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Analysis of Health Benefits versus Costs of Interventions in the Urban water system in Accra, using Quantitative Microbial Risk Assessment

Herve Labite

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Master of Science Thesis
by
Herve Labite

Supervisors
Prof. Piet Lens (UNESCO-IHE), Chairman
Dr. P. Van der Steen PhD (UNESCO-IHE), Mentor
Dr. P. Drechsel PhD (IWMI), Field supervisor

Examination committee
Prof. Piet Lens, PhD, (UNESCO-IHE), Chairman
Dr. P. Van der Steen, PhD, (UNESCO-IHE)
Dr. J.F. Schijven, (External examiner)

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To my mother, Josephine

Abstract

Quantitative microbial risk assessment was applied to the Accra urban water system. The Health Benefits were assessed in order to help decision makers to know where best to invest. The objective of the research was to assess the microbial risks generated in the Accra urban water system based on primary data and to recommend some effective interventions with a given budget.

To reach this objective, a 3 months fieldwork was conducted in Accra in order to assess the concentration of organisms in the storm open drain and recreational water; The concentration of *Escherichia coli*, Total coliforms, *Salmonella* and Helminths eggs were measured. The concentration of *E. coli* were and *Salmonella* in the storm drain water and recreational water were respectively 8.0 and 4 log 10 CFU/ 100 ml; however, *Salmonella* was not detected in seawater. The measured concentration of these pathogens in the sand were respectively 6 and 6.7 log10 CFU/g dry weight. The Helminth eggs count in the open drain was low (0.77 eggs/ l).

Using these primary data with additional data gathered through literature, a quantitative microbial risk assessment (QMRA) was undertaken to estimate the health risk. The total disease burden of Accra urban water system was 37, 000 and the contribution of sanitation was about 88%. The DALYs pppy was $5*10^{-3}$ pppy, which was above the WHO reference value (10^{-6}). The most hazardous pathway was the open drain with the contribution of 55% of total burden disease.

In order to reduce the burden of waterborne disease, five available options were listed: option A (separate sewerage), option B (sewerage treatment plant) option (sewerage network + treatment plan), option D (coverage the storm water drain) and option E (improve water supply system). The selection criteria was to avoid people to get in contact with waste water. The calculation showed that among the suggested options, the separate network associated to the sewerage treatment would avert 32, 466 DALYs per year. However taking into account the financial aspect, the coverage of the drain (option D) appeared economically feasible due to its low initial investment. Therefore this intervention appeared the most effective. This option was followed closely by the separate network. Therefore, in term of planning for future, this option could be an alternative. The option related to wastewater treatment plant alone was rejected because if there are not a suitable network, people may be exposed at different level before the wastewater would reach the plant. The option related to water supply had less impact in risk reduction

However, this health benefit assessment do not consider other aspects like life time of the options, operation and maintenance, public acceptance, cost recovering mechanisms, environmental impact. Therefore, the best choice should base on balance of criteria.

Keywords:

Quantitative microbial risk assessment, DALYs, disease burden, cost effectiveness, urban water system,

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List of symbols

ASIP:	Accra Sewerage Improvement Project
AWUS	Accra Water Urban System
CFU:	coliform unit forms
DALYs:	Disability Adjusted Life Year
IWMI:	International Water Management Institute
MRA:	Microbial Risk Assessment
SWITCH:	Sustainable Water Management Improves Tomorrows Cities' Health
QMRA	Quantitative Microbial Risk Assessment
UDD:	Urine Diversion Dehydratation
UN:	United Nations
UNESCO:	United Nations Education Scientific and Cultural Organization
UNICEF:	The United Children Fund's
WHO	World Health Organization

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1 Introduction

1.1 General

The number of people living in urban areas is increasing continuously. According to the estimation of the United Nations (2005), more than 60 % of world population is living in the cities. This problem is more serious in Africa where the rate of urban growth is the highest. The African urban population, estimated to 295 millions in 2000 will reach 748 millions by year 2030 according to the predictions (Cohen, 2006). This rapid growth of the urban population has resulted in the increases the need of basic services like the assess to appropriate water supply and sanitation. This situation could affect not only the environment but also the public health with the occurrence of communicable diseases such as water related diseases. The urban water system is the mechanism that implies a use of water, land and other resources in order to bring welfare to people. Various actions are required in order to improve people's living standards; one of them it is to intensify the efforts to provide water and sanitation services to the people without supply (GDRC, 2000).

1.2 Problem definition

As mentioned before, the population growth of urban cities especially in developing countries have resulted in serious water stress and inappropriate sanitation. Currently, nearly 300 millions people in sub-Saharan Africa do not have access to clean water and 440 millions do not have access to basic sanitation (G 8, 2007). This situation is a serious risk for human health especially for the vulnerable group like the elderly, pregnant women and children under five years. According to WHO/UNICEF (2006), at least 1.6 million children under five years die every year, due to unsafe water coupled with a lack of basic sanitation. To tackle this problem, the world leaders set the Millennium Development Goals (MDG's) and specially the goal 8 which is aim to ensure the environment sustainability (UN, 2007). it specific target number 10, halve by 2015 the proportion of people without sustainable access to safe drinking water and sanitation, has been established in order to recognize at international level the inappropriate water supply and sanitation issue.

Ghana like most of developing countries has a large number of people living in urban areas. It has been reported that 43.8 % of the population is living in urban area (Ghana Statistical Service, 2002). The mains raisons of this high urban population are due to family reason, employment, schooling, drought (Boakye-Yiadom and McKay, 2006). This rapid urbanization and growth of the population has resulted in the increase the volume of waste produced and discharged in the environment. The Ghana statistical services reported that over 60 % of households in Accra disposed their solid waste at a public dump and only 13 % of households disposed their liquid waste in sewerage connection. This practice is a health hazard for the citizen. The situation is similar with the liquid waste produced; more than 53.2 % of household disposed their liquid waste into gutters.

This situation may increase the occurrence of diarrhea diseases. According to the health statistic report (Ghana Ministry of Health, 1996 cited by Baffoe, 2007), about 400,000 cases of enteric diseases are reported annually.

Although a great effort is made to provide more resources for water and sanitation sector, a significant proportion of the world's population remained without access to safe drinking water and sanitation. This number reached 440 millions by the end of year 2004 (UN, 2007). This low coverage of water supply and sanitation services constitutes a threat for health status; it is estimated that 25 % of death disease globally, and specifically 35 % in regions such as sub-Saharan Africa is linked to unsafe water, poor sanitation and (WHO, 2005).

Besides the scarcity of resources, they are also the problem of resource partition between water supply and sanitation sector. During 1999-2000, the total investment in Africa, Asia, Latin America and the Caribbean in water supply were estimated over US$12.6 billions per year whereas the estimate for sanitation were only US$3.1 billions per years (WHO-UNICEF, 2000, cited by Paterson *et al.,* 2007).

Unfortunately, the decision makers in large cities in developing countries have limited budgets available for improving the urban water system and do not have access to tool to optimize the health benefits of their investments in the urban water system. Cost effective intervention could be an excellent tool and will help the decision makers to locate where the risk is; and to know how to allocate resources in urban water system in order to reduce significantly the health risk.

In line with the Millennium Development Goals (MDGs) 7, which is related, to ensure sustainable environment, this research is meant to show how Quantitative Microbial risk Analysis (QMRA) can be used to compare cost of interventions with the associated health benefits, for improved decision making and planning. The initiator of this research investigation is the SWITCH project them1: Urban water paradigm shift (under development of a strategic approach and of indicators for sustainability and risk assessment). The aim of SWITCH project is to achieve a paradigm shift in urban water management to get sustainable, healthy and safe urban water system (SWITCH, 2006).

This research will contribute to fill the gap of the health risk prediction related to water and sanitation by reducing the uncertainties in the previous study on quantitative microbial risk assessment for the city of Accra. The health benefit of some intervention will be examined by comparing the current number of Disability Adjusted Life Years (DALYs) to the number of DALYs averted during the implementation of each option.

1.3 Research objectives

Overall objective

The aim of this research is to assess the microbial risks generated in the Accra urban water system and to recommend management options through the optimisation of health benefits with a given budget.

Specific objectives

The specific objectives of this research are:

- To reduce the uncertainties in the MRA in the previous study (Lunani, 2007); these uncertainties are due to a number of assumptions made in that research
- To improve the prediction of the burden of waterborne diseases
- To estimate cost interventions for each problem identified
- To recommend some management options for the improvement of sanitation services based on cost effectiveness analysis

1.4 Research questions

- What is the risk of disease in the Odaw catchment, based on an improved MRA analysis?
- What is the difference between the estimated risk from this study and the previous study based on only secondary data? What could be the reasons for this difference?
- Based on cost effective analysis, what major interventions need to be done in order to reduce health risks in the Accra urban water system?

1.5 Scope

The scope of this research was limited to microbial risks assessment of the urban water system in the Odaw catchment, a case study area selected among Accra catchments. Besides MRA, cost effective interventions was also be investigated.

2 Literature review

2.1 Health risks related to the urban water system

Due to the increase of number of people living in urban area, the cities managers are facing the demand of municipal services. The water urban system like water supply, storm drainage sewage and basic sanitation was left behind; consequently, this situation could be a potential threat to citizen health and may contribute to the occurrence of communicable disease related to poor environment quality. These diseases are caused by microbial agents (Mara and Horan, 2003). The main groups of disease transmission agents are described below:

a. **Viruses:** the viruses are one of the most important hazardous organisms and cannot be seen with a light microscope. They need to infest the host in order to replicate and therefore cannot develop outside the host. Some of them are used as indicators viruses of faecal contamination of water. Among these are Hepatisis A virus, *Coronavirus*, *Rotavirus*. One of the main agents of gastroenteritis is *Rotavirus* which can be present in sewage, recreational water or drinking water; the mode of transmission of this virus is faecal oral route (Gerba, 2006).

b. **Bacteria**: they are able to multiply in the environment and can be transmitted through contact with an intermediate host or an infested host, and by ingestion of contaminated food or water. The bacterial pathogens are induced diseases of gastrointestinal track such as typhoid fever, dysentery cholera and diarrhoea (Metcalf and Eddy, 2003). Due to the complexity of detection, isolation and identification of many water related pathogens, bacterial organisms are used as indicators of pollution :

Total coliforms: this group is defined as gram-negative organisms, non-spore forming facultative anaerobic and capable to ferment lactose with the production of gas at 35^{o}C within 48h; some examples are *Escherichi coli*, *Enterobacter sp*, *Citrobacter sp*. The sources of Total coliforms organism are faecal and no faecal origin. In untreated wastewater, their number can reach $10*10^{9}$CFU/100ml (Bitton, 1994 cited by Awuah 2006).

Faecal coliforms: they are also gram-negative organisms, non-spore forming facultative anaerobic and capable to ferment lactose with the production of gas at 44^{o}C within 48h; they are main indicator of faecal pollution. However, some non-faecal organism may growth at 44^{o}C. Among this group is *Escherichia. coli*, which is faecal origin.

Escherichia. coli: More specific than Total coliforms and Faecal coliforms, this organism is one of the worldwide organisms used as indicator of faecal pollution. *E. coli* is a gram-negative organism, rod –shaped bacterium and belongs the family of Enterobacteriacea. *E. coli* is a natural inhabitant of the intestinal tract of man and animal. The presence of *E.coli* in water is an indication of faecal pollution.

c. **Protozoa:** the group of protozoa is defined as eukaryotic organisms with complex life cycle. The classification of this group is based on some criteria like the locomotion, the mode of feeding and locomotion. Outside their host, they survived in dormant stages, which called cysts or oocyts. The most commons protozoan pathogens isolated in wastewater are *Entomoeba sp*, *Giardia sp* and *Cryptosoridium* sp (Toze, 2006). Water borne transmission is the most transmission route of above organisms. The contamination of water could arise from animal and human wastes. *Giardia* is one of the most important waterborne agents (Rose *et al*., 1996); more resistant to chlorine disinfection compared to bacteria, *Giardia* cysts reached in untreated waster water a density of 3375 per liter.

Table 2-1: Classification of diseases.

Classification	Transmission	Diseases
Water-borne	Through intake of water, bathing.	Faecal oral diseases such as cholera, typhoid, etc
Water - washed	Caused by lack of water , inadequate hygiene	Scabies, trachoma, athletes foot
Water- based	Through contact with water via aquatic invertebrate intermediate hosts	Schistosomiasis, guinea worm infection
Water-related insect vector	To certain transmission through vectors proliferating in water reservoirs, other stagnant water, and through certain agricultural practises	Malaria, dengue, lymphatic filiarisis
Soil-based	Through skin, disease organism present in soil	Hookworm

Source: (Ince, 1999 and Pruss *et al*., 2002 cited by Bos *et al., 2004*)

d. **Helminths:** Helminths are intestinal parasites, which can be transmitted by faecal oral route. This group included *Ascaris sp*, *Ancylostoma sp*, *Necator sp*. The Helminth group is one of the greatest health risk related due to their persistence in the environment (WHO, 2003); the origin of Helminth disease is faecal. The transmission of Helminths infections occurred when contaminated water, soil or crop are ingested. The transmission of diseases related to Helminths involves water or soil contamination. Therefore, the environmental and behaviour changes combined to sanitation infrastructure can have a sustainable impact on Helminth control. According to Caincross (1987), a good programme to improve Helminth control must consider the earlier involvement of the users in the decision and choice of affordable disposal. The review of the past interventions around the world regarding Helminth infections revealed that the low cost sanitation options associated with health education can contribute to reduce significantly the health impact (Asaolu, 2003).

All of these organisms are responsible for disease transmission; they affect human health through various transmission pathways (table 2.1).

2.2 Microbial risk assessment

The aim of the risk assessment is to estimate the potential health effect associated to hazard. It can be applied to food or water. In general, for the procedure of qualitative risk assessment, four steps involved (Haas *et al.,* 1999):

a. **Hazard identification**: The aim of hazard identification is to gather all information about diseases and pathogens; this information should describe the conditions under the pathogens survives, grows and the causes infections.

b. **Exposure assessment:** the purpose of this step is to describe the exposure pathway, and to assess data for the dose response model; the main data needed are the concentration of pathogens, the volume ingested during each event, the duration and the exposed population

c. **Dose-response assessment (or hazard characterization).** This step characterises the relationship between the exposure level (dose) and frequency of illness or other adverse effect (response). Due the ethical consideration, a direct experiment to assess dose response is not the rule. Therefore most of dose response model are developed based on mathematical function. Among theme are:
Exponential dose – response: This model is based on the assumption that each organism has an independent and identical survival probability .
Beta – Poisson Dose – Response Model: in this model, the variation in survival probability of the pathogen host is taking into account; this variation may be due to human responses, diversity of pathogen competence or both of them.
Simple Threshold Models: This model stipulates that a minimum number of surviving organisms is required for the occurrence of the infection.

Risk (or hazard) characterization: the risk characterization involves the integration of the information gathered in the previous steps to estimate the risk in to a particular population.

2.3 Microbial risk assessment applied to urban water system

Many authors applied quantitative microbial risk assessment to urban water system (water bodies, drinking water, wastewater, recreational water).

Westrell *et al*., (2006) applied QMRA to assess the water body; they conducted field survey of river Meuse from 2001 to 2003 to assess quantitatively the risk related to *Norovirus*. In order to predict the result concentration, Poisson sample and Time series analysis model were used in that study. They noticed the presence of *Noroviruses* (NoV) in the River Meuse especially during the winter season. They concluded that NoV constitute a significant risk to people with a highest estimated concentration of 1700pdu/l.

Stanger *et al.,* (2006) applied QMRA to drinking water treatment system. They assessed the drinking water treatment plant and found that pathogens were removed significantly earlier before post clarifier step. Therefore, they concluded that the water quality could be safe for consumers. They recommended also to apply QMRA to the plants under study failures in the treatment process. Similar to this study, Howard *et al*., (2006) assessed the performance of water supply in relation to disease burden in Uganda ; they found that the risk in the distribution system was great than treatment system and furthermore the greatest risk was noticed with the alternative supplies (protected springs).

This method is applied not only for drinking water but also for the safe reuse of wastewater. Ryu *et al*., (2007) noticed that the health risk due the reuse of wastewater was associated to the method used during wastewater treatment. By assessing the risk of infection due to *Cryptosporidium* and *Giardia* in non-potable reclaimed water, they found that the risk of infection due to these organisms would met the annual risk of $1.0*10^{-4}$ with the use of chlorination and UV disinfection In contrary, that was not the case while only chlorination would be used. Westrell *et al.,* (2004) combined QMRA to HACCP to study the management of pathogens in wastewater and sewage sludge treatment. In their methodology, QMRA was considered as the first step of HACCP in order to examine the exposure pathway and furthermore hazard control purposes. Among pathogens studied, the major risk especially for the workers was noticed with *Rotavirus* and *Adenovirus* while at community level *Escherichia coli* O157:H7, EHEC and *Cryptosporidium* yielded a slight risk to population. However, the largest impact in the community will occur if children ingest sludge or through vegetables fertilised with sludge and eaten raw. Expanding the problem of the reuse of waste in agriculture in order to protect workers and consumers of vegetables, WHO (2006) has included QMRA in the new guidelines for the safe use of wastewater, excreta and grey water.

