented in this study. A total of 7 219 individuals from the 1 337 households were followed up for 110 976 person-days over the study period, which required 7 663 individual home visits.

The outcomes variables included incidence of diarrhoea; incidence of vomiting; duration of episodes; prevalence of worms and skin sores.

Findings: A total of 7 307 householders were followed for 606 631 person-days over the study period of 12 weeks. The diarrhoea incidence rate was 1.9 per 1 000 person days in exposed and 3.3 per 1 000 person days in non-exposed Areas. There was a 31% reduced risk of diarrhoea in the areas where the on-site sanitation program had been implemented to areas where it had not been implemented. The reduction was adjusted for socioeconomic status, safe water supply, education, literacy and crowding (incidence rate ratio: 0.69, 95% CI: 0.49 to 0.97; p = 0.035). Each member of the household in the exposed areas had 0.51 less episodes of diarrhoea than people living in the non-exposed areas. The intervention had by 2008 been introduced in 63 000 homesteads which would have resulted in more than 150 000 less episodes of diarrhoea.

Households with safe water had an additional protection from diarrhoea, with households that had an inside safe water supply (IRR = 0.7 (05% CI 0.6 to 0.8), an outside safe water supply (IRR = 0.9 (95% CI: 0.7 to 1.0) significantly better off than those with unsafe water.

The benefit of sanitation was three times greater in children under five than for the rest of the population.

Conclusions: Households who benefited from the on-site sanitation program have significantly fewer acute infectious water-related health outcomes. Hygiene education and safe water supply may modify this effect, but actually having a safe and functioning toilet is key to improved health in the peri-urban areas of eThekwini.

Based on the evidence that this study has produced, the EWS Department has planned and budgeted for the Control Areas to receive Sanitation, Water & Hygiene Education Programmes, to improve the health status of the people living in these communities, thereby improving the quality of life of these people.

The preliminary results of this study were presented at the Launch of the new WHO Guidelines for the Safe Use of Excreta and Wastewater, at the IWA Conference in Beijing, China in September 2006, and at the International Conference on Sustainable Sanitation, Dongsheng, China, August 2007.

Due to the extensive amount of data collected in this study and due to the large sample size, this study has provided a baseline as an international and national demographic database for future prospective studies.

Risk assessment

As a result of the urgency with which a substitute for VIPs as on-site sanitation in rural and semi-rural areas within the eThekwini municipal area was needed, there was insufficient time to subject all aspects of the technology to rigorous scientific testing. There are uncertainties, in particular, whether guidelines provided by Municipal health and hygiene education programmes may not be sufficiently protective of users exposed to microbial pathogens, originating predominantly from faeces.

The World Health Organisation has issued guidelines for the reuse of wastewater and excreta in agriculture and aquaculture, which specifies acceptable risks and removal of pathogens by either treatment or exposure barriers. These guidelines rely heavily on the concepts of risk assessment, particularly Quantitative Microbial Risk Assessment (QMRA).

The risk assessment was performed as part of the present study carried out for UD/VIP toilet users in the Zwelibomvu settlement near Durban. It aimed at evaluating exposure to microbial hazards during both operation and maintenance of a UD toilet. There were three phases in this assessment; observation phase, the questionnaire phase, and the data analysis and modelling phase.

Observation Phase

A preliminary workshop conducted with members of eThekwini EWS identified that the major health hazard of concern was exposure of waste handlers to viable *Ascaris* ova during emptying of the UD vault and exposure of household members, particularly young children, to spilled waste on the ground.

This phase focused mainly on measuring levels of *Ascaris* to which the waste handler would be exposed during emptying and burial of UD waste, and to which household members, especially children, may be exposed incidentally. Due to a lack of success in finding households that were willing to empty their own toilets within the given study period, emptying was done by students on the project and by the community members who had worked on emptying with the contractors in the area. A total of four emptiers were used, with varying combinations per toilet. The households were asked to give information about the intended fate of faecal waste; if burial, they chose the burial site. A check-sheet for observation was formulated prior to the site visits. This was completed during the emptying. The personal protective equipment worn by the operator, the amount and fate of waste remaining on tools, and the amount of residual waste remaining on the ground after burial of the vault contents were noted. The residual waste left on site and spilled material was collected back to the laboratory and weighed. This quantity was used to estimate the amount of waste to which children playing near the burial site might be exposed. The emptiers were given pre-weighed sets of gloves, which were also weighed after emptying to estimate the amount of faecal material remaining on waste handlers' hands and hence the potential faecal-oral exposure of the handlers.

The AMBIC protocol developed as part of this project was used to determine the presence of *Ascaris* ova in UD toilets from the same community, and from this the exposure of waste handlers and children was back-calculated.

Interview Phase

This phase focused broadly on the users of UD toilets. A list of questions was formulated prior to the site visit. This information, together with the description of the toilet for that particular household was used in developing a profile focusing on the nature, frequency and amount of exposure, the pathogens exposed to and the number of exposed individual per given time period.

Data Analysis and Modelling Phase

Human exposure to residual faecal matter left on-site after emptying proved to be high. In 72% of the cases there was material left exposed and 84% of the burial sites were highly accessible to humans (there were foot paths about 0.3-7m from the site). Only 12% of the households waited for some time before using the area around the burial site. None of the households marked the burial area by planting a tree over the burial site. Thus there is a potential for improved EWS hygiene education targeting specifically the handling of waste during excavation of UD vaults and burial of vaults contents.

Waste handlers typically used protective equipment when emptying; either gloves (20%) or gloves and facemasks (80%). However, it should be noted that the waste handlers in this case did not represent household members, thus their behaviour in this respect may not be representative.

Quantitative measures of material remaining on handlers' hands and spilled material left on the ground were also obtained.

The data were analysed using the Excel add-in software for risk assessment, @Risk, to calculate the probability of *Ascaris* infection as a result of different exposure scenarios during UD emptying and burial of vault contents. The results were analysed in relation to a limit considered acceptable by the USEPA for microbial hazards, *i.e.* 10^{-4} or 1 in 10 000 excess infections per year. Risks calculated for waste handling with no protective barriers was far in excess of this. However, by introducing two barriers, namely wearing of gloves and washing after waste handling, the risk was calculated as being close to the acceptable limit. This risk could be reduced to below the 10^{-4} limit by reducing the prevalence of *Ascaris* in the community through chemotherapeutic de-worming of school children.

Discussion

This was an exploratory project in several respects: firstly, since the team of researchers had no previous direct experience in onsite sanitation, and secondly, since there has been very little previous research into the processes occurring in UD wastes. As a result, much of the effort was directed towards developing and proving the techniques that could be used to characterise various aspects of UD waste.

Measurement and testing protocols

Two measurement techniques received the most attention: the anaerobic serum bottle test for characterising various aspects of biodegradation processes, chiefly biodegradability and anaerobic inhibition; and the AMBIC protocol for recovering helminth ova from UD waste containing a high proportion of sand in order to assess their prevalence and viability, which is the subject of WRC Report TT 356/08 *Prevalence and die-off of Ascaris Ova in UD/VIDP Toilets*. The AMBIC protocol represents a very significant contribution, since it has demonstrated that previous methods were unreliable in detecting *Ascaris* ova in samples containing soil, which brings into question previous ideas about the survival of these pathogens in UD waste and other soil-based systems. It is possible that previous studies underestimated helminth persistence and hence overestimated the safety of UD waste and similar waste residues.

The serum bottle test, on the other did not prove to be suitable for use on UD waste samples. This was partly due to the high and highly variable proportion of sand in the samples, which made it very difficult to obtain representative small samples, and possibly due to low biodegradability of the waste under anaerobic conditions.

Characteristics of UD wastes

The most important characteristics of the UD waste are those that are found at the time of emptying the vault, and these are related to the processes that have taken place during the filling standing and standing phases. In this project the processes and conditions that were investigated were those that apply to the eThekwini double vault system, and the results obtained do not necessarily apply elsewhere.

The most important characteristic was considered to be its *Ascaris* infectivity, followed by its moisture content and degree of biological stabilisation. The infectivity is related to the safety of handling the waste, whereas the dryness and stabilisation are directly related to the unpleasantness of handling, though they may also affect the infectivity indirectly.

The practice of sprinkling soil to cover faeces, as recommended in the eThekwini system, has the effect of reducing the average moisture fraction in the vault. However, since there is no mixing, it makes for a very non-uniform mixture, and it is not clear to what extent it dehydrates the faecal material. The overall loss of moisture from the vaults is not very effective in the eThekwini system, largely because the standing vault is closed off, reducing the circulation of air.

The material that can be expected to be removed from a standing vault will contain on average 82% inorganic solids (chiefly sand) 14% water and 4% organic solids (faecal material).

Risk assessment

The risk assessment focussed on the risk of infection with *Ascaris* associated with the emptying of the UD vaults. This was considered to be the part of the UD system which posed the greatest health risk to the community. The study concluded that there was a moderate (though unacceptable) risk, which could, however, be relatively easily managed by taking simple precautions when handling the UD waste, together with a campaign to reduce the incidence of the disease in the community, something which is desirable in any case. The health benefit study conducted by the eThekwini Department of Health provided an overall assessment of the entire system in terms of observed incidence of diseases, rather than prediction based on risk modelling. The results strongly supported the contention that the provision of UD toilet facilities assists significantly in reducing the prevalence of diseases by breaking the cycle of infection.

Recommendations

1. The results of the health impact study conducted by the eThekwini Department of Health support the assumption, which was the basis of the decision to adopt the UD sanitation system in eThekwini, that the system would lead to a safer and healthier environment for the communities to which the service is provided. The continued roll-out of the system is therefore supported.

2. The risk of *Ascaris* infection is significant for anyone who has to handle the UD waste, but it can be readily managed. The issue is most critical where emptying is to be carried out by contractors from outside the household, since they will be more frequently exposed,

and they will be more likely to spread the infection. There is a strong case for combining the provision of UD toilets with a chemo-therapeutic campaign to reduce the prevalence of ascariasis in school children.

3. Since the greatest risk of propagating diseases centres on emptying a vault and burying its contents, the physical design of the vaults should be looked at critically to make these operations as easy as possible. With the current design, the relative size and positions of the vault and the rear opening make it practically impossible to empty the vault without the handlers coming into physical contact with the waste, spilling it on the ground, and suffering cuts and grazes from the concrete edges. A system where the waste accumulates in a receptacle which can easily be remove from the vault might make emptying much safer and easier, but would have cost implications. The emptying process should be the subject of an ergonomic study to find a safe and cost effective design.

4. The largest component of the UD waste by far is the added sand. This need to be taken into account when considering filling rates, emptying frequencies and the vault volumes in the system design.

5. Drying and biological degradation of the UD waste appear to be chiefly dependent on contact with air, so the design of the toilets should aim for good air circulation through the vaults. In the current design, there is good circulation via the toilet pedestal during the filling phase, but not during the standing phase, since the pedestal hole is closed off. The design should be modified to allow circulation during the standing phase also.

ACKNOWLEDGMENTS

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The Steering Committee responsible for this project consisted of the following persons:

Mr JN Bhagwan	:	Water Research Commission (Chairman)
Prof GA Ekama	:	University of Cape Town
Mr B Pfaff	:	eThekwini Water Services
Mr JL Harrison	:	eThekwini Water Services
Mrs SAF Jackson	:	eThekwini Water Services
Mr MVG White	:	Development Corporation Ireland
Prof F Bux	:	Durban Institute of Technology
Mr DA Still	:	Partners in Development cc
Mr N Walker	:	Partners in Development cc
Mr LM Austin	:	CSIR
Ms S Büning	:	Sol Plaatje Housing Corporation
Mr H Sussens	:	Department of Water Affairs and Forestry

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1 INTRODUCTION

eThekwini Municipality is considered as one of the leading municipalities in South Africa with regard to the provision of basic sanitation services. The municipality has selected urine diversion (UD) toilets as the preferred delivery mechanism for certain communities in their area of responsibility, particularly those in rural and semi-rural areas. The first units were installed in 2003 and there were 58 000 urine diversion toilets in communities outside the urban centre at the end of 2007, built according to a constantly improving design that was initially based on a number of guiding principles. It is planned to build 10 500 new units per year.

UD systems have recently received a great deal of international attention in the context of "Ecological Sanitation" or "EcoSan". EcoSan refers to a cycle, or closed-loop system, which treats human excreta as a resource (Esrey et al., 1998). In this system, excreta are processed on site until they are free of pathogenic (disease-causing) organisms. Thereafter the sanitized excreta are recycled by using them for agricultural purposes. Key features of EcoSan are therefore:

- prevention of pollution and disease caused by human excreta;
- treatment of human excreta as a resource rather than as a waste product; and
- recovery and recycling of the nutrients.

The advantage of UD systems in EcoSan is that nutrients and pathogens are distributed differently between faeces and urine, and keeping them separate makes it easier to re-use nutrients while avoiding disease transmission.

The eThekwini system is not a full EcosSan system, because it does not address the issue of recycling the nutrients in a systematic way. The eThekwini urine diversion toilets were installed because of the municipality's experience in the logistical difficulties and excessive cost associated with the emptying of Ventilated Improved Pit (VIP) toilets, which are considered to be the minimum level of sanitation service that must be provided by a municipality in South Africa.

The municipality realised that it did not have a complete knowledge of UD toilets, hence the request for research support.

The eThekwini UD toilets have a number of unique features which were developed to suit local conditions. The basic design is a double vault dry toilet with urine diverted to a soak-away located near the unit. A pedestal is located above one pit, into which faeces, anal cleansing material and bulking agent are dropped. Once the first vault is full, the pedestal is moved to the hole above the second vault and the first is sealed and allowed to stand. Once the second vault is full, the first vault is opened via a back plate and manually emptied by the householder or a contractor. The emptied contents are buried on the householder's property and the burial site should be marked by planting a tree over it. The pedestal is then returned to its position above the first vault, the second vault is closed and is left to stand while the first refills. It is expected that each vault will take between 6 months and one year to fill, resulting in a range of age of the vault contents between 6 months and two years at the time at which they are removed from the vault.

