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Analysis of the Public Health Risks of the Urban Water System in Accra by Microbial Risk Assessment

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SWITCH

Analysis of the Public Health Risks of the Urban Water System in Accra by Microbial Risk Assessment

Master of Science Thesis
by
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Abstract

Urban water systems in large urban centres in the developing countries are in various ways related to risks of citizens. Microbial risk assessment was used to estimate the public health risks of the Accra urban water system (AUWS). The potential waterborne disease exposure routes from the sanitation system were identified as; recreational swimming, flooding of the Odaw drain, open drainage channels, UASB treatment plant and faecal septage disposal place; while from the water supply as; contaminated water distribution system and water treatment plants due to errors in the treatment processes. The predicted disease burden from the AUWS was 28,531 DALYs per year due to *Campylobacter,* rotaviruses, *Cryptosporidium* and *Ascaris;* with 91% contribution from the sanitation pathway and with rotaviruses dominating. Comparing the predicted risks with the background endemic waterborne disease incidence showed that the AUWS contributed 75% of the rotavirus cases; 37% of the *Campylobacter* cases; 21% of the *Ascaris* cases and 3% of the *Cryptosporidium* cases. The sanitation pathway was judged to be of more importance compared to the water supply pathway. The AUWS system is not safe for its citizens and therefore, it should be addressed in order to minimize the risks.

Keywords: Microbial risk assessment, public health, urban water system, DALYs, endemic waterborne disease incidence.

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List of abbreviations

AMA	Accra metropolitan assembly
AUWS	Accra urban water system
DALY	Disability adjusted life years
DB	Disease burden
EPA	Environmental protection agency
HACCP	Hazard analysis and critical control points
GWCL	Ghana Water Company Limited
ISO	International Organisation for Standardization
IWMI	International Water Management Institute
MDG	Millennium development goals
MRA	Microbial risk assessment
NACP	National AIDS/STI control programme
PPPY	Per person per year
QMRA	Quantitative microbial risk assessment
SWITCH	Sustainable water management improves tomorrow's cities health
UASB	Upflow anaerobic sludge blanket
UNDP	United Nations Development Programme
UWS	Urban water system
WHO	World Health Organization
WSP	Water safety plans

1 Introduction

1.1 General

A sustainable urban water system should over a long time perspective provide required services while protecting human health and the environment (Lundin, 1999). In developing country cities, the inadequate water supply systems, wastewater collection and treatment systems expose the residents to many risks (USAID, 2002). This is because wastewater contains a wide variety of excreted pathogens depending on the source of wastewater and diseases present in the sewage contributing community. Humans can be exposed to wastewater contaminants through several routes, including drinking water from a contaminated water supply (ingestion), swimming, bathing (dermal exposure or skin contact), and inhaling aerosols and direct exposure to sewage sludge. These exposures may potentially result in adverse health effects (Scott, 2003).

Exposure to contaminated water contributes greatly to microbial risks to human health. It is considered to be one of the major causes of diarrhoeal disease deaths occurring annually, mostly in children. Diarrhoeal diseases accounts for 21% of all deaths of children under five in developing countries (Parasher et al., 2003). However, diarrhoea is one of the directly preventable causes of under-five mortality. To be able to achieve this, underlying causes need to be identified and addressed, certain strategies, approaches and tools need to be put in place. This is why the MDGs are in place, as an example of strategies to tackle this problem (UNDP, 2003).

The eight MDGs are the world's targets for dramatically reducing extreme poverty in its many dimensions (income, poverty, hunger, disease, exclusion, lack of infrastructure and shelter) by 2015. This has to be done by promoting gender equality, education, health and environmental sustainability. The MDGs are now the centrepiece of the global development agenda and show us a viable, justifiable path forward. Of these eight goals, the fourth goal is dedicated to reducing child mortality, and its progress is assessed against target five of reducing by two-thirds, between 1990 and 2015, the under-five mortality rate (UNDP, 2003).

1.2 Background

The background of this project is SWITCH theme 1(Urban water paradigm shift) and MDG number 4: "Reduce Child Mortality".There is a need to explore an integrated approach in urban water management in order to achieve sustainability and minimum risks. The SWITCH project is aimed at contributing to this by development of sustainable urban water management schemes with minimum risks for citizen's safety and health.

1.3 Problem statement and justification

Urban Water Systems (water supply, wastewater collection, treatment, surface waters,

and groundwater) in large urban centres in the developing world are in various ways related to risks for citizens (flooding, droughts, intermittent water supply and infectious diseases). Of these risks, waterborne diseases, especially diarrhoea, are the major causes of mortality. These are caused by exposure to microbiologically contaminated water. According to the global burden of disease report of 2001, diarrhoeal diseases accounted for 1.8 million deaths (3.7%) and 58.7 million DALYs (4.2%), in developing countries (Lopez et al, 2006).

Accra as a low-income city in Africa, suffers from problems of inadequate potable water supply, unsanitary conditions and poor wastewater disposal (Songsore et al., 2005). These problems are a threat to the health of its citizens especially in terms of waterborne diseases.

There is a need to think about all the processes that will enable the prevention of microbial risks related to water, so as to reduce the disease burden and to help contribute to the achievement of the MDGs. The identification of relevant pathways for disease transmission such as for diarrhoeal diseases is essential, as this will give information on the identification of the cost-effective interventions. As a result, the few available resources could consequently be allocated where they count most.

1.4 Research objectives

Overall objectives

i). To assess the microbial health risks of the Accra urban water system

ii). To make recommendations on interventions needed to reduce microbial health risks, in order to help contribute to the achievement of MDG number 4 (Reduce Child Mortality).

Specific objectives

i). To identify the potential exposure pathways originating from the UWS that could lead to the infection of citizens of Accra with water-related diseases

ii). To predict the burden of waterborne diseases in Accra and compare it with the established disease incidence

iii). To make recommendations on interventions needed to reduce the microbial health risks

1.5 Research questions

i). What are the potential exposure pathways originating from the UWS that could lead to the infection of citizens with water-related diseases?

ii). What is the waterborne disease incidence in Accra?

iii). What is the relationship between waterborne disease incidence and the UWS in different parts of Accra?

iv). What are some of the cost-effective interventions needed to reduce the microbial health risks?

1.6 Organization of the report

The report has been organized in 8 sections. Section 1 gives a general introduction of the study, the background and the goal. Section 2 outlines the literature review of studies related to the topic. Section 3 gives a general overview of the study area and detailed methodology that was applied during the study. An overview of the Accra urban water system is outlined in section 4. Section 5 outlines the findings of the study and the general discussions. Some of the cost-effective management options are outlined in section 6 while section 7 and 8 concludes the study and gives recommendations respectively. Sources of information are outlined in the references and appendices.

2 Literature review

2.1 Classification of water-related diseases

Water-related diseases include those due to micro-organisms and chemicals in water that people are exposed to (WHO, 2006a). Faecal contamination of water can introduce a variety of pathogens into waterways, including bacteria, virus, protozoa and parasitic worms. The basis of classification is listed in table 2.1.

Table 2.1: Classification of water-related diseases

Category	Remarks	Example
Water-borne	Caused by ingestion of water contaminated by human or animal faeces or urine containing pathogenic bacteria or viruses.	Faecal-oral diseases such as cholera, typhoid, amoebic dysentery and other diarrhoeal diseases.
Water-washed	Caused by lack of water (water quantity) and linked to poor hygiene	Trachoma, scabies, athletes foot
Water-based	Through contact with water via aquatic invertebrate intermediate hosts	Schistosomiasis, dranculiasis
Water-related Insect Vector	To certain extend transmission through vectors proliferating in water reservoirs, other stagnant water, and through certain agricultural practices.	Malaria, dengue, lymphatic filariasis

Source: (Based on Ince, 1999 and Pruss et al., 2002)

2.2 Aetiology of common waterborne diseases

Table 2.2 lists the most common causes of waterborne diseases

Table 2.2: Common causes of waterborne diseases

Group	Examples
Bacteria	*Salmonella*, *Shigella*, *Campylobacter*, *Vibrio cholerae*, enterovirulent *Escherichia coli*, *Aeromonas*, *Yersinia enterecolitica* and *Clostridium perfringens*
Protozoa	*Cryptosporidium parvum*, *Giardia lamblia*, *Cyclospora cayetanensis* and *Entamoeba histolytica, Balantidium coli, Microsporidia*
Viruses	enteroviruses, rotaviruses, parvoviruses, calciviruses, Norwalk-like agents, adenoviruses, astroviruses
Helminth parasites	*Ascaris lumbricoides,*

Source: Payment and Hunter, 2001; Mara and Horan, 2003; Bitton, 2005.

2.3 Transmission routes

Transmission of water-related diseases involves the transmission of pathogens from an infected host to a susceptible host. Excreta can affect human health through various pathways, for example; respiratory (inhalation of aerosols from wastewater), faecal-oral ingestion (drinking water, food, recreational activities, soil and formites) and dermal

exposure (Haas et al., 1999). Figure 2.1 illustrates transmission via contaminated water.

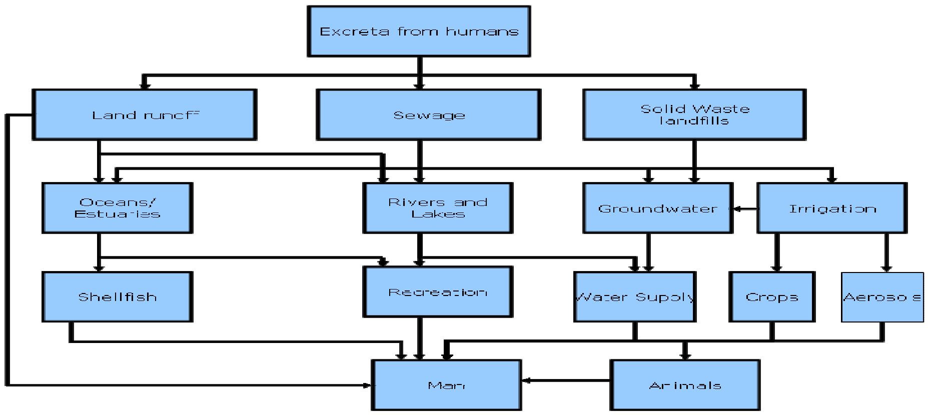


Figure 2.1: Routes of enteric micro-organism transmission

(Source: Adopted from Bitton, 2005; Haas et al., 1999)

2.4 Waterborne disease burden in developing countries

Exposure to contaminated water contributes greatly to waterborne diseases especially diarrhoeal diseases. Diarrhoeal diseases remain the leading cause of death from water-related diseases in children, accounting for 21% of all deaths of children under five in developing countries (Parasher et al., 2003). It is estimated that, on average, each child under 5 years of age in a developing country suffers from three episodes of diarrhoea per year (Kosek et al., 2003).

According to the global burden of disease report of 2001, diarrhoeal diseases accounted for 1.8 million deaths (3.7%) and 58.7 million DALYs (4.2%), in developing countries (Lopez et al, 2006). However, diarrhoea is one of the directly preventable causes of under-five mortality, if proper measures are put in place.

2.5 Exposure to microbial risks via contaminated drinking water

Contaminated drinking water has been associated with mortality from diarrhoeal diseases (WHO, 1996). Drinking water can be contaminated in various ways:

2.5.1 Surface water and groundwater

Numerous pathogenic agents have been found in freshwaters used as sources for water supplies, recreational bathing and irrigation. Major contributors to the spread of various water-borne pathogens are:

i). Raw domestic sewage due to poor drainage system, lack of proper sanitation (Fergusson, 1996; Greed, 2006; Ono et al., 2001), septic system failures and leaky sewer lines (Geldreich, 1990; Ahmed et al., 2004).

ii). Agricultural sources through agricultural runoff from grazed pastures (Jones and Hobbs, 2003; Eyles et al., 2003; Davies-Colley et al., 2002).

iii). Storm water and urban run-off (Solo-Gabrielle et al., 2000; Geldreich 1996).

Groundwater is widely considered to be microbiologically clean. However, studies have shown that pathogens through infiltration sometimes contaminate this source of water especially during seasons of strong rainfall. If the catchment is located near dairy farms, then during high rainfalls, runoff from these farms contaminated by pathogens would infiltrate the aquifers and contaminate the groundwater (Jones, 2001). The outbreak of *Escherichia coli* 0157:H7 infection that occurred at a Minnesota camp that was supplied by chlorinated spring water was attributed to the contamination due to flooding from heavy rains and to an improperly protected spring. Water samples from the same spring also tested positive for *Campylobacter jejuni and Salmonella* species (Andersson and Bohan, 2001).

2.5.2 Contaminated water distribution system

Deteriorating water treatment facilities and distribution systems pose a significant public health threat. Water that leaves the treatment plant might be safe and of high quality, but could get contaminated during distribution (Kirmeyer et al., 2001; Mara and Horan, 2003). There are various ways through which pathogens can gain entry into the distribution system:

Undisinfected/inadequately disinfected water entering the distribution system

Undisinfected or inadequately disinfected water contributes to a substantial water-borne disease burden due to pathogen breakthrough (Andersson and Bohan, 2001). This sometimes could be attributed to the lack of chemicals at the water treatment plant or due to the deterioration of the treatment facilities, or resistance by some pathogens to disinfectants (Goldstein et al., 1996). In a study done in Uzbekistan (Semenza et al., 1998), among people living in homes without piped water, those who were randomized to treat their water with chlorine had an 85% reduction in diarrhoeal rates, compared with those who did not chlorinate their water. This was also the same for the outbreak in Idaho, which was at a resort supplied by untreated well water, which became contaminated with sewage from poorly draining line (CDC, 1996). Lack of chlorination of the drinking water contributed to an epidemic of cholera that occurred in Peru in January 1991(Swerdlow et al., 1992). Outbreaks have also been attributed to lack of chlorine residuals (Semenza et al., 1998) and chlorination failure (Andersson and Bohan, 2001).

Integrity of the distribution system

In many developing countries, drinking water is supplied intermittently either as a cost-saving measure or because of water shortages (Totsuka et al., 2004). Under such conditions, the resulting low water pressure will allow the ingress of contaminated water into the system through breaks, cracks, joints and pinholes in the walls of the system. The occurrence of backflow is directly related to system pressure. Any pressure differential between the potable water and the non-potable source can lead to backflow (Kirmeyer et al., 2001). Microbial contamination can also be introduced into the distribution system through open treated water storage reservoirs (Geldreich, 1996) and existing mains repairs (Andersson and Bohan, 2001).

2.6 Exposure to microbial risks via the wastewater system

Exposure via the wastewater system could be attributed to inadequate sanitation, open drains, wastewater treatment plants, sludge disposal areas, leakey sewer system, leakey septic tanks (Mara and Horan, 2003) and wastewater reuse (Mara et al., 2007).

2.6.1 Greywater

Greywater has a low degree of faecal contamination. However, some activities, such as washing feacally-contaminated laundry (i.e. diapers), childcare and showering may add minor amounts of faecal matter to the greywater. There is some increased risk associated with greywater use because accidental cross-contamination with blackwater is possible, which may lead to microbial water contamination. Greywater may have an elevated load of easily degraded organic material, which may favour growth of enteric bacteria such as faecal indicators (Ottoson and Stenstrom, 2003). Studies have shown that people could be exposed to pathogens in greywater through various ways: accidental ingestion of contaminated kitchen water by cooks, during washing and children playing in greywater tanks/ponds. Ingestion can also occur when children playing in yards ingest contaminated soils (Haas et al., 1999).

2.6.2 Sewer overflows

Sewer overflows may occur in a spot where it offers the potential for considerable human contact such as a street or residential basement or drinking water supply (U.S. EPA, 1996). Some of the routes of exposure to pathogens in raw sewage from overflows include; direct contact with sewage that has backed up into homes, schools, institutions and playgrounds, from exposure to contaminated drinking water or groundwater, from diving, swimming, kayaking, canoeing, or other activities in recreational waters. Recreational exposure usually occurs through ingestion and also through the eyes, ears, nose, anus, skin or genitourinary tract. In 1982 in New York City, 21 police scuba divers became ill after training in sewage-contaminated waters (Dorfman, 2004). Children are especially at risk when playing in flooded playgrounds. An example of this is what happened in 1998 when hundreds of children playing in water theme park in suburban Atlanta were exposed to a deadly strain of *Escherichia coli*. Two children died of kidney failure and other complications, another 24 became ill (Rose and Grimes, 2002).

2.6.3 Wastewater treatment plants

Direct contact with the contaminated wastewater can occur if humans have access to wastewater/ sludge treatment works, sanitary landfills and resource recovery systems. These facilities emit microorganisms containing aerosols under certain conditions (Fannin et al., 1985). Wastewater workers may be exposed to microbial risks by inhalation of aerosols and gases, by dermal contact, and by ingestion. If there are wetland areas, people could accidentally come into contact with the wastewater or sludge if the areas are also used as recreational sites. In developing countries, because of economic, environmental, or political constraints, some of these facilities are located in densely populated regions of urban and suburban communities, leading to potential exposure of the surrounding population to microbial aerosols emitted from the plant (Cronholm, 1980). If wastewater is reused especially for irrigation, exposure can occur via ingestion of contaminated edible products (WHO, 2006b).

2.7 Microbial risk assessment

2.7.1 Definition and uses

Risk is the likelihood and consequence that something with a negative impact will occur. Risk analysis is a necessary component to assist in selecting priority hazards and identifying hazardous scenarios, be they qualitative or quantitative. It includes risk assessment, risk management and risk communication (NRC, 1983; Haas et al. 1999). Table 2.3 lists steps in risk analysis

Table 2.3: Steps in analysis

Step	Explanation
Risk assessment	The quantitative or qualitative characterization and estimation of potential adverse health effects associated with exposure of individuals or populations to hazardous materials and situations. MRA evaluates the likelihood of adverse human health effects that occur following exposure to pathogenic micro-organisms or to a medium in which pathogens occur
Risk management	The process for controlling risks, weighing alternatives and selecting appropriate action, accounting for risk assessment, values, engineering, economics and legal and political issues
Risk communication	The communication of risks to managers, stakeholders, public officials and the public. It includes public perception and the ability to exchange information.

MRA has numerous potential applications. It can be used to quantify risks from environmental exposure by inhalation, ingestion and dermal contact, set standards for pathogens in water or food, perform cost-benefit analysis of treatment processes to reduce exposure, determine the degree of treatment to meet risk objectives and determine required simple values to achieve target risk levels (Perceival et al., 2000). MRA is important to examine urban water systems, to assess potential human health risks and identify ways or approaches for assessing sustainability.

2.7.2 Approaches

In the context of water systems, three different approaches have been identified:

Epidemiological methods

These focus on investigating the incidence and transmission of diseases in a population, through investigation of outbreaks (Hunter et al., 2003).

Quantitative microbial risk assessment (QMRA)

QMRA is the application of principles of risk assessment to estimate the consequences from exposure to infectious microorganisms. It uses densities of particular pathogens, assumed rates of ingestion, and appropriate dose-response models for the exposed population to estimate the level of risk (Haas et al., 1999). It has been applied to wastewater systems (Westrell et al., 2004) and water supply (Howard et al., 2006). The quantitative approach to microbial risk assessment is based on the chemical risk paradigm. It involves four steps as shown in table 2.4 below.

Table 2.4: Steps in QMRA process

Step	Aim
1. Hazard identification	To describe the overall environmental setting and relevant pathogens that may cause acute or chronic effects on human health
2. Dose-response analysis	To find appropriate relationship(s) between pathogen exposure and infection or illness (from epidemiological studies)
3. Exposure assessment	To determine the size and nature of the populations exposed to each identified pathogen by route, amount and duration of exposure
4. Risk characterisation	To integrate the information from exposure and dose-response, to express public health outcomes, taking into account the variability and uncertainty of the estimations

Source: Adopted from Hunter et al., 2003

Qualitative risk assessment

This follows the principles of Hazard Analysis and Critical Control Points (HACCP). HACCP is incorporated as part of the water safety plans in the WHO's Guidelines for drinking water quality (WHO, 2004). It has been adopted in the management of pathogens in wastewater and sewage sludge reuse (Westrell et al., 2004).

In qualitative risk assessments, risk rankings are used. The rankings summarize: the likelihood of possible risk pathways, severity of outcome from each pathway, and numbers of people that may be impacted (Hunter et al, 2003). The approach is outlined in table 2.5, and illustration of a simple risk scoring in table 2.6.

Table 2.5: Possible qualitative risk assessment approach to rank or scale hazardous scenarios

Step	Comment
1. Hazard scenario	Identification of hazardous scenarios, such as massive rainfall-induced contamination of source water, filter breakthrough or loss/breakdown of chemical disinfection system etc.
2. Likelihood	Ranking or scaling of the consequence (e.g. number of events per year).
3. Consequence	Ranking or scaling of the consequence (e.g. short-term injury or ill-health through to permanent disability or death).
4. Scale of effect	Consideration of the number of people affected by the hazard scenario
5. Risk score	Different weightings may be given to (2) & (3) and multiplied to give a value for each hazard scenario.
6. Rank	Each hazard scenario is then ranked, to provide a priority list for risk management

Source: Adopted from Hunter et al., 2003

Table 2.6: Simple risk scoring table for prioritizing risks

Likelihood	Severity of consequences				
	Insignificant	Minor	Moderate	Major	Catastrophic
Almost certain	5	10	15	20	25
Likely	4	8	12	16	20
Moderate	3	6	9	12	15
Unlikely	2	4	6	8	10
Rare	1	2	3	4	5

Source: Adopted from Hunter et al., 2003

2.8 Disability adjusted life years (DALYs)

Due to the diversity of health outcomes associated with different contaminants, a common metric that can take account of differing probabilities, severities and duration

of effects is needed for comparison purposes. DALY is an example of such a metric (WHO, 2004). This makes it possible to set one standard of acceptable health risk in a population, regardless of the type of detrimental health nature of its cause (Havelaar and Melse, 2003).

The DALY is a health gap measure that extends the concept of potential years of life lost due to premature death to include equivalent years of healthy life lost by virtue of individuals being in states of poor health or disability (Lopez et al., 2006).

Uses of DALYs

- To measure the burden of disease
- To increase the allocative efficiency of the sector by identifying health interventions, that for a given budget, will purchase the largest improvement in health.
- As aid for policy making and as a reference in setting reference levels of risks (WHO, 2004)

Use of DALYs in the water-related health outcomes has been applied elsewhere (Havelaar and Melse, 2003; Howard et al., 2006; Eisenberg et al., 2006; Howard et al., 2007)

Calculation of DALYs

DALYs for a disease or health condition are calculated from the number of deaths at each age multiplied by a global standard life expectancy for the age at which death occurs. To estimate YLD for a particular course for a particular time period, the number of incident cases in that period is multiplied by the average duration of the disease and the weight factor that reflects the severity of the disease on a scale from 0 (perfect health) to 1 (dead). In summary, DALY = YLD+ YLL; where, YLL is the years of life lost in a population due to premature mortality attributable to health condition, and YLD is the healthy years of life lost in a population due to disability attributable to a health condition. One DALY can be thought of as one year of healthy life and the burden of disease as a measurement of the gap between current health status and an ideal situation where everyone lives into old age free of disease and disability (WHO, 2002; Havelaar and Melse, 2003, Lopez et al., 2006).

Definition of disease outcomes

To assess the burden of disease due to any agent, the disease outcomes or endpoints associated with this agent need to be defined (figure 2.2). In addition, their severity weights and durations must be established and the number of cases of each outcome estimated.

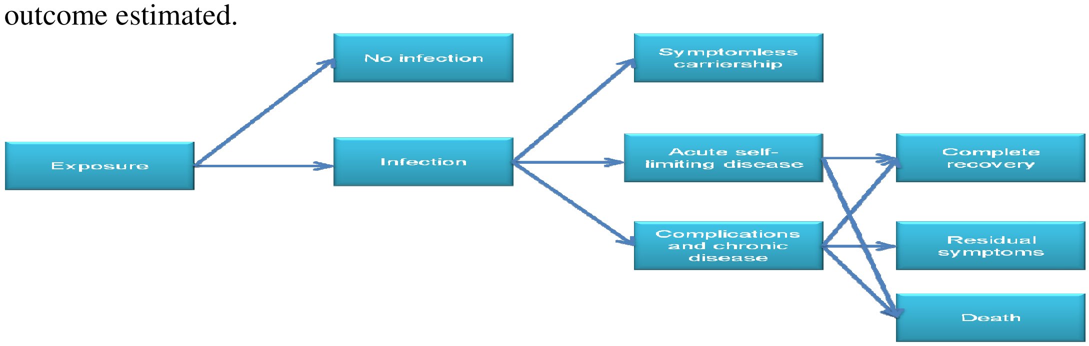


Figure 2.2: Chain model of infectious gastrointestinal disease.