Seidu *et al*., (unpublished) applied QMRA approach to assess the health risk associated with irrigation in Accra (capital of Ghana) through four scenarios: ingestion of waste water by farmers, ingestion of soil by farmers, ingestion of wastewater containing soil, consumption of different waste water irrigated lettuce. They found that the soil on farm was the greatest hazard for farmers. The median annual risk for *Rotavirus* and *Ascaris* was $99 * 10^{-2}$ and $7.6 * 10^{-2}$. They noticed also that for the consumption of lettuce, the risk depended on the irrigation water quality, and on farm contamination. However, the risk of infection due to wastewater-irrigated vegetables may depend also on the type of the vegetable. Hamilton *et al.,* (2006) investigated the potential health risk associated to the consumption of various raw vegetables irrigated with reclaimed water. In their study, Entericvirus was chosen as microbial hazard to model; the vegetables (cucumber, broccoli, cabbage or lettuce) were irrigated with secondary effluents of 5 sewage plants in California. They found that the lowest annual risk of infection occurred with cucumber because it retained the smallest volume of water and was consumed at the lowest rate.

However, they are some limitations in the assessment of health risk related to the reuse of wastewater; for instance the choice of appropriate indicator organism and the possibility of regrowth of organisms, which may lead to underestimate, or over estimate the risk (Rose *et al.,* 1996; Ottoson and Strenström, 2003). A yearly monitoring in St Petersburg in USA of wastewater plant containing various levels of pathogen showed a different pattern for organism removal (Rose *et al*., 1996). In the reclaimed water samples, while faecal coliforms were detected only in 9% of the time, Coliphages were detected in 25% of samples. In the same way, Ottoson and Strenström (2003) assessed the reuse of grey water; they noticed the capacity of regrowth of some organisms like *Salmonella*, *Escherichia coli* which may increase the faecal load. To sum up, it can been seen clearly that while in the first example the risk would be underestimate, in the second example, the risk would be overestimate due to the behaviour of organisms. Therefore for the safe reuse of water, the risk assessment should not base only on the faecal coliforms.

Some authors applied microbial risk assessment to coastal areas or especially for recreational water. Steyn *et al*., (2004) investigated the limitation of observed adverse effect level approach (OAELA) in comparison with prediction with QMRA. In their experimental site in south eastern region in South Africa, they estimated the occurrence of *Escherichia coli* and *salmonella* by using respectively OELA and QMRA. They found that with OELA the health risk is low while the QMRA to the same area revealed an unacceptable risk for either recreational water or consumptive use.

In Australia, QMRA was used as tools to monitor the recreational, water quality. This was described in recreational water safety (Roser *et al*., 2006). In that plan, three operational stages were defined: provisional assessment of the status of the lake, measurement of bathing season and dry weather water quality, and hazardous characterization. At each operational level of these steps, the water safety plan recommended to apply the QMRA approach in order to have a better understanding of hazards and risk mitigation during the implementation. As an illustration, Craig *et al*., (2003) assessed the exposure risk at recreational coastal sites; they noticed the change in risk of infection over time after each faecal contamination event. During the high contamination of recreational water, the maximum probability of infection was above 2. $1*10^{-1}$. They noticed also that the concentration of pathogens was high compared to water column; therefore, they concluded that a good monitoring programme of recreational water should include also sediment.

Considering the entire urban water system, Lunani (2007) analysed the public health risk of Accra urban system. Four pathogens were selected for the risk assessment: *Campypolobacter* (bacteria), *Rotavirus* (Virus), *Cryptosporidum* (protozoa) and *Ascaris* (Helminth). From the assessment of Accra urban water system, some potential transmission pathways and related risks were identified (table 2.2). Comparing sanitation and water supply and considering the four pathogens, the author found that sanitation pathway was responsible for the highest number of infections and symptomatic cases. The measurement of disease burden showed that they were 28,531 DALY's in total for all pathogen and the contribution of sanitation is about 91%.

Table 2-2: Ranking of severity of each pathway.

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

Source: Lunani, 2007

In the other hand, QMRA can be applied in land management; Strachan *et al.*, (2002) in UK used this method to identify the lowest risk associated with the visit of farm pasture previously grazed by ruminants; they suggested as risk mitigation measure that a minimum of 3 weeks is required associated with physical removal of feaces.

2.4 Technology options for urban water systems

2.4.1 Water supply

Water is supplied to the community from surface or groundwater sources; additionally, rainwater can be harvested especially where surface groundwater is not available. Various options are available. The table below (table 2.3) gives an overview of improved and unimproved options related to water supply and sanitation.

Table 2-3: Categorization of water supply and sanitation system

Intervention	Unimproved	Improved
Water supply	➢ Unprotected dug well ➢ Unprotected spring ➢ Cart with small tank/drum ➢ Bottled water ➢ Tanker truck ➢ Surface water (river, dam, lake, pond, stream, canal, irrigation channel)	➢ Piped water into dwelling, plot or yard ➢ Public tap/standpipe ➢ Tubewell/borehole ➢ Protected dug well ➢ Protected spring ➢ Rainwater collection
	Unimproved	**Improved**
Sanitation	➢ Flush or pour flush to street, yard, plot, open sewer, ditch, drainage way ➢ Pit latrine without slab or open pit ➢ Bucket ➢ Hanging toilet/latrine ➢ No facilities or bush or field	➢ Flush or pour flush system to piped sewer system, septic tank, pit latrine ➢ Ventilated improved pit latrine ➢ Pit latrine with slab ➢ Composting toilet *(UDD toilet)*

Source: WHO/UNICEF (JMP, 2006).

2.4.2 Sanitation

According to UNICEF (1997), sanitation is a process whereby people (men, women and children) demand, effect and sustain a hygienic and healthy environment for themselves. This is achieved through a combination of hardware (latrines), hygiene promotion and other supporting software activities and the development of an enabling environment to ensure that hardware and software can be delivered.

With the conventional sanitation system, wastewater including faeces is transported through sewers to treatment plants. Various technologies are used from simple to complex (wetland, waste stabilisation pond, activated sludge, anaerobic treatment). The conventional system consumes a huge amount of water. According to Siano *et al*., (1998), flush toilets can consume 20-40% of the drinking water. Besides the conventional system, the on site sanitation allows to process waste (faeces, urine) at the household level. Different types of latrines could be used (table 2.4).

Table 2-4 : Type of latrines on site sanitation

Options	Advantages	Disadvantages	Sources
Simple pit latrine	Cheap, simple technology	Odour and flies , risk of groundwater and surface contamination,	Nadkarni 2004
Ventilated improved pit latrine	Reduce odour and fly breeding, possibility to reuse the faeces	Slightly more complicated	GTZ 2005
Pour flush latrines (with pit or septic tank and soak away)	Suitable for community where anal washing is the common place less education about maintenance and operation	Required sufficient water supply for proper maintenance and operation high initial cost , risk of groundwater contamination ,required appropriate treatment plant	Mack 2006
Aqua –privy	Does not need piped water on site	More expensive than VIP or pour flush latrine, regular desludging required and needs careful handling	Franceys *et al*., 1992
Urine diversion toilets (UD)	Water saving, no need for sewers to transport black water, less smell, prevention of fly and mosquito, save money by using sanitised excreta and urine in agriculture		GTZ 2005
Arborloo toilet	Mobile toilets	Needs space	Morgan 2005

At the overall picture (water and sanitation), Hiessel *et al*., (1999) by assessing various options of urban water system reported that the scenario with a decentralized component is more sustainable; this scenario include rain water harvesting, reduction of water consumption to flush waste, and resource recovering. The common name behind this option is called ecological sanitation or ecosan. The ecological sanitation is an alternative approach to avoid the disadvantages of the conventional wastewater system (Werner *et al.,* 2004 cited by Langergraber *et al*, 2005). More than a specific technology, this approach considers human biological waste as a resource where source separation of faeces, urine and water takes place based on the principle that if wastes are kept separate, it could be treated differently in order to get the most use of them. Urine can be directly used as fertiliser while faeces can be sanitised and used as soil conditioner.

2.4.3 Cost and health effect of urban water management interventions

Cost effectiveness is one of the useful tools for resource allocations in many sectors including the urban water system

For example in 2007, the WHO assessed the health benefit impact of improving water and sanitation in the least developed countries. Six scenarios were studied taking account water supply alone, sanitation alone and the combination of both. The results revealed that with the implementation of low cost technology, the cost of cost water supply and sanitation improvements are cost-beneficial for all developing world regions (table 2.5). Comparing water supply and sanitation, it appeared that achieving the sanitation Millenium Development Goals (MDG's) target is economically more favorable than the water MDG target, with a global return of US$ 9 for sanitation compared to US$ 4 for water, per US$ 1 invested (WHO, 2007). In contrary, Fewtrell *et al.,* (2005) noticed that water quality interventions seem more effective and the combined interventions (water and sanitation) were not significantly more effective than single focus.

In the same manner, Hutton and Haller (2004) studied the costs and benefits of water and sanitation; they defined 7 scenario by combining water and sanitation according to some variables like type of technology (improved or not), coverage and monitoring. In their approach, the worse scenario was defined as unimproved water supply with lack of basic sanitation. Taking into account the costs and benefits of water and sanitation improvement at the global level, and considering although the worse scenario, they noticed that the benefits outweighed the cost in all world regions; and it is possible that from US$1 investment in developing regions the return would ranged from between US$5 and US$28.

Another study of health and Benefits of waster and sanitation compared three different interventions: Intervention I (sewer connection, no wastewater treatment plant), intervention II (sewerage + conventional wastewater treatment plant) and intervention III (3-Step Strategic Approach or 3-SSA). The result showed that the 3-SSA approach will help to reach the same efficiency level with less money with the conventional system. It would increase the health gain and generate income (Bos *et al*., 2004). This approach is based on waste prevention, treatment for reuse, and self-purification

capacity.

Table 2-5 : Benefit-cost ratio of water and sanitation coverage

World Region *	Achieving MDG targets for:			Universal access to:		
	Water	Sanitation	W&S	Water	Sanitation	W&S
Sub-Saharan Africa	2.8	6.6	5.7	3.9	6.5	5.7
Arab States	6.1	5.3	5.4	5.9	12.7	11.3
East Asia & Pacific	6.9	12.5	10.1	6.6	13.8	12.2
South Asia	3.5	6.9	6.6	3.9	6.8	6.6
Latin America & Caribbean	8.1	37.8	35.9	17.2	39.2	36.3
Eastern Europe & CIS	8.3	27.8	18.9	8.9	29.9	27.4
Non-OECD	**4.4**	**9.1**	**8.1**	**5.8**	**11.2**	**10.3**

Source: WHO-UNDP, 2007

Table 2-6: Initial investment cost per capita in three major world regions

IMPROVEMENT	INITIAL INVESTMENT COST PER CAPITA (US$ YEAR 2000)		
	Africa	Asia	LA & C
Water improvement			
House connection	102	92	144
Standpost	31	64	41
Borehole	23	17	55
Dug well	21	22	48
Rainwater	49	34	36
Disinfection at point of use	0.13	0.094	0.273
Sanitation improvement			
Sewer connection	120	154	160
Small bore sewer	52	60	112
Septic tank	115	104	160
Pour-flush	91	50	60
VIP	57	50	52
Simple pit latrine	39	26	60

(*Source*: Global water supply and sanitation 2000 report, cited by Hutton and Haller, 2004); LA$C = Latin America and the Caribbean and Asia/ Oceania

From all above, it can be concluded that the benefit of water and sanitation outweigh the cost especially the sanitation intervention. Therefore, actions need to be taken to improve the current situation.

In the urban water system, various options are available for sanitation but the conventional sewerage system is very expensive compared to on site and low cost technologies (table 2.6). Paterson *et al.,* (2006) mentioned that on site and low cost technologies offer the opportunity to extend sanitation to the greatest number of people. According to these authors the only way to bring sanitation technology, which is technically and economically in low income and high-density areas is the simplified sewerage or on site sanitation.

However, the appropriate measure to reach MDGs target 10 and beyond is to plan in strategic and integrated way. According to Bryce *et al.,* (2005) the achievement of the MDG's for child survival is affordable and the world
can save the lives of 6 million children each year. This could be possible if priority is given to prevention activities, to the use of integrated strategy for child survival programme (rather than parallel delivery diseases or specific intervention) and finally when expanding service at community level takes place.

3 Materials and methods

3.1 Description of the study area(s)

Accra is the capital of Ghana and the biggest city (figure 3.1). It has a population of more than 1.66 millions with the growth rate 4.4 % (Ghana statistical Service, 2002). The rainfall pattern of the city of Accra is bimodal with the major season falling between March and June, and a minor season around October. The mean rainfall is 1504 mm. The Mean temperatures vary between 24 ºC in August and 28 ºC in March (table 3.1).

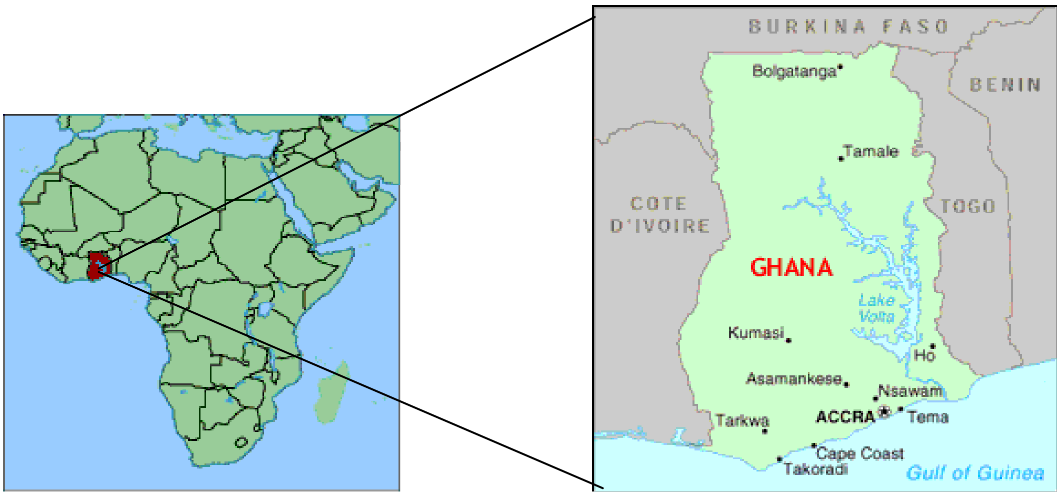

Figure 3-1: Location Map of Accra

Source: www.southtravels.com/africa/ghana/map.html

Table 3-1: Mean annual climate data of Accra

Rainfall (mm)	Temperature (0C)	Relative Humidity (%)	Sunshine duration (hrs)	Wind velocity Potential (km/day)	evaporation (mm)
810	27.1	81	6.5	251	1504

Source: Agodzo *et al.*, 2003

3.2 Description of sampling location

Figure 3-2: Map of sampling sites

3.2.1 Open drain

The criteria for sampling location at the open drain were high-density area, low income and poor sanitation. James Town and Nima were selected as sampling location (figure 3.2). James Town is a costal city with the population density of 295 person/ ha (Ghana Statistical Service, 2002); the main activity is fishing. In James Town, there is a serious need of sanitation. The toilets facilities are not well maintained and insufficient. Concerning domestic wastes generated at house level, the residents dispose them indiscriminately. The city is characterized by many open drains. Some children could be seen playing near the open drain; there were also food vendors who were selling on the street. In total, visual inspection showed a lack of sanitation.

The environment conditions in Nima are similar to those described in James town. The neighborhood of Nima is located in the North of Accra. The main activities of residents are related to business (traders, workers in the shops ...). The population density is about 404 people / ha; the residents in majority are Muslim and have migrated from the North of Ghana (personal communication with residents).

3.2.2 Recreational water

The beach is one of the recreational activities to the people in Accra. In order to assess the seawater quality, two locations were selected (labeled as Beach 1 and 2); the first location was behind the independence square and the second location was near Lapalm beach Hotel. The main criteria of site selection were the accessibility and frequentation by people.

3.3 Sampling sites and sampling collection

3.3.1 Open drain

In Accra, there are various types of open drains; these drains could be grouped into three categories (big, middle, and small). The samples were collected at the smallest drain at house level (figure 3.3). The characteristic of this type of drain is that they are connected directly to the gutters of the house. For the microbial assessment at the open drain, in each location, tree sites were identified (Nima1, Nima2, Nima3 and James Town1 , James town2 and James Town3). The samples were collected twice: the first sample was collected in the morning (between 7h30 and 9h30) and the second one in the afternoon (14h-16h).

Single grab samples of raw wastewater were collected. For *Escherichia coli* and others bacteria analysis, water samples were taken by opening a clean 250ml water sampling bottle below the water surface (figure 5); the samples for Helminths analysis were collected into 1l cleaned bottle by disturbing slightly the water surface.

3.3.2 Recreational water

The samples were obtained at two locations (Beach1, Beach2). Each location was sampled in triplicate at three different positions. Seawater and sand samples were collected (figure 3.4). For the seawater analysis, three 250 ml seawater samples were collected in sterile collecting bottles from each sites and mixed together in order to have one composite sample for bacterial assessment; samples for Helminth eggs were collected in 1l cleaned plastic bottles (figure 3.5). Similar to seawater, beach sand samples were collected in three locations in sterile disposal plastic. The composite sand samples were obtained from dry and wet sand. The samples for bacteria analysis were transported to the laboratory on ice and processed immediately within three hours.

