QUANTITATIVE HEALTH RISK ASSESSMENT FOR URBAN WATER SUPPLY IN SELECTED COMMUNITIES

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The thesis titled "**Quantitative Health Risk Assessment for Urban Water Supply in Selected Communities**" submitted by Md. Shafiul Azam, Student No. 040304114F, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of M. Sc. Engineering (Civil and Environmental) on 13th August 2005.

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I hereby certify that the research work reported in this thesis has been performed by me and this work has not been submitted elsewhere for any other purpose (except for publication).

August 2005

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Abstract

In Dhaka, water supply systems vary among communities from conventional piped water system to many improvised systems, such as hand pump fitted with tubewell, flexible pipes carrying water from main supply line, etc. In addition, there are also some shallow tubewells in slum areas. It has been found that in slum areas, piped water supply (38%) and shallow tubewells (31%) are two major water supply options. In low income areas, major options are hand pump connected with DWASA line (48%) and piped water supply (41%). Almost all connections in low come communities are individual house connections, while those of slum areas are community type. Middle and high income communities generally have house connections with reservoirs.

Microbial as well as some physico-chemical water quality parameters were tested for a total of 80 water points covering all communities. Sanitary Inspection was carried out for each water point. Sanitary condition of piped water supply without reservoir was found to be poor compared to other options. Shallow tubewell and piped water supply with reservoir, which are predominant in slum and middle / high income communities, respectively have relatively better sanitary condition. Boiling practice is common among middle and high income communities (nearly 79%). Among low income communities, the practice of boiling water is relatively low (44%); slum people usually do not boil their water.

Water quality determined through laboratory analysis was found to vary from community to community as well as from option to option. Ammonia concentration of 40% of supplies in low income community areas exceeded the Bangladesh drinking water standard, while for slum and middle/high income communities this percentage was 33% and 7%, respectively. This is probably because of the fact that a major portion of low-income community area under this study (Sabujbagh) is served by Saidabad surface water treatment plant, which is known to have high ammonia concentration during the dry season. Fifty percent of the water samples collected from different communities had sufficient chlorine at delivery end. About 46% of samples showed presence of FC. Among the supply systems, shallow tubewells were found to suffer least from microbial contamination. Hand-pumps fitted with DWASA line also suffer less from this problem. This is probably because of the fact that here water comes directly from the DWASA main, which contains some residual chlorine that acts against the microbial contamination. Piped supply without reservoir, which mostly serves the slum and the low-income areas, suffers from significant microbial contamination because here long, flexible, PVC pipes often carry water over wastelands, increasing the risk of pollution. In house connection with reservoir, if reservoirs are not cleaned frequently this can cause deterioration of microbial water quality.

Microbial water quality data were used in a Quantitative Health Risk Model to estimate and compare health risk burden of different water supply options in different communities. The upper confidence limit of DALY for middle/high income communities was found to be less (4.11 yrs /1000 py), in comparison to that of slum (15.91 yrs/ 1000 py) and low-income communities (15.57 yrs/ 1000 py).

Manifestation of waterborne diseases among different communities was estimated from a questionnaire survey, which showed higher prevalence of diarrhoea (8.5%) and typhoid (1.6%)

among low-income communities. Slum people reported slightly less prevalence of diarrhoea (2.1%) and typhoid (0.6%). Prevalence of hepatitis in both slum and low-income communities are almost similar (about 5.3%). Middle/high income communities did not report any incidence of typhoid, but reported nearly same prevalence of diarrhoea as observed among slum communities. Prevalence of diarrhoeal incidences as predicted by model is much less than the observed prevalence obtained from the questionnaire survey. This is probably due to the fact that there can be multiple sources of risk pathways contributing to diarrhoeal diseases, other than the water point.

A comparison of rural and urban water supplies shows higher health risk burden from urban water supply. Among all the water supply options, deep tubewell showed the lowest DALY values. Dugwells in rural areas appear to be the most risky option (having highest mean DALYs), while piped water supply with reservoir being the next. But unlike the users of dugwells in rural areas, middle and high income communities using piped water supply with reservoir usually boil their water, which reduces the risk significantly.

