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Application of QMRA for analyzing public health risk from drinking water supply in a low income area in Accra, Ghana

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SWITCH

Application of QMRA for analyzing public health risk from drinking water supply in a low income area in Accra, Ghana

Master of Science Thesis

by

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Dedicated to my mother, Farida
and
memory of my father, Machdar

Abstract

Accra is capital city of Ghana and it has high urbanization rates. The expansions not only affect city planning but also the urban water system. Majority of inhabitants are living in over-crowded areas with poor water quality and irregular piped water flows. The aim of this study was to assess the risk from microbial agents that people living in densely populated areas encounter from domestic drinking water supply in order to reduce the burden of disease via recommended interventions.

Three months field work was conducted to meet the objective. One hundred and ten families responded to the questionnaires which represented 4121 persons. Five pathways were identified namely household storage, private yard taps, public taps, wells and water sachets. Membrane filtration was used to enumerate the *coliform* bacteria group and for other pathogens the ratio between *E. coli* concentration and pathogens was used. After the pathogenic agents had been identified, the assessment continued for microbial risk by using dose response equations. There were two models that were applied in this equation. Beta poisson was used to estimate bacterial and viral risk while the exponential model was more suitable for protozoa and helminth related risk.

The highest re-contaminated water was found from family storage where 74% of the water samples had *E.coli* presence and the mean concentration was 13 cfu/ 100ml. By the use of dose response equation, annual symptomatic cases per pathogens were calculated. The greatest annual symptomatic case was estimated as 47,563 cases from *Campylobacter, E.coli* had 41,860 symptomatic cases per year, for *Ascaris* was 2,050 symptomatic cases annually, *Rotavirus* every year was estimated with 40.2 symptomatic cases, and the *Cryptosporidium* was estimated to have 0.36 symptomatic cases per year. From this dose response resulted, burden of disease could be calculated. The total burden of diseases from drinking water was 19,384 DALYs per year.

With the high estimated burden of diseases from drinking water, Hazard Analytical Critical Control Point (HACCP) was used to identify the critical points and ways to control it. Priorities to implement corrective action were identified from family storage due to develop the highest DALYs. Five single interventions were proposed, that are expansion of water system, leakage rehabilitation, increasing coverage of private taps connection into 100%, disinfection at point of use, hygiene promotion and multiple combinations of all. Cost effectiveness from these options was calculated by dividing the annual unit cost with DALYs averted per year. The most effective intervention was hygiene promotion with cost of USD 8 per DALYs averted while the least effective to averted DALYs was from combination of leakage rehabilitation with increasing the private connection into 100% coverage which estimated as costly as USD 3,047.

The finding from this study could be use by decision maker to make a sketch to reduce the burden of disease in low income area through the proposed options with further investigation.

Keywords: Burden of disease, cost effectiveness, critical control points, DALYs averted, diarrhoea, microbial risk assessment, waterborne disease.

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List of abbreviations

AMA : Accra Metropolitan Assembly
AVRL/GWCL: Aqua Vitens Rand Limited/ Ghana Water Company Limited
BD : Burden of Disease
CCP : Critical Control Point
CEA : Cost Effectiveness Analysis
CER : Cost Effectiveness Ratio
CFU : Colony Forming Units
DALY : Disability Adjusted Lost Year
HACCP : Hazard Analytical Control Point
IWMI : International Water Management Institute
MDG : Millennium Development Goals
MPN : Most Probable Number
NGO : Non Government Organization
PURC : Public Utilities and Regulatory Committee
Pppy : Per person per year
QMRA : Quantitative Microbial Risk Assessment
SODIS : Solar Disinfection
SWITCH : Sustainable Water management Improves Tomorrow's Cities' Health
UNDP : United Nations Development Programme
UNICEF : United Nations Children's Funds
USD : United States of America's Dollars
UV : Ultra Violet
WHO : World Health Organization

1. INTRODUCTION

1.1. General

Urban water system is an approach to integrate water supply, wastewater (including sludge) and drainage as one cycle in urban setting with aim to conserve the environment and human welfare. As defined by Larsen and Gujer (1997), services that should be provided within the system are:

1. Urban hygiene
2. Drinking water and personal hygiene
3. Prevention of flooding/draining in urban areas
4. Integration of urban agriculture into urban waste management
5. Providing water for pleasure and recreational aspect of urban culture

In developing countries, urban areas are expanding rapidly. This expansion not only effecting the city planning but also the urban water system in aspect of inadequate quantity of water supply, contaminated drinking water, lack or insufficient sanitation facilities and in overall ignorance/ irresponsibility of the people to save their environment. Consequently, human health and the environment as a whole were threatened.

Insufficient supply and low quality of water as well as lack of basic sanitation is claimed to be responsible for deaths of children under five in developing regions. UNICEF (2006) reported that annually, 1.5 million children under five years old died because of diarrhoea. Intervention in water, sanitation and hygiene sectors that reduce exposure to waterborne disease can contribute to reduction in these numbers.

Reducing child mortality and improvement of water and sanitation are two amongst Millennium Development Goals (MDG) target (target 4 and target 7). It is not easy for developing countries to reach these targets due to lack in financial, technical aspect and people awareness. Therefore, SWITCH project is interfering in urban water management to assisting countries to meet MDGs through a paradigm shift in urban water management system to be more sustainable, safe and healthy.

1.2. Problem Description

Accra Metropolitan Assembly (AMA) which is also known as city of Accra is the capital city of Ghana with total population 1,801,606 people with annual growth rate is 4.4% (Ghana district, 2009). This city is located under Greater Accra Region, which has been expanded because of urbanization and approximately covering area of 241 km^2.

The state of water and sanitation in Accra is poor. Clogging of drains because of disposed solid waste which leading to flooding in rainy days and lack of sanitation facilities, which is mainly an occurrence in high-populated areas. These are two amongst other current sanitation conditions in Accra that are jeopardizing not only the environment but also human health, especially children. With regard to potable water, GAMA has water supply from 2 waterworks, Weija and Kpong with actual capacity

169,987 m^3/day and 193,430 m^3/day respectively (SWITCH, 2009). From the same report, it was estimated that the water demand in 2007 was 479,478 m^3/day and predicted would reach 547,136 m^3/day in 2010. It is obvious that the current waterworks can not fulfil the demand and with physical loses up to 30%, lesser water delivered to the user.

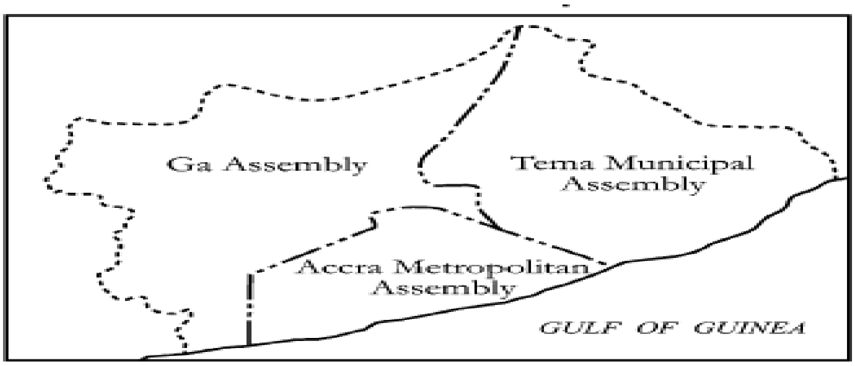

Figure 1 Map of Accra Metropolitan Assembly (AMA) within Greater Accra Region [source: Grant and Yankson, 2003)

Table below gives an overview of sources of domestic water. It shows that more than half of the population have pipe connection as either indoor pipe borne or private yard/neighbour tap. However, in reality, it was only 45% of inhabitants having that access and it flows infrequently whilst the remaining depends on other source such as water vendor (Abraham et al, 2007).

Table 1 Potable water source for households in Accra

Services/source	Percentage
Household indoor piping	50.8
Water vendor	5.8
Neighbour / private yard	37.8
Public standpipe	4.5
Borehole	0.1
Well	1.1
Natural sources	0.1
Total	100.0

[Source: UNDP, 2007]

Water from vendors is vulnerable to cross contamination due to unhygienic manner of handling and used of multiple containers from taps until it reached consumers. The quality of piped water also has been questioned because of failure during process, low pressure and leakage in distribution network, which could lead to contaminant intrusion into the system. And water quality from certain wells is also not safe to be consumed without any treatment. Consequently, by consuming this unsafe water, people jeopardized their health.

Therefore, to contribute to improvement of the quality of life of Accra's inhabitants and to achieve MDG's target, it is essential to conduct an assessment for microbial

condition in urban water system specifically in domestic potable water supply. Afterwards, feasible interventions will be recommended with consideration of cost effectiveness.

1.3. Objectives

General Objectives:
The aim of this study is to assess microbial risks that inhabitant of low income area in Accra encounter from domestic drinking water supply in order to reduce the burden of diseases through recommended interventions.

Specific Objectives:

1. To improve the existing risks assessment for domestic potable water supply and integrate with previous research from Labite (2008) an Lunani (2007)
2. To identify the critical control point (CCP) from various drinking water supply methods.
3. To forecast the impact of intervention to burden of disease, and to use it as recommendation for decision makers.
4. To estimate the cost effectiveness for controlling the hazard.

1.4. Research Question

1. What is the relative risk from the different potable water sources?
2. Does water handling practice from sources to point of use change the quality of water people consumed (using HACCP approach)?
3. What is the most efficient intervention for microbial reductions in drinking water supply that can decrease the public health risk and which is also affordable (using cost effective analysis)?
4. Is there any difference between this study and previous researches in relation to estimated level of risk to public health?

1.5. Research Boundaries

The boundary of this study is microbial risk assessment (MRA) in domestic drinking water supply as part of urban water system in poor urban settlements of Accra, specifically in Nima neighbourhood. Moreover, the cost effectiveness for applicable solution will also be assessed. Due to time limitation, the investigation will only covering potable water system and will not include hygiene practices. In the end, the result of this research will be incorporate in the spreadsheet model developed by Lunani (2007) and Labite (2008) in order to further develop the QMRA model for predictions of disease burden.

2. LITERATURE REVIEW

2.1. Water and infectious diseases

Water is essential element for living. Ironically, humans with their activities keep degrading its quality and quantity. Unsafe water, inadequate quantities of water, poor sanitation and hygiene are leading to infectious diseases and children are the most vulnerable group to be infected. Globally, every year there are more than 1.5 million children within the age of five and below are died mostly because of diarrhoea (UNICEF, 2006).

Infectious disease is one that can be transmitted from one to another and caused by microorganism such as bacteria and viruses. These microorganism are using environmental e.g. water and air as their transportation to be transmit from host to the new victims (Caincross and Feachem, 1993, Westrell, 2004).

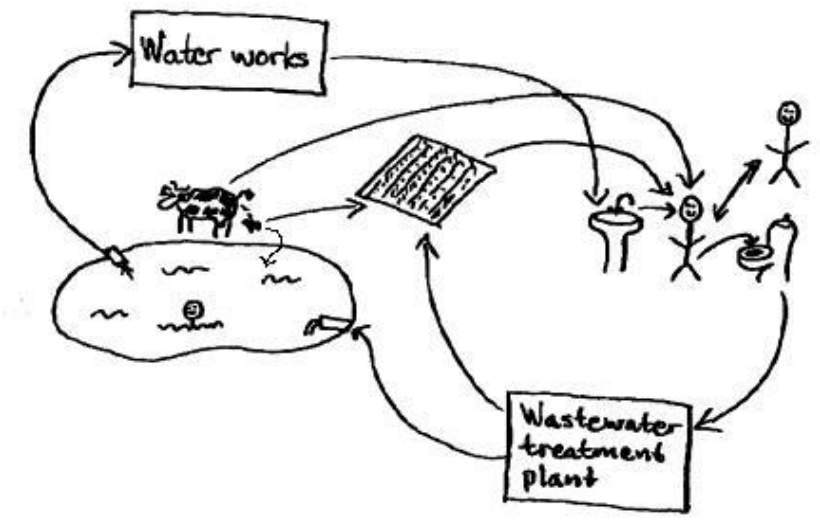

Figure 2 Circulation of pathogen in the urban environment (source: Westrell, 2004)

There are four principal routes of water-related diseases (Caincross and Feachem, 1993, Eisenberg et al, 2001, Gleick, 2002, Lunani, 2007):

1. Water borne diseases: it is occurs when the pathogen is in water, which is ingested by a person, or animal which may then become infected. Diarrhoea and cholera are some of the illnesses belong to this group.
2. Water washed diseases: caused by inadequate quantity of water and poor hygienic practices. Scabies and trachoma are part of this route.
3. Water based diseases: via contact with animals such as snail which is an intermediate hosts of the pathogen. These animals are living in contaminated water. Schistosomiasis is including in this group.
4. Water related vector diseases: through vectors especially mosquitoes which using water for breeding. Malaria and dengue are example of the illness of this transmission.

However, Howard and Bartram (2003) suggested, instead of using waterborne diseases it is better to identify it as faecal oral diseases. This terminology can reflect multiple pathway of transmission (water borne and water washed routes). And for water washed diseases it is restricted for skin and eyes infections that related to amount of water used for hygienic purposed.

2.2. Faecal-oral transmitted diseases

Pathogenic microorganisms were leaving the host (human or animals) via faeces and than using environment as their pathway to enter the new victims through ingestion (Rottier and Ince, 2003). Figure below shows five F (faeces, fluids, fingers, flies, fields and food) diagram, route of faecal-oral infections.

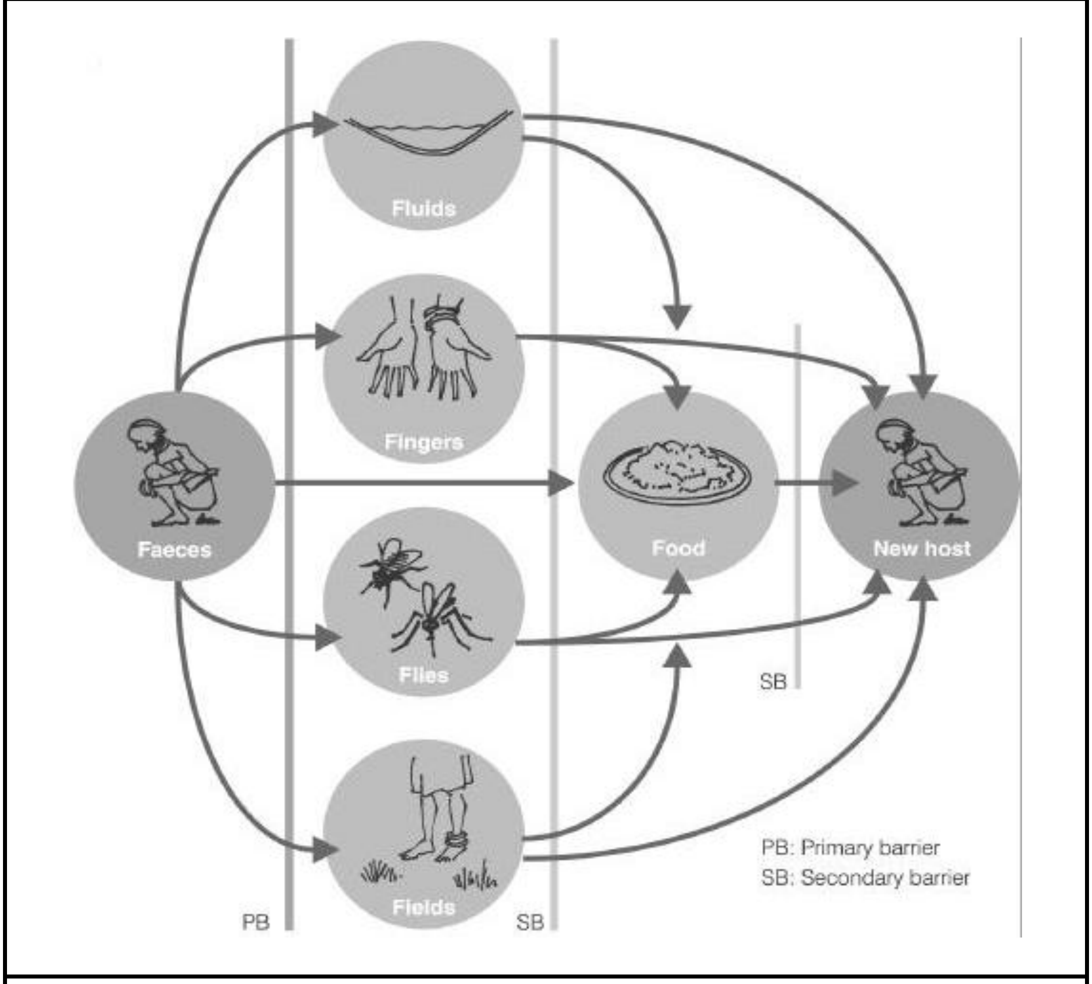

Figure 3 Faecal-oral transmission diseases (source WELL, 1998 cited by Howard & Bartram, 2003)

Next table shows pathogenic microorganisms that concern for faecal-oral infection in developing countries, which is use water as their intermediate.

Table 2 Faecal-oral pathogens of concern in developing countries

Name of microorganism	Major diseases	Major reservoirs and primary sources
Bacteria		
Salmonella typhy,	Typhoid fever	Human faeces
Salmonella paratyphy,	Paratyphoid fever	Human faeces
Shigella spp,	Bacillary dysentery	Human faeces
Vibrio cholerae,	Cholera	Human faeces & freshwater zooplankton
Enteropathogenic *E. coli,*	Gastroenteritis	
Yersinia enterocolitica	Gastroenteritis	Human faeces
Camplyobacter jejuni	Gastroenteritis	Human & animal faeces
Lepstopira spp	Lepstospirosis	Human animal faeces Human and animal urine
Enteric viruses		
Enteroviruses:		
Polio viruses	Poliomyelities	Human faeces
Rotaviruses	Gastroenteritis	Human faeces
Adenoviruses	Upper respiratory and gastroenteritis	Human faeces
Hepatitis A virus	Infectious hepatitis	Human faeces
Protozoa		
Balantidium coli	Balantidosis (dysentery)	Human & animal faeces
Cryptosporidium homonis, C. parvum	Cryptosporidiosis (gastroenteritis)	Water, human & other mammal faeces
Entamoeba hystolytica	Amoebic dysentery	
Giardia lamblia	Giardiasis (gastroenteritis)	Human & animal faeces Water& animal faeces
Helmiths:		
Ascaris lumbricoides	Ascariosis	Human & animal faeces

[Source: Ashbolt, 2004; Caincross and Feachem, 1993]

2.3. Microbial Risk Assessment (MRA)

2.3.1. Quantitative Microbial Risk Assessment (QMRA)

Description of Quantitative Microbial Risk Assessment (QMRA) by Haas et al (1999) is the application to estimate the consequences from a designed or actual exposure of pathogenic microorganism to human. It is preferable to applied quantitative approaches since it allow a better comparison of various water and sanitation system. QMRA has been implemented to development of guidelines, standard and recommendation concerning human health in relation with water and wastewater system (Bartram et al, 2001, Howard et al, 2006, Westrell, 2004).