The design was based on the following concepts:

1. Biologically-mediated stabilisation and drying of organic material was expected to occur in the pit, rendering it less unpleasant to handle;

4. Sufficient pathogen deactivation might occur during the standing phase to reduce the risk of disease transmission during manual emptying of the pit to acceptable levels;

5. Urine, which is normally sterile, is diverted to a soakaway in the ground close to the toilet structure.

The motivation for a urine-diverting design is that the volume of material that requires handling should be substantially less than in a pit latrine which receives urine and often grey water, as well as faeces and cleansing material. This allows a far smaller vault to be constructed. The smaller volume of the vault contents and their relative dryness mean that they can be removed relatively easily by the householder with an appropriately sized rake or spade.

Despite the obvious benefits of the design, there are a number of unresolved scientific, technological, social and health-related questions about how the design works from a biological and mass transfer perspective. The site-specific health and environmental risks to the householder, community and any outsiders involved in the pit emptying process also remain to be characterised. In particular the risk of infection by geohelminths such as *Ascaris* spp. has been identified as being an important factor in calculating the benefit of sanitation provision in terms of community health and quality of life. The infection cycle can be broken by a combination of hygiene education and practice, chemotherapy and improved sanitation. The fate of *Ascaris* spp. eggs in the urine diversion toilet is an important issue. Extended anaerobic conditions will result in the ultimate death of the eggs, thus it is thought that burying the contents of a urine diversion toilet may be effective in breaking the infection cycle.

The eThekwini Municipality therefore needs the design, delivery and operation of the system to be scientifically evaluated so that the design basis and operational procedures can be reassessed and adjusted.

1.1 Project aims

The project contract specifies the following aims for this project:

1. Provide a scientific basis for the design and operation of urine diversion toilets as used in eThekwini.

2. Evaluate the effectiveness of urine diversion toilets in improving the wellbeing of the user community.

3. Determine the fate of *Ascaris* spp. eggs from urine diversion toilets.

1.2 Products

The project contract specified the following products for this project:

1. An assessment of the health benefits of urine diversion toilets.

2. A qualitative model of the moisture balance and rate of stabilisation of the contents of a urine diversion toilet.

3. A risk assessment of the operation and maintenance of urine diversion toilets.

1.3 Methodology

This project involved a number of sub-projects, each of which followed its own particular methodology. The unifying principle was that each should contribute to the risk/benefit assessment of the Durban system as a whole, by provided scientific data to allow the evaluation of risks and benefits in the design and operation of the system. Some of the issues involved risks and benefits that were perceived at the start of the project, others were identified during the course of the investigations. Because of the wide scope of the investigations, where the risk involved in a topic appeared not to be critical, or the required data were available from elsewhere, the topic was not pursued.

In particular, the issue of the health benefits of providing UD toilets to communities was the subject of an extensive epidemiological investigation by the eThekwini Health Department and the University of KwaZulu-Natal Medical School, so that aspect was not investigated separately in this project. A brief summary of the findings of that investigation appears in section 5.1.

The investigations undertaken in this project fell into three main groups:

1. physical and biological processes occurring in UD waste in the toilet vaults and after being removed from the vaults and buried;

2. the occurrence and survival of pathogens in UD waste;

3. the health risks associated with the process of emptying a vault and burying the contents as recommended for the eThekwini system.

The principal conclusion of the first and second groups of investigations was that the greatest risk in the whole system was the spread of infection by geohelminths during the process of emptying the vaults and burying the contents, so the risk assessment focussed on a quantitative estimate of this risk, and on measures required to minimise it.

A substantial part of the experimental effort was devoted to developing and evaluating experimental techniques for characterising UD waste. A significant new technique, the *AMBIC protocol*, was developed for detecting geohelminth ova in samples containing soil. The AMBIC protocol represents a major advance over previously accepted methods, which were shown to probably seriously underestimate the incidence of ova in samples containing soil particles. This discovery casts doubts on the validity of previous studies on the survival of these pathogens in the soil. The probably underestimation of *Ascaris* in soil/waste mixtures, arising from low recoveries of previous detection methods for *Ascaris* ova, and those of other geohelminths, in soil, is of particular concern.

1.4 Report Outline

Chapter 1 is a general literature review on onsite sanitation systems and their associated health risks.

Chapter 2 presents the methodologies developed or used for characterising UD wastes, together with results obtained from samples taking from UD latrines in the eThekwini area.

Chapter 3 presents the studies on the main physico-chemical characteristics of UD sludge, and the processes of drying and biodegradation which determine these characteristics in the eThekwini system.

Chapter 4 considers the two issues thought to be most important in relation to the operation and maintenance of the system: the health benefits, and the risks associated with emptying the vaults and burying the contents. Since the health benefits were investigated by the eThekwini Health Department and the University of KwaZulu-Natal Medical School in a separate project, only a brief summary of their results is presented in this report.

Chapter 5 presents the overall conclusions and recommendations of the project.

2 LITERATURE

In South Africa, like other countries with water and sanitation backlogs, most of the population aspires to in-house, full-pressure water supply and flushing toilets linked to waterborne sewerage and wastewater treatment. The government recognises that the provision of these levels of services to all is neither technologically nor financially feasible, nor necessarily environmentally sustainable. Peri-urban and rural populations particularly are unsuited to the provision of such services, owing to absence of land ownership, housing density, population mobility, and inaccessible terrain.

The World Health Organisation publication *Guide to the Development of On-site Sanitation* (WHO, 1992) lists the following options for onsite sanitation, with their various advantages and disadvantages in particular circumstances: open defecation, shallow pits, simple pit latrines, borehole latrines, ventilated pit latrines, double pit latrines, pour-flush latrines, composting latrines, septic tanks and aqua-privies. In South Africa, the Ventilated Improved Pit (VIP) latrine is considered the minimum acceptable service. These dry on-site sanitation systems do not require the expense of water to dispose of urine and faeces. Once the pit is full the top structure can be moved over to another freshly dug pit and the old pit sealed. This is feasible only if there is sufficient space to relocate the pit.

South African government policy states that everyone has the right to basic sanitation (affordable, appropriate, effective, socially acceptable and sustainable), as well as free basic water for all. The encouragement of VIP usage, emphasising human dignity, has translated into status, and VIP superstructures have become immovable brick superstructures. This precludes the VIP being moved with any degree of ease, and results in pits having to be evacuated when full. Mechanical desludging equipment is expensive, vulnerable to failure, often cannot access the site and frequently cannot cope with the heavy sludge and solid matter found in the pit. The alternative is manual emptying, where people dig excreta and solid waste out of the pit, using shovel, buckets and other implements. This work is unpleasant, and poses a number of health risks if not managed carefully. For those pits that can be accessed by tanker, the average costs for emptying one pit is in the region of R600 to R1 000. The householder's contribution for emptying the pit is R80, while the balance of the cost is subsidised by the municipality (in this case, eThekwini Municipality). Clearly, this is not sustainable in the long term.

South Africa runs the risk of an outcome similar to Zimbabwe, where pits provided through sanitation programmes are now full. No mechanism is in place to empty them and new pits are not being built. (Jonga undated, citied by Austin & Holden, 1999). Unless the pit can be emptied economically, the initial investment in sanitation provision will be lost. According to a nationwide sustainability audit of sanitation facilities initiated by the Department of Water Affairs (DWAF) and other sector departments, up to 28% of toilets (or serviced households) could fail in the short to medium term, resulting in 0.46 million households (or 1.9 million people) reverting onto the backlog list before 2010 (Matingi and Associates 2005).

The government provides a subsidy for the installation of basic services, including water and sanitation, via the Municipal Infrastructure Grant (MIG). Subsidies for free basic sanitation cover the costs of hygiene promotion and the capital costs of providing a basic sanitation service to households (DWAF, 2003). The current approved subsidy, in the region of R3 000 (including VAT) per household, places an enormous burden on Water Service Authorities that have to make up the shortfall, especially when costs escalate due to increases in materials and labour costs, and where other sustainable toilet options are selected.

2.1 Onsite sanitation systems

Austin et. al. (2005) compiled a literature survey of ecological sanitation systems. Amongst there conclusions were:

An increasing awareness worldwide of the environmental problems associated with inappropriate sanitation implementation has led to the development of ecological sanitation technology. This technology is not really new, being rather a refinement of an ancient practice. It has been promoted for environmental reasons, as well as for issues such as water conservation, recycling of nutrients to arable land, easy operation, negligible maintenance costs, dignity and convenience. EcoSan has been implemented successfully in many countries and regions in various stages of development, and among communities of different socio-economic strata, religions, cultures and practices.

Some handling, at household level, of urine and faeces is required. The people that plan, design and build the toilets need to fully understand the basic principles involved and how they relate to local conditions, otherwise inappropriate selection of options may be made. Appropriate social interventions in the form of promotion, support, education and training are also prerequisites for successful implementation.

Human excreta are usually easier to handle when urine and faeces are kept separate, as in urine-diversion toilets. Urine may be handled in various ways, and guidelines exist for hygienic storage and agricultural use of urine.

Faeces need to be sanitised as far as possible within the toilet vaults in order to facilitate safe removal and further handling, especially where their re-use as a soil conditioner is required. Various methods can be employed to ensure this, including the use of additives such as ash, lime, sawdust, dry soil, etc, as well as the judicious use of heat-absorbent building materials, ventilation, moisture control and storage.

Poor handling practices may result in infection from faeces, and it is therefore essential that persons emptying the vaults and disposing of the products exercise the necessary caution. Adequate education and hygiene awareness campaigns in communities receiving ecosan toilets are therefore a prerequisite for the maintenance of public health.

Despite the vast amount of research that has been carried out on inactivation of faecal pathogens in ecosan toilets, differences of opinion still remain on the minimum storage periods and storage conditions required to ensure safety for handling and re-use. Further research is required in order to establish practical guidelines on the best designs and management methods for achieving these conditions in the vaults, which can be used with confidence in all types of settings.

The literature indicates that ecological sanitation is firmly established as an accepted technology in many countries. There are, in most cases, no socio-economic barriers to its continuing implementation, as people of all income groups, in both developed and developing countries, have installed ecosan toilets in their homes. Also, farmers of all types, rich and poor, are successfully using human excreta in their fields and food gardens to benefit the soil and enhance crop production.

In South Africa, many community sanitation schemes have been successfully implemented utilising VIP toilets. However, others have been problematic, often due to poor design and construction practices or to social factors such as a lack of community buy-in, or a combination of these. Sufficient attention is not always given to factors such as environmental impact, social issues, water-supply levels, reliability or institutional capacity. The result has often been a legacy of poorly planned and inadequately maintained systems provided by well-intentioned but short-sighted authorities and developers.

VIP toilets, correctly engineered and implemented, are a good means of providing sanitation in areas where financial factors preclude the provision of a higher level of service. These systems are not without their problems, however. Geotechnical conditions, such as hard or rocky ground, for instance, sometimes make the choice of this technology inappropriate. In other cases, non-cohesive soils will require a pit to be fully lined in order to prevent collapse of the structure. Pits should preferably also be avoided in areas with shallow water tables, especially in aquifers with high hydraulic conductivity, where rapid transmission of pollutants is possible. These toilets are also unsuited to densely populated urban or peri-urban environments.

Full pits are a further problem. In many cases the owners will not be in a financial position to empty them, even if the toilets have been constructed with this in mind (e.g. removable cover slabs). While there may be plenty of available space in rural areas to dig further pits, this will seldom be the case in densely populated urban areas. This aspect does not even take into account the cost of digging a new pit and moving or rebuilding the superstructure, so for all practical purposes the initial investment is lost when the pit fills up. Some other solution should be sought in these cases, and the ventilated improved double pit (VIDP) toilet has gone some way in addressing this problem.

If a dry toilet is designed and constructed in such a way that the faeces receptacle can be quickly, easily and safely emptied, then one of the biggest operation and maintenance problems associated with these toilets will be obviated. If the processed excreta can also be productively and safely used for agricultural purposes, and if the community is so inclined, the technology will become even more attractive. In South Africa, where many rural communities rely on subsistence agriculture, often in poor soils, and with urban agriculture becoming more common in certain communities, this is an important aspect. However, re-use of the processed excreta is not a prerequisite for the implementation of this technology, as they can be disposed of without damage to the environment.

2.2 Onsite sanitation waste characteristics

About 25-50 kg of wet faeces is produced per person per year, which contains up to 0.55 kg-N, 0.18 kg-P, and 0.37 kg-K. Elements that are contained in the diet in relatively large amounts, such as aluminium, tin, zirconium, strontium and vanadium, remain practically unabsorbed and more than 99% are excreted in faeces.

According to Lopez Zavala et al. (2002) there is a wide variability in the content of faeces, dependent on nutrition, climate, health, age and lifestyle. Based on the analysis of 26 samples, they report the following properties:

81.8% moisture; 18.2% total solids; 15.4% volatile solids; 2.8% inorganic solids. Of the volatile solids, approximately 70% are biodegradable.

On a dry basis, chemical analysis of the solids yielded:

COD:	1.45 g/g	NH_3 as N:	3.4 mg/g	Total N:	60.1 mg/g
NO3 as N:	0.03 mg/g	Cl:	4.2 mg/g	SO_4 :	1.1 mg/g
PO_4 as P:	4.5 mg/g				

The following table is taken from WRC Report 1630/1/07:

Table 2.2.1: Summary of characteristics of faeces and urine.

Source		Chaggu		P & J[1]	WRC 1630				
					Ave[2]	min[3]	max[4]	C of V[5]	No.[6]
Component	**Unit**	**Faeces**	**Urine**	**Faeces**	**Faeces**				
Total mass (wet)	g/day	70-520	1000-1500	199	-	-	-	-	-
Moisture % of wet mass	g H_2O/g wet mass	66-85	93-99.5	86	75.5	70.8	79.6	4.9%	12
Total COD	mgCOD/g wet mass	46-78	-	51	354	318	449	18%	12
	mgCOD/g dry mass	253[7]	-	364[8]	1 448	1 308	1 579	9.0%	12
Volatile solids	g VS/g dry solids %	-	-	-	69	16	89	51%	12
Total K	gK/gTS %	0.8-2.1	2.5-3.7	2.8	-	-	-	-	-
Total S	gS/gTS %	-	-	0.77	-	-	-	-	-
Total N	gN/gTS %	5.0-7.0	15-19	7.0	-	-	-	-	-

[1] Palmquist & Jonsson (Palmquist, 2003)
[2] Average measurement
[3] Minimum measurement
[4] Maximum measurement
[5] Coefficient of Variation (Standard deviation/average%)
[6] Number of observations
[7] Calculated from midpoint of each of moisture and COD ranges
[8] Calculated

2.3 Potential Health Impacts

South Africa, along with many other countries is faced with the dilemma of inadequate disposal of excreta-related human wastes into the environment (Butare and Kimaro, 2002). The World Health Organisation (WHO) estimates that 80% of all deaths in developing countries are related to water- and excreta-related diseases (Petterson and Ashbolt). Untreated excreta and wastewater contains organic matter, plant nutrients, trace elements and micronutrients as well as pathogenic bacteria, viruses and helminths, endocrine substances and medical residues.