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ABBREVIATIONS AND ACRONYMS

APSU	Arsenic Policy Support Unit
BUET	Bangladesh University of Engineering and Technology
DALY	Disability Adjusted Life Years
DTW	Deep Tubewell
DW	Dug Well
DWASA	Dhaka Water Supply and Sewerage Authority
ETEC	Enterotoxigenic Escherichia coli
FC	Faecal Coliform
ICDDRB	International Center for Diarrhoeal Disease Research Bangladesh
ITN	International Training Network
LCL	Lower Confidence Limit
LTDL	Lower Total DALY Limit
NTU	Nephelometric Turbidity Unit
OHR	Overhead Reservoir
PVC	Polyvinyl Chloride
QHRA	Quantitative Health Risk Assessment
RAAMO	Risk Assessment of Arsenic Mitigation Options
SI	Sanitary Inspection
STW	Shallow Tubewell
TTC	Thermo-tolerant Coliform
UCL	Upper Confidence Limit
UGR	Underground Reservoir
UTDL	Upper Total DALY Limit
WHO	World Health Organization
WQHI	Water Quality Health Unit
WTP	Water Treatment Plant
WHI	Water Health Index

Chapter 1
INTRODUCTION

1.1 BACKGROUND

In Bangladesh, drinking water supplies, both in urban and rural areas are often found to contain contaminants (ITN-BUET, 2004). As a result we often ingest some amount of pathogens as well as chemical contaminants with drinking water. The potential risk associated with drinking water and for each type of contaminant (chemical or biological) can be expressed in terms of infections per person per year for a particular disease or as DALYs (Disability Adjusted Life Years). DALYs are preferred because they provide a single health outcome parameter that can aggregate the many possible health outcomes arising from any or a range of single or multiple hazardous agents and via different exposure pathways. (Deere et al., 2004)

Probability of infection is based on dose-response equations developed by extensive research involving human being and other species in laboratory or based on epidemiological study. The assumptions considered in different models affect the DALY calculated and there is no rigorous requirement to follow a particular dose-response model. Nevertheless the equations should be chosen on the basis of some geological (e.g., aquifer, soil type, presence of toxic substances, interference with other chemicals), technological (e.g., which technology is encountered) and meteorological (e.g., cold or hot country) factors (Teunis and Havelaar, 2002; Haas et al., 2000; Michael et al., 2001; Yu et al., 2003)

DALY involves three different components to be considered, which include (Deere and Davison, 2004)

1. Likelihood of infection or incidence of illness by pathogens or harmful chemicals
2. The severity of the infection or health hazard
3. Duration of exposure

For example, a specific type of pathogen like Cryptosporidium Parvum, if ingested, can cause mild diarrhea with a probability of infection of 7.1%, a severity of 0.067 (a value in between 1 and 0) and a duration of 7 days. (Havelaar and Melse, 2003).

So, DALY score for mild diarrhea per infection is: $0.067 \times \frac{7}{365} \times \frac{7.1}{100} = 9.1 \times 10^{-5}$ yr.

There can be hundreds of pathogens and other contaminants in water. It is impossible to deal with every pathogen or chemical. Hence only some index pathogens are chosen representing specific groups of pathogens. Selection criteria of these index pathogens include (Deere and Davison, 2004):

1. Waterborne transmission in an established route
2. High relative mortality or morbidity
3. High prevalence in a particular system considered
4. High persistence in environment and in many cases to some treatment options

The selection of index pathogens keeps the quantitative risk assessment more manageable and focuses on the 'worst case' pathogens contributing the most of disease burdens. Estimated disease burden attributable to index pathogens gives an estimate of the overall disease burden from all pathogens. The WHO recommended index pathogens are (WHO, 2004):

1. Rotavirus (an index of viral waterborne pathogens)
2. Escherichia Coli 0157 (an index of bacteria)
3. Cryptosporidium parvum (an index of protozoan pathogens)

The choice of index pathogens should be based on background information, testing and possible epidemiological data, if available.

The hazardous chemicals are chosen based on hazards, extent of impact and occurrence. For example, in acute arsenic affected areas arsenic could be chosen as a hazardous chemical; in urban areas where chlorination is in excess, risk due to chlorine overdose could be considered; impact of heavy metals should be considered where they have significant impact.

Recently a study has been carried out to assess risks of alternate water supply options in some arsenic affected rural areas (ITN-BUET, 2004). The study assessed four alternative water supply options namely; Dug Well, Deep Hand Tubewell, Pond Sand Filter and Rainwater Harvesting System. A risk model has been developed considering three index pathogens (Rota Virus, ETEC and Cryptosporidium Parvum) and one toxic chemical (arsenic). The model takes arsenic and TTC (Thermo-tolerant Coliform) concentration as input and gives output in DALYs for each contaminant considered and total risk burden. There are many assumptions in this model and there is sufficient scope for updating the model, especially if it is to be applied in the urban context.