There are four steps in the risk assessment paradigm for human health effects (Haas et al, 1999):

1. Hazard identification: to describe acute and chronic human health effects associated with any particular hazard, including toxicity, carcinogenicity,

mutagenicity, developmental toxicity, reproductive toxicity and neurotoxicity. It is defined for human and animals.
2. Dose-response assessment: to characterize the relationship between various doses administered and the incidence of the health effect. It is primarily using animal models.
3. Exposure assessment: to determine the size and nature of the population exposed and the route, amount and duration of the exposure. This is involved monitoring of the environment, the transport, and the fate of the chemicals through the various exposure pathways.
4. Risk characterization: to integrate the information from exposure, dose response, and health steps in order to estimate the magnitude of the public health problem and to evaluate variability and uncertainty.

Hunter, Navier and Hartemann (2009) were investigated the impact of poor reliability of potable water to achieving health improvement targets by using QMRA in Kampala, Uganda. This study concludes that unreliable drinking water supply can depress improvement of public health, especially in developing regions like Uganda. It also recommends putting more effort into auditing the effectiveness of the system to prevent spreading of diseases to the community.

Westrell (2004) studied the risks of transmission of pathogenic organism in urban water and wastewater systems to human health, case study in Sweden. QMRA with specific highlight on exposure assessment was conducted. This research covered drinking water treatment and distribution, presence of noroviruses in surface water, tap water consumption risk, handling and reuse of human excreta as well as wastewater. General conclusion of this study is QMRA can be used in various situations including comparison of water and wastewater systems. For accuracy of risk estimation, monitoring of site-specific pathogens was shown to be very essential. And last but not least, implementation of the new solutions for water and sanitation systems was predicted to have a new exposure routes.

QMRA has been applied in many contexts to investigate the impact of infectious microorganism in environment to population (Ashbolt, 2004, Ashbolt et al, 2006, Godfrey and Smith, 2005, Howard et al, 2006, Lunani, 2007, Labite, 2008, Obi et al, 2003, Salgot et al, 2003). For comparative purposes in this methodology, Haas (2002) conducted research to review it. This study highlighted the data gaps in dose-response assessment, exposure assessment and effect to populations. In dose-response assessment, it is important to have consistency between outbreak data and risks extrapolated from human volunteer experiment as well as relationship between ingested doses and the consequences. In assessing risk to people, it is essential to take consideration of the differences level of exposure (variability of concentration or consumption patterns).

2.3.2. Hazard Analysis Critical Control Point (HACCP)

Hazard Analysis Critical Control Point (HACCP) is a simple technique and practical for risk detection and to be manage at daily basis. HACCP is a preventive approach for multiple barriers and controlling contamination as close to the source as possible (Deere et al, 2001). It has been applied widely within food processing and drinking water production system (Westrell et al, 2004). Jagals and Jagals (2004) stressed that HACCP

approach can provide a quality control mechanism for the potable water industry to continuously produce safe water for consumers.

To implement HACCP consistently, seven principles shall be implemented as guiding process of risk management in water supplies (Deere et al, 2001). These principles are listed below:

1. Identify hazards and preventive measures
2. Identify critical control points
3. Establish critical limits
4. Identify monitoring procedures
5. Establish corrective action procedures
6. Validate/ verify HACCP plan
7. Establish documentation and record keeping

However, these principles are flexible at application phase. In their research, Jagals and Jagals (2004) only applied four of seven principles as simplification of HACCP approach for water treatment facilities in South Africa.

In 1994, Havelaar conducted an assessment on HACCP to drinking water supply. This research was highlighted on major risk derived from microbiological agents in this system are pollution at intake water source, recontamination during storage and distributions network. It was identify that treatment process is one of the critical control points (CCP) amongst other points. Nevertheless, a preventive measure is really important to keeping safe product and it needs to be evaluated regularly.

Westrell et al. (2004) combined HACCP and QMRA to investigate management of pathogens in wastewater and sewage sludge treatment including reuse. Initial step to applied HACCP was quantitative microbial risk assessment. QMRA was performed to have a baseline of most hazardous situation for microbial contamination in the system. The result was viruses are deliver the highest risks and having more potential impact to public health compared to EHEC and *Cryptosporidium* which are more endemic level. This study also identified hazardous exposure from early process up to sludge handling. Example of controlling hazard exposure at the early stage of the process is by use protection equipment.

2.4 Disability Adjusted Life Years (DALYs)

DALY or Disability Adjusted Life Years is a common measure for examining diverse disease outcomes. It is based on measuring health gaps by calculating the difference between current conditions and a selected target (Prüss and Havelaar, 2001). In another words, it is a calculation of premature mortality (YLL) and healthy life loss because of illness or disability (YLD) which is attempt to estimate the total cost of disease (Cunningham and Cunningham, 2008). Thus, the formula is: DALY = YLL + YLD.

Twenty-two indicator conditions will be use for weighting the health impairment condition.

Table 3 Disability classes and indicator

Class	Weight	Indicator condition
1	0.00 – 0.02	Vitiligo on face, low weight
2	0.02 – 0.12	Watery diarrhoea, severe sore throat, severe anemia
3	0.12 – 0.24	Radius fracture in a stiff case, infertility, erectile dysfunction, rheumatoid arthritis, angina
4	0.24 – 0.36	Below knee amputation, deafness.
5	0.36 – 0.50	Down's syndrome, rectovaginal fistula, mild mental retardation.
6	0.50 – 0.70	Depression, blindness, paraplegia
7	0.70 – 1.00	Active psychosis, dementia, quadriplegia, severe migraine.

[Source: Havelaar and Melse, 2003; Prüss and Havelaar, 2001]

Prüss et al (2002) predicted the disease burden from water, sanitation, and hygiene to be 4.0% of all deaths and 5.7% of the total disease burden (in DALYs) that is taking place globally. It is taking into account diarrhoea diseases, schistosomiasis, trachoma, ascariasis, trichuriasis, and hookworm disease.

In his research using QMRA, Labite (2008) concluded that total disease burden of Accra urban water system was 37,000 where sanitation claimed 88% of it. DALYs per person per year was $5*10^{-3}$, which was higher than WHO standard (10^{-6} pppy). Furthermore, this result is use as recommendation to decision maker to prioritize the intervention for improvement of inhabitant health status.

2.5 Cost Effective Analysis

Cost effective analysis (CEA) is a determination of the cost from the specific intervention and its effectiveness with respect to a certain health outcome. It can be used for setting the priority of intervention to reduce the incidence of diseases. WHO developed an approach known as generalized CEA. This approach allows for a comparison of current interventions as well as to consider the implementation of recommended interventions on a sector-wide basis for a group of populations with comparable health system and epidemiology (Tan- Tores Edejer et al, 2003). In general, there are 5 steps to conducting generalized CEA (Clasen and Haller, 2008): (i) The costs and benefits of a set of proposed interventions should be investigated with the respect to the baseline condition. (ii) Effectiveness of the interventions shall be estimated. (iii) Modelling the study population based on demographic, exposure and risk data, using the effectiveness data to determine the DALY averted by each intervention compared to the baseline. (iv) Estimating the costs associated with the intervention. (v) Calculating the cost per DALY averted also interpreting the results.

CEA are widely used to make a choice of resource allocation (fund) decision in health sector (UNICEF, 2007). CEA was applied by Clasen et al (2007) to study the prevention of diarrhoea diseases through water quality interventions in developing countries. Larsen (2004) was investigated the priorities between health and hygiene using CEA as a tool. It was also used to develop the priority for controlling diseases in developing countries via investment in water supply, sanitation and hygiene promotion (Caincross and Valdmanis, 2006).

3. MATERIALS AND METHODS

3.1 Description of Study Area

3.1.1. Demography and water situation

Accra is the capital of Ghana and is located on the east coast of the country. This region is under dry equatorial climate with average rainfall 730 mm per year and it is generally hot and humid with average temperature 28 ^{o}C.

The Accra Metropolitan Assembly (AMA) covers an area of more than 200 km^2 of land, which is divided into six sub-metros namely Okaikoi, Ashiedu Keteke, Ayawaso, Kpeshie, Osu Klotey and Ablekuma (AMA, 2009). Accra is experiencing high urbanization rates that make it one of the fastest-growing cities in West Africa (Grant and Yankson, 2003). It is populated with more than 1.8 million inhabitants and annual growth rate is 4.4 %. The average of population densities is 69.3 persons per ha where it spans from the highest more than 250 person per ha in low-income area such as Nima and James town, to less than 40 person per ha in high-income areas such as Labone and Cantonments (Ghana district, 2009).

More than 60% of Accra’s residents live in over-crowded areas and Nima is one of the localities. It is administratively under Ayawaso sub-metro and it is classified as third class residential area and hosts more than 69,000 inhabitants within 158.8 hectares of area (Ghana districts, 2009). Administratively, Nima has two constituencies, namely East Nima and West Nima. East Nima is between the Kanda Highway and the Nima Highway while West Nima is defined by the Nima Highway and the concrete drain (canal) to Mamobi. However, this study only covered West Nima where the social strata is more heterogeneous and afterwards the result can be interpreted for East Nima as well and also to other densely populated neighbourhood within Accra metropolitan.

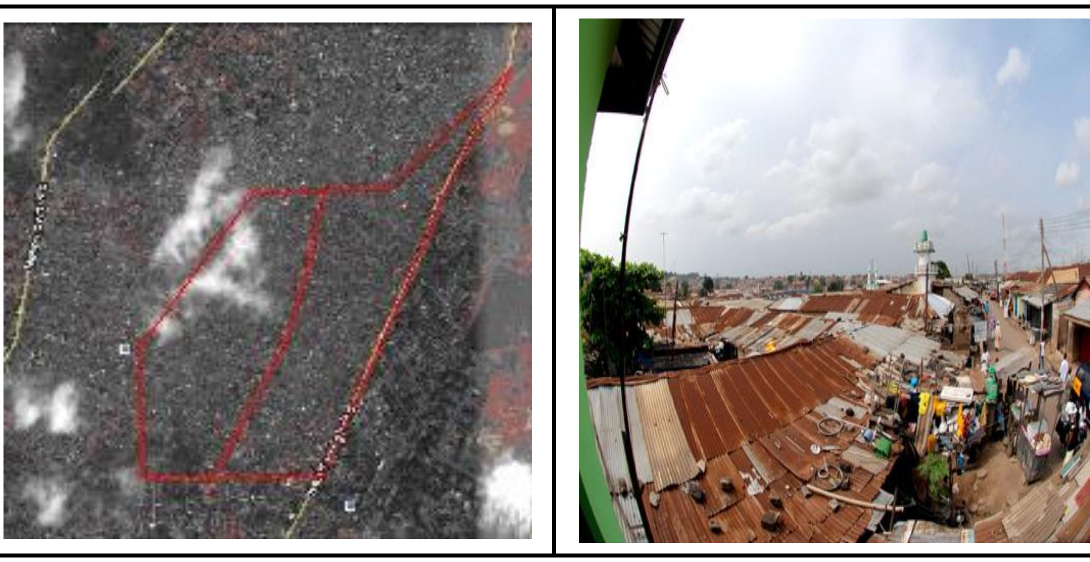

Figure 4 The division of West Nima and East Nima ; Top view of Nima area

The social strata in Nima majority are poor and trading is their main livelihood, however there are also traces of medium and higher-class households living within this

area. With regard to water supply, theoretically, this neighbourhood is connected to Ghana Water Company Limited (GWCL) however, the supply is intermittent. In average, inhabitants receive their piped water only three days per week for just a few hours (Abraham et al 2009, AVRL/GWCL 2009).

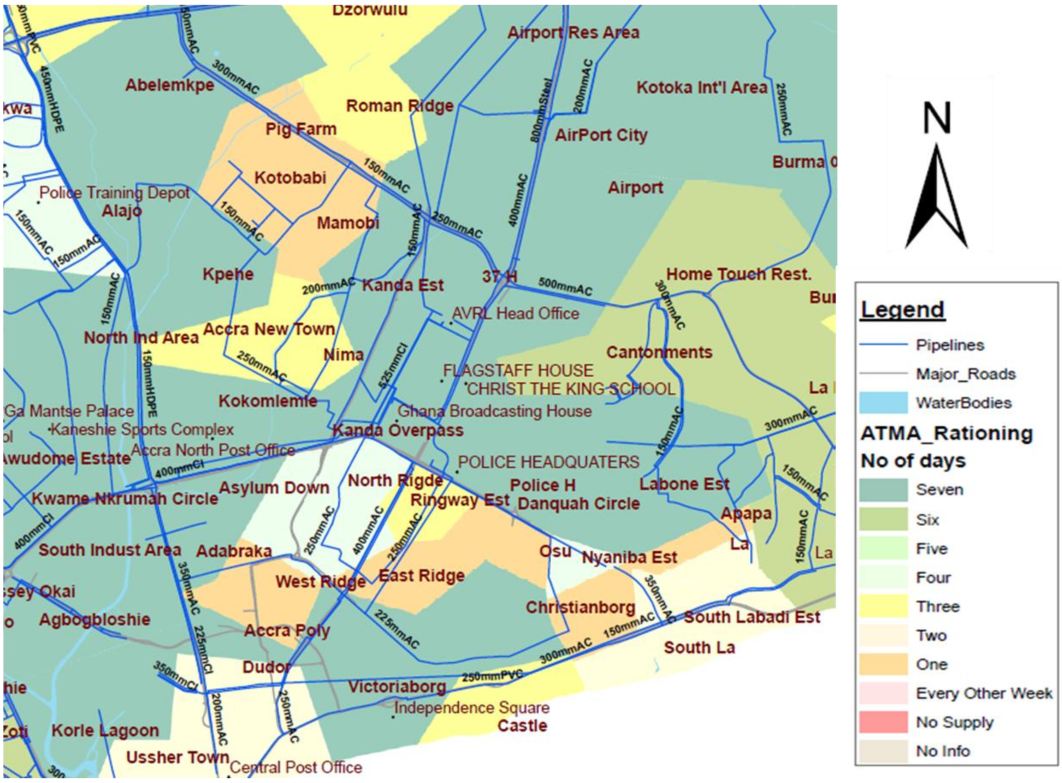

Figure 5 Rationing map of pipe water flow (source AVRL, 2009)

Type of dwelling in Nima is mostly compound houses, which are occupied by more than 10 families and on average 37 people per house. Hence, the private water connection mainly installed at their yard, no indoor pipes for each family compartment. There is no public stand-post built by municipality thus communal taps is actually belong to private vendor which is located at the streets in front of their house and people has to purchased it from the owner. Since the water flow was irregular, all the family have their own storages and for communal taps it has tank to store their water during dry period of the week. In any case, when the water is not flowing for more than 1 month, dwellers have to walk further to East Nima to fetch the water from the open dug well, or even walk more further to other areas such as Mamobi. Water tanker association were contacted by the wealthier family to delivered water during the dry periods.

3.1.2 Sampling points

In undertaking microbial risk assessment from potable water, several sampling points were selected. These sampling points were a sequence from distribution network (taps) to the point of consumption (family storage). By investigating these routes, the level of re-contamination of the drinking water could be identified. In addition to that, with the

high intake of sachet water within community, this route was also been considered to be analyzed. Detailed of each sites and number of samples taken are listed below.

1. Households water storage

For this research purpose, there are 110 water samples collected from family containers. The type of storage differs from 20 litres jerry cans up to 500 litres polytanks. In most cases, the storage was not properly covered and unhygienic manner of scooping their water with short/no handle type of dipper. Prior to water sampling, a structured 15-minutes questionnaire was conducted to collecting information on the respondent's background and their water situations.

Figure 6 Surveyed questionnaires to the household; children drinking directly from the storage and some of the type of family storages: jerry cans and metal barrel

2. Private taps connection

As described earlier, since the housing types are mostly compounds thus the water samples were collected from tap at the compounds yard. Total samples to be analyzed from private in-yard connection points were 14.

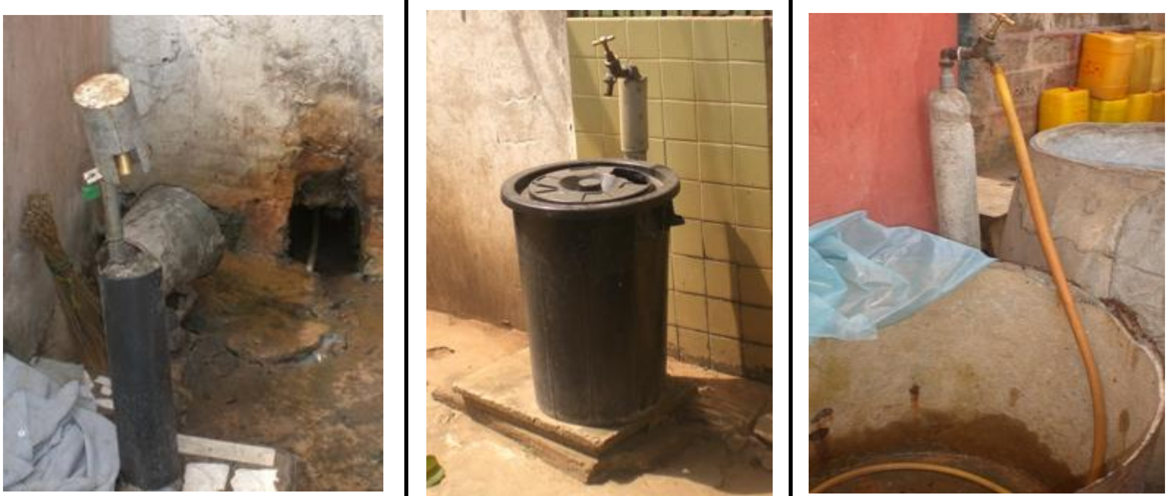

Figure 7 Private tap connections at the yard

3. Communal points

Samples for communal points were obtained from the standpipe which is not located inside the compound houses and where the neighbouring households purchased their water from it. When the water from GWCL is flowing, the samples were taken directly from the tap, however in any case that at the collection days there was no running water; it was collected from the reservoir. There are 25 samples collected from the tanks and 17 were from the public taps.

In addition to that, since some people were also fetching their water from wells in East Nima, those open dug wells were also analyzed. Sixteen samples have been collected and analyzed from this point.

Figure 8 Communal points: Polytank with tap, reservoir (in dry period they use bucket & rope to collect water) and open dug well.

4. Water sachets

Water in the sachets commonly called as pure water and it is one of the sources for the drinking water for people in Accra. It is a product from a small-scale industry using filtration and UV light as disinfection. There are many producers for this water sachets however not all of them have certification from the Ghana standard board.

Since this is also one of the means of consuming water for inhabitants of Nima hence four brands were selected to be analyzed their quality. These chosen brands were the very common to be found and consumed in Nima namely Kr, Dd, Cp and Pj. All the samples were taking in five different times each and that bring to total number of samples as 20.



Figure 9 Water sachets production process and a child drinking from sachet

5. Water tanker

For quality assurance of distributed water by tanker, AVRL/GWCL has central filling point stations within company compounds in all Accra regions. Trucks from both private and water company collect their water from it. The closest station to Nima area is located at AVRL/GWCL head office.