The inadequate and unsanitary disposal of infected human faeces leads to contamination of the ground and of sources of water. Often it provides the sites and the opportunity for certain species of flies and mosquitoes to lay their eggs, to breed, or to feed on the exposed material and to carry infection. It also attracts domestic animals, rodents and other vermin which spread the faeces and with them the potential for disease. There are a number of diseases related to excreta and wastewater which commonly affect people in the developing countries, the incidence of which can be reduced by the introduction of safe excreta disposal. Major examples are intestinal infections and helminth infestations, including cholera, typhoid and paratyphoid fevers, dysentery, hookworm, schistosomiasis and filariasis. Those most at risk of these diseases are children under five years of age, as their immune systems are not fully developed and may be further impaired by malnutrition. The diarrhoeal diseases are by far the major underlying cause of mortality in this age group, (WHO, 1992)

Among the pathogenic organisms which may be associated with faecal wastes are as follows (Butare and Kimaro, 2002):

1. *Viruses*: poliomyelitis, hepatitis (A/E), enteroviruses, rotavirus, enteric adenoviruses.

2. Of growing concern is Hepatitis A, which has been recognized as a pathogenic virus of major concern when applying wastes to land and is considered a risk for water- and food-borne outbreaks. Hepatitis E is a viral disease of emerging importance in water- and food-borne infections (Schonning and Stenstrom, 2004).

3. *Bacteria*: *Salmonella* spp. (causing typhoid paratyphoid fevers), *Shigella* (causing bacterial dysentery), *Vibrio cholerae* (causing cholera), *Mycobacterium* spp. (causing tuberculosis – relative importance of water as a transmission route??), *Escherichia coli* 0157:H7 (gastroenteritis with complications including haemolytic uremic syndrome)

4. *Protozoa*: *Entamoeba histolytica* (causing amoebic dysentery)

5. *Cryptosporidium parvum* and *Giardia lamblia/intestinalis* have been studied intensively due to the high environmental resistance and low infection doses. *Entamoeba histolytica* has recently been recognized as an infection of concern in developing countries(Schonning and Stenstrom, 2004).

6. *Helminths*: roundworms, pinworms, sheep liver flukes and shistosomes (causing bilharzias).

7. Because of their persistence in the environment, *Ascaris* and *Taenia* ova are regarded as hygienic quality indicators. Nearly one billion people world wide are infected by

hookworm, particularly in the moist tropics and subtropics. In developing nations, these infections are exaggerated by malnutrition. The infective eggs from *Ascaris* and hookworms are excreted in

faeces and requires a latency period and favourable conditions in soil or a deposit of faeces to develop into larvae and become infectious (Schonning and Stenstrom, 2004).

Inadequate sanitation, lack of access to clean potable water and poor domestic hygiene are the causes of ~ 80% of all infectious diseases *(e.g.* cholera, typhoid, hepatitis, polio, cryptosporidiosis, ascariasis, and schistosomiasis) in the world and responsible for 10-25 million deaths each year, most of them in the under 5 years age group. These diseases are mainly transmitted via the faecal-oral route through faecally contaminated water, food or soil (WHO, 1989).

Community studies show that the number of pathogens present in excreta varies as a function of the health of the host and the local environment (Schonning and Stenstrom, 2004). Communities characterised poor hygiene and a large proportion of children will generate excreta rich in enteric pathogens. The chances of these pathogens resulting in new infections in other susceptible individuals is a function of contact and exposure, which are governed by factors such as the excreted quantity and the infective dose. The probabilities of contact and exposure are further governed by the ability of different species and strains of pathogens to withstand environmental conditions outside the host's body and to persist in a stage where they can infect a new individual upon exposure. Healthy individuals do not normally excrete pathogens, therefore the pathogen load in the environment is linked to the general health status of the community. There are five possible exposure routes for pathogens spread by the faecal-oral route: 1) direct contact with untreated excreta, 2) direct contact with inadequately treated excreta, 3) consumption of crops watered or fertilised with untreated or inadequately treated excreta (with or without a withholding period since the last application of waste), 4) inhalation of pathogens, 5) transmission from animals to humans by contact with animal excreta, where the animal host may also amplify the pathogen in the environment.

Helminth infections are of particular concern in developing countries and many of these parasitic worms have human hosts. According to O' Lorcain and Holland (2000), *Ascaris lumbricoides* is a highly infectious and persistent parasite that infects a quarter of the world's population, with global estimates ranging between 800 and 1000 million people. *Ascaris lumbricoides* is one of the most significant human pathogens in the UD waste, particularly in developing communities generally and, more specifically, along the KwaZulu-Natal coastline (*i.e.* including many areas served by eThekwini Municipality). Its importance derives from the fact that it has ova which are extremely persistent in the environment outside the host. An important source of exposure for humans to *Ascaris* ova exists in regions where excreta are used as soil conditioners or fertilizers, so that both the person handling the waste and those consuming unprocessed crops grown in these soils are at risk of infection (Faust, 1955).

At the household level, the nature and concentrations of pathogens in human waste is dependent on the health and size of the family using the sanitation facility (Carrington, 2001). The risk posed by a given type of sanitation facility is dependant on the technology, the health status of the family using the toilet, and the extent to which good hygiene practices are followed. The interaction amongst these factors is too seldom considered in studies aiming to establish the "safety" of a particular sanitation technology by demonstrating the absence of the parasite eggs (Peasey, 2000). Chale-Matsau (2005) pointed out that many communities in developing countries such as South Africa do not de-worm themselves, therefore contact with untreated or inadequately treated sewage sludge, or other waste residues such as UD waste, containing viable *Ascaris* ova could lead to heavy worm infestations. Symptoms of helminth infestation are widespread, especially in developing countries, and may include gut pain, fatty or watery stools, anaemia and weight loss. Although low to moderate worm loads are often asymptomatic, the indirect effects may contribute substantially to child morbidity when associated with malnutrition, pneumonia, other enteric diseases and vitamin A deficiency (Höglund, 2001).These ailments affect humans and animals and are directly linked to faecal contamination (Simonart *et al.*, 2003). They are also linked to poor socio-economic conditions, so it is not surprising that poor communities in developing areas are characterised by a high prevalence of ascariasis. Especial care must therefore be taken when introducing a sanitation technology that potentially increases contact between householders and excreta which may contain viable *Ascaris* ova. The risks of handling waste must be clearly identified and methods of reducing risk must be instituted wherever possible.

The application of health risk assessment methodology is helpful in identifying the extent of risk and the potential benefit of various barriers to infection, allowing treatment and hygiene interventions to be targeted specifically at the most vulnerable among the exposed population and at the interventions most likely to yield the highest benefit (WHO, 2006).

2.4 Risk assessment methodology

Risk assessment is conducted in the context of the process of risk analysis. Risk analysis has three components: risk assessment; risk management and risk communication. This study concerns itself with risk assessment only, this being a process which is scientifically based, and may be conducted in a quantitative or a qualitative manner, or in a combination of the two.

The formulation of the process of microbial health risk assessment has been strongly influenced by the format adopted by the United States Environmental Protection Agency (US EPA) for chemical hazards. Variations on the US EPA format exist, but all can be reduced to the same basic outline. A health risk assessment is recognized to comprise four steps (Pettersen and Ashbolt, 2005): hazard identification; dose-response assessment; exposure assessment; and risk characterization.

Hazard identification

This generally includes some form of statement of the purpose of the risk assessment, in order to place the specific risk to be assessed in its context. The primary aim of hazard identification is to identify the hazardous agent(s) of potential significance and the principal consequences (in terms of health) which are to be quantified in the process of the risk assessment.

Dose-response assessment

The purpose of the dose-response assessment is to provide a quantitative risk of the probability of a given adverse effect (as identified in the hazard identification) corresponding to a given dose of the hazardous agent of interest. It is generally derived from controlled laboratory studies or epidemiological studies of exposed populations, and is often expressed as a mathematical relationship between the dose and the adverse effect (a dose-response relationship, which may be represented graphically as a dose-response curve).

Exposure assessment

This process moves from the more general considerations of the dose-response assessment to the characterization of the specific exposure(s) to the hazardous agent which the populations of interest are likely to encounter. It represents a balance of well-documented scientific knowledge, scientific judgments and assumptions made on the basis of knowledge of local conditions. It may take the form of statistical modelling of the fate of the hazardous agent in the environment to estimate exposure via different media (*e.g.* air, water, food) at varying distances or times from the point of release of the agent.

Risk characterization

This final step combines the outcomes of the dose-response assessment and the exposure assessment to provide, where possible, a quantitative estimate of the proportion of an exposed population of specified composition who may be expected to develop an adverse effect as a consequence of their exposure to the hazardous agent. It comprises two steps: risk estimation and risk description. Risk estimation describes the magnitude and types of effects that can result from exposure, and can be either qualitative or quantitative, depending on the method used. Risk description describes the intensity, nature and consequences of the risk. Alternatively, a particular level of risk may be deemed to be 'acceptable' and the exposure associated with this may be calculated. The 'acceptable' exposure may then be compared to the actual exposure, as determined in the exposure assessment. If the actual exposure is greater than the acceptable exposure, management or governmental intervention is indicated.

Since the major risks associated with UD toilets (as with any sanitation intervention) is the transmission of pathogenic organisms by the faecal-oral route and resultant infections in the exposed population, it is appropriate that microbial risks form the context of a health risk assessment of UD toilet operation and maintenance. Quantitative microbial risk assessment (QMRA) follows the processes outlined above, with a few considerations specific to micro-organisms as the hazardous agent (Haas, 1983; Haas *et al.*, 1999; ILSI, 2000; Pettersen and Ashbolt, 1995). The output of a QMRA is generally a quantitative estimate of risk (in terms of a probability of infection) for a specified pathogen and a specified route of exposure. In QMRA, dose-response relationships must be derived from human dose-response studies, unlike chemical risk assessments where animal toxicity tests are typically used. Human dose-response studies are mostly described by one of two semi-mechanistic models of infection, the exponential model or the beta Poisson model. These dose-response models provide a risk of infection associated with a given dose (derived from the exposure study). As pointed out above, some assumptions need to be made regarding exposure doses and routes. A QMRA can be used to compare different hazard scenarios to each other, or specific hazard scenario(s) to a defined level of acceptable risk. Variability and uncertainty remain important limitations on the applicability of the final risk estimate, and must be reported explicitly.

QMRA thus yields a quantitative risk estimate calculated on the basis of the exposure assessment and the more applicable of the available dose-response models. The result can be used to inform risk management decisions. The new WHO guidelines on reuse of excreta and wastewater in agriculture emphasise the importance of barriers to exposure, used in combination with treatment of waste, in reducing exposure to microbial hazards and hence reducing risk of infection to acceptable levels (WHO, 2006).

3 PHYSICAL AND CHEMICAL CHARACTERISTICS OF UD WASTE

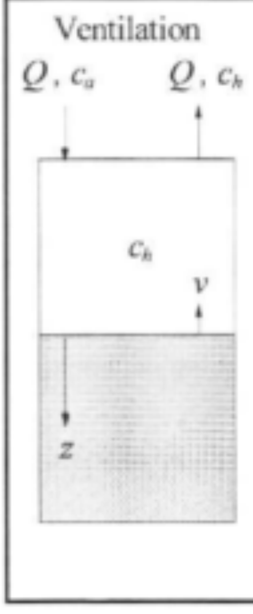
This chapter considers the processes of drying and biological degradation which take place in UD vaults, with a view to understanding the characteristics of the UD waste at the time that the vault is to be emptied. Because of the importance of understanding the degree of contamination with viable *Ascaris* ova, this characteristic has the whole of chapter 4 devoted to it.

3.1 Moisture content and drying

With a double vault latrine, one vault is used at a time. While it is filling, the contents of the idle vault are allowed to dry, hopefully to the point where they become safe and not unpleasant to handle. The vault can then be emptied in preparation for the next cycle of use. There are two obvious phases which need to be considered in analysing the drying problem, 1) while the vault is in use and gradually filling, and 2) when it is idle and its contents are undisturbed.

3.1.1 Drying during the filling phase

This analysis was undertaken to provide some theoretical guidance as to how to interpret measured data. Consequently it uses the simplest possible one-dimensional model of the solids, and a fully mixed model of the gas headspace.



Notation:

Q	:	Ventilation air flow rate (m^3/s)
c	:	moisture concentration (kg/m^3)
c_a	:	moisture concentration in atmosphere (kg/m^3)
c_f	:	moisture concentration in fresh solids (kg/m^3)
c_h	:	moisture concentration in headspace (kg/m^3)
D	:	moisture diffusion coefficient in solids (m^2/s)
H	:	mass transfer coefficient at gas-solid interface (m/s)
k	:	moisture equilibrium constant between gas and solids (-)
v	:	rate of filling (m/s)
z	:	depth coordinate (m)

The interface level is assumed to be rising at a constant rate v. The equations are developed in a moving coordinate system, in which the rising interface remains at $z = 0$, so that the bottom of the pit corresponds to $z = vt$

Moisture is assumed to diffuse homogeneously through the solids, and evaporate at the interface. The headspace is assumed to be fully mixed.

