Environmental contamination, prevalence and other risk factors for geohelminth infection in three informal settlements in Durban, South Africa

by

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Abstract

The effect of different types of sanitation facilities on soil contamination with geohelminth eggs and the associated risk factors were assessed in three informal settlements in Durban, South Africa. Adult members of 30 households in each settlement were interviewed to determine their knowledge, attitudes and perceptions on risk factors associated with geohelminth transmission. Two hundred soil samples were collected in each study settlement from areas considered potential sources of infection such as houses, pathways, sanitation facilities and washing areas. Of the total 600 soil samples collected, 190 (32%) were positive for geohelminth eggs with the eggs of *Ascaris lumbricoides*, *Trichuris trichiura* and *Taenia* spp. being recovered. Quarry Road West, where open defaecation was the most common (80%), sanitation coverage the lowest (11%) and lack of knowledge on geohelminth transmission high (97%), showed the highest levels of soil contamination (mean = 102.55eggs/100g). Stool samples were also collected from 135 children aged 1-16 years living in the three study areas. Children were found to be infected with *A. lumbricoides* and *T. trichiura* with prevalences of 33.4 and 6.5%, respectively and corresponding geometric mean intensities of 5.6 and 0.87eggs/g faeces. Some children (9.6%) also harboured dual infections. No hookworm or tapeworm infections were recorded. The results show a direct link between high levels of soil contamination and increased prevalence and infection rates. Indiscriminate defaecation by community members is recognised as the main contributing factor of geohelminth eggs in soil. The type and the number of toilets provided to a community greatly influence the success of a sanitation facility. In order to effectively control geohelminth transmission, health education and antihelminthic treatment need to accompany sanitation programmes in these areas.

Preface

The experimental work described in this dissertation was carried out in the School of Biological & Conservation Sciences, University of KwaZulu-Natal, Westville, from January 2009 to December 2010, under the supervision of Prof. C.C. Appleton and Prof. S. Mukaratirwa.

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any tertiary institution. Where work has been made of the work of others it is duly acknowledged in the text.

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Plagiarism Declaration

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1. Introduction

Slums have become a prominent feature of most urban areas in developing countries and the proportion of the world's population they house is increasing. In South Africa, the word "slum" is synonymous with "informal settlement" and refers to areas of high-density housing that are illegally set-up and do not conform to building regulations (Appleton et al., 2009). Of the 44 million people in South Africa, approximately 10% live in urban informal settlements and in KwaZulu-Natal province, five percent of the metropolitan area of the city of Durban is occupied by informal housing (Marx and Charlton, 2003; Richards et al., 2007). Informal settlements, being characterised by high levels of poverty, limited access to water supplies and inadequate sanitation facilities, support high levels of geohelminth transmission but this tends to go unnoticed by public-health officials (United Nations, 2004; Paterson et al., 2007; Appleton et al., 2009).

Most of the information relating to geohelminth epidemiology in South Africa is associated with the low-lying surrounding areas of Cape Town in Western Cape Province and the sub-tropical lowlands of KwaZulu-Natal province (Appleton and Gouws, 1996; Appleton et al., 1999; Fincham, 2001). The coastal plain of KwaZulu-Natal, including the city of Durban, is one of the most severely affected areas in terms of geohelminth infection (Appleton et al., 1999; Fincham, 2001). The most common geohelminth species affecting people living in informal settlements in Durban include the common roundworm (*Ascaris lumbricoides*), whipworm (*Trichuris trichiura*) and hookworm (*Necator americanus*).

Geohelminths infect the gastrointestinal tract of their host after ingestion of infective eggs or larvae, that require a period of development in the soil, occurs (Peng et al., 2003; Blaszkowska et al., 2011). For *A. lumbricoides* and *T. trichiura*, younger children (between ages of 5 and 15 years) are most frequently affected while in hookworm infections, intensities of infection are higher during adulthood. These three species usually appear together and it is common for an individual to be infected with all three species at the same time (Bethony et al., 2006). Negative effects of geohelminthiasis include impaired growth, malnutrition, decreased physical fitness, poor cognitive and intellectual development and decreased school attendance (Mngomezulu et al., 2002; Bethony et al., 2006). Poverty, malnutrition and improper hygienic practices characteristic of informal settlements aggravate the situation by causing increased geohelminth transmission (Jimenez-Cisneros and Maya-Rendon, 2007).

The first geohelminth survey in informal settlements in Durban was conducted by Elsdon-Dew and Freedman (1952) who investigated migrant labourers living in the Cato Crest settlement.

After two years, it was found that prevalences of *A. lumbricoides* and *T. trichiura* were 50.8% and 61.9% respectively. In 1994, Coutsoudis et al. conducted another survey in Besters and recorded prevalences of 59% and 61% for *A. lumbricoides* and *T. trichiura* in children aged 3-6 years. Using re-infection rates as a measure of endemicity, a recent study by Mosala (2001) found that the average prevalence of geohelminth infections in 10 informal settlements in Durban had increased from 29.6% in the four to six month follow-up after treatment with albendazole to 60.4% in the 12 month follow-up.

The type of sanitation facility available to a community has, for many years, been implicated as a contributing factor of geohelminth transmission. Although water-borne sanitation systems have been accepted as the "the standard", high building and maintenance cost makes them an unrealistic option for many informal settlements (Itchon et al., 2008). The primary objective of any sanitation system should be the containment and eventual die-off of faecal pathogens. This leads to the idea that the amount of pathogens present in the environment should be a useful indicator of the efficacy of a particular system (Muller et al., 1989; Korva, 2007; Paterson et al., 2007). However, a major problem in informal settlements is related to the non-usage of the available sanitation facility rather than to the facility itself. Therefore, the constant practice of indiscriminate defaecation by community members results in high levels of faecally contaminated soil in these areas. This fact, accompanied by the limited access to clean water, means that hand washing is uncommon, particularly in children, leading to the further spread of geohelminth eggs throughout the domestic environment.

Soil contamination with geohelminth eggs has been implicated as a major risk factor accounting for the high re-infection rates seen in people living in these areas. It is essential that the health status of these communities be monitored in order to implement appropriate control measures (Coutsoudis et al., 1994). Soil surveys for geohelminth eggs have been conducted in informal settlements around the world but mainly in Europe, Asia and other African countries, but no studies of this nature have been done in South Africa. Quantifying soil contamination with parasite eggs is essential in order to determine potential health risks (Zenner et al., 2002). The aim of the present study was to assess the effect of different types of sanitation facilities on soil contamination with geohelminth eggs in three informal settlements in Durban in an attempt to determine the effects on public health. Soil samples were collected from areas considered potential sources of infection namely houses, pathways, sanitation facilities and washing areas. A questionnaire was administered to adults in each study settlement to determine the overall knowledge, attitudes and perceptions of community members on important risk factors associated with geohelminth transmission. Stool sample examinations were carried out among

135 children aged 1-16 years from the three study settlements in an attempt to determine the association of the geohelminth species recorded and level of soil contamination with human prevalence and infection rates.

2. Literature Review

2.1 Definition and characteristics of informal settlements

Of the 44 million people in South Africa, approximately 10% live in urban informal settlements implying that South Africa houses an informal settlement population of 4.4 million people. However, in reality, this figure is likely to be much higher (Ngopulse, 2010). Informal settlements, or slums as they are commonly referred to, are not limited to South Africa and, in fact, have become prominent features of most urban areas in developing countries and are increasing in the proportion of the world's population they house. The city of Durban is located on the Eastern Coast of South Africa in the province of KwaZulu-Natal and the Durban Municipality encompasses an area of 2 300km^2 (Marx and Charlton, 2003). Five percent of the metropolitan area in this city is occupied by informal housing (Marx and Charlton, 2003; Richards et al., 2007). Informal settlements are defined as areas of high-density housing that are illegally set-up and do not conform to building regulations (Appleton et al., 2009). These areas are irregular in terms of layout with narrow streets and are often built on flood-prone, rocky land that makes the installation of basic facilities difficult (Paterson et al., 2007). Most of the houses built in these settlements comprise of a variety of materials such as metal sheeting, corrugated iron, plastic and timber and the floor is usually constructed by placing carpet or linoleum on the ground (Marx and Charlton, 2003). The population living in these settlements is predominantly African. In fact, almost 50% of the African population in the municipal area live in settlements. In typical informal settlements, 38.6% of residents are under the age of 16 making the dependency ratios high in these areas. Communities are faced with a range of problems such as overcrowding, accumulation of solid wastes and a lack of adequate water and sanitation facilities (Ngopulse, 2010). These factors all serve as potential health hazard risks to the residents with children being greatly affected (Coutsoudis et al., 1994). However, this tends to go unnoticed by public-health officials (Appleton et al., 2009).

The United Nations Development Declaration of 2000 has therefore brought informal settlements onto national and international development agendas (Huchzermeyer and Karan, 2006). In fact, one of the Millennium Development Goals is to improve the lives of 100 million slum dwellers globally by the year 2020. In reality, for now, informal settlements are here to stay and therefore an improvement in the quality of life for residents is essential (Richards et al., 2007). Although a number of policies have been put forward in an attempt to raise the standard of living in these areas, limited progress has been made (Ngopulse, 2010). The Metro Housing unit of eThekwini Municipality has officially recognised informal settlements as an inadequate form of housing and aims to exclude them from housing typology over the next 15 years, i.e. by

2015 (Marx and Charlton, 2003). To this end the eThekwini Municipality has developed an informal settlement programme that has two main objectives; firstly, the upgrading of already established settlements and secondly the development of "greenfield" land which comprises areas to which people living in informal settlements that are unsuitable for upgrading can be relocated.

2.2 Public health importance of geohelminths

Due to living conditions, informal settlements support high levels of geohelminth transmission (Appleton et al., 2009). Soil-transmitted helminths are parasitic nematodes that infect the gastro-intestinal tract of their host. The common roundworm (*Ascaris lumbricoides*), whipworm (*Trichuris trichiura*) and hookworms (*Ancylostoma duodenale* and *Necator americanus*) are of particular importance as human parasites with over a billion people world-wide being infected by at least one species (Bethony et al., 2006). In developing countries, characterised by poverty and poor sanitary conditions, human parasitism by helminths is of major public health importance (Mngomezulu et al., 2002; Jimenez-Ciseneros and Maya-Rendon, 2007; Navarro et al., 2008). Under such conditions, the prevalence of helminth infections can reach 90% (Bratton and Nesse, 1993).

Human infection results from contact with parasitic eggs or larvae present in the environment. Highest infection rates occur in tropical and sub-tropical regions as ova thrive in warm, moist conditions (de Silva et al., 2003; Bethony et al., 2006). The highest prevalence rates for *A. lumbricoides* occur in Africa, particularly in the coastal regions of West and Central Africa, China and Southeast Asia. Very high rates of infection for *T. trichiura* have been recorded in Southeast Asia, Southern India and Central Africa whereas hookworm infection is most common in Sub-Saharan Africa, Southeast Asia and South China (de Silva et al., 2003). For *T. trichiura* and *A. lumbricoides*, younger children (between ages of 5 and 15 years) are most frequently affected while in hookworm infections, intensities of infection are higher during adulthood. These three species usually appear together as it is common for an individual to be infected with all three species at the same time (Bethony et al., 2006). Negative effects of geohelminthiasis include impaired growth, malnutrition, decreased physical fitness, poor cognitive and intellectual development and decreased school attendance (Mngomezulu et al., 2002; Bethony et al., 2006). Another parasite that can negatively impact human health is the tapeworm *Taenia solium*. Although neurocysticercosis is more common in areas that practice primitive pig-rearing methods, in informal settlements where pigs are kept and animals gain access to human faeces, this could potentially be a serious public health problem (Cruz et al., 1989). Adult tapeworms are found in the small intestine where they produce eggs that are

contained in proglottids. These eggs are deposited in the environment in human faeces. Human infection results from the accidental ingestion of eggs present in soil or by the ingestion of undercooked pork (Cruz et al., 1989; Huerta et al., 2008). The most common symptom of neurocysticercosis is epilepsy (Cruz et al., 1989). Poverty, malnutrition and improper hygienic practices, characteristic of informal settlements, aggravate the situation by increasing transmission (Jimenez-Ciseneros and Maya-Rendon, 2007).

Exposure to infective nematode eggs is a key feature of transmission. Therefore the level of soil contamination and the rate of soil ingestion have a direct effect on rates of exposure to geohelminth infections (Wong and Bundy, 1990). According to Knightlinger et al. (1998) with *A. lumbricoides*, for example, a single egg develops into an adult worm. This implies that the greater the exposure, the greater the worm burden which results in these heavily infected hosts being the greatest transmitters of infection. Since morbidity and rate of transmission are directly related to worm burden, the intensity of infection is used to describe the severity of helminth infections. The morbidity caused by helminth infections can be expressed by disability-adjusted life years (DALYs) since infections cause more disability than death (Murray and Lopez, 1996). Exposure to infection depends on a child's behaviour and household environment as well as the socio-economic situation of the community, with poorest communities often harbouring the heaviest infections. Factors such as personal hygiene practices, housing conditions, employment status, geophagia and open defaecation all increase a person's risk of exposure (Knightlinger et al., 1998).

The effects of heavy worm burdens have been widely accepted as a consequence of competition for scarce financial resources which often results in limited expenditure on helminth control programmes (Mngomezulu et al., 2002). Helminth infections, in general, tend to be neglected by the medical community for three main reasons; (i) the world's poorest communities are the most affected, (ii) infections cause chronic illness and progress with few or no symptoms and (iii) their effect on education and economic development is difficult to quantify. The numerical threshold at which worms cause disease is still unknown as it is largely dependent on the nutritional status of the host (Bethony et al., 2006). Recently, however, the public health importance of helminth infections has become recognised by the international community when studies showed how such infections negatively impacted on school performance, future economic productivity (Bethony et al., 2006; Paterson et al., 2007) and that their combined disease burden could be as great as those of tuberculosis and malaria (Chan, 1997). In fact, globally, the estimated DALYs lost to *A. lumbricoides*, *T. trichiura* and hookworm infections combined, is 39 million compared to malaria which is estimated at 35.7million (WHO, 2002).

2.3 Factors affecting geohelminth distribution

Most of the information relating to geohelminth epidemiology in South Africa is associated with the low-lying surrounding areas of Cape Town in Western Cape Province and the sub-tropical lowlands of KwaZulu-Natal province (Appleton and Gouws, 1996; Appleton et al., 1999; Fincham, 2001; Saathoff et al., 2005). The coastal plain of KwaZulu-Natal is one of the most severely affected areas in terms of geohelminth infection (Appleton et al., 1999; Fincham, 2001; Saathoff et al., 2005).

In South Africa, there is very little information on the distribution of parasites relative to the country's topography. This information could be useful in planning cost-effective control programmes in rural areas. A study carried out by Appleton and Gouws (1996) showed that the prevalence of *A. lumbricoides* and *T. trichiura* decreased with increasing altitude, with the highest prevalences recorded along the coast (>80%). This study also showed that, over the altitudinal gradient of approximately 1700m in KwaZulu-Natal, climate does affect the prevalence rates of the three nematode species, *T. trichiura, A. lumbricoides* and *N. americanus*, with prevalence rates being highest closer to the coast, where the mean annual temperatures and rainfall are generally higher as well.

Soil provides a rich habitat for nematode species (McSorley, 2003). Factors such as soil moisture and relative humidity directly affect the survival of eggs in the environment (McSorley, 2003) which has direct consequences for the transmission of medically important species in a particular area. A number of factors such as run-off water, soil and wind erosion have been implicated in the dissemination of nematode eggs in soil and this has implications for the present study.

Nematodes are not actively mobile and this limits their movement in the soil particularly when conditions become unfavourable. Due to their size or mass, which can be equated to that of a silt particle, nematode eggs are generally found in the top 20cm of soil as they are too large to percolate downwards and therefore, when erosion after heavy rainfall takes place, eggs can be transported over large distances (Yeates et al., 1983; Appleton and Gouws, 1996; Cadet and Albergel, 1999). Due to their ability to withstand desiccation and other stresses when in an anhydrobiotic form and their small mass, they can also be passively carried by wind (Baujard and Martiny, 1994; Fincham, 2001) water (Waliullah, 1989) and the lateral or overland flow of surface particles following rain (Appleton and Gouws, 1996). After heavy rainfall, run-off is also likely to cause the movement of eggs from contaminated areas to the topsoil of other areas, particularly at the bottom of slopes (Appleton and Gouws, 1996).

Each species differs in their requirements for development, survival and dissemination in the soil. For example, the eggs of *A. lumbricoides* remain viable for many years, longer than those of *T. trichiura* which remain infective for only a few months (Peng et al., 2003; Appleton and Gouws, 1996). Furthermore, the transmission requirements for *N. americanus* are different to those of *T. trichiura* and *A. lumbricoides* due to the fact that this species lays thin-shelled eggs from which free-living larval stages hatch quickly. Hookworm also does not share the same epidemiological characteristics as the other two species (Appleton and Gouws, 1996). Generally, hookworm infections occur at altitudes of less than 150m above sea level in sandy soils with a low (<15%) clay content (Mabaso et al., 2003). An additional factor resulting in the further spread of eggs in the domestic environment is the passive dispersal of parasitic eggs by scavenging and coprophagous animals (Evans, 1988).

During the last two decades, the importance of Geographical Information Systems (GIS) in the prediction of parasitic diseases has been highlighted. The rationale behind this as noted by Saathoff et al. (2005), is that parasitic life-cycles involving a free-living stage or animal intermediate host are sensitive to environmental factors as opposed to other diseases where transmission relies on direct person to person contact. GIS creates a single database that includes large spatially referenced datasets involving various geographical parameters. This can direct control programmes to the affected areas by providing a means for spatial prediction.

Exposure to direct sunlight is critical for the die-off of parasitic eggs. A study conducted by Saathoff et al. (2005) showed an association between normalized-difference vegetation index (NDVI) and *A. lumbricoides* infection in rural northern KwaZulu-Natal. Thus the high levels of transmission seen in informal settlements can be attributed, partly at least, to the closely built houses which provide a shaded environment, protecting the soil from solar radiation therefore limiting evaporation. This provides an ideal habit for eggs to develop into infective stages (Appleton et al., 2009).