For the purpose of this study, water samples were taken from hydrant outlet hose and from trucks distribution pipe. Three trucks were selected, two belonged to the company and one was a private operator. Each of the trucks and hydrants were sampled for five consecutive times. It leads to total number of samples as 20.


Figure 10 Water tanker filling point at GWCL yard, Accra and distribution hose from the truck

3.2 Microbial identification

3.2.1 *Coliform* bacteria

All the 222 collected samples were analyzed within 6 hours after collection. In this investigation, bacterial pathogens were enumerated as described in Standard methods 9222 (APHA, 1989) by using the membrane filtration technique and Chromocult Coliform Agar (Merck) as the growth medium. Approximately 100 ml of the water sample was filtered though cellulose acetate filters with a pore size of 0.45 mm. In cases

were the result was uncountable, the process was repeated with smaller volume (10 ml). Bacterial agents were confirmed by incubating samples at 37 ^{o}C for 18 to 24 hours. Dark-blue to violet colonies were taken as presence of *E. coli*. Colonies with red colour were considered to be other *Coliform* ; *Salmonella* was the one in light blue to turquoise colour and for other *Enterobacters* group were shown in yellow or even colourless colonies.   All results were reported as colony forming units per 100 ml (cfu/ 100 ml).

Figure 11 Laboratory apparatus: Membrane filtration equipment, incubator and autoclave

3.2.2 Other pathogenic agent

From the *E.coli's* laboratory results, concentrations for virus, protozoa and other bacteria could be estimated by using the ratio between [*E. coli*] and [pathogens]. However, since the information is limited regarding the ratios for drinking water, hence an assumption was made based on related risk assessment research for other types of water such as wastewater.

The assumption for the ratio between *E. coli* and *Campylobacter* was taken from stochastic models for risk assessment in drinking water (Smeets et al, 2008). The study was using long term monitoring data for these two bacteria from a full-scale plant in Netherlands for over six years period. While for *Rotavirus*, the ratio was defined from wastewater quality for irrigation purposed (Mara et al, 2010) as well as for protozoa (Howard et al, 2006, Lunani, 2007). In summary, the ratios are shown in the Table 4.

Table 4 Ratio of [E. coli] : [Pathogens]

E. coli : Pathogen	Ratio	Remarks
E. coli : *Campylobacter*	2.4 : 1	Ratio from filtered surface water (pond)
	1 : 0.9	Ratio from ozonated water
E. coli : Rotavirus	1: 10^{-5} - 10^{-6}	
E. coli : Protozoa	1 : (10^{-5} – 10^{-7})	

(Source: Howard et al, 2006, Lunani, 2007, Mara et al, 2010, Smeets et al, 2008)

3.3 Helminth eggs analysis

Helminth eggs analysis was performed only for all the well samples and some of household storage samples (random), with a total number of 51. Analysis for this agent is consisting of four steps as described by Schwartbrod (2001).

1) **Concentration**: The initial step is sedimentation for at least 24 hours. Then, supernatant is collected as much as possible and sediment is relocated to 30 ml centrifuge tubes, which after that are centrifuged at 400g for 3 minutes.

2) **Flotation**: Supernatant is transferred to tubes and the deposit is re-suspended in 150 ml of the zinc sulphate (Zn SO_4) solution. These tubes need to be shaken vigorously and then centrifuging at 400g for 3 minutes. Then supernatant is transfer into 1 litre flask and diluted with at least 1 litre of demineralised water and later on allowed it to settle for at least 3 hours. After the settling down of the *Helminth* eggs, the supernatant is need to be sucked as much as possible and the deposit need to be re-suspended by shaking. The deposit is transfer into one or more centrifuge tubes depending on the volume of the deposits; 1 litre container is need to be rinse with demineralised water then these liquid will be added to the centrifuges tubes and then re-centrifuged at 480g for 3minutes. The deposit then will be regrouped in one tube and centrifuged again at 480g for 3 minutes.

3) **Desorption**: Those deposit will be re-suspended in 15 ml acid/ alcohol buffer solution (at 0.1 N 35% ethanol); approximately 5 ml of ethyl acetate then need to be added to the centrifuge tubes. Then shake and continue with centrifuged at 660g for 3 minutes. All the Helminth eggs will be settled down in the sediment.

4) **Counting**: In this step, it is required to separate the supernatant and deposit. Deposit needs for measurement is only 1 ml than need to be transferred on the glass slide using pipette for examination under microscope for counting.

3.4 Quantitative Microbial Risk Assessment

To determine the risk from microbial agents from drinking water exposure to human health, dose response assessment was applied to obtain the number of infection case per pathogens (Haas et al, 1999 and Westrell, 2004). Formulas that have been used are listed below.

Table 5 Dose-response equation for risk assessment

Parameters	Formula	Equation no.
Probability of infection: P_i	Beta poisson model: $P_i = 1 - [1+ (d/N_{50}) *(2^{1/\alpha} - 1)]^{-\alpha}$ (a) Exponential model: $P_i = 1 - \exp(-rd)$ (a)	3.1 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) $P_{Di} * P_i$	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; N_{50} is the dose that will affect 50% of the population; n is the frequency per year; (b) P_{Di} is the probability of infected person developing clinical diseases.

An ingested volume (d) was determined from literature as 2.9 litres per person per day. This value is only for unheated drinking water and it does not include milk, coffee, tea and other liquids for adults in hot regions (Haas et al, 1999, Howard and Bartram, 2003). Volume of water sachet sold by vendor is 0.5 litres thus this amount was taken to be the ingested volume for the people that irregular consumer of water sachets Since only children drink the water from the wells without any additional treatment, the ingested volume was assumed only 1.0 litres (Howard and Bartram, 2003). It is assumed 30% of population are children under 14 years old (Ghana district, 2009). The exposed population was established from field survey and interview, and further extrapolated to the whole population of study area with data from the GSS (Ghana Statistical Services).

Determination for frequency of water consumption per year (n) was based on frequency of piped water flowing in study area. Since in the average water were running only for 3 days per week, hence the assumption for frequency from private & communal taps are 156 days and it brings the consumption from the family storage and regular water sachets consumer into 4 days per week (208 days) which is the un-flowing days. The rate of children drinking raw water from well is assumed as once a week (52 days) as well as irregular intake for water sachets.

Table 6 Dose response parameters for risk assessment

Organisms	Parameters	Type of model	Sources
E.coli	$\alpha = 0.2099$ $N_{50} = 1120$ $P_{Di} = 0.35$	β poisson model	Haas et al, 1999; Howard & Peddley, 2004; Westrell, 2004
Campylobacter	$\alpha = 0.145$; $N_{50} = 896$ $P_{Di} = 0.3$	β poisson model	Haas et al, 1999, Westrell, 2004
Rotavirus	$\alpha = 0.2531$; $N_{50} = 6.17$ $P_{Di} = 0.5$	β poisson model	Haas et al, 1999
Cryptosporidium	$r = 0.0199$ $P_{Di} = 0.7$	exponential	Westrell, 2004
Ascaris	$r = 1$ [a] $P_{Di} = 0.39$	exponential	Westrell, 2004

Notes: [a] Dose response model for ascaris is not available yet therefore it is suggested to use the highest value of r with exponential model (Labite, 2008; Westrell, 2004)

3.5 Burden of disease

DALYs calculation for this study was done according to the literatures and previous researches (Havelaar and Melse, 2003, Howard and Pedley, 2004, Labite, 2008, Lunani, 2007). The estimation was made on the base of life expectancy in Ghana at birth, 57 years. Further, with the calculations from each pathogen, health outcomes, duration and severity, disease burden per case could be estimated. Table 7 shows the DALYs calculation per pathogen.

Table 7 Severity, duration and burden of disease for pathogen

E.coli				
Outcomes	**Severity**[b]	**Duration**[b]		**Disease burden (DALYs) per case**[c]
		days	**year**	
Watery diarrhoea	0.067	3.4	0.009	0.0006
Bloody diarrhoea	0.39	5.6	0.015	0.0060
Death from diarrhoea	1		56	56
Campylobacter				
Outcomes	**severity**	**Duration**		**Disease burden (DALYs)**
		days	**year**	
Gastroenteritis - population	0.067	5.1	0.014	0.0009
Gastroenteritis – General Practioners	0.39	8.4	0.023	0.0090
Death from gastroenteritis	1		56	56
Rotavirus				
Outcomes	**severity**	**Duration**		**Disease burden (DALYs)**
		days	**year**	
Mild diarrhoea	0.1	7	0.02	0.0019
Severe diarrhoea	0.23	7	0.02	0.0044
Death from diarrhoea	1		56	56
Cryptosporidium				
Outcomes	**severity**	**Duration**		**Disease burden (DALYs)**
		days	**year**	
Watery diarrhoea	0.067	3.4	0.009	0.0006
Death	1		56	56
Ascaris				
Outcomes	**severity**	**Duration**		**Disease burden (DALYs)**
		days	**year**	
Intestinal obstruction, population	0.024	35	0.1	0.0024
Contemporaneous cognitive deficit	0.006	28	0.08	0.0005
Death	1		56	56

Note: [b] Severity and duration for *E.coli* are from Howard & Peddley, 2004; Havelaar & Melse, 2003; for *campylobacter, rotavirus* and *cryptosporidium* are from Havelaar & Melse, 2003; for ascaris are taken from Bundy et al, 1997. [c] DALYs = severity * duration (years). [d] The year lost because of death was taken from the life expectancy at birth of Ghana – death at age 1 year (57-1 = 56 years).

Moreover, disease burden per case then multiplied by the number of cases for each pathogen to estimate burden of disease per symptomatic cases. Numbers of cases are generated from literatures. Then, to calculate DALYs per pathways, the resulted value has to be multiply with annual symptomatic cases per pathogen from QMRA. In summary, the formulas is presenting in next table.

Table 8 Burden of disease formula

	Formula	**Equation No.**
BD per symptomatic cases	Estimation of cases * DALYS	3.8
BD per pathway	BD per symptomatic cases * annual symptomatic cases (from risk assessment calculation)	3.9

(Source: Howard & Peddley, 2004; Havelaar & Melse, 2003; WHO, 2006) Notes: BD=Burden of Disease

Estimation of case development for *E.coli* was based on Havelaar and Melse (2003) which indicated that approximately 47% of the diarrhoea cases are with bloody stools. While mortality burden in developing country is estimated as 0.7% of total infection and the year of lost was based upon the death occurring at age of 1 year with life expectancy at birth in Ghana is 57 years (Howard and Pedley, 2004; WHO, 2003).

In regard to *Campylobacter*, the morbidity case was considered from gastroenteritis and approximately 6% of the infected person will develop into severe diarrhoea and will have to consult to general practitioner. The mortality from this agent is 0.1 % with average death at the age of 1 (Haas et al, 1999, Havelaar and Melse, 2003).

The diseases outcomes from *Rotavirus* infections were included mild and severe diarrhoea as well as death. Estimation for mild diarrhoea cases was 85.6% while the remaining was suffering from severe infection. In addition to that, fatality case develop from this pathogen was 0.7% and the mortality burden was calculated based on the age of death at 1 year (Havelaar and Melse, 2003, Howard et al, 2006)

Watery diarrhoea was estimated as the most common disease outcomes from *Cryptosporidium* with duration of 7.2 days and mortality could occurred especially within immuno-comprised individuals such as people living with HIV/AIDS positive and later on this group was used to calculate the burden from mortality case (Howard and Pedley, 2004). As cited by Lunani (2007) from UNAIDS report (2006), estimated prevalence for HIV/AIDS was 4.1 % in the year of 2002. With the assumption from Havelaar & Melse (2003), mortality rate among this group was 10 %. Therefore, it gives the rate for fatality case of 0.41%. The year of lost from this immuno- comprised person was estimated in 3 types of group; first estimation was 89% of HIV/AIDS infections in Ghana occur in the age group 15-49 years, then 8% in the age of 50-59 years and the remaining 3% in the age of 0-14 years (Lunani, 2007). Additionally, people with full blown of HIV/AIDS will die after approximately 1.5 years of infection. Hence, with all this assumption, the mean ages of death are 33.5 years, 56 years and 8.5 years respectively. And for weighted average for final estimation of the year lost due to *Cryptosporidium* was using the approach as been used by Howard and Pedley (2004) as well as Lunani (2007):

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

Bundy et al (2004) estimated the major disease from *Ascaris*, is intestinal obstruction with the contemporaneous effects of infection could reach 5% from all the cases. Moreover, the mortality rate in average is 0.08% where the death might occur at age of 1 year. Even though the value is low, however the infected population mostly are children thus it makes this disease is important to be controlled. Apparently this infection is also associated with mal-absorption of nutrition hence in some cases the death cause by intestinal nematode was not recognized as worming infection but as malnutrition case.

Table 9 shows the summary of estimated cases for each pathogen and the DALYs developed.

The assessment of disease burden pointed that the higher symptomatic cases of gastroenteritis was derived from E.coli is $3.95*10^{-1}$ while *Ascaris* was the lowest with

$4.70*10^{-2}$ and the major contribution for all infections were generated from mortality cases.

Table 9 Burden of disease per single symptomatic cases of gastroenteritis

Outcomes	Estimation of cases	DALYs	Burden of disease per symptomatic cases (DALYs)[a]
E. coli			
Watery diarrhoea	53%	6.24E-04	3.31E-04
Bloody diarrhoea	47%	5.98E-03	2.81E-03
Death	0.70%	5.60E+01	3.92E-01
Total			3.95E-01
Campylobacter			
Gastroenteritis	94%	9.36E-04	8.80E-04
Gastroenteritis (Severe diarrhoea)	6%	8.98E-03	5.39E-04
Death	0.10%	5.60E+01	5.60E-02
Total			5.74E-02
Rotavirus			
Mild diarrhoea	86%	1.92E-03	1.64E-03
Severe diarrhoea	14%	4.41E-03	6.35E-04
Death	0.70%	5.60E+01	3.92E-01
Total			3.94E-01
Cryptosporidium			
Watery diarrhoea	100%	6.03E-04	6.03E-04
Death	0.4%	2.25E+01	9.23E-02
Total			9.29E-02
Ascaris			
Intestinal obstruction	95%	2.30E-03	2.19E-03
Contemporaneous cognitive deficit	5.0%	4.60E-04	2.30E-05
Death	0.08%	5.60E+01	4.48E-02
Total			4.70E-02

[a] Equation 3.8

3.6 HACCP and interventions

At every identified drinking water pathway, public's health risk was estimated using QMRA and DALYs percentage per pathways. And then, the risk from each route was assessed by scoring the impact.

Table 10 Risk Score

Severity of Consequences (Impact) [a]				
Insignificant	**Minor**	**Moderate**	**Major**	**Catastrophic**
1	2	3	4	5

[a]: From Westrell (2004): Insignificant: No increase in disease incidence (<0.1); Minor: Slight increase in diarrhoea diseases (0.1<1 %) ; Moderate: Increase in diarrhoea diseases (1<5 %) ; Major: Increase in more severe diseases (0.1-5%) or large increase in diarrhoea diseases (5<25 %) ; Catastrophic: Major increase in diarrhoea diseases > 25% or >5% increase in more severe disease or large community outbreak (100 cases) or death.

If the risk factors equal or greater than moderate it means the hazard has to be considered further for corrective action. Afterwards, the level of risk was integrated into HACCP worksheet for hazard event and suitable corrective measures.

Table 11 HACCP worksheet for domestic drinking water supply

Step	Hazard	Risk	Target level (standard)	Control measure	Monitoring procedures	Corrective action
Household storages						
Private taps yard						
Communal taps dry						
Communal taps wet						
Communal wells						
Water sachets						
Water tankers						

[Source: adopted from CODEX, 1993; Deere et al, 2001; Godfrey & Howard, 2004; Havelaar, 1994]

Then, after HACCP's worksheet filled and corrective measure has been identified, further is integrated it into scenarios with recommendation interventions based on the impact to health and affordability of implementation. These scenarios would be used to forecasting the impact of suggested intervention to DALYs.

Table 12 Interventions and DALYs

No	Interventions	Effected population	Current (baseline)	DALYs	DALYs after intervention
1	Water supply capacity expansion				
2	Leakage rehabilitation				
3	100% coverage of private connections				
4	Additional treatment at point of consumption				
5	Hygiene promotion for water handling				
6	Combination in water supply system (WS, 1,2,3) only				
7	Combination in WS + HH treatment				
8	Combination in WS + Hygiene promotion				
9	Combination in HH treatment + Hygiene promotion				
10	Combination of all				

3.7 Cost effectiveness for interventions

DALYs averted was calculated based on the difference between the baseline value and the DALYs of the particular intervention. Option with the highest DALYs averted is

consider as the preferable one. However, this may not always be economically feasible. Hence, cost effectiveness ratios was estimated by annual unit cost divided by yearly DALYs averted (Clasen and Haller, 2006). The one with lowest value was considered as the most effective option.

3.8 Data Analysis

Statistical software R-console version 2.8.1 was used for statistical Mann – Whitney U-test with confidence interval 95%. And calculations for risk assessment was using Microsoft excel spreadsheet.

Figure 12 Mode of recontamination path in drinking water supply: leakage at distribution pipes, tap located near the toilet, un-cover water storage and scooping water with no-handle dipper.

4. RESULTS AND DISCUSSION

4.1 House hold survey

One hundred and ten families with the sum of 4121 persons were participating in the survey. It was accomplished in a six weeks period using structured interviews. The survey focused on the water usage and quality at household level.

Majority of the respondents depend on private vendor/neighbour's taps (60 %) while the remaining 40% have their private yard connections. Among these connections, 72% have their water for few days per week whilst 6% receive once in a week, 4% every two weeks and the remaining (19%) get their water flowing only once in a month. To cope with intermittent supply, inhabitants have to fetch water from alternate sources like communal tanks, water tanker, water sachets and even walking to adjoining communities which sometimes can be as far as 4 km. Since the water supply is unreliable, all the families have their own water storage which is diverse, ranging from 20 litres jerry can, 100 litres barrel (metal or plastic) to a polytank with a volume of 500 litres.