(Source: Pruss and Havelaar, 2001)

Examples of endpoints for various agents are as illustrated below:

Campylobacter

Outcomes following *Campylobacter* infections include gastroenteritis disease and mortality especially among the elderly in developed countries and young children in developing countries. Haas et al., (1999) report a case fatality ratio of 0.1% Gastroenteritis might be mild, lasting about 5 days or severe, lasting about 8 days. It is estimated that 6% of all C*ampylobacter* cases in the population suffer from more severe disease and will consult a general practitioner. Chronic complications may range from reactive arthritis, Reiter's syndrome and Guillain-Barre syndrome (causing acute neuromuscular paralysis) (Havelaar and Melse, 2003; Haas et al., 1999).

Cryptosporidium

Cryptosporidium leads to watery diarrhoea with a mean duration of about 7 days. The infection becomes severe in AIDS patients. It may account for 16% of cases of diarrhoea in AIDS patients and as much as 50% in the developing world (Haas et al., 1999). *Cryptosporidiosis* is mild and self limiting for the population at large but has a high mortality rate among those who test positive for HIV (Haas et al., 1999; Havelaar and Melse, 2003; WHO, 2004).

Rotaviruses

The disease outcome is as illustrated in figure 2.3. The burden of disease of rotavirus infection is extremely high. The mean duration of the disease is 7 days (Havelaar and Melse, 2003; WHO, 2004; Bitton, 2005).

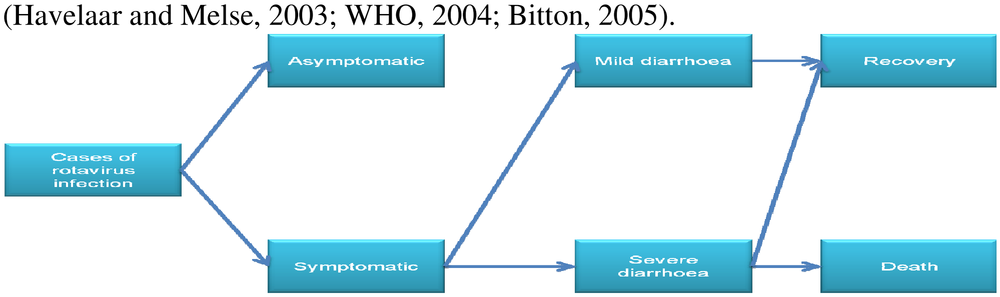


Figure 2.3 Disease model for rotavirus (Source: Havelaar and Melse, 2003)

Ascaris

The outcomes following *Ascaris* infection are as outlined in table 2.7

Table 2.7 Outcomes of *Ascaris* infection

Ascariasis sequelae	**Case definition**
High intensity infection	Infection with worms of the genus *Ascaris*, resulting in at least 20-40 worms per stool
Contemporaneous cognitive deficit	Reduction in cognitive ability in school-age children, which occur only while infection persists
Cognitive impairment	Delayed psychomotor development, impaired performance on language skills, motor skills and co-ordination that is equivalent to a 5-10 point deficit in IQ.
Intestinal obstruction	Blockage of the intestines due to worm mass

Source: Mathers et al., 2003.

3 Methodology

3.1 Study area

The study was undertaken in Accra Metropolitan Assembly (AMA), the capital city of Ghana (figure 3.1). Accra is located on the East coast of Ghana, approximately 5^0 North of the Equator, between longitudes 0^0 05' West and 0^0 20' West and between latitudes 5^0 30' North and 5^0 5' North. The city is one of the 5 districts that make the greater Accra region. AMA covers an area of 17,362 ha. It falls within the dry equatorial climatic region, and it receives an average annual rainfall of 810 mm/year. The climate is hot and humid, with mean temperatures varying from 24^0C in August and 27^0 C in March. The area is characterized by the coastal savannah vegetation type and it is subject to severe erosion due to its proximity to continental shelf, strong coastal and wind action. There is a well-established network of primary drains within the Metropolitan area. However, their poor maintenance, careless dumping of rubbish into drainage systems and poor development control has created severe flooding, siltation and pollution problems in many parts of the metropolitan area. From the 2000 population census, AMA's population stood at 1,658,937 with a population growth rate of 3.4% (Ghana Statistical Services, 2002). The overall annual average income of Accra is $915 per capita (AMA, 2002).

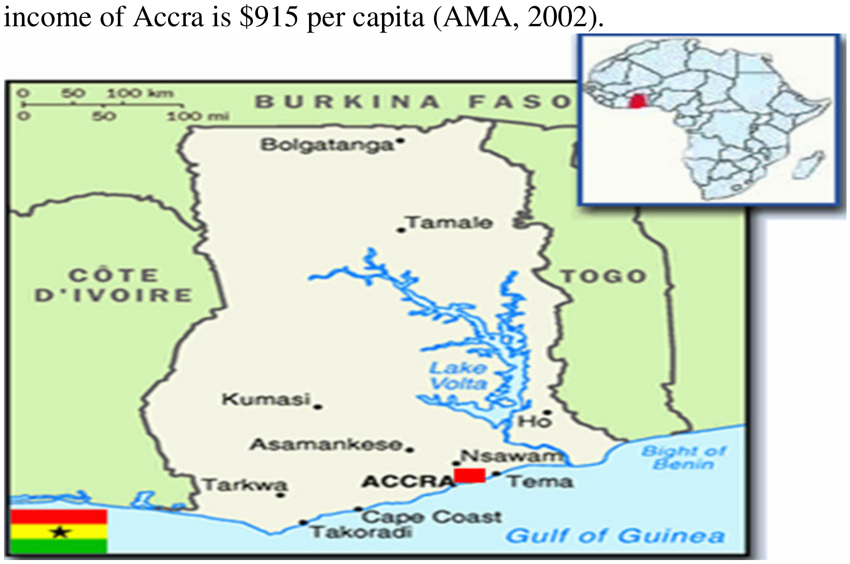


Figure 3.1: Location of Accra

3.2 Study population

The study population was 60% of AMA. This is the population that lives in the catchment of the Odaw River and Korle Lagoon (figure 3.2), (Abraham et al., unpublished). The criteria for the selection of this population was that the area is drained by the major Accra drain, the Odaw River which is also prone to flooding every year during heavy rainfall. The Odaw River flows into the ocean through the

Korle lagoon, which is also considered as one of the world's dirtiest places (IDRC, 1996). According to Songsore et al., (2005), some of the areas around the Odaw drain have a severe environmental burden.

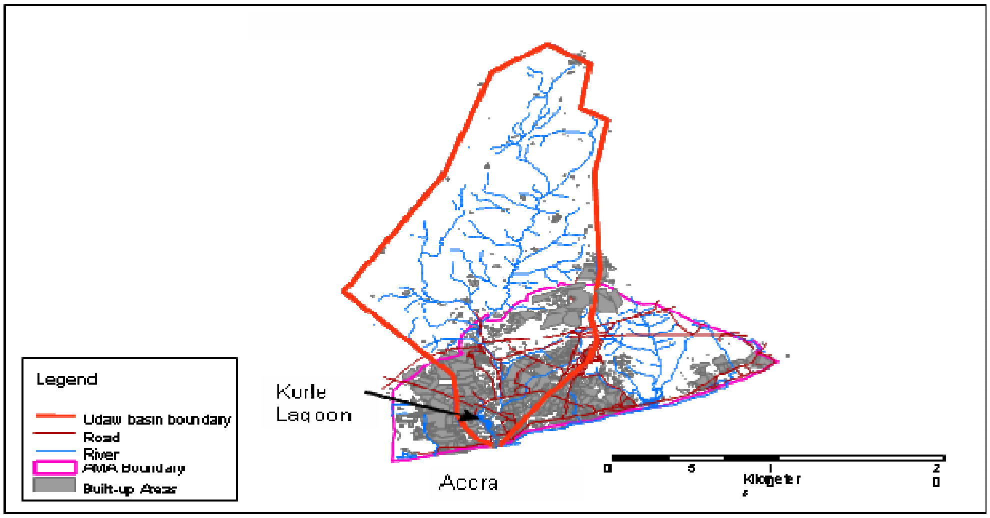


Figure 3.2: Accra and the Odaw River catchment area (Source: Adopted from IWMI)

3.3 General methodology

3.3.1 Desk study

Literature review was done in order to gather baseline information on the Accra urban water system and to identify parameters to be used in risk calculations.

3.3.2 Fieldwork

This was done by visiting various institutions (appendix 1) for obtaining secondary data and for interviews with key staff. For every visit, a checklist of data (appendix 1) was used in order to make sure that all the relevant information from every institution had been obtained. Secondary data obtained included waterborne disease incidence dating from 2003 to 2005. Water quality data for Weija and Kpong water treatment plants was also obtained from the two treatment plants. Observation was also used to identify key exposure points/scenarios

3.3.3 Microbial risk assessment

The steps outlined in Haas et al., (1999), were followed. The steps are outlined in detail below:

3.3.3.1 Hazard identification

In this case, a hazard was defined as the pathogen that causes waterborne diseases. All pathogens that are excreted in faeces could potentially be found in wastewater (Mara and Horan, 2003; Bitton, 2005). Literature review was done in order to identify waterborne pathogens that occur in Ghana. The pathogens identified (table 3.1), had

been detected either in sewage, or stools of infected people. Due to the large range of pathogens causing waterborne illness: bacteria, protozoa, viruses and helminths (Payment and Hunter, 2001), only four reference pathogens (WHO, 2004) were chosen to be used in the study since it is not feasible to assess all the impacts of all waterborne pathogens in a risk assessment at the same time.

Table 3.1: Wastewater pathogens occurring in Ghana as identified from literature

Pathogen	Associated disease	Reference
Salmonella typhi	Typhoid fever	Mills-Robertson et al., 2003; Nakano et al., 1990; Mensah et al., 1999; Mensah et al., 2000; Sackey et al., 2001
Vibrio cholerae	Cholera	Newman et al., 2004; Newman, 2001
Shigella dysenteriae	Bacillary dysentry	Nakano et al., 1990; Mensah et al, 1999, Mensah et al., 2001; Sackey et al., 2001
Campylobacter jejuni	Gastroenteritis	Nakano et al., 1990; Sackey et al., 2001
Pathogenic *E. coli*	Gastroenteritis, hemolytic uremic syndrome	Nakano et al., 1990; Mensah et al., 1995; Mensah et al, 1999; Mensah et al., 2001; Sackey et al., 2001
Ascaris lumbricoides	Ascariasis – intestinal obstruction in children (small intestine)	Nakano et al., 1990
Giardia lamblia	Giardiasis (affects GI tract)	Nakano et al., 1990
Entamoeba histolytica	Amoebic dysentery (affects the gastrointestinal tract)	Nakano et al., 1990
Rotavirus agent	Infantile acute gastroenteritis	Nakano et al., 1990
Staphylococcus aureaus	Gastroenteritis	Mensah et al., 1995; Mensah et al., 2000; Agbodaze et al., 2005,
Cryptosporidium parvum	Gastroenteritis	Ayeh-Kumi, unpublished

3.3.3.2 Exposure assessment

Using the conceptual model, (figure 3.3), a survey was done to determine the possible exposure points. This was complemented with interviews from water/wastewater experts. Some principles of Hazard Analysis and Critical Control Points (HACCP) procedure (Hunter et al., 2003; Westrell et al., 2004) were followed at the drinking water treatment plants in order to identify critical points of pathogen breakthrough.

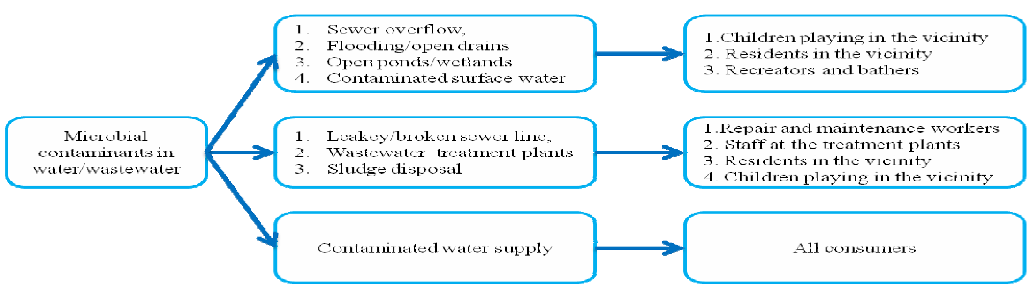


Figure 3.3 Conceptual model showing potential exposure pathways to waterborne pathogens

Exposure volumes were determined from literature, while exposure doses were determined from data obtained at the water treatment plants (water supply) as well as literature (sanitation). The exposed population was determined by field surveys and by interviews with people with knowledge on the particular exposure

point. The 2000 national population census (Ghana Statistical Services, 2002) was used to determine the exposure population exposed to flooding of the Odaw drain, open drainage channels and contaminated water supply. Determination of the exposed population and ingested pathogen dose is outlined in detail below:

3.3.3.2a Sanitation

i). Recreational swimming

The faecal septage that is disposed of at the Lavender disposal point (marine disposal) flows downstream to some of the beaches that are frequented to in Accra. Labadi beach was chosen as one of the exposure point since it is among the largest in Accra. The exposure volume was assumed to be 100ml, and the mean bathing time was assumed to be 2 hours per day (Ashbolt et al., 1997). The concentration of pathogens in the recreational water was taken from literature (table 3.2) based on the concentrations in raw sewage. A dilution factor of 1000 (Ottoson, 2005) was used to estimate the final concentration in the recreational water.

Table 3.2: Pathogen concentrations in raw sewage (WHO, 2003)

Pathogen	**Concentration, cfu/100ml**	**Concentration, cfu/100ml (With dilution factor of 1000 [a]**
Campylobacter	10^4-10^5	55
Rotaviruses	400-85000	42.7
Cryptosporidium parvum cysts	0.1-39	0.02
Ascaris spp	0.5-11	0.006

[a] *Based on the assumption found in Ottoson, (2005).*

Number of Swimmers per year

Determination of number of swimmers was done by interviewing workers at the Labadi beach, and by estimating from the amount of revenue (beach fee) collected per day. It was found out that the number of swimmers/beach goers varies with seasons. It was estimated that more than 100,000 people visit the beach each year but only about 50% of these swim (table 3.3). An assumption was made that 60% of the total number of swimmers (49,796), came from the Odaw catchment (the study population). Thus the exposure population for recreational swimming was 29,878.

Table 3.3: Number of swimmers per year

Season	**Number of swimmers**			
	Weekdays	**Weekends**	**Public holidays**	**Total**
January - April (Harmattan)	60-100 Average: 80			9600
May-July (rainy)	10-15 Average: 13			1196
August-December	100-200 Average: 150	400-500 Average: 450	1000-2000 Average: 1500	39000
Total per annum				**49796**

ii). Flooding of the Odaw drain

Interviews with key stakeholders revealed that flooding occurs every year during the rainy season and many people are affected. This is also reported in Songsore et al.,

(2005). Discussions with various experts from some of the institutions outlined in 3.2, led to the assumption that every 100m from the drain floods. Using this information, the affected area was calculated (table 3.4). Determination of the population affected was done using information from IMDC, (2000). Where the population density of the affected area was not known, the population density of the AMA (250 people/Ha) was used (Ghana Statistical Service, 2002).

Table 3.4: Population exposed to flooding of the Odaw drain

Residential area	Area in ha [a]	Population density/ha	Population affected
Korle Gonno	7.4	47	348
James town	7.4	295	2183
Korlebu hospital area	10.9	250	2725
Lartebiokorshie	10.9	171	1864
Ussher town	12	250	3000
South Industrial Area	25.4	21	534
Adabraka	16.2	177	2868
Awudome estate	9.4	250	2350
North Industrial area	9.4	95	893
Kokomlemle	19.75	171	3378
Kpehe	23	291	6693
Alajo	42.9	276	11801
Kotobabi	13.6	313	4257
Dzorwulu Residential	33.8	29	981
Roman Ridge	16.9	22	372
Airport Residential	27.25	48	1308
Police Training Department and Telecom University area	31.4	250	7850
Ablemkpe	15.7	62	974
Asylum Down	20	192	3840
Accra New town	10.35	458	4741
Mamobi	10.35	250	2588
Nima	41.4	404	16726
Christian Village	34.35	250	8588
West Legon	68.9	250	17225
Shiashe	13.1	11	145
South Legon	13.1	250	3275
East Legon	26.2	11	283
Total			**111,790**

[a] *Area affected by floods*

21.2% of the total population in AMA is 0-9 years (Ghana Statistical Service, 2002), thus 23,699 children. Different exposure scenarios were identified for this pathway as shown in table 3.5. Ingestion volumes were estimated from literature (Westrell et al., 2004) while frequency was based on people's knowledge that flooding occurs once per year.

Table 3.5: Exposure during flooding of the Odaw drain

Exposure	Volume ingested (ml) [a]	Frequency (/annum)	Affected population [b]
2. Unintentional ingestion of flood water	1	1	111,790
3. Unintentional immersion at lagoon	30	1	10
4. Children playing in flood water	1	1	23,699

[a] *Westrell et al., 2004;* [b] *From table 3.4*

Pathogen concentration in the Odaw drain

Faecal coliform concentration in the Odaw River was found to be 1,217,500-cfu/100ml (Nana-Amankwaah, unpublished). The faecal coliforms were assumed to be *E. coli* (Howard et al., 2006). The ratios of [*E. coli*]: [pathogen] in table 3.6 were used to calculate the concentration of *Campylobacter,* rotaviruses, *Cryptosporidium* and *Ascaris* (table 3.7).

Table 3.6: Ratio of [*E. coli*]: [pathogen]

Ratio	Median (90% confidence interval)
Ratio of [*E. coli*]: [virus]	10^5 (10^4 to 10^6)
Ratio of [*E. coli*]: [bacteria]	10^5 (10^4 to 10^6)
Ratio of [*E. coli*]: [protozoa]	10^6 (10^5 to 10^7)
Ratio of [*E. coli*]: [protozoa]	10^6

Source: Adapted from Howard et al., 2007; Mara et al., 2007.

Table 3.7: Pathogen concentrations in Odaw drain [a]

Pathogen	Concentration, cfu/100ml	Concentration, cfu/1ml	Concentration, cfu/30ml
Campylobacter	12.8	0.13	3.84
Rotaviruses	12.8	0.13	3.84
Cryptosporidium	1.2	$1.2*10^{-2}$	0.36
Ascaris	1.2	$1.2*10^{-2}$	0.36

[a] *Based on the faecal coliform concentration of 1,217,500 cfu/100ml in the Odaw drain (Nana-Amankwaah, unpublished) and the [E. coli]: [pathogen] ratio in table 3.6.*

iii). The UASB treatment plant

The UASB treatment plant near Korle lagoon was designed to treat sewage from Accra Metropolitan Assembly. Currently, only 5% of the population in AMA is connected to the sewerage network (Obuobie, 2006). During the study period, the plant was not working. This is because, the industrial discharge and storm water drains were apparently also connected to the plant and since it wasn't designed to handle such; it broke down (personal communication with the plant manager).

The plant still receives raw sewage but then there is a by-pass from the inlet works direct to the Sea. There were 10 workers who desludge the inlet works on a monthly basis, 3 laboratory workers who take samples from the inlet works daily for laboratory analysis, 10 workers who remove debris from the inlet works daily during the rainy season (May-July). Interviews with workers revealed that they sometimes do experience diarrhoea, coughing, nausea and skin irritation. Table 3.8 shows exposure scenarios at the UASB treatment plant.

Table 3.8: Exposure at the UASB treatment plant

Exposure	Volume ingested (ml)	Frequency (/annum)	Affected population
5. Workers desludging the UASB treatment plant once monthly	5 [a]	12	10
6. Workers removing debris from the inlet works daily during the rainy season	1 [a]	90	10
7. Workers taking samples from the inlet works for laboratory analysis	0.1 [b]	1	3

[a] *Estimated from Westrell et al., 2004;* [b] *Estimated from Ashbolt et al., 2005*

Estimation of the pathogen concentrations in the UASB (table 3.9) inlet works was based on the pathogen concentrations in the raw sewage (table 3.2).

Table 3.9: Estimation of pathogen concentration at the UASB inlet works [a]

Pathogen	Cfu/5ml	Cfu/1l	Cfu/0.1ml
Campylobacter	2,750	550	55
Rotaviruses	2135	427	42.7
Cryptosporidium	1	0.2	0.02
Ascaris	0.29	$5.8*10^{-2}$	$5.8*10^{-3}$

[a] *Based on pathogen concentration in raw sewage in table 3.2*

iv). Faecal septage disposal place

70 % of the population in AMA use septic tanks for domestic sewage treatment (Obuobie et al., 2006). When the septic tank fills up, the faecal septage is then collected and disposed off on a hill, about 30 meters from the sea and allowed to flow into the sea. At the disposal place, popularly known as Lavender hill, there is always a tanker arriving after every 3 minutes (figure 3.3). There were about 100 workers handling this exercise. The place is also used for open defecation as shown in figure 3.4 below. Children from nearby schools, apart from defecating at the place, also use it as a play ground. This could lead to them ingesting some contaminated sand.

Figure 3.3: Disposal of septage in the sea (Lavender hill, Accra)

Figure 3.4: Open defecation at Lavender hill, Accra

The same place is also used by fishermen, who while pulling out the nets from the water (figure 3.5); come into direct contact with the septage as it flows into the sea. As it was observed, these fishermen were sometimes covered by the wave at the shore and therefore, it was assumed that the scenario could lead to them ingesting some contaminated water

Figure 3.5 Fishermen pulling out a net from the sea at Lavender hill

Table 3.10 summarises exposure scenarios at the faecal septage disposal point.

Table 3.10: Exposure at the UASB treatment plant

Exposure	Volume ingested (ml)	Frequency (/annum)	Affected population
8. Workers handling septage	1 [a]	317 [b]	100
9. Children playing with contaminated sand	5 [c]	2 [d]	8037 [e]
10.Fishermen ingesting contaminated water at the shore	1	1	10

[a] *Adapted from Ashbolt et al., 2005;* [b] *Transport is daily except on Sundays*
[c] *Adapted from Westrell et al., 2004*
[d] *Adjusted from the value assumed for developed countries (Westrell et al., 2004), as this happens more frequently in developing countries*
[e] *Half the population of children from Korle Gonno and Mamprobi because the study only targeted children of school age. The population of Korle Gonno is 24082 and for Mamprobi is 51730 (IMDC, 2000). 21.2% of the population are children 0-9 years (Ghana Statistical Service, 2002).*

Table 3.11 shows estimation of pathogen concentration in the faecal septage based on literature.

Table 3.11: Estimation of pathogen concentration in the faecal septage based on literature

Pathogen	Cfu/L	Cfu/5ml	Cfu/1ml	Reference
Faecal coliform	10^7	$5*10^4$	10^4	SaniCon, 2002
Cryptosporidium	10^2-10^3	2.8	0.6	SaniCon, 2002
Helminth eggs	20-60,000	150	30	Strauss et al., 1997, Mara 1978)
Campylobacter	100	0.5	0.1	Estimation [a]
Rotavirus	100	0.5	0.1	Estimation [a]

[a] *Based on ratios in table 3.6 and faecal coliform concentration of 10^7cfu/litre.*

v). Open drainage channels

AMA is characterized by many open drainage channels as had been observed during the field survey. This is also reported in Obuobie et al., (2006). In addition, Songsore

et al., (2005), identified open drainage channels as one of the environmental health problems in AMA. Most people have connected gutters from their houses to the open drains (figure 3.6) and therefore, the domestic wastewater is discharged directly into these drains. During the survey, children could be seen playing near the open drains and stagnant pools.

Figure 3.6 Gutters from the house connected directly to the open drain

This was therefore identified as one of the exposure points. Children were identified as the exposed population as they would ingest sand/any other contaminated formites/droplets of water as they play. Songsore et al., (2005) describes that the environmental burden in Greater Accra is highest in the low income areas and therefore, this is the population that was identified for study. Table 3.12 shows the population of children 0-4 years in the low income residential communities of Odaw catchment. Frequency of exposure was assumed to be 4; this was adjusted from the value (2) proposed for child playing at wetland inlet for developed countries (Westrell et al., 2004), as it was assumed that playing near open drains/with contaminated sand happens more frequently in developing countries than developed ones. The same authors were used to estimate the exposure volume of 5g per exposure. The concentration of pathogens in the soil was assumed to be the same as that of the open drainage channels.