2.4 Risk factors associated with geohelminth transmission

2.4.1 Inadequate sanitation facilities

A basic sanitation system, safe drinking water and good hygiene practices are fundamental to the health and well-being of a community (Itchon et al., 2008). Nations and individuals around the world are faced with a range of water problems such as water scarcity and contamination, unsustainable use of groundwater and ecological degradation (Gleick, 2002). However, as Gleick (2002) points out, the heart of the world's water problems rests in the failure to provide basic sanitation and water supplies to large numbers of people and the implications for human

health that results from this failure. In fact, WHO/UNICEF (2000) estimates that every second person does not have access to adequate sanitation and one in five people lack access to safe and affordable drinking water. The majority of such affected populations live in Africa and Asia (Langergraber and Muellegger, 2005). Rapid population growth, increased urbanisation and the influx of people into cities, particularly in developing countries, have increased the numbers of people living in these areas and has resulted in increased environmental pollution (Langergraber and Muellegger, 2005; Paterson et al., 2007). Most of the current growth in cities is concentrated in peri-urban areas which often comprise high-density, low-income communities and informal settlements. The high-density housing and poor living conditions in informal settlements increases the spread of disease, making adequate sanitation facilities even more crucial than in rural communities (Paterson et al., 2007). Parasites and pathogens found in human excreta have detrimental effects on human health (Langergraber and Muellegger, 2005). The main risk involved in disease transmission is the contamination of the domestic environment with faeces. Therefore, the main objective of any sanitation system is to promote the containment and eventual die-off of faecal pathogens, in an attempt to reduce the prevalence rates of faecally-transmitted diseases in the environment (Muller et al., 1989; Korva, 2007; Paterson et al., 2007).

In most countries, the two available options to tackle sanitation problems can be described as "flush and forget" or "drop and store" (Ersey et al., 2001). Although water-borne sanitation is accepted as "the standard", high building and maintenance costs make it an unrealistic option for many developing countries, especially those with minimal resources (Itchon et al., 2008) (Itchon et al., 2008). Another factor that needs to be taken into consideration is that water-borne sanitation systems, such as the flush toilets that are currently in use around the world, are systems that deplete water resources which could otherwise be used for human consumption or other domestic activities in these areas (Itchon et al., 2008). In the last two decades, it has become clear that water is a finite resource. The ever-increasing human population results in less water being available to meet the needs of more people, this increases the competition for water and it is often the poor communities that are left without their share (UNICEF, 2006). Water supply and sanitation are invariably linked (Itchon et al., 2008). Due to the large investments costs involved in setting up centralized sewerage systems, the concept of Ecological Sanitation (EcoSan) has been introduced into rural and some peri-urban communities in an attempt to offer sustainable solutions modelled on decentralized systems (Langergraber and Muellegger, 2005). EcoSan principles view household wastes and human excreta as resources (rather than waste) that, when sanitized, can be re-used (Langergraber and Muelleger, 2005).

For these reasons, water-less toilets, such as pit latrines and urine diversion toilets, have emerged as a viable option for sanitation in many developing countries (Itchon et al., 2008). These toilets provide a more practical option for sanitation as installation and maintenance costs are less expensive, no water is required for flushing (only hand washing) and human excreta, once treated and stabilized, can be used as fertilizer. According to Paterson et al. (2007), pit latrines and urine diversion toilets are the most appropriate and affordable types of sanitation facility for low-density informal settlements and rural areas. If used properly, on-site sanitation technologies can have the same health benefits as conventional sewerage. However, in informal settlements, where space is a limiting factor, sewerage is a better option. Poor drainage and risk of ground water contamination make on-site sanitation unsuitable.

In order for any sanitation option to be successful, it has to be accepted by the community, making the choice of toilet in any particular area a critical point (Langergraber and Muellegger, 2005). Therefore, any alternative needs to be easy to maintain and as comfortable as flush toilets and must aim to raise the standard of living, for example people want indoor sanitation facilities offering comfort and privacy (Langergraber and Muellegger, 2005). Also, the condition of the available sanitation facility determines whether or not community members will use them (Muller et al., 1989). When introducing a sanitation facility to a community an important factor that needs to be considered is that decisions of community members are influenced by emotions and rationality alone may leave them unconvinced (Langergraber and Muellegger, 2005)

Improvement of sanitation facilities plays a vital role in improving public health as ineffective sanitation options will result in the dispersion of pathogens to the environment. Environmental contamination therefore serves as a useful indicator of the efficacy of a particular sanitation system and as Muller et al. (1989) noted, *'Faecal pollution of the household environment is due more to promiscuous defaecation than to poor construction or maintenance of latrines'*. These authors concluded that the distribution of *Ascaris* eggs in soil, relates more to the problem of non-usage of the latrine than to the latrine itself and suggested that if at least 20% of the population do not use the available sanitation option, the type of sanitation facility is unlikely to make any difference in environmental contamination.

Epidemiological studies have shown that improvements in sanitation are often more effective in reducing the incidence of disease than improved water supplies (Korva, 2007). Pro-poor sanitation technologies are therefore essential as they allow a greater number of people to be provided with adequate sanitation (Paterson et al., 2007). These advances are important as the consequences of inadequate sanitation systems are not limited to human suffering but also affect

a country's economy. Improvements in sanitation lead to improvements in the health and the quality of life of communities. This eventually leads to a better standard of living and increases the economic productivity of nations by reducing the estimated DALYs for faecally-transmitted diseases (Korva, 2007; Paterson et al., 2007).

2.4.2 Geophagy

Geophagy, or soil-eating as it is commonly known, is the term used to describe the deliberate ingestion of earth or soil (Abrahams and Parsons, 1996; Geissler et al., 1998). Geophagy is a world-wide phenomenon and is not restricted to a particular time period, region, race or age-group (Abrahams and Parsons, 1996). Geophagy, until recently has been synonymous with the term pica which describes a situation in which an individual consumes unsuitable substances (Allport, 2002). Humans need a variety of nutrients to stay healthy. Poorer communities have difficulty in meeting their nutritional needs and therefore they resort to consuming what would be deemed non-food substances (Allport, 2002). Geophagy originated in the tropics and is most common amongst the world's poorest communities (Abrahams and Parsons, 1996; Koç et al., 1999) and may adversely affect human health if soil is consumed in excess or inappropriately. It is dependent on a number of cultural, social, behavioural and psychological factors. Symptoms associated with geophagy include tooth abrasion, geohelminth infections, lead poisoning, anaemia, muscle weakness, sluggishness, lassitude and impaired mental function (Abrahams and Parsons, 1996; Koç et al., 1999; Allport, 2002).

Geophagy, in many societies, is an accepted practice of women and children but not adult males and it tends to decrease with age in boys but not girls (Abrahams and Parsons, 1996; Saathoff et al., 2002). According to Allport (2002), this practice, however, is not limited to women and children and in some studies, entire populations have been reported to be geophagous. This author reports on pregnant women, in particular, in many regions such as South and Central America, Africa, India and Nepal, ingesting soil. The suggestion is that due to the fact that maintaining a balanced diet is essential, many pregnant women around the world consume soil due to its assumed nutritional benefits(Allport, 2002). For example, certain clays in Africa are rich in calcium giving pregnant women up to 80% of their RDA (Recommended Daily Allowance). In other places, consuming a minimum of 20g of soil per day from clay pits and termite mounds provides women with more than 100% of the RDA for iron. Consuming a small amount of clay daily is said to relieve the symptoms of pregnancy by neutralizing stomach acid. It is also suggested that clay plays a role in removing toxins from food (Allport, 2002).

Recently, studies have been conducted to determine the possible association of geophagy and geohelminth infection (Geissler et al., 1998; Saathoff et al., 2002). Saathoff et al. (2002) reported that high proportions of children eat soil on a daily basis. Indeed soil consumption is an important risk factor for geohelminth transmission in poorer communities characterised by inadequate sanitation facilities and water supplies and areas where open defaecation is common practice. The amount and type of soil consumed and the location where the soil is collected are important factors contributing to high infection rates.

A study by Geissler et al. (1998) was conducted on Kenyan primary school children and aimed to investigate the role of geophagy in acquiring geohelminth infections, assess its consequences and its cultural context. The study showed that the most commonly eaten soil type was the surface of termite mounds which was found to be contaminated with *A. lumbricoides* eggs. Previous studies have shown that termites collect faeces (Herrick and Lal, 1996; Coe, 1997). In addition, adults and children were known to defaecate behind termite mounds (Geissler et al., 1998). A combination of these two factors could explain the high egg recovery rates from termite mounds. A positive correlation was found between the intensity of *T. trichiura* and *A. lumbricoides* infection in children and geophagy but not between hookworm infection and geophagy. This is biologically plausible as the eggs of *T.trichiura* and *A. lumbricoides* are transmitted via the faecal-oral pathway and the eggs of hookworm desiccate quickly (Geissler et al., 1998).

Saathoff et al. (2002) also investigated how socio-economic status is associated with geophagy and how the consumption of different soil types relates to geohelminth infection in rural school children in northern KwaZulu-Natal. This study also found a positive relationship between consuming soil from termite mounds and infection with *A. lumbricoides*, again highlighting geophagy as an important risk factor in the epidemiology of *A. lumbricoides* infection. Another study by Mosala (2001) on geohelminth transmission among slum-dwelling children in 10 informal settlements in Durban also found a causal relationship between geophagy and geohelminth infection. In fact, the highest intensities of re-infection were associated with geophagy.

In a study in two children's homes in Jamaica, Wong and Bundy (1990) concluded that most geohelminth infections resulted from the ingestion of contaminated soil. These authors found that the density of geohelminth eggs in the surface soil decreased over a two month period and therefore suggested that exposure to infection can be further reduced once additional soil contamination is limited by chemotherapy.

Geissler et al. (1998) and Allport (2002) suggest that the nutritional status of the individual affects the need to consume soil and therefore many people are not willing to change this habit because of the nutritional benefits they believe geophagy offers. Also, geophagy forms part of the cultural and traditional practices of many communities (Saathoff et al., 2002). Therefore, health education, which enables people to avoid negative health impacts whilst still accepting geophagy as a normal practice, is essential (Saathoff et al., 2002). Previous studies have suggested finding "safe soil", free of faecal contamination or heating the soil through baking or frying before consumption.

2.5 Recovery of geohelminth eggs from soil

2.5.1 Previous soil surveys assessing environmental contamination

Parasitic diseases affect both human and animal health (Zenner et al., 2002). Most of what is known of geohelminth epidemiology relies on the examination of stool samples from study populations. Various techniques used to recover helminth ova from faeces are available and many have also been applied to soil samples in an attempt to assess environmental contamination, an important factor in re-infection following treatment (Appleton et al., 2009). Soil is the most common reservoir for geohelminth eggs and quantifying egg loads in the soil is essential for analytical epidemiological studies to determine the potential health risks (Zenner et al., 2002). Few authors have however reported on the recovery of geohelminth egg loads in soil. Much of the work done to date focuses on the recovery of *Toxocara* eggs from soil and recovery rates vary among the different studies (Zenner et al., 2002).

The methods most frequently used to recover helminth eggs from soil are flotation techniques that rely on differences between the specific gravity (SG) of the flotation solution and the eggs (Dryden et al., 2005). According to David and Lindquist (1982), the specific gravity is defined as the ratio of the mass of an entity to the mass of an equal volume of water at 4ºC or other specified temperatures. Therefore the SG of a particular helminth egg is greatly dependant on its mass and volume which is determined by the amounts of solids and water present. These authors suggest that the flotation solution should have a specific gravity that is intermediate between the debris and eggs. However, the specific gravity must not be too high as to result in the damage or distortion of eggs (David and Lindquist, 1982). Rather it should be slightly higher than that of the heaviest egg. For example, the eggs of *Taenia* spp. have higher specific gravities than those of *Ascaris lumbricoides* due to the greater mass per unit volume, even though these eggs are smaller in size. Examples of SG for the eggs of other species of soil-transmitted helminths: *Toxocara canis* 1.09, *Toxocara cati* 1.10, *Ascaris suum* 1.13, *Trichuris*

suis 1.13, *Trichuris vulpis* 1.15 and *Taenia* sp. 1.23 (David and Lindquist, 1982). Recovery of eggs using the flotation method is affected by various other parameters in addition to the SG of the flotation solution selected, viz; sample size, degree of soil contamination, soil texture, pre-treatment and the length of the flotation period (Wong and Bundy, 1990; Zenner et al., 2002).

Various studies have been conducted in different areas in an attempt to assess environmental contamination. Tables 1.1 and 1.2 provide a review on soil studies that have been conducted in other countries, highlighting the differences in methods used in both sample collection and egg recovery and include a summary of the main findings of each study. These studies have adopted variations to one of two main methods when it comes to the collection of soil samples; either the area to be surveyed is plotted and samples collected from particular points within the specified area or more commonly, samples are randomly collected from potential transmission foci. This tends to be the more common approach as chances of egg recovery are greatly increased due to the uneven distribution of helminth eggs in soil. Most methods used to recover helminth eggs from collected samples generally make use a pre-treatment and flotation solution in attempt to separate the eggs from the soil particles. The pre-treatment and flotation solutions vary among different studies.

Table 1.1: Previous soil studies investing soil contamination with geohelminth eggs.

Study	Aims	Sampling method	Recovery method	Main Findings
Brown (1927)	Investigated the etiology of *Ascaris* infestations in and around Penonomé, a rural area in Panama.	n=13 soil samples Sweepings were made from the yard and the floor of huts. The amount of soil collected ranged from 55-565g at each sampling site.	1) The soil was mixed by shaking samples in a two quart jar. 2) One to four 10g portions were used in each isolation. Method based on Caldwells (MSS).	Generally, egg recovery rates were low with many sample collection points yielding a negative result. Of the total samples, 84.6% were positive for *Ascaris* eggs.
Muller et al. (1989)	Evaluated the Improved Latrine Programme in Mozambique using *Ascaris lumbricoides* eggs in the soil of household yards as indicators.	n= 780 soil samples (The amount of soil samples collected from each household varied from 3 to 37). Approximately 30mℓ of soil was collected from each sampling site using a core sampler.	1) Eggs were recovered by using a sequence of screening, flotation and filtration techniques. 2) Tween-40 was used as a pre-treatment solution. 3) A supersaturated $MgSO_4$ solution with 5% KI was the flotation solution used.	In 35 households, *A. lumbricoides* eggs were recovered from at least one sampling point. Of the total sites, 12% were positive. The mean rate of recovery = 2.1 to 3.7eggs/25mℓ of soil.
Chongsuvivatwong et al. (1999)	Aimed to document the level of soil contamination with helminth eggs around houses in endemic villages in Southern Thailand in both the dry and rainy seasons.	n=800 soil samples (50 households, each with four sampling sites) A 200g soil sample was collected from the top soil at each sampling site.	1) Samples were dried overnight and passed through a 150μm sieve 2) Two gram soil samples were used. 3) Sucrose solution (SG 1.2) was the flotation solution used. 4) After centrifugation, the sediment was viewed microscopically.	The eggs of *Trichuris trichiura* were the most common. The household yard showed the greatest contamination with eggs being detected in 58% of samples during the dry and 88% of samples during the rainy season. There was no significant difference in the rate of recovery between the dry and rainy seasons.

*n= sample size

Study	Aims	Sampling method	Recovery method	Main Findings
Rai et al. (2000)	Investigated the status of soil contamination with parasitic helminth eggs in Kathmandu Valley and two rural areas outside the valley.	n=156 soil samples Samples were collected from water taps, playgrounds, vegetable gardens and alongside roads. A sample of 200-250g of soil was collected from a depth of 2cm.	1) Samples were dried overnight and passed through a 150mm mesh sieve. 2) Two grams of soil were placed in a test tube. 3) Tween-20 was used as the pre-treatment solution e) Sucrose solution (SG 1.2) was the flotation solution used.	Of the total samples, 36.5% contained helminth eggs. Multiple helminth species were found in 22.8% of samples. The mean rate of recovery = 6eggs/ 2g of soil.
Hayward et al. (2006)	Aimed to determine the extent of nematode contamination in sandpits of registered pre-schools, daycare centres and kindergartens in Bloemfontein, South Africa.	n=110 soil samples Five 20g samples were taken from each sandpit (one from each corner and one from the centre). Each 20g sample was taken from two depths: the top 3cm and from a depth of 10cm. Both 10g samples were combined in the same collecting bag.	1) 100g of soil was passed through a 20 μm sieve. 2) Tween-80 was used as a pre-treatment solution. 3) Magnesium sulphate (SG 1.18) was used as a flotation solution.	Of the 22 pre-schools tested, 63.6% were contaminated. The most common species found were *Toxocara* sp (54.5%), *Ascaris lumbricoides* and *Trichuris trichiura* (22.7%).

*n= sample size

Study	Aims	Sampling method	Recovery method	Main Findings
Legesse and Gebre-Selassie (2007)	Assessed environmental contamination in Jimma, Ethiopia, using the presence of *Ascaris lumbricoides* eggs in the soil as an indicator.	n= 300 soil samples Soil samples were collectedfrom the yards of each household by scratching and sweeping the superficial layer with a sheet of iron. A sample of 200-300g of soil was collected from each sampling point.	1) Sugar flotation technique. 2) Dried soil was passed through a sieve with a mesh pore size of 250μm. 3) A NaOCl solution was used as the pre-treatment solution. 4) Concentrated saccharine solution was the flotation used.	Helminth eggs were recovered in 41.3% of soil samples. The eggs of *Ascaris lumbricoides* were found in 37.3% of samples. Other species recovered were *Trichuris trichiura* (0.7%), hookworm (1%), *Enterobius vermicularis* (2%) and *Strongyloides stercoralis* (0.3%).
Chukwuma et al. (2009)	Aimed to determine the prevalence and risk factors of geohelminth infections among school children in Ebenebe Town, Nigeria.	n= 220 soil samples Soil samples were collected from three primary schools. A sample of 20g was collected down to a depth of 2cm.	1) Five grams of each sample were combined with formal water and homogenised. 2) The suspension was passed through a wet cheese cloth. 3) Ether was then added to the filtrate. 4) After centrifugation, the sediment was viewed microscopically.	Geohelminth eggs were recovered in 53.6% of samples. Species recovered included; *Ascaris* sp. (24.0%), hookworm (25.1%) and the larvae of *Strongyloides* (9.54%).
Amadi and Uttah (2010)	Aimed to determine human contact activities with contaminated soil and the relative importance of these foci in geohelminth transmission among six communities of Abua, Nigeria.	n=595 soil samples Soil samples were collected using a quadrat that was thrown at random The top 15cm of soil in each quadrat was collected.	1) Water was added to the soil samples. 2) The samples were passed through a series of sieves with different mesh pore sizes (1000μm, 212 μm and 63μm). 3) 10% of formalin was added. 4) Eggs and larvae recovered were viewed microscopically	Of the total samples collected, 44% contained the eggs of *A. lumbricoides*, 17% the eggs of *Trichuris* sp. and hookworm eggs were found in 29% of samples.