Since urban water supply also suffers from water quality problems, this type of model can also be applied in urban areas. For example, the Dhaka WASA is supplying water to a large number of subscribers. The water that is supplied to the city dwellers is free from arsenic, but often not free from pathogens, which primarily occur due to contamination in the distribution network. Though in affluent communities people often boil water to kill pathogens, in low income communities and slum areas, people mostly drink the supply water directly. Thus, health risk burden on low-income communities are probably much higher than that on high-income communities. However, no work has been done to assess health risk burden of different segments of urban population as a result of poor water quality.

1.2 OBJECTIVES OF THE STUDY

The overall objective of this study was to assess health risk burden resulting from poor water supply in Dhaka city using a quantitative health risk model.

The specific objectives were to:

1. collect the baseline information on water quality of Dhaka city with a view to establishing the specific parameters for a risk model;
2. measure selected water quality parameters in the water supply of different areas of Dhaka city including slum as well as affluent areas;
3. review the available health risk models and to adapt a Quantitative Health Risk Model for estimating the risk burden of water supply;

4. assess and compare health risk of different communities of Dhaka city;
5. compare urban and rural health risk burden from water supplies; and
6. assess health status of selected urban communities though questionnaire survey and compare results with model output.

1.3 METHODOLOGY

Collection of Baseline Data

Baseline data on water supply scenario in Dhaka city have been collected from secondary sources and through a reconnaissance survey.

Measurement of Water Quality

Samples of drinking water have been collected from different communities of city population. Sampling points within Dhaka city have been chosen based on socio-economic setting. Water samples have been collected from selected households of middle/high income, low income, and slum communities. Different water supply systems like house connection with or without reservoir, public standpost and hand tubewell have been considered in sampling plan. After sampling, microbial water qualities have been tested. The water samples have been analyzed primarily for Fecal Coliform and E-coli. In addition to testing microbial qualities, some physical and chemical parameters have been tested. The respondents were asked about other aesthetic qualities like color, turbidity and conductivity. Also the sanitary condition in the vicinity of the water points has been assessed by standard sanitary inspection (SI) forms.

Literature Review and Selection of Model

Available literatures on risk assessment have been reviewed. Based on different risk assessment techniques, a quantitative health risk model has been selected. Some modifications in the model have also been made to make the model more suitable for application in the urban context.

Application of the Model

Water quality and other data have been used in the risk model to assess health risk burden for different socio-economic settings and also for different water supply technologies.

Comparative study of risk burden for slum, low-income and middle or high-income communities have been made. Available data on rural water supplies have been used to compare rural and urban water supplies in terms of health risk burden. Health status of selected urban communities has been assessed through questionnaire survey, and the results gathered from questionnaire survey have been compared with model results to assess applicability of the health risk model.

1.4 ORGANIZATION OF THE THESIS

The whole thesis is organized into five chapters including this introduction chapter. In chapter two, a general description of urban water supply, particularly focusing on water supply in Dhaka by DWASA, has been presented. This consists of a brief description of Dhaka WASA, its function and institutional capacity, the supply system, system components and potential hazards.

Chapter two discusses quantitative health risk model, the methodologies involved and the adaptations made for this particular study. The different stages in risk model are described with examples, and at every stage the adjustment with the study is discussed. At the end, a process-step diagram of risk model for this study is presented.

Chapter four discusses the main work done in this study. At first the methodologies in the study are broadly discussed, and the different techniques and tools are interpreted. Results of water quality analysis and questionnaire survey have been presented in this chapter. Model application and model output have been described in detail.

Chapter five is the concluding chapter consisting of the major conclusions and recommendations for future study.

Chapter 2

URBAN WATER SUPPLY AND HAZARDS

2.1 INTRODUCTION

In Dhaka city there are more that 10 million people. This is an enormous undertaking for the water agencies to supply adequate water to all its population. The scarcity of water is a common problem now-a-days.

In Dhaka groundwater is the principal source of water supply. 'Dhaka Water Supply and Sewerage Authority (DWASA) is entrusted with the massive task of water supply in Dhaka city. Groundwater in Dhaka city is extracted through 426 deep tubewells and distributed to the city people though distribution networks. In addition to this deep tubewells there are two major surface water treatment plants at Saidabad and Chandnighat, and one smaller unit in Narayanganj.

In sparsely developed slum areas, DWASA supply water has not yet been ensured. This is also applicable for some rapidly growing low-income community areas. In both areas, illegal water collection is very common. Illegal water connections include collection of water from the nearest legal water point by using flexible, PVC or GI pipe, handpump fitted with WASA main line, etc. In addition to this, some NGOs (e.g., DSK) have also installed some shallow tubewells in slum areas.