Figure 3-3: Sampling at open drain

Figure 3-4: Sampling at the beach

Figure 3-5: containers for sample collection

3.4 Enumeration of *Bacteria*

Open drain and sea water samples were analyzed for bacteria by using spread plate method with Chromocult Coliform Agar (CCA) according to the manufacturer's instruction (Merck).The samples were diluted due to water turbidity (especially those from open drain). The Solutions for the dilutions were made by using a ratio of 1 liter of deminaralised water, 1gram of peptone and 8.5 grams of sodium chloride. The dilutions were done by diluting the sample in series: after shaking, 1ml of raw sample was transferred to 9ml of sterile dilution solution in order to achieve 1:10 (10^{-1}); this first dilution was shaken and 1ml of that first solution was transferred to 9ml of sterile

dilution so that the total dilution is 1:100 (10^{-2}). Greater dilutions were achieved by following the same procedure. 0.1ml of that solution was transferred to Agar plates and incubated for 24h at 37°C. All dark-blue to violet colonies were counted as *Escherichia coli*, all red colonies as other coliforms, all light blue colonies were counted as *Salmonella* and all the yellow or colourless colonies were range in the group of others Enterobacters.

Sand: bacteria analysis were proceeded as described previously. However, some preliminary steps were performed for sand analysis. The moisture content was recorded by measuring the weight of sand before and after oven drying. Approximately the equivalent in wet weight of 10g of dry weight was mixed with 90ml of solution for the dilution. The samples were shaking vigorously and 10ml of soil solution was transferred to 90ml in order to achieve the first dilution; the next dilution was achieved by transferring from the first dilution 10ml to 90ml of solution for dilution. The procedure was repeated until the desired dilutions were achieved

3.5 Helminths eggs analysis

Helminth eggs analysis was done according to the method as described by Schwartbrod *et al*., (1998). This method consists of four steps:

1) Concentration: this was carried out by applying sedimentation and centrifugation during all stages. The first step is to allow the samples collected to sediment for at least 24h. After sucking up the supernatant as much as possible, the sediment was transferred to 30ml centrifuge tubes and centrifuged at 400g for 3min.

2) Flotation: The supernatant was removed from all the tubes and the deposit was re suspended in 150ml of the solution of zinc sulphate ($ZnSO_4$). These tubes were shaken vigorously and centrifuged at 400g for 3min. The supernatant was transferred into 1l flask and diluted with at least 1l of tap water. These 1l containers were allowed to settle at least for 3hrs. After the settling down of the Helminth eggs, the supernatant was sucked as much as possible and the deposit was re suspended by shaking. The deposit was transferred into one or more centrifuge tubes according of the volume of deposit; the 1l container was rinsed with tap water and the rinsing liquid was added to the centrifuged tubes and recentrifuged at 480g for 3mn. The deposit was regrouped in one tube and centrifuged again at 480g for 3mn.

3) Desorption: The deposit was re suspended in 15ml acid/alcohol buffer solution (at 0.1N at 35% ethanol); about 5ml of ethyl acetate was added to the centrifuge tubes. The mixture was shaken and centrifuged at the speed of 660g for 3mn. All the Helminth eggs will settle down in the sediment.

4) Counting: The supernatant was poored away as much as possible in order to leave about 1ml of deposit. the deposit was transferred with pipette on slide for examination under the microscope for Helminths eggs counting.

Figure 3-6: Laboratory manipulations: 1-Medium preparation; 2-Preparation of tubes for dilution; 3-Plates after incubation at 34 ^{o}C for 24h; 4-Centrifuge tubes for Helminths eggs analysis

3.6 Quantitative microbial risk assessment

Table 3-2: Dose response equations used in the risk assessment.

Parameters		Formula	Equation number
probability of infection : P_i	Beta Poisson model	$P_i = 1 - [1 + \frac{d}{N_{50}} (2^{1/\alpha} - 1)]^{-\alpha}$ (a)	3.1
	exponential model	$P_i = 1 - \exp(-rd)$ (a)	3.2
Annual probability of infection : P_{yearly}		$P_{yearly} = 1 - (1 - P_i)^n$	3.3
Infection per year		P_{yearly} * exposed population	3.4
Probability of developing disease per single exposure: P_D		$P_D =$ (b) $P_{DI} \times P_i$	3.5
Annual probability of developing illness: $(P_D)_{yearly}$		$(P_D)_{yearly} = 1 - (1 - P_D)^n$	3.6
Annual symptomatic cases		$(P_D)_{yearly}$ * exposed *population*	3.7

Source: Haas *et al.*, 1999; [a]α and r are the parameters describing the probability of infection; d is the dose of ingested pathogens and N_{50} the dose that will infect 50% of the population; n is the frequency per year. P_{DI} is the probability of infected person developing clinical disease

Table 3-3: Dose response parameters used in the risk assessment

Organisms	Parameters	Type of model	Sources
Campylobacter	α=0.145; N_{50}=896; P_{DI} = 0.3	ß Poisson model	Haas *et al.*,1999 WHO, 2004
Salmonella	α=0.3126 N_{50}=23600; P_{DI} = 0.3 [a]	ß Poisson model	Haas *et al*, 1999
Rotavirus	α=0.2531; N_{50}=6.17 P_{DI} = 0.5	ß Poisson model	Haas *et al.*, 1999 WHO, 2004
Cryptosporidium	r =0.0199; P_{DI} =0.7	Exponential	Teunis *et al* , 2000
Ascaris	r = 1 [b] ; P_{DI} = 0.39	Exponential	Haas *et al.*,1999 Assumption according to Teunis et al ., 2004

[a] The P_{DI} value for Campylobacter was used for *Salmonella*; [b] dose response model for *Ascaris* is not available yet; therefore, it is suggested to use the highest value of r with exponential model. (Teunis *et al*, 2000, cited by Winstrell, 2004)

The quantitative microbial risk assessment procedure was followed in accordance to Haas *et al.,* (1999). This method consists of four steps: hazard assessment, exposure assessment dose response analysis and risk characterization. The principle of QMRA is based on dose response relationship; it is used to predict the health risk of a particular population due to the exposition to the pathogens. In undertaking the QMRA, it is essential to have data. The outputs of the measurement of pathogens concentration at open drain and beach will serve as primary data. During the fieldwork, a few people were also interviewed in order to estimate the frequency and exposed population at the beach exposure. The additional data will be collected through the literature. The basic equations for risk assessment are outlined above.

3.7 DALYs calculation

In QMRA, the health assessment is presented as the risk of infection; some of these infections may lead to illness or fatality. Another possibility is the use of the Disability Adjusted Life Years (DALYs) to assess the health status. DALYs is the sum of life years lost to premature mortality and years lived with disability adjusted for severity (Murray and Lopez, 1997). For each pathogen, the disease burden per case per pathogens was calculated for each outcome, taking into account the severity and the duration. In 2007, Lunani reported that the disease burden of Accra water system for due to of *Campylobacter*, *Rotavirus*, *Crytosporidium* and *Ascaris* were respectively 0.06, 0.039, 0.09 and 0.05. The calculation of disease burden due to Salmonella is outline below:

Salmonella:
The genus *Salmonella* is a member of family of Enterobacteriaceae. The main reservoirs are food, animal and human The outcomes of *Salmonella* are Mild diarrhea and severe gastrointestinal illness with the duration between 3-7 days. However, for some patients the disease could be fatal; the fatality ratio is 0.1% (Haas, 1999). Severe gastrointestinal illness may result in complications. The main important sequel during the complications is Reactive arthritis (ReA) (Kemmeren *et al.,* 2006); this could be followed by Inflammatory Bowel disease (IBD) which is chronic intestinal disorder. Kemmeren *et al*., (2006) assessed the disease burden due to *Salmonella* based on data from The Netherlands. Due to the absence of data from Ghana or from another developing country, the incidence, duration and the severity of each outcome used in this study was based in the highest prediction of their model. The life expectancy in Ghana is 57 years (Ghana statistical service, 2002). From table 3.4, the disease burden per case due to *Salmonella* is 0.011.

Table 3-4: Severity, duration and disease burden per case of Salmonella

Outcomes	Incidence	Severity	Duration (days)	Duration (years)	Burden disease per case
Gatroenteritis					
No GP	0.83	0.067	5.58	0.015	$8.5*10^{-4}$
GP only	0.15	0.393	10.65	0.029	$1.7*10^{-3}$
Hospitalisation	0.005	0.393	16.15	0.044	$0.87*10^{-3}$
Fatal	$1.3*10^{-4}$	1	56	0.153	$0.2*10^{-4}$
Total					**$2.7*10^{-3}$**
ReA					
No GP	0.11	0.127	222	0.608	$8.5*10^{-3}$
GP only	$2.2*10^{-3}$	0.21	222	0.608	$2.8*10^{-4}$
Hospitalisation	$4.5*10^{-4}$	0.37	222	0.608	$1.0*10^{-4}$ **$8.9*10^{-3}$**
Total					
IBD	$7*10^{-5}$	0.26	57	0.156	**$2.8*10^{-6}$**
Total disease burden					**0.011**

Source: Adopted from Kemmeren *et al*., (2006)

3.8 Cost effectiveness

The cost effectiveness tools was applied to Accra Urban water System in order to obtain efficient allocation of financial resource. Usually the value of costs needed to be use cautiously due to many parameters which involve (fluctuation, materiel use, topography, costumer choice, population density, ..). The approach adopted in this study was the qualitative description of the cost. The main steps of cost analysis were described below:

3.8.1 List of options

At each exposure route, the health risk was assessed with the QMRA. In oder to reduce the health risk in Accra Urban Water System (AUWS), some options was suggested; it must be noticed that this list is not considered as exhaustive; the suitable option among those suggested was selected taking into account the health impact and the cost.

3.8.2 Cost assessment

Due to the difficulty to estimate the full cost related to each option, a comparison among the options was made. As an illustration, each option will be scored according to the description in the table 3.5 from lower score to the higher score.

Table 3-5: Scores per unit costs

Scores	1	2	3	4
explanation	Cheapest	Less costly	Acceptable	Costly

3.8.3 Number of DALYs of each option

The DALYs of each option was assessed in comparison to the baseline DALYs; baseline DALYs is the current situation without any intervention. The approach used was to estimate in percentage the DALYs of each option at all exposure routes. Finally knowing the baseline DALYs at each exposure route, the number of DALYs was calculated for each suggested option. The lower is the DALYs, better will be suggested option

3.8.4 Cost effectiveness

The approach used was to achieve the highest decrease in DALYs with a fixed budget (DALYs averted per unit cost).

DALYs averted: the DALYs averted was calculated based on the difference between the baseline value and the DALYs of the specific option. The good option will be identified with the highest DALYs averted. However, this interpretation does not consider the economical feasibility.

Ratio: DALYs averted / score per unit cost: this ratio gives a good indication about the economical feasibility. The suggested option, which may have the greatest value of this ratio, would maximize the DALYs averted considering health improvement and the cost aspect.

Figure 3-7: Example of exposure at the beach: 1-beach used for open defecation; 2-sludge discharge in the ocean

Figure 3-8: Example of exposure at open drain: people are sitting nearby, selling and eating food

3.9 Data analysis

The values of microbial parameters where transformed into log10 if necessary. The statistical package for social science, SPSS for windows version 14 and Excel spreadsheet for Monte Carlo analysis were used. For statistical analysis, the values were compared to a confidence interval of 95%.

4 Results and discussion

4.1 Microbial assessment of some major pathways

4.1.1 Microbial assessment at the open drain

Two open drains canal were surveyed during this study (Nima and James Town). The samples were collected in the morning and the afternoon.

The mean concentration of Helminths eggs from two locations was 0.7 egg/l with the maximum value of 3eggs/l. The Helminths eggs were expected to be higher due to the composition of wastewater, which may contain also black water besides grey water (Obuobie *et al,* 2006). The number of eggs counted was very low compared to others studies. In Morocco, Nsom Zamo *et al* ., (2003) by assessing the domestic wastewaters quality in the city of Kenitra found that the mean concentration of Helminths parasites was about 31eggs/l in untreated wastewater. The low value of Helminth eggs could be attributed to the sampling method; the characteristic of Helminths eggs it to settle down in the bottom of water in the sediment or in the faeces. Similar conclusion was mentioned by Moubarrad *et al.,* (2007). They assessed the behavior of Helminths eggs along the channel in Morocco and they found that the concentration of the parasites in the sediment was high compared to the water sample is high.

Concerning the bacterial, the concentration of the organisms in both sampling sites was shown in figure 4.1 and 4.2. For most of the organisms under study, there was no significant difference (table 4.1) between the morning concentration of bacteria and the afternoon one (Kruskal-Wallis Test, P values in table, n = 9 x 2) (table 4.1).

Table 4-1: P value : Comparison Nima and James Town

Locations	*E coli*	Total Coliforms	*Salmonella*	Others Enterobacters
Nima	0.1	<0.05*	0.8	0.9
James Town	0.2	0.3	0.7	0.5

* Significant at 0.05 level

However, in Nima the level of Total Coliforms in drain in the morning differed slightly to the afternoon one.

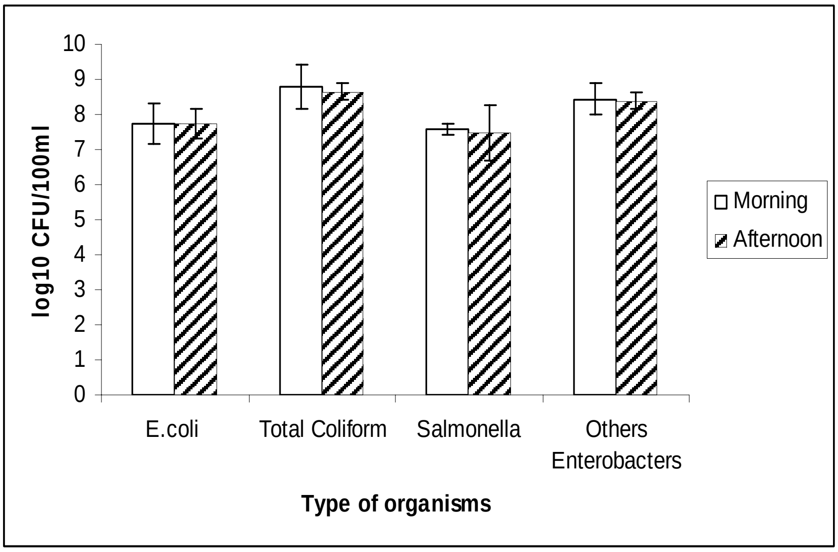

Figure 4-1: Microbial assessment of the drain in Nima

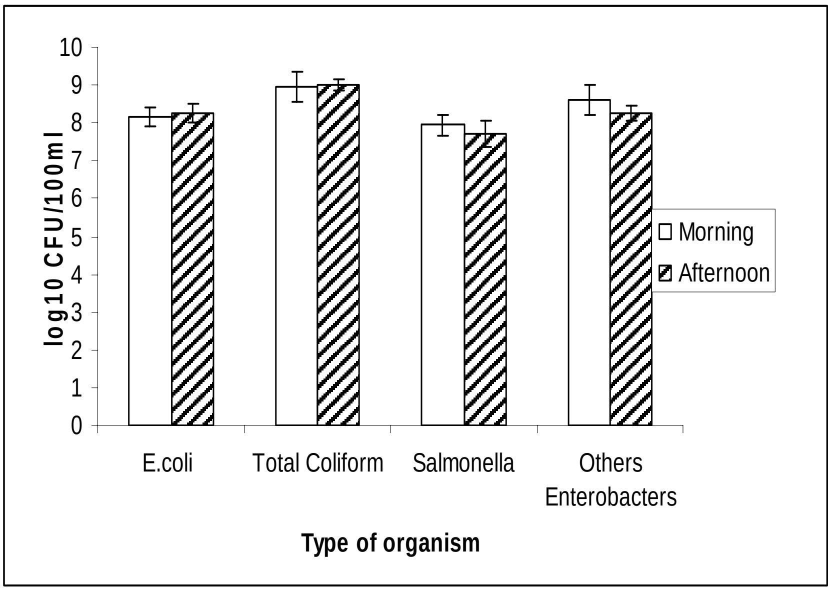

Figure 4-2: Microbial assessment of the drain in James Town

The overall mean concentration of the organisms in the open drain showed a high level of pollution (table 4.2). This result is comparable to those found by others authors who assessed the water quality in the drain used for irrigation. Gbewonyo (2007) assessed the water quality in the open drain in farmers sites. In that study, the results showed that the level of faecal coliforms reached $2*10^7$CFU/100ml. Gbireh, (1999, cited by Obuobie *et al.,* 2006) found a similar result. This author found that the value of faecal coliforms at various sources of water used for irrigation in Accra (drain, river,) range from 10^5 to $*10^8$CFU/100ml. This level of faecal bacteria could be attributed to the lack of sanitation. In Accra, less than 13% of the population has sewerage connection

(Ghana Statistical Service, 2002). The problem of water quality in Ghana is not limited only to Accra. In Kumasi, the survey of water used for irrigation showed that the level of faecal and total coliforms were above 10^6/100ml (Obuobie *et al*, 2006).