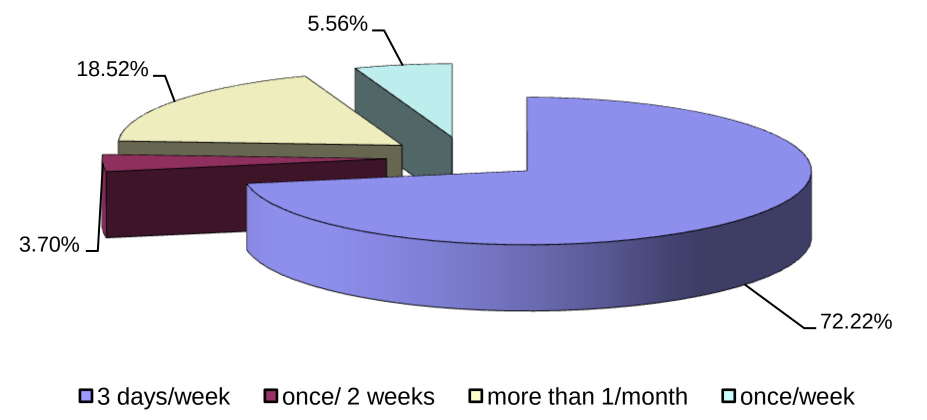

Figure 13 Frequency of the piped water flows

Regarding the water quality aspect, more than half of the respondents expressed satisfaction. Only 2% considered the quality as bad while the perceptions from the remaining 46% were moderate. The reason as to why some considered the water quality as bad is because after a dry period of the taps, the first re-opened is turbid and occasionally has mosquito larvae. On the other hand, only 1% gives additional treatment to their water in the storage while the majority keep using it as it is. Despite that some of the respondents complained about the quality and yet did not deliver extra treatment. However during the "dry piped" period, the majority continue to consume the water from the storage while 41% prefer to purchase sachets water as a routine drinking water source. The reason why the people did not add extra treatment is because they believe the water has been treated well by the water works and to give extra treatment at family level, such as boiling, is costly in relation to the fuel for heating.

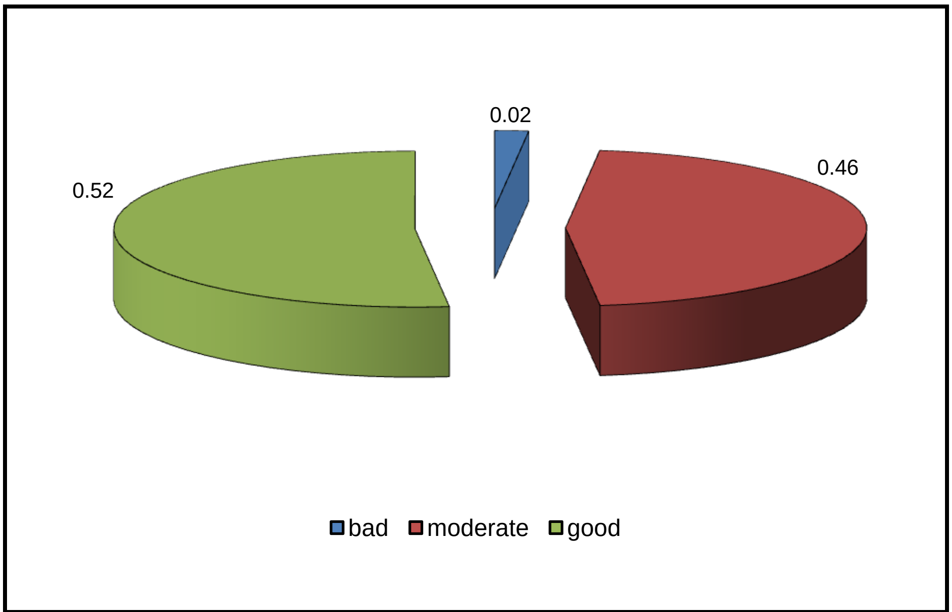

Figure 14 Perspectives of piped water quality

During the storage, 48% of the families reported the water quality declined by mentioning turbidity, appearance of mosquito larvae and changed colour. The decrease of water quality during storage may be due to improper cover of the storage and frequency of cleaning the vessels. Most of the families clean their containers once per week (41%), then 35% did it twice in a week, followed by once per month (7%), everyday (6%), every 2 weeks (5%), once every 3 months (3%) and 1% respectively for every 2 months, once per year and never. Cross contamination at the point of use will be further discussed in the next section.

4.2 Microbial quality of drinking water

As described in 3.2, enumeration of bacterial agents was performed by the membrane filtration technique to estimate *Coliform* densities. Water samples were collected from family containers, private taps at the compound yard, communal taps (during “dry” periods samples were taken from the tanks), public open dug wells, water sachets from vendors and water tankers. In general, mean of the results of laboratory analysis are listed in table below.

Table 13 Mean of *E. coli* from different drinking water pathways

Drinking water pathway	Number of samples	Mean *E. coli* cfu/100 ml
Household storages	110	12.95
Private taps yard	14	0.23
Communal taps dry (tank)	25	7.71
Communal taps wet	17	0.5
Communal wells	16	37.8
Water sachets	20	0.11
Water tankers	20	0.8

Apparently, results for the mean of *E. coli* from private taps had the same value as cited by Lunani (2007) from Cobbina (2004). The research was done in 3 different district

areas in Accra and the samples were taken from the taps. Ranges of faecal coliform, which was assumed as *E. coli*, were estimated between 0-10 cfu/100 ml with an average of 0.23 cfu/100 ml. Furthermore, from AVRL/GWCL water distribution monitoring data, it was shown that in 2009 the average of faecal contamination in Nima area was 2.6 MPN/100 ml, while the water quality from the treatment plant was complied with the standard (appendix C). From these results, it is clear that re-contamination happened within the distribution network. Probability of cross contamination in distribution systems is due to leakage, low pressure and biofilm growth in the pipes.

Furthermore, the data were statistically analyzed using the Mann-Whitney U-test to find difference between the obtained results and the WHO standard. It is shown that the outlet from taps (private yards & communal taps during wet period) were not significantly different (p= 0.0789 and 0.0801, respectively) from the standard (i.e. 0 cfu/100 ml) as well as from the water sachets (p=0.3421).

Table 14 U-test result to compare the water point with WHO standard

Sample points	Mean	median	P value	Significance level
Family storage	12.95	4	2.20E-16	***
Private taps yard	0.23	0	0.0789	n.s
Communal tap wet	0.5	0	0.0801	n.s
Communal tap dry (tank)	7.71	2	4.58E-05	***
Communal wells	37.8	47	2.53E-07	***
Water sachets	0.11	0	0.3421	n.s
Water tanker	0.8	0	0.0021	**

n.s: not significant; *: significant at α = 5%; ** significant at α = 1%; ***: significant at α = 0.1 %

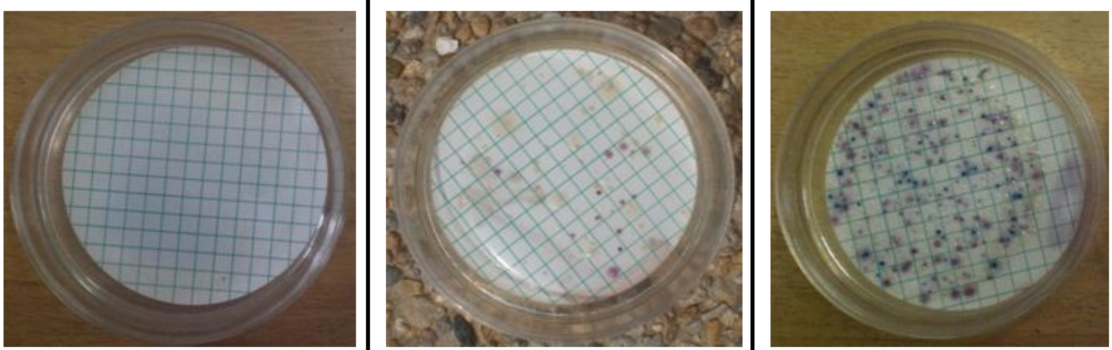

Figure 15 Result from bacteria enumeration: from bottled water (as baseline), private yard tap and family storage.

Afterwards, these *E. coli* results were interpreted further to others pathogenic agents, *Campylobacter, Rotavirus* and *Cryptosporidium* by using the ratio between pathogen and *E. coli* as described in section 3.2.2. The concentration for *Ascaris* was based on the laboratory analyses.

Based on the findings above, the microbial quality of the drinking water was decreasing from the sources to the point of use (family containers). This happens due to cross contamination during the transportation from the treatment plant to the users such as leakage and low pressures in the pipes. The leakage percentage within Accra is estimated as 30 % (AVRL/GWCL, 2009) and to make it worse, it was observed that some of the pipes are placed on the open sewer which mostly contains domestic waste water as well as solid waste.

The problem of post – source contamination is frequently experienced in developing countries (Jensen et al, 2002, Nala and Jagals, 2002, Oswald et al, 2007, Quick et al, 1999). Declining of the quality after storage occurred due to improper covering of barrels as the major storage facility, unhygienic mode of scooping water and the use of multiple receptacles in fetching water from the taps to the household containers. Nala and Jagals (2002) clearly indicated that family containers are a common factor for cross contamination since these vessels are in a poor state of hygiene. In addition to that, lack of secondary treatment (e.g. boiling, chlorination) and unhygienic environment is also another factor of the reduction of the quality of water at consumer level. The magnitude of re-contamination within the drinking water from the taps to the user in the study area is shown in the figure below.

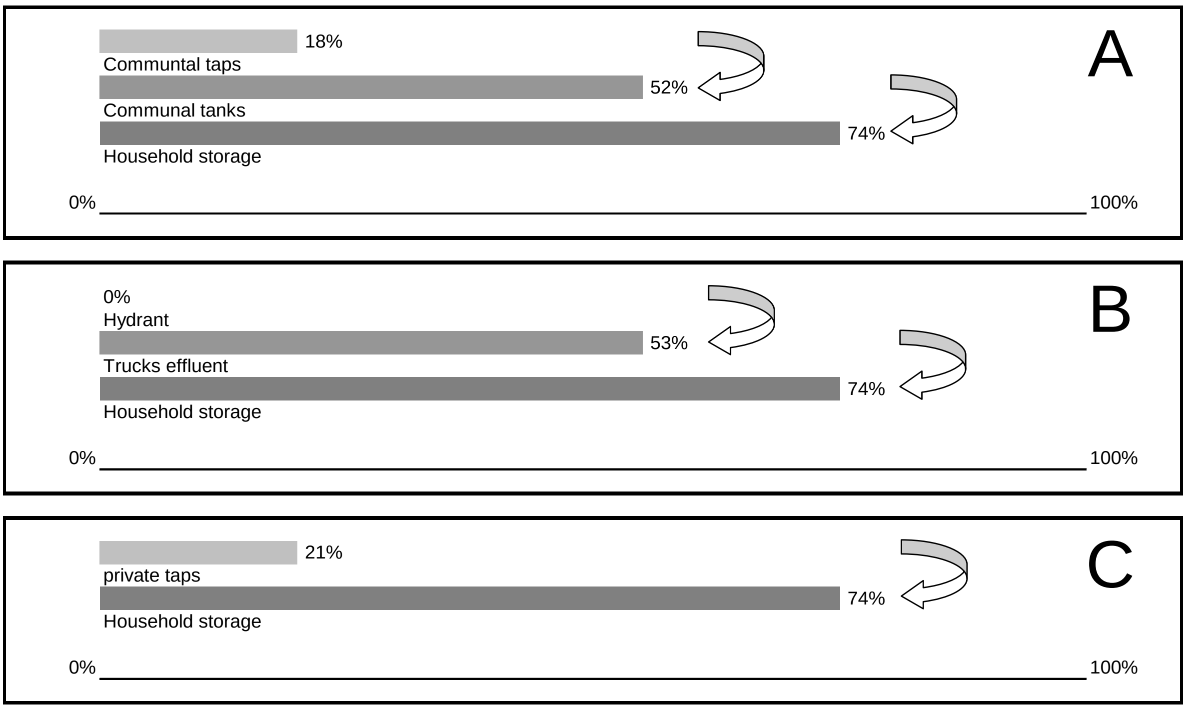

Figure 16 Increasing of *E. coli* contamination in drinking water. The percentage shows the number of contaminated samples. A: from communal points, B: from water tankers, C: private connections.

4.3 Microbial risk assessment

Quantitative microbial risk assessment (QMRA) was used as a means in estimating the risk from microbial contamination in the water supplies system. This approach required

the assessment of exposure risk from reference pathogens. These pathogenic agents are *E. coli*, *Campylobacter*, *Rotavirus*, *Cryptosporidium* and *Ascaris*. The rationale behind the selection of the references is that these agents are widely used as the indicator for water quality, since it is well-known that these pathogens can be transmitted through contaminated drinking water and thus, lead to infections to the receptors (WHO, 2006). The presence of *E. coli* indicates recent contamination of the water with faecal matter (Kimani – Murage and Ngindu, 2007)

Five, out of seven, drinking water pathways were assessed for their exposure risk. Two routes, communal tanks and water tanker were excluded with regards to fact that people were not drinking directly from these sources. Water coming from communal tanks and water tanker were incorporated into household storage.

The assumption made for volume of water ingested and frequency of drinking was explained in section 3.4. The number of exposed population was determined by the percentage of the respondents answer for specific route and then extrapolated to the entire number of inhabitants in Nima (table 15).

Table 15 Affected people per pathways in Nima

Pathway	Percentage to total respondents	Number of affected people in Nima [c]
Household storages	46%	3.17E+04
Private taps yard	17%	1.17E+04
Communal taps wet	25%	1.73E+04
Communal wells	3%	2.07E+03
Water sachets (regular taking)	9%	6.21E+03
Water sachets (irregular consumers) [b]	91%	6.28E+04

[a] This value is derived from only 10% respondents using wells and only children is drinking raw water from wells. Number of children is assumed as 30% of total population. [c] Estimated by percentage of population * total population in Nima (69,000). [b] This percentage was equal to the sum of all the pathways minus the regular water sachets consumers based on the observation that people were taking water sachets while they were away from home.

Based on these assumptions and the dose response formula, the risk from each drinking water route was assessed. Beta-Poisson model was used to estimate risk from bacteria and virus while protozoa and helminth were fit in exponential model (Haas et al 2009, Soller, 2006, Westrell, 2004). Table 16 shows the calculation from dose response equation for every pathogenic agent per drinking water pathways.

Ingestion dose was derived by mean of concentration multiplied by volume of ingestion. The highest probabilities of ingestion dose were derived from *E. coli* from wells ($3.78 * 10^1$) and closely followed by family containers ($3.77 * 10^1$). Ingestion dose of *Cryptosporidium* from irregular drinking water sachets indicated is the lowest amongst all the pathways per pathogen with the value of $5.00 * 10^{-9}$.

With regards to annual probability of infection via the various pathways (Table 16), the range for *E. coli* is $1.27 * 10^{-2}$ up to 1, then for *Campylobacter* between $4.36*10^{-2}$ to 1, *Rotavirus* is in the range from $1.54*10^{-6}$ to $4.64*10^{-3}$, *Cryptosporidium* is $5.17*10^{-9}$ to $1.56*10^{-5}$ and lastly for *Ascaris* is 1. From all the pathways, the lowest probability was found from consumed sachets water and the highest likelihood was from family storage. These results have higher level compared with Lunani (2007) which estimated the risk

per year from contaminated water at distribution network to be $5.8*10^{-3}$ for *Rotavirus*, $1.9*10^{-3}$ for *Campylobacter* and $4.1*10^{-6}$ for *Cryptosporidium*. The different tendency in likelihood of infection might appear due to the variation of value that has been used in the ratios of *E.coli* and the pathogen and also in the route of transmission. In this study the pathways were assessed in sequences from taps to point of use while Lunani (2007) generalized those as distribution network which might only cover the water from the taps. In comparison with acceptable annual risk as recommended by US EPA, 1 per 10,000 people (Hunter & Fewtrell, 2001), these results estimated that most of the exposure from bacteria, virus and nematode was exceeding the suggested value while the risk from protozoa was still below. In other words, people in Nima are having a high likelihood to be ill by only consuming their drinking water.

Figure below shows annual symptomatic cases per pathogen. A total indicative case from drinking water pathways was estimated as 91,514.6 cases every year. The greatest annual symptomatic case was derived from *Campylobacter* with 47,563 numbers per year from total routes. The lowest case was derived from *Cryptosporidium* where the contribution for symptomatic cases per year is 0.36 cases. If the highest cases per pathogen were listed in rank, *Campylobacter* would be the greatest then followed by *E. coli* with 41,860 cases per year, *Ascaris* with 2,051 cases annually, *Rotavirus* has 40.24 cases per year, and the last one would be *Cryptosporidium.* In addition, by breaking it down per route, household storage was pointed as the source of highest indicative cases followed by communal taps, while the least cases were derived from irregular consumption of water sachets. The rationale behind these values was related to the parameters used in calculation. For family storage it was due to the high ingestion dose as well as numerous affected populations (46%). Even though the highest affected population was estimated from irregular water sachets consumption (91%) however, the frequency of intake per year was assumed low as well as the dose. In summary, these 3 parameters are independent and very important to calculated annual symptomatic cases per route per pathogen.

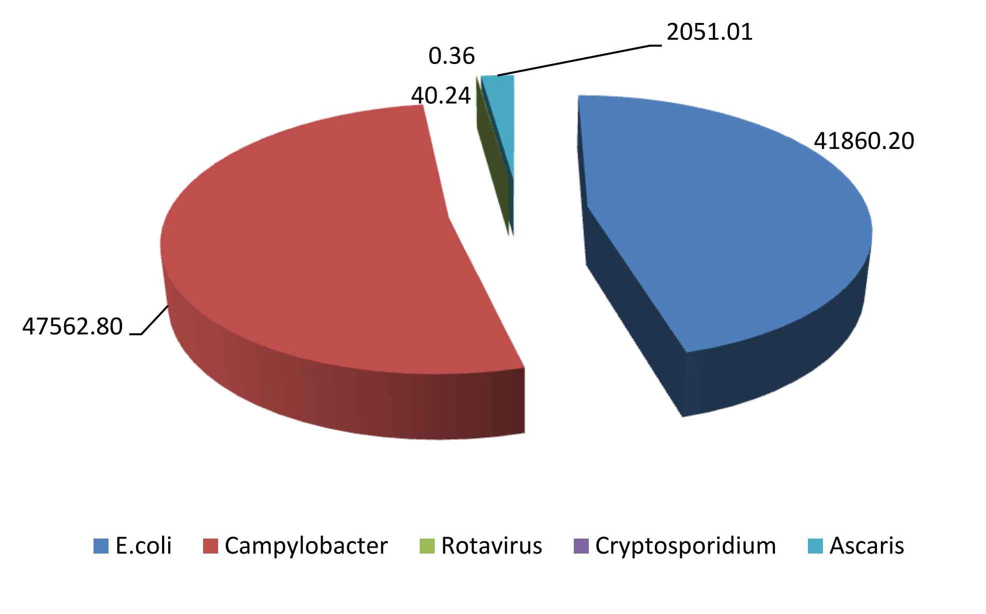

Figure 17 Annual symptomatic cases from each pathogen from sum of the pathways

Table 16 Ingestion doses and probability of infection per single exposure for each pathogen per pathways – *E.coli*

Pathway	Ingested volume in liter[a]	Mean of pathogen concentration	Ingestion doses[b]	Frequency per year	Probability of infection per single exposure	Exposed population	Annual probability of infection[d]	Annual no. of infection per exposure point[e]	Probability of developing illness[f]	Annual probability of developing illness[g]	Annual symptomatic cases [h]
E.coli											
Household storages	2.9	1.30E+01	3.77E+01	2.08E+02	1.24E-01	3.17E+04	1.00E+00	3.17E+04	4.35E-02	1.00E+00	3.17E+04
Private taps yard	2.9	2.30E-01	6.67E-01	1.56E+02	3.24E-03	1.17E+04	3.97E-01	4.66E+03	1.13E-03	1.62E-01	1.90E+03
Communal taps wet	2.9	5.00E-01	1.45E+00	1.56E+02	6.97E-03	1.73E+04	6.64E-01	1.15E+04	2.44E-03	3.17E-01	5.47E+03
Communal wells	1	3.78E+01	3.78E+01	5.20E+01	1.24E-01	2.07E+03	9.99E-01	2.07E+03	4.36E-02	9.01E-01	1.87E+03
Water sachets (regular taking)	2.9	1.00E-01	2.90E-01	2.08E+02	1.42E-03	6.21E+03	2.55E-01	1.59E+03	4.96E-04	9.80E-02	6.09E+02
water sachets (sometimes)	0.5	1.00E-01	5.00E-02	5.20E+01	2.45E-04	6.28E+04	1.27E-02	7.95E+02	8.58E-05	4.45E-03	2.79E+02

[a] Assumptions for volume ingested and frequency was explained in section 3.4. [b] Ingestion dose = ingested volume * mean of agent. [c] Estimation is based on equation 3.1. [d] Estimation is based on equation 3.3. [e] Estimation is based on equation 3.4 . [f] Estimation is based on equation 3.5 . [g] Estimation is based on equation 3.6 . [h] Estimation is based on equation 3.7.