2.2 DHAKA WATER SUPPLY AND SEWERAGE AUTHORITY

2.2.1 Background, Administration and Responsibilities

Dhaka Water Supply and Sewerage Authority (DWASA) was established under the water supply and sanitation ordinance, 1963. It looks after construction, expansion, operation and maintenance of water supply, sanitary sewage works and drainage system in Dhaka. According to the ordinance of 1963, DWASA was supposed to look after solid waste collection and disposal but the authority did not take it up and this component has been excluded in the amended act of 1996. As a result this activity remained with the Dhaka City Corporation (DCC). However, the storm water drainage which was looked after by Department of Public Health Engineering (DPHE) was transferred to DWASA by a government order in 1986. The responsibility of water supply to Narayanganj Pouashava was placed under DWASA in 1990. The WASA ordinance, 1965 has been repealed and replaced by Act 6 of 1996. Under this Act, the power of the authority is vested on a 12 member Board. Only 2 members are from the government and the rest are from water users, city corporation/pourashava, trade bodies and professional bodies. The chairman of the Board is appointed by the Government from among the members of the Board.

As per the new Act, a managing Director (MD) looks after the day to day activities of the Authority. He is supported by three Deputy Managing Director (DMDs). The functions of these DMDs involve financial, administrative, technical, planning and development activities. They are supported by officers and employers posted at the head office, six zonal offices and the treatment plant at Pagla. According to Management Information Report of August 1997, the total manpower of DWASA is 3265 against sanctioned posts of 3137. The department-wise breakdown is as follows:

Engineering Department	2105
Commercial Department	598
Secretarial (including Computer)	562
Total	3265

The primary responsibility of the DWASA are (1) To construct, operate, develop and maintain the necessary infrastructure to extract, treat and reserve water in order to supply pure water to the people, industries and the commercial organizations, (2) To construct, operate, maintain and develop waste treatment and disposal system, and (3) To construct, operate, maintain and develop storm sewer in order to remove the water logging problem of Dhaka City.

2.2.2 Water Supply Activities

The DWASA service area has been divided into seven zones of which six are in Dhaka and one is in Narayanganj. Table 2.1 presents recent statistics on DWASA services.

Table 2.1 Water supply system of DWASA

Sl. No.	Description	Unit	Position as on 30/06/01	Position as on 30/06/02	Position as on 30/06/03	Position as on 30/06/04	Position as on 30/06/05
1	Deep tubewells in operation	Nos.	353	394	391	402	418
2	Water treatment plant	Nos.	3	3	3	3	3
3	Water line	km	2127.48	2127.48	2358.86	2475.62	2520.91
4	Water connection	Nos.	191,087	202,894	212,543	217,003	225,489
5	Overhead tank in operation	Nos.	38	38	38	38	38
6	Public standpipes	Nos.	966	970	970	970	949

Source: DWASA, 2005

Table 2.2 shows that the DWASA water supply is heavily dependent on groundwater with more than 82 percent of total water production coming from groundwater source. It should be noted that besides domestic water demand, industrial and commercial institutions exert a significant demand on DWASA water.

Table 2.2 Source-wise water production of DWASA in July 2005

Source	Production capacity (MLD)	Actual production (MLD)	Production as % of capacity	Source-wise % of production
Groundwater	1,365.03	1,245.35	91.23%	82.51%
Surface water	310.10	263.97	85.12%	17.49%
Total	1675.13	1,509.32	90.10%	100.0%

Source: DWASA, 2005

2.2.3 Water Quality Monitoring by Dhaka WASA

According to DWASA sources, the groundwater and surface water extracted by the WASA are monitored regularly through its own Quality Control and Research Division. According to DWASA, the quality of groundwater supplied is in most cases within the acceptable limits set by the WHO guidelines (Saha, 2001). There is provision for chlorination to prevent contamination in the supply line. Like groundwater, the surface water is also chlorinated before it is delivered into the supply line. Color, pH, turbidity, odor, temperature, dissolved oxygen, alkalinity, hardness, chloride, residual chlorine, calcium, total coliform and fecal coliform are usually tested in the quality control and research laboratory of the organization. In addition, groundwater samples from DTWs are also tested for arsenic every three months and river water samples are tested for chromium and aluminum every six months. Water samples are also collected from the supply lines by DWASA Quality Control and Research Division and the parameters listed above are tested (Saha, 2001). According to DWASA, necessary mitigation measures are adopted if there is any change in the quality of water.

2.3 HAZARDS IN URBAN WATER SUPPLY

Hazards can be microbial or chemical and both need to be taken care of. Before discussing the hazards in drinking water a description of piped water supply system is thought to be relevant at this stage. The total piped water supply system can be broadly divided into major components as follows:

Source → Collection → Treatment → Distribution → Consumer

In Dhaka city, the source of supply water can be either groundwater water or surface water. In case of groundwater in context of Dhaka city very little treatment is needed. So after extraction water is usually chlorinated and supplied to distribution network. In case of surface water, treatment involves processes such as coagulation, filtration, chlorination, etc.