The partial differential equation describing the moisture transport within the bed is derived from a balance over a differential slice located between z and $z+dz$

Moisture in = moisture out + moisture accumulating

$$\left[v \cdot c - D\frac{\partial c}{\partial z}\right]_z = \left[v \cdot c - D\frac{\partial c}{\partial z}\right]_{z+dz} + \frac{\partial c}{\partial t} \cdot dz$$

$$\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial z^2} - v \cdot \frac{\partial c}{\partial z}$$

[3.1.1]

The boundary and initial conditions for this partial differential equation are as follows:

$\frac{\partial c}{\partial z} = 0$ at $z = vt$; $t > 0$ (No diffusion at the bottom of the pit)

[3.1.2]

At the surface the balance includes moisture added with fresh solids, moisture carried by the filling velocity, moisture lost by transfer to the air and moisture diffusing into or out of the underlying solids.

$$v \cdot c_f - v \cdot c - H \cdot (c - k \cdot c_h) + D\frac{\partial c}{\partial z} = 0$$

$D\frac{\partial c}{\partial z} - (v + H) \cdot c + (Hk \cdot c_h + v \cdot c_f) = 0$ at $z = 0$; $t > 0$

[3.1.3]

The initial condition involves the first layer of solids with no underlying layers:

$v \cdot c_f - v \cdot c - H \cdot (c - k \cdot c_h) = 0$ at $t = 0$, which corresponds to $z = 0$

(A balance between the drying rate and the addition of moisture in fresh solids)

This is rearranged to $c = \frac{v \cdot c_f + Hk \cdot c_h}{v + H} = c_0$ at $t = 0$; $z = 0$

[3.1.4]

The solution to equation [3.1.1] with boundary conditions [3.1.2] and [3.1.3] and initial condition [3.1.4] is simply

$c = \frac{v \cdot c_f + Hk \cdot c_h}{v + H} = c_0$ for $t > 0$ and $0 < z < vt$

The implication of this is that the solids dry from c_f to c_0 while they remain on the surface, but once they become covered they do not dry any further until filling stops (since they are continuously being overlaid by solids with the same moisture content). This further implies that the evaporation rate is constant, and therefore c_h is constant. The evaporation rate is given by $AH\cdot(c-k\cdot c_h)$ where A is the area of the interface between solids and air.

The moisture balance for the head-space is:

$$Q\cdot c_a + AH\cdot(c-k\cdot c_h) = Q\cdot c_h$$

[3.1.5]

Eliminating c_h between [3.1.4] and [3.1.5] gives:

$$c = c_0 = \frac{(Q+AHk)v\cdot c_f + QHk\cdot c_a}{(Q+AHk)v+QH}$$

This solution can be expressed in dimensionless form:

$$\frac{(c-k\cdot c_a)}{(c_f-k\cdot c_a)} = \frac{1+\Theta}{1+\Theta+\Lambda} \quad \text{where} \quad \Lambda = \frac{H}{v} \quad \text{and} \quad \Theta = \frac{AHk}{Q}$$

or alternatively

$$\frac{(c-k\cdot c_a)}{(c_f-k\cdot c_a)} = \frac{1+\Theta}{1+\Theta\cdot(1+\Psi)} \quad \text{where} \quad \Psi = \frac{\Lambda}{\Theta} = \frac{\left(Q/A\right)}{kv}$$

[3.1.6]

If it is assumed that the air reaches equilibrium with the moist solids then the moisture balance can be written as:

$A\cdot v\cdot(c_f-c) = Q\cdot(c_h-c_a)$, and the equilibrium expressed as $c = k\cdot c_h$

Combining these equations and rearranging yields: $\dfrac{(c-k\cdot c_a)}{(c_f-k\cdot c_a)} = \dfrac{1}{1+\Psi}$

[3.1.7]

Equation [7] is a limiting form for equation [6] for high values of the mass transfer coefficient and low values of Q/A (i.e. for $\Theta \gg 1$)

Not all the variables in these groups are readily amenable to independent control. To achieve low moisture content, Ψ should have a high value. Θ has less of an effect because it appears in both the numerator and the denominator.

The convective mass transfer coefficient H is quite strongly related to $\dfrac{Q}{A}$, the specific aeration rate. A rough correlation, which is suggested for situations where no better information is available, is given in the Chemical Engineer's Handbook (Perry and Green, 1999):

$h_c = 8.8\, G^{0.8} / d^{0.2}$ where h_c is the heat transfer coefficient (J/m^2/s/K), G is the gas mass-velocity (kg/m^2/s) and d is a characteristic dimension (m) of the apparatus.

For the air-water system h_c and H are approximately related by:

$H = h_c / C_s$ where C_s the humid heat capacity of the air (J/kg/K)

$G = \rho \cdot (Q / A)$ where ρ is the density of the air (kg/m^3)

Thus $\Theta = 8.8 \dfrac{k\rho^{0.8}}{C_s d^{0.2}} \left(\dfrac{Q}{A}\right)^{-0.2}$

(the factor 8.8 is only correct if all quantities are expressed in SI units)

All this implies that there is very little that can be done to affect the value of Θ, since increasing Q will increase H, and these will largely compensate for each other. The aeration rate Q will be determined by details of the physical design, chiefly the stack configuration, as well as environmental factors such as wind speed. The filling rate v is the volumetric rate of solids addition divided by the surface area A, and is therefore a design parameter.

The moisture equilibrium constant k is a property of the solids and a function of temperature. In a laboratory drying experiment, samples taken from a latrine were exposed to controlled humidities between 60 and 85% at 25°C to determine k. Because the users had added sand to the faecal matter in the latrine, the samples were ashed to determine the organic content, which was found to be about 6% by mass (10% by volume). Based on the assumption that all the moisture retention would be associated with the organic material in the samples, and none with the sand, the value of k at 25°C was calculated to be $4.35 \times 10^4 \cdot x_o$, where x_o is the volume fraction of organic material in the sample.

Adding sand as a filler also has some self-compensating influences. Assuming that it is dry to start with, it immediately reduces the effective value of the initial moisture content c_i; however it also increases values of the equilibrium constant k and the filling rate v, both of which adversely affect the drying rate. In terms of the net effect on removing moisture from the system, the effect is negative; however in terms of the average dryness of the pit contents, the effect is positive. A further negative effect is that the pit will be filled substantially quicker.

In order to assess the implications of the mathematical model for Durban conditions, a scenario was constructed using values which were considered appropriate in Durban. Some of the values were inferred from the samples taken from actual toilets that were used in the drying experiments.

For a household of four persons, the daily inputs to the toilet were taken to be:

Table 3.1.1: Estimated quantities entering vault per day

	Mass (g)	Volume (mL)	Water (% mass)	Water (g)
Faeces	500	500	77	385
Soil	1770	1100	15	273
Total	2270	1600	29	658

N.B. toilet paper and additional rinsing water were not considered.

For a 1m^2 surface area this gives a rise rate v of 1.85×10^{-8} m/s.

The air conditions were taken as 25°C and 80% relative humidity, which is probably optimistic with respect to the average temperature.

From the laboratory drying experiments the equilibrium diagram for the moisture content of the solids and water vapour was found to be:

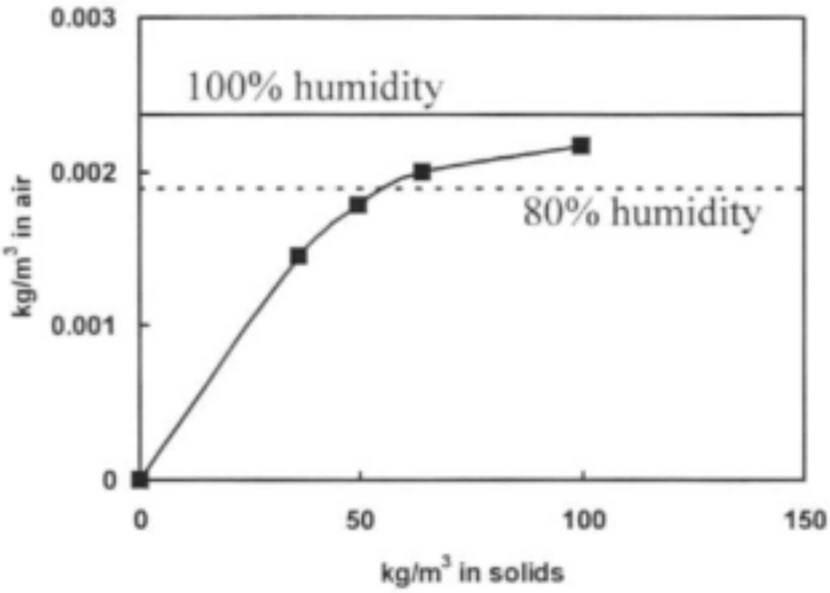


Figure 3.1.1: Equilibrium relationship between moisture in air and moisture in UD solids.

The curved shape of the graph is a problem for the mathematical analysis, which assumes a constant equilibrium ratio, i.e. a straight line relationship. Unfortunately the non-linearity occurs just around the ambient humidity in Durban. To accommodate this, the model was applied using an average value for the slope, and the result checked against the limiting case where the air leaves the vault at 100% humidity, i.e. the maximum possible evaporation per kilogram of air.

The other major variable is the rate of air circulation through the vault. Since this is not known, the analysis considered a range of flow rates up to 50 l/min, which was intuitively considered to be higher than might be expected without any powered circulation.

The results were plotted as the fractional degree of drying $\frac{(c-k\cdot c_a)}{(c_f-k\cdot c_a)}$ vs. the flow rate Q.

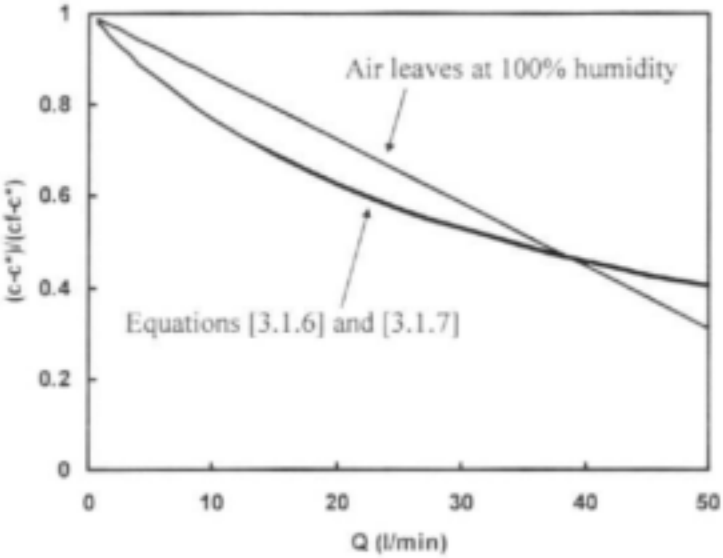


Figure 3.1.2: Dimensionless dryness as a function of air circulation rate.

The plots for equations [3.1.6] and [3.1.7] proved to be almost indistinguishable, showing that the mass transfer coefficient is not a limiting factor. However 100% humidity limit reduced the calculated degree of drying for circulation rates below 40 L/min.

Ryan and Mara (1983) indicate 18 m^3/h as a typical circulation rate which would be achieved with a 100 mm diameter vent pipe in a ventilated pit latrine (VIP). This translates to 300 L/min, which is well above the 40 L/min cross-over point. Hence, equation 3.1.6 is the limiting condition for drying at higher circulation rates.

At 300L/min equation 3.1.6 predicts that the material should in fact be quite dry. However, the analysis is based on the assumption that the limiting factor is the mass transfer from the surface to the air, which is unlikely to remain true as the moisture content drops. The Figure 3.1.3 shows the moisture content predicted by equation 3.1.6 for the initial composition presented in table 3.1.1

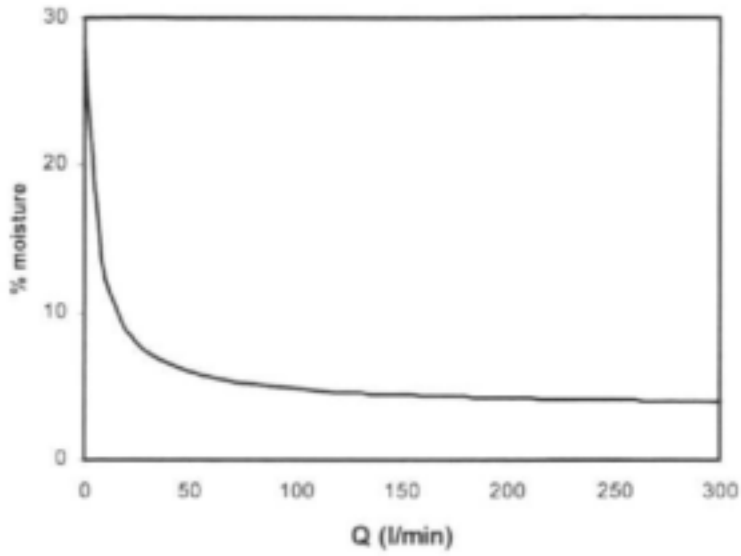


Figure 3.1.3: Predicted moisture content as a function of air circulation rate.

3.1.2 Drying during the standing phase

During the standing phase the vault is closed off, apart from the vent pipe, so the circulation rate will be largely eliminated, and the evaporation can be expected to be little.

The 100% humidity limit can easily be applied to the standing phase also: 25 l/min of air operating between 80% humidity and 100% humidity at 25°C will remove about 62 kg of water per year. When it is considered that the amount of water added in normal use is about 0.6 kg per day, or 240 kg during the 1 year filling phase, about half the water could be expected to be removed over the expected 2 year cycle of operation.

3.1.3 Experimental observations

Observations on working latrines are reported in section 3.3. The moisture content of samples taken from the surface layer and a layer below the surface are shown in the next section (Figure 3.2.2). These results are influenced by the variability of the UD material properties (which can be attributed to the variable amounts of soil added to the vault together with the difficulties in obtaining homogenous samples); however they do provide some support for the model. In Figure 3.1.4, the line shows the relationship between ash content and moisture content that would be maintained as the material of table 3.1.1 dries, while the points reflect the measurements on UD vault contents.