*n= sample size

Study	Aims	Sampling method	Recovery method	Main Findings
Moura et al. (2010)	Aimed to build the data required to assess the effect of sanitation measures in two indigenous territories, Faxinal IT and Ivaí IT in Paranà, Southern Brazil.	n=243 soil samples

A 200g soil sample was collected from each site at a depth of 5cm in an area of $0.16m^2$. | Three techniques were used for each sample: 1) Baermann method (using a 30g aliquot of sample) 2) Modified method of Faust et al. (20g aliquot of soil, a zinc sulphate, SG 1.4, flotation solution was used 3) Lutz method (50g aliquot of soil) | Of the samples obtained from Faxinal and Ivaí, 75.7% and 96.2% respectively were contaminated. |
| Gyoten et al. (2010) | Studied the contamination of soil with helminth eggs in order to develop control measures for helminthiasis in primary schools in Mai Trung Commune, Northern Vietnam | n=90 soil samples

A 200g soil sample was collected from each site from the superficial soil layer (0-3cm) using a plastic pipe (6cm in diameter) | 1) Samples were dried overnight and passed through a 150μm mesh sieve 2) Two gram soil samples were used. 3) A sucrose centrifugal flotation method was used to detect helminth eggs | Of the collected samples, 12.2% were positive. *Ascaris* sp. eggs comprised 94% of the detected eggs. The numbers of *Enterobius vermicularis* and *Capilaria hepatica* eggs were low. No *Trichuris trichiura* eggs were detected. |
| Blaszkowska et al. (2011) | Looked for developmental stages of geohelminths in the samples of fields, kitchen gardens, yards and composts in rural areas of Lodz district, Poland. | n=150 soil samples

A soil sample of about 300mℓ was collected from the superficial soil layer at each sampling site. | 1) Samples were sifted through a 2mm mesh sieve. 2) 20g portions were placed in a Erlenmmayer's flask. 3) A saturated sodium nitrate solution (SG 1.3) was the flotation solution used. 4) After centrifugation, the sediment was viewed microscopically. | The highest mean density of geohelminth eggs in 100g of soil was detected in composts (44.0), then in fields (28.5) and yards (18.0). |

*n= sample size

Table 1.2: Previous soil studies investigating soil contamination with the eggs of *Toxocara* sp.

Study	Aims	Sampling method	Recovery method	Main Findings
Habluetzel (2003)	Estimated the soil contamination with *Toxocara canis* eggs in the Marche region of Italy.	n=154 soil samples Thirty four samples were collected from six public parks and 120 samples were collected from 60 farms.	1) From the collected soil sample 250g of soil was measured. 2) The sample was passed through a wide mesh sieve, rinsed with water and allowed to sediment. 3) A sugar-NaNO$_3$ solution was the flotation solution used.	Of samples collected, 24% from public parks contained the eggs of *Toxocara* sp. Rates of recovery ranged from 0.2 to 3.6eggs/100g of soil. Of the 60 farms, 52% contained *Toxocara* sp. eggs.
Gawor et al. (2008)	Indentified the environmental and personal risk factors for toxocariasis in rural and urban areas of central Poland.	n=1940 soil samples Soil samples were collected from around 80 households in rural areas and from 11 towns in urban regions. Ten gram soil samples were collected from the superficial soil layer (up to 5cm depth) at each sampling point.	1) Dried soil samples were passed through a mesh. 2) Tween-80 was the pre-treatment solution used. 3) ZnSO$_4$ (SG 1.52) was the flotation solution used.	The overall rate of soil contamination by Toxocara eggs was 21.1% in urban areas and 27.5% in rural areas.
Avcioglu and Burga (2008)	Investigated the environmental contamination of public parks in Ankara, Turkey, with *Toxocara* eggs and evaluated their seasonal prevalence.	n=259 soil samples Samples were collected from 40 public parks. A sample of 250-300g of soil was collected from a depth of 10cm.	1) A 50g subsample was used. 2) The sample was vortexed and passed through a 250μm sieve. 3) Distilled water was used as the pre-treatment solution. 4) NaCl solution (SG 1.18) was the flotation solution used.	Of the total parks, 45% were contaminated with *Toxocara canis* eggs and 15% with *Toxocara cati*. The mean rate of recovery = 2.57eggs/50g of soil.

*n= sample size

2.5.2 Comparative studies to determine the most efficient recovery method

Recovery rates vary across studies but in general, recoveries from soil samples tend to be much lower than those from faecal samples. Ultimately soil surveys aim to determine the public health implication of environmental contamination therefore the choice of recovery technique is crucial. In an attempt to determine the most efficient method of recovering ova from soil, the idea of artificially seeding soil with eggs, such that exact concentrations are known, has been investigated.

Oge and Oge (2000) carried out a study to determine the relative efficiency of the most commonly used techniques in the recovery of *Toxocara canis* eggs from soil. For this study, *T. canis* eggs were obtained from the uteri of female worms. Sand was subjected to heat sterilisation at 150ºC for 30 minutes. Fifty gram aliquots of sand were experimentally contaminated with 10, 100 and 500 unembryonated eggs, respectively and the process was repeated 10 times. Each egg density was mixed with 3mℓ of water and then artificially seeded in the sand with each sand sample being mixed thoroughly and only examined after the second day of contamination. Six different techniques, using different flotation solutions and having different specific gravities and washing steps were tested; Deumer (1984), Düwel (1984), Quinn et al. (1980), Dunsmore et al. (1984) and Kazacos (1983).

The methods by Deumer (1984), Düwel (1984), Quinn et al. (1980), Dunsmore et al. (1984), Dada (1979) and Kazacos (1983) used $ZnCl_2$-$NaCl$ (SG 1.3), $NaCl$ (SG 1.19), $MgSO_4$ (SG 1.27), $NaNO_3$ (SG 1.22), $ZnSO_4$ (SG 1.18-1.20) and $ZnSO_4$ (SG 1.20) flotation solutions, respectively. Washing steps varied, with no washing step for Deumer's method while water (Düwel, 1984), Tween 80 (Quinn et al., 1980; Dunsmore et al., 1984), NaOH (Dada, 1979) and Tween 40 (Kazacos, 1983) were used for the other methods. Similarly, re-suspension of the sediment in the flotation solution varied, with no re-suspension in two of the methods (Deumer, 1984; Düwel, 1984) while the other four methods used re-suspension (Quinn et al., 1980; Dunsmore et al., 1984; Dada, 1979; Kazacos, 1983). The method developed by Dunsmore et al. (1984) showed a significantly better egg recovery rate than the others. This study showed that egg recovery rates were higher for sandy soils than from soils that had a high clay or silt content. These authors suggest that the recovery of *T. canis* eggs is greatly improved by passing the sample through a series of sieves with decreasing mesh pore sizes, using flotation solutions of high density (preferably a SG of 1.2 or 1.3), and re-suspending the sediment in the flotation solution.

A second and very important study by Ruiz de Ybàñez et al. (2000) involved the collection of soil samples from a public park in Murcia, Spain. *Toxocara canis* eggs were obtained from canine faeces using the formal-ether concentration technique. One hundred grams of soil were artificially seeded with a 15mℓ of faecal suspension containing 280 400 eggs. Four of the most commonly used methods were used on the soil samples. The first was the Washing technique (based on Dada, 1979) where ten aliquots of 1g of soil each were weighed and transferred into 12mℓ test tubes. Nine millilitres of distilled water were added to each tube, and after being shaken for 1 minute, the tubes were centrifuged at 1500rpm for 5minutes. Once the supernatant was removed, a flotation solution, saccharose (SG 1.27) was added to make up a volume of 10ml. The mixture was shaken and transferred into five McMaster chambers, which were then examined microscopically for the presence of *T. canis* eggs. A second technique was used, based on the method by Laborde et al. (1980) which involved passing the sample through a series of sieves. In this method, ten 50g soil samples were passed through a set of three sieves with mesh pore sizes of 300µm, 120µm and 63 µm and washed using running tap water. The residue in the last sieve was washed into a 250ml container and allowed to sediment for 15minutes. After the liquid was decanted, the pellet was collected in 50mℓ test tubes to which a flotation solution, saccharose (SG 1.27) was added, before examination. A third method called the Vacuum technique was also applied to the soil samples where ten 15g soil samples were weighed and 25ml of distilled water was added. The samples were mixed for 3 minutes and then passed through a 1mm^2 nylon sieve into a Büchner funnel using a suction pump attached to a flask. The filtrate was then transferred into 50ml test tube and centrifuged at 1500rpm for 5 minutes. The supernatant was removed and the pellet was re-suspended in the saccharose (SG 1.27) flotation solution and the presence of eggs was detected using the McMaster chamber. Finally, a method adopted by the World Health Organisation was used. In this method, ten 20g samples of soil were treated with 200mℓ of 30% bleach (NaClO) in tap water and allowed to stand for 30 minutes with agitation. Three hundred and seventy five millilitres of water was added to the mixture which was shaken and allowed to sediment for 10-15 seconds. The liquid was decanted into 50mℓ test tubes and the sediment discarded. The test tubes were centrifuged for 15 minutes at 1500rpm and the pellet analysed after flotation in the same saccharose solution.

During this process, pre-treatment solutions to facilitate the separation of eggs from soil particles included: distilled water, 1% Tween 20, 0.2 M acetoacetic solution (pH 5) and 0.1 N sodium hydroxide. Flotation solutions included: saccharose (SG 1.20), saccharose (SG 1.27),

saturated sodium chloride (SG 1.20), saturated zinc sulphate (SG 1.20), magnesium sulphate (SG 1.28), magnesium sulphate plus 5% potassium iodide (SG 1.32) and sodium nitrate (SG 1.35). The results of the study showed that average egg recovery was 542.52 (99.1%) for the Washing method, 485.62 (89.43%) for the sieving method, 211.03 (38.86%) for the Vacuum technique and 207.99 (38.30%) for the WHO technique. Recovery techniques involving sieving and washing were more efficient while the most efficient flotation solution was zinc sulphate (SG 1.20).

Recovery of eggs from soil samples depends on a number of factors: environmental conditions, sampling sites, soil texture, selection of recovery method, flotation solution and type of wash (Oge and Oge, 2000). Increasing the sample size increases the probability of recovering eggs. Geohelminth eggs have a patchy or aggregated distribution in soil so it is essential that a representative sample be collected. By mixing together several samples and processing a subsample, the errors associated with this kind of distribution are minimised. Kazacos (1983) also suggested using larger amounts of soil to improve recovery rates because naturally contaminated soils tend to have low concentrations of eggs.

Ajala and Asaolu (1995) concluded that soil texture was an important variable affecting egg recovery rates. Sandy soils were suggested to be more homogenous and the larger-sized particles allowed eggs to be extracted more easily than clay soils (Ruiz de Ybàñez et al., 2000). Egg recovery rates from sandy soils were also significantly higher than from loam with clay soils having the lowest recovery rates (Ajala and Asaolu, 1995). Egg recovery rates of 100% are rare, although percentages of over 90% have been recorded. Gaspard and Schwartzbrod (1993) recorded rates of 83 and 100% for loamy and sandy soils, respectively while Dunsmore et al. (1984) recorded values of 91.4%.

3. Materials and Methods

3.1 Study area

The study was carried out between 2009 and 2010 in three informal settlements in Durban, KwaZulu-Natal, South Africa. Durban has a sub-tropical climate and is located on the coastal plain with altitudes ranging from 0-290 metres above sea level. During sampling, the mean daily mid-summer temperatures ranged between 15 and 28ºC (World Weather and Climate Information, 2011).

The type of sanitation facility available to the community influenced selection of the study settlements. Informal settlements selected were also those where community leaders gave their consent and the site was easily accessible by car. Three informal settlements were selected based on these criteria namely: Briardene (29.80'S, 31.01'E), Quarry Road West (29.80'S, 30.97'E) and Smithfield (29.79'S, 31.01'E).

The three study areas differ in their general characteristics (Table 3.1). When discussing the size of the settlement in terms of area, Smithfield (59784.6m^2) and Briardene (43885.8m^2) are larger than Quarry Road West (21022.0m^2) however Quarry Road West houses a greater number of people than the other to settlements with an estimated population size of 2500 people. Each settlement makes use of a different sanitation facility. In Briardene, flush toilets located inside the houses are used while in Smithfield, pit latrines situated a few metres from the homes are used and in Quarry Road West only eight chemical toilets are available for use by the entire community. Many household owners in Briardene have built make-shift homes or "shacks" around the main houses which are normally rented out. Since these make-shift homes are not equipped with toilets or water, tenants are forced to practice open defaecation when the main house owner is not home. In Quarry Road West, open defaecation is a common practice due to the lack of maintenance of the available toilets. Therefore, community members prefer to defaecate in the surrounding bushes or on the banks of the river running alongside the settlement. In general, younger children in Smithfield are not permitted to use the latrines, so they defaecate either alongside the latrine or on newspaper that is later discarded into the latrine. In Smithfield, no improvements in sanitation have been made in terms of the type of facility implemented since 2001. This settlement is still making use of pit latrines. However, the sanitation coverage still remains high with many houses having their own pit latrines. In Briardene and Quarry Road West, improvements in sanitation facilities have been made. In Briardene, the whole settlement has now (2011) been provided with flush toilets whereas in 2001 only part of the settlement had flush toilets. The remaining part made use of chemical

toilets and pit latrines. Sanitation coverage remains the same. Quarry Road West previously made use of pit latrines but now has been provided with chemical toilets, however, sanitation coverage still remains low.

Briardene is the only settlement provided with piped water while in Quarry Road West and Smithfield a single standpipe is available for water collection. In the latter two settlements, washing of clothing and cooking utensils is done in the vicinity of the water source as it is difficult for women to carry large amounts of water to their homes. For this reason, the water collection points in all three settlements are referred to as the washing areas in the current study. Often the tap is left running resulting in muddy soil surrounding the area. Water needed for other household activities is carried to the household and disposed of in the surrounding area resulting in damp soil around the house accompanied by an unpleasant odour. Only in Briardene are pathways between houses paved. There are no designated children's play areas in any of the study settlements. In all three areas, dogs and cats roam freely. Run-off from higher to lower ground is a constant occurrence in both Smithfield and Briardene since these settlements are built on steep slopes. Quarry Road West is the smallest of the three settlements and is built on level ground.

Table 3.1: Comparison of the general characteristics of the three selected study settlements

General characteristics										
Settlement	Altitude (metres above sea level) (Mosala, 2001)	Area (m^2)	No. of house-holds present	Estimated population size	Type of housing	Distance between houses (metres)	Type of sanitation	Sanitation Coverage (Mosala, 2001)	Water supply	Soil type (Mosala, 2001)
Briardene	45 to 85m	43885.8	303	1273	Low-cost houses	2-5	Flush toilets	80%	Piped water system	Clay mixed with dark grey shale
Quarry Road West	0m (built on level ground)	21022.0	588	2500	Make-shift homes/ shacks	0.5-2	Chemical toilets	11%	standpipe	Sandy clay and clay
Smithfield	25 to 75m	59784.6	190	1145	Make-shift homes/ shacks	1-5	Pit latrines	70%	standpipe	Shale and dark grey clay

*Chemical toilets refer to toilets using chemicals to deodorize the waste instead of piping it away (as in flush toilets) or storing it (as in pit latrines). Portable toilets are universally chemical

*Information on the number of households present and the estimated population sizes of each settlement was obtained from community health workers living in each area.

Figure 3.1: Briardene informal settlement showing (a) low-cost housing with paved walkways (b) flush-toilet located inside house (c) make-shift home built alongside the main house and (d) washing done in vicinity of household.

Figure 3.2: Quarry Road West informal settlement showing (a) the only standpipe present (b) chemical toilets located alongside the road (c) and (d) narrow spaces between closely built houses (0.5 to 2m).

Figure 3.3: Smithfield informal settlement showing (a) a pit latrine located a few metres away from the dwelling, (b), (c) and (d) illustrating the settlement's rural character.

3.2 Preparatory phase

Permission to carry out the study in each of the settlements was obtained through eThekwini Municipality staff, who contacted the council present in each study area. Meetings were held with community leaders who appointed a well-known community member to assist with the project. The aims and objectives of the study were explained to the designated community member who then explained the purpose of the study to the rest of the community. Once approval was obtained, the study proceeded.

3.2.1 Questionnaires

In each selected settlement a questionnaire was administered in Zulu to 30 households through an interview conducted by the designated community member (Appendix A). The sample size

was calculated using the equation $n=1.96^2pq/L^2$, where n=sample size, p=expected prevalence, q=1-p and L=limits of error on the prevalence and the expected prevalence was set at 80%. During the selection of households, a random sampling method was followed. The questionnaire was designed to obtain information on the overall knowledge, attitudes and perceptions of community members on the risk factors mainly associated with soil-transmitted helminths. Accompanying the questionnaire was a consent form which clearly explained the purpose of the study, included contact details of the researcher and supervisors (for any additional information that might be required) (Appendices B1 and B2). Participants were assured of the confidentiality of results and also given the choice to withdraw from the study at any stage. Only adults participated in the questionnaire. It must be noted that in Quarry Road West, although the settlement has a total of 588 households, following the council's instructions, field work was only conducted in one section consisting of 245 households and not the entire settlement.