After treatment water is supplied into the distribution network. Pumping is necessary to make adequate pressure in the network. From the distribution network water is supplied to service reservoirs or public standpost. Sometimes water is pumped into service reservoir and supplied to consumer. At last water is transported to the consumers by house tap connection or public-stand-post. In some cases water is also reserved temporarily in underground or overhead reservoir at consumer end. The generic flow system diagram of urban water supply system is given in Fig. 2.1.

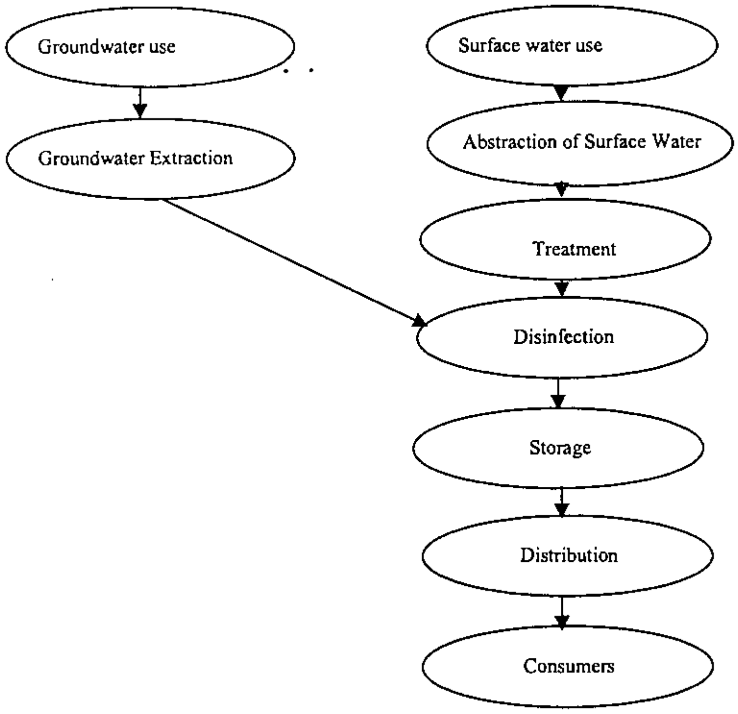

Fig. 2.1: Generic flow diagram of urban water system

Hazards can occur at every steps of the process flow diagram. Hazards can be microbial, chemical, physical or radiological. In the following sections different hazards, hazard identification, hazardous events, prioritizing hazards and control of hazards are discussed.

2.3.1 Hazard Identification

Hazards may occur or be introduced throughout the water system, from source to consumer. Effective risk management, therefore, requires identification of all potential hazards, their sources, possible hazardous events and an assessment of the risk presented by each.

The hazard identification step, therefore, requires consideration of all potential biological, physical, chemical and radiological hazards that could be associated with the water supply. Hazard identification should start with the water sources, and then progress through the validated flow diagram. At each step the objective is to identify what could happen to lead to contamination and the associated control measures for each hazard. The water safety plan team should also consider influencing factors such as:

- Variations due to weather
- Accidental or deliberate contamination
- Pollution source control practices
- Wastewater treatment processes
- Drinking water treatment process
- Receiving and storage practices
- Sanitation and hygiene
- Distribution maintenance and protection practices and
- Intended consumer use

The classification of hazards is described below.

Biological Hazards

The biological hazards include pathogens such as:

- Bacteria
- Viruses
- Protozoa and
- Helminths

Non-pathogenic organisms that influence the acceptability of drinking-water should also be considered. These include Asellus and Cylops.

It is not necessary or practical to completely eliminate microorganisms from drinking water supply systems. What is required is to keep numbers of pathogens blow levels determined to represent an acceptable level of risk as outlined in water quality targets.

Pathogens in water supply systems generally originate from human or animal faecal material containing raw water or that finds its way into the water supply delivery system. Common sources of contamination include sewage, birds faeces, vermin in or around reservoir, backflow from unprotected connections or during low/no pressure condition, etc.

Chemical Hazards

A chemical hazard can be considered as any chemical agent that may compromise water safety or suitability. According to source of chemical hazards, they can be grouped as shown in Table 2.3.

