Chapter 7

Management Practices Regarding Sewage Sludge Use in Agricultural Land

7.1 Introduction

The preceding sections have revealed the types of microorganisms found in sludge, their potential to persist in soil and crops as well as the risk associated with this persistence. This section focuses on managing the risk through appropriate management practices.

This chapter sought to indicate that if farmers adhere to the regulations stipulated regarding application of sewage sludge to agricultural land, application of sewage sludge should not present a risk to food safety. This would ensure that noxious pathogens such as *E.coli* and *Salmonella* spp would not be transferred into the food chain when using sewage sludge in selected agricultural practices.

7.2 International Trends Regarding Microbiological Sludge Quality

The US Part 503, subpart D pathogen reduction requirements for sewage sludge are divided into two categories, namely Class A and Class B. The implicit goal of the Class A requirements is to reduce the pathogens in sewage sludge (including enteric viruses, pathogenic bacteria and helminth ova) to below detectable levels. The goal of Class B requirements is to reduce pathogens in sewage sludge to levels that are unlikely to pose a threat to public health and the environment. Another category, exceptional quality (EQ) refers to sewage sludge that has met the Part 503 pollutant concentration limits. While Both A and B have site restrictions, EQ may be land applied without site restrictions (EPA, 1999).

Mexico adopted the US guidelines, with a few modifications to suite their environment and sludge quality (Jimenez *et al*., 2003). They use similar limits for heavy metals and Faecal coliforms and modified the limits for *Salmonella* spp and helminth ova (Jimenez *et al*., 2003).

In Australia, regulatory responsibility is carried out by individual states. Recently, the national guidelines (National Water Quality management Strategy (NWQMS): *Draft Guidelines for Sewage Management – biosolids Management*) have been drafted. These draft guidelines define three pathogen grades (P1, P2 and P3), which are based on prescribed treatment processes and microbiological standards. Vector attraction reduction measures are also detailed.

Grade P1 biosolids are considered suitable for unrestricted use, and grades P2 and P3 have increasing degrees of restrictions (Reid, 2003). The P1 grade includes microbiological criteria of <1 *Salmonella* per 50 grams dw and <100 *E.coli* (or thermotolerant coliforms) per gram dw. The microbiological standards for grade P2 are <10 *Salmonella* per 50 grams dw and <1000 *E.coli* (thermotolerant coliforms) per gram dw (Reid, 2003).

In South Africa, sewage sludge is classified into three types, namely A, B and C. This classification is based on the decreasing order of potential to cause odour nuisances and fly breeding as well as to transmit pathogenic organisms to humans and the environment (WRC, 1997). There is an additional type D, which is similar in hygienic quality to Type C. However, as Type D is produced for unrestricted use, the metal and inorganic content are limited to acceptable low levels.

Sewage sludge generally contains a number of pathogenic microorganisms (as indicated in Chapters 2 and 3). As it is impossible to analyse for all pathogenic organisms, only the numbers of *Ascaris* ova, *Salmonella* spp and *Faecal coliforms* are included in the analysis as indicator organisms for determining hygienic quality of Type C and type D sludge.

7.3 Factors that can Influence Sludge Management Practice in South Africa

There are a number of factors that affect the South African population and need to be taken into consideration to ensure adequate protection of human health with regard to sewage sludge use. These include the following:

i Compromised Immune Systems

A large number of South Africans are immuno-compromised as a result of the high incidents of HIV/AIDS, which translates into diverse disease profiles such as cholera, tuberculosis and more recently meningitis. Cancer patients, as a result of the treatment they receive, tend to have suppressed immune systems. Other groups with weak immune systems include children and the elderly. Appropriate management of land application of sewage sludge has to place these individuals into consideration.

ii Poverty and Unemployment

Large areas in South Africa are rural with the majority of people living in these areas being unemployed and consequently living below the poverty line (Parliamentary Bulletin, 1996). Due to limited skills and illiteracy of a large fraction of the population in the country, the rate of unemployment has increased in recent years. These populations have to be taken into consideration when formulating management practice for land application of sewage sludge. Sludge producers and farmers should communicate at a level so that communities will comprehend the risks and benefits of sludge use.

iii Population density

There is an increase in population size as a result of social behaviours, religions, teenage pregnancies and immigration particularly from neighbouring countries. There is also a tendency for people from rural areas to move to cities for an improved quality of life, resulting in an upsurge of urbanization, especially in Provinces with better socio-economic status such as Gauteng, Western Cape and KwaZulu-Natal. This resulted in dense informal settlements with limited hygiene practices. Sewage sludges from these areas are likely to have high incidence of pathogens (Chapter 3).