However all these values are below those found in this research; this could be explained by the fact that in this study, the concentration of pathogens was measured at the drain connected directly to the houses. Therefore, because of dilution, the concentration may decrease later slightly. The presence of *Salmonella* was not surprising. It is established that at high-density organisms like faecal coliforms, *Salmonella* must be present (Morinigo *et al,* 1993 cited by Elmanama *et al.,* 2004).

In Accra, the water of the drain is used for irrigation; but due to the high concentration of pathogens, this practice could be a serious risk for farmers and consumers. According to the WHO, the reference value recommended for safe reuse of wastewater in agriculture is 1000CFU/100ml for faecal coliforms. Therefore, the wastewater quality in Accra exceeded the guidelines.

Table 4-2: Concentrations of organisms at the open drain

Type of organisms	*Escherichia coli*	Total coliform	*Salmonella*	Others Enterobacters
Log10 CFU/100ml	8.0	8.8	7.7	8.4

4.1.2 Microbial assessment at the beach

The seawater quality and monitoring is essential because if water is polluted people and especially bathers may contract diseases .

Seawater: the concentration of organisms was low in seawater (table 4.3). The comparison of the concentration of *Escherichia coli*, and Total coliform at the drain and the seawater revealed a dilution factor of 10, 000. A similar study was done by Elmanama *et al.,* (2005) at the Gaza beach; the value of *faecal coliform* measured in seawater was 2, 585 CFU/100ml. The concentration of measured organisms in this study need to be considered cautiously due to the limitation of the number of samples. Indeed, the marine water is highly variable in time, space and vulnerable to many factors like tidal effect, sampling site, environment conditions, type of microbial which may affect the concentration of organisms (Shibata *et al.,* 2004).

Sand: In parallel to seawater, the sand at the beach was monitored (table 4.4). The values were high in comparison to the seawater. This finding were consistent with others authors: higher feacal indicators were obtained in sand than in sea water (Elmanama *et al.,* 2005; Shibata *et al.,* 2004; Fleming *et al.,* 2006). Bonilla *et al.*, (2007) by assessing the faecal indicators organisms in South Florida (in USA) found that the level of faecal indicator in dry sand were 100 fold time higher than in the water column.

From table 4.3 and 4.4, it can be seen that composition of indicators organisms and their concentration were higher in the sand than the seawater. In Accra, the problem of sewage contamination occurs because the sewage is directed into the ocean without any treatment (Obuobie, 2006) and this could explain values measured in this study. However, this high concentration in the sand could be explained by others mechanisms. According to some authors, the sand offers a suitable condition for organisms, due to it large area and may act as reservoirs for microbial contaminants (USEPA, 1999, cited by Tonaya *et al.,* 2008).

Table 4-3: Concentrations of organisms in seawater

Type of organisms	*Escherichia coli*	Total coliforms	*Salmonella*	Others Enterobacters
Log10 CFU/100	3.6	4.6	0	5.9

Table 4-4: Concentrations of organisms in the sand

Type of organisms	*Escherichia coli*	Total coliforms	*Salmonella*	Others Enterobacters
Log10 CFU/g of dry weight	6	6.7	4.8	6.7

4.1.3 Ratios *Escherichia. coli* /pathogens

The ratios *Escherichia coli* / Total coliforms, and *Escherichia coli* / *Salmonella* were calculated. The ratios *E. coli* pathogens were not the same from the open and the beach. In all sites under consideration (open drain, seawater, sand), it was found that Total coliforms were 10 times higher than *Escherichia coli* (table 4.4). The Person's correlation test showed a correlation between *Escherichia coli* and Total coliforms at open drain but the predicted value was low: r=0.46 (table 4.6); Ottoson and Stenstrom (2003) find 0.74 as ratio *E. coli* / Total coliform in grey water. Concerning the recreational water, Noble *et al*., (2003) find a strong correlation between *E . coli* and Total coliform in seawater; the spank rank correlation (r) for all the sites in that research was above 0.85. Shibata *et al* (2004) noticed also a correlation between *E coli* and coliform in the seawater (r=0.702).

The use of indicators organisms is still a debate among the researchers. Concerning the use of faecal coliform, it is proved that faecal and total coliforms occurred naturally in soil especially in tropical environment (Toranzos, 1991 cited by Fleming *et al.,* 2006). It is also established that *E. coli* and Total colifoms survive shorter in marine environment than many organism like Enterrocci (Noble *et al.,* 2003). The same remark is valid for *Salmonella*. The detection of *Salmonella* in the absence of indicators of faecal pollution has been reported (Morinigo *et al.,* 1993). In another study, the correlation was found between *Salmonella* and faecal coliform (Elmanama *et al.,* 2005). All these contradicting findings demonstrated the limitation of the use of indicators organisms.
A possible explanation could be the complexity and the interaction of different parameters (Bell, 1975).

Table 4-5: Ratios Escherichia coli / pathogens

Indicators organisms	Open drain	Sand	Sea water
E. coli/Total coliform	0.13	0.15	0.11
E. coli / Salmonella	2.86	1.6	

Therefore, the question is which indicators to use? According to Campos (2008), an ideal indicator should be present in faeces of human and warm – blooded animals, persistent in water and could be removed by water treatment, easily detectable and do not grow in natural waters; *Escherichia coli* remains the organisms which best fulfill these criteria. However Noble *et al.,* (2003) suggested to define the appropriate indicators to limited areas because of changes in environmental parameters (sunlight, salinity, temperature, levels of suspended solids, types of waste water inputs).

Table 4-6: statistical result of correlation test

Indicator study	Open drain	Beach sand	Sea water
E. coli/Total coliform	0.46* (<0.05)	0.58 (0.22)	0.48 (0.36)
E. coli / Salmonella	0.3 (0.1)	0.43 (0.38)	

*significant at 0.05 level; the first value is Pearson coefficient; the second in bracket is the probability

4.2 Quantitative microbial risk assessment

4.2.1 Hazard identification

The first step in the risk assessment is to select the reference pathogen. According to WHO (2003), *Escherichia coli*, O157:H7, *Cryptosporidium*, *Rotavirus*, *Ascaris* are capable to provide a reasonable confidence for risk assessment. In this study, *campylobacte*r, *Salmonella*, *Rotavirus* , *Cryptosporidum and Ascaris* were considered the for risk assessment.

4.2.2 Exposure assessment of sanitation system

Six main exposure routes were assessed in this study (table 4.8); the concentration of pathogens, the dose ingested per exposure, the frequency and the numbers of persons who may be affected were determined. Following the exposure routes of Accra's urban water system, all the input mentioned above for risk assessment that correspond to a single exposure were determined.

Table 4-7: Exposure routes in Accra water urban system

Accra water urban system	Exposures routes
Sanitation	Recreational swimming and sand
	Flooding of Odaw drain
	Open drain
	UASB
Water supply	Water treatments plant
	Water distribution system

Source: Adopted from Lunani (2007)

Table 4-8: Ratio E . coli / pathogens

Ratios	Median (90% confidence interval
Ratio of (*E.coli*): (Virus)	10^{-5}
Ratio of (*E.coli*): (Bacteria)	10^{-5}
Ratio of (*E.coli*): (Protozoa)	10^{-6}
Ratio of (*E.coli*): (Helminth)	10^{-6}

Source: Howard *et al.,* 2007; Mara *et al.*, 2007 cited by Lunani, 2007

Concentration of pathogens: primary data were collected at the tree exposure routes. The concentrations of pathogens were measured at the open drain, seawater and beach sand. For the others pathways, the concentration of pathogens were derived from the secondary data collection or from the literature based on the ratio *E. coli* / pathogen (table 4.8). However, the use of ratio may over estimate or underestimate the concentration of pathogens (Campos, 2007); the behavior of pathogens may differ from one exposure route to another one due to the difference of environment condition. It was assumed that *Salmonella* and *Campylobacter* had the same concentration (they belong the same group of bacteria).

1 Beach

a. Seawater

The measured concentration of *E .coli* in seawater was 10^4CFU/100ml. The ratio *E. coli* pathogens were used to calculate the concentration of pathogen in seawater (table 4.8 and 4.9). Helminths eggs and *Salmonella* were not found in seawater. The concentration of S*almonella* and Helminths eggs was zero.

Table 4-9: Pathogens concentrations in seawater

Pathogens	*Salmonella*	*Campylobacter*	*Rotavirus*	*Cryptosporidium*	*Ascaris*
CFU/100 ml	0 [a]	$1.7*10^{-2}$ [b]	$1.7*10^{-2}$ [b]	$1.7*10^{-3}$ [b]	0 [a]

[a] Measured values; [b] Estimated from the ratio *E. coli* / pathogens

b. Sand

The concentration of Salmonella was $9*10^5$CFU/g dry weight. It was assumed that *Campylobacter* and *Salmonella* had the same concentration. The *E. coli* measured was 10^6CFU/g dry weight. The concentration of Helminths eggs was zero. The table 4.10 showed the concentration of all pathogens in the sand.

Table 4-10: Pathogens concentrations in the sand

Pathogens	*Salmonella*	*Campylobacter*	*Rotavirus*	*Cryptosporidium*	*Ascaris*
CFU/g dry weight	910500 [a]	910500 [b]	15 [c]	17 [c]	0 [a]

[a] Measured value; [b] assumed to have the same concentration with Salmonella.
[c] Estimated from the ratio E coli : pathogens (table 4.8)

c. Determination of number exposed people and frequency and volume ingested

In Accra people go to beach for various purpose like resting, listening music, have conversation in open space, swimming or playing with water or sand. Among all this activities, the health risk at the beach are related to the both last activities.

The determination of number of exposed people and the frequency were assessed through the interviews (at the beach and in the market). The first interview was done at each sampling site at the beach (during sampling collection) and the second one in neutral area at Madina market. The result of the control group was adjusted in order to estimate the frequency and the population exposed (table 4.11).

The frequency was adjusted to 2 (per year); for the population exposed, besides the swimmers, those who played were taking into account. The number of exposed population to the seawater was adjusted to 30 % of the population of Odaw catchment ($9*10^5$) and 10 % of the population of Odaw catchments were exposed to sand.

Table 4-11: Frequency and population exposed

Locations	Number of people interviewed	Frequency (year)	Number people who swim (in %)	Number of people who plays with water in (%)	Number of people who plays in the sand in (%)
Independence square (beach)	26	3	46	26	19
LaPalm beach	33	4	60	21	15
Mean result of sites 1 and 2	30	3.5	53	23	16
Control at Madina (market)	51	1.4	17	4	21

The exposure volume has been reported variable. Some authors suggested 50 ml as the volume ingested (Westrell *et al*., 2004; Ottoson, 2004) or 100 ml during each swimming event (Haas et al 2004). In this study, the volume used was 75ml (table 4.12).

Table 4-12: Exposure at the beach

Locations	Volume exposed (in ml or g)	Frequency (year)	Exposed population
Recreational swimming	75 [a]	2 [c]	298609 [c]
Beach sand	5 [b]	2 [c]	99536 [c]

[a] Mean value (Westrell *et al*, 2004; Ottoson, 2004; Haas *et al*, 2004). [b]Westrell, 2004.
[C] adjusted from the interview

2 Flooding of the Odaw drain

During heavy rainfall, flood may occur which can expose people specially children. Three exposures routes to the children were identified during flooding events: ingestion of floodwater, immersion at lagoon and playing in flood water. The faecal coliforms concentration in the Odaw river was $1*10^6$ CFU/100ml (Nana-Amankwaah, unpublished, cited by Lunani, 2007). Base on the ratio *E. coli* pathogens, the concentration of pathogens was calculated; *Salmonella*, *Campylobacte*r, and *Rotavirus* had the same concentration: $1.2*10^1$CFU/ml *Cryptosporidium* and *Ascaris* were 1.2 CFU/100ml.

The volume ingested, frequency and the number of people exposed are described in table 0-12 (appendix D).

3 The UASB treatment plant

- **Pathogen concentration**

In this study, the measured concentration of *E. coli* in the open drain (at house level) was used to calculate the concentration of pathogens. The measured concentrations of *Escherichia coli* was 10^8 CFU/100 ml, therefore the concentration of pathogens were estimated based on the ratio *E. coli*/ pathogens (table 4.13).

Table 4-13: Estimation of the pathogens concentration at the UASB inlet work

Pathogens	*Salmonella*	*Campylobacter*	*Rotavirus*	*Cryptosporidium*	*Ascaris*
CFU /100 ml	1200	1200	12 00	120	120

The frequency of exposure, the number of persons exposed at each exposure routes are shown in table 0-13 (appendix D).

4 Faecal septage disposal

At this exposure route, three pathways were identified:
1-the workers handling septage,
2-children playing with contaminated sand and
3-the fishermen ingested contaminated water at the shore

In Accra, faecal septage is collected and disposed at the beach. The concentration of *Escherichia coli* was assumed to be the same with those measured in the open drain; therefore, the concentration of pathogens were shown in table 24.

The number of population is 75,812 (Korle Gonno and Mamprobi); the proportion of children is 21.2% of the population and half of the children are school age (8,036); it was assumed that half of children in school age could be exposed. Therefore, the exposed population was 4,018 (table 4.14)

Table 4-14: Volume ingested, frequency and population exposed at the feacal septage place

Exposure routes	Volume ingested (ml)	Frequency (year)	Affected[b] population
Workers handling septage	1 [a]	317 [c]	100
Children playing with contamined sand	5 [b]	2 [c]	4018[d]
Fishermen ingesting contaminated water at the shore	1	1	10

[a] Ashbolt *et al.,* 2005; [b] Westrell *et al*, 2004 ; [c] Lunani, 2007 ; [d] Ghana statistical service (2002) ; the number of children (0-4 years) was 8037. It was assumed that half of them might be exposed

5 Open drain

- **Pathogen concentration**

The concentration of pathogens was measured at two locations in Accra (Nima and James Town). This measurement do not consider rain period and the low density area (table 4.2).

Table 4-15: Estimation of the pathogens concentration at the open drain

Pathogens	*Salmonella*	*Campylobacter*	*Rotavirus*	*Cryptosporidium*	*Ascaris*
CFU /100 ml	$4.3*10^{7}$ [a]	$4.3*10^{7}$	$12*10^{+2}$ [b]	$12*10^{+2}$ [b]	$12*10^{+2}$ [b]

[a] field measurement; [b] based on the ratio *E. coli* / pathogens (table 4.8)

- **Determination of population exposed frequency, volume and frequency**

The population exposed was based on the population of children of hight residential area. The population of children of Odaw cachtment was estimated as 81,272 (Ghana Statistical Service, 2002). However the locality of Adedenkpo is not in the category of residential area (Colan-consult, 1997). Furthermore, it was assumed that 2/3 of children would be exposed. Therefore, in this study the exposed population at the open drain with children was estimated as 5, 264. The volume and frequency were assumed to be 5 and 4; this was adjusted from the value 1 and 2 suggested by Westrell *et al.*, (2004).

Table 4-16: Summary of frequency, volume ingested and exposed population

Order	Exposures	Volume ingested (ml or g)	Frequency (per year)	Exposed population
1	Recreational swimming	75	2	298, 608
2	sand	5	2	99, 536
3	Unintentional ingestion of flood water	1	1	111, 790
4	Unintentional immersion at lagoon	30	1	10
5	Children playing in flood water	1	1	23, 699
6	Workers desludging the UASB treatment plant	5	12	10
7	Workers removing debris from the UASB inlet works daily during the rainy season	1	90	10
8	Workers taking samples from the UASB inlet works for laboratory analysis	0.1	1	3
9	Workers handling septage at the faecal septage disposal place	1	317	100
10	Children playing with contamined sand at the faecal septage disposal place	5	2	4, 018
11	Fishermen ingesting contamined water at the shore next to the faecal septage disposal point	1	1	10
12	Children playing near open drainage channels	5	4	5, 2624

6 Ingested doses at sanitation pathway

The table 4.17 showed that the doses ingested varied according to the exposure routes. The highest dose would occur at the open drain channel; this was followed by beach sand. However, the ingested dose was low in the case of seawater. Among all the exposure routes, seawater had the lowest concentration.

Table 4-17: Ingested doses at each exposure

	Exposures	*Campylobacter*	*Salmonella*	*Rotavirus*	*Cryptosporidium*	*Ascaris*
1	Recreational swimming	0.0E+00	0.0E+00	1.3E-02	1.3E-03	0.0E+00
2	sand	4.6E+04	4.6E+04	7.4E-01	7.4E-01	0.0E+00
3	Unintentional ingestion of flood water	1.2E-01	1.2E-01	1.2E-01	1.2E-02	1.2E-02
4	Unintentional immersion at lagoon	3.7E+00	3.7E+00	3.7E+00	3.7E-01	3.7E-01
5	Children playing in flood water	1.2E-01	1.2E-01	1.2E-01	1.2E-02	1.2E-02
6	Workers desludging the UASB treatment plant	6.1E+01	6.1E+01	6.1E+01	6.1E+00	6.1E+00
7	Workers removing debris from the UASB inlet works daily during the rainy season	1.2E+01	1.2E+01	1.2E+01	1.2E+00	1.2E+00
8	Workers taking samples from the UASB inlet works for laboratory analysis	1.2E+00	1.2E+00	1.2E+00	1.2E-01	1.2E-01
9	Workers handling septage at the faecal septage disposal place	1.2E+01	1.2E+01	1.2E+01	1.2E+00	1.2E+00
10	Children playing with contamined sand at the faecal septage disposal place	6.1E+01	6.1E+01	6.1E+01	6.1E+00	6.1E+00
11	Fishermen ingesting contamined water at the shore next to the faecal septage disposal point	1.2E+01	1.2E+01	1.2E+01	1.2E+00	1.2E+00
12	Children playing near open drainage channels	2.1E+06	2.1E+06	6.1E+01	6.1E+00	3.5E-02

4.2.3 Dose response calculations and risk characterization for the sanitation system with point estimate

1 Probability of infection per single exposure

The open drain channels had the highest probability of infection for most of the pathogen (table 4.18): *Cryptosporidium*, *Salmonella*, *Campylobacter* and *Rotavirus*. Beside the open drain, *Rotavirus* had a high probability of infection at the exposure route related to faecal septage and UASB. *Ascaris* had the highest probability of infection at faecal septage exposure.