Table 2.3 Different types of chemical hazards

Chemicals from watershed/ catchments	Chemicals from reservoir storage	Chemicals from water treatment process	Chemicals from distribution
Nitrate Arsenic Fluoride Pesticides Other heavy metals Organic Toxicants Herbicides Rodenticides	Algal toxins Cleaners Liner chemicals Lubricants Pesticides Herbicides	Flocculants pH adjusters Disinfection by-products Impurities in treatment chemicals	Copper Lead Cleaners Petroleum products Liner Chemicals

Physicals Hazards

Physical hazards may affect water safety by posing a direct risk to health (e.g., choking hazards), by reducing the effectiveness of treatment (e.g., affecting the quantity of residual disinfectants) or by making water unacceptable to consumer and driving them to use more contaminated water sources. The most common physical hazard in water is sediment within the water supply. Sediments and particulates can also include pipe materials, pipe liner materials, sloughed biofilm or iron and manganese films. Suspended or resuspended sediments can contain toxic chemicals or can have pathogens attached and can co-transport other hazards.

Radiological Hazards

Radiological contamination of drinking-water generally occurs as a result of contamination by man-made sources of radiation. Contamination can arise from:

- Naturally occurring radioactive species in drinking-water sources
- The contamination of water from the mining industry and
- Radionuclide from the medical or industrial use of radioactive materials

2.3.2 Hazardous Events

Once hazards are listed it is important to consider the corresponding events that lead to their entry into the drinking-water supply. These might be termed hazardouse events or hazard causes.

Hazardous events can cause contamination directly and indirectly. For example, pathogens can enter water supplies directly from faeces. However, cynobacterial toxins result from growth of toxigenic cyanobacteria which are in turn promoted by a combination of factors. Factors such as nutrients, which can promote cyanobacteria proliferation, can lead to water becoming unsafe and should be considered as contributory factors leading to the presence of a hazard.

For distribution system, the situation is somewhat different, as the primary purpose is the prevention of contamination being introduced or re-growth in the pipes. In distribution systems an example of a hazard-pathway-receptor relationship is a pipe running at low pressure within a soil saturated with contaminated surface water derived from a leaking sewer above the main.

2.3.3 Controlling Hazards

Control measures are identified by considering the hazardous events that can cause contamination of water, both directly and indirectly, and the activities that can mitigate the risks from those events. These are the steps in supply that directly affect water quality and which collectively ensure that water consistently meets health-based targets. They are actions, activities and processes applied to prevent or minimize hazards occurring.

Flow diagrams are particularly valuable to support the identification of control measures. This is because it simplifies the task conceptually. There can be hundreds of control measures for a large system or for a water safety plan covering many small systems. Control measures are effective in reducing the levels of hazards (microbial or chemical) in a number of ways, such as:

- Reducing their entry into the water supply
- Reducing their concentration once in the supply or
- Reducing their proliferation

Control measures can be engineered or non-engineered. Engineered control measures include well-head protection, drinking water treatment plants, disinfection plants, storage reservoir and backflow protection. Non-engineered control measures are numerous and primarily include water safety considerations.

Resource and Source Protection

By decreasing contamination of source water, the amount of treatment and quantity of chemicals needed is reduced. This may reduce the production of treatment by-products and minimize operational costs.

Effective resource and source protection include the following elements:

- Developing and implementing a catchment management plan, which includes control measures to protect surface and groundwater sources.
- Ensuring that planning regulations include protection of water resources (land use planning and watershed management) from potentially polluting activities, and that the environmental regulations are properly enforced.
- Promoting awareness in the community about the impact of human activities on water quality.

Examples of specific control measures are shown below.

Source water and catchments

- Designated and limited use of sources
- Registrations of chemicals used in catchments
- Resource mixing/ destratification to reduce growths of cyanobacteria, anoxic hypolimnion and solubilisation of sedimentary manganese and iron
- pH adjustment of reservoir water
- control of human activities within source boundaries
- control of wastewater effluents
- regular inspection of source

- protection of waterways
- runoff interception
- security to prevent sabotage and tampering

Water extraction and storage system

- Use of available water storage during and after periods of heavy rainfall
- Appropriate choice of off-take depth from reservoir
- Proper well construction including casing, sealing and well-head security
- Proper location of wells
- Water storage systems to maximize retention times
- Securing tanks from access by animals
- Security to prevent unauthorized access, sabotage and tapping and tampering

Water Treatment

After source water protection, the next barriers to contamination of drinking water system are use of appropriate water treatment processes. Source waters of very high quality may only require watershed protection and disinfection. Control measures may include pre-treatment, coagulation-flocculation-settling, filtration and disinfection.

Pretreatment includes roughing filters, micro-strainer, off-stream storage and bank-side filtration. Pretreatment options may be compatible with a variety of treatment processes ranging in complexity from simple disinfection to membrane processes. Pretreatment can have the advantage of reducing or stabilizing the microbial load to the treatment processes.