Continue - Ingestion doses and probability of infection per single exposure for each pathogen per pathways - *Campylobacter*

Pathway	**Ingested volume in liter**[a]	**Mean of pathogen concentration**	**Ingestion doses**[b]	**Frequency per year**	**Probability of infection per single exposure**	**Exposed population**	**Annual probability of infection**[d]	**Annual no. of infection per exposure point**[e]	**Probability of developing illness**[f]	**Annual probability of developing illness**[g]	**Annual symptomatic cases** [h]
					Campylobacter[i]						
Household storages	2.9	1.17E+01	3.39E+01	2.08E+02	2.18E-01	3.17E+04	1.00E+00	3.17E+04	3.17E-02	9.99E-01	3.17E+04
Private taps yard	2.9	2.07E-01	6.00E-01	1.56E+02	1.10E-02	1.17E+04	8.21E-01	9.64E+03	3.30E-03	4.02E-01	4.72E+03
Communal taps wet	2.9	4.50E-01	1.31E+00	1.56E+02	2.28E-02	1.73E+04	9.72E-01	9.80E+03	6.83E-03	6.57E-01	6.61E+03
Communal wells	1	9.07E+01	9.07E+01	5.20E+01	3.10E-01	2.07E+03	1.00E+00	2.07E+03	9.31E-02	9.94E-01	2.06E+03
Water sachets (regular taking)	2.9	9.00E-02	2.61E-01	2.08E+02	4.89E-03	6.21E+03	8.33E-01	3.97E+03	1.47E-03	2.63E-01	1.64E+03
water sachets (sometimes)	0.5	9.00E-02	4.50E-02	5.20E+01	8.57E-04	6.28E+04	4.36E-02	2.74E+03	2.57E-04	1.33E-02	8.34E+02

[a] Assumptions for volume ingested and frequency was explained in section 3.4. [b] Ingestion dose = ingested volume * mean of agent. [c] Estimation are based on equation 3.1 for [d] Estimation are based of equation 3.3. [e] Estimation are based of equation 3.4 . [f] Estimation are based of equation 3.5 . [g] Estimation are based of equation 3.6 . [h] Estimation are based of equation 3.7. [i] Estimation for mean of Campylobacter are based on the ratio explained in 3.2.2 for ozonated water except for wells where the ratio from filtered water was used.

Continue - Ingestion doses and probability of infection per single exposure for each pathogen per pathways - *Rotavirus*

Pathway	Ingested volume in liter[a]	Mean Mean of pathogen concentration	Ingestion doses[b]	Frequency per year	Probability of infection per single exposure	Exposed population	Annual probability of infection[d]	Annual no. of infection per exposure point[e]	Probability of developing illness[f]	Annual probability of developing illness[g]	Annual symptomatic cases [h]
					Rotavirus [j]						
Household storages	2.9	1.30E-05	3.77E-05	2.08E+02	2.24E-05	3.17E+04	4.64E-03	1.47E+02	5.66E-06	1.18E-03	3.74E+01
Private taps yard	2.9	2.30E-07	6.67E-07	1.56E+02	3.96E-07	1.17E+04	6.17E-05	7.24E-01	1.98E-07	3.09E-05	3.62E-01
Communal taps wet	2.9	5.00E-07	1.45E-06	1.56E+02	8.60E-07	1.73E+04	1.34E-04	2.32E+00	4.30E-07	6.71E-05	1.16E+00
Communal wells	1	3.78E-05	3.78E-05	5.20E+01	2.24E-05	2.07E+03	1.17E-03	2.41E+00	1.12E-05	5.83E-04	1.21E+00
Water sachets (regular taking)	2.9	1.00E-07	2.90E-07	2.08E+02	1.72E-07	6.21E+03	6.28E-05	7.45E-04	4.04E-10	8.40E-08	5.22E-04
water sachets (sometimes)	0.5	1.00E-07	5.00E-08	5.20E+01	2.97E-08	6.28E+04	1.54E-06	9.69E-02	1.48E-08	7.71E-07	4.84E-02

[a] Assumptions for volume ingested and frequency was explained in section 3.4. [b] Ingestion dose = ingested volume * mean of agent. [c] Estimation is based on equation 3.1. [d] Estimation is based on equation 3.3. [e] Estimation is based on equation 3.4 . [f] Estimation is based on equation 3.5 . [g] Estimation is based on equation 3.6 . [h] Estimation is based on equation 3.7. [j] Estimations for mean of *Rotavirus* are based on the ratio explained in 3.2.2 the minimum value in the ratio (10^{-6}) was chosen since the assessment was performed for drinking water

Continue - Ingestion doses and probability of infection per single exposure for each pathogen per pathways – *Cryptosporidium and Ascaris*

Pathway	Ingested volume in liter[a]	Mean of pathogen concentration	Ingestion doses[b]	Frequency per year	Probability of infection per single exposure	Exposed population	Annual probability of infection[d]	Annual no. of infection per exposure point[e]	Probability of developing illness[f]	Annual probability of developing illness[g]	Annual symptomatic cases [h]
***Cryptosporidium*[k]**											
Household storages	2.9	1.30E-06	3.77E-06	2.08E+02	7.50E-08	3.17E+04	1.56E-05	4.95E-01	5.25E-08	1.09E-05	3.47E-01
Private taps yard	2.9	2.30E-08	6.67E-08	1.56E+02	1.33E-09	1.17E+04	2.07E-07	2.43E-03	9.29E-10	1.45E-07	1.70E-03
Communal taps wet	2.9	5.00E-08	1.45E-07	1.56E+02	2.89E-09	1.73E+04	4.50E-07	7.76E-03	2.02E-09	3.15E-07	5.44E-03
Communal wells	1	3.78E-06	3.78E-06	5.20E+01	7.52E-08	2.07E+03	3.91E-06	8.10E-03	5.27E-08	2.74E-06	5.67E-03
Water sachets (regular taking)	2.9	1.00E-08	2.90E-08	2.08E+02	5.77E-10	6.21E+03	2.11E-07	1.31E-03	4.04E-10	1.47E-07	9.16E-04
water sachets (sometimes)	0.5	1.00E-08	5.00E-09	5.20E+01	9.95E-11	6.28E+04	5.17E-09	3.25E-04	6.96E-11	3.62E-09	2.27E-04
Ascaris											
Communal wells	1	2.50E-01	2.50E-01	5.20E+01	2.21E-01	2.07E+03	1.00E+00	2.07E+03	8.63E-02	9.91E-01	2.05E+03

[a] Assumptions for volume ingested and frequency was explained in section 3.4. [b] Ingestion dose = ingested volume * mean of agent. [c] Estimation is based on equation 3.2. [d] Estimation is based on equation 3.3. [e] Estimation is based on equation 3.4 . [f] Estimation is based on equation 3.5 . [g] Estimation is based on equation 3.6 . [h] Estimation is based on equation 3.7. [k] Estimations for mean of *Cryptosporidium* are based on the ratio explained in 3.2.2 , the minimum value in the ratio (10^{-7}) was chosen since the assessment was performed for drinking water.

4.4 Burden of disease

The key component of QMRA implementation is to define the burden of disease from specific pathogens and it is expressed in DALY. Burden of disease per symptomatic cases was calculated in section 3.5. Then by using equation 3.9, disease burden per pathways for each pathogen was estimated.

Further, by breaking it down as per route of transmission, it is revealed that the major contribution for burden of disease in drinking water was from family's container with the value of 14,376 DALYs followed by regular intake from communal taps 2,540 DALYs then private taps as 1,023 DALYs, from wells it was 952 DALYs, and lastly is from water sachets, where for regular consumption it was developed 334 DALYs while irregular intake was only 158 DALYs. Figure 18 shows the burden of disease per pathogen for every pathway.

If the separation was based on the pathogenic agents, it was shown that the major burden of disease was derived from *E.coli* as 85.3% and the least contributor was *Cryptosporidium* with 0.0002%. Pathogens in between based on their rank were *Campylobacter* with 14.1%, *Rotavirus* as 0.08%, and then *Ascaris* contributed for 0.5%. Hence the total disease burden from drinking water was 19,384 DALYs**.**

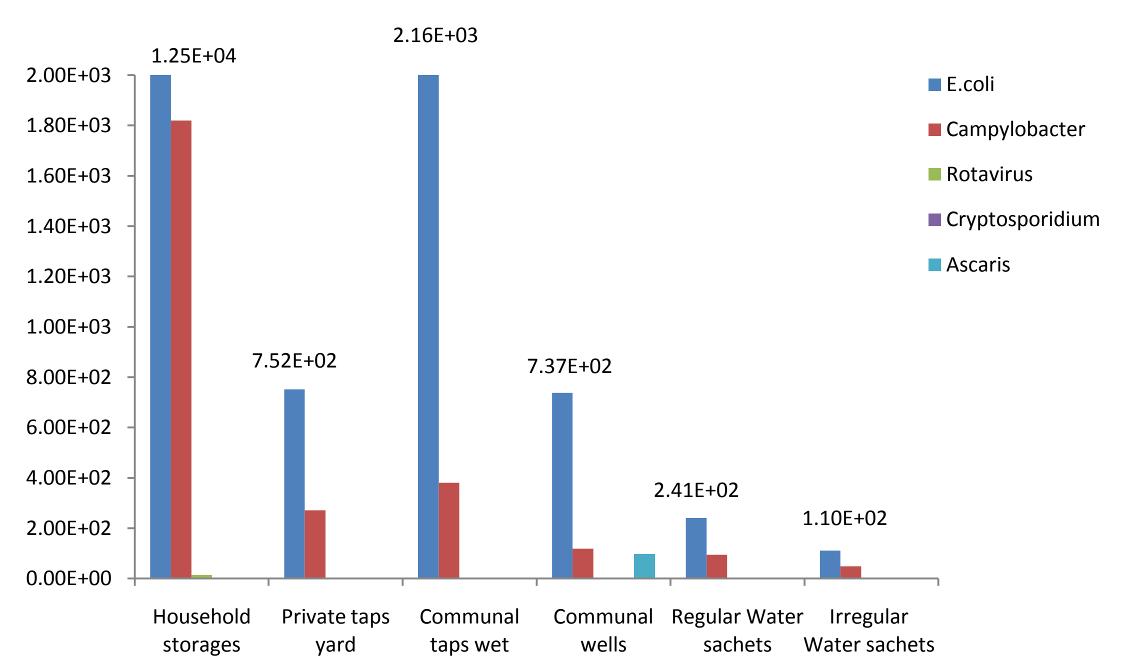

Figure 18 Disease burden per pathway per pathogen

WHO (2006) set the reference level of DALYs per person per year as 10^{-6}, however on their website as part of the rolling revision of its drinking water guidelines, in the section for level of protection, WHO (2007) set more realistic and achievable level such as 10^{-5} - 10^{-4} DALYs per person per year. Nevertheless, it has to be consistent to accomplish higher and safer quality. Mara and Sleigh (2010) used this adjusted level, 10^{-4} DALYs per person per year for their QMRA study in a developing country. Hence, result from this study was also compared with the standard level of 10^{-4} DALYs per person per year.

The result from disease of burden per pathogen (total DALYs/ total population) in Nima is, from *E.coli* $2.4*10^{-1}$ DALYs per person per year, *Campylobacter* $3.96 *10^{-2}$ DALYs per person per year, *Rotavirus* $2.3*10^{-4}$ DALYs per person per year, *Cryptosporidium* $4.85 *10^{-7}$ DALYs per person per year and *Ascaris* $1.40*10^{-3}$ DALYs per person per year. These values lead to total disease burden for gastroenteritis as 0.28 per person per year, which means that people were experiencing disability from this infection more than a quarter of the years annually. Comparing these values with the standard of 10^{-4} DALYs per person per year, it shows that bacterial and helminth were exceeding the reference, while viral was just slightly over and protozoa was still below the standard level. Same pattern was also observed when compared with the study results from Labite et al (2010) for QMRA in Accra urban water system, where *Campylobacter* was 10 times greater, and *Ascaris* were 70 times folded while for *Rotavirus* 0.007 times lesser and Cryptosporidium was 0.0012 times lower. The difference might be developed from dose response calculation where variation of assumption was applied, as well as from the number of total population in the study area.

4.5 Comparing the risk assessment incidence and endemic incidence

Comparison of endemic incidence with risk assessment incidence was developed by converting the incidence from risk assessment into incidence per 10,000 populations and then relates it with reported morbidity data. Table 17 shows the morbidity trend from Nima's clinic in 2007. Normally, data from the health centre in developing country is considerable underestimate since only a small proportion of the population are likely to seek for health assistance in the clinic due to financial issues and misconception of the disease seriousness (PURC-Consortium, 2008; Bundy, 1997). Hence, to estimate real number of cases in the study area, those reported cases had to be adjusted to account for underreporting. Assumption for underreporting was based on Lunani (2007) for waterborne disease incidence in Accra, with the rate of 82%.

Table 17 Morbidity Trend - Nima Government Clinic 2007

Diseases	No. of reported cases	No. of underreported cases [a]	Total incidence in study area	Incidence per 10,000 people
Malaria	5417	24677.44	30094.44	3.01
Upper Respiratory Infection	1013	4614.78	5627.78	0.56
Hypertension	581	2646.78	3227.78	0.33
Skin Infection	538	2450.89	2988.89	0.30

Rheumatism	395	1799.44	2194.44	0.22
Diarrhoea	328	1494.22	1822.22	0.18
Gynaecological Condition	280	1275.56	1555.56	0.16
Pregnancy and Related Infections	251	1143.44	1394.44	0.14
Oral Condition	187	851.89	1038.89	0.10
Home Accident	182	829.11	1011.11	0.10
Others	5874	26759.33	32633.33	3.26
Total	**15,046**	**68,542.89**	**83,588.89**	

Source: PURC-Consortium, 2008. [a] Estimation based on Lunani (2007), rate of underreported is 82%

Enteropathogenic agents such as *Rotavirus* and *E. coli* have been identified as significant pathogens in diarrhoea diseases. The severity of the etiological agent can be assessed by the setting in which it was most frequently isolated (community or inpatients). The severe agents should be more common in inpatients while the less severe would occur more frequently in community settings. Median proportions of diarrhoea episodes to each cause of diarrhoea could therefore be applied to calculate the number of diarrhoea by aetiology.

Next table shows the distribution of diarrhoea aetiology among children in Sub-Saharan Africa (Boschi-pinto et al. 2006). Since in this table *E. coli* is the sum from ETEC (Entero-Toxigenic *Escherichia coli*) and EAEC (Entero-Adherent pathogenic *Escherichia coli)*, it becomes the leading agent for the infection.

Table 18 Median of the Proportions of Etiological Agents of Diarrhoea disease

Etiological agent	**Contribution**			**Incidence per 10,000 people[b]**
	Community	**Inpatient**	**Total**	
E. coli [a]	12.7 %	22.6 %	35.3 %	0.06
Campylobacter	5.9 %	17.7 %	23.6 %	0.04
Rotavirus	6.2 %	19.6 %	25.8 %	0.04
Cryptosporidium	6.5 %	n/a	6.5 %	0.01

(source: Boschi-pinto et al, 2006)
[a] For *E.coli* it was a sum from ETEC and EAEC. [b] Diarrhoea cases per 10,000 population in table 18 * total contribution.

Incidence of diarrhoea from risk assessment was converted into incidence per 10,000 populations with proportions per aetiological agents (Table 19). This data was afterwards compared to the endemic diarrhoea incidence (Table 17). Based on this estimation, it was revealed that the incidence from risk assessment for bacterial agents was much greater than reported incidence of diarrhoea from the clinic while viral was estimated more than 30 times higher, though protozoa roughly had 0.3 times lower incidences compared to endemic occurrence. The least incidence of diarrhoea developed from *Cryptosporidium* could be related to the impact from this pathogen was predicted only from immuno-comprised person.

Nima's clinic was not the only health centre in the neighbourhood; therefore it is possible that inhabitants consulted other health care as well. Moreover, by comparing the risk

assessment with reported cases from only 1 clinic it might have led to an under or over estimation of the result.

Table 19 Incidence of diarrhoea per 10,000 populations from risk assessment

Pathways	Incidence/ 10,000 population[a]			
	E.coli	***Campylobacter***	***Rotavirus***	***Cryptosporidium***
Household storages	1623.64	1084.26	1.40	$3.26 * 10^{-03}$
Private taps yard	97.39	161.47	0.01	$1.60 * 10^{-05}$
Communal taps wet	279.63	226.23	0.04	$5.12 * 10^{-05}$
Communal wells	95.45	70.36	0.05	$5.33 * 10^{-05}$
Water sachets	31.14	55.93	0.00	$4.92 * 10^{-06}$
Water sachets (irregular)	14.30	28.54	0.00	$2.14 * 10^{-06}$
Total	**2141.54**	**1626.79**	**1.50**	$\mathbf{3.39 * 10^{-03}}$

[a] Annual symptomatic cases divided (Table 16) by the population of Nima (69,000) * 10,000 * % of contribution per agent (Table 17)

Table above stressed that the family storages was the main pathways to generated diarrhoea incidence in the community especially with *E.coli* as the major contributor of the illness. Hence action should be taken targeting this pathway due to numerous population exposed to this route as well as the frequency.

4.6 Options for improvement

4.6.1 Development of interventions

In order to control the risk from every pathway, ranking of threat was defined. Scoring for risk factor was explained in the section 3.6. Afterwards, based on this rank, scenario analysis was developed for the interventions. From section 4.4, it was clear that the most unsafe route was from family storage and irregular water sachets consumption was considered as more safe. However, to get the score to be applied in HACCP matrix, these DALYs per pathway were translated into percentage. Furthermore, as defined by Westrell (2004) these percentages were interpreted into impact to develop the score.