Table 4-18: Probability of infection per single exposure[a]

Exposures	*Campylobacter*	*Salmonella*	*Rotavirus*	*Cryptosporidium*	*Ascaris*
Recreational swimming	0.0E+00	0.0E+00	7.3E-03	5.2E-06	0.0E+00
sand at the beach	7.2E-01	5.9E-01	2.2E-01	3.1E-03	0.0E+00
Unintentional ingestion of flood water	2.3E-03	1.3E-05	6.2E-02	5.1E-05	1.2E-02
Unintentional immersion at lagoon	5.5E-02	3.9E-04	4.4E-01	1.5E-03	3.1E-01
Children playing in flood water	2.3E-03	1.3E-05	6.2E-02	5.1E-05	1.2E-02
Workers desludging the UASB treatment plant	2.7E-01	6.5E-03	7.2E-01	2.5E-02	1.0E+00
Workers removing debris from the UASB inlet works daily during the rainy season	1.3E-01	1.3E-03	5.8E-01	5.1E-03	7.1E-01
Workers taking samples from the UASB inlet works for laboratory analysis	2.1E-02	1.3E-04	2.9E-01	5.1E-04	1.1E-01
Workers handling septage at the faecal septage disposal place	1.3E-01	1.3E-03	5.8E-01	5.1E-03	7.1E-01
Children playing with contamined sand at the faecal septage disposal place	2.7E-01	6.5E-03	7.2E-01	2.5E-02	1.0E+00
Fishermen ingesting contamined water at the shore next to the faecal septage disposal point	1.3E-01	1.3E-03	5.8E-01	5.1E-03	7.1E-01
Children playing near open drainage channels	8.4E-01	8.7E-01	7.2E-01	2.5E-02	3.4E-02

[a] Estimated using equation 3.1 and 3.2 and exposures listed in table 4.16

2 Annual probability of infection per single exposure and number of annual infections

a. Beach

At the beach, the annual probability of infection due to *Rotavirus* was high ($1.5*10^{-2}$) compared to *Cryptosporidium* ($1*10^{-5}$) (see table 4.20); during the measurement, it was noticed that the concentration of Helminths eggs and *Salmonella* was zero. The maximum number of infection was $4*10^{-3}$ and was due to *Rotavirus*. The low risk with the recreational water could be explained by the inappropriate conditions for suitable growth of organisms. Craig *et al.*, (2003) observed that the survival of *Salmonella sp* was always greater in coastal sediment than the overlying water. The assessment of the sand (exposure 2) showed a high value for annual probability with *Campylobacter Salmonella* and *Rotavirus*; consequently, the number of infections due to these organisms was within magnitude 10^{+5} (table 4.20). For the beach users, it can be concluded that the sand posed a greater health risk. However this risk is related to the time spend at the beach (Bonilla *et al.*, 2007).

Table 4-19: Probability of infection (annual) from sanitation pathway[a]

Exposures[b]	*Campylobacter*	*Salmonella*	*Rotavirus*	*Cryptosporidium*	*Ascaris*
1	0.0E+00	0.0E+00	1.5E-02	1.0E-05	0.0E+00
2	9.2E-01	8.3E-01	4.0E-01	6.1E-03	0.0E+00
3	2.3E-03	1.3E-05	6.2E-02	5.1E-05	1.2E-02
4	5.5E-02	3.9E-04	4.4E-01	1.5E-03	3.1E-01
5	2.3E-03	1.3E-05	6.2E-02	5.1E-05	1.2E-02
6	9.8E-01	7.5E-02	1.0E+00	2.6E-01	1.0E+00
7	1.0E+00	1.1E-01	1.0E+00	3.7E-01	1.0E+00
8	2.1E-02	1.3E-04	2.9E-01	5.1E-04	1.1E-01
9	1.0E+00	3.4E-01	1.0E+00	8.0E-01	1.0E+00
10	4.7E-01	1.3E-02	9.2E-01	5.0E-02	1.0E+00
11	1.3E-01	1.3E-03	5.8E-01	5.1E-03	7.1E-01
12	1.0E+00	1.0E+00	9.9E-01	9.7E-02	1.3E-01

[a] Estimated using equation 3.3; [b]exposures listed in table 4.16

Table 4-20: Annual infection per exposure route[a]

Exposures[b]	*Campylobacter*	*Salmonella*	*Rotavirus*	*Cryptosporidium*	*Ascaris*
1	0.0E+00	0.0E+00	4.3E+03	3.1E+00	0.0E+00
2	9.2E+04	8.2E+04	4.0E+04	6.1E+02	0.0E+00
3	2.6E+02	1.5E+00	6.9E+03	5.7E+00	1.4E+03
4	5.5E-01	3.9E-03	4.4E+00	1.5E-02	3.1E+00
5	5.5E+01	3.1E-01	1.5E+03	1.2E+00	2.9E+02
6	9.8E+00	7.5E-01	1.0E+01	2.6E+00	1.0E+01
7	1.0E+01	1.1E+00	1.0E+01	3.7E+00	1.0E+01
8	6.4E-02	4.0E-04	8.7E-01	1.5E-03	3.4E-01
9	1.0E+02	3.4E+01	1.0E+02	8.0E+01	1.0E+02
10	1.9E+03	5.2E+01	3.7E+03	2.0E+02	4.0E+03
11	1.3E+00	1.3E-02	5.8E+00	5.1E-02	7.1E+00
12	5.3E+04	5.3E+04	5.2E+04	5.1E+03	6.9E+03
Total	**1.5E+05**	**1.4E+05**	**1.1E+05**	**6.0E+03**	**1.3E+04**

[a] Estimated using equation 3.4; [b]exposures listed in table 4.16

b. Flooding of the drain

The probability and the number of infection due to the flooding of the drain (exposure 3, 4, 5) were low in comparison to others routes. However, considering the specific pathway related to flooding of the drain, the highest probability of infection was recorded during the unintentional immersion at lagoon (exposure 4). This could be explained by the large volume ingested during the immersion. At this exposure route, *Campylobacter* had the highest probability of infections ($5.5*10^{-2}$). However, the number of infections due to the unintentional immersion in the lagoon is low. This is due to the low number of exposed people. The highest number of infections occurred during the unintentional ingestion of floodwater (exposure 3). *Rotavirus* had the highest number of infections ($6.9.*10^{3}$). This was followed by *Ascaris* ($1.4 *10^{3}$).

c. The UASB treatment plant

The annual risk of infection and annual infection of the exposure 8 was less in comparison to exposure routes 6 and 7 because of the lowest ingested volume (0.1 ml). The highest probability of infection (1) was noticed at exposure 6 and 7; this was due to *Campylobacter*, *Rotavirus* and *Ascaris*. The maximum yearly infection due these organisms was 10. The annual risk of infection and annual infection due to *Salmonella* and *Cryptosporidium* was low at all the exposures.

d. Faecal septage disposal points

Ascaris had the highest probability of infection at all exposures routes related to faecal septage. with the probability 1; this means that it is quite certain for children who played at the faecal septage points to be infected due to *Ascaris*. This was followed by *Rotavirus* with the maximum probability of infection of $7.2*10^{-2}$. The maximum infection due to *Ascaris* and *Rotavirus* was respectively $4*10^{3}$ and $3.7*10^{3}$. *Cryptosporidiu*m had the lowest risk of infection and annual infection.

e. Open channels drain

At the open drain, the risk of infection was the highest for all the pathogens under studies. The measured concentration at this exposure routes showed a high value of the concentration of pathogens. These risk estimates are in contrast with the study of Razak *et al.*, (unpublished); while the annual probability of infection due to *Ascaris* was $1.3*10^{-1}$ in this study, these authors find that the annual risks due to *Ascaris* was within a magnitude of 10^{-2} for the accidental ingestion of wastewater of the drain. It is expected that due to their permanent contact with wastewater, the annual risk of infection for farmers should be high compared to the risk at the open drain for children.

In total, the number of infection was $4.1*10^{5}$ and the major contribution were from the sand and open drain (table 4.21); considering all the pathogens, the occurrence of infection was due to *Salmonella*, *Campylobacter*, and *Rotavirus* .This was followed by *Ascaris* and *Cryptopsoridium*. The number of infection was within magnitude 10^{+5} due to *Salmonella*, *Campylobacter*, and *Rotavirus*; the number of infection due to *Ascaris*, *Cryptosporidium* was respectively within 10^{+4} and 10^{+3}(table 4.21). The contribution of *Salmonella* was due to the high concentration measured at the open drain and the beach sand; the maximum number of infection due to *Rotavirus* could be explained by it high infectivity. The contribution of *Ascaris* was great than those of *Cryptosporidium* because of choice of high risk (r=1).

Lunani (2007) found a similar trend for the infection due to the same pathogens. However they were difference of factor 10 for all the pathogens except *Ascaris*; this could be explained by the fact the exposure route related to beach sand was not taking into account; there were not a big difference between the values used in both studies for *Ascaris.*

Table 4-21: Contribution to each exposure to the Annual infection

No	Exposure route	Number of infection	Contribution of each exposure point (in %)
1	Recreational swimming	4.3E+03	1.1
2	sand at the beach	2.1E+05	52
3	Unintentional ingestion of flood water	8.5E+03	2
4	Unintentional immersion at lagoon	8.0E+00	0
5	Children playing in flood water	1.8E+03	0.5
6	Workers desludging the UASB treatment plant	3.3E+01	0.04
7	Workers removing debris from the UASB inlet works daily during the rainy season	3.5E+01	0
8	Workers taking samples from the UASB inlet works for laboratory analysis	3.5E+01	0
9	Workers handling septage at the faecal septage disposal place	1.3E+00	0.1
10	Children playing with contaminated sand at the faecal septage disposal place	4.1E+02	2.4
11	Fishermen ingesting contaminated water at the shore next to the faecal septage disposal point	9.9E+03	0.0
12	Children playing near open drainage channels	1.4E+05	41
	TOTAL	**4.1E+05**	

3 Probability of developing illness per single exposure and annual symptomatic cases

Table 4-22: Probability of developing illness per single exposure from sanitation pathway[a]

Exposures[b]	*Campylobacter*	*Salmonella*	*Rotavirus*	*Cryptosporidium*	*Ascaris*
1	0.0E+00	0.0E+00	3.6E-03	3.7E-06	0.0E+00
2	2.2E-01	1.8E-01	1.1E-01	2.2E-03	0.0E+00
3	6.9E-04	4.0E-06	3.1E-02	3.6E-05	4.7E-03
4	1.7E-02	1.2E-04	2.2E-01	1.1E-03	1.2E-01
5	6.9E-04	4.0E-06	3.1E-02	3.6E-05	4.7E-03
6	8.2E-02	2.0E-03	3.6E-01	1.8E-02	3.9E-01
7	3.9E-02	4.0E-04	2.9E-01	3.6E-03	2.7E-01
8	6.4E-03	4.0E-05	1.4E-01	3.6E-04	4.5E-02
9	3.9E-02	4.0E-04	2.9E-01	3.6E-03	2.7E-01
10	8.2E-02	2.0E-03	3.6E-01	1.8E-02	3.9E-01
11	3.9E-02	4.0E-04	2.9E-01	3.6E-03	2.7E-01
12	2.5E-01	2.6E-01	3.6E-01	1.8E-02	1.3E-02

[a] Estimated using equation 3.5; [b]exposures listed in table 4.16

The probability of illness is variable according to the exposure route and the pathogens. Taking into account all the exposures route and all the pathogens under studies, the exposure route 2 and 12 had a highest probability of developing illness for most of the pathogens *(Campylobacter, Salmonella, Rotavirus* and *Cryptosporidium).* For *Ascaris* the exposure route 6 and 10 had the highest probability of infection due to *Ascaris* (table 4.22).

Annual probability of developing illness per single exposure and annual symptomatic cases

The exposure route 7 and 9 had the highest annual probability of developing illness, which was equal to 1 for all the pathogens; additionally, the probability of developing illness due to *Ascaris* was equal to 1 at exposure 6 (table 4.23).

Table 4-23: Annual probability of developing illness[a]

Exposures[b]	*Campylobacter*	*Salmonella*	*Rotavirus*	*Cryptosporidium*	*Ascaris*
1	0.0E+00	0.0E+00	7.3E-03	7.3E-06	0.0E+00
2	3.8E-01	3.2E-01	2.1E-01	4.3E-03	0.0E+00
3	6.9E-04	4.0E-06	3.1E-02	3.6E-05	4.7E-03
4	1.7E-02	1.2E-04	2.2E-01	1.1E-03	1.2E-01
5	6.9E-04	4.0E-06	3.1E-02	3.6E-05	4.7E-03
6	6.4E-01	2.3E-02	1.0E+00	1.9E-01	1.0E+00
7	9.7E-01	3.5E-02	1.0E+00	2.8E-01	1.0E+00
8	6.4E-03	4.0E-05	1.4E-01	3.6E-04	4.5E-02
9	1.0E+00	1.2E-01	1.0E+00	6.8E-01	1.0E+00
10	1.6E-01	3.9E-03	5.9E-01	3.5E-02	6.3E-01
11	3.9E-02	4.0E-04	2.9E-01	3.6E-03	2.7E-01
12	6.9E-01	7.0E-01	8.3E-01	6.9E-02	5.3E-02

[a] Estimated using equation 3.6; [b]exposures listed in table 4.16

Table 4-24: Annual symptomatic cases from each exposure point from the sanitation pathway

Exposure	*Campylobacter*	*Salmonella*	*Rotavirus*	*Cryptosporidium*	*Ascaris*
1	0.0E+00	0.0E+00	2.2E+03	2.2E+00	0.0E+00
2	3.8E+04	3.2E+04	2.1E+04	4.3E+02	0.0E+00
3	7.7E+01	4.4E-01	3.4E+03	4.0E+00	5.3E+02
4	1.7E-01	1.2E-03	2.2E+00	1.1E-02	1.2E+00
5	1.6E+01	9.4E-02	7.3E+02	8.5E-01	1.1E+02
6	6.4E+00	2.3E-01	1.0E+01	1.9E+00	1.0E+01
7	9.7E+00	3.5E-01	1.0E+01	2.8E+00	1.0E+01
8	1.9E-02	1.2E-04	4.3E-01	1.1E-03	1.3E-01
9	1.0E+02	1.2E+01	1.0E+02	6.8E+01	1.0E+02
10	63E+02	1.6E+01	2.4E+03	1.4E+02	2.5E+03
11	3.9E-01	4.0E-03	2.9E+00	3.6E-02	2.7E+00
12	3.6E+04	3.7 E +04	4.4E+04	3.6E+03	2.8E+03
TOTAL	**7.6E+04**	**7.1E+04**	**7.4E+04**	**4.3E+03**	**6.0E+03**

[a] Estimated using equation 3.7; [b]exposures listed in table 4.16

The number of cases due to *Campylobacter*, *Salmonella* and *Rotavirus* was within the magnitude 10^4 (table 4.24). For *Cryptosporidium* and *Ascaris* the number of cases were within magnitude 10^3. the highest number of infection was noticed at the open drain; this exposure route was followed by sand. The total number of cases was $2.3*10^{+5}$.

The comparison of the number of infections and cases show a change of pattern. This could be attributed to the capacity of pathogen to induce illness. The value of the probability of infected person developing clinical diseases was high with *Rotavirus* and *Cryptosporidium* (table 3.2); the number of infections due to *Rotavirus* and *Cryptosporidium* was great at the open drain than seawater and sand. This may explain the highest number of cases at the open drain.

In summary, the total number of cases for sanitation system was $2.3*10^5$. The highest number of cases occurred at the open drain and the sand. The comparison among pathogens revealed the highest contributors were *Campylobacter*, *Salmonella* and *Rotavirus* . This was followed by *Ascaris* and *Cryptosporidium*.

4.2.4 Risk assessment to water supply

A quantitative microbial risk assessment method applied to water supply system in Accra showed that there was health risk in water treatment and distribution system (Lunani, 2007) assessed the health risk due to *Campylobacter, Rotavirus* and *Cryptosporidium* at eight exposures routes : (table 0-14 and 0-15) (appendix E):

1) Power outage at Weija treatment plant
2) Power outage at Weija treatment plant
3) Disinfection error at Kpong treatment plant
4) Coagulation error at Kpong treatment plant
5) Filtration error at Kpong treatment plant
6) Contaminated distribution system
7) Pollution entering part of system without pressure (108 hours per week)
8) Pollution entering part of system without pressure (120 hours per week)

In this study, the health risk associated to Salmonella at the water supply exposure routes was assessed (table 4.25). It was assumed that *Salmonella* and *Campylobacter* had same concentration, therefore the same ratio *E. coli* /pathogen was applied to them.