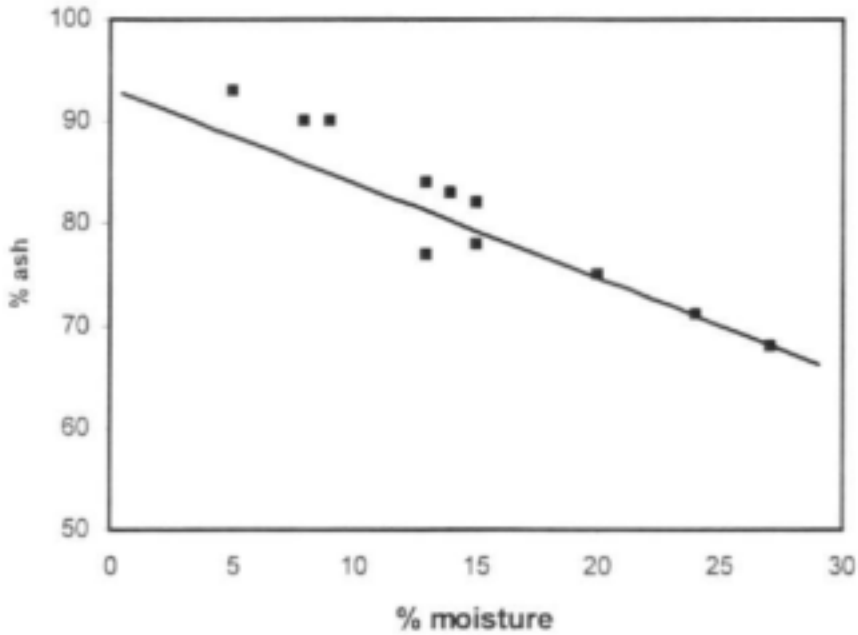


Figure 3.1.4: Comparison of measured moisture content in samples from 5 UD vaults with model mass balance line.

Of the 5 vaults where data are available for the surface layer and a buried layer, in only one case is surface layer wetter than the buried layer, for the rest the moisture contents of the two layers are similar, with the fresher surface layer being slightly drier than the older surface layer.

3.1.4 Conclusions

This mathematical analysis was carried out primarily to a framework for interpreting experimental results. It has shown that the moisture content during the filling phase should remain approximately constant, if the material entering the vault is approximately constant. Assessing the moisture content of a vault during the filling phase is thus largely a matter of obtaining a sufficiently representative sample of the inhomogeneous material.

The analysis has also highlighted the importance of the air circulation rate for achieving good drying. It is therefore an unsatisfactory feature of the Durban system to close off the vault during the standing phase, since it means that very little further drying will occur.

3.2 Survey of physical and chemical characteristics

This section of the report is based on the work of two students, Stephania Mantovanelli and Natalie Beard, who between them analysed samples from 11 different UD toilets. The main thrust of both projects was to characterise the process of biodegradation in the pits using the anaerobic *serum bottle test* (Remigi and Foxon, 2006). This technique collects and analyses the biogas evolved from a sample of material contained in a serum bottle. Unfortunately neither investigation were successful in terms of this objective, as the serum bottle technique proved to be unsuitable for applying to UD waste because the quantities of gas evolved were too low and erratic for meaningful conclusions to be drawn from them. However both carried out a battery of supporting tests on the samples, and re-analysis of these results has yielded a reasonably consistent characterisation of the contents of UD vaults, and offered a possible explanation of why the serum bottle tests results were inconclusive.

3.2.1 Sampling

15 samples were collected from the vaults of 11 UD toilets; some of them were at the time in use while others were full of faecal material, ready to be emptied. All samples were collected in an area near Durban called Zwelibomvu (*red soil*) between Pinetown and Mariannhill.

The collection was made in some cases directly from the vaults while on other occasions from the toilet pedestal. Since the aim of the work is to investigate the processes occurring in UD toilets, only toilets that appeared to be properly maintained were chosen, rejecting the ones full with plastics, papers and different kind of rubbish. The samples were then taken to the laboratory where they were classified, divided into top and middle layer and stored in the cold room (4°C) till they were used for the experiments.

Figure 3.2.1 Taking a sample through the rear opening of a vault. The sampling tube is the PVC pipe in the foreground of the picture.

- Samples 1 to 3: were all collected from the same toilet, taken from various points around the centre of the vault;
- Sample 4 was taken from the same UD vault as samples 1 to 3, but 2 months later.
- Sample 5: collected from a standing vault;
- Samples 6 and 7: both collected from the same toilet immediately below the centre of the toilet bowl. The aim of this was to compare two samples that were supposed to be almost identical. The vault had not been in use for about 2 months at the time of the sampling.
- Samples 8, 9 and 10: collected the from 3 different UD toilets, all of them from vaults that had been standing out of use for about 2 months.
- Samples 11 to 15: collected from 5 separate vaults that had been standing unused for an unknown time; these samples were all taken from about 30 cm below the surface.

The samples were collected using a plastic tube which had a plastic system to grab the sample while withdrawing the tube from the vault.

3.2.2 Chemical and physical analysis

The following tests were carried out:

- Drying at 105°C to determine moisture and total solids content.
- Ignition at 550°C to determine volatile solids and inorganic solids content.
- Chemical oxygen demand determined according to the University of Cape Town standard method (Lakay *et al*, 2000).

Unfortunately the drying and ignition tests were not carried out on samples 1 to 4, leaving sample 5 as the only one from a filling vault with a complete set of data (the remaining samples all came from standing vaults).

3.2.3 Results

The first impression of the measured data is that all the quantities are highly variable, with few discernable trends. Even results that were considered as replicate determinations often differed considerably. However it was evident that the inorganic solids were negatively correlated with all the other measurements. This suggested the hypothesis that the variability could be explained by regarding the vault contents as a highly non-uniform mixture of faecal matter and sand, which is consistent with the way that material is introduced to the vault. To check this hypothesis, the measurements were compared with a reference model which calculated the characteristics of mixtures of fresh faeces and sand (regarded as inorganic solids) in different proportions. The comparison is shown in the following graphs. Figure 3.2.2 plots the results of the physical tests, and Figure 3.2.3 plots the results of the COD analyses.

In Figure 3.2.2 the solid symbols are used for samples taken from below the surface of the vault contents, while the open symbols indicate samples taken from the surface. The lines are the model predictions, which are based on the assumption that the faecal material consists of 75.5% moisture and 24.5% solids, of which 69% are volatile (organic) and 31% are inorganic. The added sand is assumed to contain 99% inorganic solids and 1% moisture. As can be seen from the diagram, the model corresponds well to the data, which means that variations in the proportion of added sand are the most significant factor in the differences between samples. It was decided to plot all the 'replicates' of measurements as individual points, as the inorganic solids content could be significantly different in the different parts of the sample that were used for the analyses. Although the model lines represent all the results quite well, it can be seen that there is a discernable difference in the positions of surface samples and buried samples, with the surface samples showing a somewhat higher average inorganic content than the buried samples. This trend is apparently contradicted by the one surface sample number 5 that comes from a vault that was in use and filling, as opposed to all the others which came from standing vaults.

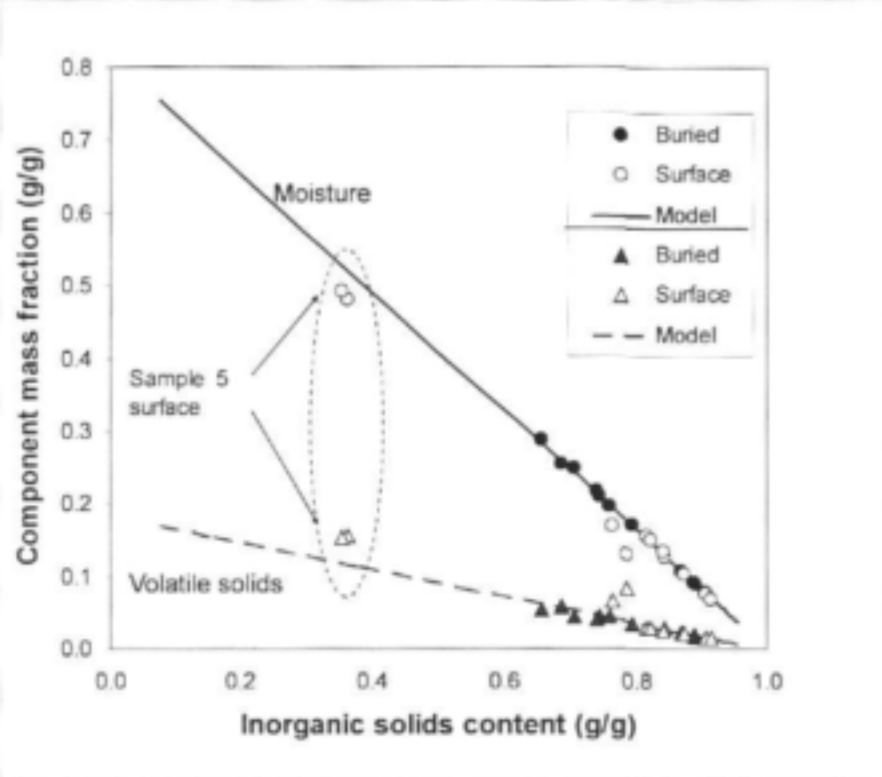


Figure 3.2.2 Moisture and volatile solids fractions of UD vault contents as a function of inorganic solids content.

The same trends are observed with the COD results (Figure 3.2.3), although with much more scatter in the data. Unlike the physical measurements, where moisture, volatile solids and inorganic solids were all determined as part of one procedure performed on the same sub-sample, the COD and inorganic solids came from different sub-samples, which probably had different inorganic contents. Thus any correlation between the two variables within replicate measurements cannot be observed. In order to give an impression of the resulting measurement uncertainties, each sample is represented by a cross formed by plotting all the replicate determinations for COD against the average inorganic solids determination for the sample (vertical line), and all the inorganic solids replicate determinations against the average COD for the sample (horizontal line).

The correspondence between the COD and volatile solids results in Figures 3.2.2 and 3.2.3 is supported by Figure 3.2.4 which plots COD against volatile solids. In spite of the scatter, the slope of the regression line is 1.49 gCOD/gVSS which is very close to the generally accepted figure for municipal sewage of 1.48 gCOD/gVSS (Wentzel et al., 2006)

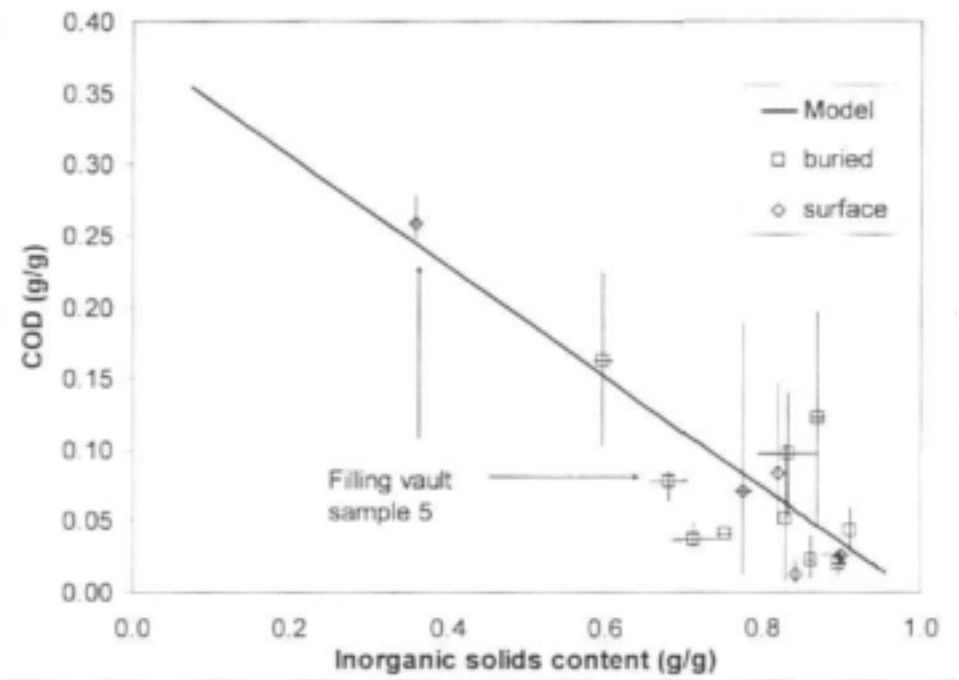


Figure 3.2.3 COD of UD vault contents as a function of inorganic solids content.

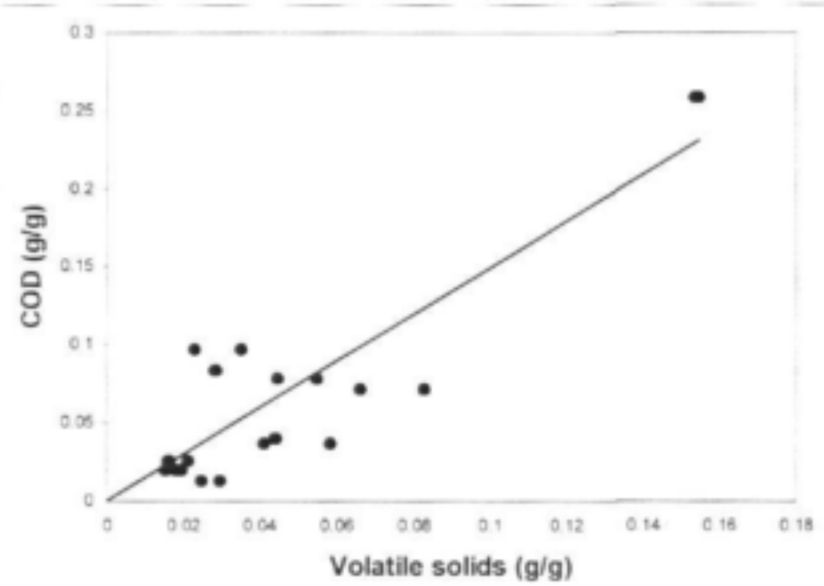


Figure 3.2.4 Relationship between COD and volatile solids in UD vault samples.

3.2.4 Discussion

Thus far, the data might appear to indicate that the only factor determining the composition of a sample is the amount of sand that was mixed with the faecal material by the user as it was added to the vault, and that nothing changes significantly thereafter. However, removal of faecal material by biological degradation would simply cause points on the volatile solids and COD graphs to move towards the high inorganic solids side while remaining on the model lines. The different distributions along the line of buried and surface samples suggest that the hypothesis that nothing changes in the vault is too restrictive. A less restrictive hypothesis is that some biological degradation occurs, and this is accompanied by a proportional, or at least approximately proportional, loss of moisture, so that the points on the moisture graph also follow the model line.

