HEALTH RISK ASSESSMENT OF THE OPERATION AND MAINTANANCE OF URINE DIVERSION TOILETS IN eTHEKWINI MUNICIPALITY

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Abstract

The eThekwini Municipality (Durban, South Africa) has adopted urine diversion (UD) dry toilets for the provision of basic, safe, dignified and sustainable sanitation in rural areas in the greater Durban region. This decision was driven by shortcomings of ventilated improved pit latrines (VIPs) in many of the areas administered by the Municipality. However, due to the urgency of the need for this intervention, it was not possible to complete scientific evaluation of UD as a sanitation solution in the greater Durban context prior to its implementation. A joint scoping workshop was held by the Pollution Research Group and eThekwini Water and Sanitation, to identify data gaps and to design specific studies to address these. One question addressed was whether quantitative microbial risk assessment could be applied productively as a decision-making tool in guiding policy decisions for sanitation implementation and community education. Studies were initiated by the Pollution Research Group to better define the extent of direct exposure of waste handlers and incidental exposure of household members to UD waste. Data generated from studies of pathogen prevalence in UD wastes, and observational studies on community practices in the operation and maintenance of the toilets, were used to develop a more regionally relevant quantitative risk assessment of the operation and maintenance of urine diversion toilets. Most likely exposure scenarios had already been defined as part of the initial PRG/eThekwini scoping workshop. The conventional steps of hazard identification, dose-response assessment, exposure assessment and risk characterisation were followed to develop probability-based distributions of risk of infection by Ascaris for the community sections identified as being most at risk. The risk estimates developed were compared to recognised guidelines for acceptable risk of infection. The effect of introducing barriers to exposure (hence to infection) on risk were evaluated. Using only two barriers to exposure (wearing gloves and washing after waste handling), it was shown that risk could be reduced to near aceptable levels.

INTRODUCTION

South Africa, along with many other countries is faced with the dilemma of inadequate disposal of excreta-related human wastes into the environment. The World Health Organisation (WHO) estimates that 80% of all deaths in developing countries are related to water- and excreta-related diseases (1). 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 (2).

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 (3). 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 determined 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. *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 (4). *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 (5).

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. 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 (6). Chale-Matsau (7) 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 (8).These ailments affect humans and animals, and are directly linked to faecal contamination of the home environment (9). 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 reasons for selection of UD toilets over ventilated improved pit latrines (VIPs) as on-site sanitation provision by eThekwini Municipality has been presented in a number of sources (10). 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 and 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 paper describes efforts to identify and quantify the major health risks associated with UD toilets, specifically as implemented by eThekwini Municipality.

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 (11). 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. The World Health Organisation has issued guidelines for the reuse of wastewater and excreta in agriculture and aquaculture (11), 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).

The risk assessment framework as adopted by the USEPA, and recognised as required as part of a QMRA, 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 (11). 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 (12). 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 (13). 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) (12). 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 risk, 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 (11).

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 (14). 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 (15). 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 here 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.

Materials and Methods

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 and by students. 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 site visits. 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 (16). 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 UD toilets. A list of questions was formulated prior to site visits, based on theoretical exposure routes and amounts. The questions 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 likely to be 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, (17) 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 (18). 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 (17) :

$$\mathbf{P_{inf} = 1 - exp(-rd)} \qquad [1]$$

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.

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

$$\mathbf{P_{yearly} = 1-(1-P_{inf})^n} \qquad [2]$$

Where

n is the number of exposure events in one year (17).

Results from the field study of *Ascaris* ova in spilled waste and on handlers' hands were corrected for approximately 75% percentage recovery (16). 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 (19). The sampled input values are then used in as input to the model equation to yield a distribution of output values rather than a single output value. The benefit 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 excess infections per year, or 10^{-4} (17). The impact of various interventions which would provide a barrier between the hazard *(Ascaris* ova) and the exposed individual (waste handler) was also modelled.

Results and Discussion

A total of 25 questionnaires were completed during the field visit to Zwelibomvu. Responses are presented in Table 1. 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).

Table 1: Toilet usage by the Zwelibomvu community members.

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

However, this is not conclusive since at the time of interview most community members had no experience with emptying, and outside assistance was used in empting toilets in this study. 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.