3.3 Soil sample collection

3.3.1 Sampling design

For the collection of soil samples, a $50cm^2$ quadrat and cylindrical (15 x 6cm) core sampler were used. The sampling design used during this study was derived from previously used methods (Muller et al., 1989, Hayward et al., 2006). Each of the three study settlements varied in size, therefore a standard method, which could be applied to all three areas, was devised (Figure 3.4). This allowed for comparisons to be made between settlements and the study could also be replicated. Sampling sites where potential exposure to infective eggs might occur represented the focal point for the design to optimize the chances of egg recovery. Each settlement was visually plotted and an approximation of a house in the centre of the settlement was made. From this house, four other houses (one from each corner of the settlement), situated an equal distance away from the centre house, were selected. The average distance between the corner and centre houses varied in each settlement from 150-200 metres in both Briardene and Smithfield to 15-20 metres in Quarry Road West. Four pathways running between these houses were included. Samples were also collected around three toilets and one washing area in each settlement.
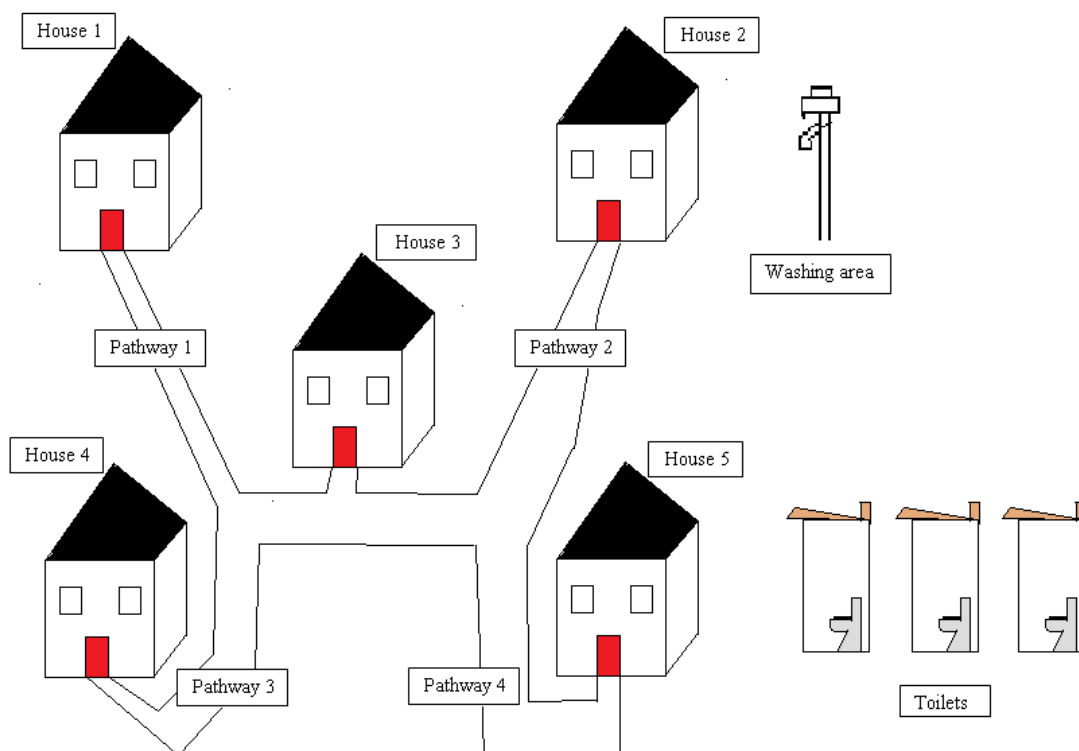
Figure 3.4: Basic soil sampling design applied to all three study settlements

At each sampling site the quadrat was placed on the ground and two soil samples were taken at each corner with the core sampler, one 1-5cm deep (the "surface" sample) and the other 10-15cm deep (the "deeper" sample). A total of eight samples was thus taken from each quadrat. Samples were placed individually in plastic Ziploc bags and stored at 4ºC.

At the houses, eight samples were taken by placing the quadrat 1-2m in front of the main entrance to the house. Eight samples were also taken from each selected pathway by placing the quadrat in the middle of the walkway at the appropriate location. In the case of toilets and washing facilities, four quadrats were placed in a north, south, east and west arrangement around each individual facility (a total of 32 samples was collected per facility). The northern direction was taken to be at the entrance of the toilet and the front of the washing area. In some areas, not all four sides of the facility were accessible. In this case, 32 samples were still collected but two quadrats, for example, may have been placed in the same direction. It must be noted that in Briardene, all toilets are located inside homes therefore during sampling, the four quadrats were placed around the outside of the house. Different houses were selected for the collection of samples from around toilets and houses in this settlement. In Quarry Road West,

the chemical toilets were situated alongside the main road. Therefore in Briardene and Smithfield, the three houses selected were next to each other closest to the main road.

3.3.2 Sample analysis

Soil sampling was conducted during the mid-summer months (January and February) while stool sampling from children was carried out during school holidays and over weekends (December and January).

3.3.2.1 Recovery of helminth ova from soil

The AmBic method, developed by D. Hawksworth and C. Archer (University of KwaZulu-Natal) was used in the recovery of helminth ova from soil samples. A brief account of this method was included in a report by Buckley et al. (2008). The method has since been modified by Archer and is being prepared for separate publication

A 20g sample of soil was weighed into 250mℓ plastic beakers and 100mℓ of ammonium bicarbonate (NH_4HCO_3) hereafter called the AmBic solution was added. Each beaker was then placed on a magnetic stirrer for 20 minutes to ensure that the entire sample was exposed to the AmBic solution in order for the eggs to dislodge from soil particles. Once the sample was thoroughly mixed, it was passed through a set of two sieves with mesh pore sizes of 100μm on (upper) and 20μm (lower) and washed using running tap water. The beaker was rinsed thoroughly and this water was filtered as well. Any remaining clumps of soil were broken up manually on the 100μm filter to ensure that all the eggs were released and could pass through to the 20μm filter. The sample remaining on the 20μm sieve was then transferred into four 15ml conical polypropylene (Bibby-Sterilyn®) centrifuge tubes. The tubes were centrifuged at 2500rpm for 3.5 minutes. After centrifugation, the supernatant was discarded. A zinc sulphate ($ZnSO_4$) flotation solution with a specific gravity (SG) of 1.3 was gradually added to the test tubes, vortexing between additions, until the 13mℓ mark was reached. The tubes were then centrifuged for 3.5 minutes at 2000rpm. The supernatants from each of the tubes were emptied onto a 20μm sieve and rinsed using running tap water. This reduced the SG to ensure that the eggs were not damaged by the zinc sulphate solution and allowed them to sediment on centrifugation. The residue was collected into a 250ml beaker and transferred into two 15ml tubes and centrifuged at 3000rpm for 3.5 minutes. The supernatant from each tube was carefully removed using a pasture pipette and the final deposits were placed onto two microscope slides with coverslips and examined under a compound microscope, counting and categorizing the helminth ova present. The eggs of *A. lumbricoides* were further classified into those that were

undeveloped, dead and potentially viable based on morphological characteristics. Egg counts were expressed as eggs/20g of soil.

3.3.2.2. Chemical solution make-up

The AmBic solution is a saturated ammonium bicarbonate (Merck chemicals) solution made by adding 119g per 1000mℓ deionised water to give a saturated solution.

Zinc sulphate ($ZnSO_4$) heptahydrate (Merck chemicals) solution was made by adding approximately 500g to 880ml of deionised water to give a specific gravity (SG) of 1.3. A hydrometer was used to check the SG which was adjusted to 1.3 by the addition of more chemical or water, depending on whether it was too high or too low. The SG of the solution facilitates the floating of *Ascaris* and other helminth ova.

3.4 Stool sample collection

3.4.1 Study population

The study population comprised 135 children aged 1-16 years from the three settlements. Before faecal samples could be taken, parents/guardians were given consent forms which clearly explained the purpose of the study, included contact details of the researcher and supervisors, assured parents and guardians of the confidentiality of results with regard to each child and that participation was voluntary (Appendices C1 and C2). Basic demographic data such as age, sex and physical address were also collected for each child. Once samples were analysed, parents and guardians were given letters referring infected children to the nearest clinic for antihelminthic treatment (Appendix D). This study aimed to target 50 children per settlement. Children falling within the specified age group living in different houses were selected but could only be included if parents/guardians gave their consent. However due to the unwillingness of parents to participate, 50 samples were only obtained in Quarry Road West. In Smithfield and Briardene 38 and 47 samples were collected, respectively.

3.4.2 Collection of stool samples

Parents or guardians assisted children with the collection of samples. Prior to collection, time was taken to explain the benefits of the study in an attempt to ensure that sample collection would be carried out correctly and that samples would be obtained from the child and nobody else. Parents were given sterile containers, wax paper and wooden applicator sticks. One sample was collected from each child. One to two drops of formalin were added to each container before they were stored at 4ºC to prevent fungal contamination.

3.4.3 Sample analysis

Intensity of infection was determined using the Kato-Katz faecal thick smear technique (Katz et al., 1972; Archer and Appleton, 2002). Duplicate 41.7mg Kato-Katz thick smears were prepared from each stool sample. A workable number of slides were prepared each time to ensure that the slides were examined within an hour of preparation to account for any hookworm eggs that might be present. Intensities of infection were measured as the number of eggs per Kato-Katz smear and expressed as the geometric mean (GM) egg output, in eggs/g (epg) faeces. According to WHO (2002) guidelines, intensities of infection for *A. lumbricoides* were expressed as light (1-4999 epg), moderate (5000-49 000 epg) and heavy ($\geq$ 50 000 epg). Similarly, *T. trichiura* infections were also expressed as light (1-999 epg), moderate (1000-9999 epg) and heavy ($\geq$ 10 000 epg). The prevalences of infection were expressed as a percentage of the total number of samples examined per settlement. Samples were examined within 48 hours of collection.

3.5 Data analysis

Descriptive statistics were used in the analysis of questionnaires. Results were expressed as means $\pm$ standard error (range) or as number of individuals (%). Data for helminth egg counts for both soil and stool samples were log transformed (count + 1) and geometric means (GM) were calculated from the transformed data. The non-parametric, Kruskal-Wallis ANOVA by Ranks and Multiple Comparison tests were used to determine differences in the total egg counts between sampling sites, soil layers and egg types recovered in soil samples among the selected informal settlements. Prevalence of geohelminth infections (%) in children was calculated as the number of children infected by a specific geohelminth species divided by the total number of children examined multiplied by 100. Intensities of infection were expressed as geometric means (eggs/g faeces) $\pm$ standard error, calculated using log transformed data. The Kruskal-Wallis ANOVA by Ranks and Multiple Comparison tests were also used to determine between-settlement differences in the prevalences and intensities of geohelminth infections. The level of significance was set at p$\leq$0.05. The highly skewed data resulting from the large number of negative samples did not allow for the statistical analysis of interaction effects. Data were analysed using the statistical package STATISTICA 6.

3.6 Ethical considerations

The study protocol was approved by the Humanities and Social Sciences Ethics Committee of the University of KwaZulu-Natal. The study protocol for soil sample collection and questionnaires was approved under reference number HSS/1001/2009 (2/12/2009) and for stool sample collection under the reference number HSS/0979/2010 (8/09/2010) (Appendix E).

4. Results

4.1 Questionnaire Analysis

During questionnaire analysis, the respondents were grouped under four main categories namely; mother, father, grandparent or other, which referred to either an uncle, aunt or guardian to children living in that household or in some cases, adults living together in a single home. In both Briardene (46.7%) and Quarry Road West (43.3%) the main respondents were mothers. In Smithfield, however, a greater number of respondents (53.3%) fell into the "other" category followed by mothers (46.7%). Low percentages of fathers were interviewed with 10% and 16.7% being recorded in Briardene and Quarry Road West respectively. In both these areas, the remaining 40% fell under the "other" category.

Table 4.1 shows that Briardene and Smithfield had the greater number of occupants per household. In some cases as many as 12 or 13 people were living in a single house. Briardene had the most children with an average of one child per household while Quarry Road West and Smithfield had fewer children with averages of 0.6±0.8 and 0.7±0.8, respectively. The overall population permanently residing in these settlements comprised mainly of adults and teenagers (older than 15 years of age).

Table 4.2 shows the extent of geophagy in the three study settlements. Overall, the reported observed geophagy was 50% in children and 46.7% in adults. An important point that must be noted is that it was made clear to the respondents that the question referred to children and adults living in that particular settlement only. For children, geophagy varied from 47% (Briardene) to 53% (Smithfield) while for adults it varied from 43% (Briardene and Smithfield) to 53% (Quarry Road West). Appealing to eat (11.1%), a craving during pregnancy (5.6%) and as a source of nutrients (2.2%) were the most common reasons given for geophagy. These reasons varied from settlement to settlement with appealing to eat ranging from 0% (Smithfield) to 23% (Quarry Road West), a craving during pregnancy from 3% (Briardene) to 7% (Quarry Road West and Smithfield) and as a source of nutrients from 0% (Quarry Road West and Smithfield) to 7% (Briardene). The sources of ingested soil were the market (20%), vicinity of household (11.1%) and shaded areas in the settlement (6.7%). Quarry Road West recorded the highest percentage of respondents for the market (30%) and shaded areas (13%) as sources of ingested soil while in Smithfield soil collected from the vicinity of households (27%) was the preferred choice.

The extent of sanitation coverage and usage is shown in Table 4.3. The sanitation facilities used were flush toilets for Briardene, chemical toilets for Quarry Road West (a total of 8 for the entire community) and pit latrines for Smithfield. Overall, 90% of the household members interviewed used the available sanitation facilities. However, the occurrence of open defaecation was high in these settlements. Community members most commonly used the bush with the percentages varying from 30% (Briardene) to 80% (Quarry Road West). The use of public toilets (1.1%) and open areas in the vicinity of households (1.1%) was rare and restricted to Briardene community members.

Table 4.4 summarises the overall knowledge and perceptions on geohelminth transmission in each study area. Overall, a high percentage (82.2%) of respondents was aware of geohelminths and this varied from 73% (Briardene) to 97% (Smithfield). Despite a high awareness, a similarly high percentage of community members did not know the routes of transmission (82.2%) of geohelminths and ways of preventing infection (83.3%). Lack of knowledge on geohelminth transmission varied from 73% (Briardene) to 97% (Quarry Road West) and that on prevention varied from 67% (Briardene) to 97% (Quarry Road West). Overall, low percentages of respondents recognised contact with soil (13.3%) and improper personal hygiene (2.2%) as risk factors for geohelminth transmission. Similarly, low percentages knew of preventive measures such as not ingesting soil (2.2%) and practising proper personal hygiene (4.4%). The main options cited for treatment of infected individuals were the clinic (21.1%), purchasing of drugs from doctors or pharmacies (16.7%) and the treatment of children at school (2.2%).

Table 4.1: Demographic data for households in Briardene, Quarry Road West and Smithfield informal settlements.

Settlement	N	Number of occupants per household		
		Mean number of children ± SE (range) (<15yrs)	Mean number of adults ± SE (range) (>15yrs)	Total occupants per household
Briardene	30	1.2±0.3 (0-6.0)	3.0±0.4 (1.0-11.0)	4.2±0.5 (1.0-13.0)
Quarry Road West	30	0.6±0.8 (0-2.0)	2.2±0.9 (1.0-5.0)	2.8±1.2 (1.0-6.0)
Smithfield	30	0.7±0.8 (0-3.0)	3.5±2.7 (1.0-11.0)	4.4±3.0 (1.0-12.0)

N= No. of households surveyed

SE = Standard Error of mean

Table 4.2: Geophagy (soil eating) in Briardene, Quarry Road West and Smithfield informal settlements.

Settlement	N	Reported observed geophagy (%)		Reasons for soil ingestion (%)			Sources of ingested soil (%)		
		in children	in adults	Appealing to eat in terms of taste and smell	A "craving" during pregnancy	As a source of nutrients	Purchased from market place	Vicinity of household	Shaded areas in the settlement
Briardene	30	14 (47)	13 (43)	3 (10)	1 (3)	2 (7)	5 (17)	1 (3)	2 (7)
Quarry Road West	30	15 (50)	16 (53)	7 (23)	2 (7)	0	9 (30)	1 (3)	4 (13)
Smithfield	30	16 (53)	13 (43)	0	2 (7)	0	4 (13)	8 (27)	0
Total	90	45 (50.0)	42 (46.7)	10 (11.1)	5 (5.6)	2 (2.2)	18 (20.0)	10 (11.1)	6 (6.7)

N = No. of households surveyed

Table 4.3: Sanitation coverage and use in Briardene, Quarry Road West and Smithfield informal settlements (only flush toilets were situated inside houses).

Settlement	N	Type of toilet present	Number of household members regularly using toilets (%)	Areas of defaecation other than the available sanitation facility (%)		
				Bushes	Public toilets	Vicinity of household (open areas)
Briardene	30	flush toilets	27 (90)	9 (30)	1 (3)	1 (3)
Quarry Road West	30	chemical toilets	27 (90)	24 (80)	0	0
Smithfield	30	pit latrines	27 (90)	10 (33)	0	0
Total	90		81 (90.0)	43 (47.8)	1 (1.1)	1 (1.1)

N = No. of households surveyed

Table 4.4: Knowledge on the transmission of geohelminths in Briardene, Quarry Road West and Smithfield informal settlements.

Settlement	N	Awareness of geohelminths (%)	Knowledge of geohelminth transmission (%)			Three main options for the treatment of infected individuals (%)			Knowledge on prevention of worm infections (%)		
			Do not know	Contact with Soil	Improper personal hygiene	Clinic	Purchase medicine from the doctor/ pharmacy	Children treated at school	Do not know	Do not ingest soil	Practice proper personal hygiene
Briardene	30	22 (73)	22 (73)	6 (20)	2 (7)	7 (23)	3 (10)	1 (3)	20 (67)	2 (7)	2 (7)
Quarry Road West	30	23 (77)	29 (97)	1 (3)	0	7 (23)	5 (17)	0	29 (97)	0	0
Smithfield	30	29 (97)	23 (77)	5 (17)	0	5 (17)	7 (23)	1 (3)	26 (87)	0	2 (7)
Total	90	74 (82.2)	74 (82.2)	12 (13.3)	2 (2.2)	19 (21.1)	15 (16.7)	2 (2.2)	75 (83.3)	2 (2.2)	4 (4.4)

N = No. of households surveyed

4.2 Recovery of helminth eggs from soil

A total of 600 soil samples (200 per settlement) was collected from the three study areas. Of the 600 samples, 190 (32%) were positive for helminth eggs. Eggs of two species of nematodes (*Ascaris lumbricoides* and *Trichuris trichiura*) and unidentified cestodes, *Taenia* spp. eggs were recovered (Figure 4.1). In the three study areas, the total number of samples positive for *A. lumbricoides*, *T. trichiura* and *Taenia* spp. were 23, 15 and 16% respectively. Figure 4.2 shows several pseudo-parasites that were commonly seen in the soil.