If the above hypothesis is accepted, then the data suggest the following:

1. faecal material is combined erratically with sand as it enters the vault, forming a highly non-homogenous mixture;

2. while it remains in contact with air on the surface, some faecal material is removed by aerobic degradation, causing a decrease in both the volatile solids and moisture content;

3. once it becomes covered over and is removed from direct contact with air, both degradation and evaporation stop, or almost stop, so that the buried contents of a filling vault do not change significantly;

4. in the standing phase, slow aerobic degradation and evaporation continue at the surface of the heap, with little happening below the surface.

If this is correct, the degradation process proceeds in a remarkably similar way to the drying process described in section 4.1 – indeed it seems necessary for the two processes to proceed in parallel to explain figure 3.2.2. However, these mechanistic conclusions should be viewed with caution, as they are based on data from a set of experiments that were designed around the hypothesis that the degradation would chiefly anaerobic. It now seems that the reason that the anaerobic tests were unsuccessful could be that conditions in the heaps are not conducive to anaerobic digestion. In particular it is unfortunate that there are data for only one filling vault.

Although the data are insufficient to provide a clear picture of the processes occurring in the vault, it does give a good idea of what will be encountered when emptying a vault that has been through a standing phase. Table 3.2.1 summarises the data on material from standing vaults.

Table 3.2.1 Summary of properties of material taken from standing vaults

Property (% mass)	Range	Average
Moisture	7 - 31	14
Total solids	69 - 93	86
Inorganic solids	58- 92	82
Organic solids	1.5 – 11	4
COD (g/g)	0.006 – 0.28	0.07

Because of the way in which faeces and sand was added to the vault, the mixture is very non-homogeneous, so the range of local compositions is wide.

What is chiefly missing from this information is the proportion of the organic solids that is still biodegradable. The 80% average inorganic content has an important implication for the rate at which vaults fill, and consequently how often they need to be emptied.

4 HEALTH BENEFITS AND RISKS

In order to address the project aim *to evaluate the effectiveness of urine diversion toilets in improving the wellbeing of the user community* it was intended that a study of the health benefits of providing UD toilets and an assessment of the risks involved in using them would be carried out. However, the health benefit study evolved into a separate project carried out by a different team of researchers, so only a brief summary of their main findings is included in this report.

The most critical risk associated with the eThekwini UD system that was identified was the risk of exposure of householders to helminth ova during the process of emptying a vault and burying the contents. A study undertaken for eThekwini on the fate of the waste after burial and the microbiological safety of food crops grown over buried waste indicated no significant risks.

4.1 Health benefits

The Environmental Health Department and Water and Sanitation Section (EWS) from eThekwini Municipality, in collaboration with the World Health Organisation (WHO-Geneva), Swedish Institute of Infectious Disease Control (Sweden), The Nelson R Mandela School of Medicine (UKZN – Durban) conducted an epidemiological study to evaluate the health outcomes of providing UD toilets, together with provision of water and hygiene programmes. The study took the form of an observational analytical cohort study, and compared health outcomes in intervention areas (receiving UD toilets, water and hygiene education) to those control areas of similar socio-economic and demographic stratification, but without UD toilets.

Study Sample: Using a multistage random sampling process, 639 households in three areas exposed to the interventions and 668 households in three non-exposed areas were selected.

Data Collection: Each household was visited by trained field workers every 2 weeks for six visits. A baseline household questionnaire and observation check list was completed, followed by 5 fortnightly visits to observe and question about householders health. Recall bias was reduced by field workers repeatedly visiting households every two weeks.

Exposure variables: Type of sanitation used, hygiene and sanitation knowledge, socio-economic education, occupational and literacy and demographic data.

Outcomes variables: Episodes of diarrhoea, vomiting, worms and skin infections as well as the duration of each episode.

Findings: A total of 7307 householders were followed for 606 631 person-days over the study period of 12 weeks. The diarrhoea incidence rate was 1.9 per 1000 person days in exposed and 3.3 per 1000 person days in non-exposed Areas. There was a 31% reduced risk of diarrhoea in the areas where the on-site sanitation program had been implemented to areas where it had not been implemented. The reduction was adjusted for socioeconomic status, safe water supply, education, literacy and crowding (incidence rate ratio: 0.69, 95% CI: 0.49 to 0.97; $p = 0.035$). Each member of the household in the exposed areas had 0.51 less episodes of diarrhoea than people living in the non-exposed areas. The intervention had by every 2008 being introduced in 63,000 homesteads which would have resulted in more than 150,000 less episodes of diarrhoea.

Households with safe water had an additional protection from diarrhoea, with households that had an inside safe water supply (IRR = 0.7 (05% CI 0.6 to 0.8), an outside safe water supply (IRR = 0.9 (95% CI: 0.7 to 1.0) significantly better off than those with unsafe water.

The benefit of sanitation was three times greater in children under five than for the rest of the population.

Conclusions: Households who benefited from the on-site urine diversion program have significantly fewer acute infectious water-related health outcomes. Hygiene education and safe water supply may modify this effect, but actually having a safe and functioning toilet is key to improved health in the peri-urban areas of eThekwini.

The preliminary results of this study were presented at the Launch of the WHO Guidelines on the Safe Use of Excreta and Wastewater, at the Conference of the International Water Association in Beijing, in China in September 2006, (WHO, 2006) and at the International Conference on Sustainable Sanitation, Dongsheng, China, August 2007 (Lutchminarayan et al., 2007a) The complete results of the study are presented in an eThekwini Health Department report (Lutchminarayan et al., 2007b).

Due to the extensive amount of data collected in this study and the large sample, this study has provided a baseline as an international and a national demographic site for future prospective studies. Sub-sets of the study populations have already been used as sites for studies of the occurrence of protozoan and helminthic parasites in UD toilets in use (UKZN/SMI collaborative study), and of grey water generation and use (WRC Project K5/1639), currently in progress.

4.2 Risk assessment

The reasons for selection of UD toilets over VIPs as on-site sanitation provision by eThekwini Municipality have been presented in various preceding sections. As a result of the urgency with which a substitute for VIPs as on-site sanitation in rural and semi-rural areas within the eThekwini municipal area was needed, there was insufficient time to subject all aspects of the technology to rigorous scientific testing. There are uncertainties about aspects of UD toilet operation maintenance; in particular, that guidelines provided by Municipal health and hygiene education programmes may not be sufficiently protective of users exposed to microbial pathogens, originating predominantly from faeces. This section describes efforts to identify and quantify the major health risks associated with UD toilets, specifically as implemented by eThekwini.

The World Health Organisation has issued guidelines for the reuse of wastewater and excreta in agriculture and aquaculture (WHO, 2006), which specifies how acceptable health risks may be achieved through removal of specified health hazards, either by either treatment or by implementation of exposure barriers. These guidelines rely heavily on the concepts of risk assessment, particularly Quantitative Microbial Risk Assessment (QMRA).

Risk assessment framework as adopted by the USEPA comprises four steps: hazard identification, exposure assessment, dose-response assessment and risk characterization. Hazard identification aims at identifying the range of pathogens of concern and health implications associated with them. It relies on clinical and surveillance data (WHO, 2003). Exposure assessment focuses on the magnitude of exposure (specifies the amount of microorganisms the population is exposed to per duration time) for a given exposure scenario. It also determines the possible transmission routes exclusively for the study population. Dose-response assessment characterizes the interaction between the dose of microorganisms consumed and the associate effects caused in the exposed population. It generally relies on human or animal challenge studies and provides a quantitative estimate of the risk to which the population is exposed, using epidemiological and clinical data to develop a risk model (ILSI, 2000). Risk characterization uses the information from both the exposure and the dose-response assessments in calculating and assessing the probability of infection in the exposed population (Petterson and Ashbolt, 2002). It comprises of two steps: risk estimation and risk description. Risk estimation describes the magnitude and types of effects that can result from exposure, and can be either qualitative or quantitative, depending on the method used. QMRA, by definition, relies on quantitative estimation of risk. Risk description places this estimate in context by describes the intensity, nature and consequences of the risk for the identified exposure scenario(s) (ILSI, 2000). One example of how the results of a QMRA could be applied is comparison of the modelled risk to a recognised maximum acceptable risk for different pathogens. If the modelled risk is higher than the acceptable, then exposure barriers can be devised to minimize the exposure risk, *e.g.* specified hygiene interventions. Revised risk estimates can then be compared to the defined acceptable risk, and the process iterated until a combination of protective measures is identified which will provide adequate protection of the exposed population. One of the benefits of the approach advocated in the new WHO guidelines is this iteration of the QMRA, until a suitable combination of protective measures is identified to reduce risk to acceptable levels. Such a process provides for inherently greater flexibility in responding to health hazards than more conventional guidelines which simply provide acceptable levels of potentially pathogenic micro-organisms (WHO, 2006).

The first step in any risk assessment is to define the hazard to be assessed. The present risk assessment study confines itself specifically to exposure of community members using and maintaining UD toilets, as provided by eThekwini Municipality.

It was suggested by eThekwini Water and Sanitation (EWS) that a risk assessment-based approach may be useful in identifying the areas of greatest risk in the operation and maintenance of UD toilets, and in developing the most effective interventions to reduce such risks, if any. A workshop involving members of the UKZN PRG and EWS was held, with the objective of considering whether and how risk assessment concepts such as QMRA could be applied to the evaluation of UD operation and maintenance. This corresponds to the hazard identification step of the risk assessment process, as identified above. The major points that arose from the workshop were as follows:

1. The major microbial hazard was identified as the helminthic parasite, *Ascaris* (roundworm), which is endemically present in the coastal areas in and around Durban (Saathoff *et al.*, 2004). Occurrence is thought to decline towards the western boundaries of the eThekwini municipal regions, but it remains a major health problem, especially in

pre-school and school-age children (Kvalsvig *et al.*, 1998). It was decided, therefore, that any QMRA activity should focus on this pathogen.

2. The major exposure routes of interest were identified as being those arising from the excavation and burial of solid waste from filled UD vaults which had been allowed to stand for a period of approximately one year. Two exposed groups were identified: (i) waste handlers (UD faecal waste), after the standing period, during vault excavation and burial of the waste, (ii) and exposure of children to waste spilled accidentally and left on the ground after burial of the waste.

3. Data gaps, which made it difficult to conduct a QMRA specifically tailored to the eThekwini implementation of urine diversion, were identified, and studies that could be undertaken to address the identified data gaps were identified. One such gap is a quantitative description of exposures typically associated with the eThekwini implementation of UD toilets.

The objectives of the risk assessment presented in this section were therefore as follows:

(i) to produce a quantitative assessment of potential exposure of handlers of UD faecal waste after the standing period, during vault excavation and burial of the waste, and exposure of children to spilled waste left on the ground

(ii) to use these data to develop an exposure model for exposure to faecal waste during and after vault excavation and waste burial.

(iii)_ to implement the exposure model in a quantitative microbial risk assessment.

(iv) to demonstrate the use of the outcomes of the risk assessment in guiding the selection of intervention methods which would allow risk to be reduced to acceptable levels.

4.2.1 Methodology

The study was carried out in the Zwelibomvu area, about 20 km West-South-West of Durban. It aimed at evaluating exposure to microbial hazards during both operation and maintenance of a UD toilet. There were three phases in this assessment; the observation phase, the interview phase, and the data analysis and modelling phase.

Observation Phase

This phase focused mainly on the potential microbial hazards to the operator (waste handler), during emptying and burial of UD waste; and to children exposed to spilled waste on the ground whilst playing in the area shortly after waste burial Due to lack of success in finding households that were willing to empty their toilets within the given study period, emptying was done by the community members who have worked on emptying with the contractors in the area. A total of four emptiers were used, with varying combinations per toilet. The households were asked to give information about the intended fate of faecal waste; if burial, they chose the burial site. A check-sheet for observation was formulated pre-site visit. This was completed for each toilet emptied, focusing exclusively on exposure routes. The following observation and measurements were made:

(i) The personal protective equipment (PPE) worn by the operator during emptying was recorded.

(ii) The quantity of material left on working tools (*e.g.* spades) was observed.

(iii) The residual waste left on site was collected back to the laboratory and weighed,

(iv) The quantity of waste left on the hands of UD handlers was estimated by providing handlers with pre-weighed gloves, which were re-weighed upon return to the laboratory. The difference in mass per set of gloves was taken to be representative of waste left on one handler's hands.

Samples of waste from UD toilet vaults of varying standing period were also collected in the same field visit. The *Ascaris* ova load in the toilets was estimated by analysing these samples using the AMBIC protocol described earlier. The *Ascaris* ova content in waste on tools, workers, hands and spilled waste collected on site was back-calculated from counts recorded for the toilet vaults after standing.

Interview Phase

This focused on the behaviour of users of a UD toilet. A list of questions was formulated pre-site visit, based on theoretical exposure routes and amounts. They focussed on hygiene habits employed by children and adults, the usefulness of the talks given by the EWS personnel on UD use, general ideas on the UD technology and compliance with the EWS guidelines on using and taking care of the toilet. This information, together with the description of the toilet for that particular household, was used in developing a profile focusing on the nature, frequency and amount of exposure, the pathogens to which householders were exposed, and the number of exposed individuals per given time period.

Data Analysis and Modelling Phase

The framework for risk assessment, as used by the USEPA for chemical and adapted for assessment of microbial health risks, (Haas *et al.*, 1999) was used to analyse the data collected. The single hit exponential model was used for *Ascaris*; it is based on the probability that single hit of the organisms will result in infection. Since there are no published values for the model parameter r, a value of 1 was assigned to it. This equates to an assumption that each exposure to an *Ascaris* ovum potentially leads to infection (Schönning and Stenstrom, 2004). Since both male and female worms are required to establish the life cycle phase in the human host, this is recognised as being a conservative assumption.