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 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.

Table 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%

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 3) and spilled material left on the ground (Table 4) were also obtained. Spilled material was covered with sand in some instance. This is reflected in the data set as absent values. These data sets were used to formulate the input distributions for risk modelling.

Table 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

Toilet No.	Gloves before (g)	Gloves after (g)	Material left on gloves (g)	Emptier	Glove No.
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
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 subject to the same constraints regarding true independence of samples as noted in the footnote to Table 3. 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: 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

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 1 shows the distributions fit to three inputs. Figure 1A shows the distribution of ova in waste as sampled from UD toilet vaults; Figure 1B shows the distribution of waste material on handlers' hands; Figure 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.

Considering Figure 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 were 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 cases measured, 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 1B and 1C show similar representations, but use different mathematical forms to model their probability distributions.

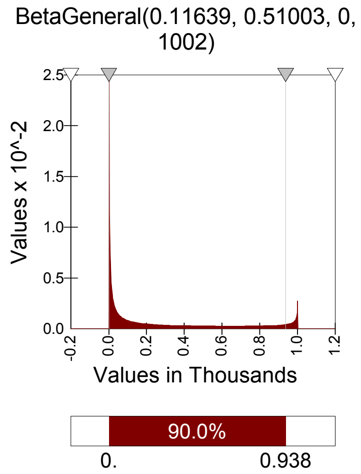

Fig 1A: Distribution of ova/g in waste sampled from UD vaults

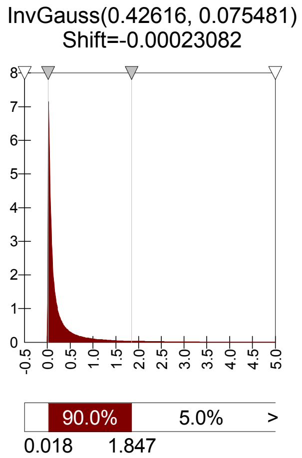

Fig 1B: Distribution of waste material on handlers' hands (g)

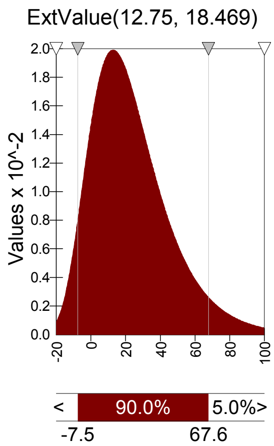

Fig 1C: Distribution of spilled material left on the ground (g) after waste burial.

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 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 (19).

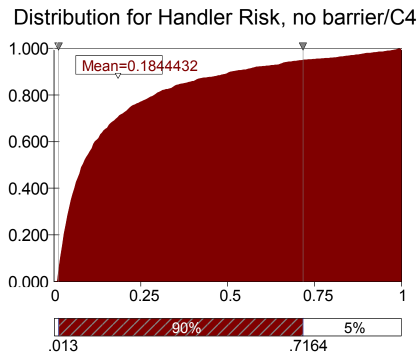

Figure 2: Cumulative frequency distribution of risks (without a barrier) to waste handlers based on waste left on hands.

Examples of output distributions are given in Figures 2 and 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 Figure 1 represents the frequency at each point on the y-axis while Figure 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 Figure 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 Figure 3.

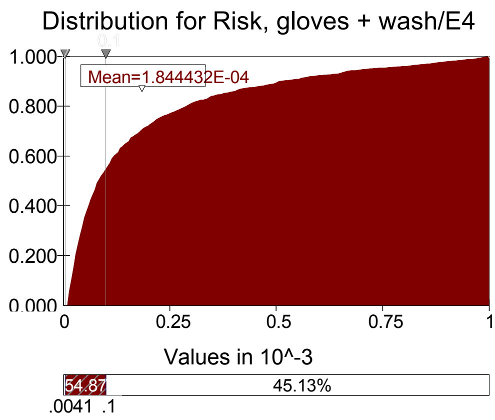

Figure 3: Cumulative frequency distribution of risks to waste handlers with two barriers (washing hands and wearing gloves).

The value of this representation can be seen in Figure 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 $\leq 10^{-4}$ 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.

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 (15). 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 that several simple interventions, 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.

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