Table 20 Risk factor scoring

Step	Percentage of DALYs	Impact	Score
Household storages	74%	Catastrophic	5
Private taps yard	5 %	Moderate	3
Communal taps wet	13%	Major	4
Communal wells	5%	Moderate	3
Water sachets (regular)	2%	Moderate	3
Water sachets (irregular)	1%	Minor	2

(Adapted from WHO, 2006 and Westrell et al, 2004)

Prior to the scenarios development, corrective action for each step was identified using HACCP methods as presents in Table 21. HACCP is a management matrix that is developed to assure safe drinking water from every step and is widely used for piped

water safety plans. In this study, HACCP matrix was not only used for piped water origin (taps and family storages) but also for wells and water sachets to develop a comprehensive inventory of hazard and ways of controlling, and later to ensure safe water for the people. As described in 3.6, the corrective action should be considered when the risk factor is greater than moderate and thus, based on the results in the previous table most of the routes should be measured.

Table 21 HACCP for drinking water pathways

Step	Hazard events	Risk level	Target level	Control measure	Monitoring procedures	Corrective action
Household storages	Pathogen contamination scooping water & no proper cover	5	Absent of all pathogens	Hygienic cover for storage. Using a long handle of dipper. Additional treatment at HH level	Cover is remains hygienic in place. Dipper keeps in hygienic place when not in use. Disinfection practices at HH level. Regular water quality monitoring	Promotion and implementation of affordable HH disinfection. Hygiene promotion for the family
Private taps yard	Cross contamination from leakage	3	Absent of all pathogens	Leakage detection and rehabilitation	Regular field inspection by GWCL	Any leakage identified will be repaired immediately
Communal taps wet	Cross contamination from leakage	4	Absent of for all pathogens	Leakage detection and rehabilitation	Regular field inspection by GWCL	Any leakage identified will be repaired immediately
Communal wells	Cross contamination from sewer	3	Absent of all pathogens	Safe distance from latrines and sewer. No crack at the floor	Regular sanitary inspection	Immediate repaired of the crack in the floor. Re-located the wells if close to latrines or open sewer. Hygiene promotion
Water Sachet	Pathogen contamination from unhygienic media and process	3	Absent of all pathogens	Hygienic practices during process. Change media regularly	Regular quality assurance of the processed water from the owner and authorities	Quality assurance policy.

[Source: adopted from CODEX, 1993; Deere et al, 2001; Godfrey & Howard, 2004; Havelaar, 1994]

The next chosen intervention was made based on the effectiveness of diarrhoea reduction as investigated by Fewtrel et al (2005) as well as UNICEF (2007). Next chart shows that point of use water treatment has greater efficiency of reducing the infection than the intervention for the water supply system and treatment at the source. House hold water treatment could decline the incidence up to 39% while the treatment at the source only could reduce 11%. The rationale is because it was identified by this research and other studies that there was significant increase of contamination after water stored. This chart separated between hand washing with soap and hygiene promotion. It was highlighted that hand washing practices could reduce diarrhoea up to 44% while the hygiene promotion contribute for a decrease of 28%. However, in the next proposed scenario of intervention, these two interventions were merged as a general hygiene promotion which made the average 36% of reduction.

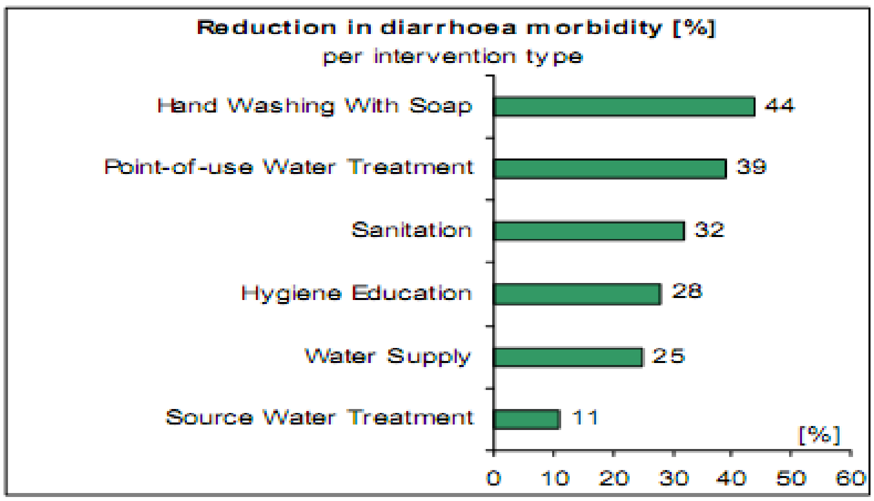

Figure 19 Reduction in Diarrhoea Morbidity per intervention type (Source, Fewtrel et al, 2005, UNICEF, 2007)

Intervention were selected and listed in order of the sequences from the water supply system until household level. This could also be interpreted in a way that the level of intervention was addressed from higher authority levels which had the option of more advance solutions and narrow down into family level where simple solutions were proposed.

Lee and Schwab (2005) highlighted that in developing countries the presence of a public water distribution network is often an indicator of improved water supply. However, it should not be assumed that it will always provide adequate water quantity and quality to the people. Failures in distribution system could be generated from loss of adequate chlorine residual, low water pressure and intermittent service which can lead to the declining of the supplied water to the consumer (WHO and UNICEF, 2000). Interruption of services is affected by water availability and could also be affected from some other factors, for example the capacity of the treatment plant and the season. Disruption of the water supply has been linked to a number of disease outbreaks in developing regions (Lee

and Schwab, 2005). Therefore, to reduce the probability of diarrheal infection in the community, first proposed intervention is to expand the water system and hence, people will receive water more regularly, and even more to reduce the preserving time of the water in the family vessels.

The average rate of water loss in the developing world was estimated between 37% - 41% (WHO and UNICEF, 2000). If leaks occur in the pipeline where the faecal contamination exists in the environment, the contaminants could be introduced to the supplies and later threaten the health of the beneficiaries. With the leakage reaching 30% within the study area, therefore the second option is rehabilitation of leakage within the distribution network as one of the methods to reduce cross contamination.

To improve public health, Caincross and Valdamanis (2006) were also pointed out to enhanced convenient access to safe water which is further defined as improved water supply. Household connections, public standpost, borehole and rainwater collection were among the technology that considered as improved. For this study, the proposed intervention for improving the access was to increase the household connection. The assumption was that all the public taps would be replaced with private connections, but however the bulk water in the system remained the same. This connection could reduce up to 63% of diarrheal illness while public sources could only decrease 17% (Caincross and Valdamanis 2006).

Then after that, the next step was at the point of consumption. From the laboratory examination it was shown that the water quality declined at the household level thus the fourth intervention is to introduce extra disinfection process at household level. Chlorination has demonstrated its effectiveness in inactivation of microbial pathogens; however, some enteric viruses and protozoa are more resistant to chlorine disinfectant (Stanfield et al, 2003, WHO, 2006). The next alternative is boiling the water before consumption, though it seems like not feasible to the poor community since it means they have extra expenses to purchase fire-wood (Field survey). Since all the organisms are susceptible to UV light (Stanfield et al, 2003), using solar radiation as disinfection method (SODIS) was also considered as the option to increase the water quality. Hence, treatment at the point of use by using chlorine and SODIS were chosen for the next interventions.

Possible sources of household storage contamination include unclean water containers, unhygienic domestic water handling practices, natural contamination from the domestic environment as a result of uncovered containers and biofilm occurrence in plastic containers (Fewtrel *et al.*, 2004). Hence the next option is to promote hygienic behaviour. Since the majority of people in Nima were using cup-type of scooper, thus the message would be to include hand washing with soap practice along with safe excreta disposal messages as well as domestic animal control.

Table 22 Intervention relation to DALYs

No	Options	Effected population	Scenario effect [a]	DALYs after intervention [b]
1	Water supply capacity expansion, at least the frequency increase into 5d/week	69,000	Reduction of diarrhoea 25% from taps route & HH storage	14899.31
2	Leakage rehabilitation (water supply)	69,000	Reduction of diarrhoea 25% from taps route	18493.21
3	100% coverage of private connection	69,000	Reduction of diarrhoea 63% from taps route [b]	16,767.30
4	Additional treatment at point of consumption with Chlorination or SODIS	69,000	Reduction of diarrhoea 39% from HH storage & public tanks	13777.59
5	Hygiene promotion	69,000	Reduction of diarrhoea 36% [c] applied for all routes	12583.23
6	Combination in water supply system (WS, 1,2,3) only	69,000		12,937 - 16,531
7	Combination in WS + HH treatment	69,000		8,732 - 11,161
8	Combination in WS + Hygiene promotion	69,000		8,712 - 12,975
9	Combination in HH treatment + Hygiene promotion	69,000		10,278
10	Combination of all	69,000		6,002 - 7,984

[a] Based on empirical estimation by Fewtrell et al, 2005 and UNICEF, 2007. [b] Based on empirical estimation by Caincross and Valdamanis 2006 [c] Estimated DALYs before intervention (4.4) at related pathways * (100 – percentage of reduction).

Table above is showing the effect of intervention to reduced DALYs. To obtain the reduction effect from the suggested option, assumptions were made based on literature and then applied to QMRA spreadsheet for specific pathways. It was resulted that option one could reduce up to 23% because with the expansion of the water system means less water interruption which also could lead to less water being stored in the containers. Leakage rehabilitation was estimated to reduce as 5% since this option was only affecting the water from the pipes and in addition to that the burden of diseases from this route was relatively small and thus, the outcome for the general DALYs reduction was also low. And for 100% coverage of private yard taps, it was estimated to reduce 13% of total DALYs. Baseline DALYs from household storage were estimated high, therefore intervention at these points of consumption resulted relatively high reduction as 29% from total DALYs. Promotion on hygienic practices was assumed only targeting the communities, thus it made the water sachets industries were not gaining benefit from this

intervention, but however the general reduction was considered as high as 29%. The last proposed interventions were combinations from all options. Combination on improvement at the water supply system was estimated to reduce DALYs between 15% - 33%, then to add up this option with disinfection at household level it will lead to 41- 55% of reduction. To combine household treatment with hygiene promotion, it could decrease the DALYs as much as 69%. And lastly, by attaching all the combination with promotion on hygiene practice, it would decrease the diarrhoea incidence between 59 - 69%. These estimates show that the disease burden is declined greatly by multiple interventions, most of which are being attached to behavioural change.

4.6.2 DALYs averted per intervention

Estimation for DALYs averted per interventions was based on the difference between the baseline value and the DALYs of the particular intervention. Option with the highest DALYs averted is considered as the preferable one. Next table presents the DALYs averted after intervention.

Table 23 DALYs averted per intervention per year

Intervention	DALYs baseline	DALYs after Intervention	DALYs averted
Water supply capacity expansion	19,384.07	14899.31	4,484.76
Leakage rehabilitation (water supply)	19,384.07	18493.21	890.86
100% coverage of private connection	19,384.07	16,767.30	2,616.78
Total DALYs with point of use treatment (Chlorine or SODIS)	19,384.07	13777.59	5,606.48
Hygiene promotion only	19,384.07	13840.43	5,543.64
Combination in water supply system (WS, 1,2,3) only	19,384.07	12,937 - 16,531	2,853 - 6,447
Combination in WS + HH treatment	19,384.07	8,732 - 11,161	8,223 - 10,283
Combination in WS + Hygiene promotion	19,384.07	8,712 - 12,975	6,409 - 10,672
Combination in HH treatment + Hygiene promotion	19,384.07	10,278	9,106
Combination of all	19,384.07	6,002 - 7,984	11,400 - 13,382

Outcome from leakage rehabilitation was the lowest with only 890.86 DALYs averted. The low effect from leakage rehabilitation is due to the fact that it only improves the water from distribution point and further it would get re-contamination during the transportation from taps until it is consumed. In case of point of use, the effect was only for water from household storage, however since this route was estimated with high DALYs thus the impact from these pathways reduced significantly. DALYs averted from household treatment was estimated as 5,606.48 while from hygienic behaviour it was averted as much as 6,800.85 DALYs. Multiple interventions in the water supply

system and distribution could only gain 2,853 - 6,447 DALYs while the highest averted were 11,400 - 13,382 DALYs originating from the combination of all the options. This result was in line with Eisenberg et al (2007) that the interventions should be integrated depending on the critical pathways that pathogens potentially transmit to human hosts and the consequent method to block them.

4.7 Cost effectiveness

4.7.1 Cost estimation

By definition, cost-effectiveness is the financial cost of producing a unit of effect, such as a reduction in the number of diarrhoea cases through some intervention, for example are point-of-use treatment and hygiene promotion (WELL, 2005). Effectiveness is defined as change in conditions and behaviours resulting from the interventions. The result that it has for health is here defined as impact and whether that impact is achieved at the lowest possible cost. Thus to make the selection of intervention, unit cost per option are listed below and further to be used for estimating cost effectiveness.

Table 24 Cost estimates for intervention

No	Intervention	Unit cost (USD) per capita per year	Effect of intervention (DALYs)[a]
1	Water supply capacity expansion [b]	121 (hardware and software)	Reduction 23% and more frequent piped water flowing
2	Leakage rehabilitation (water supply) [c]	24 (hardware and software)	Reduction 5%
3	100% coverage of private connection [d]	102 (hardware and software)	Reduction of 63% from private taps and communal taps no longer available
4a	Chlorination [e]	0.33 (hardware) + 0.65 (soft ware)	Reduction 29 % and 1095 L of treated water/ year [f]
4b	SODIS [g]	0.16 (hardware) + 0.65 (soft ware)	Reduction 29 % and 547.5 L of treated water/ year [h]
5	Hygiene Promotion [i]	0.65	Reduction 29%
6	Combination in water supply system (WS, 1,2,3) only	126 - 247	Reduction 15% -33%
7	Combination in WS + HH treatment	25 - 248	Reduction 42% -55%
8	Combination in WS + Hygiene promotion	24.65 - 223.65	Reduction 33% - 55%
9	Combination in HH treatment + Hygiene promotion	1.65	Reduction 69%
10	Combination of all	25.65 - 248	Reduction 59% - 69%

[a] Percent of reduction based on calculation by plotting the reduction from table 22 into DALYs calculation
[b] Estimated from Rida analysis report for water supply improvement in Greater Accra Region (SWITCH, 2009). [c]Based on Japan development project in India for water loss and reduction control. This cost included survey, monitoring & leakage detection, recording, repairs leaks & meters and others required

equipment as well as cost for consultation services (Tsuchiya, 2004). [d] Estimated from Caincross and Valdamis (2006) for house connection cost per capita in Africa region. [e] Hardware: assumed 150 ml of sodium hypocholite designated to treat 1000 L, thus the calculation with average price in Africa of $ 0.3/ bottle. Thus the calculation = $ 0.3/ bottle * (3 L/cap/day * 365 days/year)/ 1000 L (Clasen and Haller, 2008). Soft ware in here is socialization of the technique. [f] based on (3 L/cap/day * 365 days/year)/ 1000 L. [g] Hardware: in average $0.04 per bottle (price in Accra based on field survey) x recommended 2 bottles per person (alternate 1 bottles in sun, 1 bottles as alternate each day), used for 6 months; capacity based on 2 x 1.5L bottles (Clasen and Haller, 2008) Soft ware in here is socialization of the technique [h] Based on 1 bottles * 1.5 litres * 182.5 days (6 months) * 1 year/ 6 month. [i] Based on the hygiene program in Burkina Faso for 3 years period, the cost included administration, start up, house to house visit, discussion with health authorities, hygiene education sessions and hygiene theme performance (Christoffers et al, 2003).

As presented in Table 24, the most costly single intervention was to increase the frequency of piped water by expansion of the water system which requires USD 121 per capita per year. This estimation was based on the Rida analysis report from SWITCH (2009) to expand the current water supply system in Greater Accra region by increasing the capacity at the treatment plant as well as extracting from new sources. An increased quantity of water supply might also improve health by encouraging better hygiene practices and less retention time for water in the storages (Fewtrell et al, 2005).

The lowest cost derived from single intervention was from hygiene promotion, USD 0.65 per capita per year, which is including hand washing with soap promotion, safe water storage and in the end behavioural changes. This cost was only for soft ware (education and promotion), it does not include the cost for providing the necessity such as soap or water vessels. For point of use treatment, the cost estimated for hardware (chlorine solution and bottles for SODIS) was USD 0.33 and USD 0.16 for chlorination and SODIS respectively. However to implement this option it requires socialization and training, thus the price was added with software costs with same rate as hygiene promotion.

Combinations of all the proposed intervention were estimated quite additive to decrease diarrhoea up to 69%. The cost of multiple interventions had a big range from only USD 1.65 per person for the combination of point of use treatment with hygiene promotion to as costly as USD 248 per capita from the combination of all the suggested interventions.

In practice all of those costs are not personal expenses of the beneficiaries. For most of the interventions, the cost will be funded by the public and private sector or even NGOs and donor agencies, although at the implementation phase all of the stake holders should be involved. While for the option for household treatment it shall be the combination between implementer agencies and the users, where the agency delivers the education related to the treatment and the family provides the hardware (e.g. bottles for SODIS).

4.7.2 Cost effectiveness of interventions

The cost effectiveness ratio (CER) was calculated by dividing the annual unit cost (Table 24) with yearly DALYs averted per suggested intervention (Table 23) (Clasen and Haller 2008). The lowest value is considered as the most effective. However, CER are based on

gross cost of the interventions. Figure 19 illustrates the cost effectiveness from each intervention.