Estimation of pathogen concentration in the open drainage channels

The pathogen concentration in the open drainage channels (table 3.13) was assumed to be the same as in the Odaw River, which had a faecal concentration of 1,217,500 cfu/100ml (Nana-Amankwaah, unpublished). The faecal coliforms were assumed to be *E. coli* (Howard et al., 2006). The concentration of *Campylobacter,* rotaviruses, *Cryptosporidium* and *Ascaris* were calculated based on the ratio of [*E. coli*]: [pathogen] in table 3.6.

Table 3.12: Population of children exposed to hazards from open drainage channels

Residential community	Total Population	Number of children (0-4 years) [a]
Accra Central	8446	887
Adedenkpo	22250	2336
James town	42300	4442
Korle Dudor	25824	2712
Korle Gonno	24082	2529
Accra New Town	50685	5323
Mamprobi	51730	5432
Nima	63781	6697
Sabon zongo	21507	2258
Tudu	11688	1227
Abeka	83137	8729
Bubuashie	72787	7643
Abossey Okai	85097	8935
Alajo	46688	4902
Avenor	6299	661
Kokomlemle	24750	2599
Kotobabi	44175	4638
Lartebiokorshie	41876	4397
North Industrial area	15754	1654
Odorkor	24950	2620
South Industrial area	6204	651
Total	**774,010**	**81,272**

[a] *10.5% of the population are children aged 0-4 years (Ghana Statistical Service, 2002)*

Table 3.13: Estimation of pathogen concentration in the open drainage channels [a]

Pathogen	Concentration, cfu/5ml
Campylobacter	0.64
Rotaviruses	0.64
Cryptosporidium	0.06
Ascaris	0.06

[a] *Based on the faecal coliform concentration of 1,217,500 cfu/100ml in the Odaw river (Nana-Amankwaah, unpublished) and the [E. coli]: [pathogen] ratio in table 3.6.*

3.3.3.2b Water supply

In this section, some principles of HACCP were applied to assess the efficiency of the water treatment plants. HACCP is a principle applied to identify key pathogen breakthrough points within the treatment processes (Hunter et al., 2003).The processes of removal of microbes from water include pre-treatment, coagulation, flocculation, sedimentation, filtration and disinfection (LeChevallier and Au, 2004). Therefore, these were identified as the critical points that could lead to pathogen breakthrough during treatment. The critical points were then observed to ascertain whether they were working under appropriate conditions. In the event, some errors (table 3.14) were identified which could possibly lead to the pathogen breakthrough. These were: power outage (disinfection errors and coagulation errors) and filtration errors at Weija water treatment plants; and coagulation, disinfection and filtration errors at Kpong treatment plants.

Table 3.14 Incidents at Weija and Kpong treatment plants

Incident	Frequency(/ annum)	Duration, hours/incident	Consequence
Weija			
Power outage	1040 (20 in a week) [a]	0.08 (5 minutes)	No coagulation/no chlorination as the pumps will not function. In the absence of coagulation, slow sand filtration will achieve minimal performance (WHO, 2004)
Clogging of filters with algae	1	24 (1 day)	Inadequate removal of pathogens
Kpong			
Inadequate disinfection [b]	365[b]	24	Inadequate removal of pathogens
Filter backwashing problem	1	24	Inadequate removal of pathogens
No Coagulation [c]	365	24	Low removal of microbes during this stage and the filtration stage

[a] *Taken as the most frequent. Sometimes they are higher*
[b] *The Chlorine pump was not working and therefore Calcium hypochlorite was used. The plant is designed to use 12 bags of 45 kg/ day but due to inadequate manpower for mixing, only 5 bags are used. This had been going on for the past 1 year.*
[c] *This was a normal operation based on the assumption that the source water had a very low turbidity and thus no coagulation needed.*

Literature based methodology (WHO, 2004) was used to estimate the likely removal of pathogens through different treatment processes by assigning log removal credits for every treatment process present (table 3.15). This methodology has also been applied in related studies (Howard et al., 2006; Eisenberg et al., 2006).

Table 3.15: Log reduction of micro organisms in drinking water by various processes [a]

Process	Bacteria	Viruses	Protozoa
Coagulation/flocculation/sedimentation			
Baseline removal	0.2 (30%)	0.2 (30%)	0.2 (30%)
Maximum removal	1 (90%)	0.52 (70%)	1 (90%)
Granular high-rate filtration			
Baseline removal	-	-	0.52 (70%)
Maximum removal	2 (99%)	3 (99.9%)	3 (99.9%)
Slow sand filtration			
Baseline removal	0.3 (50%)	0.1 (20%)	0.3 (50%)
Maximum removal	2.3 (99.5%)	4 (99.99%)	2 (99%)
Chlorination [b]			
Median and range of removal	3.5(2.5-5.0)	2.0(1.5-3.0)	0.4(0-1)

[a] *Source: Adopted from WHO, 2004*
[b] *Adopted from Westrell et al., (2003), showing median and range of removal*

Table 3.16 shows log reduction/treatment effect of pathogens at the two treatment plants in the event of failures.

Table 3.16: Log/treatment effect of pathogens at the two treatment plants in the event of failures, based on table 3.15

Incident	*Campylobacter*	Rotavirus	*Cryptosporidium* [a]
Weija treatment plant			
1. Power Outage (Disinfection error, coagulation error, filtration error)			
Coagulation/ Flocculation	0	0	0
Slow sand filtration [b]	0.3	0.1	0.3
Chlorination	0	0	0
Total log reduction	**0.3**	**0.1**	**0.3**
Treatment effect	***0.4988***	***0.2057***	***0.4988***
2. Filtration error			
Coagulation/ Flocculation	1	0.52	1
Slow sand filtration	0	0	0
Chlorination	3.8	2.3	0
Total log reduction	**4.8**	**2.83**	**1**
Treatment effect	***0.999984***	***0.99852***	***0.9***
Kpong treatment plant			
3. Disinfection error			
Coagulation/ Flocculation [c]	0.5	0.26	0.5
Rapid sand filtration [d]	1	1.5	1.5
Chlorination [e]	1.6	1	0
Total log reduction	**3.1**	**2.76**	**2**
Treatment effect	***0.9992***	***0.9983***	***0.99***
4. Coagulation error			
Coagulation/ Flocculation [c]	0.5	0.26	0.5
Rapid sand filtration [d]	1	1.5	1.5
Chlorination [e]	1.6	1	0
Total log reduction	**3.1**	**2.76**	**2**
Treatment effect	***0.9992***	***0.9983***	***0.99***
5. Filtration error			
Coagulation/ Flocculation	0.5	0.26	0.5
Rapid sand filtration	0	0	0
Chlorination	1.6	1	0
Total log reduction	**2.1**	**1.26**	**0.5**
Treatment effect	***0.992***	***0.945***	***0.6838***

[a] *Chlorine was assumed to have no effect on Cryptosporidium (WHO, 2004)*
[b] *If there is no coagulation, slow sand filtration will only achieve baseline removal (table 3.15)*
[c] *50% removal was assumed since the required log removal is a combination of both coagulation and filtration (Stanfield et al., 2003). Currently no coagulation takes place at Kpong treatment plant*
[d] *50% removal was assumed since effective filtration depends on effective coagulation (LeChevallier and AU, 2004; Stanfield et al., 2003)*
[e] *Using 5 bags of the disinfectant instead of 12 means that only 42% disinfection is achieved*

Volume of drinking water per day

The volume of water consumed per day was estimated to be 2.9 litres per person. This was based on a study done in Bangladesh, another developing country (Watanabe et al., 2004, as cited in Howard et al., 2007). This could be a source of uncertainty as drinking water volume varies from place to place.

Estimation of pathogen concentrations in raw water

Table 3.17 shows average pathogen concentration in raw water at the two treatment plants. This was estimated form the microbiological results of 2001 to 2006(Weija) and 2006 (Kpong).

Table 3.17: Average daily pathogen concentration in raw water at the two treatment plants

Treatment plant	**Thermotolerant coliforms (MPN/100 ml)**	**Reference**
Weija	16	Weija microbiological reports
Kpong	8	Kpong microbiological reports

E. coli concentrations were estimated based on the assumption that 95% of the thermotolerant coliforms were *E. coli* (WHO, 1996). This assumption was also used in the estimation of risks attributable to water supply in Kampala (Howard et al., 2006). This therefore translated into 152 *E. coli*/litre, in the raw water at Weija treatment plant and 76 *E. coli/*litre in the raw water at Kpong treatment plant respectively. Estimates of the pathogen concentration in the raw water at the two treatment plants (table 3.18) were done based on the *E. coli*]: [pathogen] ratios in table 3.6.

Table 3.18: Concentration of pathogens in the raw water at the two treatment plants

Pathogen	**Ratio of *pathogen: E .coli*** [a]	**Pathogen concentration/litre**	
		Weija [b]	**Kpong** [c]
Campylobacter	$1:10^5$	$1.5*10^{-3}$	$7.6*10^{-4}$
Rotavirus	$1:10^5$	$1.5*10^{-3}$	$7.6*10^{-4}$
Cryptosporidium	$1:10^6$	$1.5*10^{-4}$	$7.6*10^{-5}$

[a] [E. coli]: [pathogen]; [b] 152 E. coli/litre in raw water; [c] 76 E. coli/litre in raw water

The drinking water quality (table 3.19) was then determined using the following formula:

$C_D = C_R * (1 - PT)$ (Source: WHO, 2004) **(3.1)**

Where:

C_D = Drinking water quality

C_R = Raw water quality, organisms per litre

PT = Treatment effect

Dilution in the distribution system in the event of power outage at Weija

Two plants at Weija, namely: Candy and Bamang have a raw water storage tank. These plants operate by a combination of pumping and gravity. In the event of power outage, water will still flow and therefore pass through all stages untreated. It takes workers about 5 to 10 minutes to shut down the plant in the event of power outage. Water will still flow for 5 minutes without treatment but then it will mix with the already treated water in the reservoir that has some chlorine residual. The volume of water treated at Weija is about 170,000 m^3/day. This is about 118,056 litres/minute. Therefore 590,278 litres of untreated water will reach the reservoir and mix with clean water containing chlorine residual. The assumption made therefore was that the treated water in the reservoir will dilute the incoming untreated water and therefore the pathogens reaching the consumers will be very minimal.

Table 3.19: Drinking water quality based on the calculation of estimated log removals following failure events

Pathogen	Raw water quality (cfu/l)	Treatment effect (PT)	Drinking water quality (cfu/l)[a]	Cfu/2.9 litres[b, c]
Weija				
Power outage[c]				
Campylobacter	$1.5*10^{-3}$	0.4988	$7.5*10^{-4}$	$7.6*10^{-6}$
Rotavirus	$1.5*10^{-3}$	0.2057	$1.2*10^{-3}$	$1.2*10^{-5}$
Cryptosporidium	$1.5*10^{-4}$	0.4988	$7.5*10^{-5}$	$7.6*10^{-7}$
Filtration error				
Campylobacter	$1.5*10^{-3}$	0.999984	$2.4*10^{-8}$	$7.0*10^{-8}$
Rotavirus	$1.5*10^{-3}$	0.99852	$2.2*10^{-6}$	$6.4*10^{-6}$
Cryptosporidium	$1.5*10^{-4}$	0.99	$1.5*10^{-5}$	$4.4*10^{-5}$
Kpong				
Disinfection error				
Campylobacter	$7.6*10^{-4}$	0.9992	$6.1*10^{-7}$	$1.8*10^{-6}$
Rotavirus	$7.6*10^{-4}$	0.99826	$1.3*10^{-6}$	$3.8*10^{-6}$
Cryptosporidium	$7.6*10^{-5}$	0.99	$7.6*10^{-7}$	$2.2*10^{-6}$
Coagulation error				
Campylobacter	$7.6*10^{-4}$	0.9992	$6.1*10^{-7}$	$1.8*10^{-6}$
Rotavirus	$7.6*10^{-4}$	0.99826	$1.3*10^{-6}$	$3.8*10^{-6}$
Cryptosporidium	$7.6*10^{-5}$	0.99	$7.6*10^{-7}$	$2.2*10^{-6}$
Filtration error				
Campylobacter	$7.6*10^{-4}$	0.992	$6.1*10^{-6}$	$1.8*10^{-5}$
Rotavirus	$7.6*10^{-4}$	0.945	$4.2*10^{-5}$	$1.2*10^{-4}$
Cryptosporidium	$7.6*10^{-5}$	0.6838	$2.4*10^{-5}$	$7.0*10^{-5}$

[a] *based on equation 3.1*
[b] *CD*2.9 litres,*
[c] *The final water quality in the 2.9 litres following power outage at Weija plant was based on the r dilution within the distribution system, as explained in the previous paragraph.*

Estimation of number of people exposed

The population of Odaw river catchment is 995,363 people (60% of the AMA population) (Abraham et al., unpublished). Weija treatment plant contributes 65% (646,986 people) of the total domestic water to AMA while Kpong treatment plant contributes 35% (348,378 people) (Personal communication with station manager, Weija treatment works).

Risk of infection from the distribution system

Interviews with various people revealed that there were intermittent water supplies in Accra as well as fluctuations in pressure. It has also been estimated that only approximately 25% of residents have a 24hr water supply. About 30% have an average of 12hrs service every day for five days a week. Another 35% have service for two days each week while the remaining residents on the outskirts of Accra are completely without access to piped water supply (Wateraid, 2006). Ghana Water Company estimates that upto 30% of water supplied to Accra is lost through pipe leakages (GWCL, 1997). In addition, it is estimated that there are about 120-150 pipe breakages per month and these will last for a period of about 24 hours before they are discovered. Leakage incidents range from 500-600 per month and mostly last between 3-7 days before they are discovered and repaired. Most leakages are due to illegal connections.

Microbiological quality of tap water

Secondary data was used to determine the concentration of pathogens in the tap water in AMA (Cobbina, 2004). Research was done on three different districts in western Accra (Bortianor, Accra North West 1 and Accra West). 135 samples were analysed for water quality parameters over a five-month period. The results showed a mean faecal coliform of 0.23-cfu/100ml with a range of 0-10-cfu/100ml, mean total coliform of 6.2-cfu/100ml with a range of 0-120-cfu/100ml and mean residual chlorine of 0.4mg/l with a range of 0.1-1.4mg/l. Faecal coliforms were reported in only two of the five months, thus in 40% of the time. The study also showed that tap water had chlorine concentrations that decreased with increased distance from the water treatment plant. Social survey was also conducted and the respondents complained that water quality was sometimes poor as it was coloured with dirt particles especially when taps were re-opened after closure. In addition, respondents said that they experienced odour problems and pipe breakages.

Using the above study, a crude estimate of probability of infection with pathogens from the water distribution system was done with the assumptions that the concentration of pathogens was a representation of the whole system in Accra Metropolitan Assembly. This assumption could either underestimate the risk or overestimate due to the fact that some parts of Accra experienced more problems with their water supply compared to the rest. In addition, the rate of intermittent supply was unequally distributed (Wateraid, 2006).

The faecal coliforms were assumed to be *E. coli* (Howard et al., 2006). Therefore pathogen concentration in the Accra water distribution system (table 3.20) was calculated based on the [*E. coli*]: [pathogen] ratios in table 3.6 and the faecal coliform concentration of 0.23-cfu/100ml (Cobbina, 2004).

Table 3.20: Pathogen concentration in Accra Water distribution system

Treatment plant	Concentration, cfu/litre	Concentration, cfu/2.9 litres
Campylobacter	$2.3*10^{-5}$	$6.7*10^{-5}$
Rotavirus	$2.3*10^{-5}$	$6.7*10^{-5}$
Cryptosporidium	$2.3*10^{-6}$	$6.7*10^{-6}$

[a] *Based on faecal coliform concentration of 0.23-cfu/100ml (Cobbina, 2004)) and [E. coli]: [pathogen] ratios in table 3.6*

Population exposed to contaminated water in the distribution system

The population in the Odaw catchment is 995,363. Accra New town with a population of 50,685 (Ghana Statistical services) has no water supply (GWCL, unpublished). Therefore, the population of people exposed is 944,678.

Frequency of exposure to contaminated water in the distribution system

Cobbina, (2004), reported that faecal coliforms were present in 2 months out of the five months that the study was undertaken. This is 40% of the study time. Using the above study, an assumption was made that faecal coliforms were present in 40% of the year thus 146 days.

Risk of infection from the distribution system using incidents

In the absence of adequate data on the distribution network, risk of infection could be estimated based on incidents. Westrell et al., (2003), assumed effects for each recorded failure in the distribution system of the city of Gothenburg, Sweden. Failures in the distribution system were derived from the incidence reports of 20 years and personnel interviews. When cross-connections with pressurized sewage pipes were detected as the cause of contamination, the concentration of pathogen ingress into the pipes was deduced from pathogen data from sewage and the dilution of sewage in the drinking water. The pathogen concentrations in the drinking water were then translated to a risk of infection to the exposed consumers taking the size of the affected areas and the duration of the incidents before they were discovered.

In this study, the approach of Westrell et al., (2003), was adopted. About 30% of the population have an average of 12hrs service every day for five days a week (60 hours/week with water). Another 35% have service for two days each week (48 hours/week with water) (Wateraid, 2006). From this, it was assumed that the time that there was no water in the pipe, microbes gained access into the pipes via diffusion amongst other pathways (Karim et al., 2001 as cited in LeChevallier et al., 2003).

Table 3.21: Incidents in the distribution system

Incident	Frequency (per annum) [a]	Consequence [b]	Population affected
Pollution entering part of system without pressure (108 hours per week)	234	0.1% sewage	298,609 [c]
8. Pollution entering part of system without pressure (120 hours per week)	260	0.1% sewage	348,378 [d]

[a] *based on the number of days/annum without water in the pipe;* [b] *Adjusted from Westrell et al., (2003)*
[c] *30% of the Odaw catchment population that receives water 12 hours every day, five days a week (Wateraid, 2006);*
[d] *35% of the Odaw population that receives water 2 days every week (Wateraid, 2006)*

The final water quality reaching the consumers was based on the dilution in the distribution system.

3.3.3.3 Dose- response assessment

Point estimate (Haas et al., 1999) was used to estimate the probability of infection, while illness (symptomatic cases) was chosen as the final endpoint. The daily dose of pathogens consumed was converted to a daily probability of infection (P_I) according to the dose-response relationships in table 3.22. The annual probability of infection per person, annual infections, probability of developing disease following infection and yearly symptomatic cases were calculated using the formulas in table 3.23.

Table 3.22: Dose-response relationships for the pathogens used in the study

Organism	Model [a]	Parameters	Reference	Equation number
Campylobacter	Beta-Poisson $P_I = 1-\left[1+\frac{N}{N_{50}}\left(2^{1/\alpha}-1\right)\right]^{-\alpha}$	α= 0.145 N_{50}=896	Haas et al., 1999	**3.2**
Rotavirus	Beta-Poisson $P_I = 1-\left[1+\frac{N}{N_{50}}\left(2^{1/\alpha}-1\right)\right]^{-\alpha}$	α= 0.2531 N_{50}=6.17	Haas et al., 1999	**3.2**
Cryptosporidium	Exponential $P_I = 1-\exp(-rd)$	$r=4.19*10^{-3}$	Teunis et al., 1996	**3.3**
Giardia [b]	Exponential $P_I = 1-\exp(-rd)$	r=0.0199	Teunis et al., 1996	**3.3**
Ascaris [b]	Exponential $P_I = 1-\exp(-rd)$	r=0.0199	Assumption	**3.3**

[a] P_I is the probability of infection, α and r are parameters describing probability of infection; N=dose of ingested pathogens, N_{50}= number that will infect 50% of the population.
[b] Since no published dose-response parameters for Ascaris were identified in literature, the value (r=0.0199) for Giardia lamblia was used as they have the same infective dose (Bitton, 2005).

Table 3.23: Formulas for annual infections and symptomatic cases

Item	Formula	Explanation	Reference	Equation number
Annual probability of infection (P_{yearly})	$P_{yearly} = 1-(1-P_I)^n$	P_I= probability of infection/single exposure n=exposures/year	Haas et al., 1999	**3.4**
Infections per year	P_{yearly}* exposed population	-	-	**3.5**
Probability of developing disease (P_D)/ single exposure	$P_D = P_{DI} \times P_I$	P_D = risk of an infected person becoming ill P_{DI} = probability of an infected person developing clinical disease. P_I=risk/single exposure	Haas et al., 1999	**3.6**
Annual probability of developing illness $(P_D)_{Yearly}$	$(P_D)_{Yearly} = 1-(1-P_D)^n$	-	Haas et al., 1999	**3.7**
Annual Symptomatic cases	$P_D)_{Yearly}$ * exposed population	-		**3.8**

[a] The P_{DI} values used were: Campylobacter =0.3, rotavirus=0.5, Cryptosporidium=0.7(Adapted from WHO, 2004). The P_{DI} value for Giardia (0.39) (Haas et al., 1999) was used for Ascaris.

3.3.3.4 Risk characterization

The final results were expressed as annual number of symptomatic cases per exposure route. Number of symptomatic cases per pathogen from all exposure routes was then summed up in order to be compared with the endemic waterborne disease incidence in Accra. A ranking was then performed according to table 3.24 in order to identify the most risky pathway.

Table 3.24: Risk rankings based on estimated disease rates for each exposure route

Item	Definition
Catastrophic	Major increase in diarrhoeal disease (or any other chosen disease >25% or 5% increase in more severe disease or large community outbreak (100 cases) or death
Major	Increase in more severe diseases (0.1-5%) or large increase in diarrhoeal diseases (5-<25%)
Moderate	Increase in diarrhoeal disease (1-<5%)
Minor	Slight increase in diarrhoeal diseases (0.1 -<1%)
Insignificant	No increase in disease incidence (<0.1%)

Source: Adopted from Westrell et al., 2004

3.3.4 Prioritization of the pathways using disability adjusted life years (DALYs)

Disease burden from every pathogen and every pathway was estimated. DALY, as a measure was chosen to compare health effects of pathogens included in the study; to compare the predicted risk with the WHO reference level of risk of 10^{-6} DALYs pppy (WHO, 2004), and as a criterion to prioritize the pathways. The disability adjusted life year (DALY) is an indicator of the time lived with a disability and the time lost due to premature mortality (Lopez et al., 2006; WHO, 2004).

DALYs were calculated as described in literature (Havelaar and Melse, 2003; WHO, 2004; Howard et al., 2006). The average life expectancy at birth for Ghana, 57 years (UNDP, 2006) was used in the calculation of the DALYs. Use of national life expectancy to calculate DALYs has also been applied in Uganda (Howard et al., 2006) and Bangladesh (Howard et al., 2007).

For each pathogen, health outcomes, duration and severity weights were identified as outlined below. Chronic syndromes were not included in defining the health outcomes due to lack of data for all the pathogens in developing countries. The disease burden per case was then multiplied by the number of cases for every pathogen. This was then summed up in order to obtain the total disease burden from the urban water system in Accra. The severity weights and duration of disease for *Campylobacter* and rotaviruses were based on Havelaar and Melse, (2003).

Campylobacter

The outcomes for *Campylobacter* were considered as morbidity due to gastroenteritis and mortality, with a case fatality ratio of 0.1% (Haas et al., 1999) Havelaar and Melse, (2003) report that approximately 6% of the infected population will develop severe diarrhoea and will consult a general practitioner. Death may occur especially in the elderly and the young children in developing countries. Therefore, the mortality burden was based on an average age of death of I year.

Rotaviruses

The disease outcomes included mild diarrhoea, severe diarrhoea and death. The case fatality of 0.7% used by Howard et al., (2006), was applied here. It is estimated that 85.6% of the cases will develop mild diarrhoea, while 14.4% will develop severe diarrhoea (Havelaar and Melse, 2003).The mortality burden was based on the age of death of 1 year (Howard, 2006), because rotavirus disease contributes greatly to childhood mortality in developing countries.