iv Sparse Sanitation

Adequate sanitation in South Africa is still limited to cities, with the majority of people living in rural areas having no access to sanitation. People in these communities rely on surface water or water from wells for all household activities including drinking, bathing and cooking. If sludge is not adequately treated, runoff from the land to which sewage sludge is applied could lead to contaminated wells, and eventually infecting the waters from which these communities drink.

v Cultural diversity

South Africa is home for a number of diverse cultures. Some groups have developed a habit of deliberately ingesting soil, a practice that has to be taken into consideration with regard to using sewage sludge for soil amendment. If adequately treated sludge is used, the chances of individuals ingesting soil to be infected will be reduced or eliminated. Management practice may also prohibit soil ingestion in these areas through warnings.

vi Climatic conditions

The survival of microorganisms depends on the surrounding temperature and humidity conditions. South Africa is a semi-arid country. The survival of and the potential infection of microorganims in sludge will be reduced by the high ultra-violet radiation and desiccation, as most microorganisms will not proliferate under these conditions.

vii Soil structure

Agricultural land in South Africa are carbon depleted in some areas as a result of high microbial activity. As a result, the number of pathogens from humans sources added to soil from sewage sludge will be relatively small compared with the densities of pathogens present in soil. Thus introduced pathogens into soil have a minimal chance of survival as a result of competition (Apedaile, 2001; Forcier, 2002).

7.4 Exposure pathways

The U.S EPA used various risk assessment procedures to develop exposure pathways to establish the risk factor to humans and the environment (Table 7.1). The risk assessment section discussed in Chapter 6 has demonstrated the possibility of infection through some of these pathways if inadequately treated sludge is used in agricultural land. An effective management plan is necessary to protect the public from infection through these pathways. Pathways 1, 2, 3, 11 and 13 (Table 7.1) are of particular concern regarding human health safety.

Risk is defined as follows:

Risk = Hazard X Probability of infection

As shown in chapter 6, the risk of infection regarding sewage sludge use is regarded as acceptable if 1 in 10 000 ($1:10^4$) infections occurs per year (Haas, 1996). Models computed in this section, have shown that the risk of infection from contaminated crops become reduced as the period between application and harvest is increased.

Table 7.1 Exposure pathways for land applied sludge (WRC, 1997)

No.	Pathway	Description
1	Sludge-Soil Plant-Human	Consumers in regions heavily affected by spreading of sludge
2	Sludge-Soil Plant Human	Farmland converted to residential home garden five years after reaching maximum sludge application
3	Sludge-Soil Human	Farmland converted to residential use five years after reaching maximum sludge application with children ingesting sludge-amended soil
4	Sludge-Soil-Plant-Animal-Human	Households producing a major portion of their dietary consumption of animal products on sludge-amended soil
5	Sludge-Soil-Plant-Human	Households consuming livestock that ingest sludge-amended soil
6	Sludge-Soil-Plant-Animal	Livestock ingesting food or feed crop grown in sludge-amended soil
7	Sludge-Soil-Animal	Grazing livestock ingesting sludge/soil
8	Sludge-Soil-Plant	Crops grown on sludge-amended soil
9	Sludge-Soil-Soil Biota	Soil biota living in sludge-amended soil
10	Sludge-Soil-Soil Biota-Biota Predator	Animals eating soil living in sludge amended soil
11	Sludge-Soil-Airborne Dust-Humans	Tractor operator exposed to dust from sludge-amended soil
12	Sludge-Soil-Surface Water/Fish-Humans	Humans eating fish and drinking water from watersheds draining sludge-amended soils
13	Sludge-Soil-Air-Human	Humans breathing fumes from any volatile pollutants in sludge
14	Sludge-Soil-Groundwater-Human	Humans drinking water from wells surrounded by sludge-amended soils

7.5 Ranking of the Exposure Pathways for South African Conditions

Both the healthy individuals and those with compromised immune systems need consideration. Healthy individuals are however less susceptible to infection. People closely affected by the agricultural sludge application are the farm family, as they live on the farm, and people living close to such farms (EPA, 2003).

In chapter 6, it was shown that the ingestion of crops grown in sewage-amended soil may pose minimal probability of infection (pathways 1,2, 4, 6, 8), as a result of the advantageous climatic conditions. Thus, adequately treated sewage sludge is less likely to pose any unacceptable risk with regard to exposure pathways for both the healthy and the immuno-compromised individuals, as the pathogen load in this sludge is expected to be minimal. Safety for using sludge can be enhanced by following the recommendations regarding its application (WRC, 1997). The restrictions require that sludge is mixed or covered with soil (WRC, 1997), reducing the pathogen load per area as a result of dilution.