Figure 4.1: Three species of helminth eggs were recovered from soil samples: (a) *Taenia* spp. egg, scale bar = 100µm. The eggs of *Taenia* spp. are characterised by a striated outer shell layer and contain a hooked oncosphere, (b) undeveloped *Ascaris lumbricoides* egg showing mamillated outer shell, scale bar = 200µm, (c) *A. lumbricoides* egg containing a potentially

viable larva, scale bar = 200µm, (d) dead *A. lumbricoides* egg showing mamillated outer shell but no embryo inside, scale bar = 100µm, (e) embryonated *Trichuris trichiura* egg, scale bar = 100µm, (f) *T. trichiura* egg with larva hatching from one of the bipolar plugs that are characteristic of these eggs, scale bar = 200µm.
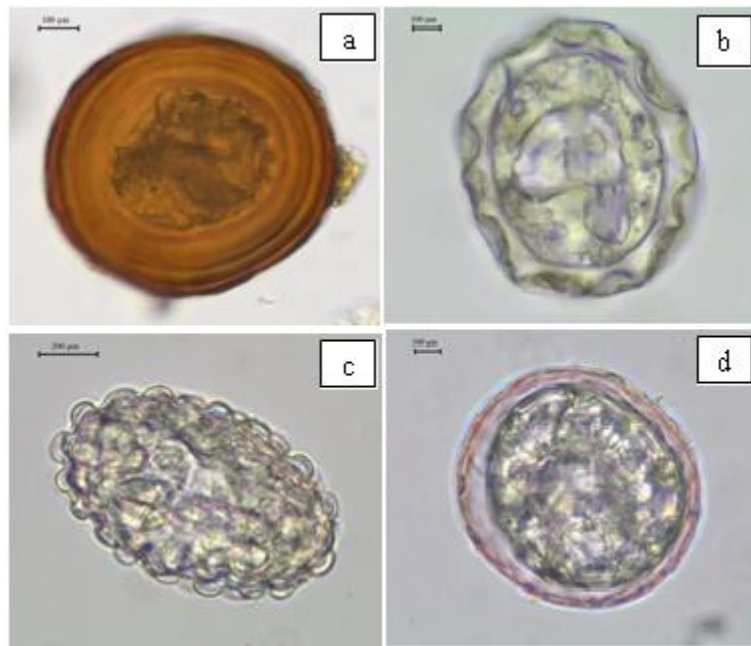
Figure 4.2: (a) - (d) artefacts or pseudo-parasites recovered from soil samples. These resemble parasite eggs however they are usually pollen, fungal or plant material. (a) scale bar = 100µm, (b) scale bar = 100µm, (c) scale bar = 200µm and (d) scale bar = 100µm.

Samples were scored as positive if a single egg of one or more of the above mentioned geohelminth species was recovered (Table 4.5). There was a significant difference between the egg types recovered from each settlement (H=19.24; p=0.0007) with *Taenia* spp. eggs being the most common. Although the difference was not statistically significant (p>0.05), greater numbers of eggs were recovered from the surface soil layer (top 5cm) than from the deeper soil layer (10-15cm deep) in all three settlements. Due to the variability in egg counts, the numbers of eggs recovered (Table 4.6) are expressed as geometric means (GM) ± standard error (eggs/20g of soil), calculated using log transformed data. In Table 4.7, egg counts are expressed

as total number of eggs recovered (eggs/80g of soil) in the surface and deeper soil layers from each sampling site in the three settlements.

Table 4.5 lists the number of positive samples for each egg type recovered from the four sampling sites in the three study settlements. The number of samples positive for helminth eggs varied in each study area. Quarry Road West yielded the greatest egg recovery rate (57%, 114/200) while Briardene (27%, 54/200) and Smithfield (11%, 22/200) yielded lower recovery rates. In all three study areas, higher numbers of positive samples were recovered around the toilets and washing areas. The highest levels of soil contamination with *A. lumbricoides* eggs occurred in Quarry Road West with undeveloped (14%, 28/200), potentially viable (21%, 42/200) and dead eggs (27%, 54/200) being recovered. This settlement also had the highest egg recoveries for both *Taenia* spp. eggs (35%, 70/200) and the eggs of *T. trichiura* (24%, 48/200). Overall soil contamination with *A. lumbricoides* eggs was relatively low in both Briardene (1.25%, 2/200) and Smithfield (4.5%, 10/200). In Briardene, the dominant species was *T. trichiura* with eggs being recovered in 19% (38/200) of the samples. Low numbers of *Taenia* spp. eggs (6%, 12/200) were recovered in this settlement. In Smithfield, the eggs of *Taenia* spp. were the most common with 7% (14/200) of the samples being positive. Low numbers of *T. trichiura* eggs (1.5%, 3/200) were also recovered.

Table 4.6 shows the geometric mean number of eggs recovered from soil samples from the four sampling sites in the three study settlements. The egg counts were low. Overall, the total numbers of eggs recovered were significantly higher (H=30.65; p=0.0001) for Quarry Road West compared to the other two settlements. However, the difference in the total number of eggs recovered between Briardene and Smithfield was not statistically significant (p>0.05). Smithfield had the lowest level of soil contamination. For Quarry Road West, the highest geometric mean number of eggs was recovered from soil samples collected around the toilets (2.35eggs/20g) followed by washing areas (1.43eggs/20g). In contrast, the washing areas recorded the highest geometric mean numbers of eggs for Briardene (0.78eggs/20g) and Smithfield (0.23eggs/20g). Although the number of eggs recovered from the washing area in Quarry Road West was higher than those recorded for the other two settlements, this was the second highest source of faecal contamination in this settlement. For both Briardene (0.39eggs/20g) and Smithfield (0.14eggs/20g) the pathways were the second highest source of faecal contamination. In all three study areas, the lowest numbers of eggs were recovered around the houses with geometric means of 0.43eggs/20g in Quarry Road West, 0.24eggs/20g in Briardene and 0.07eggs/20g in Smithfield. However, differences in the numbers of eggs recovered from the four sampling sites were not statistically significant (p>0.05).

Table 4.5: The number (%) of positive soil samples for each egg type recovered from the four sampling sites in Briardene, Quarry Road West and Smithfield informal settlements.

Site	N	Egg type recovered	Briardene	Quarry Road West	Smithfield
Toilets	96	*A. lumbricoides* (undeveloped)	0	22 (22.9)	1 (1)
		A. lumbricoides (viable)	0	32 (33.3)	1 (1)
		A. lumbricoides (dead)	1 (1.0)	33 (34.4)	4 (4.2)
		T. trichiura	19 (19.8)	13 (13.5)	1 (1)
		Taenia spp.	5 (5.2)	38 (39.6)	2 (2.1)
Washing Area	32	*A. lumbricoides* (undeveloped)	0	5 (15.6)	0
		A. lumbricoides (viable)	1 (3.1)	6 (18.8)	0
		A. lumbricoides (dead)	3 (9.4)	17 (53.1)	0
		T. trichiura	12 (37.5)	21 (65.6)	0
		Taenia spp.	6 (18.8)	7 (21.9)	8 (25.0)
Houses	40	*A. lumbricoides* (undeveloped)	0	0	0
		A. lumbricoides (viable)	1 (2.5)	3 (7.5)	0
		A. lumbricoides (dead)	1 (2.5)	2 (5.0)	0
		T. trichiura	5 (12.5)	3 (7.5)	2 (5.0)
		Taenia spp.	1 (2.5)	10 (25.0)	2 (5.0)
Pathways	32	*A. lumbricoides* (undeveloped)	0	1 (3.1)	0
		A. lumbricoides (viable)	0	1 (3.1)	1 (3.1)
		A. lumbricoides (dead)	0	2 (6.3)	2 (6.3)
		T. trichiura	2 (6.3)	11 (34.4)	0
		Taenia spp.	1 (3.1)	15 (46.9)	2 (6.3)
Total	200		54 (27)	114 (57)	22 (11)

N = Sample size per settlement

*For each individual study settlement, 200 soil samples were collected. Therefore a combined total of 600 soil samples were collected from the three informal settlements in this study.

Table 4.6: Geometric mean (± SE) number and range of *Ascaris lumbricoides, Trichuris trichiura* and *Taenia* spp. eggs recovered from soil samples (eggs/20g) from each sampling site in Briardene, Quarry Road West and Smithfield informal settlements.

Site	N	Egg type recovered	Briardene	Quarry Road West	Smithfield
Toilets	N = 96	*A. lumbricoides* (undeveloped)	0	0.39±0.11 (0-6.22)	0.01±0.01 (0-0.69)
		A. lumbricoides (viable)	0	0.77±0.15 (0-7.07)	0.01±0.01 (0-0.69)
		A. lumbricoides (dead)	0.01±0.01 (0-0.69)	0.56±0.11 (0-5.31)	0.04±0.02 (0-1.10)
		T. trichiura	0.17±0.04 (0-1.61)	0.14±0.04 (0-1.79)	0.01±0.01 (0-0.69)
		Taenia spp.	0.04±0.02 (0.0.69)	0.49±0.08 (0-3.81)	0.02±0.01 (0-1.10)
Washing Area	N = 32	*A. lumbricoides* (undeveloped)	0	0.16±0.07 (0-1.60)	0
		A. lumbricoides (viable)	0.02±0.02 (0-0.69)	0.23±0.09 (0-2.30)	0
		A. lumbricoides (dead)	0.08±0.04 (0-1.10)	0.25±0.10 (0-2.20)	0
		T. trichiura	0.41±0.11 (0-2.20)	0.16±0.06 (0-1.10)	0
		Taenia spp.	0.27±0.11 (0-2.20)	0.62±0.13 (0-2.30)	0.23±0.08(0-1.95)
Houses	N = 40	*A. lumbricoides* (undeveloped)	0	0	0
		A. lumbricoides (viable)	0.02±0.02 (0-0.69)	0.05±0.03 (0-0.69)	0
		A. lumbricoides (dead)	0.02±0.02 (0-0.69)	0.03±0.02 (0-0.69)	0
		T. trichiura	0.12±0.07 (0-1.79)	0.05±0.03 (0-0.69)	0.03±0.02 (0-0.69)
		Taenia spp.	0.02±0.02 (0-0.69)	0.29±0.08 (0-1.95)	0.03±0.02 (0-0.69)
Pathways	N = 32	*A. lumbricoides* (undeveloped)	0	0.02±0.02 (0-0.69)	0
		A. lumbricoides (viable)	0	0.02±0.02 (0-0.69)	0.02±0.02(0-0.69)
		A. lumbricoides (dead)	0	0.04±0.03 (0-0.69)	0.08±0.05(0-1.39)
		T. trichiura	0.37±0.22(0-5.69)	0.24±0.10 (0-2.77)	0
		Taenia spp.	0.02±0.02(0-0.69)	0.39±0.08 (0-1.39)	0.04±0.03(0-0.69)

N = Sample size per settlement

Figures 4.3-4.5 show the individual recovery rates of the different helminth eggs from the three settlements. Figure 4.3 shows the mean numbers of each egg type recovered from the four sampling sites in Briardene. In Briardene the difference in egg recovery rates between sampling sites was not statistically significant ($p>0.05$) but there was a significant difference in the type of egg recovered (H=25.31; p=0.00001). *T. trichiura* eggs were predominant followed by *Taenia* spp. eggs. High geometric means for *T. trichiura* eggs were recorded in the washing areas (0.41eggs/20g) and pathways (0.37eggs/20g) while for *Taenia* spp. eggs it was the washing areas (0.27eggs/20g). No undeveloped *A. lumbricoides* eggs were found in the soil and geometric means for dead and viable *A. lumbricoides* were low (0.02eggs/20g).

Figure 4.3: The mean numbers of helminth eggs (geometric means ± SE) in soil samples collected from the four sampling sites in Briardene informal settlement. Helminth eggs recovered were classified as *A. lumbricoides* (dead) (■), *A. lumbricoides* (viable) (■), *T. trichiura* (■) and *Taenia* spp. (■).

Figure 4.4 shows the mean numbers of each egg type recovered from the four sampling sites in Quarry Road West. There was no significant difference in the type of egg recovered but the total number of eggs recovered varied significantly according to sampling site (H=22.79; p=0.00001) with greatest numbers being recovered around the toilets. All egg types were recovered from each sampling site. Washing areas (0.62eggs/20g) recorded the highest geometric mean of *Taenia* spp. eggs and houses (0.29eggs/20g) the lowest. Most *T. trichiura* eggs were found

along the pathways (0.24eggs/20g). Eggs counts for undeveloped, dead and viable *A. lumbricoides* eggs were highest around the toilet with geometric means of 0.39, 0.56 and 0.77eggs/20g of soil, respectively.

Figure 4.4: The mean numbers of helminth eggs (geometric means ± SE) in soil samples collected from the four sampling sites selected in Quarry Road West informal settlement. Helminth eggs recovered were classified as *A. lumbricoides* (undeveloped) (■), *A. lumbricoides* (dead) (■), A. *lumbricoides* (viable) (■), *T. trichiura* (■) and *Taenia* spp. (■).

Figure 4.5 shows the low egg counts obtained in Smithfield informal settlement. There was no significant difference in the total number of eggs recovered from the different sampling sites (p>0.05) but differences in the types of eggs recovered were statistically significant (H=12.07; p=0.02). All egg types were found only around the toilets. The eggs of *Taenia* spp. were the most abundant followed by *A. lumbricoides* eggs. *Taenia* spp. eggs were found in all four sampling sites with the highest number recovered around the washing area (0.23eggs/20g). The eggs of *A. lumbricoides* were only recovered around the toilets and along pathways. Low *T. trichiura* egg counts were recorded around the toilets (0.01eggs/20g) and houses (0.03eggs/20g).
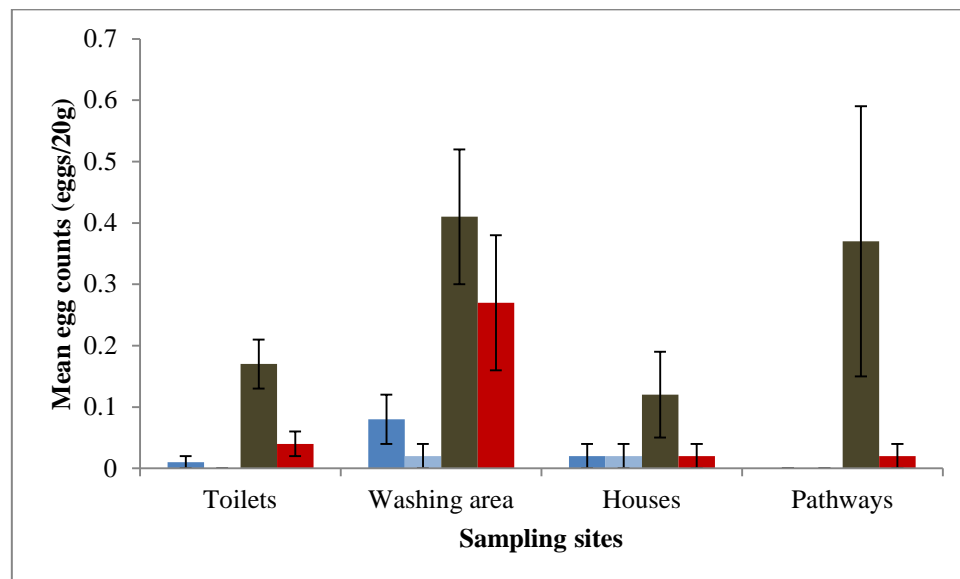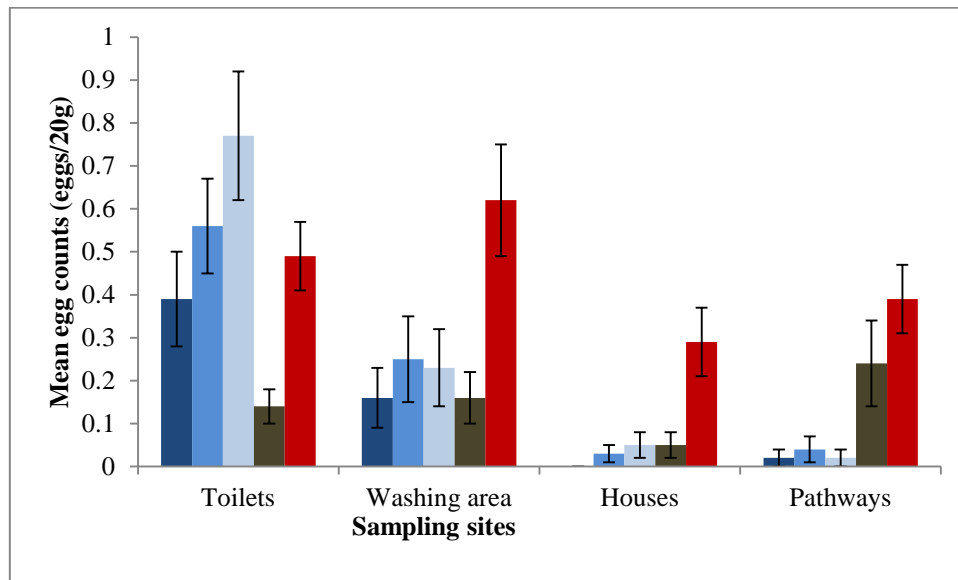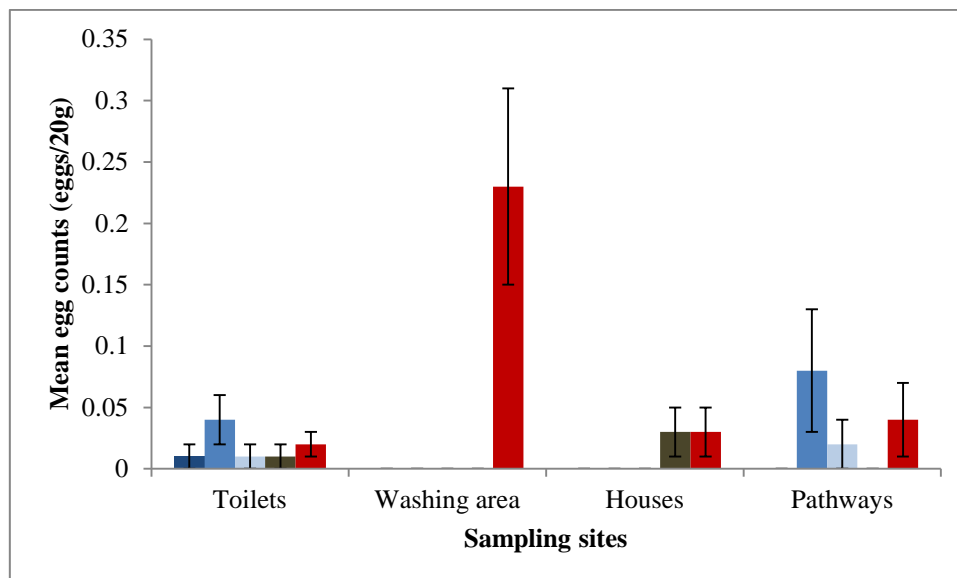
Figure 4.5: The mean numbers of helminth eggs (geometric means ± SE) in soil samples collected from the four sampling sites selected in Smithfield informal settlement. Helminth eggs recovered were classified as *A. lumbricoides* (undeveloped) (■), *A. lumbricoides* (dead) (■), A. *lumbricoides* (viable) (□), *T. trichiura* (■) and *Taenia* spp. (■).