Cryptosporidium

The disease outcome was taken to be watery diarrhoea with a mean duration of 7.2 days (Havelaar and Melse, 2003). *Cryptosporidiosis* is mild and self limiting for the population at large but has a high mortality rate among those who test positive for HIV/AIDS (WHO, 2004). This group was used to calculate the mortality burden. The approach used by Howard et al., (2006), was applied here. The HIV/AIDS prevalence rate in Accra was estimated to be 4.1% in 2002 (UNAIDS, 2006). The mortality rate among this group was assumed to be 10% (Havelaar and Melse, 2003), thus giving a case fatality rate of 0.41%. The years-of-life-lost among this group was calculated in three different groups. NACP, (2001), estimate that 89% of HIV/AIDS infections in Ghana occur in the age group 15-49 years, 8%in the age group 50-59 years and 3 percent in the age group 0-14 years. The mean age of death for each age group was calculated based on the information that a person with full blown AIDS will die after approximately 1.5 years (NACP, 2001). This gave the mean age of death at 33.5 years, 56 years and 8.5 years respectively. The estimate on the years-of-life-lost due to cryptosporidiosis was based on a weighted average as shown in equation 3.9:

$$[(57-33.5)*89\%] + [(57-56)*8\%] + [57-8.5)*3\%] = 22.5 \text{ years lost} \qquad \textbf{(3.9)}$$

Ascaris

The disease outcomes following *Ascaris* infection were defined as high intestinal obstruction in children and contemporaneous cognitive deficit (reduction in cognitive ability in school age children) (Mathers et al., 2003). It is estimated that 5% of the cases will develop contemporaneous cognitive deficit. The mean duration was taken to be 35 days and 28 days (Bundy et al., 1997) and severity weights were taken to be 0.024 and 0.006 (Lopez et al., 1996), respectively. Death might occur in some children, and therefore, the mean age of death was assumed to be 1 year with a case fatality of 0.08% (Crompton, 1999).

Table 3.25 shows the severity, duration and disease burden for pathogens included in the study.

Table 3.25: Severity, duration and disease burden per case for pathogens included in the study

Pathogen	Outcomes	Severity [a]	Duration [a b]	Disease burden per case in DALYs [c, d]
		Campylobacter		
	Gastroenteritis- population	0.067	5.1 days (0.014 years)	1*0.067*0.014 = $9.0*10^{-4}$
	Gastroenteritis- General Practitioner (6% of cases)	0.39	8.4 days (0.023 years)	1*6% (GP)*0.39*0.023= $5.0*10^{-4}$
	Death	1	56 years	1*0.1%(death)*56=0.056
Total disease burden per case				**0.06**
		Rotavirus		
	Mild diarrhoea (85.6% of all cases)	0.1	7 days (0.02 years)	1*85.6%*0.10*0.02=0.002
	Severe diarrhoea (14.4% of all cases)	0.23	7days (0.02 years)	1*14.4%*0.23*0.02=$7.0*10^{-4}$
	Death	1	56 years	1*0.7%(death)*56=0.392
Total disease burden per case				**0.39**
		Cryptosporidium		
	Watery diarrhoea	0.067	7.2 days (0.02 years)	1*0.067*0.02=0.0013
	Death	1	22.5 years	1*0.41%(death)*22.5=0.09
Total disease burden per case				**0.09**
		Ascaris		
	Intestinal obstruction, population	0.024	35 days (0.1 years)	1*0.024*0.1=0.0024
	Contemporaneous cognitive deficit (5% of all cases)	0.006	28 days (0.08 years)	1*5%*0.006*0.08=$2.4*10^{-5}$
	death	1	56 years	1*0.08% (death)*56=0.045
Total disease burden per case				**0.05**

[a] *The severity weights and duration of disease for Campylobacter, rotavirus and Cryptosporidium were form Havelaar and Melse, (2003). Duration of disease following Ascaris infection was taken from Bundy et al., (1997), while the severity weight was taken from Lopez et al.,(2006).*
[b] *the years of life lost following death from Campylobacter, rotavirus and Ascaris was taken to be the life expectancy at birth of Ghana – death at age of 1 year (57-1=56 years); as for Cryptosporidium, this was calculated from the HIV/AIDS group who already have a reduced life expectancy.*
[c] *The sources of case fatalities included: Campylobacter (Haas et al., 1999); rotavirus (Howard et al., 2006), Cryptosporidium (based on the 10% HIV/AIDS prevalence in Accra), Ascaris (Crompton, 1999).*
[d] *DALYs = Number (of symptomatic cases)*severity weight*duration in years*

3.3.5 Assumptions used in the risk assessment

For each exposure pathway, the assumptions made are as listed in table 3.26:

Table 3.26: Assumptions made during the risk assessment

Exposure	Assumptions
Recreational swimming	1. Pathogen concentrations were estimated from raw sewage (WHO,2003) 2. Dilution factor of 1000 (Ottoson, 2005) was assumed 3. Recreational water was assumed to be fully mixed 4. Frequency was assumed to be 7 swims per year (Haas et al., 1999) 5. Number of swimmers was assumed to be 50% of those who visit the beach and that 60% of the swimmers came from the Odaw catchment. 6. Ingestion volume was assumed to be 100ml per swim and a swim assumed to last 2 hours (Ashbolt et al, 1997)
Flooding of the Odaw drain	1. Frequency of exposure for the 3 pathways was assumed to be 1 per year based on the people's knowledge of flood occurrence per year 2. Ingestion volumes were assumed based on Westrell et al., 2004 3. The *E. coli:* pathogen ratio was assumed to be 1:10^5 for *Campylobacter* and Rotavirus 1:10^6 for *Cryptosporidium* and *Ascaris*(Adapted from Mara et al.,2007; Howard et al., 2007) 4. Pathogen concentration was taken from a previous study of Odaw river (Nana-Amankwaah, unpublished)
UASB treatment plant	1. Pathogen concentrations were estimated from raw sewage (WHO, 2003) 2. Ingestion volumes were assumed based on Westrell et al., 2004 and Ashbolt et al., 2005 3. Frequency of exposure for laboratory analysts was assumed to be once per year
Faecal septage disposal point	1. Pathogen concentrations were estimated from Sanicon, 2002; Straus et al., 1997; Mara, 1978 2.1 g of soil was assumed to be 1ml of water (Westrell et al., 2004) 3. Frequency of exposure of children was assumed to be 2. This was an adjustment to the value (1) assumed for developed countries (Westrell et al., 2004) 3. The population of Korle Gonno and Mamprobi was used to determine the number of children exposed, and then it was assumed that half the number of these children visits the faecal septage disposal point once per year.
Open drainage channels	1. Pathogen concentration in open drains was assumed to be similar with Odaw 1. Pathogen concentration in open drains was assumed to be similar with Odaw drain 2. Frequency of exposure of children was assumed to be 4.This was adjusted from the value (2) proposed for child playing at wetland inlet for developed countries (Westrell et al., 2004). 3. The population of children used came from the Low income residential places as these had the greatest problems associated with open drains (Songsore et al., 2005).
Water treatment plants	1. Log reduction of pathogens in different treatment processes was assumed based on literature (WHO, 2004; Westrell et al., 2003) 2. Ingestion volume of 2.9 litres per day assumed based on Howard et al., 2007 3. The *E. coli:* pathogen ratio was assumed to be 1:10^5 for *Campylobacter* and Rotavirus, and 1:10^6 for *Cryptosporidium* (Adapted from Mara et al.,2007; Howard et al., 2007)
Water distribution system	1. It was assumed that during the time when there was no water in the pipes, pathogens would gain entry into the pipe (Karim et al., 2001) 2. Secondary data on pathogen concentration from a previous MSc study (Cobbina, 2004) was assumed to be a representation of the whole distribution system in AMA

3.3.6 Determination of waterborne disease incidence

Waterborne disease data for 2003, 2004 and 2005 was obtained from Accra Metropolitan Assembly (AMA) health service. The criterion was to include only those diseases that are transmitted by ingesting contaminated water.

3.3.6.1 Adjusting for Underreporting

Due to underestimation of hospital morbidity data (Mead *et al.,* 1999; Wang *et al*., 2006), reported cases have to be adjusted to account for underreporting.

In AMA, 5 hospitals (37 Military, Mana Mission, Legon, Ridge and Trust hospital) do not report to the AMA Health Service, and therefore, data from these hospitals was not obtained. In order to have a rough estimate of cases from these hospitals, the average number of cases per month from the hospitals that do report to AMA health services was calculated. The result (average value) was then allocated to the five hospitals with an assumption that the reported cases were equally distributed among hospitals. These were then adjusted for underreporting.

While establishing the trend and disease burden of bacillary dysentery in China (1991-2000), Wang *et al*., (2006) found out that the median underreporting rate was 69% (15% hospital- based surveillance and 54% published community surveys). In UK, a study reported that national surveillance systems would detect only 31.8%, 7.9% and 3% of *Salmonella, Campylobacter* and rotavirus infections respectively (Wheeler et al., 1999). This shows that the underreporting rates for the same pathogens were 68.2%, 92.1% and 97% respectively. The above studies were used to estimate the underreporting rate of 82% (average of 69%, 68.2%, 92.1% and 97%) in AMA. The adjusted incidence was then calculated using the following formula:

Adjusted rate = original rate/ (1-underreporting rate/100) **(3.10)**

This was considered as the greatest source of uncertainty as this could still underestimate the underreporting rate in Accra.

4 Description of the Accra urban water system

This chapter describes the Accra Urban Water System. It is based on local literature and information from the GWCL.

4.1 Water supply

The GWCL is responsible for the provision and quality control of domestic piped water in Accra. AMA is supplied with water from two sources; Weija and Kpong water works as shown in figure 4.1.

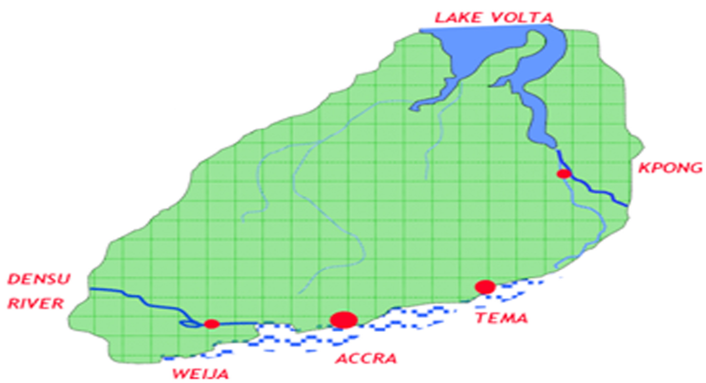


Figure 4.1: Accra urban water system

(Source: Adopted from Lundehn and Morrison, 2006)

Weija water works

Weija is located 15km west of Accra. It supplies water to Accra west and Accra northeast districts. Raw water is drawn from River Densu and passed through three treatment plants that work in parallel; Adam Clark, Pintsh -Bamag and Candy Patterson . Adam Clark has aeration tank-contact tank-clarifying chambers-slow sand filtration-disinfection stages and uses only pumping; while Pintsh -Bamag and Candy Patterson have raw water tank-sedimentation tanks-clarifying chambers-slow sand filtration-disinfection, stages and uses both pumping and gravity flow. Monthly production from the three plants is $5.1*10^6$ m^3. The treated water is transported by gravity.

Kpong Water Works

Kpong waterworks is located 75km northeast of Accra, close to the Akosombo dam. It supplies water to Tema, eastern and central Accra. Raw water is drawn from the Volta River and passed through two plants working in parallel; Kpong Old plant and Kpong New plant. The New plant has a mixing basin-clarriflocculators-disinfection-rapid gravity filtration stages. In the mixing basin, sodium carbonate, lime, chlorine and aluminium sulphate are introduced. During the study period, the above chemicals were no longer being used in the mixing basin because the quality of water in the

Volta River was considered to be very good. In addition, the chlorinator was out of order and so calcium hypochlorite (with 60% available chlorine) was the only disinfectant that was being used. The plant is designed to use 12 drums (45 kg each) of Calcium hypochlorite per day but due to inadequate manpower to carry out the mixing, only 5 drums are used per day. These are spread out within the 24 hour period. Monthly production from the two plants is $6.4*10^6$ m^3. From the new Kpong plant, a high-lift pumping station delivers treated water via a 54 km long pipeline (1050 mm diameter) to the Tema terminal reservoir, a storage tank in the north of Tema.

According to the GWCL, water demand for Accra city is 331,818m^3/day but this is not met. To meet their demands, some residents and private establishments use water vendors, boreholes, wells, ponds and springs. It is estimated that 80% of the population of Accra is served by piped water. The system is characterized by intermittent supplies. It has been estimated that only approximately 25% of residents have a 24-hours water supply. About 30% have an average of 12-hours service every day for five days a week. Another 35% have service for two days each week while the remaining residents on the outskirts of Accra are completely without access to piped water supply (Wateraid, 2006). The GWCL estimates that upto 30% of water supplied to Accra is lost through pipe leakages (GWCL, 1997). Table 4.1 shows the distribution of households in AMA by source of drinking water.

Table 4.1: Distribution of households in AMA by source of drinking water.

Source of Water	**Percentage**
Indoor piping	34.7
Private standpipe	30.9
Water vendors	23.4
Other private source	1.3
Communal standpipe	9.5
Well	0.3
Total	**100**

Source: Adopted from Benneh et al., 1993.

4.2 Sanitation

Drainage in Accra consists of natural drains and a few major storm water drains. Small gutters also serve as storm water drains and also convey domestic effluent. A review by Obuobie et al., (2006), shows that about 5% of the population in AMA is connected to the sewer network, 20% use public toilets, 5% use bucket latrines while 70% use septic tanks (figure 4.2). From this, Accra is considered to have the best sanitation facilities in Ghana.

There are three main waste treatments plants in Accra. The UASB is the largest sewage treatment plant treating sewage from the 5% of the population that is connected to the sewer network. During the study period, the plant was not working and the sewage was consequently diverted to the sea. Two other faecal treatment plants are located at Achimota and Teshie Nungua (figure 4.3). However, they are badly maintained or out of order. Untreated faecal sludge ends up being disposed of in nearby streams (Achimota, Teshie) or at the seashore, KorleGonno (Lavender hill).

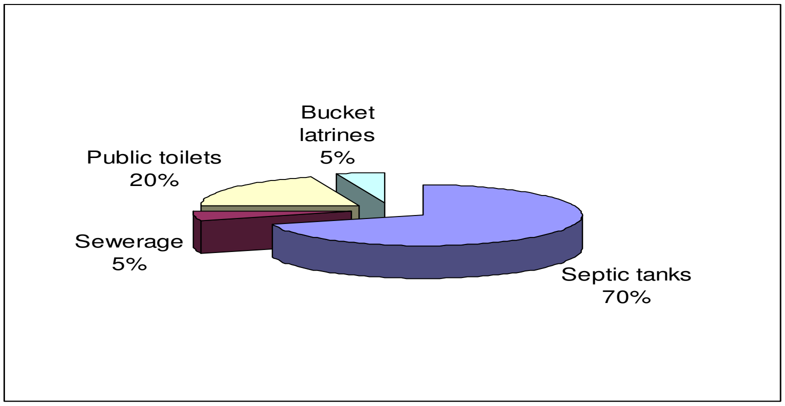


Figure 4.2: Means of nightsoil collection in Accra:

(Source: Obuobie et al., 2006)

Currently more than half of Accra's collected faecal sludge is dumped into the ocean (figure 4.3) (Obuobie et al., 2006). Greywater is discharged into open drains and streams via gutters connected directly from the houses. Korle lagoon is the major wetland in Accra and it receives the waste water through the Odaw River, which is the main urban water storm with a catchment area covering more than 60% of the city.

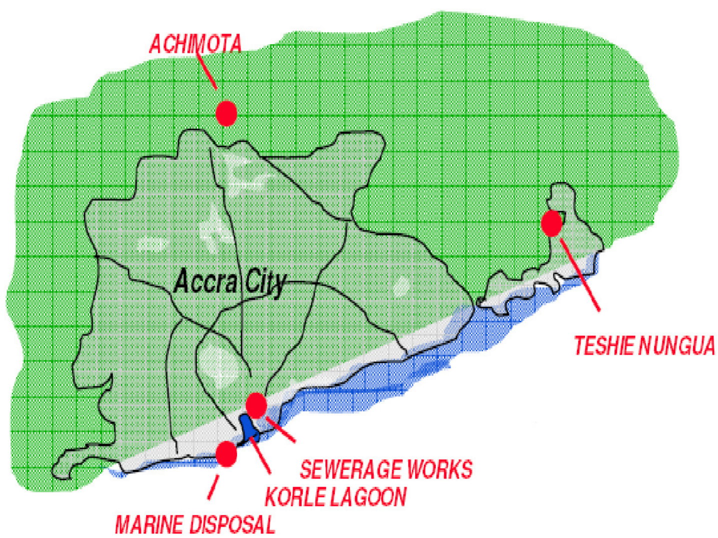


Figure 4.3: Accra urban wastewater system

(Source: Adopted from Lundehn and Morrison 2006)

5 Results and discussions

5.1 Hazard identification

Four pathogens were selected for the risk assessment. These were mainly reference pathogens (WHO, 2004). *Campylobacter* was chosen to represent bacteria because of its ability to develop into a chronic outcome; the Guillain-Barre syndrome (Haas et al., 1999; Havelaar and Melse 2003). Rotavirus was chosen to represent viruses because it is the major cause of viral gastroenteritis throughout the world, it is responsible for millions of childhood deaths per year in developing countries and because of its low infective doses (Mara and Horan, 2003; Bitton, 2005). *Cryptosporidium* was chosen to represent protozoa as it is a serious problem among AIDS patients. It is currently considered to be of major importance for drinking water safety due to its high infectivity and because of its resistance to chemical disinfection. Concentrations at levels below detection limit of current methods have been reported to lead to waterborne outbreaks (Goldstein et al., 1996). Lastly, *Ascaris* was chosen to represent the nematodes because of its low infective doses and the high worm burden caused by *Ascaris* in developing countries (Bitton, 2005; de Silva et al., 2003).

5.2 Exposure assessment

Table 5.1shows the various points of exposures from the sanitation pathway that were identified, assumptions on ingestion volumes, frequency and number of exposed population. There were five major pathways: recreational swimming, flooding of the Odaw drain (exposures 2, 3 and 4), UASB treatment plant (exposures 5, 6 and 7), faecal septage disposal point (exposures 8, 9 and 10) and open drainage channels.

Recreational swimming was chosen because of the fact that Labadi beach is located downstream of the faecal septage disposal place (Lavender hill, Accra) and it is frequented by many people. Exposure to flooding of the Odaw drain was chosen because this is the largest open drain in AMA and it overflows during the rainy season affecting many people (AMA, 2002; Songsore et al., 2005; Abraham et al., unpublished). The UASB treatment plant was chosen because workers were seen handling waste from the inlet works without protective clothing. Faecal septage disposal point was chosen based on the criteria detailed in section 3.3.3.2 and the fact that it was frequented by children, who could suffer especially if they ingest the helminth eggs. Lastly, the open drainage channels were also included based on the high environmental burden associated with them as outlined in Songsore et al., 2005.

Table 5.2 shows the various points of exposures from the water supply pathway that were identified, assumptions on ingestion volumes, frequency and number of exposed population. There were two major pathways: water treatment plants (exposures 1, 2, 3, 4 and 5) and water distribution system (exposures 6, 7 and 8).

Table 5.1: Points of exposure from the sanitation pathway with assumptions on ingestion volumes, frequency and number of exposed population [a]

Type of exposure	Volume ingested (ml)	Frequency (per year)	Exposed population
1. Recreational swimming	100	7	29,878
2. Unintentional ingestion of flood water	1	1	111,790
3. Unintentional immersion at lagoon	30	1	10
4. Children playing in flood water	1	1	23,699
5. Workers desludging the UASB treatment plant	5	12	10
6. Workers removing debris from the UASB inlet works daily during the rainy season	1	90	10
7. Workers taking samples from the UASB inlet works for laboratory analysis	0.1	1	3
8. Workers handling septage at the faecal septage disposal place	1	317	100
9. Children playing with contaminated sand at the faecal septage disposal place	5	2	8037
10. Fishermen ingesting contaminated water at the shore next to the faecal septage disposal point	1	1	10
11. Children playing near open drainage channels	5	4	81,272

[a] *Detailed methodology for deriving the ingestion volumes, frequency and exposed population is outlined in section 3.3.3.2a*

Table 5.2: Points of exposure from the water supply pathway with assumptions on ingestion volumes, frequency and number of exposed population [a]

Type of exposure [b]	Volume ingested (litres)	Frequency (per year)	Exposed population
1. Power outage at Weija treatment plant	2.9	3.6	646,986 [c]
2. Filtration error at Weija treatment plant	2.9	1	646,986 [c]
3.Disinfection error at Kpong treatment plant	2.9	365	348,378 [d]
4.Coagulation error at Kpong treatment plant	2.9	365	348,378 [d]
5.Filtration error at Kpong treatment plant	2.9	1	348,378 [d]
6. Contaminated distribution system	2.9	146 [e]	944,678 [f]
7. Pollution entering part of system without pressure (108 hours per week) [g]	2.9	234	298,609
8. Pollution entering part of system without pressure (120 hours per week) [h]	2.9	260	348,378

[a] *Detailed methodology for deriving the ingestion volumes, frequency and exposed population is outlined in section 3.3.3.2b*

[b] *Exposures 1, 2, and 5 were based on incidents while 3 and 4 were based on normal operations at Kpong treatment plant (explanations are found in table 3.14)*

[c] *65% of AMA population;* [d] *35% of AMA population*

[e] *40% of the year, estimated after a previous MSc study findings (Cobbina, 2004)*

[f] *Population of Odaw catchment without the population of Accra New Town (50,685) as it is without water supply (GWCL, unpublished).*

[g] *30% of the population receive water 12 hours a day, five days a week (Wateraid, 2006)*

[h] *35% of the population receive water twice a week (Wateraid, 2006).*

Table 5.3 shows doses of pathogens ingested for every exposure point, with high doses for C*ampylobacter* and rotaviruses in exposure 5 and 6, and *Ascaris* in exposure 9, for the sanitation pathway.

Table 5.3: Ingestion doses [a] for various pathogens in every exposure point

Type of exposure	*Campylobacter*	Rotavirus	*Cryptosporidium*	*Ascaris*
Sanitation				
1. Recreational swimming	55	42.7	$2.0*10^{-2}$	$6.0*10^{-3}$
2. Unintentional ingestion of flood water	$1.3*10^{-1}$	$1.3*10^{-1}$	$1.2*10^{-2}$	$1.2*10^{-2}$
3. Unintentional immersion at lagoon	3.84	3.84	$3.6*10^{-1}$	$3.6*10^{-1}$
4. Children playing in flood water	$1.3*10^{-1}$	$1.3*10^{-1}$	$1.2*10^{-2}$	$1.2*10^{-2}$
5. Workers desludging the UASB treatment plant	2,750	2,135	1	$2.9*10^{-1}$
6. Workers removing debris from the UASB inlet works daily during the rainy season	550	427	$2.0*10^{-1}$	$5.8*10^{-2}$
7. Workers taking samples from the UASB inlet works for laboratory analysis	55	42.7	$2.0*10^{-2}$	$5.8*10^{-3}$
8. Workers handling septage at the faecal septage disposal place	$1.0*10^{-1}$	$1.0*10^{-1}$	$6.0*10^{-1}$	30
9. Children playing with contaminated sand at the faecal septage disposal place	$5.0*10^{-1}$	$5.0*10^{-1}$	2.8	150
10. Fishermen ingesting contaminated water at the shore next to the faecal septage disposal point	$1.0*10^{-1}$	$1.0*10^{-1}$	$6.0*10^{-1}$	30
11. Children playing near open drainage channels	$6.4*10^{-1}$	$6.4*10^{-1}$	$6.0*10^{-2}$	$6.0*10^{-2}$
Water supply				
1. Power outage at Weija treatment plant	$7.6*10^{-6}$	$1.2*10^{-5}$	$7.6*10^{-7}$	-
2. Filtration error at Weija treatment plant	$6.9*10^{-8}$	$6.4*10^{-6}$	$4.4*10^{-6}$	-
3.Disinfection error at Kpong treatment plant	$1.8*10^{-6}$	$3.8*10^{-6}$	$2.2*10^{-6}$	-
4.Coagulation error at Kpong treatment plant	$1.8*10^{-6}$	$3.8*10^{-6}$	$2.2*10^{-6}$	-
5.Filtration error at Kpong treatment plant	$1.8*10^{-5}$	$1.2*10^{-4}$	$7.0*10^{-5}$	-
6. Contaminated distribution system	$6.7*10^{-5}$	$6.7*10^{-5}$	$6.7*10^{-6}$	-
7. Pollution entering part of system with low pressure (108 hours per week)	$1.0*10^{-4}$	$7.9*10^{-5}$	$3.7*10^{-8}$	-
8. Pollution entering part of system with low pressure (120 hours per week)	$1.1*10^{-4}$	$8.4*10^{-5}$	$4.0*10^{-8}$	-

[a] *Cfu/ingestion volumes for every exposure points listed in table 5.1 and 5.2. Determination of ingestion doses is outlined in detail in section 3.3.3.2*

5.3 Dose response assessment and risk characterization

5.3.1 Sanitation pathway

5.3.1.1 Probability of infection per single exposure

Table 5.4 shows the probability of infection per exposure point following single exposure. Exposure 5 (workers desludging the UASB treatment plant) had the highest probability of infection for rotaviruses ($8.8*10^{-1}$) and *Campylobacter* ($5.7*10^{-1}$). Exposure 9 (children playing with contaminated sand) had the highest probability of infection for *Ascaris* ($9.5*10^{-1}$) and *Cryptosporidium* ($1.2*10^{-2}$).