Sludge use is regarded as yielding an unacceptable exposure if the risk of infection or consequent is greater than 1: 10^4 (Haas, 1996). For instance if sewage sludge use result in 1:10 deaths or acute infections leading to disease profiles such as hemolytic uremia, the risk is unacceptable. The probability of such infection is high (Table 7.2). If sludge use result in sporadic ailments or occasional symptoms, the probability of infection does not pose an unacceptable risk (Table 7.2).

Table 7.2 Generic risk rating matrix based on human health. Numbers 1 to 10 indicate the probability of a hazard occurring

Hazard	**Probability of hazard occurring**					
Loss of life	10	8	6	4	2	1
Acute illness	8	6	4	2	1	0
Chronic illness	6	4	2	1	0	0
Sporadic ailments	4	2	1	0	0	0
Occasional symptoms	4	2	1	0	0	0
No effect	0	0	0	0	0	0
The risk	$1:10^1$	$1:10^2$	$1:10^3$	**$1:10^4$**	**$1:10^5$**	**$1:10^6$**

If type A or B sludges are used, the probability of infection may be increased. Tables 7.3 and 7.4 provides the risk ranking for both healthy and immuno-suppressed individuals respectively, with regard to application of the three sludge types. Individuals with weakened immune systems present a high probability of infection. For this reason, the ranking was quantified to reflect high probability of infection when using type A and type B sludges compared to using type C or D. This will be a problem, particularly for exposed crops such as root crops, including carrots and potatoes. However these risks can easily be managed by prohibiting the use of type A and B wastewater sludge on such vegetable types and also on public parks or recreational facilities.

Some members of the population may be exposed to multiple pathways (Harrison, 1999). For instance, some adults and children who have a habit of ingesting soil, may be exposed to pathway 3 in addition to other exposure pathways, while this may not be the case in adults who do not practice geophagia in their cultures (Hunter, 1993). The concentration of pathogens in sludge-amended agricultural soil can be reduced by mixing the sludge and soil properly (effecting a dilution). If sludge is applied during warm summer days, a rapid pathogen die-off can be encouraged such that soil ingestion would not lead to serious infections (pathway 3, 7).

Some pathogens are capable of being air borne, often influenced by windy dry days. Farm workers are at the risk of inhaling dust borne pathogens during application, which can result in infection of the respiratory tract. This exposure can be prevented by ensuring that each farm worker is provided with a protective clothing such as a mask capable of covering both the nostril and mouth area, during sludge application. People neighbouring the farms can be protected from aerosols by irrigating the agricultural land following sludge application (Apedaile, 2001). Also, wetting the treated dry sludge prior application may reduce emission of bio-aerosols. This would ensure that few particles are suspended in the air (pathway 11 and 13).

Pathogens in the soil can enter a water body through runoff and erosion. However, the concentration of pathogens in the leachate from agricultural land may be diluted in the watersheds/groundwater system before reaching a nearby well used for drinking (EPA, 2003). Regular monitoring of such water bodies will ensure that the number of pathogens present in such water is kept at acceptable levels (pathway 12 and 14), such that these waters would not pose a health risk for rural communities who using the resource.

Ecological receptors are also exposed to contamination through ingestion of terrestrial or aquatic food items. Their food chain include vegetation, soil and prey items in their diet that they obtain from the farm field where sewage sludge is applied (EPA, 2003). These receptors include beef or diary cattle raised by the farm family. Protecting these receptors will ensure that humans feeding on their products (such as meat or milk) are protected. However, as the pathway between sludge and the ecological receptor is often long (4,5, 6, 9, 10 and 12), pathogen load may well be reduced to such an extent that the risk is negligible. Human enteric pathogens such as *Salmonella* spp are capable of surviving in warm-blooded animals (Jones, 1980). Humans can be protected from infection by avoiding raw products from such animals. For instance, by employing adequate cooking of meat products and effective pasteurization of milk.

Table 7.3 Risk ranking per pathway for sludge types with regard to Healthy individuals

Pathways	Type A Sludge	Type B sludge	Type C/D Sludge
1	6	4	0
2	6	4	0
3	8	6	0
4	4	2	0
5	4	2	0
6	4	2	0
7	4	2	0
8	6	4	0
9	6	4	0
10	6	4	0
11	4	2	0
12	4	2	0
13	4	2	0
14	6	4	0

Table 7.4 Risk ranking per pathway for sludge types with regard to immuno-compromised individuals (including HIV/AIDS and cancer patients)

Pathways	Type A Sludge	Type B sludge	Type C/D Sludge
1	8	6	0
2	8	6	0
3	10	8	0
4	8	6	0
5	8	6	0
6	8	6	0
7	8	6	0
8	8	6	0
9	8	6	0
10	8	6	0
11	10	8	0
12	10	8	0
13	10	8	0
14	10	8	0

7.6 Risk Management

The main challenge in risk management is not in predicting potential infection due to pathogens in sewage sludge, but being able to introduce the interventions necessary to prevent the occurrence of such infections. In most countries around the world, recycling sewage sludge to agricultural land is still regarded as the best practical environmental option. Understanding the pathways and the fates of contaminants derived from sewage sludge, and their ultimate effect on the environment and on human health is a useful tool in designing safety procedures regarding sewage sludge use in agricultural land.