Table 4-25: Risk assessment of Salmonella at water supply pathway

	Exposure	Ingested doses	Probability of infection per single exposure	Annual probability of infection	Annual infections	Total of annual infections	Probability of developing illness per single exposure	Annual probability of developing illness	Number of cases	Total of number of cases
Water treatment	1	0.002175	2.35E-07	8.47E-07	0.548054	6.9E-01	7.06E-08	2.54E-07	0.164416	2.1E-01
	2	6.96E-08	7.53E-12	7.53E-12	4.87E-06		2.26E-12	2.26E-12	1.46E-06	
	3	1.77E-06	1.91E-10	6.99E-08	0.024335		5.74E-11	2.1E-08	0.007301	
	4	1.77E-06	1.91E-10	6.99E-08	0.024335		5.74E-11	2.1E-08	0.007301	
Water distribution	5	1.77E-05	1.91E-09	2.79E-07	0.097342	2.7E+00	5.74E-10	8.38E-08	0.029202	8.2E-01
	6	6.67E-05	7.22E-09	1.05E-06	0.995244		2.16E-09	3.16E-07	0.298573	
	7	0.0001	1.08E-08	2.53E-06	0.755937		3.25E-09	7.59E-07	0.226781	
	8	0.0001	1.08E-08	2.81E-06	0.97992		3.25E-09	8.44E-07	0.293976	
	6	6.67E-05	7.22E-09	1.05E-06	0.995244		2.16E-09	3.16E-07	0.298573	
	7	0.0001	1.08E-08	2.53E-06	0.755937		3.25E-09	7.59E-07	0.226781	
	8	0.0001	1.08E-08	2.81E-06	0.97992		3.25E-09	8.44E-07	0.293976	

4.2.5 Comparing water supply and sanitation

The figures 4.3 and 4.4 showed the overview of Accra urban water system. The number of infection and cases mainly was due to the pathogens: *Campylobacter*, *Salmonella*, and *Rotavirus*. *Salmonella* was present at high density at the open drain and beach sand; the number of infections and cases recorded due to *Rotavirus* could be explained by its high infectivity (Haas, 1999). In total, the number of infections and cases were respectively $4.1*10^5$ and $2.3*10^5$. The contribution of sanitation was more than 94% of the total infections and number of cases.

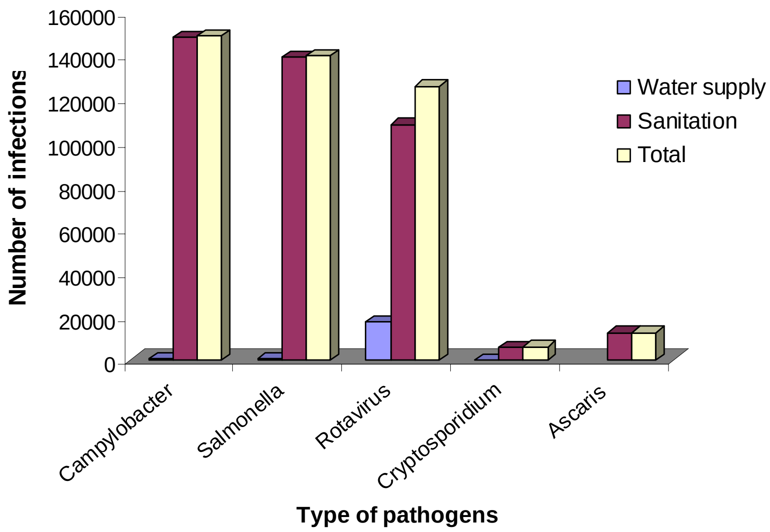

Figure 4-3: Number of infections per year from sanitation and water supply

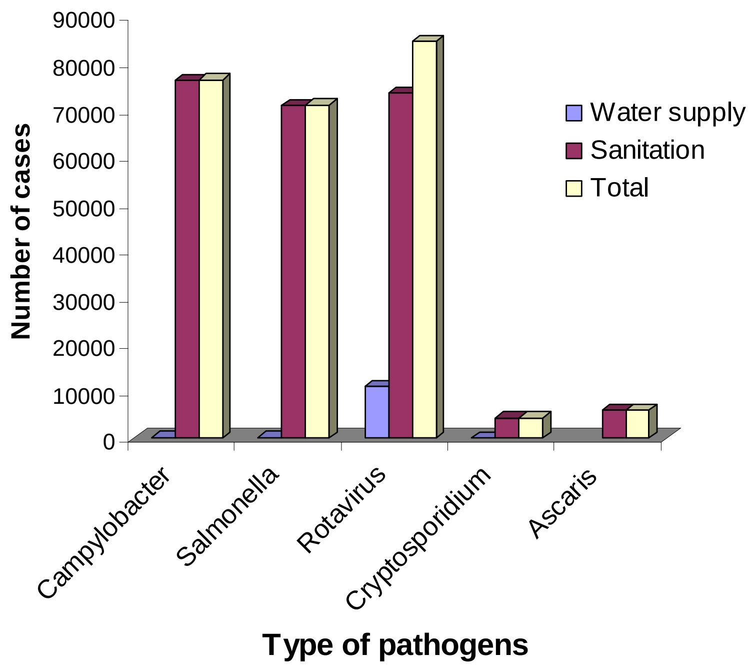

Figure 4-4: Number of cases per year from sanitation and water supply

4.2.6 Disease burden from Accra urban water system

The comparison of pathogens showed that *Rotavirus* had the highest DALYs (about $3.0*10^4$) with the contribution of 90% of total DALYs; this was followed by and *Campylobacter, Salmonella* with the contribution respectively of 6% and 2% of DALYs. The total disease burden of Accra urban water system was 37 000 and the contribution of sanitation was about 88%. From all above, the contribution of sanitation pathway is major in the burden of disease in Accra urban water system specially the exposure route related to the open drain (figure 4.5).

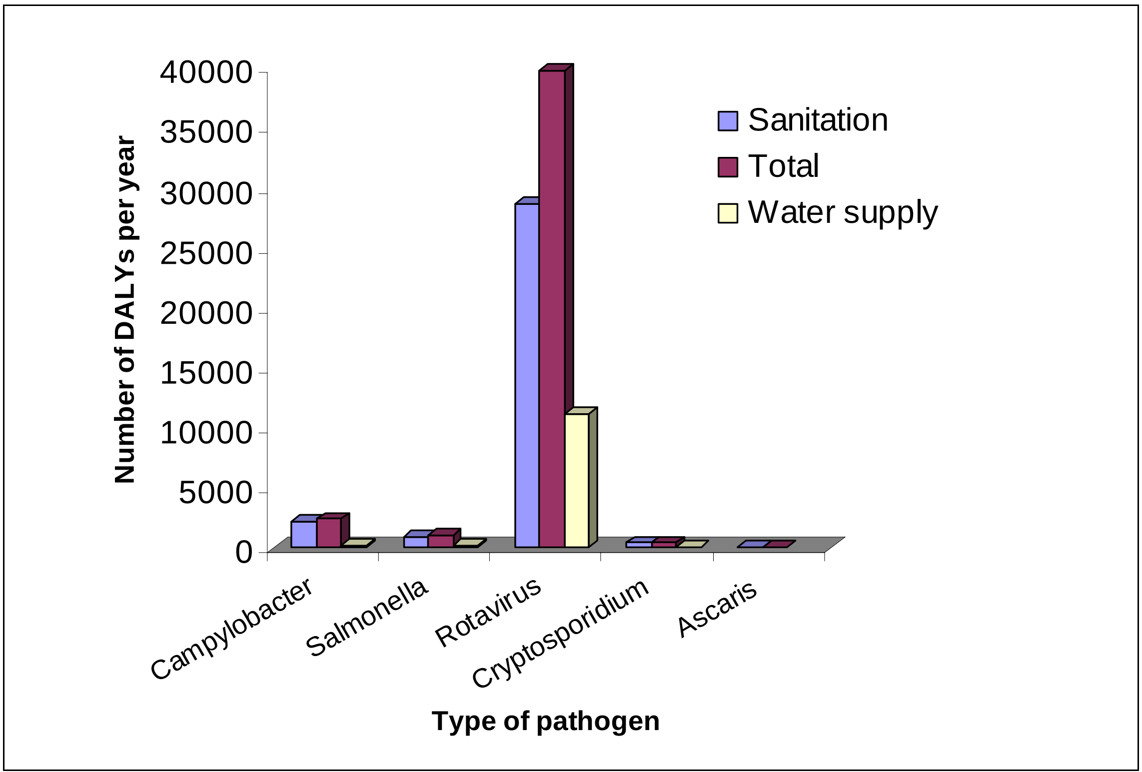

Figure 4-5: Number of DALYs from sanitation and water supply

In the new guideline of WHO (2006), the health based target was recommended for health risk assessment. According to WHO, the acceptable level of DALYs per person per year (pppy) to avoid health adverse effect is 10^{-6} DALYs per pppy. Referring to the AUWS, the result showed that the DALYs pppy was $5*10^{-3}$ pppy, which was above the reference value. Considering all the exposure routes, the DALYs ppp was within 10^{-2} (figure 4.6).

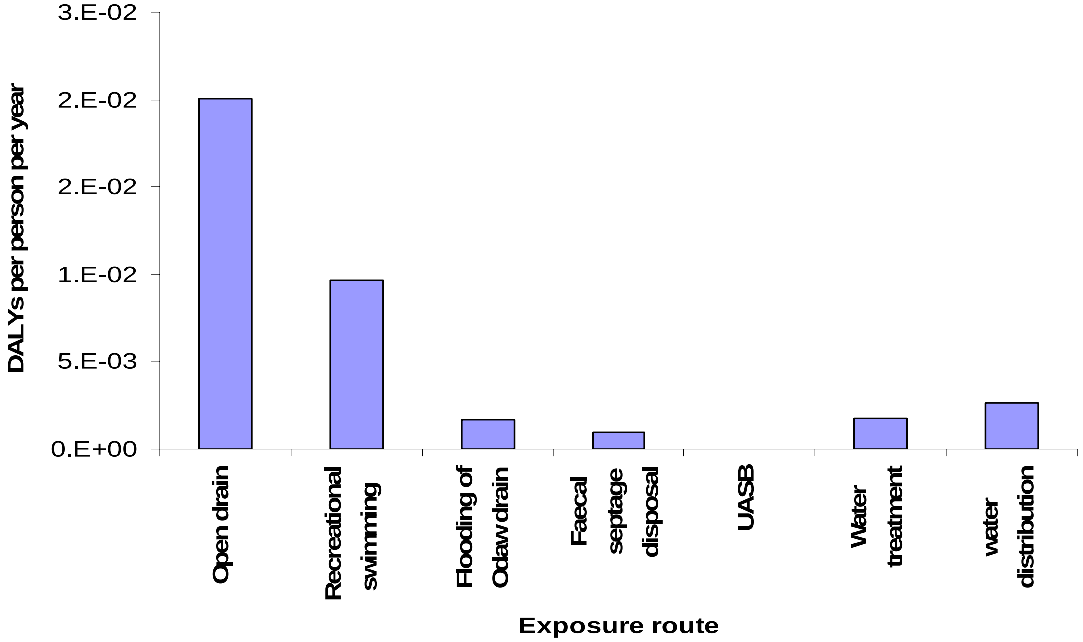

Figure 4-6.: Number of DALYs per person per year from sanitation and water supply

4.2.7 Comparison of endemic incidence and risk assessment incidence

In order to assess the severity of the exposures routes, the estimated risk with the QMRA was compared to the endemic waterborne disease incidence. the incidence rate reported by Lunani (2007) was used; in order to consider all the diarrhoeal diseases due to *Salmonella*, beside fever typhoid, a rate of 28.3% was taking into account (Paniagua *et al.*, 2007) Considering the water supply and sanitation system, the open drain had the highest incidence with *Salmonella* (64 %.) followed by *Cryptosporidium* (41%). This was followed by the recreational swimming pathway. The contribution of water supply to the incidence to the waterborne disease was low (table 4.26).

Table 4-26: Incidence per 10.000 from risk assessment and percentage contribution to the endemic waterborne disease incidence

Exposure	*Campylobacter*	*Salmonella*	*Rotavirus*	*Cryptosporidium*	*Ascaris*
Sanitation					
Open drain	92 (24)	351 (64)	47 (5)	38 (41)	11 (5)
Recreational swimming	97 (25)	303 (55)	25 (2.64)	4 (4.8)	0 (1.0)
Flooding of Odaw drain	0.2 (0.06)	0 (0)	4.4 (0.4)	0 (0.05)	3 (4.3)
Faecal septage disposal	5 (1)	18 (0.04)	3 (0.28)	2 (2.36)	10 (1.3)
UASB	0 (0.01)	0.2 (0.)	0 (0)	0 (0.05)	0 (0.03)
Water supply					
Water treatment	0.1 (0.02)	0.3 (0.06)	4.8 (0.51)	0.1 (0.15)	0
water distribution	0.4 (0.09)	1.4 (0.2)	7 (0.75)	0 (0.03)	0

The first value in each column is the risk assessment incidence per 10,000 population. The second value (in parentheses) s the percent contribution of each pathway to the background endemic waterborne disease incidence of Odaw catchments

Table 4-27: Ranking of severity of each pathway

Exposure	*Campylobacter*	*Salmonella*	*Rotavirus*	*Cryptosporidium*	*Ascaris*
Sanitation					
Open drain	Catastrophic	Catastrophic	Minor	Catastrophic	Minor
Recreational swimming	catastrophic	Catastrophic	Insignificant	Insignificant	Insignificant
Flooding of Odaw drain	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
Faecal septage disposal	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
UASB	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
Water supply					
Water treatment	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
water distribution	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant

From table 4.26, the ranking of severity was defined and most of the pathogens (*Campylobacter, Salmonella, Rotavirus and Cryptosporidium*) appeared catastrophic at the open drain. Therefore, the consequence of this pathway is major on the whole AWUS. Secondly, the recreational swimming was catastrophic with *Salmonella*. These both pathways belong to the sanitation system. In conclusion, the sanitation pathway had a significant impact on water borne disease transmission. The most hazardous pathway was the open drain and followed by recreational swimming

4.2.8 Prioritization of the exposure pathways using DALY's

The figure below showed the contribution of each pathway to the total DALY'S. the highest DALYs was noticed at the open drain with the contribution of 55% to the total DALYs. This was followed by the recreational swimming pathway. Therefore, the priority of the further interventions should address particularly these exposure routes.

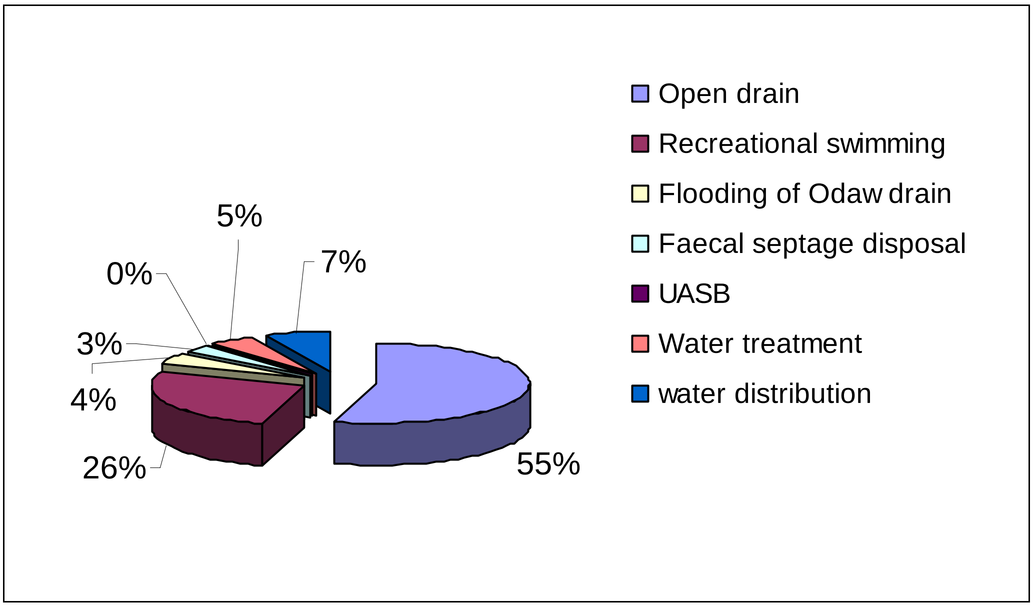

Figure 4-7: Contribution of each exposure pathway to the total disease burden disease from water supply and sanitation

This prioritization of the exposure pathways differed slightly to those suggested by Lunani (2007) who suggested the recreational swimming as first priority and followed by the open drain; however, in her study, the difference in term of disease contribution between these two pathways was less than 1%. The difference between both studies could be explained by these reasons:
-the difference of factor100 for the values used for the concentration of pathogens at the open drain
-the variability of pathogens; in this risk assessment, *Campylobacter*, *Ascaris* were not taking in to account at the recreational swimming because these organisms were not detected during the assessment.

4.3 Health benefit assessment and costs

In this section, the costs and the effects of different options were assessed in order to guide the priority setting. This method was applied in Uganda (another developing country) to improve the performance of water supplies in relation to health effect (Howard et al., 2006).