Table 5.4: Probability of infection per single exposure from the sanitation pathway [a]

Exposure [b]	*Campylobacter*	Rotaviruses	*Cryptosporidium*	*Ascaris*
1	$2.6 * 10^{-1}$	$6.9 *10^{-1}$	$8.4*10^{-5}$	$1.2*10^{-4}$
2	$2.5*10^{-3}$	$6.5*10^{-2}$	$5.0*10^{-5}$	$2.4*10^{-4}$
3	$5.8*10^{-2}$	$4.4*10^{-1}$	$1.5*10^{-3}$	$7.1*10^{-3}$
4	$2.5*10^{-3}$	$6.5*10^{-2}$	$5.0*10^{-5}$	$2.4*10^{-4}$
5	$5.7*10^{-1}$	$8.8*10^{-1}$	$4.2*10^{-3}$	$5.7*10^{-3}$
6	$4.6*10^{-1}$	$8.3*10^{-1}$	$8.4*10^{-4}$	$1.2*10^{-3}$
7	$2.6*10^{-1}$	$6.9*10^{-1}$	$8.4*10^{-5}$	$1.2*10^{-4}$
8	$1.9*10^{-3}$	$5.2*10^{-2}$	$2.5*10^{-3}$	$4.5*10^{-1}$
9	$9.2*10^{-3}$	$1.8*10^{-1}$	$1.2*10^{-2}$	$9.5*10^{-1}$
10	$1.9*10^{-3}$	$5.2*10^{-2}$	$2.5*10^{-3}$	$7.7*10^{-2}$
11	$1.2*10^{-2}$	$2.1*10^{-1}$	$2.5*10^{-4}$	$1.2*10^{-3}$

[a] *Estimated using equations 3.2;* [b] *Exposures listed in table 5.1*

5.3.1.2 Annual probability of infection and annual infections

Table 5.5 shows annual probability of infection from the sanitation pathway.

Table 5.5: Probability of infection (annual) from the sanitation pathway [a]

Exposure [b]	*Campylobacter*	Rotaviruses	*Cryptosporidium*	*Ascaris*
1	$8.8*10^{-1}$	1	$5.9*10^{-4}$	$8.3*10^{-4}$
2	$2.5*10^{-3}$	$6.5*10^{-2}$	$5.0*10^{-5}$	$2.4*10^{-4}$
3	$5.8*10^{-2}$	$4.4*10^{-1}$	$1.5*10^{-3}$	$7.1*10^{-3}$
4	$2.5*10^{-3}$	$6.5*10^{-2}$	$5.0*10^{-5}$	$2.4*10^{-4}$
5	1	1	$4.9*10^{-2}$	$6.6*10^{-2}$
6	1	1	$7.3*10^{-2}$	$1.0*10^{-1}$
7	$2.6*10^{-1}$	$6.9*10^{-1}$	$8.5*10^{-5}$	$1.2*10^{-4}$
8	$4.5*10^{-1}$	1	$5.5*10^{-1}$	1
9	$1.8*10^{-2}$	$3.3*10^{-1}$	$2.4*10^{-2}$	1
10	$1.9*10^{-3}$	$5.2*10^{-2}$	$2.5*10^{-3}$	$4.5*10^{-1}$
11	$4.7*10^{-2}$	$6.1*10^{-1}$	$1.0*10^{-3}$	$4.8*10^{-3}$

[a] *Estimated using equation 3.4;* [b] *Exposures listed in table 5.1*

Recreational swimming

The probability of infection was $8.8*10^{-1}$ (table 5.5) pppy for a water quality of 55 *Campylobacter*/100ml (table 5.3), 1 pppy for a water quality of 42.7 rotaviruses/100ml, $5.9*10^{-4}$ pppy for a water quality of 0.02 *Cryptosporidium*/100ml and $8.3*10^{-4}$ pppy for a water quality of 0.006 *Ascaris*/100ml. The ingestion dose for *Campylobacter* was higher than for Rotavirus, but the latter achieved the highest annual probability of infection due to its high infectivity. The probability of infection resulting from recreational swimming in polluted waters of Accra is substantial especially for viruses and bacteria. This pathway also gave the highest number of annual infections from *Campylobacter* (26,247) and second highest from rotaviruses (29,878) (table 5.6). However, the annual infections were only 18 for *Cryptosporidium* and 25 for *Ascaris* due to the low pathogen concentrations in the ingestion volume.

Table 5.6: Annual infections per exposure point from the sanitation pathway [a]

Exposure [b]	*Campylobacter*	Rotaviruses	*Cryptosporidium*	*Ascaris*
1	26,247	29,878	18	25
2	279	7,266	6	27
3	1	4	0	0
4	59	1,540	1	6
5	10	10	0	1
6	10	10	1	1
7	1	2	0	0
8	45	100	55	100
9	147	2,633	192	8,037
10	0	1	0	5
11	3,831	49,616	81	387
Total	**30,630**	**91,060**	**354**	**8,589**

[a] *Estimated using equation 3.5;* [b] *Exposures listed in table 5.1*

Flooding of the Odaw drain

The highest probability of infection pppy was achieved through unintentional immersion in the lagoon (exposure 3), with a probability of rotavirus infection of $4.4*10^{-1}$ pppy (table 5.5); this is because this exposure had a high ingestion volume (table 5.1) and dose (table 5.3) compared to exposures 3 and 4. Unintentional ingestion of floodwater (exposure 2) and children playing in floodwater (exposure 4) had the same probability of infection for all the pathogens as the ingestion doses were similar (table 5.3).

Rotaviruses had the highest number of annual infections (table 5.6) with 7,266 infections from exposure 2 and 1,540 infections from exposure 4. This was followed by *Campylobacte*r with 279 infections in exposure 2 and 59 infections in exposure 4. *Ascaris* and *Cryptosporidium* had the least cases. As much as exposure 3 had the highest annual probability of infection, annual infections from this pathway were the lowest (4 for rotaviruses, 1 for *Campylobacter* and no infection from both *Cryptosporidium* and *Ascaris)* due to the lowest number (10) of exposed population (table 5.1).

The UASB treatment plant

The highest probability of infection pppy was achieved by; workers removing debris from the UASB inlet works (exposure 6) and workers desludging the UASB treatment

plant (exposure 5) (table 5.5). The probability of infection for viruses and bacteria was 1 in both cases and 0.1 for the *Ascaris* in exposure 6. This could be explained by high ingestion doses especially for exposure 5 with a wastewater quality of 2,750 *Campylobacter*/5ml, 2,135 rotaviruses/5ml, 1 *Cryptosporidium/*5ml and 0.29 *Ascaris*/5ml (table 5.3). Exposure 6 had a slightly higher probability of infection from *Ascaris* (0.1 pppy) and *Cryptosporidium* (0.073 pppy) than exposure 5 ($6.6*10^{-2}$ pppy for *Ascaris* and $4.9*10^{-2}$ pppy for *Cryptosporidium),* even though the ingestion dose for exposure 5 was much higher than for exposure 6 (table 5.3). This was due to the higher exposure frequency (90 times) in exposure 6 (table 5.1). The annual probability of infection from exposure 7 (workers taking samples from the UASB inlet works for laboratory analysis) was lowest due to a very low ingestion volume (0.1ml). There is a high risk of infection if workers are exposed to aerosols or droplets at the wastewater treatment plants (Bitton, 2005).

Since infection was certain for rotaviruses and *Campylobacter* in exposures 5 and 6, all the people exposed (10) (table 5.1) were infected in these particular exposure points (table 5.6). *Cryptosporidium* and *Ascaris* had the least number of annual infections from this pathway with a total of 1 and 2 respectively.

Faecal septage disposal point

The highest probability of infection pppy was achieved by exposure 8 (workers handling septage), with 1 for both rotavirus and *Ascaris* (table 5.5). This was followed by exposure 9 (children playing with contaminated sand), which also had 1 for *Ascaris.* The ingestion doses for exposure 9 were higher than for exposure 8 but the high probability of infection in exposure 8 was due to a high exposure frequency (table 5.1).

This pathway had the highest infections from *Ascaris* (8,142 in total) due to high ingestion doses for this particular pathogen compared to other pathways (table 5.3). Helminth eggs are dense and will settle down by sedimentation and therefore, will be found in large numbers in sludge/septage (Bitton, 2005). High number of infections from *Ascaris* makes the pathway risky due to the high worm burden contributed by *Ascaris* in developing countries (de Silva et al., 2003). Though exposure 8 had the highest annual probability of infection, the annual infections were much lower than for exposure 9, due to high exposed population in exposure 9 (table 5.1). Exposure 10 (fishermen ingesting contaminated water at the shore) had the least number of annual infections with only 5 for *Ascaris* and 1 for rotaviruses. But this doesn't mean that this pathway is not risky at all; the lower number of infections is due to the small population exposed.

Open drainage channels

The highest annual probability of infection was achieved by rotaviruses and the least by *Cryptosporidium* (table 5.5). This exposure contributed the highest number of infections from rotaviruses (49,616), and second highest for *Ascaris* (387) (table 5.6). The high number of children (81,272) (table 5.1) exposed in this pathway makes it to be more risky and should be addressed.

Summary: Risk of infection from the sanitation pathway

Rotaviruses had the highest annual probability of infection (table 5.5) followed by *Campylobacter*. Exposure 8 and 9 gave the highest probability of infection pppy from *Ascaris*. Overall, the pathway contributed 91,060 (table 5.6) total annual infections from

rotaviruses with 54% of the cases from exposure to open drainage channels and 33% from recreational swimming (figure 5.1). The second highest number of infections was from C*ampylobacter* (30,360), with recreational swimming contributing 86% and open drainage channels contributing 13%. *Ascaris* had 8,589 infections in total with faecal septage point contributing 94% and open drainage channels contributing 5%. However, there were only 354 cases of *Cryptosporidium* with faecal septage disposal point contributing 54% and open drainage channels contributing 23% of the total cases.

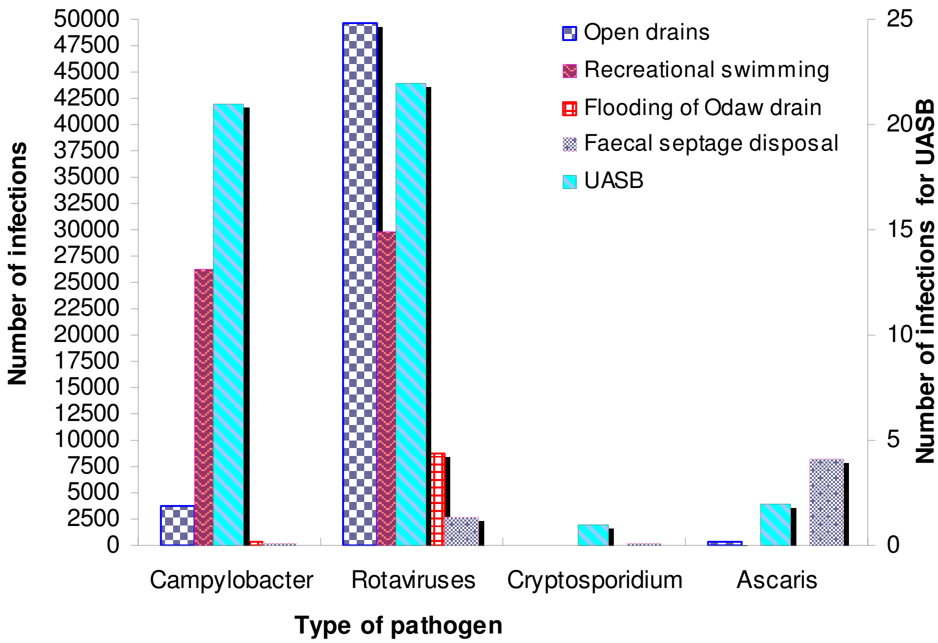


Figure 5.1: Annual infections from the sanitation pathway

5.3.1.3 Probability of developing illness and annual symptomatic cases

The probability of developing illness per single exposure ranged from $2.6*10^{-2}$ to $4.4*10^{-1}$ for rotaviruses, $5.7*10^{-4}$ to $1.7*10^{-1}$ for *Campylobacter*, $3.5*10^{-5}$ to $8.4*10^{-3}$ for *Cryptosporidium* and $4.7*10^{-5}$ to $3.7*10^{-1}$ for *Ascaris* (table 5.7).

Table 5.7: Probability of developing illness per single exposure from the sanitation pathway [a]

Exposure [b]	*Campylobacter*	Rotaviruses	*Cryptosporidium*	*Ascaris*
1	$7.8*10^{-2}$	$3.5*10^{-1}$	$5.9*10^{-5}$	$4.7*10^{-5}$
2	$7.5*10^{-4}$	$3.3*10^{-2}$	$3.5*10^{-5}$	$9.4*10^{-5}$
3	$1.7*10^{-2}$	$2.2*10^{-1}$	$1.1*10^{-3}$	$2.8*10^{-3}$
4	$7.5*10^{-4}$	$3.3*10^{-2}$	$3.5*10^{-5}$	$9.4*10^{-5}$
5	$1.7*10^{-1}$	$4.4*10^{-1}$	$2.9*10^{-3}$	$2.2*10^{-3}$
6	$1.4*10^{-1}$	$4.2*10^{-1}$	$5.9*10^{-4}$	$4.7*10^{-4}$
7	$7.8*10^{-2}$	$3.5*10^{-1}$	$5.9*10^{-5}$	$4.7*10^{-5}$
8	$5.7*10^{-4}$	$2.6*10^{-1}$	$1.8*10^{-3}$	$1.8*10^{-1}$
9	$2.8*10^{-3}$	$9.0*10^{-2}$	$8.4*10^{-3}$	$3.7*10^{-1}$
10	$5.7*10^{-4}$	$2.6*10^{-2}$	$1.8*10^{-3}$	$3.0*10^{-2}$
11	$3.6*10^{-3}$	$1.1*10^{-1}$	$1.8*10^{-4}$	$4.7*10^{-4}$

[a] *Estimated using equation 3.6,* [b] *Exposures listed in table 5.1*

The highest annual probability of developing illness from rotaviruses was achieved by exposures 1, 5, 6, 8 with a probability of/equal to 1 (table 5.8). Exposures 5 and 6 had

the highest for *Campylobacter,* while exposure 8 had the highest for *Ascaris* (1) and *Cryptosporidium* ($4.3*10^{-1}$).

Table 5.8: Probability of developing illness (annual) from the sanitation pathway [a]

Exposure [b]	*Campylobacter*	Rotaviruses	*Cryptosporidium*	*Ascaris*
1	$4.3*10^{-1}$	$9.5*10^{-1}$	$4.1*10^{-4}$	$3.3*10^{-4}$
2	$7.5*10^{-4}$	$3.3*10^{-2}$	$3.5*10^{-5}$	$9.4*10^{-5}$
3	$1.7*10^{-2}$	$2.2*10^{-1}$	$1.1*10^{-3}$	$2.8*10^{-3}$
4	$7.5*10^{-4}$	$3.3*10^{-2}$	$3.5*10^{-5}$	$9.4*10^{-5}$
5	$8.9*10^{-1}$	1	$3.5*10^{-2}$	$2.6*10^{-2}$
6	1	1	$5.2*10^{-2}$	$4.1*10^{-2}$
7	$7.8*10^{-2}$	$3.5*10^{-1}$	$5.9*10^{-5}$	$4.7*10^{-5}$
8	$1.7*10^{-1}$	1	$4.3*10^{-1}$	1
9	$5.5*10^{-3}$	$1.7*10^{-1}$	$1.7*10^{-2}$	$6.0*10^{-1}$
10	$5.7*10^{-4}$	$2.6*10^{-2}$	$1.8*10^{-3}$	$3.0*10^{-2}$
11	$1.4*10^{-2}$	$3.6*10^{-1}$	$7.0*10^{-4}$	$1.9*10^{-3}$

[a] *Estimated using equation 3.7;* [b] *Exposures listed in table 5.1*

Table 5.9 shows annual symptomatic cases contributed by each exposure point. There were a total of 63, 666 cases for rotaviruses with open drainage channel having the highest contribution of 46 % followed by recreational swimming with 45% (figure 5.2). *Campylobacter* had the second highest cases (14,301) with recreational swimming contributing 91% and open drainage channels contributing 8%. Exposure 9 contributed the highest percentage of total symptomatic cases from *Ascaris* (95%) and *Cryptosporidium* (53%). From this, it can be considered that exposure 9 is more risky due to the seriousness of ascariasis in children and cryptosporidiosis in immunocompromised patients, because the disease might persist in AIDS patients (Haas et al., 1999).

Table 5.9: Annual symptomatic cases from each exposure point in the sanitation pathway [a]

Exposure [a]	*Campylobacter*	Rotaviruses	*Cryptosporidium*	*Ascaris*
1	12,955	28,333	12	10
2	84	3,633	4	10
3	0	2	0	0
4	18	770	1	2
5	9	10	0	0
6	10	10	1	0
7	0	1	0	0
8	17	100	43	100
9	44	1,382	134	4,852
10	0	0	0	2
11	1,164	29,125	57	152
Total	**14,301**	**63,366**	**252**	**5,128**

[a] *Estimated using equation 3.8;* [b] *Exposures listed in table 5.1*

In summary, the sanitation pathway alone contributes greatly to the waterborne disease burden in the Odaw catchment and efforts should be made to address the situation.

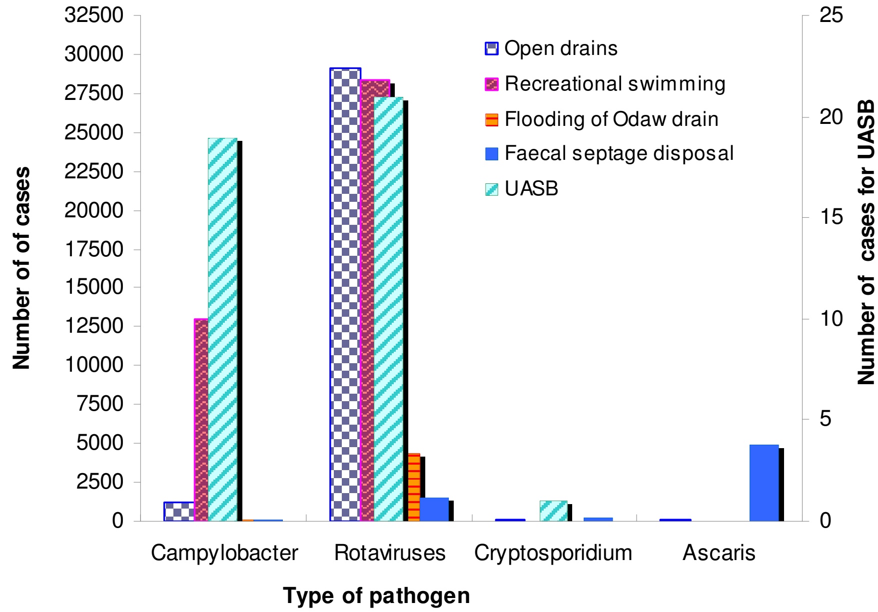


Figure 5.2: Annual symptomatic cases from the sanitation pathway

5.3.2 Water supply pathway

5.3.2.1 Probability of infection per single exposure

Table 5.10 shows the probability of infection per exposure point in the water supply pathway following single exposure. The probability of infection ranged from $2.3*10^{-6}$ to $7.1*10^{-5}$ for rotaviruses, $1.3*10^{-9}$ to $2.1*10^{-6}$ for *Campylobacter* and $1.7*10^{-10}$ to $2.9*10^{-7}$ for *Cryptosporidium.*

Table 5.10: Probability of infection per single exposure from the water supply pathway [a]

Exposure [a]	***Campylobacter***	**Rotavirus**	***Cryptosporidium***
1	$1.5*10^{-7}$	$7.1*10^{-6}$	$3.2*10^{-9}$
2	$1.3*10^{-9}$	$3.8*10^{-6}$	$1.8*10^{-7}$
3	$3.4*10^{-8}$	$2.3*10^{-6}$	$9.2*10^{-9}$
4	$3.4*10^{-8}$	$2.3*10^{-6}$	$9.2*10^{-9}$
5	$3.4*10^{-7}$	$7.1*10^{-5}$	$2.9*10^{-7}$
6	$1.3*10^{-6}$	$4.0*10^{-5}$	$2.8*10^{-8}$
7	$1.9*10^{-6}$	$4.7*10^{-5}$	$1.6*10^{-10}$
8	$2.1*10^{-6}$	$5.0*10^{-5}$	$1.7*10^{-10}$

[a] *Estimated using equations 3.2 and 3.3;* [b] *Exposures listed in table 5.2*

5.3.2.1Annual probability of infection and annual infections

The annual probability of infection from the water treatment plants was very low (table 5.11) due to low doses of pathogen ingested compared to the water distribution system (table 5.3). The annual probability of infection following power outage (exposure 1) at Weija treatment plant was $2.6*10^{-5}$ for rotaviruses, $5.4*10^{-7}$ for *Campylobacter* and $1.2*10^{-8}$ for *Cryptosporidium*. For filtration error (exposure 2) at Weija, the probability of infection ranged from $1.3*10^{-9}$(*Campylobacter)* to $3.8*10^{-6}$ (rotaviruses). The low probability of infection in the event of power outage could be due to the short duration

(table 5.1) and because it was assumed that the contaminated water was diluted by a day's treated water that was already in the reservoir.

Table 5.11: Probability of infection (annual) from the water supply pathway [a]

Exposure [b]	*Campylobacter*	Rotavirus	*Cryptosporidium*
1	$5.4*10^{-7}$	$2.6*10^{-5}$	$1.2*10^{-8}$
2	$1.3*10^{-9}$	$3.8*10^{-6}$	$1.8*10^{-8}$
3	$1.2*10^{-5}$	$8.4*10^{-4}$	$3.4*10^{-6}$
4	$1.2*10^{-5}$	$8.4*10^{-4}$	$3.4*10^{-6}$
5	$3.4*10^{-7}$	$7.1*10^{-5}$	$2.9*10^{-7}$
6	$1.9*10^{-3}$	$5.8*10^{-3}$	$4.1*10^{-6}$
7	$4.5*10^{-4}$	$1.1*10^{-2}$	$3.7*10^{-8}$
8	$5.5*10^{-4}$	$1.3*10^{-2}$	$4.4*10^{-8}$

[a] *Estimated using equation 3.4;* [b] *Exposures listed in table 5.2*

At Kpong treatment plant, the annual probability of infection (table 5.11) was higher than at Weija in all the pathogens, especially in exposure 3 (disinfection error) and exposure 4 (coagulation error). These two were normal operations due to inadequate manpower (exposure 3) and due to the assumption that the source water was clean and therefore, coagulation chemicals were not needed (exposure 4). Coagulation is very important especially for removal of *Cryptosporidium* which is resistant to disinfection (LeChevallier and AU, 2004; Stanfield et al., 2003).

The annual probability of infection for exposure 6 (contaminated distribution system) was $5.8*10^{-3}$ for rotaviruses, $1.9*10^{-3}$ for *Campylobacter* and $4.1*10^{-6}$ for *Cryptosporidium* (table 5.11). Exposure 7 (distribution system with low pressure, 108 hours/week) and exposure 8 (distribution system with low pressure, 120 hours/week) had the highest probability of infection for rotaviruses and *Campylobacter*.