Table 7.6 provides a generic presentation of probability of exposure and severity of hazard. Description of hazard severity is provided in Table 7.5.

Table 7. 5. Pathogen potential rating

Pathogen load	**Description**
High	Pathogens are present in sufficient quantities to cause concern
Medium	Pathogens could be present at levels of concern
Low	Pathogens present in sludge, but monitoring indicates minimal levels
Negligible	Pathogens not present in sufficient quantities in sludge to cause concern

Table 7.6 Risk ranking based on the probability of exposure and severity of hazard

		Probability of exposure			
		Frequent	***Reasonably probable***	***Occasional***	***Remote***
Hazard severity	***High***	Higher risk			
	Medium		Medium risk		
	Low			Lower risk	
	Negligible				Acceptable risk

The quality of sewage sludge and the probability of exposure of humans to the sludge determine the risk of contracting an infection. The sludge quality in this study is determined by the concentration of pathogens in sewage sludge. In raw (untreated) sludge, it is expected that there will be large numbers (high concentration) of disease causing pathogens. Application of such sludge would certainly pose a 'higher risk' of infection. Type B sewage sludge (WRC, 1997) could yield 'medium risk'. Types C and D are likely to yield 'lower risk' as they contain limited pathogenic organisms (WRC, 1997). As indicated in Table 7.2, the frequency of exposure and the pathogen content determines the extent of the risk of infection. This implies that if sewage sludge is properly treated prior to application to land, and the periods between applications, and between application and harvesting are managed properly, the risk of contracting infection becomes an 'acceptable risk'. If farmers adhere to the 8 tons/ha application and the sludge is well mixed with the soil and evenly spread, this will result in dilution of the sewage sludge. The natural die-off of the microorganism will occur (as demonstrated in Chapter 4) placing the hazard severity on the lower or negligible end.

Although there are presently no known cases of infection or illness implicating sewage sludge use in South Africa, considering the country's large population of immuno-compromised individuals as a result of the high incidence of HIV/AIDS, it is necessary to introduce advanced precautionary steps to prevent any occurrence of such infections.

Proper training in taking precautionary measures can reduce the chances of infection during sludge handling by farm workers and personnel working at the WWTPs. Continued proper management of sludge application to agricultural land will require that effective skills transfer is implemented to increase the pool of personnel knowledgeable regarding sludge use and management.

Scientific community need to work closely with sludge producers providing advise on efficient but cost effective techniques that can be used to reduce pathogen load.

Adequate sewage sludge treatment should ensure that offensive odours are not generated from the final product, reduce vector attraction and that pathogen regrowth is controlled (EPA, 1999).

Direct soil ingestion by toddlers or people who have adopted this habit represents a risk of infection for this group if sludge is inadequately treated.

Management may reduce a risk of infection by not allowing entry into the premises or by educating these individuals.

7.7 Conclusion and Recommendations

Use of untreated (raw) sludge should not be allowed on any exposed crops or root crops.

Farmers who are the recipients of sludge, have a responsibility to adhere to proposed application rates and to educate farm workers on the precautionary measures necessary for sludge handling.

For type B sludge, the period between sludge application and harvesting should be such that pathogen reduction in soil is ensured. This study has shown that significant pathogen reduction can occur in 12 weeks (3 months) following application (Chapter 4). Prolonging this period will reduce the risk of infection. EPA (1999) recommend a 14 month harvest restriction for crops that touch the soil.

Sludge application may also be done well in advance (3 months) prior to planting thus ensuring that the period between harvesting and application is long.

Access to land applied with sewage sludge may also be prohibited through fencing and/or penalty for those who do not comply. In this way, the receptor will be removed from the pathway, thus the risk of potential infection will be reduced.

Comprehensive management plan that involves regular monitoring processes and public awareness campaigns needs to be in place to ensure understanding by the public of the benefits of sewage sludge and steps taken to ensure sludge safety.

Monitoring techniques need to be well documented, rapid, less complicated, cost effective and enforced.

Sludge producers may enhance safety use by supplying information to farmers indicating the product quality and emphasizing the necessary precautions to be taken.

7. 8 References

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