Table 4.7 shows the number of *A. lumbricoides*, *T. trichiura* and *Taenia* spp. eggs in the surface (top 5cm) and deeper (10-15cm deep) soil layers from the four sampling sites in the three study settlements. Egg counts are given as the total number of eggs/80g of soil in the surface and deeper soil layers. The highest numbers of eggs were recovered in Quarry Road West with most samples being positive with at least one egg. In this settlement, higher numbers of *A. lumbricoides* eggs were recovered from the surface soil layers around the toilets (0 - 1953eggs/80g of soil) compared to deeper soil layers (0 – 884eggs/80g of soil). The eggs of *Taenia* spp. and *T. trichiura* followed the same trend but with lower counts than those of *A. lumbricoides*. In Briardene, total egg counts were generally low. The eggs of *T. trichiura* and *Taenia* spp. showed the greatest recovery around the washing areas. Recovery rates for the eggs of *A. lumbricoides* were low with only two samples being positive (1egg/80g of soil). Recovery rates in Smithfield were very low with no eggs being found in the majority of soil samples. In this settlement, *Taenia* spp. eggs were the most abundant and their highest recovery was 19 eggs/80g of soil from the surface soil layer around the washing area. Although, higher numbers of eggs were generally recovered from the surface rather than the deeper soil layer in all three study settlements, this difference was not statistically significant ($p > 0.05$).

Table 4.7: The total number of *A. lumbricoides*, *T. trichiura* and *Taenia* spp. eggs recovered (eggs/80g of soil) from the surface (top 5cm) and deeper (10-15cm deep) soil layers at each sampling site in Briardene, Quarry Road West and Smithfield.

Sampling site	Position of quadrat	N	Briardene						Quarry Road West						Smithfield					
			A. lumbricoides		*T. trichiura*		*Taenia* spp.		*A. lumbricoides*		*T. trichiura*		*Taenia* spp.		*A. lumbricoides*		*T. trichiura*		*Taenia* spp.	
			top	deeper	top	deeper	top	deeper	top	deeper	top	deeper	top	deeper	top	deeper	top	deeper	top	deeper
Toilet 1	North	96	0	0	0	4	2	0	193	884	1	1	10	9	0	0	0	0	0	0
	South		0	0	2	0	0	0	1953	482	5	0	29	2	0	0	0	0	2	0
	East		0	0	0	0	0	0	17	10	4	2	17	4	0	0	0	0	0	0
	West		0	0	2	3	0	0	28	2	0	0	1	0	0	0	0	0	0	0
Toilet 2	North		1	0	1	1	0	0	13	2	7	2	57	6	0	0	0	0	0	0
	South		0	0	0	0	1	0	2	0	0	0	1	2	1	0	1	0	0	0
	East		0	0	0	2	1	0	1	5	0	0	5	0	0	0	0	0	0	0
	West		0	0	0	1	0	0	1	0	0	0	2	1	0	0	0	0	0	0
Toilet 3	North		0	0	0	0	0	0	124	6	3	1	5	0	4	1	0	0	0	0
	South		0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0
	East		0	0	3	0	1	0	2	5	0	0	8	1	0	0	0	0	0	0
	West		0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0
Washing Area	North	32	3	0	0	0	0	0	0	1	4	0	2	4	0	0	0	0	0	0
	South		1	0	1	2	0	0	29	3	1	1	15	2	0	0	0	0	0	0
	East		0	0	14	5	5	0	11	3	1	1	13	8	0	0	0	0	9	3
	West		0	0	6	2	16	0	1	0	0	0	2	1	0	0	0	0	19	0
House 1		40	0	0	1	5	0	1	1	1	1	0	3	3	0	0	0	0	0	1
House 2			0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
House 3			0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0
House 4			0	0	0	1	0	0	0	0	0	0	10	2	0	0	0	0	0	0
House 5			0	1	2	1	0	0	0	1	0	0	1	4	0	0	3	0	2	0
Pathway 1		32	0	0	0	0	0	0	2	0	4	15	7	2	0	0	0	0	1	0
Pathway 2			0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
Pathway 3			0	0	0	0	0	0	1	0	2	0	4	0	3	3	0	0	0	1
Pathway 4			0	0	295	61	0	1	0	1	2	0	3	2	0	0	0	0	0	0

4.3 Geohelminth infections in children in the three informal settlements

Only the eggs of *A. lumbricoides* and *T. trichiura* were observed in the stool samples from children (Figure 4.6). The prevalences and intensities of the geohelminth infections measured in children in the three study settlements are summarised in Figures 4.7 and 4.8 respectively.
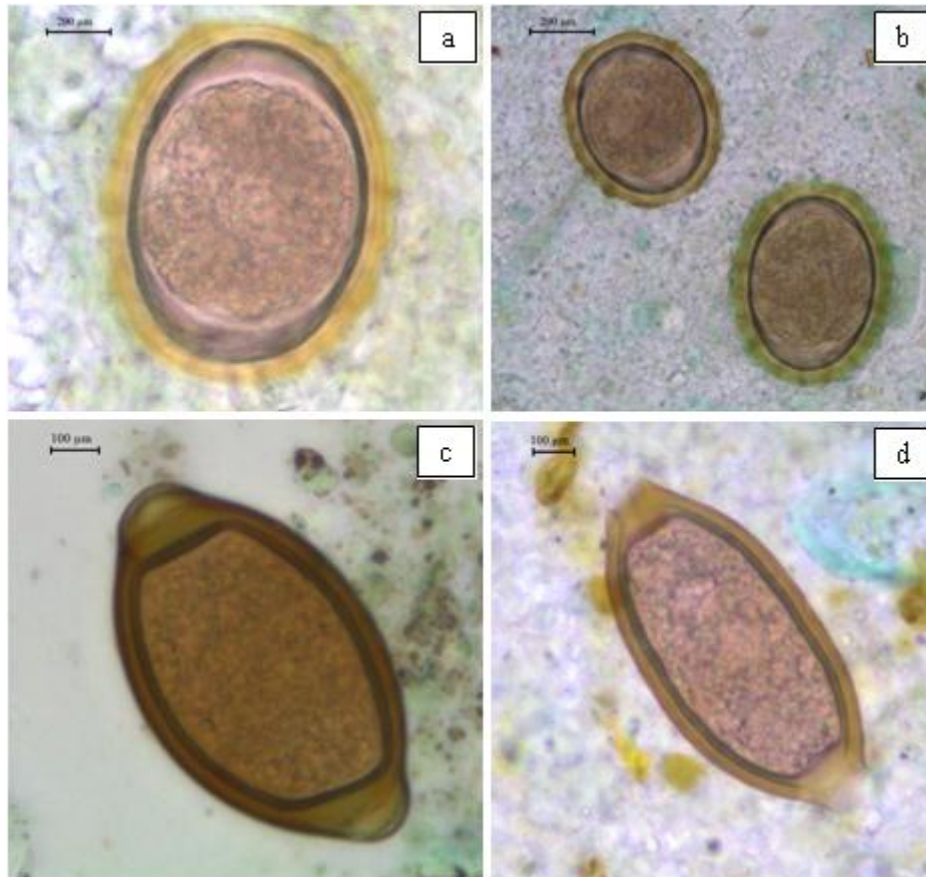
Figure 4.6: Eggs of two different helminth species were observed in stool samples from children, (a) and (b) undeveloped *Ascaris lumbricoides* eggs, scale bars = 200 μm, (c) and (d) *Trichuris trichiura* eggs, scale bars = 100μm. Eggs of both species require a period of development in the soil before they become infective.

4.3.1 Prevalences of geohelminth infections

The prevalence of *A. lumbricoides* infection was much higher than that of *T. trichiura* in all three settlements (Figure 4.7). The highest prevalences for both *A. lumbricoides* (42%) and *T. trichiura* (10%) were recorded in Quarry Road West. Quarry Road West (42%) recorded a significantly higher *A. lumbricoides* infection compared to Briardene (31.9%; p=0.02) and Smithfield (26.3%; p=0.009). However, there was no significant difference in the prevalence of *A. lumbricoides* infections between Briardene and Smithfield. The prevalence rates for *T. trichiura* were consistently low, at 4.3%-10% (mean=6.5%) and there was no significant differences in its prevalence among the studied settlements. Dual infections were highest for Quarry Road West (24%) and were much lower for Briardene (2.1%) and Smithfield (2.6%). There was no significant difference between prevalence of geohelminth infections and age or sex of children (p>0.05). No hookworm or tapeworm infections were seen.
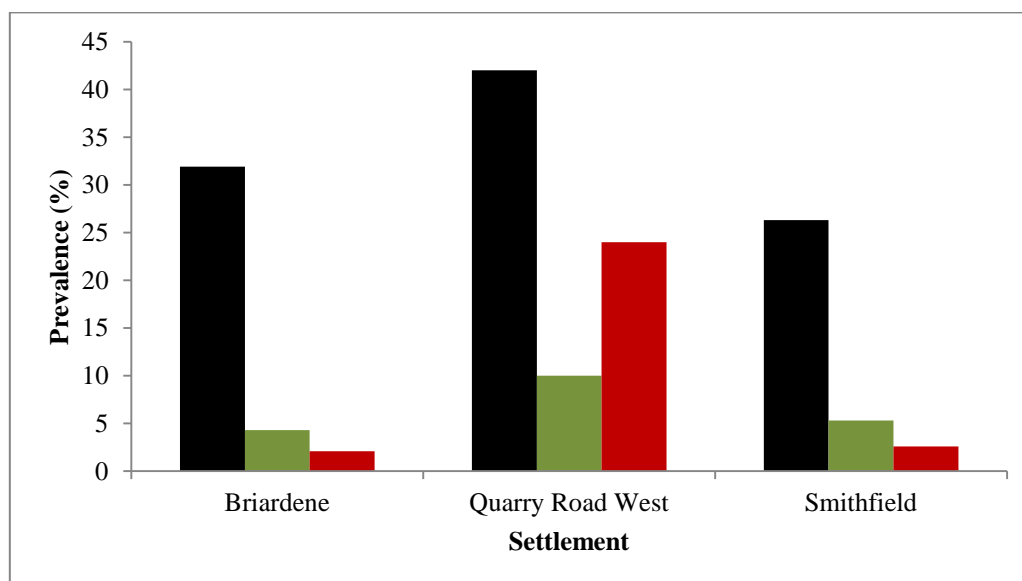
Figure 4.7: Mean geohelminth prevalences recorded in the three study settlements. *Ascaris lumbricoides* (■), *Trichuris trichiura* (■), dual infection (■).

4.3.2 Intensities of geohelminth infections

Figure 4.8 shows the intensities of *A. lumbricoides* and *T. trichiura* infections in children living in the three study settlements. In all three settlements, *T. trichiura* infections were light and children were found to be moderately infected with *A. lumbricoides*. Quarry Road West had the highest intensities of infection for both *A. lumbricoides* (6.0eggs/g) and *T. trichiura* (1.9eggs/g). The between-settlement differences in the intensities of *A. lumbricoides* (H=16.81; p=0.0002; with a geometric mean of 3.73eggs/g) and *T. trichiura* (H=16.78; p=0.0002; with a geometric mean of 0.87eggs/g) were statistically significant. Quarry Road West recorded a significantly higher intensity of *A. lumbricoides* infection compared to Briardene (p=0.007) and Smithfield (p=0.003) but however there was no significant difference between Briardene and Smithfield. The intensity of *T. trichiura* infection varied significantly (p=0.04) between Briardene and Quarry Road West but it did not differ significantly between Smithfield and Briardene or Smithfield and Quarry Road West (p>0.05). There was no significant difference between intensities of geohelminth infections and age or sex of children (p>0.05).

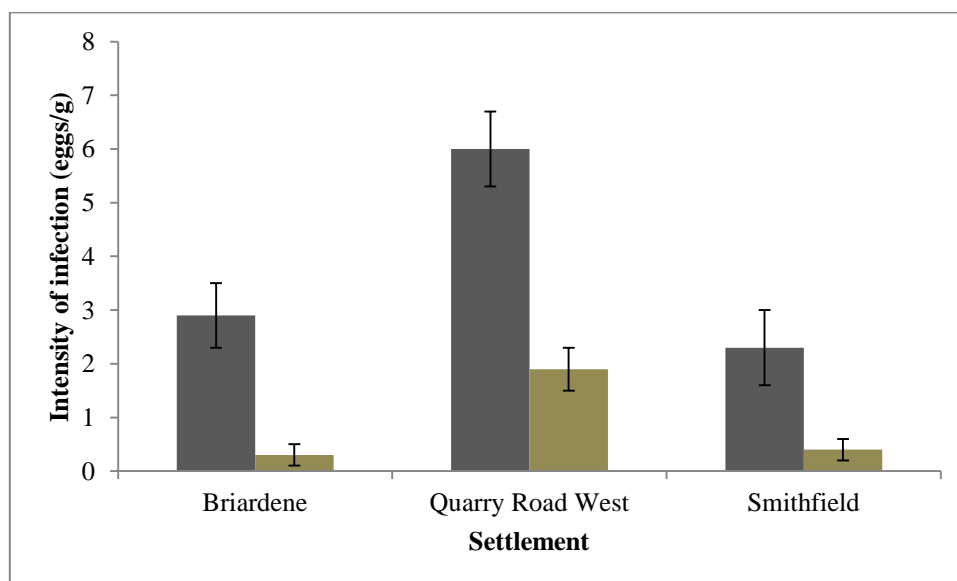Figure 4.8: The intensities of *Ascaris lumbricoides* (■) and *Trichuris trichiura* (■) infection (geometric mean eggs/g faeces ± SE) seen in the total 135 children aged 1-16 years in the three study settlements (N=47 in Briardene, N=50 in Quarry Road West and N=38 in Smithfield).

5. Discussion

From the results of the present study, it is evident that the environment in informal settlements is contaminated with geohelminth eggs. Soil surveys in other parts of the world have shown soil recovery rates of helminth eggs to be generally low (Muller et al., 1989; Rai et al., 2000; Chukwuma et al., 2009; Amadi and Uttah, 2010; Blaszkowska et al., 2011). Similarly, low soil recovery rates (32%) were recorded during the present study. These findings are similar to the Nepalese study by Rai et al. (2000) in which 36.5% of soil samples were positive for helminth eggs and that of the Italian study by Habluetzel et al. (2003) where soil contamination of urban sites with *Toxocara* spp. eggs was found to be 24%. Due to the low rate of soil contamination in the present study, samples were taken to be positive if a single egg was recovered. This is important as it takes only the distribution of geohelminth eggs, and not abundance into consideration.

The results of the present study showed that the overall soil contamination varied significantly among the study areas. The highest level of soil contamination was recorded in Quarry Road West (mean=102.55eggs/100g). This finding is probably due the fact that Quarry Road West had the lowest sanitation coverage (i.e. the proportion of houses provided with sanitation facilities) (11%) and the highest housing density of the three study areas with houses built between 0.5 and 2.0m from each other. In support of this, Mosala (2001) concluded that increased housing density and house crowding increased the numbers of infective eggs in the environment. Due to the large numbers of people and a lack of maintenance of toilets present in this settlement, community members prefer to defaecate in the surrounding bushes (80%) increasing the spread of helminth eggs in the soil. This finding is in keeping with that of Muller et al. (1989) who concluded that community members are unlikely to use a facility that is in an unsatisfactory condition.

One would assume that soil contamination increases in communities making use of less advanced sanitation options (e.g. pit latrines). However, even though Smithfield had the least advanced sanitation option of the three study areas, soil contamination was the lowest (mean=0.96eggs/100g). The low levels recorded in this settlement can probably be attributed to the higher sanitation coverage (70%) and the lower levels of indiscriminate defaecation (33%).This finding is of particular importance as it demonstrated the fact that improvements in sanitation alone are inadequate at improving public health, a recurring conclusion of many geohelminth surveys (Brown, 1927; Muller et al., 1989; Rai et al., 2000).

Despite being provided with flush toilets, which are considered the most effective facility at containing faecal pathogens, and a high sanitation coverage (80%), Briardene showed a higher level of soil contamination (mean=11.8eggs/100g) than Smithfield. This finding could partly be due to the high number of occupants per household accompanied by the presence of make-shift homes without a flush toilet, making open defaecation a common occurrence in this settlement (36%). These findings are similar to those of Legesse and Gebre-Selassie (2007) who conducted a sanitary survey of residential areas in Jimma, Ethiopia. A major observation of their study was the higher prevalence of *Ascaris* ova in what was regarded as a community of higher socio-economic status making use of flush type ablution facilities. To interpret their observation, household members were re-interviewed by the researchers. People explained that they were not always comfortable sharing the one toilet with many people and this lead to indiscriminate or open defaecation, which is similar to the situation that exists in Briardene.

In a study evaluating the Improved Latrine Programme in Mozambique, Muller et al. (1989) found that the latrine was not the major source of faecal pollution in the environment. These authors suggested that, if this was the case, there would be a gradient of pollution, higher at the latrine and less so further away. This conclusion was due to the fact that latrine entrances contained lower number of eggs than the dwelling itself. This is an interesting observation that can be applied to results of the present study. In Smithfield, higher numbers of eggs were recovered at washing areas, houses and pathways than from the latrine itself. This suggests that in this settlement, the pit latrine was not the primary contributor of geohelminth eggs in the environment. In Briardene, assessment of the situation is more difficult due the fact that toilets are located inside the homes. This meant that during sampling, the collection of samples from houses and toilets coincided. However, the fact that higher numbers of eggs were recovered along pathways suggests that promiscuous defaecation is more likely to occur in areas away from the home. In Quarry Road West however, the inadequacy of sanitation facilities was the major source of faecal pollution since there was a progressive decrease of soil contamination from the toilets to the washing area, houses and pathways. The toilets present increased the spread of eggs in the environment in two ways; firstly, the heavily infected soil surrounding the toilets resulted in the dispersion of faecal matter to other areas, particularly after rain, and secondly, due to the unwillingness of community members to use the unsatisfactory facilities, indiscriminate defaecation was high.

In Quarry Road West, the highest levels of soil contamination were recorded around the toilets and *A. lumbricoides* was the dominant species in this settlement. Due to the higher prevalences and intensities of *A. lumbricoides* recorded in this settlement, this finding is not surprising. The

overall level of soil contamination with *A. lumbricoides* eggs (61.5%) recorded was higher than that Chukwuma et al. (2009) who recorded a percentage of 24% but lower than those of Brown (1927) and Muller et al. (1989) where the percentage of positive samples were 84.6 and 78%, respectively. In Briardene and Smithfield, the greatest egg recoveries occurred around the washing areas and the dominant species in these settlements were *T. trichiura* and *Taenia* spp., respectively. The recovery of helminth eggs from around the washing areas is a cause for concern in terms of public health since water for all domestic activities is collected from these areas. In Briardene, contaminated water sources could be partly responsible for the prevalences of *A. lumbricoides* and *T. trichiura* recorded in this settlement since both species of eggs were recovered from washing areas. This finding is supported by Muller et al. (1989) however, in contrast, results of a study by Brown (1927) showed that infection from water supply was unlikely in their study area. Due the potential role that water collection points or washing areas may play in geohelminth transmission, particularly in communities provided with a single source, determining the soil contamination surrounding these facilities should be further investigated. In all three study areas, samples collected from houses had the lowest numbers of eggs present. This is important as it confirms that open defaecation is more likely to occur in areas away from the home and out of sight, a finding supported by Chukwuma et al. (2009).