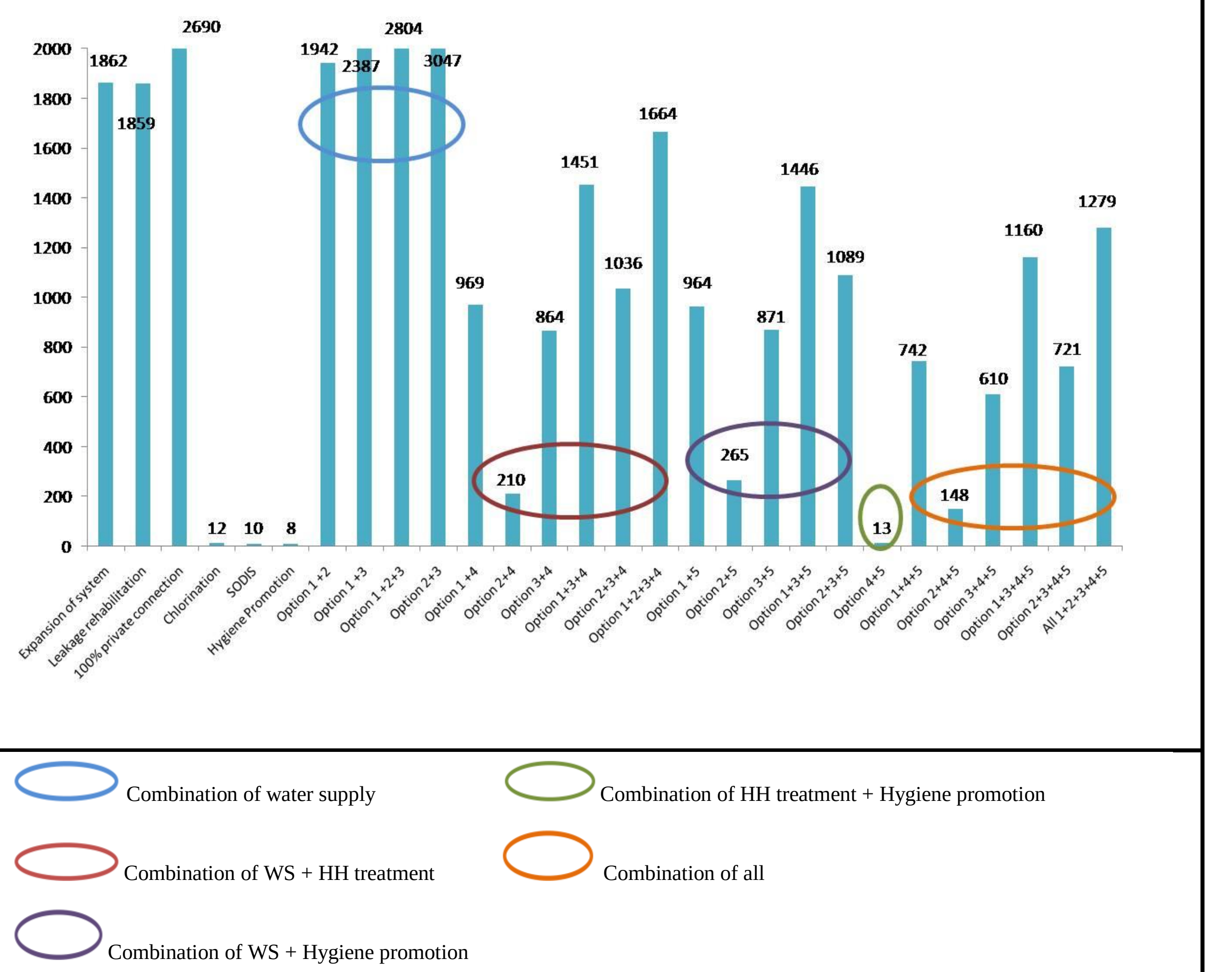

Figure 20 Cost in USD per DALYs averted for every intervention

Intervention in hygiene behaviour was the most cost effective with cost approximately USD 8 and followed by point of use treatment with SODIS and chlorination as USD 10 and USD 12 respectively. Multiple interventions resulted more costly with range between USD 13 to USD 3,047 per DALYs averted. The least cost effective for single intervention was estimated from expanding the private connection into 100% coverage which is as costly as USD 2,690 per DALYs gained. These results were in line with UNICEF working document (2007) as well as Caincross and Valdmanis (2006) which also pointed that hygiene promotion (including hand washing with soap) was the most cost effective intervention with average of USD 3.35 globally. It was also considered that disinfection at household level was cost effective with USD 20-24. Nevertheless, the intervention in water supply system was considered as very costly due to the high investment cost with low effect in the DALYs reduction.

4.7.3 Integrating CEA for drinking water with sanitation

Labite et al. (2010) calculated the cost effectiveness for intervention in water and sanitation for Odaw catchment area in Accra where 995,363 people lived in. The result was that the intervention on improvement in water supply system (upgrading treatment plant and distribution network) was less effective to reducing the diarrhoea compared to the investment in sanitation. However, this estimation was developed without any detail investigation on the drinking water pathways up to consumers' level. Moreover, for intervention in water supply system, cost estimation was not available for them, thus the cost effectiveness in USD per DALYs averted could not be calculated though it is logic that investment to enhance water system could be very costly. For the improvement of sanitation facilities and sewerage coverage, it was required USD 742 per DALYs averted. Then by combining this option with connection to treatment plant the cost was higher, USD 1,105 per DALYs averted. The most effective cost from sanitation was USD 516 for intervention in covering road side drainage.

Data from Labite (2010) was developed from a bigger affected population; however it is still useful to give a general picture regarding the interventions in urban sanitation sectors. Therefore, the result from present study were integrated with resulted from Labite et al (2010) to develop a better illustration for WASH interventions and presented in next table per sector.

Table 25 Cost effectiveness of WASH (USD/DALYs averted)

Intervention	Cost effectiveness (USD)
Sanitation	
Improvement of sanitation facilities and sewerage coverage plus connection to treatment plant	1,105
Improvement of sanitation facilities and sewerage coverage	742
Covering road side drainage	516
Water	
Water system expansion	1,862
Leakage rehabilitation	1,859
100% private connection	2,690
Household disinfection	10-12
Combination water system improvement	1,942 - 3,047
Combination of water system improvement with household water treatment	210 - 1,664
Hygiene Promotion	
Hygiene promotion only	8
Combination of water system improvement with Hygiene promotion	265 -1,089
Combination of Household water treatment with Hygiene Promotion	13
Combination from all water's intervention with hygiene promotion	148 - 1,279

Even though the combinations with the sanitation sector were not calculated, this compilation matrix clearly shows that the most effective investment was via hygiene promotion and the highest costs were from the combination in water supply, specifically

leakage rehabilitation and increased coverage of private connection into 100%. This was consequent with Clasen and Haller (2008) where they estimated that basic intervention for water at source base, for example an installation of borehole, could be as costly as USD 322 per DALYs averted in African regions, while in western pacific regions it could reach to USD 1,077 per DALYs averted. Hence it is justified that more advance interventions would be very expensive.

It is noteworthy to mention that, even though the hygiene promotion is shown as the most cost effective intervention, in practice the change can not be reached instantly. In addition to that, to monitor behavioural change is more challenging than monitoring the infrastructures since the human is far more complex then arranged building blocks. Therefore, in implementing hygiene promotion activities the support and good will from all the stake holders is required with long term plan for implementation, while the improvement in the infrastructure could be achieved in shorter period of time with strong quality assurance enforcement.

4.8 Uncertainties

The results from this research should be interpreted with prudence, given that there were assumptions made to estimate the risk assessment which could lead to uncertainties. Nevertheless, this study could give approximation condition regarding the public health risk to be used as a sketch for decision making.

The uncertainties of this study were generated from:

1) Number of samples for private and public taps, 14 and 17 respectively and 16 for wells it may not be sufficient to assess the concentration of pathogens in these routes.

2) Risk assessment for *Campylobacter*, *Rotavirus* and *Cryptosporidium* were developed from the ratio between concentration of *E. coli* and other pathogens. The ratio could not be accurate for the reason that it was originally for waste water (virus and protozoa) and from recorded data that has been used for stochastic modelling in The Netherlands for drinking water (*Campylobacter*). In addition to that, the association between the occurrences of one agent (e.g. *E. coli*) with the presence of other pathogen (e.g. *Rotavirus*) were reported as poor correlation (Ashbolt, et al, 2001).

3) Ingested volume for irregular water sachet consumer and children drinking raw well water might be under/over estimated. Estimation for others pathways was based on adult intake while children or elderly people might take lesser volume of water.

4) Frequency of consumption annually also could lead to inaccuracy of risk estimation, especially from wells and irregular water sachet consumption.

5) The rate of underreporting of morbidity cases at the Nima clinic. This might under or over estimate the real incidence.

6) Unit cost per intervention might be under or ever estimated due to the values derived from other countries' case studies and regional level.

7) Reduction from proposed intervention might be a flaw, especially for expanding the water system and the leakage rehabilitation, due to very limited research available for the relation between these options and water quality improvement.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

Based on estimation made by applying QMRA in domestic drinking water which also included HACCP and cost effectiveness approaches, the result of study are listed below.

1. Health status of people living in urban poor of Accra specifically in Nima is on threat and ironically the risks are generated from drinking water routes.

2. Five risk pathways from potable water were identified: family containers, private yard taps, communal taps, open dug well and water sachets. Amongst those routes, the most hazardous point was household storage while consuming water sachets was considered safer. Family storage considered unsafe due to poor hygienic practices of the people as well as by mean of multiple receptacle before it storage and consumptions. In another words, the water quality decreased from the sources to the point of use.

3. Most symptomatic cases per year were derived from family storage route. For this pathway, bacterial agent was identified with the highest annual symptomatic case as well as for other pathways. A high indicative case yearly was based on high dose of contaminant, numerous people were affected as well as frequency of consumptions.

4. Total disease of burden for Nima is 19, 384 DALYs where the major contributor was *E.coli* (85.3 %). Reference level used in this study was 10^{-4} DALYs per person per year as defined by WHO in the level of protection of rolling revision of its drinking water guidelines. Bacterial and helminth were exceeding the standard while viral was estimated slightly over the reference and protozoa were estimated still below it. Total of disease burden for Nima inhabitant was estimated as 0.28 per person per year. This meant that more than a quarter of their life in a year, people were having disability due to gastrointestinal illness originally from drinking water.

5. There were 5 single suggested interventions namely; expansion of water system, leakage rehabilitation, increased the private connection to 100% coverage, point of use treatment (chlorine and SODIS), hygiene promotion and multiple interventions; which was a various combination from single interventions. Based on cost effectiveness analysis, hygiene promotion was the most cost effective as USD 8 per DALYs averted and this option could reduce DALYs as 29% in Nima. However it is more challenging to implement this simple intervention compared to improvement in the water system since it is required long term implementation to notice the effect.

6. In general, this study is given higher estimated risk and DALYs from drinking water pathways compared to previous researches from Lunani (2007) and Labite (2008). The difference might be generated from various assumptions that been used, detail drinking water routes and number of exposed population. The similarity that these studies have is all the result of DALYs per person per year is generally exceeding the WHO reference level of 10^{-4} DALYs per person per year.

5.2 Recommendations

From the finding of this study, the recommendations are:

1. This study found that the greater risks in water supply system are deterioration in the distribution system and point of use. This means that more emphasis for improvement at these points rather than at the treatment plant process.

2. In addition to previous point, concerning the budget availability at the authority, it is suggested to decision maker to make a priority of intervention based on cost effective per disease burden averted. Furthermore, it also important to consider the implementation and monitoring aspect of the suggested option to ensure the sustainability.

3. For further studies:
    i. Expand the study area to middle and high income area to have comprehensive figure of the risk from drinking water pathways in Accra.
    ii. More investigation on morbidity report of water borne disease to have better comparison between risk assessment and endemic incidence.
    iii. More investigation for basic intervention in sanitation (e.g. family latrines) and their cost effectiveness to reduce diarrhoea.
    iv. Improve the uncertainties

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APPENDICES

Appendix A: Household questionnaires

QUESTIONARE UNESCO-IHE Accra Water Quality Survey
Location: Date:
Remark:

This is a survey about domestic water quality and use in Accra conducted by student at UNESCO-IHE, Delft – The Netherlands. Your participation is completely voluntary and you do not have to answer any question if you do not want to.

Background Questions:

1. Are you the head of household? [Yes] [No] Gender of Respondent: [M] [F]
   If NO – Who is? [Wife] [Husband] [Mother] [Father] [Other :]
2. What is the head of household's occupation? [ ]
   Respondent's occupation?
3. What is the highest level of education completed by the head of household?
   [Less than Secondary School] [Secondary School] [University and higher]
   Respondent's education?
4. How many people are in your household? [ ]
5. Please estimate your household's monthly income. [ ]
   How would you categorize your monthly income? [Very Low], [Low], [Middle], [High], [Very High]

The next section has questions about how you normally get water for use in your home:

6. What is the main way you get water for your home? [ ] *[Jump to that question]*
   And is this the only way (name other)? [ ](*Jump then also to those*)
7. Do you ever receive water from the water company piped directly to your home/yard?
   [Yes] [No] If YES – How often does the water flow?
   [Every day] [A few times a week] [Once a week] [Once every 2 weeks] [Less than once every 2 weeks]
   ∞ How much of this piped water do you use every day?
   ∞ Do you pay for piped water? [Yes] [No] I f YES – How much per month?
   To whom?
8. Do you get water from trucks selling water? (Tankers?)
   If YES – How often? [Every day] [A few times a week] [Once a week] [Once every 2 weeks] [Less than 1/ 2 weeks]
   ∞ How much water do you buy? *(Try to estimate tank by looking at it.)*
   ∞ How much do you pay?
   ∞ Truck tanker? Or truck with Polytank?
9. Do you get water from a public standpipe? [Yes] [No] If YES – How often?

[Every day] [A few times a week] [Once a week] [Once every 2 weeks] [Less than once every 2 weeks]

∞ How much of this water do you use every day? (estimate)

∞ Do you pay for this water? [Yes] [No] If YES – How much?

10. Do you get water from a neighbor's house? Or a private seller? Or a broken pipe? Bore hole? Well? *(circle)* If YES – How often? [Every day] [A few times a week] [Once a week] [Once every 2 weeks] [Less than 1/2 weeks]
    ∞ How much of this water do you use every day? *(estimate)*
    ∞ Do you pay for this water? [Yes] [No] If YES – How much?
11. During the rainy season, do you collect and use rain water? [yes] [no]
    If YES – What percentage of your overall water use is rain water during this time? (estimate)
12. Do you store water? [Yes] [No] If YES – How?
    ∞ What is the capacity of your family tank/ storage?
    ∞ Does the tank/storage allow you to always have water?
    ∞ How often do you clean your storage? [Once a week] [Once every 2 weeks] [Once every 1 months] [other:]
13. What source of water do you use for the following household tasks?
    Drinking :
    Bathing :
    Cooking :
    Wash Dishes / Clothes:
    Toilet Water :
14. Do you feel that you get enough water to meet your daily needs? [Yes] [No]
    If NO, how do you cope with water shortage?

Now we would like to hear your thoughts on the water quality in your area:

15. What do you think about the water quality in your area? [Bad] [Moderate] [Good] (Brief explanation)
16. Does your water smell? Turbid? Has colour? Wormy/insect during stored?
    After how long the water qualities in the storage change?
17. Do you do anything to treat your drinking water? [Yes] [No]
    If YES, How? [Let it settle] [Boiling] [Filtration] [Alum] [Disinfectant/chlorine] [other:]
18. Are there any illnesses in your household history related to water (e.g. diarrhoea, dysentery, typhoid)? [Yes] [No], if it YES name it:
19. What suggestions do you have for improving water quality in your area? (for GWCL or others)

(Adapted with modification from Ahn et al, 2008)

Appendix B: Sanitary inspection/ sample monitoring form

HOUSEHOLD Date

Name of family		Sample No
House condition		
Environment condition surrounding house		
Tap water is running/not		
No. of storage		
Volume of storage		
Type of storage		
Visual observation of the water in the tank		
Cover over the tank		
Additional treatment (Chlorine, alum, filtration, etc)		

PRIVATE TAP/ COMMUNAL TAP/PUBLIC TANK/ WELL Date

Type of source (standpost/ well/ neighbor taps)		Sample No
Location		
Vicinity of fecal contamination/ other pollution		
Drainage condition (e.g. any water stagnant)		
Floor condition (e.g. any crack)		
Pump/rope & bucket/ hose/ taps condition		
Remark		

Water tanker Date

Company name		Sample no
Truck plate no. and volume of tank		
Additional treatment at filling station (e.g. chlorine)		
Vicinity of any recontamination into tank		
Tank clean up/ time		
Ever used to transport other liquids besides drinking water		
Filler hose/ discharge pipe into tank condition		
Distribution hose condition		
Cover condition of the tank		

Water sachet Date

Brand		sample no
Registered no		
Visual condition of the water		
Visual condition of the package (tear etc)		
Volume		
Purchased from		

Appendix C: Water quality data in 2009 from AVRL/GWCL

Monthly average water quality from Weija TP

Period	Residual Cl_2	*E. coli* MPN/100 ml
Jan-09	0.9	0
Feb-09	1.1	0
Mar-09	0.9	0
Apr-09	0.9	0
May-09	1.0	0
Jun-09	0.7	0
Jul-09	0.6	0
Aug-09	0.6	0
Sep-09	0.5	0
Oct-09	0.5	0

AVRL/GWCL Water Quality data at distribution points

Month	Location	E.Coli MPN/100 ml	1 ml total plate count 37 ^{0}C
Jan-09	E78/10 Adenku street Nima	0	0
	E115/10 Adenku street Nima	0	0
	E60/10 Adenku street Nima	0	0
	E18/10 Adenku street Nima	0	0
	E26/10 Adenku street Nima	0	0
	E40/10 Adenku street Nima	0	0
Jul-09	E 122/2Nima	5	8
	E 109/2 Nima	5	32
	E 82/2 Nima	5	12
	E 66/2 Nima	3	20
	E 51/2 Nima	1.1	19
	E 32/2 Nima	1.1	23
	E 71/2 Nima	3	37
	E 163/2 Nima	3	25
	E 14/2 Nima	3	9
Aug-09	E 275/13 Mahogany Ext Nima	5	10
	E 222/13 Mahogany Ext Nima	5	4
	E 201/13 Mahogany Ext Nima	5	7
	E 267/13 Mahogany Ext Nima	5	6
	E 231/13 Mahogany Ext Nima	3	3
	E 212/13 Mahogany Ext Nima	5	2
	E 251/13 Mahogany Ext Nima	3	8
	E 209/13 Mahogany Ext Nima	5	5

(Source: AVRL/GWCL, Water Quality data 2009)

Appendix D: Laboratory analysis result

1. **Bacterial enumeration using Membrane filtration with Chromocult *coliform* agar**

Household storage

E.Coli	Total Coliforms	Salmonella	Other Enterobacters
51	51	0	51
4	45	0	51
12	50	0	51
0	20	0	35
0	22	0	30
42	51	0	51
0	50	0	40
0	51	0	20
12	30	0	0
0	51	0	51
0	0	0	10
1	51	0	20
0	0	0	20
51	51	0	51
4	19	0	32
3	51	0	51
40	51	0	51
47	51	0	51
5	35	0	48
30	42	0	48
4	51	0	51
4	47	0	51
3	45	0	47
5	42	0	40
7	40	0	30
51	50	0	51
9	50	0	50
8	46	0	48
50	50	0	30
30	51	0	10
0	51	0	40
0	49	0	38
0	51	0	51
45	51	0	51
4	49	0	51
1	30	0	45
5	51	0	50
0	51	0	51

3	50	0	51
14	51	0	51
1	51	0	51
2	47	0	51
0	40	0	51
50	51	0	51
38	29	0	50
45	51	0	51
47	51	0	51
23	42	0	51
31	51	0	51
0	51	0	51
2	31	0	50
50	50	0	51
11	50	0	51
38	51	0	51
50	50	0	52
5	48	0	51
31	34	0	48
1	36	0	35
12	11	0	32
3	51	0	51
0	51	0	51
0	40	0	51
2	51	0	51
0	51	0	51
25	50	0	50
40	51	0	10
37	51	0	50
15	42	0	31
10	32	0	21
0	30	0	24
28	46	0	38
0	33	0	41
4	39	0	50
7	24	0	40
14	48	0	50
2	30	0	37
0	40	0	50
45	50	0	50
4	51	0	50
0	50	0	50
0	50	0	50
50	50	0	50
0	50	0	51