If an acceptable annual risk of infection of 1 in 10,000 as suggested by the US EPA (Eisenberg et al., 2001; Macler and Regli, 1993) were to be applied, then it would mean that exposures 6-8 are above the acceptable risk (for *Campylobacter* and rotaviruses) and would be a threat to the community. Exposures 7 and 8 were based on intermittent water supplies, and studies show that these supplies entail a high risk of contamination, creating substantial health hazards (Totsuka et al., 2004). Exposure 3 and 4 were just slightly higher (9 in 10,000) than the acceptable annual risk of infection (for rotavirus). Even though this is minimal, it could have a negative impact on the community, if the situation continues that way, and if the raw water quality deteriorates further.

Table 5.12: Annual infections per exposure point in the water supply pathway [a]

Exposure [a]	*Campylobacter*	Rotavirus	*Cryptosporidium*
1	0.3	17	0.01
2	0	2	0.01
3	4	292	1
4	4	292	1
5	0.1	25	0.1
6	179	5501	4
7	133	3266	0
8	190	4500	0.02
Total	**510**	**13,895**	**6**

[a] *Estimated using equation 3.5,* [b] *Exposures listed in table 5.2*

From table 5.12, exposure 6 had the highest number of annual infections for rotaviruses (5500) and *Cryptosporidium* (4), while exposure 8 had the highest number of annual infections for *Campylobacter* (190). Figure 5.3 shows that incidents in the water

distribution system contributed the highest number of infections from all pathogens. The infections from the water treatment plants were insignificant.

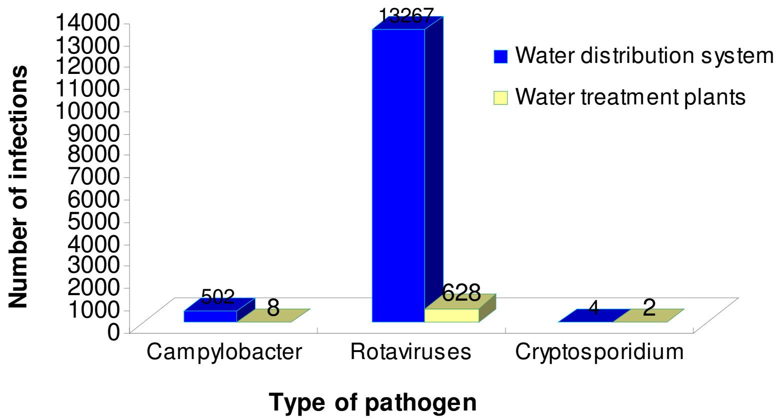


Figure 5.3: Annual infections from the water supply pathway

5.3.2.2 Probability of developing illness and annual symptomatic cases

The probability of developing illness per single exposure in the water supply pathway ranged from $1.2*10^{-6}$ to $2.5*10^{-5}$ for rotaviruses, $3.9*10^{-10}$ to $6.3*10^{-7}$ for *Campylobacter* and $1.1*10^{-10}$ to $2.0*10^{-7}$ for *Cryptosporidium* (table 5.13).

Table 5.13: Probability of developing illness following single exposure [a]

Exposure [b]	*Campylobacter*	Rotavirus	*Cryptosporidium*
1	$4.5*10^{-8}$	$3.6*10^{-6}$	$2.2*10^{-9}$
2	$3.9*10^{-10}$	$1.9*10^{-6}$	$1.3*10^{-8}$
3	$1.0*10^{-8}$	$1.2*10^{-6}$	$6.4*10^{-9}$
4	$1.0*10^{-8}$	$1.2*10^{-6}$	$6.4*10^{-9}$
5	$1.0*10^{-7}$	$3.6*10^{-5}$	$2.0*10^{-7}$
6	$3.9*10^{-7}$	$2.0*10^{-5}$	$2.0*10^{-8}$
7	$5.7*10^{-7}$	$2.4*10^{-5}$	$1.1*10^{-10}$
8	$6.3*10^{-7}$	$2.5*10^{-5}$	$1.2*10^{-10}$

[a] *Estimated using equation 3.6;* [b] *Exposures listed in table 5.1*

Exposure 8 had the highest annual probability of developing illness from rotaviruses and *Campylobacter* while exposure 6 had the highest for *Cryptosporidium* (table 5.14).

Table 5.14: Probability of developing illness (Annual) from the sanitation pathway [a]

Exposure [b]	*Campylobacter*	Rotavirus	*Cryptosporidium*
1	$1.6*10^{-7}$	$1.3*10^{-5}$	$8.1*10^{-9}$
2	$3.9*10^{-10}$	$1.9*10^{-6}$	$1.3*10^{-7}$
3	$3.7*10^{-6}$	$4.2*10^{-4}$	$2.4*10^{-6}$
4	$3.7*10^{-6}$	$4.2*10^{-4}$	$2.4*10^{-6}$
5	$1.0*10^{-7}$	$3.6*10^{-5}$	$2.0*10^{-7}$
6	$5.5*10^{-5}$	$2.8*10^{-3}$	$2.7*10^{-6}$
7	$1.3*10^{-4}$	$5.5*10^{-3}$	$2.6*10^{-8}$
8	$1.6*10^{-4}$	$6.5*10^{-3}$	$3.1*10^{-8}$

[a] *Estimated using equation 3.7;* [b] *Exposures listed in table 5.2*

Annual symptomatic cases were few from the water supply pathway with 151 cases for C*ampylobacter,* 6,849 cases for rotaviruses and only 5 for *Cryptosporidium* (table 5.15). The water distribution system contributed 99% of the total *Campylobacter*

cases, 95% of the total rotavirus cases and 60% of the total *Cryptosporidium* cases (figure 5.4). The low number of symptomatic cases especially from the water treatment plants was due to the very low ingestion doses (table 5.3).

Table 5.15: Annual symptomatic cases from single water supply pathway [a]

Exposure [b]	***Campylobacter***	**Rotavirus**	***Cryptosporidium***
1	0	8	0
2	0	1	0
3	1	146	1
4	1	146	1
5	0	12	0
6	52	2641	3
7	40	1638	0
8	57	2257	0
Total	**151**	**6849**	**5**

[a] *Estimated using equation 3.8;* [b] *Exposures listed in table 5.2*

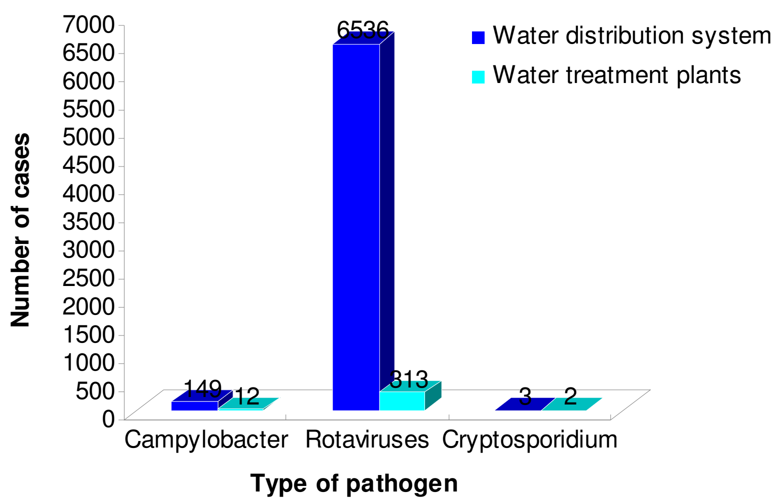


Figure 5.4: Annual symptomatic cases from the water supply pathway

Even though the incidence from the water supply is low, the public health burden associated with diseases might be significant especially if the diseases develop into chronic syndromes (Pruss and Havelaar, 2001). For example, in AIDS patients, infection with *Cryptosporidium parvum* leads to gastroenteritis in virtually all cases. Only 30% of AIDS patients have remission, the rest suffer from cryptosporidiosis until death (Havelaar and Melse, 2003). This in developing countries might be a source of untold misery to both the infected and the affected due to economic hardships, and therefore efforts should be made to ensure that the risk of infection is reduced.

5.4 Comparing sanitation and water supply

In total, there were 31,140 infections for C*ampylobacter,* 104,955 for rotaviruses, 360 for *Cryptosporidium* and 8,589 for *Ascaris.* The sanitation pathway contributed 98% of the total *Campylobacter* infections, 87% of rotavirus infections, 98% of *Cryptosporidium* infections and 100% of *Ascaris* infections (figure 5.5).

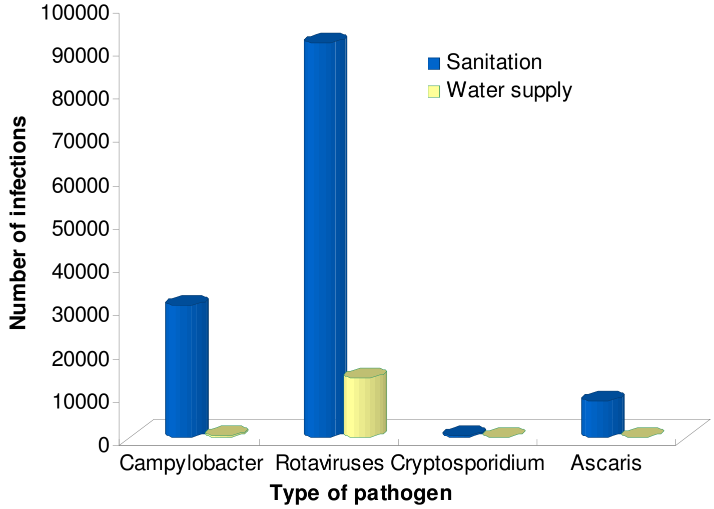


Figure 5.5: Annual infections from sanitation and water supply

Overall, the sanitation pathway contributed the highest number of symptomatic cases with 99% for *Campylobacter,* 90% for rotavirus, 98% for *Cryptosporidium* and 100% for *Ascaris* (figure 5.6). Rotaviruses had the highest cases compared to the other two pathogens. The risk from the water supply pathway could have been underestimated due to the unreliability of data especially the one that was obtained at the two water treatment plants. In summary, the sanitation pathway in Accra is more risky compared to the water supply pathway and contributes greatly to the waterborne disease incidence. This calls for immediate interventions in this pathway.

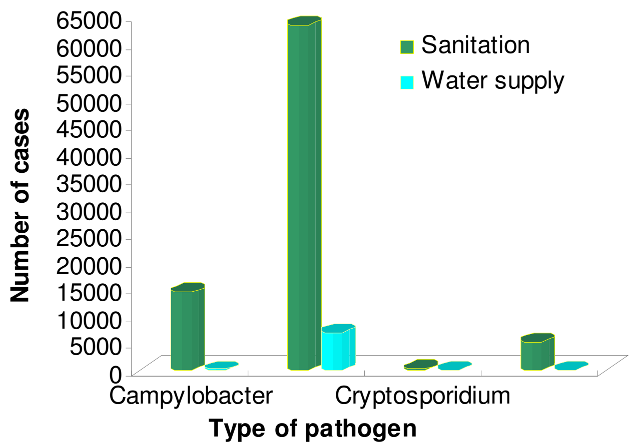


Figure 5.6: Annual symptomatic cases from sanitation and water supply

5.5 Disease burden (in DALYs) from the Accra urban water system

DALY as a metric measure was used to compare different outcomes from the pathogens included in the study. From figure 5.7, the DALYs per case due to rotavirus was much greater (0.39) compared to the rest of the pathogens. This is because the case fatality ratio for rotavirus was high (0.7%) compared to the rest. The case fatality ratio for *Ascaris* (0.08%) (Crompton, 1999), was low because death following infection with this particular pathogen is rare. This was also the case with *Campylobacter;* with a case

fatality ratio of 0.1% (Haas et al., 1999). Calculation of the mortality burden of *Cryptosporidium* was only based on the HIV/AIDS positive group, which already had a diminished life expectancy due to the disability from this disease. All these explains why the disease burden per case due to *Campylobacter, Cryptosporidium* and *Ascaris,* was lower than for rotavirus. It can be concluded that rotavirus has a more severe impact per case than the rest of the pathogens and therefore, interventions should be geared towards reducing the DB due to this pathogen.

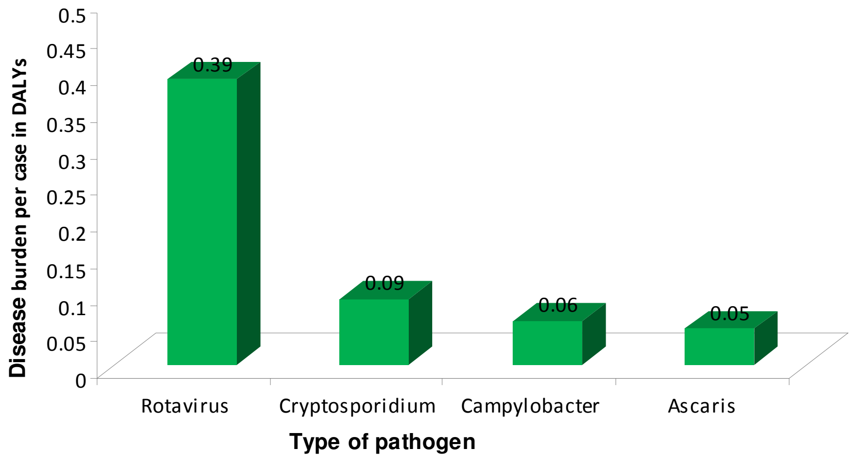


Figure 5.7: DALYs per case per pathogen

(As calculated in table 3.25)

Using the DB per case per every pathogen in figure 5.7, the total DB from the Accra urban water system was calculated as described in section 3.3.4.

Figure 5.8 shows the total disease burden as contributed by every pathogen. There were 28,531 DALYs in total with 91% contribution from sanitation. In addition, rotaviruses had the highest contribution (96%) to the total DALYs. There were 27,384 DALYs due to rotaviruses, with 90% contribution from sanitation and 867 DALYs due to *Campylobacter* with 99% contribution from sanitation. The DALYs due to Ascaris and *Cryptosporidium* were very minimal, with only 256 DALYs due to the former, from sanitation alone and 24 DALYs due to the latter. This shows that sanitation contributes greatly to the waterborne DB in Accra, with rotavirus dominating the DB.

The DALY per person per year from the AUWS is $3.0*10^{-2}$ (total DALYs/total population in the Odaw catchment of 995363). If the reference risk of $1.0*10^{-6}$ DALYs per person per year (WHO, 2004) were to be applied, then it means that the DB from the AUWS is 30,000 times higher than the WHO reference value. This is a threat to the citizens of Accra, and efforts should be made to reduce this risk.

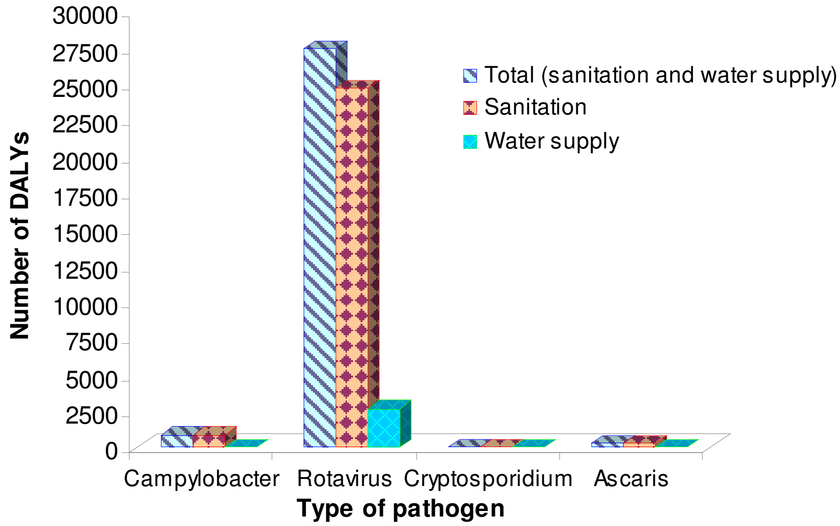


Figure 5.8: Disease burden from the Accra urban water system

5.6 Established waterborne disease incidence

Waterborne diseases in AMA

According to the Accra Metropolitan Assembly health services, these were as listed in table 5.16 below:

Table 5.16: Type of waterborne diseases as reported by AMA health service

Disease	Aetiological agent
Typhoid	*Salmonella typhi*
Cholera	*Vibrio cholerae*
Diarrhoeal diseases	Unkwon
Infectious hepatitis	Hepatitis A virus
Intestinal worms	Helminths

Adjusted waterborne disease incidence based on 82% underreporting rate

The waterborne disease incidence in AMA was adjusted for underreporting using 82% underreporting rate (see section 3.3.6.1).

Diarrhoeal diseases of unknown aetiological agent contributed greatly to the waterborne disease incidence in AMA with an average annual incidence of 1157 cases per 10,000 population (figure 5.9). This was followed by intestinal worms with an average annual incidence of 182 cases per 10,000 population. Infectious hepatitis was the lowest with only 8 cases per 10,000 population.

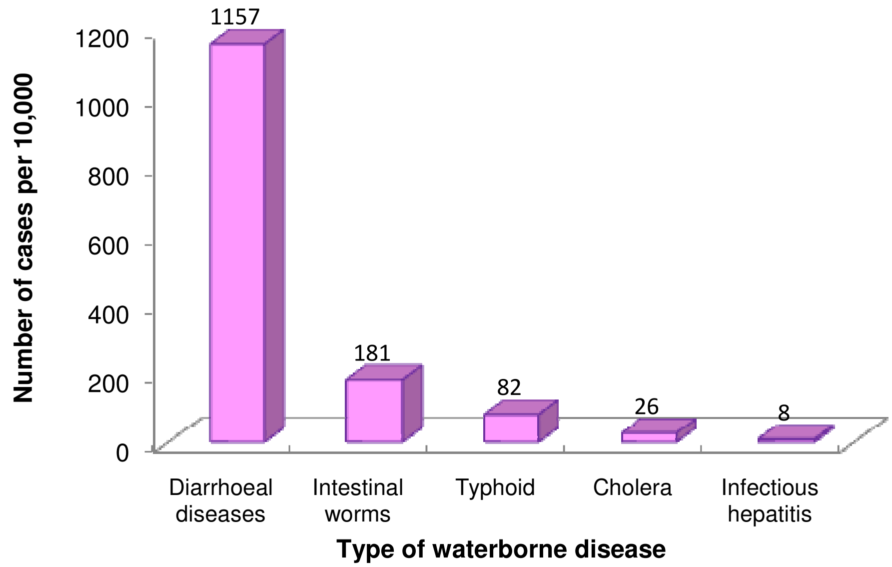


Figure 5.9: Average annual incidence in AMA per 10,000 calculated from the 2003-2005 data

Spatial distribution of waterborne disease incidence in AMA

The total waterborne disease incidence per every sub-metro was calculated (table 5.17) and then ranked by comparing the highest and the lowest values (figure 5.10).

Table 5.17: Spatial distribution of waterborne disease incidence in AMA

Sub-metro	Typhoid	Cholera	Diarrhoeal diseases	Infectious hepatitis	Intestinal worms	Total
Ablekuma	61	28	682	11	107	**889**
Ashiedu Keteke	396	45	4344	24	493	**5302**
Ayawaso	56	26	925	5	220	**1232**
Kpeshie	15	8	787	3	126	**936**
Okaikoi	20	42	1394	2	185	**1643**
Osu Klottey	416	37	2492	21	369	**3345**

From table 5.17, Ashiedu Keteke had the highest number of cases per 10,000 (5302) followed by Osu Klottey (3345).These two sub-metros contain some of the low income places in AMA (AMA, 2002), with some located near the Korle lagoon (Boadi and Kuitunen, 2002), which is regarded as the world's dirtiest places (IDRC, 1996). Sanitation facilities around this place are very poor. In addition, Songsore et al., (2005), report that areas around this lagoon have the greatest environmental burden in AMA.

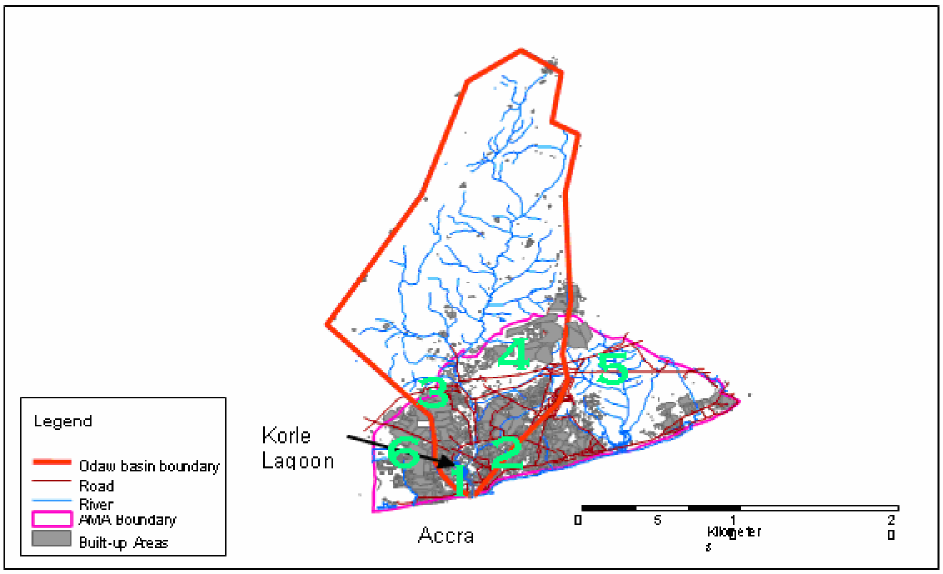
According to Eisenberg et al., (2001), social conditions in which an individual lives play a role in the transmission of diseases. People subject to poverty are more likely to suffer disease due to increased exposure to pathogens from inadequate environmental conditions. This, in addition to poor environmental conditions could explain why the waterborne disease incidence is highest in the two sub metros (figure 5.9) compared to the rest of the sub-metros in AMA.

Table 5.18 shows percentage contribution of every type of waterborne disease to the total incidence in every sub-metro. Diarrhoeal diseases of unknown aetiological agent had the highest contribution in all the sub-metros.

Table: 5.18 Percentage contributions to the incidence by every waterborne disease in every sub-metro [a]

Sub-metro	Typhoid	Cholera	Diarrhoeal diseases	Infectious hepatitis	Intestinal worms	Total
Ablekuma	7	3	77	1	12	**100**
Ashiedu Keteke	7	1	82	1	9	**100**
Ayawaso	5	2	75	0	18	**100**
Kpeshie	2	1	84	0	13	**100**
Okaikoi	1	3	85	0	11	**100**
Osu Klottey	12	1	75	1	11	**100**

[a] *Based on table 5.17*



1-Ashiedu Keteke; 2-Osu Klottey; 3-Okaikoi; 4-Ayawaso; 5-Kpeshie, 6-Ablekuma

Figure 5.10: Spatial distribution of waterborne disease incidence in AMA

Waterborne disease incidence in the Odaw catchment

Table 5.19 shows average annual waterborne disease incidence in the Odaw catchment taken as 60% of the total AMA population. Ashiedu Keteke, Ayawaso and Okaikoi were considered to be 100% in Odaw catchment.

5.19: Average annual waterborne disease cases and incidence in Odaw catchment

Disease	Incidence per total population [a]	Incidence per 10,000 [a]
Typhoid	10,533	106
Cholera	3,505	35
Diarrhoeal diseases	155,986	1567
Infectious hepatitis	983	10
Intestinal worms	24,473	246

[a] *Ashiedu Keteke, Ayawaso and Okaikoi contributed 100% of the cases while Ablekuma, Kpeshie and Osu Klottey contributed 60%.*

Contribution by each aetiological agent to diarrhoeal diseases in the Odaw catchment

Contribution to the diarrhoeal diseases by *Campylobacter,* rotavirus and *Cryptosporidium* was determined based on the percentage contribution by each

pathogen from literature (table 5.20), with rotavirus having the highest contribution (60%).