The assessment of health risk related to Accra urban water supply showed that, the main hazardous pathways were the open drain and the beach. Due to the lack of resource in developing countries, WHO suggested to implement the interventions options that are low cost, feasible and do not require heavy maintenance (WHO, 2005, cited Paterson *et al,* 2006). A Range of options is available to improve the sanitation system in Accra. Five options were investigated:

4.3.1 List of suggested options

The suggested option was based of the report of Accra sewerage improvement project initiated by the Government of Ghana in 1996 (ASIP, 2005) in order to address the problem of sanitation. In this study, some of options mentioned in that project will be investigated with the cost benefit analysis

Option A: Separate Sewerage net work
In this type option, wastewater is carried by separated pipe. The main advantage is to avoid the problem of mixing of wastewater and storm water. The idea behind this approach is that the storm water could be discharged in the environment and the wastewater may be conveyed to the appropriate treatment plant before ending in the environment.

Option B: Sewage treatment plant

In the ASIP, waste stabilization was chosen as treatment plant due to its low cost and low level of maintenance compared to others technologies. Therefore, this option was selected as one possible option. This option ensures that the wastewater will be treated in appropriate way before ending in the environment.

Option C: Sewerage net work + treatment plant

This option ensures that the sewage effluent will be treated in appropriate way before ending in the environment.

Option D: coverage of the drain

There are many open channel drains in the city of Accra. The are built as side drain along the road. Few of them are covered. The type and size vary considerably from the house level to the main collector. The main purpose of these drains is to collect storm water. However, in Accra, grey water is also diverted into the open drains and sometimes people dump garbage inside them. The water in the drain flowed into Odaw river without any treatment and finally the latter ends up in the ocean. For the health purpose, a solution could be to cover them in order to reduce the exposure of people especially children.

Option E: improve water supply system

The assessment of water supply system showed that the failure in the treatment or distribution process affected the drinking water quality. A decision could be for example to invest in the improvement of the drinking water quality.

4.3.2 Cost estimated for listed options

As described previously (in section 3.8), due to the lack and the fluctuation of financial value, a qualitative description was made in order to estimate the cost. According to the cost description in the Accra sewerage improvement project, the sewerage network and the sewage treatment plant had the same cost. Based on this, each option was given economic scores (table 4.28). The option F had the lowest score. This was because the problem identified during water risk assessment was not related to the upgrading of the plant but to failure process during treatment and distribution of drinking water system. A highest score were affected to the options C. the cost of drain coverage was assumed to be less than option A or B.

Table 4-28: Details for scoring

Options	Scores per unit cost
A: Sewerage net work	2
B: sewage treatment plant	2
C: Sewerage net work + treatment plant	4
D: coverage of the drain	1.6
E : improve water supply system	0.7

4.3.3 Estimation of DALYs for suggested option

The DALYs of suggested options were calculated based on the baseline condition. For each option, a percentage was applied to all exposure routes in comparison to the baseline. The lower is the percentage the lower will be the DALYs and consequently lower the health risk. Therefore, the DALYs of each options was calculated (4.29).

Table 4-29: DALYs per each available option [a]

Exposure routes	DALYs per year (Baseline)	Options				
		A	B	C	D	E
Open drain	19 955	(5) 998	(100) 19 955	(3) 597	(8) 1596	(100) 19 954
Recreational swimming	9 626	(100) 9626	(1) 96	(1) 96	(100) 9626	(100) 9626
Flooding of Odaw drain	16 334	(10) 163	(100) 1634	(8) 130	(2) 33	(100) 1634
Faecal septage disposal	989	(50) 494	(1) 10	(0) 0	(100) 988	(100) 988
UASB	10	(100) 10	(5) 0.5	(97) 10	(100) 10	(100) 10
Sanitation	32 214	11 291	21 695	835	12 254	32 213
Water treatment	1762	(95) 1673	(80) 1, 409	(75) 1, 321	(100) 1762	(10) 176
Water distribution	2588	(95) 2458	(80) 2, 070	(75) 1, 950	(100) 2588	(10) 258
Water supply	4350	4132	3, 450	3, 262	4350	435
Total	36 563	15 424	25, 175	4, 097	16 604	32 648

[a] The first value in bracket is the number of DALYs as a percentage of the baseline estimate; the second value (without bracket) is the expected number of DALYs per year with the implementation of each option

4.3.4 Health effectiveness per intervention

1. **DALYs averted**

In order to estimate the DALYs adverted during the implementation of the various interventions, The DALYs of each option was compared to the baseline condition. The option (E) related to water supply had the lowest impact on the health risk (figure 4.8).

The highest risk reduction occurred with the option C. Therefore, the option related to sewerage network associated to sewage treatment plant would have a big impact in the health status improvement in Accra urban system. However, this could be achieved only if there are sufficient financial resources to implement this option. The DALYs averted with the options A and C was great than the option B. So the option related to sewerage treatment plant alone showed less impact.

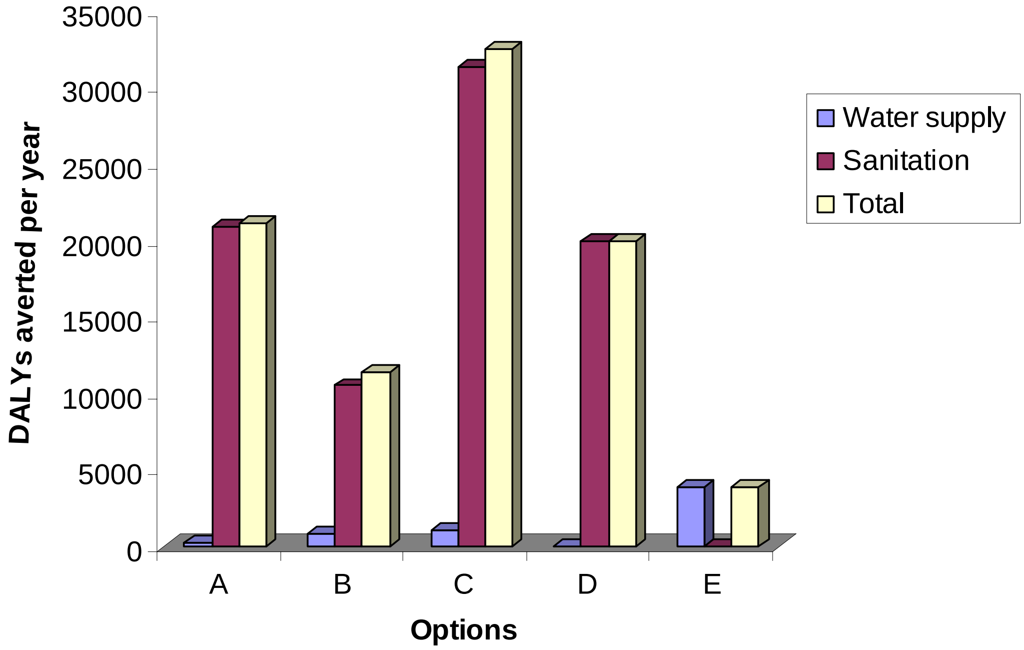

Figure 4-8: DALYs averted per option in Accra water urban system

2. **Ratio DALYs averted per unit cost**

Taking into account the financial issue , the DALYs averted per unit cost was calculated (table 4.30). The option D related to the coverage of the drain seems more economically feasible and had the highest DALYs averted per year per unit cost. This was followed by the option A with sewerage network. The intervention related to waste water plant had less impact compared to sewerage system. This result showed that in order to improve the health risk related water urban system; the priority should be given to the sewerage system.

Table 4-30: DALYs averted per year per unit cost for water supply and sanitation of Accra urban water system

List of Options	A	B	C	D	E
Open drain	9, 478	0	4, 839	11, 474	0
Recreational swimming	0	4, 765	2, 382	0	0
Flooding of Odaw drain	735	0	375	1, 000	0
Faecal septage disposal	247	489	247	0	0
UASB	0	5	0	0	0
Sanitation	10, 460	5, 259	7, 844	12, 475	0
Water distribution	44	176	110	0	2, 265
Water treatment	65	259	161	0	3, 327
Water supply	108	435	272	0	5, 593
Total	**10, 569**	5, 694	8, 116	**12, 475**	5, 592

4.3.5 QMRA and risk characterization with interval estimates

The aim of interval estimate is provide to provide a range a distribution by taking into account the variability (Haas, 1999). The model used was 1000 simulations of Monte Carlo techniques with excel spreadsheet. As illustration in this study, interval estimates method was applied to tree pathways: recreational swimming, sand and open drain

1. **Exposure assessment**

In order to perform interval estimates for these parameters, some assumptions were made; the distribution was assumed linear for all the parameters; the lower limit and upper limit were assumed 10% of the baseline value used in the previous risk characterization (table 4.31 and 4.32). However for parameter (r) describing the Helminth risk, the extreme value was chosen (1); therefore the interval estimate was defined from 0 to 1 .

Table 4-31: Parameters describing the risk

Parameters	Point estimates	Range of values	
		lower limit	upper limit
Conversion factor *E coli/* pathogens	0.00001	0.000001	0.0001
Conversion factor *Salmonella / Campylobacter*	1	0.9	1.1
N50*campylobacyer*	896	806.4	985.6
Alpha *campylobacter*	0.145	0.1305	0.1595
N50 *Rotavirus*	6.1	5.553	6.787
alhpa *Rotavirus*	0.2531	0.22779	0.27841
N50 *Salmonella*	23600	21240	25960
alhpa *Salmonella*	0.0313	0.2817	0.3443
r *cryptosporidium*	0.00419	0.003771	0.004609
r Helminth	1	0	1
P_{DI}		0	1

Table 4-32: determination of frequency, volume ingested, population exposed and concentration of organisms

Exposure routes	Parameters	point estimate	Range of values	
			lower limit	upper limit
Recreational swimming	Volume ingested	70	50	100
	Frequency	2	1	6
	E coli	1666	0	5000
	population exposed	298608	250000	3500000
Beach sand	Volume ingested	5	1	6
	Frequency	2	1	3
	Ecoli	1470000	315000	3600000
	salmonella	910500	135000	2376000
Open drain	Volume ingested	5	3	6
	frequency	2	2	7
	E coli	122083333.3	0	560000000
	Salmonella	42638888.89	0	175000000
	Helminth	0.77	0	3

2. Risk characterization

Comparing with point estimate method, the number of infections and cases due to *Campylobacter, Salmonella, Rotavirus and Ascaris* were within the same magnitude (table 4.20 and 4.33, table 4.24 and 4.34). For *Cryptosporidum*, the median risk was high compared to point estimate method; there was a difference factor range to 10 to 1000. This is an illustration of the point estimate method, which may over or underestimated the risk.

Table 4-33: Median number of infection per single exposure

Exposures	*Campylobacter*	*Salmonella*	*Rotavirus*	*Cryptosporidum*	*Ascaris*
seawater	*	*	2,798 (87-9,937)	614 19-2,052	*
sand	87, 644 (65,137-102,517)	97,483 (84,172-108,025)	96,052 (81,604-107,426)	97,472 (60,757-108,567)	*
open drain	52,397 (47,585-57,539)	52,404 (47,632-57,571)	52,182 (47,144-57,538)	50,800 (13,799.-7,467)	4,824 (120-23,657)

The number in brackets represents 95% confidence interval. *the measured concentration of Salmonella, and helminth were zero during the measurement

Table 4-34: Median number of yearly infection per single exposure

Exposures	*Campylobacter*	*Salmonella*	*Rotavirus*	*Cryptosoridum*	*Ascaris*
seawater	*	*	67 (2-415)	67. (2-415)	*
sand	52, 000 (2, 700-100, 000)	64, 000 (3, 461-102,45)	64, 000 (3, 200-10, 000)	64, 000 (3, 583-103, 434)	*
open drain	45, 782 (3, 763-56, 635)	46, 270 (4, 000-56, 667)	44, 803 (3, 514-56, 560)	41, 000 (1, 687-56, 284)	2015.324 (25.54243-15634.31)

The number in brackets represents 95% confidence interval. *the measured concentration of Salmonella, and Helminth were zero during the measurement

4.4 Using QMRA for planning investment

The QMRA was applied to Accra urban water system in order to assess the health and define some major intervention. In order to carry on the procedure of QMRA, the microbial concentration was assessed at some major pathways of AWUS: open drain, seawater and sand.

The measured concentration at all the sites showed a high value of *Escherichia coli* ; it is a similar situation for *Salmonella;* however *Salamonella* was not detecting in seawater. In Accra less than 13% are connected to sewerage system (Ghana statistical service 2002). More than 50% of household disposed their liquid in the gutters. Therefore, the value of indicators found was not surprising. However, there are some limitations in this measurement. for the open drain assessment this study was carried during dry period on area with high density population. it was expected that the concentration should be low in area with low population density. Another limitation was the number of samples.

Knowing the concentration of indicators at some pathways, the risk calculation was done. One of the major problems in QMRA assessment is the lack of data; in this study, it was assumed that the concentration of pathogen at open drain, faecal septage and UASB plant are the same. The ratio *E. coli* / pathogens were used to estimate the concentration of pathogen at some exposure routes. This may under or overestimate the risk. This ratio may vary due to the changes in environmental conditions; Cowel (1978) reported that a variety of organism appears in specific ecosystem due to the change of environmental condition. however at least this provide a first information to assess the health risk. the method used for risk assessment was point estimates risks. The greatest risk was noticed at the open drain; this was followed by the recreational water.

From the risk assessment, it appeared that there is a serious need to address the sanitation issue in Ghana especially in Accra. The following showed as example how health benefit could be used for decision-making. The cost was based on the cost estimation in Accra Sewerage project (ASIP, 2005). The option related to sewerage network associated to waste water treatment is an ideal solution; the implementation of this option would reduce significantly the diseases; however, it is very costly policy. In addition, the decision to improve the sewerage network alone or to build only a waste treatment plant would not give entire satisfaction. Even if the sewerage would be improved, it is necessary to treat the sewage before ending it into the environment. In the same way, the existence of wastewater treatment plant alone do not reduce the exposure at others pathway like the open drain.

In this model, the option related to coverage of the drain seems more the most effective in risk reduction due to the low investment. Therefore the decision makers could apply this intervention. The health benefit of this intervention was followed closely by the one related to separate network. So this intervention should be considered also. For the future planning for new area, it is cardinal to consider at the beginning the sewerage network due to his high health benefit.

However, this assessment should be treated with cautions; the only criterion under consideration was the risk reduction due to the exposition to wastewater. This cost calculation did not consider some constraints like cost recovery mechanism, public participation, maintenance of the system, lifetime.

All this constraints are necessary to ensure the sustainability of the interventions with the implication of all stakeholders; according to Carter et al (1999) in any intervention related water supply and sanitation, a chain of four essential links should involve and the failure: motivation, maintenance, cost recovery and continuously support. The involvement of all stakeholders is a prerequisite to achieve the improvement of water urban system. As an illustration with the implementation of the participatory approach in the Malawi rural piped scheme program, the smallest schemes were performing well after 26 years of completion (Kleemeier, 2000).

Finally, it appeared that a suitable allocation of resources based on cost benefit analysis with the sustainability approach would help to reduce the burden of disease due to water and supply in Accra water urban system. Furthermore, this may help to achieve the MDGs. According to WHO (2004), the achievement of the global MDG target in water and sanitation would bring substantial economic gains from both health and other benefits: each US$1 invested would yield an economic return of $3 and 34$ depending on region.

4.5 Uncertainties

The findings of this study should be used with cautions. Due to lack of data, besides primary data some secondary data were collected during the risk assessment; this could generated some uncertainties, which were listed below:

The method used for risk characterization was one of the weaknesses of this study. The approach related point estimate method does not consider the variability and uncertainty of the parameters;

1) The number of sample at the open drain (38), recreational swimming (6) may not be sufficient to assess the concentration of pathogens.

2) During the concentration measurement, the effect of rain was not taking account; this may increase the health risk at some exposures routes.

3) The concentration of pathogens may be under or over estimated because the same ratio *E. coli* / pathogen was used at all exposure routes.

4) The risk calculation of water supply was based on the data reported by Lunani (2007)

5) The concentration of pathogens at open drain, faecal septage, UASB was assumed to be the same

6) Secondary data were used to assess the risk due to water supply; this may under or overestimate the risk.

7) The method used to estimate (point estimate) do not consider variability and uncertainty;

8) The cost calculation was limited only to the contact waste water exposed population;

5 Conclusions and recommendations

5.1 Conclusions

The general observation from the literature is that, due to the rapid growth of the population, cities are under pressure and the health of citizens is compromise. The key challenge for decision makers is to have access to useful tools like quantitative risk assessment in order to identify the threat of health citizen and to decide where to invest. The outputs of this study are:

- The total disease burden of Accra urban water system was 37, 000 and the contribution of sanitation is about 88%. The DALYs pppy was $5*10^{-3}$ pppy, which was above the WHO reference value (10^{-6}). The most hazardous was the open drain with the contribution of 55% of total burden disease

- The most hazardous pathway are the exposure routes related to open drain and recreational swimming

- The health benefit tool was applied to Accra urban water system. The intervention related to water supply had less impact in the risk reductions in Accra water urban system. so the decision maker knows in which sector to invest to improve health risk

- Among the options listed, the separate sewerage system associated to sewerage treatment plant had the highest risk reduction. This option would advert more than 87 % DALY s per year in the Accra urban system. However if financial aspect is taking into account, the most effective option is to cover the drain. in new area the option related to sewerage network associated to waste water treatment plant could be implemented.