The single hit exponential model takes the following form (Haas *et al.*, 1999) :

$$P_{inf} = 1 - \exp(-rd)$$
(4.2.1)

Where :

P is the probability of infection

r is the constant assuming that a single hit with any one in the community will result in infection d is the dose of ingested *Ascaris* ova (Haas *et al.*,, 1999)

Annual risk of exposure for *Ascaris* was also estimated using the equation expressed as:

$P_{yeary} = 1-(1-P_{inf})^n$
(4.2.2)

Where n is the number of exposure events in one year

Results from the field study of *Ascaris* ova in spilled waste and on handlers' hands were corrected for approximately 75% percentage recovery (Hawksworth *et al.*, 2005). The calculated corrected exposures to *Ascaris* ova were used to substitute for d in the equation above. Risks were calculated using @Risk (Palisade Software) which functions as an add-in tool to Microsoft Excel. In this software, values in equations can be entered as a distribution of values rather than as a single number. Monte Carlo simulation, which involves iterative calculations of output based on values sampled from the input range (Kreinin, 2001), can then be used to yield a distribution of output values rather than a single output value. The value of this approach is that it allows for assessment of uncertainty (spread of distribution) associated with the output, which is as important as the measure more central tendency (*e.g.* mean risk) in deciding on an appropriate response to the calculated risk. The exposure risk output was compared to the USEPA's acceptable risk for microbial infection, *i.e.* 1 in 10 000 *infections per year, or* 10^{-4} *(Haas et al., 1999, Rodda and Genthe, 199). The impact of* various interventions which would provide a barrier between the hazard *(Ascaris* ova) and the exposed individual (waste handler) was also modelled.

4.2.2 Results and Discussions

A total of 25 questionnaires were completed during the field visit to Zwelibomvu. Responses are presented in Table 4.2.1.

Table 4.2.1: Toilet usage by the Zwelibomvu community members.

Toilets used before UD		
Pit		None
88%		12%
Preferred toilet		
Pit	UD	Either
54%	42%	4%
Toilet used in addition to the UD		
Pit		None
21%		79%
Most common suggestions for improving sanitation provision		
Enlarge the vault	No emptying	Want flush toilets
46%	13%	8%

Users' acceptance of UD toilets differed depending on their previous experiences. All respondents who had had no sanitation system before were happy with UD toilets as a sanitation system. Respondents who had had pit toilets before tended to compare both systems in terms of hygiene, health concerns and how well it fitted their lifestyles. These users often preferred pit latrines, and 21% of these respondents were still using pit toilets in addition to the UD. This percentage represented mainly of older community members who found it difficult to accept the change and those who viewed UD toilets as just another option imposed on them by the Municipality. There was however, a bigger concern in both these groups about the vault filling up too quickly; almost half of the respondents (46%) suggested enlarging the vault. Surprisingly, emptying did not seem to be the point of main concern (only 13% suggested that the toilet should not require emptying).

However, this is not conclusive since at the time of interview most community members had no experience with emptying. Also surprising was the low proportion of users wanting flushing toilets instead of UD toilets. This may indicate that EWS campaigns to educate users about the limitations regarding possible sanitation system were successful in this community.

Table 4.2.2: Cleanliness and personal hygiene adopted by the UD users

Had provision for hand-washing	0%
Washed hand with soap after emptying	100%
Uncovered pedestal	44%
Exposed unused vault	12%
Flies present	42%

However, this may not be truly representative of practices in the community since none of the community members had yet emptied their own toilets, and outside assistance was used in empting toilets in this study.

None of the respondents had provision for washing hands after using the toilet; however, they all insisted on being aware of health implications associated with this practice (Table 4.2.2). About half of the respondents (44%) left the pedestal uncovered after using the toilets, 12% left the vault on the standing period uncovered and 42% of the toilets observed had flies. This demonstrates a possible exposure route and a health concern since the UD toilets are supposed to reduce the probability of spread of infection by insect vectors.

The potential for human exposure to residual faecal matter left on-site after emptying was high. In 72% of the cases there was material left exposed after waste burial and 84% of the burial sites were highly accessible to humans (there were foot paths about 0.3-7m from the site). Only 12% of the households waited for some time before using the area around the burial site (exclusion period). None of the households marked the burial area. Thus there is a potential for improved EWS hygiene education targeting specifically the handling of waste during excavation of UD vaults and burial of vaults contents. However, it should be noted that there is some inherent bias in the emptying data since, while householders participated in directing emptying, very few were willing to participate in the act of vault emptying. This task was done by the experimenters and EWS personnel, hence householder practices are not truly represented and emptying practices at each toilet cannot truly be considered an independent variable.

Quantitative measures of material remaining on handlers' hands (Table 4.2.3) and spilled material left on the ground (Table 4.2.4) were also obtained. Spilled material was covered with sand in some instance. This is reflected in the data set as absent values.

Table 4.2.3: **The amount of faecal material to which each handler is exposed via hand contact, calculated as the difference between mass of gloves after emptying and mass before emptying.**

Toilet No.	Gloves before (g)	Gloves after (g)	Material left on gloves (g)	Emptier	Glove No.
1	16.10	17.83	1.73	2	11
1	15.36	16.01	0.64	1	12
2	14.46	14.47	0.01	1	41
2	14.82	14.84	0.02	3	43
2	15.25	15.28	0.03	4	44
3	16.36	17.39	1.03	2	15
3	16.15	16.80	0.65	1	17
4	15.34	16.02	0.67	1	48
4	14.65	15.25	0.60	2	58
5	16.47	16.54	0.07	2	2
5	16.80	18.02	1.21	1	3
5	16.47	17.08	0.61	3	16
6	16.74	16.77	0.03	1	22
6	17.34	17.74	0.40	2	25
7	16.34	16.38	0.04	2	23
7	16.19	16.25	0.06	1	26
8	14.22	14.24	0.02	2	28
8	14.85	14.88	0.03	1	35
9	16.34	17.41	1.07	1	55
9	15.27	15.95	0.68	2	56
10	17.84	18.06	0.23	1	6
10	15.57	15.61	0.04	2	24
11	16.52	17.69	1.17	2	4
11	16.49	17.63	1.15	1	9
12	15.09	15.12	0.03	1	45
12	14.20	14.25	0.05	2	46
13	15.31	16.01	0.70	1	5
13	17.02	17.74	0.73	2	8

Table 4.2.3 continued: The amount of faecal material to which each handler is exposed to via hand contact, calculated as the difference between mass of gloves after emptying and mass before emptying.

Toilet No.	Gloves before (g)	Gloves after (g)	Material left on gloves (g)	Emptier	Glove No.
14	17.76	17.80	0.04	2	14
14	15.09	16.80	1.71	1	18
15	15.43	15.48	0.04	2	19
15	14.78	16.29	1.51	1	20
16	14.40	14.42	0.03	1	27
16	15.03	15.13	0.10	2	29
16	15.20	15.25	0.05	3	37
17	14.86	15.02	0.16	2	49
17	14.56	14.87	0.31	1	54
18	16.93	16.97	0.03	1	10
19	14.19	14.26	0.07	1	47
20	15.46	15.90	0.44	2	1
20	17.02	17.30	0.28	4	7
21	14.54	14.59	0.05	1	31
21	14.62	14.67	0.05	3	33
21	14.47	14.55	0.08	2	36
22	15.00	16.59	1.59	1	59
23	14.72	14.92	0.20	1	51
23	15.53	15.86	0.32	2	60
24	15.04	15.08	0.04	1	52
25	17.22	17.26	0.05	1	21

The data from these tables are not truly representative of what should happen in the eThekwini system, because the emptying was carried out by the project members rather than householders, and their attitudes towards health risks may have been significantly different. For purposes of illustrative calculations presented here, these constraints have been ignored, but would need to be accounted for in a more rigorous treatment of the data.

Table 4.2.4: The residual material left exposed after emptying per toilet, calculated as difference between mass of bags after collection of spilled material and mass before collection.

Toilet #	Bags before (g)	Bags after (g)	Material left exposed (g)
1	4.10	43.27	39.17
2	4.15		
3	4.15	141.76	137.61
4	4.07		
5	4.12	17.32	13.20
6	4.10	19.32	15.22
7	4.13	80.80	76.67
8	4.12		
9	4.14	51.39	47.25
10	4.16	36.34	32.18
11	4.09	15.04	10.95
12	3.92		
13	4.18	57.99	53.81
14	4.10	40.64	36.54
15	4.14	20.10	15.96
16	4.42	17.56	13.14
17	4.47		
18	4.46	23.03	18.57
19	4.43	24.44	20.01
20	4.49	47.49	43.01
21	4.46		
22	4.45	49.55	45.10
23	4.46		
24	4.49		
25	4.47	11.82	7.35

Statistical Modelling

Quantitative data were entered as data ranges in a Microsoft Excel spreadsheet and specified as an input range in @Risk. The spread of input data can then be viewed as a frequency distribution. Figure 5.2.1 shows the distributions fit to three inputs. Figure 5.2.1A shows the distribution of ova in waste as sampled from UD toilet vaults; Figure 5.2.1B shows the distribution of waste material on handlers' hands; Figure 5.2.1C shows the distribution of spilled material left on the ground after burial of waste. Frequencies are shown on the y-axis; the values in the input range (ova/g; g waste on hands; g waste on ground) are shown on the x-axis. The bar shown below each graph shows the 90% confidence limits.

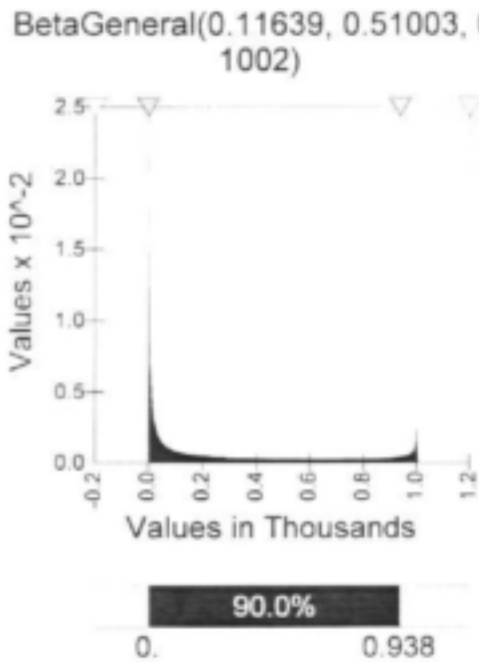


Fig 4.2.1A: Distribution of ova/g in waste sampled from UD vaults

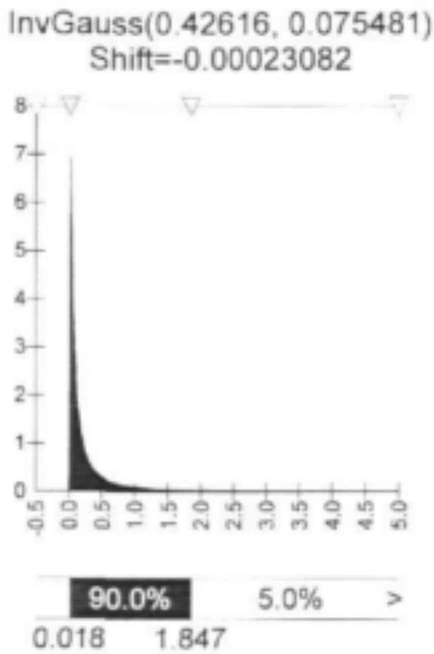


Fig 4.2.1B: Distribution of waste material on handlers' hands (g)

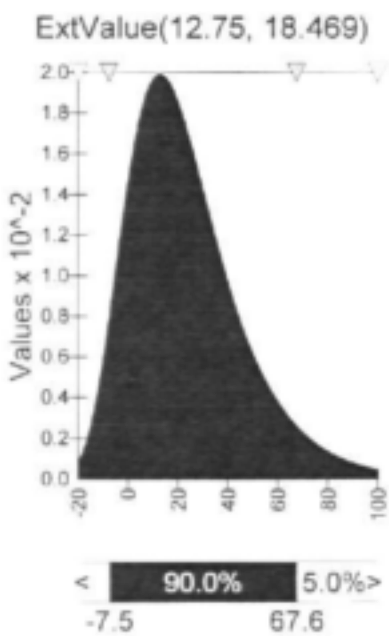


Fig 4.2.1C: Distribution of spilled material left on the ground (g) after waste burial.

Considering Figure 4.2.1A, it indicates that samples of UD waste may contain between 0 and 1002 ova/g. The height of the curve for any number of ova/g is an indication of the fraction of samples which will be found to have that load. Thus, the most common situation will be that the sample contains no ova; the chances of finding loads between about 300 and 900 ova/g are about constant; and there is a slight increase in the chance of finding very high loads between 900 and 1002 ova/g. Because the probability density function covers all possible cases, the area under the curve must be 1, which determines the scaling of the curve. The bar under the graph is an integrated summary of the probability distribution, indicating that 90% of all samples will have loads of between 0 and 938 ova/g. Figures 4.2.1B and 4.2.1C show similar representations, but use different mathematical forms to model their probability distributions.

The process by which a person might become infected by *ascaris* is then modelled as a sequence of stochastic events with the depicted probability distributions. A handler will get a random amount (g) of waste onto his hands, which will contain a random load of ova (ova/g), thereby exposing him to a random number of ova. Converting exposure to infection is also a random event, with probability modelled by equation 4.2.2. In Monte Carlo simulation, each stochastic event is modelled by a random number generator with a probability distribution which can be programmed. Each number put out by the generator represents a single outcome of the process e.g. the amount of waste on a person's hands after emptying a particular pit. Thus the result of a single run of the model might be that a handler gets 0.2 g of waste on his hands containing 3 ova, which does not result in an infection (each event being generated with the appropriate probability). In order to construct the overall probability of infection, the model is run a large number of times, and statistics are gathered on the outcomes.

Models were run using Monte Carlo simulation with 1 000 iterations and results presented as a frequency distribution or cumulative distribution of calculated risk values. Typically, between 500 and 1000 model iterations are run (Kreinin, 2001).

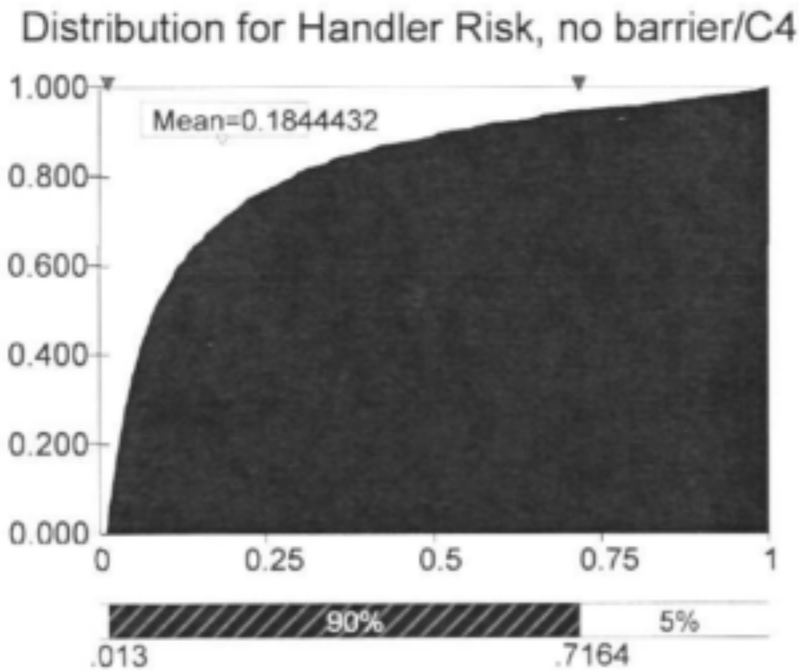


Figure 4.2.2: Cumulative frequency distribution of risks (without a barrier) to waste handlers based on waste left on hands.