Table 5.20: Contribution by each aetiological agent to diarrhoeal diseases

Pathogen	Contribution (%)[a]	Cases contributed by each pathogen[a]	Incidence per 10,000[b]
Campylobacter	25[c]	38,997	392
Rotaviruses	60[d]	93,592	940
Cryptosporidium	6.1[e]	9,515	96

[a] *Percentage (column 2) of diarrhoeal disease cases(155,986) in table 5.19.*
[b] *Cases divided by population of Odaw catchment (995363)*10,000;* [c] *Havelaar et al., 2000.*
[d] *Thapar and Sandersson, 2004;* [e] *Adal et al., 1995.*

5.7 Comparison of endemic incidence and risk assessment incidence

Waterborne disease incidence from risk assessment was converted into incidence per 10,000 population using (table 5.21). This was then compared to the endemic waterborne disease incidence (table 5.20). Percentage contribution from each exposure to the endemic waterborne disease incidence was also calculated. Open drainage channels as an exposure point had the highest contribution in rotaviruses (31%) followed by recreational swimming (30%), which also had the highest contribution for *Campylobacter* (33%). Faecal septage disposal point had the highest contribution from *Ascaris (*20%) and *Cryptosporidium (*2%). From the water supply, water distribution system had the third highest contribution from rotaviruses (7 %).

Table 5.21: Incidence per 10,000 from risk assessment and percentage contribution to the endemic waterborne disease incidence [a]

Exposure	*Campylobacter*	Rotavirus	*Cryptosporidium*	*Ascaris*
Sanitation				
1. Recreational swimming	130 (33)	285 (30)	0.1 (0.1)	0.1 (0.04)
2. Flooding of the Odaw drain (exposures 2-4)	1 (0.3)	44 (5)	0.1 (0.1)	0.1 (0.04)
3. UASB treatment plant (exposures 5-7)	0.2 (0.1)	0.2 (0.02)	0.01 (0.01)	0 (0)
4. Faecal septage disposal place (exposures 8-10)	1 (0.3)	15 (2)	2 (1)	50 (20)
5. Open drainage channels	12 (3)	293 (31)	1 (1)	2 (1)
Water supply				
1. Water treatment plants (exposures 1-5)	1 (0.01)	3 (0.3)	0.02 (0.02)	-
2. Distribution system (exposures 6-8)	1.5 (0.4)	66 (7)	0.03 (0.03)	-

[a] *The first value in each column is the risk assessment incidence per 10,000 population. The second value (in parentheses) is the percent contribution of each pathway to the background endemic waterborne disease incidence of Odaw catchment (table 5.20)*

A ranking (table 5.22) was done according to the suggested definition of severity of consequences as listed in table 3.3, in order to identify the most hazardous pathway. The severity of consequences caused by rotaviruses was catastrophic for recreational swimming and open drainage channels, major for flooding of the Odaw drain and the water distribution system. The severity of consequences caused by *Campylobacter* was

catastrophic for recreational swimming and moderate for open drainage channels. Faecal septage disposal point had major severity of consequences from *Ascaris* and moderate severity of consequences from rotavirus and *Cryptosporidium*. The rest were either minor or insignificant. From the above, the sanitation pathway is very hazardous to the citizens of Accra compared to the water supply, and the greatest impact to the community would arise if people ingest contaminated water while swimming and if children ingest contaminated sand/water while playing near open drainage channels. However, the water distribution system also had substantial risks especially from rotaviruses and therefore it should not be ignored due to the large population exposed to this pathway.

Table 5.22: Ranking of severity of each pathway [a]

Exposure	*Campylobacter*	Rotavirus	*Cryptosporidium*	*Ascaris*
Sanitation				
1. Recreational swimming	Catastrophic	Catastrophic	Minor	Insignificant
2. Flooding of the Odaw drain (exposures 2-4)	Minor	Major	Minor	Insignificant
3. UASB treatment plant (exposures 5-7)	Minor	Insignificant	Insignificant	Insignificant
4. Faecal septage disposal place (exposures 8-10)	Minor	Moderate	Moderate	Major
5. Open drainage channels	Moderate	Catastrophic	Moderate	Minor
Water supply				
1. Water treatment plants (exposures 1-5)	Insignificant	Minor	Insignificant	-
2. Water distribution system (exposures 6-8)	Minor	Major	Insignificant	-

[a] based on the severity of consequences listed in table 3.3

5.8 Prioritization of the exposure pathways using DALYs

In order to increase the allocative efficiency of resources, pathways had to be prioritized so that the most significant pathway is addressed first. The total number of DALYs per exposure pathway was calculated using the procedure described in section 3.3.4. The results were then used to prioritize the pathways as shown in figure 5.11 below. The exposure pathway that contributed the highest percentage to the total DALYs (28,531) was recommended to be given the highest priority

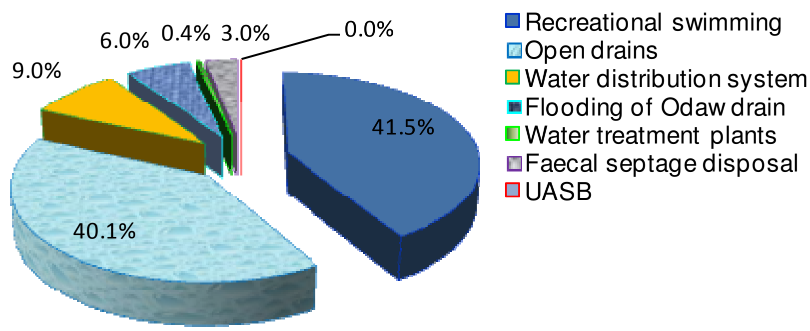


Figure 5.11: Percentage contribution of the pathways to the total DB (in DALYs) from the AUWS

From figure 5.11, recreational swimming had the highest contribution (42%) to the total DALYs. This was followed closely by open drainage channels (40%). Water

distribution system was third; flooding of Odaw drain fourth and faecal septage disposal fifth. The percentage contribution by the water treatment plants and the UASB were insignificant.

Applying the reference risk of $1.0*10^{-6}$ DALYs per person per year, then it would mean that nearly all the pathways pose a threat to the citizens of Accra. This is because the DALYs pppy from the pathways are several magnitudes higher than the reference risk (table 5.23). Therefore, all pathways need to be addressed in order to reduce the risk.

Table 5.23: Comparison of DALYs pppy from every pathway with reference level.

Exposure pathway	**DALYs per year**	**DALYs pppy [a]**	**Comparison with reference level ($1.0* 10^{-6}$ DALYs pppy [b])**
Recreational swimming	11,829	$1.0*10^{-2}$	10,000 times higher
Open drains	11,441	$1.0*10^{-2}$	10,000 times higher
Water distribution system	2,558	$3.0*10^{-3}$	3,000 times higher
Flooding of Odaw drain	1,725	$2.0*10^{-3}$	2,000 times higher
Faecal septage disposal	845	$8.0*10^{-4}$	800 times higher
Water treatment plants	123	$1.0*10^{-4}$	100 times higher
UASB	9	$9.0*10^{-6}$	9 times higher

[a] *Total DALYs from each pathway divided by Odaw population of 995,363*
[b] *WHO, (2004)*

Due to the large population of children exposed to hazards from the open drains, this pathway should be addressed first, instead of the recreational swimming. Interventions in this pathway will also mean addressing flooding of the Odaw drain pathway as it is also an open drain.

Due to the diverse sources of pollution in recreational waters (raw sewage discharge, bather shedding, storm water runoff, agricultural sources etc), it will not be so important to address recreational swimming pathway before the faecal septage disposal point pathway. This is because the frequency of exposure for the workers in the latter was high and the population of children exposed was large compared to recreational swimming. In addition, this pathway scored very high for *Ascaris,* which is a major contributor to the worm burden in developing countries. On the other hand, recreational swimming was identified as an exposure point only after ascertaining that the septage disposed of at Lavender hill, flows downstream to the beaches. If the disposal of septage is properly addressed, the risks associated with recreational swimming would also reduce as the amount of pathogen concentration from raw sewage in the recreational waters will be minimal. Addressing the problem of faecal septage would also mean addressing the problem of overflowing septic tanks.

Water distribution system should be the third pathway to be addressed. This pathway should be considered important due to the large population exposed. If any major contamination occurs, many people will be at risk of infection.

In summary, a suggestion is given that if possible, intervention in the Accra urban water system should following order;

i). Open drainage channels
ii). Flooding of the Odaw drain and faecal septage disposal
iii). Water distribution system
iv). Recreational swimming
v). Water treatment plants
vi). UASB

5.9 Uncertainties

The results from this study should be interpreted with an understanding that the risk assessment was based on many assumptions which could have created uncertainties. However, the results could make a good contribution towards decision making. The uncertainties are as outlined below.

Most of the exposure frequencies, especially for the sanitation pathway were based on data from developed countries and environmental conditions in those countries might be different from developing countries. In addition, calculation of yearly probability of infections assumed that an individual is exposed to a constant concentration of pathogens all the time. This might not be the case as pathogen concentrations in any medium varies all the time, and there in no constant level of contaminations to which individuals are exposed to at all times (Haas et al., 1999).

The ingestion volumes for water supply and recreational swimming were same for all age groups. This brings a lot of errors as individual persons consume different amounts of water or food (Haas et al., 1999). Adults may be expected to drink larger volumes of water than newborn infants. In addition, children might swallow more water during swimming than adults (Cheung et al., 1990).

For recreational swimming, pathogen concentrations were only estimated from raw sewage. This did not take into account the various other diverse sources of pollution in recreational waters like bather shedding, especially children (Deere et al., 2001), or storm water discharge which could increase the concentration. In addition, the dilution factor of 1000 assumed could have created errors, as it was based on studies done in developed countries (Ottoson, 2005). The frequency of exposure was taken to be seven times per year but it could be higher/lower for some people.

Raw water quality data from the water treatment plants could have been the greatest source of error. This is because the microbiological quality of raw water was always recorded as 16MPN/100ml or >16MPN monthly average. This was the same for the period 2001-2006. It could not be established as to what was the real value if >16MPN/100ml was recorded. At Kpong treatment plant, the monthly average microbiological quality of raw water was either 8 or >8MPN/100ml. It is very unusual for the quality of raw water to be almost the same for so many years, as there could be variations, and is expected to be high during heavy rainfall (Jones, 2001). Therefore, it was uncertain whether the predicted incidence from the water treatment plants was a true representation of this pathway. In addition, estimating the removal of pathogens by treatment processes was also considered to be a source of error. Treatment removal efficiencies may vary greatly for a particular process and pathogen removals may be overestimated or underestimated. The ratio of *E. coli*: pathogen was taken to be constant throughout the year yet it could vary with seasons.

The *Giardia* model used for *Ascaris* could have been another source of uncertainty in the calculation of probability of infection for *Ascaris*. Even though their infective doses might almost be the same, it has not been established whether the dose-response relationship is the same for these pathogens.

Another source of uncertainty is the underreporting rate (82%) that was used to adjust the established waterborne disease incidence in AMA. To address this in future, epidemiological surveys need to be carried out.

Reducing uncertainty

The risk assessment used point estimate, which even though it offers easy communication of results to decision makers, it does not give additional information on the level of uncertainty. Full Monte Carlo analysis should be used in future as this incorporates the uncertainty distribution (Haas et al., 1999).

Concentration of pathogens from different transmission pathways in Accra should be determined. Laboratory analysis of water quality needs to be carried out by future investigators themselves, instead of relying on secondary data. In addition, studies on volume of drinking water consumption in Accra should be undertaken.

6 Management Options

This section gives some management options in general, for the pathways discussed in section five.

Integrated approach to the management of the urban water system

An integrated approach of running the system is highly recommended. There is need for liaison of all the institutions and stakeholders involved. The government of the republic of Ghana should ensure that the Ministry of Health; the Ghana Water Company; the Environmental Protection Agency; the Ghana sewerage company, the waste management department and the ministry of education and other research institutions (Water research institute, IWMI, Water aid among others), work together to ensure that the Accra urban water system is safe for its citizens.

6.1 Water supply

From the assessment, water distribution system had a higher risk compared to the water treatment plants. The distribution system therefore needs a safety improvement. The risks were mainly due to pathogen ingress into the pipes due to low pressure in the event of intermittent water supplies. Some of the causes of intermittent supplies in Accra are:

i). High demand

The water that is provided for by the GWCL per day is not enough to meet the demand of the population of Accra. This therefore, has resulted into intermittent supplies or water rationing. The water distribution system of Accra, which was built 40 years ago, is inadequate to meet the high demands of the current population.

ii). Mismanagement

The second reason for intermittency could be mismanagement of the distribution system in Accra. The GWCL estimates that 30% of the water that leaves the treatment plants is lost through leakage. If there is proper management and leakages are identified and repaired, the amount of water lost could be reduced and subsequently, hours of intermittency reduced.

iii). Inadequate electricity

High levels of electricity rationing in Accra could also lead to intermittent supplies.

The issue of intermittency should be addressed. The government should ensure that water supply is upgraded to 24 hours a day to ensure that at least there is some adequate pressure in the pipe network. This will minimize pathogen ingress into the pipes in the event of low pressure, and consequently, hazards to the consumers will be minimized. However, there is a challenge to upgrading to a 24 hours/day supply. This is because the

high demand in Accra already exceeds the capacity of the existing system. Therefore, it is highly recommended that the existing system (water treatment plant and water distribution) is upgraded.

Secondly, good operation and maintenance is recommended, so that leakages can be detected on time and repaired. Tools appropriate for leak detection methods should be improved. This will reduce water loss and the duration of intermittent supply will also reduce.

At Kpong treatment plant, a new chlorine pump should be provided. In addition, coagulation should be re-introduced for effective removal of low concentrations of especially *Cryptosporidium.*

Water safety plan (WSP)

A system approach is recommended for the management of the water supply system of Accra. The GWCL should prepare, implement and evaluate a WSP. A WSP is an improved risk management tool designed to ensure the delivery of safe drinking water (Godfrey and Howard, 2005). This will make an organization to understand the system, identify hazardous scenarios and address them on time; identify any training requirements of the human resource and institute culture change in the issues of water management. The procedure for establishing the water safety plan is outlined in Godfrey and Howard, 2005). In addition, the GWCL should consider adopting, implementing and being certified to one of the formal management systems; quality management system (ISO 9001:2000) or Hazard Analysis and Critical Control Points (now called food safety management system based on ISO 22000:2006). This will add value to the system as it involves experienced external auditors to check the system compliance more often.

6.2 Sanitation

The sanitation system in Accra needs a total overhaul. Dumping of untreated septage into the environment (Lavender hill) should be minimized. This should be done by treating the septage before disposal.

The faecal sludge treatment plants at Teshie Nungua and Achimota should be repaired and upgraded for the treatment of faecal septage. In addition, the UASB treatment plant at Korle Gonno should also be repaired. Proper operation and maintenance of the treatment plants is highly recommended. The government should provide funds and improve skills and capacity of the people to manage the system. If operation and maintenance is neglected, the plants will break down again as soon as they are repaired.

The provision of pit latrines in the residential areas near the faecal septage disposal place will reduce the number of people/children who frequent the area for open defecation purposes, and thus exposure to this pathway will be minimized. Workers handling the faecal sludge should be given protective clothing to minimize exposure to hazards.

Dumping of solid waste into the open drains should be stopped. This will minimize clogging of the drains and the subsequent stagnation of wastewater and flooding during rainy seasons. Stricter rules and better enforcement of the environmental law should be enhanced. In addition, health education and public awareness on this issue should be enhanced.

Open drains should be covered. Although this could be long term, it will minimize the many health hazards from this pathway.

Small bore/settled sewerage system is recommended as this is appropriate in areas which already have septic tanks, like Accra. This is an improved version of the sewerage system, designed to receive only the liquid portion of household waste for off-site treatment and disposal. Retention period of accumulated septage is three years. This type of sewerage system is cheaper to install and easier to construct. Mara, (2006), estimates that the system costs 60% of the total cost of conventional sewerage, and it is even much cheaper in areas which already have existing septic tanks. The advantages and disadvantages of this type of system are outlined in table 6.1.

Table 6.1 Description of small bore

Description	Advantages	Disadvantages
It is an improved version of the sewerage system, which has incorporated the requirements of high density, low income communities. It uses smaller diameter pipes, laid at flatter gradients. It has three main components. ✓ The house connection which collects wastewater from all households ✓ The interceptor tanks, which remove solids from sewage ✓ Small bore, which convey the solid-free effluent away.	1. Sewers can be designed for full flow conditions and hence smaller diameter and lesser cost 2. Need not be laid at steeper gradient to maintain self-cleansing velocity and hence lesser depth of excavation. 3. Much cheaper to install and easier to construct 4. Operates on very little water 5. Can be applied in high density communities	1. The interceptor tanks need periodic desludging and hence a centralized maintenance system with vacuum tanker is required. 2. Illegal connection to the system may cause problems, for example clogging

Source: Mara, 2006.

7 Conclusions

This chapter summarises the findings of the study.

1. Some of the potential transmission routes originating from the AUWS were identified. From the sanitation system, the routes identified were: recreational swimming in contaminated beaches; flooding of the Odaw drain; the UASB treatment plant; faecal septage disposal place and open drainage channels. From the water supply system, the routes identified were the water treatment plants due to errors in the treatment processes and the contaminated distribution system.

2. The established waterborne disease incidence was highest in Ashiedu Keteke sub-metro and lowest in Ablekuma sub-metro.

3. The urban water system contributed greatly to the endemic waterborne disease incidence in AMA. It contributed 75% of the rotavirus cases; 37% of *Campylobacter* cases; 21% of *Ascaris* cases and 3% of *Cryptosporidium* cases. Rotaviruses contributed 78% of the total cases from risk assessment.

4. The disease burden from the Accra urban water system is substantial. There was a total of 28, 531 DALYs, with sanitation contributing 91%. This is an equivalent of $3.0*10^{-2}$ DALYs pppy which is 30,000 times higher than the reference value of $1.0*10^{-6}$ DALYs pppy, set by WHO. In addition, rotaviruses dominated the DB.

5. The risk from AUWS would have a significant impact to the community as shown in table 7.1. The largest impact to the Accra community would arise if children ingest contaminated sand/water while playing near open drainage channels and if people swim in contaminated beaches. Overall, the sanitation pathway was judged to be of more importance than the water supply pathway.

Table 7.1: Ranking of severity of each pathway [a]

Exposure	***Campylobacter***	**Rotavirus**	***Cryptosporidium***	***Ascaris***
Open drainage channels	Moderate	Catastrophic	Moderate	Minor
Flooding of the Odaw drain	Minor	Major	Minor	Insignificant
Faecal septage disposal place	Minor	Moderate	Moderate	Major
Water distribution system	Minor	Major	Insignificant	-
Recreational swimming	Catastrophic	Catastrophic	Minor	Insignificant
Water treatment plants	Insignificant	Minor	Insignificant	-
UASB treatment plant	Minor	Insignificant	Insignificant	Insignificant

[a] *Arranged in order of priority*

6. The AUWS is not safe for its citizens and therefore, it should be addressed in order to minimize the risks.

8 Recommendations

This chapter gives recommendations to the findings from the study.

1. Further research on microbial risk assessment of the urban water system in Accra should be done. The research should incorporate full Monte Carlo analysis so as to give frequency of distributions. In addition, variability and sensitivity analysis need to be done.

2. Stakeholders should be involved from the beginning so that more information is provided.

3. One pathway should be investigated at time as this gives more room for intensive investigation. In addition, the size of the area to be investigated need to be minimized. In view of this, Ashiedu Keteke and Osu Klottey should be the next area of focus as these were the sub-metros that had the highest endemic waterborne disease incidence.

4. Other further studies recommended are:

    i). Volume of drinking water by residents of Accra
    ii). Microbial concentration of surface waters in Accra,
    iii). Pressure transients in the water distribution system
    iv). Pathogen concentrations of soils adjacent to the drinking water pipelines and soils adjacent to the open drains
    v). Identification of more exposure pathways in the AUWS

5. There are other sources of water in Accra like water tankers and boreholes/wells. The study did not address risks from these sources and therefore, it is recommended they be addressed in future because they also form part of AUWS.

6. The disease surveillance in AMA should be strengthened in the form of community based disease surveillance system so as to improve on the on reporting.

7. Funding is recommended so that options identified in section 6 are implemented. This if done, the health hazards from the AUWS will be minimized.

8. The UNESCO-IHE should subscribe to Medline, PubMed and ProMed in future, if studies of this kind are carried out. This is for the purposes of obtaining more literature on waterborne diseases.

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Appendices

Appendix 1: Institutions visited and checklist for data collection.

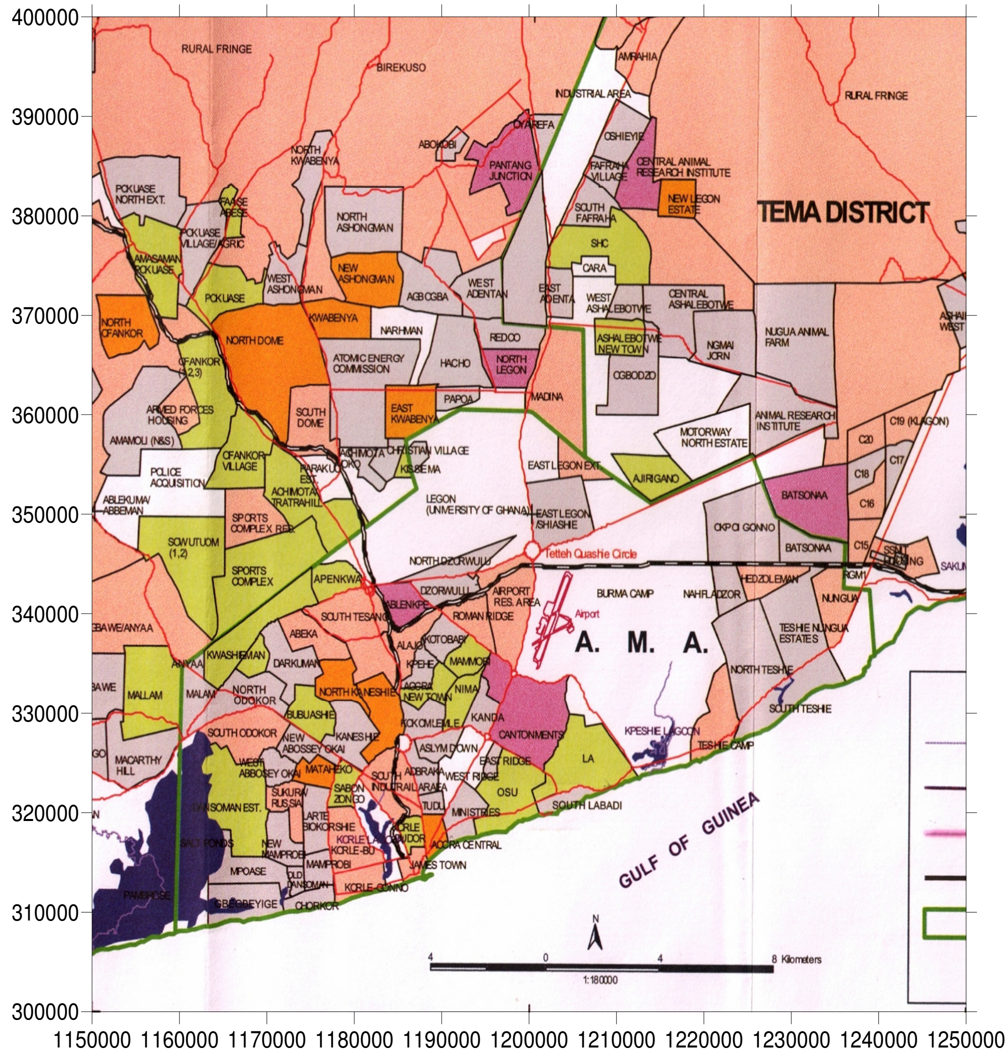
Institutions visited

- ✓ Accra Metropolitan Assembly Health Services
- ✓ Accra Metropolitan Assembly, Waste Management Department
- ✓ Environmental Protection Agency
- ✓ Ghana Statistical Service
- ✓ Ghana Water Company Limited
- ✓ International Water Management Institute
- ✓ Korlebu Referral and Teaching Hospital
- ✓ Kpong water treatment plant
- ✓ Ministry of Health
- ✓ National Disaster Management Organization
- ✓ Noguchi memorial Hospital
- ✓ School of Public Health, University of Ghana
- ✓ Water Research Institute
- ✓ Weija water treatment plant