Coagulation, flocculation, sedimentation and filtration remove particles, including micro-organisms (bacteria, viruses and protozoa). It is important that processes are optimized and controlled to achieve consistent and reliable performance. Chemical coagulation is the most important step in determining the removal efficiency of coagulation/flocculation/infiltration processes. It also directly affects the removal efficiency of granular media filtration units and has direct impacts on the efficiency of the disinfection process.

Various filtration processes are used in drinking water treatment, including granular, slow sand, pre-coat and membrane (micro-filtration, ultra-filtration, nano-filtration and reverse osmosis) filtration. With proper design and operation, filtration can act as a consistent and effective barrier for microbial pathogens and may in some cases be the only treatment barrier.

Application of an adequate level of disinfection is an essential element for most treatment systems to achieve the necessary level of microbial risk reduction. Estimation of the level of microbial inactivation through the application of the CT concept (product of disinfectant concentration and contact time) for a particular pH and temperature required for the more resistant microbial pathogens ensures that other sensitive microbes are also effectively controlled.

The most commonly used disinfection process is called chlorination. Ozone, ultraviolet irradiation, chloramination and chlorine dioxide are also used. These methods are effective in killing bacteria and can be reasonably effective in inactivating viruses and many protozoa, including Giardia. Cryptospodium is not inactivated by the concentrations of chlorine and chloamines that can be safely used in drinking water and the effectiveness of ozone and chlorine dioxide is limited. However ultraviolet light is effective in inactivating Cryptospodium.

Piped Distribution System

Water entering the distribution system must be bacteriologically safe and ideally should also be biologically stable. The disinfection system must provide a secure barrier to post-treatment contamination as the water is transported to the user. Residual disinfection will provide partial protection against microbial contamination, but may also make mask the detection of contamination through conventional faecal indicator bacteria such as E-Coli, particularly by resistant organisms. Water distribution system should be fully enclosed and storages should be securely roofed with external drainage to prevent contamination.

The control measures to protect distribution system can be listed as follows:

- regular maintenance of the distribution system
- availability of backup systems

- maintaining an adequate disinfection residual
- implementation of cross contamination and backflow prevention devices
- fully enclosed distribution systems and storages
- maintenance of a disinfection residual
- appropriate repair procedures including subsequent dinsinfection of water mains
- maintaining adequate system pressure
- maintaining security to prevent sabotage, illegal tapping and tampering

2.4 CONCLUSION

Urban water supply system is composed of long distribution networks, complicated collection and treatment and it is essential to ensure safety at every components. The various hazards can undermine the whole system and pose risks of waterborne diseases. Understanding the whole system, assessing the risk and prioritizing risk management routinely are essential to make piped water supply safe.

Chapter 3

RISK ASSESSMENT OVERVIEW

3.1 INTRODUCTION

Quantitative Health Risk Assessment (QHRA) involves the use of models to estimate the disease burden associated with specific exposure routes. Epidemiological tools are used for quantifying observed disease burdens. It has the advantage that they are based on estimates of disease burdens on observations of actual *in situ* populations. However, in practice the required data are either unavailable or involve extensive time and cost to acquire.

An important benefit of QHRA models is that they can be applied with the current understanding since current mathematical and logical expressions are fitted to the available data. So they provide a current estimate of disease burden.

Uncertainties involved in QHRA models can be explicitly identified and the effect of these uncertainties on estimated disease burden can be illustrated. Based on the uncertainties a logical framework can be worked out for future modifications of the model.

3.2 METHODOLOGIES OF RISK ASSESSMENT MODELLING

The classical risk assessment model involves the following five stages (WHO/FAO 2003).

1. Problem Formulation
2. Hazard Identification
3. Exposure Assessment
4. Does-Response Assessment
5. Risk Characterization

3.2.1 Problem Formulation

The first stage, problem formulation, involves defining the question and the scope of the assessment. In the context of urban water supply system, the health risk burden associated with water supply option in different socio-economic settings is the first thing to assess. It is also important to compare the health risk with the reference level of risk prescribed by the World Health Organization. A comparative study could also be made on different water supply patterns and amongst different communities.

Descriptions of a "reference level of risk" in relation to water are typically expressed in terms of specific health outcomes –for example, a maximum frequency of diarrhoeal disease or cancer incidence or maximum frequency of infection (but not necessarily disease) with a specific pathogen. There is a range of water-related illnesses with differing severities, including acute, delayed and chronic effects and both morbidity and mortality. Effects may be as diverse as adverse birth outcomes, cancer, cholera, dysentery, infectious hepatitis, intestinal worms, skeletal fluorosis, typhoid etc. Decisions about risk acceptance are highly complex and need to take account of different dimensions of risk. In addition to the "objective" dimensions of probability, severity and duration of an effect, there are important environmental, social, cultural, economic and political dimensions that play important roles in decision-making. Negotiations play an important role in these processes. The outcome may very well be unique in each situation. Notwithstanding the complexity of decisions about risk, there is a need for a baseline definition of tolerable risk for the development of guidelines and as a departure point for decisions in specific situations.