Legesse and Gebre-Selassie (2007) recorded high recovery rates for *A. lumbricoides* eggs (37.3%), much higher than the overall results of this study however, their *T. trichiura* egg recovery rates were much lower at 0.7%. A recent study by Blaszkowska et al. (2011)investigated contamination of soil by eggs of geohelminths in rural areas of Lodz district (Poland). Soil samples were collected from fields, kitchen gardens, yards and composts using a method of sampling similar to that of the current study. The average density of eggs in samples collected from kitchen gardens was 0.4eggs/100g of soil which is lower than the present study where average egg counts from houses were 2.25eggs/100g in Briardene, 3.8eggs/100g in Quarry Road West and 0.5eggs/100g in Smithfield. Results of the current study were also higher than those of Mizgajska et al. (2001) who investigated sources of *Toxocara* sp. contamination in urban and rural environments in Poland. In their study egg recovery rates were highest around houses with a mean of 1.11eggs/100g. Other recovery rates included; 0.36eggs/100g in the streets and roads, 0.46eggs/100g in parks and public gardens, 0.23eggs/100g in sandpits and 0.06eggs/100g on playgrounds. The values recorded in Quarry Road West and Briardene were also much higher than those recorded by Jarosz (2001) and Dubná et al. (2007), who recorded mean egg densities of 3.75/100g of soil with *Toxocara* eggs in the Elblag area of Prague and 6.2eggs/100g of soil with feline and canine ascarid eggs in public parks in the city, respectively.

Nock et al. (2003) investigated geohelminth eggs in soil and stool from pupils of primary schools in Samaru and Zaria, Nigeria. Of the 1 120 soil samples, only 12% were positive. Eggs of *Ascaris* sp. and *Trichuris* sp. were recovered in 4.6 and 4.0% of samples, respectively. Their findings are thus similar to the low recovery rates in Smithfield where only 11% of the soil samples contained eggs. The recovery rates of *A. lumbricoides* were also similar with 4.5% of samples containing eggs, however only 1.5% of samples contained *T. trichiura* eggs in the current study, lower than that of Nock et al. (2003).

Rai et al. (2000) attributed differences in results of various studies to the technique employed, particularly where samples are collected in similar areas. Most methods generally involve the use of a pre-treatment and flotation solution in an attempt to separate the eggs from the soil particles. Therefore, one would assume that it is mainly the pre-treatment and flotation solutions that distinguish one method from another. The higher recoveries recorded in the present study can be attributed to the method of recovery used. Many soil studies making use of various methods have been reviewed but a modification of the AmBic method for the recovery of helminth ova was chosen due to the previous high recoveries recorded. The original method reported a mean recovery of 77%±1.4 of *A. lumbricoides* ova from Urine Diversion waste (Hawksworth et al., 2005). Much of the work done using the AmBic method focused on the recovery of *Ascaris* ova from solid waste particularly from UD toilets. Since UD waste consists of a combination of faecal matter and soil, it was assumed that this method could potentially yield high recoveries for soil samples as well. Since egg recovery rates from soil are generally low, the AmBic method was appropriate for this study as it allowed a larger sample size to be used and the combination of sieving and washing techniques increased the likelihood of egg recovery. The ammonium bicarbonate solution that was used as the pre-treatment solution promoted the separation of eggs from the soil particles as it is said to disrupt the electrostatic forces between the eggs and the soil particles thereby resulting in the dissociation of the eggs from the soil particles (Hawksworth et al., 2005). The use of sieves with different mesh pore sizes efficiently separated the debris from the eggs ensuring a cleaner deposit after centrifugation for microscopic examination. The continuous washing of the sample with running tap water not only further promoted the separation of eggs from soil particles but also ensured that eggs were not damaged by the pre-treatment or flotation solutions. The SG (1.3) of the flotation solution used (zinc sulphate) was high enough to promote the flotation of all helminth eggs without damaging or distorting them.

Even though the difference was not statistically significant, generally, greater numbers of eggs were recovered in the surface soil layer (top 5cm) than in the deeper layer (10-15cm) in all three

settlements. Helminth eggs in different stages of development were also recovered suggesting that there is continual accumulation of fresh faecal material in the soil since these eggs require a period of development before they become infective. Hence, these areas create focal points for transmission. Faecally-contaminated areas are particularly hazardous for children as common childhood behaviour, such as playing and their curiosity to explore, increases chances of exposure, a finding in agreement with Knightlinger et al. (1998) and Mosala (2001).

The results of the present study showed that children living in the studied informal settlements were infected with *A. lumbricoides* and *T.trichiura* and eggs of both geohelminths were recovered from soil samples collected in the study areas. Hence, since geophagy was also shown to be a common practice in both children and adults of the study areas, the soil could probably be a source of infection of these children. In support of this, previous studies have shown a strong association between geohelminth infection rates and geophagous behaviour in study populations (Geissler et al., 1998; Mosala, 2001; Saathoff et al., 2002). Mosala (2001) found that geophagous children living in informal settlements had higher intensities and prevalences of *A. lumbricoides* infection than non-geophagous children. However, geophagy only had a significant effect on *T. trichiura* prevalences and intensities after a 12 month follow-up (Mosala, 2001). Higher frequencies and intensities of infection were also reported in children with silica present in their stools (Mosala, 2001). Hence, although no attempt was made to critically analyse the link between geophagous children and infection rates in the current study, the presence of silica in stool samples suggest that these children were consuming soil, making geophagy a possible contributing factor to geohelminth infections in the study area. In addition, despite a high awareness on geohelminths, the studied community was shown to lack knowledge on the transmission routes and preventive measures of geohelminths. The lack of knowledge on transmission routes such as contact with soil and improper hygiene, and the unawareness of preventive measures such as not ingesting soil and practising proper personal hygiene, could play a significant role in geohelminth infections of children in the study areas. The implementation of health education programmes in informal settlements is therefore essential if geohelminth infections are to be brought down. In Durban, clinics provide free antihelminthic treatment therefore health education programmes should also aim to encourage community members to make use of these facilities whilst educating them on the routes of transmission and possible means of prevention.

The mean prevalences of *A. lumbricoides* and *T. trichiura* reported in this study were much lower than those of Mosala (2001) who recorded mean prevalences of 90% for *A. lumbricoides* and 79.6% for *T. trichiura* infections in the same study area. Similarly, Eldson-Dew and

Freedman (1952) and Coutsoudis et al. (1994), reported higher prevalences of the two geohelminths compared to the current study. In the present study, children tended to harbour light *T. trichiura* and moderate *A. lumbricoides* infections. Only a small number of children had heavy infections, a finding common to other studies (Chan, 1997; Mosala, 2001). Results of the questionnaire showed that 39.7% of community members of the three study areas have previously received antihelminthic treatment which could be partly responsible for the light and moderate intensities observed. This finding is supported by Chukwuma et al. (2009) who attributed the high prevalence of geohelminths to the fact that 70% of children in their study population had never received treatment.

This study also demonstrated that the prevalences and intensities for both *A. lumbricoides* and *T. trichiura* infections in children differed significantly between study areas. The higher prevalences and intensities recorded for Quarry Road West compared to the other study areas could probably be attributed to a higher noted soil contamination rate and the lowest sanitation coverage. This finding is in agreement with that of Chukwuma et al. (2009) where the highest prevalence rates were recorded in areas with the highest environmental contamination. Navarrette and Torres (1994) also recognised the potential role that sanitation coverage may play in geohelminth infections after results of their study associated the highest infection rates with areas with lower sanitation coverage. In Briardene, although sanitation coverage remains the same, the whole settlement has now been provided with flush toilets whereas in 2001 only part of the settlement had flush toilets while the remaining part made use of chemical toilets and pit latrines. It is these improvements in sanitation that could have been partly responsible for the decreased prevalences and intensities observed in the present study.

Mosala (2001) also found that children living in make-shift homes or shacks that are closely built are at a greater risk of infection and that intensities of infection are also usually higher. In support of this, results of the current study showed lower prevalences and intensities of infection in Briardene which comprised mainly of low-cost houses built of mud and bricks. However, despite a higher *T. trichiura* soil contamination in Briardene, higher *A. lumbricoides* prevalence and infection rates were recorded in children compared to *T. trichiura*. This finding is supported by Rai et al. (2000) who found *A. lumbricoides* to be the predominant species (57.9%) in children in Kathmandu valley, Nepal. However, outside the valley, soil contamination with *A. lumbricoides* eggs decreased to 15.4% and *T. trichiura* became the predominant species at 38.5% but infection rates with *A. lumbricoides* still remained higher. These authors suggested that the higher levels of soil with *T. trichiura* eggs could be due the different animals present and partly due to the difference in desiccation tolerance of the two species since soil samples

were collected from outside the valley during the dry season. Since a greater number of *T. trichiura* eggs were only recovered in Briardene in the present study and Briardene and Smithfield are similar in terms of general characteristics such as domestic animals present, soil type and environmental conditions, further investigation into possible reasons for this finding needs to be done.

No hookworm infections were seen in the current study. Generally, hookworm infections occur at altitudes of less than 150m above sea level in sandy soils with a low (<15%) clay content (Mabaso et al., 2003). Although all three study settlements lay at altitudes less than 150m, soil types at both Briardene and Smithfield consisted mainly of shale with high clay contents (38%) (Mosala, 2001) which do not support the transmission of hookworm. Even in Quarry Road West, where the soil type was conducive to hookworm transmission, no infection was found. These findings are similar to those of Mosala (2001) who detected hookworm infections only at baseline in areas unlikely to support hookworm transmission and therefore concluded that infections detected had been acquired outside the study settlements. Archer and Appleton (2002) also found hookworm prevalences to be low (approximately 1.9%) when children from Carrington Heights Junior Primary School in Durban were tested for intestinal helminth infections.

Geohelminth infections abound in informal settlements are not only due to the poor living conditions of these areas but also as a consequence of environmental factors that support the development and dispersion of geohelminth eggs. The soil contamination rate and prevalences of geohelminth infections noted in the present study can also be attributed to the fact that informal settlements in Durban provide the ideal conditions for the survival of eggs in soil in terms of both climatic conditions and rainfall. Temperature, relative humidity and light affect the viability of eggs. The eggs of *A. lumbricoides*, for example, can remain viable for two to three years in temperate climates (10 – 15°C) and for ten to twelve months in tropical climates (20 – 30ºC) (Strauss, 2000).

Rainfall not only provides essential moisture for the development of eggs to larval stages but also contributes to dispersal of eggs throughout the domestic environment. Heavy rainfall causing run-off and erosion distributes eggs both horizontally (across wide areas) and vertically (into deeper soil layers and down steep slopes) (Appleton and Gouws, 1996; Cadet and Albergel, 1999; Mosala, 2001). Both Briardene and Smithfield are built on steep slopes resulting in faecally contaminated soil being transported to lower areas of the settlement during rain. Prost (1987) suggested that horizontal transport leads to the concentration of eggs where puddles are formed. Due to run-off, stagnant pools of water were visible at various points in

Briardene and these increased in number after rain. However, no attempt was made in the present study to determine egg loads at these points. In Quarry Road West, the effect of ongoing erosion of the river bank after heavy rain coupled with frequent open defaecation occurring in this area further contributes to the high levels of soil contamination noted in the domestic environment. This finding is consistent with both Mosala (2001) and Chukwuma et al. (2009) who concluded that rain contributed to the spread of parasitic eggs in the environment from areas of open defaecation in the surrounding bushes.

Saathoff et al. (2005) reported an association between the normalized-difference vegetation indices (NDVI) and *A. lumbricoides* infection in rural northern KwaZulu-Natal and concluded that their survival in the soil was greatly dependant on moisture and limited exposure to direct sunlight. Plants flourish in areas that have enough water and the shade they create protects the underlying soil from solar radiation therefore limiting evaporation and providing ideal conditions for eggs to develop to infective stages. In Quarry Road West, the closely built houses mimic the shading effects of vegetation promoting the survival of eggs in the soil and hence further contributing to the high levels of soil contamination and prevalences recorded in this settlement. However, in Smithfield, the lower egg recovery rates can at least partly be attributed to the limited number of shaded areas as this settlement maintains a rural characteristic with the houses being built further apart. Eggs in the soil here are susceptible to desiccation due to the constant exposure to sunlight, particularly in the summer months when soil samples were collected.

An additional factor contributing to the spread of geohelminth eggs may be the passive dispersal of eggs by scavenging and coprophagous animals. The Ratzooman (Rat Zoonosis Management) project indicated that rats (*Rattus* spp.) in Durban are coprophagous suggesting that they may be attracted to human faeces when deposited indiscriminately in the area. The eggs of *A. lumbricoides* were found in the faeces of 27% of the *Rattus norvegicus* (brown rat) and 9% of the *Mus musculus* (house mouse) captured at the Cato Crest informal settlement in Durban (Appleton and Archer, 2006). Traub et al. (2002) recovered the eggs of *T. trichiura* and viable *A. lumbricoides* eggs in dog faecal samples. Since domestic animals and rodents are common in all three study settlements, their role in the dispersal of eggs should be further investigated. Brown (1927) suggested that *Ascaris* eggs are transported upon bare feet or shoes resulting in their further distribution throughout the domestic environment which probably also contributes to the dispersal of eggs in the study settlements particularly in Quarry Road West where the soil was found to be heavily contaminated.

A surprise finding of this study was the generally low rate of soil contamination with *A. lumbricoides* eggs in both Briardene and Smithfield. *A. lumbricoides* is regarded as the most prolific soil-transmitted helminth, with 1.3 billion infections globally (Jiménez, 2007; Navarro et al., 2008). The presence of a thick, multi-layered shell makes eggs resistant to adverse environmental conditions and conducive to a long life-span in the soil, longer than those of *T. trichiura* which remain infective for only a few months (Appleton and Gouws, 1996; Peng et al., 2003). Due to its persistence in the environment, *A. lumbricoides* has been used as indicator organism for faecal pollution in the environment in many epidemiological studies e.g. Muller et al. (1989), Knightlinger et al. (1998) and Legesse and Gebre-Selassie (2007).

Brown (1927) noted that eggs found in soil samples represent a fraction of what could be present in the environment. The fact that *A. lumbricoides* eggs were recovered in all three study settlements confirms their presence in the soil. But helminth eggs are not evenly distributed in the soil, in fact, they are generally concentrated in "egg banks" which are faecally contaminated areas. The set sampling design applied to this study could be responsible for the low levels of recovery for an egg type that should otherwise be the predominant helminth species in the soil. Each of the three study settlements varied in size, with Briardene and Smithfield being much larger than Quarry Road West. In order to compare the between-settlement differences, the same sampling design was used in all three areas. Although this design incorporated sampling sites that were potential transmission foci, the larger sizes of both Briardene and Smithfield meant that soil samples were not collected from a large percentage of their areas which may have contributed to the low egg counts.

The higher prevalences recorded in children for *A. lumbricoides* in all three study areas suggest that contaminated soil is not the only source of infection. *A. lumbricoides* eggs have been found adhering to fruit, vegetables, cooking utensils, furniture, door handles, money and fingers (Kagei, 1983). Since regular hand washing is not a common practice in these areas this explanation is plausible.

A second finding that deserves attention was the high level of soil contamination with *Taenia* spp. eggs. These eggs were the predominant egg type, being recovered in all four sampling sites in all three study settlements. Quarry Road West showed the greatest soil contamination for these eggs compared to Smithfield and Briardene. The fact that large numbers of *Taenia* spp. eggs were present is important as it raises the question about the source of these eggs since no human infections were recorded either in this study or by Appleton et al. (2009). Nevertheless, a previous study by Trönberg et al. (2010) showed a high occurrence of *Taenia* spp. (18%) in faeces collected from UD (Urine Diversion) toilets in rural KwaZulu-Natal. In addition,

unpublished work on sludge samples from VIP (Ventilated Improved Pit Latrines) toilets located in informal and formal settlements showed that 80% were positive for *Taenia* sp. eggs (as yet UNPUBLISHED WRC REPORT as project is ongoing). These studies suggest that *Taenia* does occur in people. An infected individual typically voids large numbers of eggs in a single proglottid increasing the spread of these eggs in the domestic environment. Therefore the *Taenia* spp. eggs recovered from soil in the present study could possibly, in part, be attributed to human infections. A possible limitation of this study could be the fact that stool sample examination was restricted to children and perhaps a better understanding on the role of human infection on the levels of *Taenia* spp. eggs in the soil would have been obtained if a larger sample population was used and if stool samples were collected from households that yielded positive results.

The *Taenia* spp. eggs recovered could also have, in part, come from the faeces of stray cats and dogs that are free to roam throughout the settlements. Huerta et al. (2008) evaluated the relationship between the parasite contamination of the soil and the presence of neurocysticercosis in a rural community in Mexico. Results of the Mexican study showed that the overall environmental contamination with *Taenia* sp. eggs was high, but the high frequencies of households with *Taenia* sp. eggs in the soil (25.3%) were much lower than the numbers of tapeworm carriers (2.7%). These authors suggested a possible explanation for this finding is that the *Taenia* sp. eggs could have come from other cestodes that infect domestic animals. The appearance of these eggs in soil makes distinguishing between different taeniids such as *T. saginata*, *T. solium*, *T. pisiformis* and *Echinococcus* spp., difficult. Another study, in which *Taenia* sp. eggs were recovered, although at a much lower contamination rate (0.72%), was conducted by Acioglu and Burgu (2008). These authors also suggest that their results could be misleading since *Taenia* sp. eggs closely resemble those of *Echinococcus* voided by stray dogs. However, of particular interest in the present case is the fact that no *Toxocara canis* or *Toxocara cati* eggs were recovered from soil samples. The specific gravity of the flotation solution (SG 1.3) was high enough to promote the flotation of these eggs which have specific gravities of 1.09 (*T. canis*) and 1.10 (*T. cati*) respectively (David and Lindquist, 1982). This finding further suggests that infected humans could be the main contributing sources of *Taenia* spp. eggs in the domestic environment. Soil contamination with these eggs can potentially affect human health therefore the need for appropriate standardized techniques such as PCR to determine the source of the detected eggs is highlighted (Huerta et al., 2008). It should also be noted that no pigs are kept in any of the three study settlements.