Checklist for data collection

Title	List of data
General	➢ Accra population ➢ Waterborne disease incidence
Water supply	➢ Water supply distribution network map (AMA Map) ➢ Population served by piped water supply including percentage in each sub-metro ➢ Low lying areas ➢ Areas experiencing intermittent water supply/frequency of intermittent supplies ➢ Areas experiencing leakages in the pipes ➢ Areas of high/low pressure in the pipes ➢ Areas having open drains ➢ Areas that experience flooding ➢ Microbiological quality of raw water (influent) at the treatment plant ➢ Microbiological quality of treated water leaving the treatment plant ➢ Microbiological quality of water at the consumer's tap
Water treatment plants	➢ Which treatment processes do you use? ➢ What type of disinfectants do you use? what is the dosage/contact time? ➢ Do you experience any power shortages? How often? ➢ If yes, in the event of a power shortage, what do you do? ➢ Any water quality data? ➢ Do you change the dosage levels in the events of heavy rainfall? ➢ Do you monitor the chlorine residual levels? Any data? ➢ What is the source of your raw water? ➢ How often do you backwash the sand filters?
Wastewater	➢ Location of sewers(sewer network) ➢ Population served by sewer network ➢ Location of wastewater/sludge treatment plants ➢ Low lying areas ➢ Areas having open drains/lagoons/open lagoons ➢ Areas that experience flooding ➢ Areas experiencing sewer overflows ➢ microbiological quality of sewage before and after treatment ➢ Microbiological quality of storm water
Floods	➢ Causes of floods, date of occurrence, frequency ➢ Flood damage and extent ➢ Flood prone areas ➢ Performance of drainage works in the flooded area ➢ Number of times area has been flooded in the past ➢ Rainfall amount, intensity and duration ➢ Number of people affected

Appendix 2: Map of Accra city showing residential locations



Source: Songsore et al., 2005

Appendix 3: Data used for constructing charts

Data used for constructing charts

Exposure	***Campylobacter***	**Rotaviruses**	***Cryptosporidium***	***Ascaris***
Figure 5.1 : Annual infections from the sanitation pathway				
Open drains	3,831	49,616	81	387
Recreational swimming	26,247	29,878	18	25
Flooding of Odaw drain	339	8,810	7	33
Faecal septage disposal	192	2,734	247	8,142
UASB	21	22	1	2
Figure 5.2: Annual symptomatic cases from the sanitation pathway				
Open drains	1,164	29,125	57	152
Recreational swimming	12,955	28,333	12	10
Flooding of Odaw drain	102	4,405	5	12
Faecal septage disposal	61	1482	177	4,954
UASB	19	21	1	0
Figure 5.5: Annual infections from sanitation and water supply				
Sanitation	30,630	91,060	354	8,589
Water supply	510	13,896	6	0
Figure 5.6: Annual symptomatic cases from sanitation and water supply				
Sanitation	14,301	63,366	252	5,128
Water supply	161	6,848	5	0
Figure 5.8: Disease burden (in DALYS) from the Accra urban water system				
Total (sanitation and water supply)	867	27,384	24	256
Sanitation	858	24,713	23	256
Water supply	9	2,671	1	0
Figure 5.11: Percentage contribution of the pathways to the total DB (in DALYS) from the AUWS				
Exposure	**DALYS**			
Recreational swimming	11,829			
Open drains	11,441			
Water distribution system	2,558			
Flooding of Odaw drain	1,725			
Faecal septage disposal	845			
Water treatment plants	123			

Appendix 4: AMA waterborne disease incidence for the period 2003-2005

Hospital/Polyclinic	Typhoid	Cholera	Diarrhoeal disease	Infectious hepatitis	Intestinal worms
Data for 2003					
Achimota	10	0	2980	1	121
Ridge	0	0	51	0	57
PML	73	3	4879	8	61
Accra Mental	0	0	0	0	0
Adabraka	310	0	475	13	14
Kaneshe	126	2	2669	13	302
La	7	0	3086	0	31
Maamobi	29	0	2157	6	676
Mamprobi	195	2	3853	73	830
Ussher	94	2	1375	26	595
K'Bu	172	4	749	13	13
Castle	12	0	150	0	5
Stadium	168	0	509	0	107
Makola	109	0	22	0	11
Airport	37	0	3	0	52
Mallam Atta	114	0	160	0	45
Parliament	0	0	67	0	0
Dansoman	2	2	855	10	269
James camp	0	0	29	0	22
PHC MIMA 441	79	0	4	0	2
TUC	1	0	92	0	6
Nima Government	0	0	99	2	100
37 Military	0	0	0	0	0
Legon	0	0	0	0	0
Police	9	0	158	0	33
Fire centre	0	0	24	3	1
Trust	0	0	0	0	0
Total	**1547**	**15**	**24446**	**168**	**3353**
Data for 2004					
Achimota	0	242	2466	0	556
Ridge	0	33	527	3	642
PML	45	64	4157	19	131
Accra Mental	0	0	0	0	0
Adabraka	185	0	468	1	34
Kaneshe	14	14	2992	5	553
La	21	72	2823	4	1970
Maamobi	11	189	1947	5	717
Mamprobi	118	17	3291	72	707
Ussher	117	18	1177	32	550
K'Bu	645	86	3523	43	27
Castle	92	0	295	0	56
Stadium	101	0	552	2	144
Makola	625	0	4	0	4
Airport	185	0	28	0	300
Mallam Atta	50	0	154	0	47
Parliament	1	0	109	0	0
Dansoman	2	64	865	13	50
James camp	0	0	16	0	38
PHC MIMA 441	0	0	11	0	0
TUC	76	0	92	0	29
Nima Government	0	0	206	8	55
37 Military	0	0	0	0	0
Legon	0	0	0	0	0
Police	52	0	983	6	108
Fire centre	0	0	94	0	6
Trust	0	0	0	0	3
Total	**2340**	**799**	**26780**	**213**	**6727**

Data for 2005

Hospital/Polyclinic	Typhoid	Cholera	Diarrhoeal disease	Infectious hepatitis	Intestinal worms
Achimota	0	141	2134	0	87
Ridge	0	0	0	0	0
PML	288	54	6051	13	161
Mental	0	0	0	0	0
Adabraka	175	1	577	14	6
Kaneshe	0	85	2833	0	538
La Poly	25	1	6785	27	0
Maamobi	5	96	4074	1	750
Mamprobi	130	432	4157	57	1025
Ussher	140	76	2780	15	825
Korle Gonno	0	0	0	0	0
Castle	33	17	184	1	49
Stadium	237	0	608	1	63
Makola	396	0	213	0	18
Airport	0	0	0	0	0
Mallam Atta Government	88	0	199	0	99
Parliament	81	0	114	6	0
Dansoman	448	176	1781	22	63
James camp	0	0	17	0	20
PHC MIMA 441	78	0	2	0	36
TUC C	84	2	55	0	0
Nima Government	0	3	172	13	122
37 Military	0	0	0	0	0
Legon	0	0	0	0	0
Police	0	0	0	0	0
Fire Centre	0	0	37	0	0
Trust	0	0	0	0	0
Mana Mission	0	0	0	0	0
Total	**2208**	**1084**	**32773**	**170**	**3862**

Appendix 5: AMA population

AMA population by sub-metro and gender

Sub-metro	Population	Gender		Gender ratio: Males to 100 females
		Male	**Female**	
Ablekuma	518,112	253,458	264,654	95.8
Ashiedu Keteke	88,717	41,766	46,951	89
Ayawaso	335,394	168,009	167,385	100.4
Kpeshie	387,013	191,203	195,810	97.6
Okaikoi	233,067	115,623	117,444	98.4
Osu Klottey	96,634	47,314	49,320	95.9
Total AMA	**1,658,937**	**817,373**	**841,564**	**97.1**

Source: Ghana Statistical Service, 2002

AMA population by age and gender

Age group	Average (male and female)	Male	Female
0-4	10.5	10.5	10.5
5-9	10.7	10.6	10.8
10-14	10.4	9.8	10.9
15-19	11.3	10.8	11.8
20-24	11.8	12.1	11.5
25-29	10.5	10.6	10.5
30-34	8	8	8
35-39	6.5	6.4	6.5
40-44	5.3	5.4	5.2
45-49	4.2	4.5	3.9
50-54	3.1	3.2	2.9
55-59	2	2.2	1.9
60-64	1.6	1.7	1.5
65-69	1.2	1.2	1.2
70-74	0.8	0.8	0.8
75-79	0.6	0.6	0.6
80-84	0.5	0.5	0.5
85-89	0.5	0.6	0.5
90-94	0.2	0.2	0.2
95+	0.3	0.3	0.3
Total	**100**	**100**	**100**

Source: Ghana Statistical Service, 2002

Residential communities in the Odaw catchment

Residential Community	Population (2000)	Growth rate % (95/2000)	Area (Ha)	Density per Ha (2000)	Persons per house	Socio-ecological classification
Accra Central	8446	3.0	743	114		Low income- old Ga
Adedenkpo	22250	1.1	1197	186		Low income- old Ga
James town	42300	1.2	1435	295	21.3	Low income- old Ga
Korle Dudor	25824	2.8	1554	166		Low income- old Ga
Korle Gonno	24082	0.7	5157	47	18.0	Low income- old Ga
Accra New town	50685	1.5	1106	458	14.8	Low income-old migrant
Mamprobi	51730	4.1	1334	388	10.3	Low income-old migrant
Nima	63781	1.4	1580	404	19.6	Low income-old migrant
Sabon Zongo	21507	3.4	370	581	11.9	Low income-old migrant
Tudu	11688	3.9	451	259		Low income-old migrant
Abeka	83137	6.8	3103	268		Low income
Bubuashie	72787	5.9	2375	306		Low income
Abossey Okai	85097	4.0	3680	231	11.3	Low income
Alajo	46688	6.4	1694	276		Low income
Avenor	6299	4.1	814	77		Low income
Kokomlemle	24750	1.6	1451	171	12.3	Low income
Kotobabi	44175	4.5	1411	313		Low income
Lartebiokorshie	41876	3.9	2453	171		Low income
North Industrial Area	15754	8.3	1660	95		Low income
Odorkor	24950	4.4	2769	90		Low income
South Industrial area	6204	1.1	2986	21		Low income
Adabraka	30631	0.8	1735	177	12.4	Middle income
Assylum Down	15337	3.0	79.8	192		Middle income
Kaneshie	21168	1.2	2634	80	9.6	Middle income
North Kaneshie	36599	4.5	1699	215		Middle income
Tesano	36670	4.4	3706	99		Middle income
Abelemkpe	12598	3.7	2041	62		High income
Achimota	32402	4.5	327.2	99		High income
Airport resident	18014	1.4	374.5	48		High income
Dzorwulu	5429	3.7	186.5	29		High income
East Legon	2978	2.2	270.0	11		High income
Kpehe	32287	5.4	110.8	291		High income
Cantonments	12213	1.4	580.9	21		High income
Ridge/W Ridge	6775	1.0	305.3	22	9.5	High income
Total catchment	**1037111**	**3.7**	**7349**	**141**		
Total Accra	**1,658,937**	**3.8**		**127**		
% catchment/Accra	**58.4%**		**139950**	**111.2%**	**11.3**	

Source: IMDC, 2000

Appendix 6: Microbiological quality of tap water in Accra

Microbial concentrations (cfu/100ml) of tap water in selected districts in Accra

FAECAL COLIFORM/cfu/100ml									
BORTIANOR									
MONTH	**CLARK**	**CANDY**	**BAMAG**	**MA1**	**MA2**	**MA3**	**TT1**	**TT2**	**TT3**
NOV	0	0	0	0	0	0	0	0	0
DEC	0	0	0	0	0	0	0	0	0
JAN	0	0	0	0	10	0	0	0	0
FEB	0	0	0	0	0	0	2	0	0
MAR	0	0	0	0	0	0	0	0	0
ACCRA NORTH- WEST I									
MONTH	**AW1**	**AW2**	**AW3**	**TE1**	**TE2**	**TE3**	**DA1**	**DA2**	**DA3**
NOV	0	0	0	0	0	0	0	0	0
DEC	0	0	0	0	0	0	0	0	0
JAN	0	0	0	0	0	0	0	0	0
FEB	0	0	0	0	0	0	0	0	0
MAR	0	0	0	0	0	0	0	0	0
ACCRA WEST									
MONTH	**KG1**	**KG2**	**KG3**	**MP1**	**MP2**	**MP3**	**MT1**	**MT2**	**MT3**
NOV	0	0	0	0	0	0	0	0	0
DEC	0	0	0	0	0	0	0	0	0
JAN	0	N/A	3	0	0	0	0	0	0
FEB	2	0	0	10	0	1	0	0	1
MAR	0	0	0	0	0	0	0	0	0
TOTAL COLIFORM/cfu/100ml									
BORTIANOR									
MONTH	**CLARK**	**CANDY**	**BAMAG**	**MA1**	**MA2**	**MA3**	**TT1**	**TT2**	**TT3**
NOV	1	0	0	1	0	10	0	2	0
DEC	2	0	0	3	0	3	0	1	0
JAN	0	0	0	0	22	0	15	0	2
FEB	0	0	0	0	0	0	5	3	6
MAR	0	0	0	0	0	0	0	0	0
ACCRA NORTH-WESTI									
MONTH	**AW1**	**AW2**	**AW3**	**TE1**	**TE2**	**TE3**	**DA1**	**DA2**	**DA3**
NOV	1	1	0	3	24	0	0	120	120
DEC	7	1	1	0	0	0	1	1	1
JAN	0	12	2	23	40	0	29	29	29
FEB	2	1	0	1	3	0	2	0	0
MAR	0	0	0	1	0	0	0	0	0
ACCRA WEST									
MONTH	**KG1**	**KG2**	**KG3**	**MP1**	**MP2**	**MP3**	**MT1**	**MT2**	**MT3**
NOV	22	4	0	0	2	0	15	5	3
DEC	0	0	0	9	2	11	0	0	5
JAN	3	N/A	5	1	3	2	23	20	35
FEB	20	0	0	29	25	20	8	7	27
MAR	1	1	1	0	0	0	2	0	0

Key: AW- Awudome; DA- Darkuman; KG- Korle Gonno; MA- Malam; MP- Mamprobi; MT- Mataheko; TE- Tesano; TT- Tettegbu; WH- Weija headworks

(Source: Cobbina, 2004)

Appendix 7: Water distribution for East Accra

Water supply for East Accra

District	Areas
	Areas with good (or regular supply)
Accra East	Regimanuel, Manet, N.T.H.C., Volta Estate, Nungua, Buade, Okpei, Gonno, Adogonno, Baatsona
Dodowa	Agomeda, Doryumu, Kodiabe, Mobole and Upper Dodowa
North East	Adjirigano, Otanor, American House area, Otinshie, Haatso, Madina Zongo, Old road, Nkwantanang, Ritz junction, West Adenta, SSNIT flats, Adenta, Adenta Housing down and Chridge, Alajooman Christian Service centre
North	Kokomlemle, Roman Ridge, Alajo, Airport, Haatso, Nima West, GIMPA, Achimota school, Circle area, Kwabenya, Parakuo, Christian village, Legon, Papao, Dzorwulu, Ablenkpe, 37 Military hospital, West Legon, Kanda, Pig Farm, Mamobi market
Central	Adabraka, Ministries, Asylum-Down, Makola, Kanatamanto, Aditrom, Osu
	Areas with fair supply
Accra East	Cantonments, port of Labadi, Burma camp, parts of Teshie, parts of Labadi
Dodowa	Lower Dodowa, Nanoman and kpone, Bawaleshie
North East	Mempasem (Mark Okai Down), Bawaleshie, East Legon, Adenta Sakora, East Adenta, Approtech, Pantang Mechanical Llyod, Old police station area-Madina, North Legon, Redco flats and Estates and Agbogba, Libya quarters
North	Pillar 2, Tesano, Part of Roman Ridge, Nima Market, Kotobabi down, Dome, Dome old town, South Dome, North Dome, Achimota JSS, Achimota school, Pig farm, Nima East
Central	James town, mills road (Piccadilly), Bukom, Central Accra
	Areas with poor supply
Accra East	Parts of Labadi, Agyeman, Kojo Sardine, MATS, Teshie, Manna Mission area, Teshie camp 2 area, Western GREDA Estates
Dodowa	Sassabi, Oyibi and Mensah Bar
North East	Ashongman, Pokuase, Rawlings Circle, Social welfare top, Doku clinic Down, Madina, Frafraha and ARS
North	Accra Newtown, Abofu, Pig Farm, Taifa Old Town, Kotobabi police station and polyclinic, Kwabenya, Regimanuel estate, TV 3, Part of roman Ridge
Central	Nyaniba, Ako-Adjei, Kuku Hill, Papaye, North Ridge, Ringway Estates, Korle Wokon
	Areas with no supply
Accra East	Staff college, Teshie Nshorna
Dodowa	Dodowa Numosi, Fiakonya and Asasi
North East	Doku Clinic Top, Dele Clinic in Madina, Ashalley Botwe (Old town, New town), Echoing Hill and Ogbojo, Nmai Djorn
Accra North	Okoe village, Pokuasi, Taifa Burkina, New town, Dome old town
Central	Nil

Source: Ghana Water Company Limited (operational report of May 2006).

Appendix 8: Water quality report from the water treatment plants (Source: Weija and Kpong treatment plants)

Weija water quality report for 2000

INDICATOR		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
MPN index	Raw	16.0	16.0	16.0	16.0	16.0	>16.0	16.0	16.0	16.0	16.0	16.0	16.0
(MPN/100ml)	Final	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2
Pathogen (E. coli	Raw	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
detection)	Final	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent
Chlorine dosage	Raw	-	-	-	-	-	-	-	-	-	-	-	-
level (Kg/hr)	Final	13.0	12.0	12.0	11.5	13.0	13.0	12.0	13.0	13.0	13.0	14.0	15.0
Res. Chlorine	Raw	-	-	-	-	-	-	-	-	-	-	-	-
level (mg/l)	Final	1.7	2.1	1.1	1.4	1.9	1.6	1.7	1.1	1.9	1.8	1.5	1.2
Turbidity	Raw	14.4	13.5	13.2	14.0	15.0	14.5	13.6	13.0	12.4	14.0	14.8	15.8
	Final	1.3	1.2	1.1	1.2	1.1	1.2	1.2	1.0	1.0	1.0	1.2	1.4

Weija water quality report for 2001

INDICATOR		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
MPN index	Raw	16.0	16.0	16.0	16.0	>16.0	>16.0	>16.0	>16.0	>16.0	>16.0		
(MPN/100ml)	Final	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	2.2		
Pathogen (E. coli	Raw	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
detection)	Final	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent
Chlorine dosage	Raw	-	-	-	-	-	-	-	-	-	-	-	-
level (Kg/hr)	Final	10+CaH	9+CaH	8+CaH	CaH	CaH	5+CaH	CaH	CaH	CaH	10	5+CaH	5+CaH
Res. Chlorine	Raw	-	-	-	-	-	-	-	-	-	-	-	-
level (mg/l)	Final	1.0	0.7	0.5	0.3	0.5	0.7	1.2	0.6	0.8	0.9	0.5	0.1
Turbidity	Raw	10.8	15.3	18.0	15.5	10.8	10.0	23.2	17.1	16.0	13.7	10.8	10.0
	Final	1.9	2.2	2.7	3.8	2.6	2.1	2.1	1.9	1.4	1.4	2.8	1.6

Weija water quality report for 2002

INDICATOR		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
MPN index	Raw	16.0	16.0	16.0	16.0	>16.0	>16.0	>16.0	>16.0	>16.0	>16.0		
(MPN/100ml)	Final	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	2.2		
Pathogen (E. coli	Raw	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present		
detection)	Final	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent		
Chlorine dosage	Raw	-	-	-	-	-	-	-	-	-	-		
level (Kg/hr)	Final	CaH	CaH	CaH	8+CaH	10	10	8+CaH	6+CaH	6+CaH	CaH		
Res. Chlorine	Raw	-	-	-	-	-	-	-	-	-	-		
level (mg/l)	Final	0.6	0.7	0.4	0.5	0.6	0.7	0.5	0.1	0.1	0.05		
Turbidity	Raw	11.2	13.1	17.0	17.7	16.5	14.0	16.0	17.5	18.0	22.0		
	Final	1.6	2.1	2.1	1.7	1.2	1.1	1.6	1.9	1.8	1.5		

Weija water quality report for 2003

INDICATOR		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
MPN index	Raw	>16.0	>16.0	>16.0	16.0	>16.0	>16.0	>16.0	>16.0	>16.0	>16.0	>16.0	>16.0
(MPN/100ml)	Final	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2
Pathogen (E. coli	Raw	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
detection)	Final	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent
Chlorine dosage	Raw	-	-	-	-	-	-	-	-	-	-	-	-
level (Kg/hr)	Final	14	13	1.5	14	13	13	14	CaH	12	11	11	11
Res. Chlorine	Raw	-	-	-	-	-	-	-	-	-	-	-	-
level (mg/l)	Final	1.2	1.3	1.2	1.3	0.9	0.3	0.5	0.4	1.2	0.75	0.6	0.3
Turbidity	Raw	20.0	22.0	24.0	25.5	34.7	37.3	37.0	31.8	26.3	24.0	22.0	16.5
	Final	1.6	2.0	2.0	2.3	2.3	2.0	1.9	1.9	2.0	2.3	2.2	1.9

Weija water quality report for 2004

INDICATOR		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
MPN index	Raw	16.0	16.0	>16.0	>16.0	>16.0	>16.0	16.0	>16.0	>16.0	>16.0	>16.0	16.0
(MPN/100ml)	Final	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2
Pathogen (E. coli	Raw	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
detection)	Final	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent
Chlorine dosage	Raw	-	-	-	-	-	-	-	-	-	-	-	-
level (Kg/hr)	Final	15	13	14	15	15	15	16	16	14	16	14	15
Res. Chlorine	Raw	-	-	-	-	-	-	-	-	-	-	-	-
level (mg/l)	Final	0.6	0.6	0.8	1.3	1.0	1.0	1.0	1.1	0.9	1.0	0.8	0.8
Turbidity	Raw	23.7	29.0	24.4	28.7	32.0	22.5	14.2	19.2	14.6	16.0	19.0	17.0
	Final	2.1	1.0	1.6	2.0	1.8	1.6	1.4	1.2	1.	1.1	1.0	1.0

Weija water quality report for 2006

INDICATOR		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
MPN index	Raw	16.0	16.0	16.0	>16.0	>16.0	>16.0	16.0	>16.0	>16.0	>16.0	>16.0	>16.0
(MPN/100ml)	Final	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2
Pathogen (E. coli	Raw	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
detection)	Final	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent
Chlorine dosage	Raw	-	-	-	-	-	-	-	-	-	-	-	-
level (Kg/hr)	Final	CaH	CaH	CaH	CaH	CaH	CaH	CaH	CaH	CaH	CaH	CaH	CaH
Res. Chlorine	Raw	-	-	-	-	-	-	-	-	-	-	-	-
level (mg/l)	Final	0.2	0.3	0.1	0.2	0.5	0.6	0.7	0.8	0.7	0.6	0.6	0.7
Turbidity	Raw	15.8	15.4	16.0	17.3	21.0	22.7	18.3	19.0	20.5	18.0	19.0	18.3
	Final	1.0	1.0	1.2	1.1	1.1	1.2	1.0	1.0	1.0	1.0	1.0	1.0

Kpong water quality report for 2006

INDICATOR		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
MPN index (MPN/100ml)	Raw	>8	>8	>8	>8	>8	>8	>8	>8	>8	>8	>8	>8
	Final	0	0	0	0	0	0	0	0	0	0	0	0
Plate count No./ml	Raw	100	100	100	100	51	51	51	35	52	52	86	100
	Final	0	0	0	0	0	0	0	0	0	0	0	0
Total solids mg/l	Raw	30	33	35	30	32	32	32	36	33	33	30	30
	Final	33	38	36	32	32	32	32	32	37	37	32	34
Suspended solids mg/l	Raw	0	1	4	2	0	0	0	5	2	2	2	0
	Final	0	4	2	0	0	0	0	0	1	1	0	0
Calcium Hypochlorite dosage level (mg/L)	Raw	-	-	-	-	-	-	-	-	-	-	-	-
	Final	0.6	0.3	0.9	0.8	1	0.9	1.1	1.1	1.1	1.2	1.2	1.2
Res. Chlorine level (mg/l)	Raw	-	-	-	-	-	-	-	-	-	-	-	-
	Final	1.4	0.8	1.4	1.0	1.2	1.1	1.2	1.1	1.1	1	0.9	0.9
Turbidity FTU	Raw	1	1	1	2	1	1	1	2	2	2	2	2
	Final	<1	1	1	>1	>1	>1	>1	>1	<1	<1	<1	<1