5.2 Recommendations

The following recommendations are made from this study:

- It is suggested to decision maker to select in priority the intervention related to sanitation for improvement of health status in urban water system; the study described the risk reduction for each option. With limited budget, decision maker able to decide.

- The problem of sanitation is not related to technology; therefore all stakeholders should involve in priority setting

For further studies, it is suggested to:

1) Assess the pathogen concentration at the open drain at low-density area; this should include dry and rain period.

2) Continue the assessment of microbial concentration at the beach include the sand;

3) Feasibility of urine and feces recovering in order to take advantage of the economies of scale and to avoid the cost related to the treatment.

4) Improvement of risk assessment related to water supply

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Appendix

Appendix A: survey question

No:
Sex:
Age (Optional):

Where are you leaving in Accra? :

How often do you come to the beach in the year?
1-less than 5 ☐ **2-less than 10** ☐

3- less than 15 ☐ **5-More than 15** ☐

Are you in contact with sea water?
No ☐

Yes ☐ **how?: swimming** ☐ **playing in the sand** ☐ **walking in** ☐ **water**

Appendix B: Microbial assessment

Table 0-1: Log CFU/ 100 ml of bacteria: open drain

Dates	Location	Period	Sites	logEc	logtc	logsal	logother
08/01/2008	Nima	Morning	1	8.1	9.0	7.5	8.4
11/11/2008	Nima	Morning	1	8.1	9.3	0	8.1
16/01/08	Nima	Morning	1	8.3	9.0	7.8	8.8
08/01/2008	Nima	Morning	2	6.7	8.6	0	8.2
11/11/2008	Nima	Morning	2	0	7.2	0	7.6
16/01/08	Nima	Morning	2	7.0	9.2	0	9.1
08/01/2008	Nima	Morning	3	7.7	8.8	0	8.4
11/11/2008	Nima	Morning	3	8.2	9.0	0	8.4
16/01/08	Nima	Morning	3	8.0	9.1	7.5	8.8
08/01/2008	Nima	Afternoon	1	8.2	9.0	0	8.3
11/11/2008	Nima	Afternoon	1	0	8.6	0	8.4
16/01/08	Nima	Afternoon	1	7.8	8.6	6.7	8.7
08/01/2008	Nima	Afternoon	2	7.3	8.7	7.5	8.2
11/11/2008	Nima	Afternoon	2	0	8.6	0	8.3
16/01/08	Nima	Afternoon	2	0	8.2	0	8.5
08/01/2008	Nima	Afternoon	3	8.1	8.9	8.2	8.3
11/11/2008	Nima	Afternoon	3		8.5	0	7.9
16/01/08	Nima	Afternoon	3	7.3	8.7	0	8.7
08/01/2008	James Town	Morning	1	8.0	9.0	8.0	8.0
11/11/2008	James Town	Morning	1	8.3	9.1	0	8.5
16/01/08	James Town	Morning	1	7.7	9.3	7.6	9.0
08/01/2008	James Town	Morning	2	8.3	9.1	0	8.4
11/11/2008	James Town	Morning	2	8.6	9.1	8.2	8.8
16/01/08	James Town	Morning	2	8.2	9.1	8.2	9.0
08/01/2008	James Town	Morning	3	8.3	8.9	7.5	8.6
11/11/2008	James Town	Morning	3	0	8.0	0	8.0
16/01/08	James Town	Morning	3	8.0	9.1	8.1	9.0
08/01/2008	James Town	Afternoon	1	8.3	9.1	7.5	8.4
11/11/2008	James Town	Afternoon	1	8.4	9.3	8.2	8.5
16/01/08	James Town	Afternoon	1	8.3	8.8	7.2	8.3

08/01/2008	James Town	Afternoon	2	8.0	9.0	7.2	8.3
11/11/2008	James Town	Afternoon	2	8.1	9.0	8.0	8.3
16/01/08	James Town	Afternoon	2	8.1	9.0	7.9	8.3
08/01/2008	James Town	Afternoon	3	8.3	9.1	7.7	8.2
11/11/2008	James Town	Afternoon	3	7.9	8.8	7.8	7.8
16/01/08	James Town	Afternoon	3	8.7	9.0	7.8	8.5

Ec= *Escherichia coli*; tc= total coliform; other= others enterobacteriacea
Sal= *Salmonella*

Table 0-2: Helminth eggs count at the open drain

Dates	Location	Period	Sites	logec	logtc	logsal	logother	Helminths
08/01/2008	Nima	Morning	1	8.1	9.0	7.5	8.4	0
11/11/2008	Nima	Morning	1	8.1	9.3	0	8.1	0
16/01/08	Nima	Morning	1	8.3	9.0	7.8	8.8	0
08/01/2008	Nima	Morning	2	6.7	8.6	0	8.2	1
11/11/2008	Nima	Morning	2	0	7.2	0	7.6	0
16/01/08	Nima	Morning	2	7.0	9.2	0	9.1	1
08/01/2008	Nima	Morning	3	7.7	8.8	0	8.4	0
11/11/2008	Nima	Morning	3	8.2	9.0	0	8.4	0
16/01/08	Nima	Morning	3	8.0	9.1	7.5	8.8	2
08/01/2008	Nima	Afternoon	1	8.2	9.0	0	8.3	0
11/11/2008	Nima	Afternoon	1	0	8.6	0	8.4	1
16/01/08	Nima	Afternoon	1	7.8	8.6	6.7	8.7	0
08/01/2008	Nima	Afternoon	2	7.3	8.7	7.5	8.2	2
11/11/2008	Nima	Afternoon	2	0	8.6	0	8.3	0
16/01/08	Nima	Afternoon	2	0	8.2	0	8.5	1
08/01/2008	Nima	Afternoon	3	8.1	8.9	8.2	8.3	0
11/11/2008	Nima	Afternoon	3		8.5	0	7.9	0
16/01/08	Nima	Afternoon	3	7.3	8.7	0	8.7	0
08/01/2008	James Town	Morning	1	8.0	9.0	8.0	8.0	0
11/11/2008	James Town	Morning	1	8.3	9.1	0	8.5	0
16/01/08	James Town	Morning	1	7.7	9.3	7.6	9.0	3
08/01/2008	James Town	Morning	2	8.3	9.1	0	8.4	1
11/11/2008	James	Morning	2	8.6	9.1	8.2	8.8	3

	Town							
16/01/08	James Town	Morning	2	8.2	9.1	8.2	9.0	2
08/01/2008	James Town	Morning	3	8.3	8.9	7.5	8.6	0
11/11/2008	James Town	Morning	3	0	8.0	0	8.0	0
16/01/08	James Town	Morning	3	8.0	9.1	8.1	9.0	0
08/01/2008	James Town	Afternoon	1	8.3	9.1	7.5	8.4	0
11/11/2008	James Town	Afternoon	1	8.4	9.3	8.2	8.5	0
16/01/08	James Town	Afternoon	1	8.3	8.8	7.2	8.3	0

Table 0-3: Log CFU / 100 ml of bacteria: sand

Dates	**Sites**	**E. coli**	***Total Coliform***	**Salmonella**	**Others Enterobacters**	**Helminths**
20/01/2008	Independence square	6.0	7.3	5.4	7.3	0
22/01/2008	Independence square	6.6	7.0	4.8	6.8	0
24/01/2008	Independence square	6.0	6.3	4.4	6.3	0
20/01/2008	Lapalm	6.3	7.3	5.3	7.2	0
22/01/2008	Lapalm	5.5	6.5	4.4	6.4	0
24/01/2008	Lapalm	6.0	6.4	4.1	6.1	0

Table 0-4: Log CFU / 100 ml of bacteria seawater

Dates	**Sites**	**E. coli**	***Total Coliform***	**Salmonella**	**Others Enterobacters**	**Helminths**
20/01/2008	Independence square	0	4.3	0	5.7	0
22/01/2008	Independence square	0	3.7	0	4.2	0
24/01/2008	Independence square	0	0	0	5.9	0
20/01/2008	Lapalm	3.7	4.6	0	5.6	0
22/01/2008	Lapalm	0	3.7	0	4.5	0
24/01/2008	Lapalm	3.7	4.3	0	5.4	0

Appendix C: Selected statistical result

I-Descriptive statistic

Table 0-5 : descriptive statistics: Open drain

	N	Minimum	Maximum	Mean	Std. Deviation
logecoli	30	6.70	8.75	8.0096	.44714
logtc	36	7.18	9.30	8.8555	.40925
logsalom	21	6.70	8.24	7.7256	.39739
logenter	36	7.60	9.11	8.4158	.34359
Valid N (listwise)	21				

Table 0-6 : descriptive statistics: Seawater

	N	Minimum	Maximum	Mean	Std. Deviation
LOGE_COL	2	3.70	3.70	3.6990	.0000
LOGTC	5	3.70	4.60	4.1204	.4039
LOGENTER	6	4.18	5.92	5.2281	.7013
Valid N (listwise)	2				

Table 0-7: Descriptive Statistics: Beach sand

	N	Minimum	Maximum	Mean	Std. Deviation
logec	6	5.50	6.56	6.0513	.35792
logtc	6	6.33	7.26	6.7860	.44410
logsl	6	5.13	6.38	5.7320	.50138
logother	6	5.13	6.38	5.7320	.50138
Valid N (listwise)	6				

II-Are they any significant difference between the morning and afternoon sampling of the open drain?

Table 0-8: Kruskal wallis test

Locations		E._COLI	Total coliform	Salmonella	Others Enterobacters
Nima	Chi-Square	1.795	4.306	.011	.384
	df	1	1	1	1
	Asymp. Sig.	.180	.038	.916	.535
James Town	Chi-Square	1.319	.860	.096	3.619
	df	1	1	1	1
	Asymp. Sig.	.251	.354	.756	.057

a Kruskal Wallis Test
b Grouping Variable: PERIOD

III-Pearson correlation test

Table 0-9: Correlations: drain

		LOGECOLI	LOGTC	LOGSALOM	LOGENTER
LOGECOLI	Pearson Correlation	1.000	.465(**)	.311	-.080
	Sig. (2-tailed)	.	.010	.170	.674
	N	30	30	21	30
LOGTC	Pearson Correlation	.465(**)	1.000	.576(**)	.546(**)
	Sig. (2-tailed)	.010	.	.006	.001
	N	30	36	21	36
LOGSALOM	Pearson Correlation	.311	.576(**)	1.000	.107
	Sig. (2-tailed)	.170	.006	.	.646
	N	21	21	21	21
LOGENTER	Pearson Correlation	-.080	.546(**)	.107	1.000
	Sig. (2-tailed)	.674	.001	.646	.
	N	30	36	21	36

** Correlation is significant at the 0.01 level (2-tailed)

Table 0-10: Correlations: seawater

		LOGECOLI	LOGETOTC	LOGSALMO	LOGENTOR
LOGECOLI	Pearson Correlation	1.000	.582	.435	.456
	Sig. (2-tailed)	.	.225	.388	.363
	N	6	6	6	6
LOGETOTC	Pearson Correlation	.582	1.000	.947	.978
	Sig. (2-tailed)	.225	.	.004	.001
	N	6	6	6	6
LOGSALMO	Pearson Correlation	.435	.947	1.000	.991
	Sig. (2-tailed)	.388	.004	.	.000
	N	6	6	6	6
LOGENTOR	Pearson Correlation	.456	.978	.991	1.000
	Sig. (2-tailed)	.363	.001	.000	.
	N	6	6	6	6

Table 0-11: Correlation sand

		logec	logtc	logsl	logother
logec	Pearson Correlation	1	.582	.435	.435
	Sig. (2-tailed)		.225	.388	.388
	N	6	6	6	6
logtc	Pearson Correlation	.582	1	.947(**)	.947(**)
	Sig. (2-tailed)	.225		.004	.004
	N	6	6	6	6
logsl	Pearson Correlation	.435	.947(**)	1	1.000(**)
	Sig. (2-tailed)	.388	.004		.000
	N	6	6	6	6
logother	Pearson Correlation	.435	.947(**)	1.000(**)	1
	Sig. (2-tailed)	.388	.004	.000	
	N	6	6	6	6

** Correlation is significant at the 0.01 level (2-tailed)

Appendix D: Risk assessment sanitation: system

Table 0-12: Parameters used for flooding of the drain

Exposure routes	Volume ingested (ml) [a]	Frequency (year)	Affected[b] population	Sources
Untentional ingestion of flood water	1	1	111790	[a] Westrell et al, 2004
Unintentional immersion at lagoon	30	1	10	[b]Ghana statistical service
Children playing in flood water	1	1	23699	

Table 0-13: Parameters used at the UASB treatment plant

Exposure routes	Volume ingested (ml) [a]	Frequency (year)	Affected[b] population	Sources
Workers dessludging the UASB treatment plant nonthly	5	12	10	[a] Westrell et al, 2004
Workers removing debris from the inlet works daily during the rainy season	1	90	10	[b]Ghana statistical service
Workers taking samples from the inlet works for laboratory analysis	0.1	1	10	23

Appendix E: Risk assessment: water supply

Table 0-14: data used for exposure assessment of water supply system of Accra

Exposure	Volume ingested(l)	Concentrations in drinking water (CFU/l)	Concentration of *E. coli*	Population exposed	Frequency
Power outage at Weija treatment plant	2.9	7.5 *10-4	7.6*10-6	646986	3.61
Filtration error at Weija treatment plant		2.4 *10-8	7.0 *10-8		1
Disinfection error at Kpong treatment plant		6.1 *10-7	1.8 *10-6	348378	365
Coagulation error at Kpong treatment plant		6.1 *10-7	1.8 *10-6		365
Filtration error at Kpong treatment plant		6.1*10-6	1.8*10-5		365
Contaminated distribution system		2.3*10-5	6.7*10-5	944678	146
Pollution entering part of system with low pressure (108 hours per week)		2.4 *10-8	3.5*10-5	298609	234
entering part of system with low pressure (120 hours per week)		6.1 *10-7	3.8*10-5	348378	260

Source: Lunani, 2007

Table 0-15: Risk calculation

Exposure	Probability of infection per single exposure			Annual probability of infection			Annual infections from each exposure point		
	Campy	*Rot*	*Crypto*	*Campy*	*Rot*	*Crypto*	*Campy*	*Rot*	*Crypto*
Power outage at Weija treatment plant	4.16E-05	0.002055	9.11E-07	0.00015	8.55E-08	3.28E-06	96.83453	0.055324	2.122609
Filtration error at Weija treatment plant	1.33E-09	3.79E-06	1.82E-07	1.33E-09	3.79E-06	1.82E-07	0.000861	2.449403	0.117923
Disinfection error at Kpong treatment plant	3.38E-08	2.24E-06	9.23E-09	1.23E-05	0.000816	3.37E-06	4.30068	284.3508	1.174271
Coagulation at Kpong treatment plant	3.38E-08	2.24E-06	9.23E-09	1.23E-05	0.000816	3.37E-06	4.30068	284.3508	1.174271
Filtration error at Kpong treatment plant	3.38E-07	7.23E-05	2.92E-07	4.94E-05	0.010495	4.26E-05	17.20238	3656.357	14.83261
Contamined distribution system	1.28E-06	3.96E-05	2.79E-08	0.000186	0.005762	4.08E-06	175.8687	5442.81	3.854567
Pollution entering part of system without pressure (108 hours per week)	1.91E-06	4.69E-05	1.55E-10	0.000447	0.010909	3.63E-08	133.5633	3257.428	0.010833
Pollution entering part of system without pressure (120 hours per week)	1.91E-06	4.98E-05	1.68E-10	0.000497	0.012875	4.36E-08	173.1337	4485.372	0.015181

Source:Lunani, 2007

Appendix F: Monte Carlo analysis

Table 0-16: median risk of infection per single exposure

Exposures	*Campylobacter*	*Salmonella*	*Rotavirus*	*Cryptosporidum*	*Ascaris*
seawater	*	*	0.005 (0.0003-0.014)	0.001 (0-0.003)	*
Sand	0.676 (0.578-0.729)	0.892 (0.798-0.930)	0.854 (0.768-0.896)	0.972 (0.456-1)	*
open drain	0.845 (0.775-0.878)	0.89285 (0.732-0.924)	0.828 0.593-0.888	0.858 (0.058-1)	0.024 (0-0.102)

The number in brackets represents 95% confidence interval. *the measured concentration of Salmonella, and helminth were zero during the measurement

Table 0-17: Median risk of yearly infection per single exposure

Exposures	*Campylobacter*	*Salmonella*	*Rotavirus*	*Cryptosoporidum*	*Ascaris*
seawater	*	*	0.01 (0-0.031)	0.002 (0.0001-(0.006)	*
sand	0.887 (0.664-0.969)	0.892 (0.797-0.930)	0.854 (0.768-0.896)	0.972 (0.456-1)	*
open drain	0.999 (0.977-1)	1 0.983-1	1 0.951-1	0.857 0.058-1	0.1 (0.002-0.430)

The number in brackets represents 95% confidence interval. *the measured concentration of Salmonella, and helminth were zero during the measurement