In conclusion, egg recovery data in the present study confirmed environmental contamination as a major risk factor accounting for the continual re-infection seen in people living in informal settlements in Durban. These results show a direct link between high levels of soil contamination and increased frequencies of geohelminth infections. Indiscriminate defaecation by community members was the main contributing factor of helminth eggs in soil, and not the type of sanitation facility. Although advanced sanitation options such as flush toilets are considered to be more effective at containing faecal pathogens, this study showed that the number of systems available to a community, irrespective of the type of facility, can have a greater effect on reducing levels of soil contamination. The installation of water-borne sanitation is not a viable option for many informal settlements. If alternatives, in particular dry toilets such UD or VIP toilets, are to be introduced to a community, the beneficial health effects of such facilities must be explained to users in an attempt to encourage community members to use them at all times. Improvements in sanitation facilities alone will be ineffective at reducing the levels of environmental contamination if open defaecation persists in these areas. Large investment costs are involved in continuing efforts to improve sanitation in informal settlements therefore these conclusions highlight key issues that need to be addressed in order for a sanitation programme to be successful.

The findings of this study are in keeping with those suggested by the current literature. The implications of this study on public health are of importance both locally and countrywide. The prevalence and intensity of *A. lumbricoides* and *T. trichiura* infections in the study populations show that these nematodes are endemic to informal settlements. In order to effectively control geohelminth transmission, health education and antihelminthic treatment need to accompany sanitation programmes in these areas. Also the different characteristics of each settlement must be taken into consideration to allow the implementation of appropriate control measures. Overall attitudes of community members need to be changed which is not an easy feat. The suggested management strategy would be to educate school-going children in the hope that they would demonstrate new behaviours in the home which will eventually lead to gradual change in the attitude of the community as a whole. These results also emphasize the fact that improving public health needs to be a community-based initiative because improvements by a single household will have little effect on the overall rates of environmental contamination.

The methods utilised in this study in terms of both sampling design and the method of recovery of helminth eggs from soil can be used as a building blocks for future research in informal settlements. A possible limitation of this study could have been the set sampling design applied to each study area. Due to the larger sizes of both Briardene and Smithfield compared to Quarry

Road West, soil samples were not collected from a large percentage of their areas. Therefore, when devising a method of sampling, the size of the settlement is an important factor that needs to be taken into consideration to maximise egg recoveries. Since recovery rates from soil are generally low, greater numbers of samples from a wider area are suggested. The method used to recover eggs from soil is also a crucial factor. Methods making use of both sieving and washing techniques, similar to the one used in this study are suggested to be most effective. Previous studies have shown a link between soil contamination in the household environment and an infected individual living in the home. Unfortunately, due to the unwillingness of parents or guardians to participate in this study, stool samples were not necessarily collected from children living in households were soil samples were collected. Future studies of this nature should therefore attempt to examine stool samples from individuals living in the same houses where soil samples will be collected to determine the effect of levels of soil contamination in the household environment on prevalence and infection rates of household members.

The results of this study represent an important contribution to the current knowledge on environmental contamination with regards to sanitation in informal settlements, and highlights key issues that need to be addressed in order to successfully lower geohelminth transmission in these areas.

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6. Appendix

Appendix A

Questionnaire on the living habits of people from various settlements

[Interviewer please fill in on the provided lines and circle all appropriate answers]

Section A: General information

1) Person interviewed

        a) Mother

        b) Father

        c) Grandparents

        d) Other (specify) _____

1.1) Occupation of interviewee: _____

2) Number of people living in household? _____

3) How many people are between the ages of:

        a) 5 – 15yrs   _____

        b)   > 15yrs   _____

5) How many people go to school? _____

6) Where do the children in your household normally play?

        a) Playground (If there is a designated general play area)

        b) In the vicinity of the household

        c) Other (specify)_____

Section B: Geophagy

7) Is it normal for the children to eat soil? _____

8) Have you ever observed either yours or other children ingesting soil?   yes / no

9) Do adults ingest soil?   yes / no

10) If yes, give reasons why adults ingest soil

a) _____

b) _____

c) _____

d) _____

11) In your area where are the specific places that people get soil from?

_____

Section C: Sanitation

12) Presence of a toilet?   yes / no

13) Do the members of your household regularly use the toilet?   yes / no

      13.1) If yes, do other members of the community regularly use the toilet?   yes / no

      13.2) If no, where to people relieve themselves? _____

14) What do you think the dangers of open defaecation are?

a) _____

b) _____

c) _____

Section D: Geohelminth infection

15) Do you know about worms?   yes / no

16) Have you ever been infected?   yes / no

      16.1) If yes, were you treated?   yes / no

      16.2) If yes, by whom were you treated? _____

17) How are these worms spread? _____

18) Have any of your family members been infected?   yes / no

19) What is your suggestion to prevent worm infections? _____
_____
_____
_____

Appendix B

B.1 Document of informed consent for participation in the questionnaire (in English)

- The title of this project is the study of worm eggs in soil
- This study aims to find out where these eggs are in the soil as well as how many are present at each point
- Contact details: Kelleen Rajcoomar

  BSc (Honours)

  University of KwaZulu-Natal (Westville Campus)

  (031) 260 3233

- For further information you are welcome to contact the project supervisors:
  1) Prof CC Appleton: (031) 260 1187

  2) Prof S Mukaratirwa: (031) 260 1338

- This study is important because worms are very common in children in settlements. If we can learn more about this problem, control measures can be put in place.
- You are only required to complete the questionnaire once. You will not have to do anything else.
- It will not cost anything.
- Questionnaire responses will be kept confidential and anonymous
- You can choose whether or not you would like to answer the questionnaire
- Participation is voluntary and if you would like to withdraw your answers afterwards, you are free to do so.

I………………………………………………………………………………(full names of participant) hereby confirm that I understand the contents of this document and the nature of the research project, and I consent to participating in the research project.

I understand that I am at liberty to withdraw from the project at any time, should I so desire.

SIGNATURE OF PARTICIPANT   **DATE**

………………………………………………………………………………………………………

B.2 Document of informed consent for participation in the questionnaire (in Zulu)

- Lolu cwaningo lumayelana namaqanda ezikelemu emhlabathini
- Inhloso ukuthola kahle ukuthi atholakala kuphi nendawo emhlabathini lamaqanda Kanye nobuningi bawo
- Contact details (Xhumana): Kelleen Rajcoomar

  BSc (Honours)

  University of KwaZulu-Natal (Westville Campus)

  (031) 260 3233

- Uma udinga ukwazi kabanzi wamukelekile ukuthintana nalaba onzululwazi:
  1) Prof CC Appleton: (031) 260 1187

  2) Prof S Mukaratirwa: (031) 260 1338

- Lolu cwaningo lubalulekile ngoba izikelemu ziyinkinga ejwayekile ethinta kakhulukazi abantwana, ukwazi ngazo kabanzi kuzosiza ekutheni zikwazi ukubeka nofundisa ngemigomo ezosiza ekugwemeni lenkinga yezikelemu.
- Uyacelwa ukuba uphendule lemibuzo kube Kanye nje qha.
- Ukunazindleko
- Izimpendulo zakho zizothathwa njenge mfihlo futhi negama lakho alizu kuvezwa ndawo.
- Awuphoqiwe ukuphendula lemibuzo futhi uma usushitsha umqondo ngokuba ingxenye yaloluhlelo uvumelekile ukuzikhipha noma yinini.

Mina………………………………………………………..(igama nesibongo) ngiyaqinisa ukuthi ngiyaqonda ngokushicilelwe kulombhalo nangohlobo locwaningo ngiyaliqonda futhi angiphoqiwe muntu ukuzimbandakanya nalo.

Ngiyazi ukuthi nginelungelo lokuzikhipha kuloluhlelo noma yinini.

SIGNATURE OF PARTICIPANT   DATE

……

Appendix C

C.1 Document of informed consent issued to parents/guardians for the collection of stool samples from children (in English)

- The title of this project is the study of worm infections in children
- This study aims to find out if and/or how heavily infected children are
- Contact details: Kelleen Rajcoomar

    BSc (Honours)

    University of KwaZulu-Natal (Westville Campus)

    (031) 260 3233

- For further information you are welcome to contact the project supervisors:
    1) Prof CC Appleton: (031) 260 1187

    2) Prof S Mukaratirwa: (031) 260 1338

- This study is important because worms are very common in children in settlements. If we can learn more about this problem, control measures can be put in place.
- Your children are only required to give two stool samples. You will not have to do anything else.
- It will not cost anything.
- All information will be kept confidential and anonymous
- You can choose whether or not you would like your child/children to participate
- Participation is voluntary and if you would like to withdraw afterwards, you are free to do so.

I……………………………………………………………………(full names of participant) hereby confirm that I understand the contents of this document and the nature of the research project, and I consent to participating in the research project.

I understand that I am at liberty to withdraw from the project at any time, should I so desire.

SIGNATURE OF PARTICIPANT   **DATE**

……………………………………………………………………………………………………

C.2 Document of informed consent issued to parents/guardians for the collection of stool samples from children (in Zulu)

- Lolu cwaningo lumayelana namaqanda ezikelemu emhlabathini
- Inhloso ukuthola kahle ukuthi atholakala kuphi nendawo emhlabathini lamaqanda Kanye nobuningi bawo
- Contact details (Xhumana): Kelleen Rajcoomar

    BSc (Honours)

    University of KwaZulu-Natal (Westville Campus)

    (031) 260 3233

- Uma udinga ukwazi kabanzi wamukelekile ukuthintana nalaba onzululwazi:
  1) Prof CC Appleton: (031) 260 1187

  2) Prof S Mukaratirwa: (031) 260 1338

- Lolu cwaningo lubalulekile ngoba izikelemu ziyinkinga ejwayekile ethinta kakhulukazi abantwana, ukwazi ngazo kabanzi kuzosiza ekutheni zikwazi ukubeka nofundisa ngemigomo ezosiza ekugwemeni lenkinga yezikelemu.
- Uyacelwa ukuba uphendule lemibuzo kube Kanye nje qha.
- Ukunazindleko
- Izimpendulo zakho zizothathwa njenge mfihlo futhi negama lakho alizu kuvezwa ndawo.
- Awuphoqiwe ukuphendula lemibuzo futhi uma usushitsha umqondo ngokuba ingxenye yaloluhlelo uvumelekile ukuzikhipha noma yinini.

Mina………………………………………………………..(igama nesibongo) ngiyaqinisa ukuthi ngiyaqonda ngokushicilelwe kulombhalo nangohlobo locwaningo ngiyaliqonda futhi angiphoqiwe muntu ukuzimbandakanya nalo.

Ngiyazi ukuthi nginelungelo lokuzikhipha kuloluhlelo noma yinini.

SIGNATURE OF PARTICIPANT   DATE

…………………………………………………………………………………………………

Appendix D

Letters issued to parents/guardians after the examination of stool samples informing them on the infection status of children

D.1 Letter referring infected children to the nearest clinic (in English)

University of KwaZulu-Natal

School of Biological and Conservation Sciences

Westville Campus

University Road

Westville

3629

To whom it may concern

Your child_____ (House no._____) has been found to be infected with worms and must be taken to the nearest clinic for treatment as soon as possible.

Yours faithfully

_____

Kelleen Rajcoomar

MSc student

_____   _____

Prof CC Appleton   Prof S Mukaratirwa

Supervisor   Co-supervisor

D.2 Letter referring infected children to the nearest clinic (in Zulu)

University of KwaZulu-Natal

School of Biological and Conservation Sciences

Westville Campus

University Road

Westville

3629

Kulowo eqondene naye

Ingane yakho_____ (Inombolo yendlu_____)

Itholakale ukuthi itheleleke ngezikelemu umfana/intombazane kudingeka ukuthi umthathe umyise eclinic eseduze ukuze athole usizo ngokushesha.

Yimina ozithobayo

_____

Kelleen Rajcoomar

Umfundi we MSC

_____   _____

Prof CC Appleton   Prof S Mukaratirwa

Umphati   Umsizi ka Mphati

D.3 Letter informing parents/ guardians that no geohelminth infections were seen in children therefore no treatment was required (in English)

University of KwaZulu-Natal

School of Biological and Conservation Sciences

Westville Campus

University Road

Westville

3629

To whom it may concern

Your child_____ (House no._____) does not have worms.

Yours faithfully

_____

Kelleen Rajcoomar

MSc student

_____   _____

Prof CC Appleton   Prof S Mukaratirwa

Supervisor   Co-supervisor

D.4 Letter informing parents/ guardians that no geohelminth infections were seen in children therefore no treatment was required (in Zulu)

University of KwaZulu-Natal

School of Biological and Conservation Sciences

Westville Campus

University Road

Westville

3629

Kulowo eqondene naye

Ingane yakho_____ (Inombolo yendlu_____)

Ayinazo izikelemu.

Yimina ozithobayo

_____

Kelleen Rajcoomar

Umfundi we MSC

_____   _____

Prof CC Appleton   Prof S Mukaratirwa

Umphati   Umsizi ka Mphati

Appendix E

UNIVERSITY OF KWAZULU-NATAL

University of KwaZulu-Natal
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22 December 2009

Ms K Rajcoomar
P O Box 113
MOUNT EDGECOMBE
4300

Dear Ms Rajcoomar

PROTOCOL: Study of the distribution and abundance of parasite eggs in soil
ETHICAL APPROVAL NUMBER: HSS/1001/2009: Faculty of Science and Agriculture

In response to your application dated 02 December 2009, Student Number: **204502104** the Humanities & Social Sciences Ethics Committee has considered the abovementioned application and the protocol has been given **FULL APPROVAL.**

PLEASE NOTE: Research data should be securely stored in the school/department for a period of 5 years.

I take this opportunity of wishing you everything of the best with your study.

Yours faithfully

Professor Steve Collings (Chair)
HUMANITIES & SOCIAL SCIENCES ETHICS COMMITTEE

SC/sn

cc: Prof. C C Apleton
cc: Prof. S Mukaratirwa
cc: Ms M Francis

Founding Campuses: ■ Edgewood ■ Howard College ■ Medical School ■ Pietermaritzburg ■ Westville

UNIVERSITY OF
KWAZULU-NATAL

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E-mail : naidoos4@ukzn.ac.za

09 September 2010

Ms K Rajcoomar
P O Box 113
MOUNT EDGECOMBE
4300

Dear Ms Rajcoomar

PROTOCOL: Study of the distribution and abundance of parasite eggs in soil
ETHICAL APPROVAL NUMBER: HSS/0979/2010 :   Faculty of Science and Agriculture

In response to your application dated 08 September 2010, Student Number: **204502104** the Humanities & Social Sciences Ethics Committee has considered the abovementioned application and the protocol has been given **FULL APPROVAL.**

PLEASE NOTE: Research data should be securely stored in the school/department for a period of 5 years.

I take this opportunity of wishing you everything of the best with your study.

Yours faithfully

Professor Steve Collings (Chair)
HUMANITIES & SOCIAL SCIENCES ETHICS COMMITTEE

SC/sn

cc: Prof. C Appelton (Supervisor)
cc: Ms. T Revashunkar

Appendix F

Table 6.1: Mean number of geohelminth eggs recovered [mean ± SE (range)] in soil samples from each sampling site in Briardene, Quarry Road West and Smithfield informal settlements.

Site	N	Egg type recovered	Briardene	Quarry Road West	Smithfield
Toilets	N = 96	*A. lumbricoides* (undeveloped)	0	9.11±5.77 (0-500)	0.01±0.01 (0-1)
		A. lumbricoides (viable)	0	25.16±13.83 (0-1174)	0.01±0.01 (0-1)
		A. lumbricoides (dead)	0.01±0.01 (0-1)	4.61±2.23 (0-202)	0.06±0.03 (0-2)
		Taenia spp.	0.05±0.02 (0-1)	1.68±0.55 (0-44)	0.03±0.02 (0-2)
		T. trichiura	0.28±0.07 (0-4)	0.27±0.08 (0-5)	0.01±0.01 (0-1)
Washing Area	N = 32	*A. lumbricoides* (undeveloped)	0	0.31±0.16 (0-4)	0
		A. lumbricoides (viable)	0.03±0.03 (0-1)	0.56±0.30 (0-9)	0
		A. lumbricoides (dead)	0.13±0.07 (0-2)	0.63±0.30 (0-8)	0
		Taenia spp.	0.69±0.31 (0-8)	1.47±0.40 (0-9)	0.47±0.21 (0-6)
		T. trichiura	0.94±0.32 (0-8)	0.25±0.09 (0-2)	0
Houses	N = 40	*A. lumbricoides* (undeveloped)	0	0	0
		A. lumbricoides (viable)	0.03±0.03 (0-1)	0.08±0.04 (0-1)	0
		A. lumbricoides (dead)	0.03±0.03 (0-1)	0.05±0.03 (0-1)	0
		Taenia spp.	0.03±0.03 (0-1)	0.57±0.19 (0-6)	0.05±0.03 (0-1)
		T. trichiura	0.38±0.16 (0-5)	0.08±0.04 (0-1)	0.05±0.03 (0-1)
Pathways	N = 32	*A. lumbricoides* (undeveloped)	0	0.03±0.03 (0-1)	0
		A. lumbricoides (viable)	0	0.03±0.03 (0-1)	0.03±0.03 (0-1)
		A. lumbricoides (dead)	0	0.06±0.04 (0-1)	0.16±0.11 (0-3)
		Taenia spp.	0.03±0.03 (0-1)	0.66±0.15 (0-3)	0.06±0.04 (0-1)
		T. trichiura	11.34±9.35 (0-295)	0.72±0.47 (0-15)	0

N = Sample size

Table 6.2: The prevalences (%) and intensities [geometric means ± SE (range)] of *Ascaris lumbricoides* and *Trichuris trichiura* infections in children in Briardene, Quarry Road West and Smithfield informal settlements. Children found to be uninfected and those harbouring dual-infections are also reported. No *Taenia* infections were found.

Settlement	N	Prevalences of infection				Intensities of infection	
		A. lumbricoides (%)	*T. trichiura* (%)	Dual-infection (%)	No infection seen (%)	*A. lumbricoides*	*T. trichiura*
Briardene	47	15 (31.9)	2 (4.3)	1 (2.1)	29 (61.7)	2.9±0.6 (0-11.7)	0.3±0.2 (0-6.5)
Quarry Road West	50	21 (42.0)	5 (10.0)	12 (24.0)	12 (24.0)	6.0±0.7 (0-12.4)	1.9±0.4 (0-8.2)
Smithfield	38	10 (26.3)	2 (5.3)	1 (2.6)	25 (65.8)	2.3±0.7 (0-11.7)	0.4±0.2 (0-5.0)

N= Sample size