15	51	0	51
20	51	0	51
0	30	0	51
30	51	0	51
2	2	0	40
2	51	0	0
15	50	0	51
2	51	0	51
0	51	0	51
3	40	0	41
0	50	0	50
0	48	0	49
6	51	0	51
0	51	0	51
10	51	0	51
30	51	0	50
3	50	0	51
20	51	0	51
0	51	0	52
1	51	0	51
0	40	0	51
6	51	0	51
15	51	0	51
2	46	0	50
3	40	0	47
4	42	0	42
5	38	0	30

Private yards

E.Coli	Total Coliforms	Salmonella	Other Enterobacters
0	7	0	25
1	11	0	35
0	12	0	21
1	23	0	34
0	1	0	29
0	2	0	39
0	46	0	50
0	8	0	35
0	8	0	18
1	26	0	31
0	8	0	20
0	0	0	21
0	12	0	35
0	30	0	51

Communal Taps

E.Coli	Total Coliforms	Salmonella	Others Enterobacters
1	20	0	30
0	50	0	42
0	50	0	48
0	50	0	48
0	51	0	51
0	26	0	30
0	23	0	34
0	39	0	30
1	31	0	37
0	16	0	31
0	10	0	25
0	15	0	29
0	25	0	51
0	25	0	30
0	15	0	20
0	50	0	51
7	51	0	51

Communal Tanks

E.Coli	Total Coliforms	Salmonella	Others Enterobacters
0	0	0	49
5	50	0	47
6	49	0	40
4	50	0	50
4	51	0	50
2	51	0	51
10	15	0	51
0	40	0	30
0	23	0	29
2	32	0	33
0	51	0	50
0	51	0	50
0	47	0	50
0	38	0	48
0	29	0	50
0	9	0	30
3	36	0	39
3	15	0	41
45	51	0	52
41	51	0	51
0	20	0	50
10	51	0	51
0	50	0	50
50	51	0	51
0	50	0	51

Wells

E.Coli	Total Coliforms	Salmonella	Others Enterobacters
51	30	0	51
51	51	0	51
51	30	0	50
51	51	0	52
45	52	0	51
51	51	0	53
51	40	0	51
47	51	0	49
42	50	0	10
50	51	0	51
10	51	0	50
7	53	0	51
40	51	0	10
47	49	0	50
15	51	0	52
9	51	0	51

Water Tankers

E.Coli	Total Coliforms	Salmonella	Others Enterobacters
0	11	0	26
1	38	0	34
0	38	0	31
1	39	0	32
0	29	0	35
0	45	0	40
2	37	0	42
1	46	0	47
0	18	0	28
0	35	0	41
0	24	0	42
0	41	0	39
0	40	0	32
2	43	0	45
4	41	0	50
4	50	0	50
0	35	0	29
0	41	0	45
0	45	0	44
1	42	0	39

Water Sachets

E.Coli	Total Coliforms	Salmonella	Other Enterobacters
0	4	0	30
2	20	0	50
0	8	0	20
0	1	0	21
0	6	0	35
0	2	0	10
0	1	0	20
0	1	0	21
0	1	0	16
0	0	0	8
0	1	0	15
0	0	0	4
0	0	0	20
0	0	0	28
0	3	0	35
0	1	0	20
0	0	0	10
0	1	0	5
0	1	0	8
0	0	0	12

2. Helminthes

Wells

No	Number	Type of Helminth
1	0	
2	0	
3	1	*Ascaris lumbricoides*
4	0	
5	0	
6	0	
7	1	*Strongyloides stercoralis*
8	0	
9	0	
10	0	
11	1	*Ascaris lumbricoides*
12	0	
13	0	
14	0	
15	1	*Ascaris lumbricoides*
16	0	

Household storages

no	Number	Type of Helminth
1	0	
2	0	
3	0	
4	0	
5	0	
6	0	
7	0	
8	0	
9	0	
10	0	
11	0	
12	0	
13	1	*Ascaris lumbricoides*
14	0	
15	1	*Strongyloides stercoralis*
16	0	
17	0	
18	0	
19	0	
20	0	
21	0	
22	0	
23	0	
24	0	
25	0	
26	0	
27	0	
28	0	
29	0	
30	0	
31	0	
32	0	
33	0	
34	0	
35	0	

Appendix E: Descriptive statistic

Household storage

E.Coli	
Mean	12.9450
Standard Error	1.5997
Median	4
Standard Deviation	16.7010
Skewness	1.1989
Confidence Level(95.0%)	3.1708

Private taps

E.coli	
Mean	0.23077
Standard Error	0.12163
Median	0.00000
Standard Deviation	0.43853
Skewness	1.45113
Confidence Level(95.0%)	0.26500

Communal taps

E.coli	
Mean	0.5
Standard Error	0.4378
Median	0
Standard Deviation	1.7512
Skewness	3.8731
Confidence Level(95.0%)	0.9331

Communal Tanks

E.coli	
Mean	7.7083
Standard Error	3.0393
Median	2.0000
Standard Deviation	14.8894
Skewness	2.2801
Confidence Level(95.0%)	6.2872

Water Tankers

E.coli	
Mean	0.8421
Standard Error	0.2988
Median	0
Mode	0
Standard Deviation	1.3023
Skewness	1.6738
Confidence Level(95.0%)	0.6277

Water Sachets

E.coli	
Mean	0.1053
Standard Error	0.1053
Median	0
Mode	0
Standard Deviation	0.4588
Skewness	4.3589
Confidence Level(95.0%)	0.2211

Wells

E.coli	
Mean	37.8
Standard Error	4.5431
Median	47
Mode	51
Standard Deviation	17.5955
Skewness	-1.0759
Confidence Level(95.0%)	9.7440

Helmiths wells	
Mean	0.25
Standard Error	0.1118
Median	0
Standard Deviation	0.4472
Skewness	1.2778
Range	1
Confidence Level(95.0%)	0.2383

Helmiths HH storage	
Mean	0.0606
Standard Error	0.0422
Median	0
Mode	0
Standard Deviation	0.2423
Skewness	3.8608
Confidence Level(95.0%)	0.0859

Appendix F: CEA calculation for option of interventions

DALYs Baseline:

Pathways	E.coli	Campylobacter	Rotavirus	Cryptosporidium	Ascaris	Total
Household storages	1.25E+04	1.82E+03	1.47E+01	3.22E-02	0.00E+00	**14375.60**
Private taps yard	7.52E+02	2.71E+02	1.43E-01	1.58E-04	0.00E+00	**1023.41**
Communal taps wet	2.16E+03	3.80E+02	4.56E-01	5.05E-04	0.00E+00	**2540.02**
Communal wells	7.37E+02	1.18E+02	4.76E-01	5.26E-04	9.64E+01	**952.21**
Regular Water sachets	2.41E+02	9.39E+01	4.38E-02	4.85E-05	0.00E+00	**334.47**
Irregular Water sachets	1.10E+02	4.79E+01	1.91E-02	2.11E-05	0.00E+00	**158.36**
Total	**16540.7703**	**2730.9859**	**15.8670**	**0.0334**	**96.4165**	**19384.07**
DALYs pppy	**2.40E-01**	**3.96E-02**	**2.30E-04**	**4.85E-07**	**1.40E-03**	**0.28**
	85.33%	**14.09%**	**0.08%**	**0.0002%**	**0.50%**	**100.00%**

DALYs affected from interventions:

Pathway	Intervention						
	1	2	3	4	5	1+2	1+2+3
Household storages	10781.70	14375.60	14375.60	8769.12	9200.38	10781.70	10781.70
Private taps yard	767.56	767.56	946.66	1023.41	1023.41	575.67	1079.38
Communal taps wet	1905.02	1905.02	0.00	2540.02	2540.02	1428.76	0.00
Communal wells	952.21	952.21	952.21	952.21	609.41	952.21	952.21
Regular Water sachets	334.47	334.47	334.47	334.47	334.47	334.47	334.47
Irregular Water sachets	158.36	158.36	158.36	158.36	158.36	158.36	158.36
total	**14899.31**	**18493.21**	**16767.30**	**13777.59**	**13840.43**	**14231.17**	**13306.12**

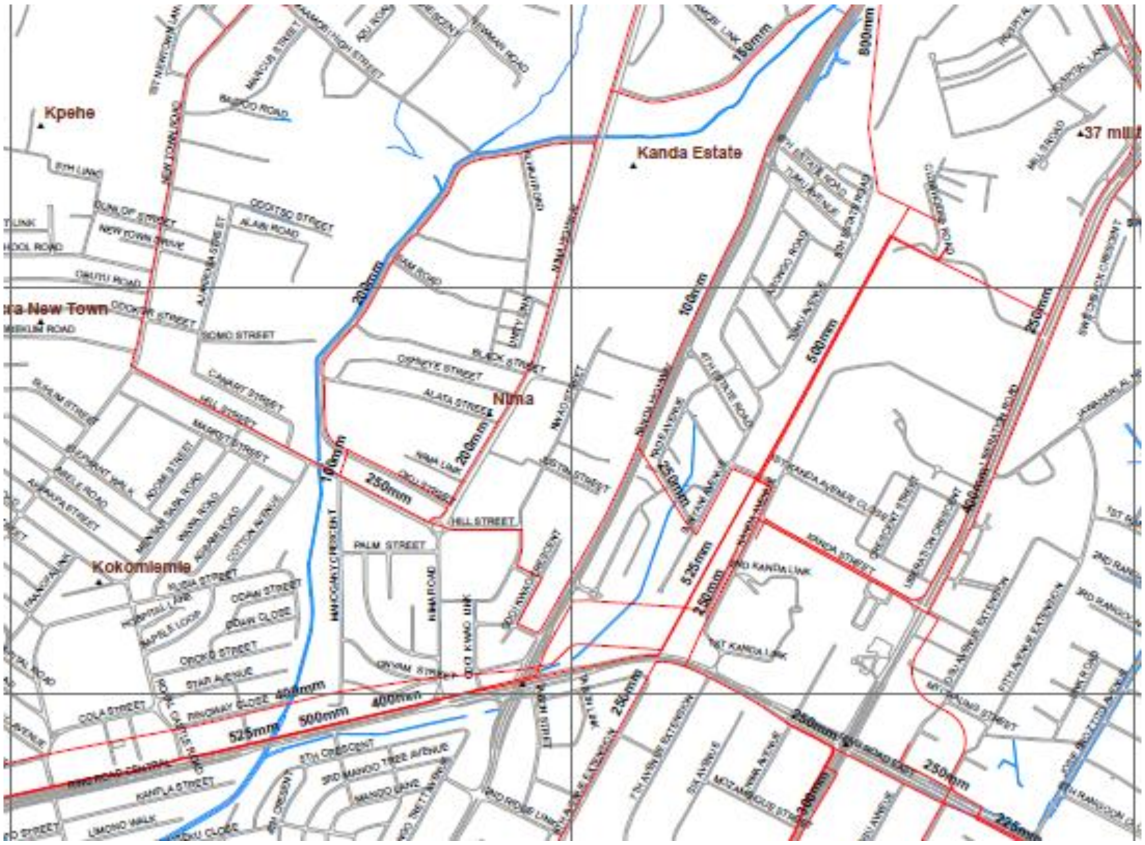
Pathway	Intervention					
	1+2+3+4	all	2+3	2+3+4	2+3+4+5	2+3+5
Household storages	6576.84	4209.18	14375.60	8769.12	5612.23	9200.384
Private taps yard	1079.38	690.80	709.99	709.99	454.39	709.9922
Communal taps wet	0.00	0.00	0.00	0.00	0.00	0.4411
Communal wells	952.21	609.41	952.21	952.21	609.41	952.2069
Regular Water sachets	334.47	334.47	334.47	334.47	334.47	334.4696
Irregular Water sachets	158.36	158.36	158.36	158.36	158.36	158.3629
total	**9101.26**	**6002.22**	**16530.63**	**10924.15**	**7168.87**	**11355.8566**

Pathway	Intervention			
	2+4	2+4+5	2+5	3+4
Household storages	8769.12	5349.16	9200.38	8769.12
Private taps yard	946.66	946.66	767.56	946.66
Communal taps wet	0.00	0.00	1905.02	0.00
Communal wells	952.21	609.41	609.41	952.21
Regular Water sachets	334.47	334.47	334.47	334.47
Irregular Water sachets	158.36	158.36	158.36	158.36
total	**11160.81**	**7398.06**	**12975.20**	**11160.81**

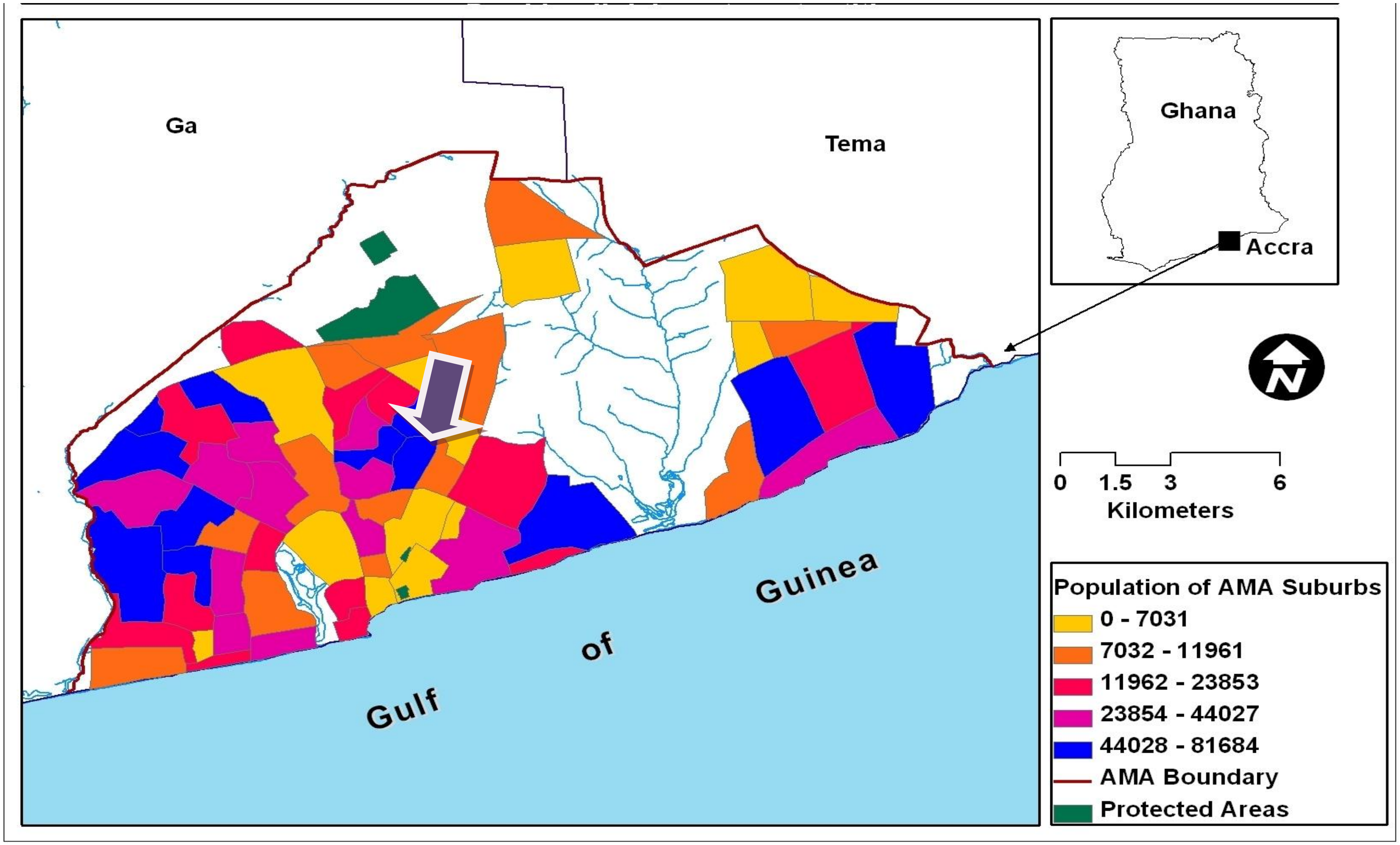
Summary CEA calculation

Intervention	Unit cost	DALYs			% reduction	Cost (USD) /DALYs averted
		Baseline	After intervention	Averted		
Single Options						
Expansion of system	121	19384.07	14899.31	4,484.76	**23**	**1862**
Leakage rehabilitation	24	19,384.07	18493.21	890.86	**5**	**1859**
100% private connection	102	19,384.07	16767.3	2,616.78	**13**	**2690**
Chlorination	0.98	19,384.07	13777.59	5,606.48	**29**	**12**
SODIS	0.81	19,384.07	13777.59	5,606.48	**29**	**10**
Hygiene Promotion	0.65	19,384.07	12583.23	6,800.85	**35**	**7**
Water supply system only (WS)						
Option 1 +2	145	19,384.07	14231.17	5,152.90	**27**	**1942**
Option 1 +3	223	19,384.07	12936.73	6,447.34	**33**	**2387**
Option 1 +2+3	247	19,384.07	13306.12	6,077.95	**31**	**2804**
Option 2+3	126	19,384.07	16530.63	2,853.44	**15**	**3047**
WS + HH treatment						
Option 1 +4	122	19,384.07	10694.45	8,689.62	**45**	**969**
Option 2+4	25	19384.07	11160.81	8,223.26	**42**	**210**
Option 3+4	103	19384.07	11160.81	8,223.26	**42**	**864**
Option 1+3+4	224	19,384.07	8731.87	10,652.20	**55**	**1451**
Option 2+3+4	127	19384.07	10924.15	8,459.93	**44**	**1036**
Option 1+2+3+4	248	19,384.07	9101.26	10,282.82	**53**	**1664**
WS+ Hygiene Promotion						
Option 1 +5	121.65	19,384.07	10675.11	8,708.96	**45**	**964**
Option 2+5	24.65	19384.07	12975.2	6,408.87	**33**	**265**
Option 3+5	102.65	19384.07	11249.29	8,134.79	**47**	**871**
Option 1+3+5	223.65	19,384.07	8712.53	10,671.55	**55**	**1446**
Option 2+3+5	126.65	19384.07	11355.86	8,028.22	**41**	**1089**
HH treatment + Hygiene Promotion						
Option 4+5	1.65	19384.07	10277.91	9,106.16	**69**	**13**
All						
Option 1+4+5	122.65	19,384.07	7984	11,400.08	**59**	**742**
Option 2+4+5	25.65	19,384.07	7398.06	11,986.01	**62**	**148**
Option 3+4+5	103.65	19384.07	7661.14	11,722.94	**60**	**610**
Option 1+3+4+5	224.65	19,384.07	6021.41	13,362.66	**69**	**1160**
Option 2+3+4+5	127.65	19384.07	7168.87	12,215.20	**63**	**721**
All 1+2+3+4+5	248	19,384.07	6002.22	13,381.85	**69**	**1279**

Appendix G: Maps



Distribution pipeline in Nima and surrounding area



Population densities in Accra Metropolitan Assembly area (arrow is pointed to Nima)