Examples of output distributions are given in Figures 4.2.2 and 4.2.3. These depict cumulative frequency distributions of risk. Cumulative frequency is shown on the y-axis and calculated risk value on the x-axis. The 90th percentile limits are again shown by the bar below the graph. Note that Fig 4.2.1 represents the frequency at each point on the y-axis while Fig 4.2.2 shows cumulative frequencies, i.e. the y-value at any given x-value up to and including the indicated x-value.

The cumulative distribution of risks to handlers based only on the waste remaining on handlers' hands is shown in Fig 4.2.2. The distribution of risks to handlers assuming a 1 log reduction in exposure as a result of each of two exposure barriers – wearing gloves during waste handling and washing after waste handling – is shown in Fig 4.2.3.

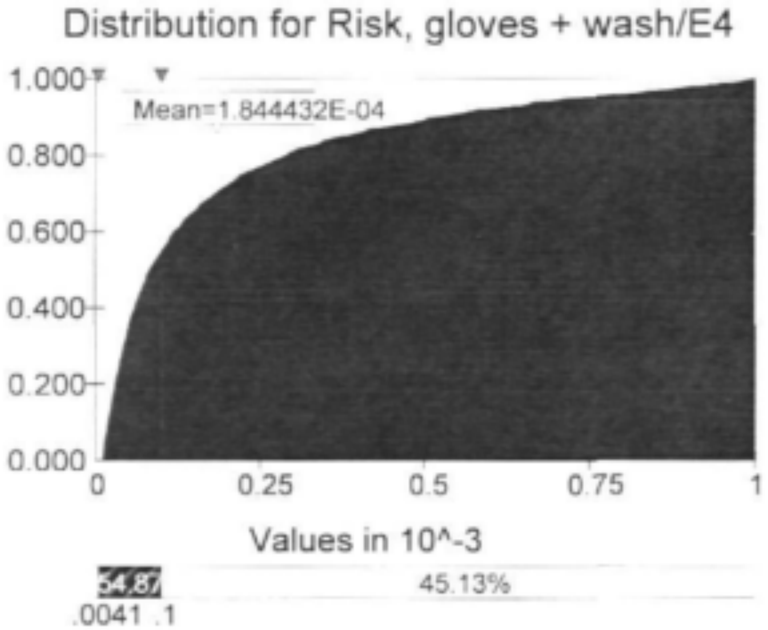


Figure 4.2.3: Cumulative frequency distribution of risks to waste handlers with two barriers (washing hands and wearing gloves).

The value of this representation can be seen in Fig 4.2.3. By adding 2 exposure barriers, risk of *Ascaris* infection can be reduced to close to the range considered acceptable by the USEPA for microbial hazards, *i.e.* 10^{-4} or 10 000 excess infections per year. By moving the vertical bar to 0.1×10^{-3} on the x-axis (a risk of 10^{-4}), the corresponding cumulative frequency up to and including this value is approximately 55%. In other words, risk of infection is $\leq10^{-4}$ for 55% of exposures sampled in Monte Carlo simulation. This allows risk managers to conduct a desk study regarding the conditions required to reach the acceptable risk, thereby greatly reducing the number of interventions which require field testing.

Although risks to children as a result of spilled waste were calculated, the uncertainty associated with this assessment was considered too large to have any confidence in their value for guiding decision-makers. Rather, the concerns raised regarding observed spillage on the ground, lack of marking of the burial site of the waste, and lack of an exclusion period for entry of children to the area between the UD toilet and the burial site should be used to guide decision-makers in adjusting community education programmes to provide protection for community members, particularly children, with access to the area during and after burial of UD waste.

4.2.3 Conclusions

This study indicates that risk to UD waste handlers is high in the absence of any barriers to exposure, but can be reduced significantly by adding simple barriers to exposure. Overall risk can probably be reduced to well within acceptable limits (10^{-4} or 10 000 excess infections per year) by adding chemotherapeutic intervention (de-worming) of children in schools (Kvalsig *et al.*, 1998). Such a practice would, over time, also reduce the reservoir of viable ova in the soil around households and toilets.

Although the study undertaken here was intended more as an experimental investigation into the usefulness of QMRA than as a true guide to management practices, it has revealed several interventions which, added to the existing package of sanitation by UD toilets, free basic water supply and hygiene education already being implemented by eThekwini, would probably dramatically reduce *Ascaris* prevalence in the eThekwini Municipal region.

5 DISCUSSION AND RECOMMENDATIONS

This was an exploratory project in several respects: firstly, since the team of researchers had no previous direct experience in onsite sanitation, and secondly, since there has been very little previous research into the processes occurring in UD wastes. As a result, much of the effort was directed towards developing and proving the techniques that could be used to characterise various aspects of UD waste.

5.1 Measurement and testing protocols

Two measurement techniques received the most attention: the anaerobic serum bottle test for characterising various aspects of biodegradation processes, chiefly biodegradability and anaerobic inhibition; and the AMBIC protocol for recovering helminth eggs from UD solids in order to assess their prevalence and viability.

The AMBIC protocol (presented in detail in WRC report TT 356/08) represents a very significant contribution, since it has demonstrated that previous methods were unreliable in detecting the eggs, which brings into question previous ideas about the survival of these pathogens, since they may have been derived from unreliable measurements.

5.2 Characteristics of UD wastes

The most important characteristics of the UD waste are those that are found at the time of emptying the vault, and these are related to the processes that have taken place during the filling standing and standing phases. In this project the processes and conditions that were investigated were those that apply to the eThekwini double vault system, and the results obtained do not necessarily apply elsewhere.

The most important characteristic was considered to be its *Ascaris* infectivity, followed by its moisture content and degree of biological stabilisation. The infectivity is related to the safety of handling the waste, whereas the dryness and stabilisation are directly related to the unpleasantness of handling, though they may also affect the infectivity indirectly.

The practice of sprinkling soil to cover faeces, as recommended in the eThekwini system, has the effect of reducing the average moisture fraction in the vault. However, since there is no mixing, it makes for a very non-uniform mixture, and it is not clear to what extent it dehydrates the faecal material. The overall loss of moisture from the vaults is not very effective in the eThekwini system, largely because the standing vault is closed off, reducing the circulation of air.

The material that can be expected to be removed from a standing vault will contain on average 82% inorganic solids (chiefly sand) 14% water and 4% organic solids (faecal material). A summary of the measure characteristics is shown in Table 5.2.1

Table 5.2.1: Summary of properties of UD waste from standing vaults

Property (% mass)	Range	Average
Moisture	7 - 31	14
Total solids	69 - 93	86
Inorganic solids	58- 92	82
Organic solids	1.5 – 11	3.7
COD (g/g)	0.006 – 0.28	0.07

5.3 Risk assessment

The risk assessment focussed on the risk of infection with *Ascaris* associated with the emptying of the UD vaults. This was considered to be the part of the UD system which posed the greatest health risk to the community. The study concluded that there was a moderate (though unacceptable) risk, which could, however, be relatively easily managed by taking simple precautions when handling the UD waste, together with a campaign to reduce the incidence of the disease in the community, something which is desirable in any case.

The health benefit study conducted by the eThekwini Department of Health provided an overall assessment of the entire system in terms of observed incidence of diseases, rather than prediction based on risk modelling. The results strongly supported the contention that the provision of UD toilet facilities assists significantly in reducing the prevalence of diseases by breaking the cycle of infection.

5.4 Recommendations

1. The results of the health impact study conducted by the eThekwini Department of Health support the assumption, which was the basis of the decision to adopt the UD sanitation system in eThekwini, that the system would lead to a safer and healthier environment for the communities to which the service is provided. The continued roll-out of the system is therefore supported.

2. The risk of Ascaris infection is significant for anyone who has to handle the UD waste, but it can be readily managed. The issue is most critical where emptying is to be carried out by contractors from outside the household, since they will be more frequently exposed, and they will be more likely to spread the infection. There is a strong case for combining the provision of UD toilets with a chemo-therapeutic campaign to reduce the prevalence of ascariasis in school children.

3. Since the greatest risk of propagating diseases centres on emptying a vault and burying its contents, the physical design of the vaults should be looked at critically to make these

operations as easy as possible. With the current design, the relative size and positions of the vault and the rear opening make it practically impossible to empty the vault without the handlers coming into physical contact with the waste, spilling it on the ground, and suffering cuts and grazes from the concrete edges. A system where the waste accumulates in a receptacle which can easily be remove from the vault might make emptying much safer and easier, but would have cost implications. The emptying process should be the subject of an ergonomic study to find a safe and cost effective design.

4. The largest component of the UD waste by far is the added sand. This need to be taken into account when considering filling rates, emptying frequencies and the vault volumes in the system design.

5. Drying and biological degradation of the UD waste appear to be chiefly dependent on contact with air, so the design of the toilets should aim for good air circulation through the vaults. In the current design, there is good circulation via the toilet pedestal during the filling phase, but not during the standing phase, since the pedestal hole is closed off. The design should be modified to allow circulation during the standing phase also.

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7 CAPACITY BUILDING AND TECHNOLOGY TRANSFER

7.1 Students

Name	Level	Race	Gender
S Mantovanelli	MSc	W	F
S Pillay	BSc Honours	I	F
C Nwaneri	BSc Honours	B	F
D Starzak	BSc Honours	W	F
M Mnguni	BSc Honours	B	M
N Beard	BSc Honours	W	F
S MKhize	BSc	B	M

7.2 Theses

Natalie Beard (BSc Honours): T*he use of serum bottle tests to determine anaerobic biodegradation in Urine Diversion (UD) waste*, University of KwaZulu-Natal (2007)

Mluleki Mnguni (B.Sc Honours) *Assessment of Exposure to Microbial Hazards During Operation and Maintenance of Urine Diversion (UD) Toilets in the eThekwini Municipal Region*, University of KwaZulu-Natal (2007)

Stephania Mantovanelli (MSc), *Biodegradation of the contents of Urine Diversion Toilets in eThekwini*, Politecnico di Milano (2006)

7.3 Papers

C.J. Brouckaert, T Ridgeway, and C.A. Buckley , *A mathematical analysis of the drying of faeces in a urine diversion toilet – sensitivity analysis*, Third International Conference on Ecological Sanitation, Durban, 23 – 26 May 2005

M. Guness, S. Jackson, N. Rodda, M. Smith, D. Trotter, N. Macleod and C. Buckley, *Impact of buried urine diversion waste on environmental quality and plant growth*, Third International Conference on Ecological Sanitation, Durban, 23 – 26 May 2005

T Gounden, W Pfaff, N Macleod, CA Buckley, *Provision of Free Sustainable Basic Sanitation: The Durban Experience*, 32nd WEDC International Conference, Colombo, Sri Lanka, 2006

N. Rodda, W. Pfaff, T. Gounden, C. Buckley, *Health risk assessment of the operation and maintenance of a urine diversion toilet*, WISA Biennial Conference and Exhibition, Durban, 21-25 May 2006

C Nwaneri, S Mkhize, K Foxon, N Rodda and C Buckley, *Application of a protocol for the characterisation of the contents of a urine diversion toilet vault*, WISA Biennial Conference and Exhibition, Durban, 21-25 May 2006

JN Bhagwan, D Still, CA Buckley, KM Foxon, *On-site dry sanitation – when last did we look down the pits?*, World Toilet Summit 2007, New Delhi, India, 31st October to 3rd November 2007.

Other related WRC reports available:

Scientific support for the design and operation of ventilated improved pit latrines (VIPS) and the efficacy of pit latrine additives.

Buckley CA; Foxon KM; Brouckaert CJ; Rodda N; Nwaneri C; Balboni E; Couderc A; Magagna D

This project proposed to undertake field and laboratory investigations of VIPs and their contents in and around the eThekwini Municipal area in order to understand the conditions found in the pits and to propose design and operating practice that will extend the life of pits. The standard VIP design was found to be effective for the accumulation and degradation of faecal sludge. However, it was observed that the ability of a VIP latrine to function as an improved sanitation system i.e. to provide hygienic separation of human waste from human contact, to limit the transport of pathogens from human waste by vectors such as rodents and insects, to reduce nuisance associated with flies and odour and to preserve the dignity of the user, was compromised in a number of respects due to poor construction, bad user habits, and during pit emptying operations. It was observed that poor construction or lack of maintenance often resulted in essential features of the VIP latrine design being missing or damaged, including vent-pipes, flyscreens, pedestal lids, doors and back plates. Under these conditions, there were usually problems with odours and flies. Bad user habits resulted in rapid accumulation of pit contents, particularly when poorly degradable anal cleansing material such as magazines, plastic bags or stones were used. In many cases pit latrines appeared to double as waste disposal sites, resulting rapid filling of the latrines.

During pit emptying operations, significant risk of infection of workers and community members with human pathogens originating from the pit contents is expected due to difficulties in removing pit latrine contents and separating faecal sludge from solid waste. Examination of face masks worn by workers engaged in emptying pit latrines and screening the exhumed contents indicated that viable ova of a number of helminth species including Ascaris, Trichuris and Taenia spp (roundworm, whipworm and tape worm) may be present in pit latrine contents and that these constitute a significant health risk to workers involved in handling pit latrine contents, and community members who have access to the area around the pit latrine during and after pit emptying operations.

Finally, commercial pit latrine additives were found to contain large concentrations of active micro-organisms with the ability to utilise organic substrates. However, neither the field trials, nor the laboratory trials provided evidence that the use of these products could result in a significant reduction in either mass or volume of pit latrine contents.

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