A reference level of risk enables the comparison of water-related diseases with one another and a consistent approach for dealing with each hazard. For the purposes of these Guidelines, a reference level of risk is used for broad equivalence between the levels of protection afforded to toxic chemicals and those afforded to microbial pathogens. For these purposes, only the health effects of waterborne diseases are taken into account. The reference level of risk is 10^{-6} disability-adjusted life-years (DALYs) per person per year, which is approximately equivalent to a lifetime excess cancer risk of 10^{-5} (i.e., 1 excess case of cancer per 100000 of the population ingesting drinking-water containing the substance at the guideline value over a life span). For a pathogen causing watery diarrhoea with a low case fatality rate (e.g., 1 in 100000), this reference level of risk would be equivalent to 1/1000 annual risk of disease to an individual (approximately 1/10 over a lifetime). The reference level of risk can be adapted to local circumstances on the basis of a risk–benefit approach. In particular, account should be taken of the fraction of the burden of a particular disease that is likely to be associated with drinking-water. Public health prioritization would normally indicate that major contributors should be dealt with preferentially, taking account of the costs and impacts of potential interventions. This is also the rationale underlying the incremental development and application of standards. The application of DALYs for setting a reference level of risk is a new and evolving approach. A particular challenge is to define human health effects associated with exposure to non-threshold chemicals.

3.2.2 Hazard Identification

The original QHRA model developed by ITN BUET was limited to three index pathogens and one chemical hazard. For this particular study in Dhaka city, the model input of arsenic is always set to zero as groundwater of Dhaka is free of arsenic. So the focus was on the three index pathogens and they are described below.

3.2.2.1 Index Pathogens

There are over 100 waterborne gastrointestinal pathogens (Deere and Davison, 2004). Undertaking a QHRA assessment for all these would be an extensive process. However, pathogens can be grouped with one pathogen being selected from each group as a representative of itself and the others. Selection criteria for index pathogens are (Deere and Davison, 2004):

- Waterborne transmission in an established route
- High relative resistance to environmental inactivation compared to others in the group
- High relative prevalence in the community of interest compared to others in the group
- High relative specific infectivity compared to others in the group
- High relative morbidity or mortality consequence compared to others in the group
- High relative resistance to water treatment compared to others in the group.

The use of index pathogens makes the quantitative health risk assessment more manageable in scope. Also at the same time it focuses on the worst case pathogens. Index pathogens have high relative infectivity and symptom severity, high relative source abundance and resistance to removal and inactivation. Index pathogens are expected to provide maximum contribution to overall risk burden of all pathogens, and hence estimation of risk burden on index pathogens is approximated to be the overall risk burden.

WHO recommended the following pathogens as index pathogens (WHO, 2004):

- Rotavirus (as an index of virus)
- Escherichia coli 0157 (as an index of bacteria)
- Cryptosporidium parvum (as an index of protozoa)

Rotavirus

The selection of rotavirus as viral index is reasonable for Bangladesh since the infection is relatively common in Bangladesh. Probably this is the most common gastrointestinal virus. (Deere and Davison, 2004). In addition to this, a good does-response model based on human feeding trials is available.

Escherichia coli 0157

The bacterial index pathogen E. coli 0157 was proposed by WHO (2004) because of its symptom severity, the probability of severe illness and death from infection by E. coil 0157 is much higher than for many other bacterial gastrointestinal pathogens.

Cryptosporidium Parvum

The selection of cryptosporidium parvum as the protozoan index pathogen is reasonable. It is an established and relatively common cause of waterborne disease outbreaks. (Lee et al., 2002). In addition to this a good does-response model based on human feeding trials is available.

This is acknowledged that the drinking water as a significant transmission routes for those index pathogens have not yet been established in all contexts. Moreover it is not clear whether or not other pathogens are more significant than the chosen indices in terms of waterborne transmission and disease burden. However, it is likely that the estimation of disease burden based on the above-mentioned pathogens would provide an acceptable estimate of total disease burden due to gastrointestinal pathogens from waterborne exposure of urban water supply.

3.2.2.2 Other Hazards

Potential carcinogenic chemical should be considered as an input of QHRA model. In Bangladesh where groundwater is severely polluted by arsenic, it can be used as a chemical hazard. But as this study is focused on Dhaka City urban water condition and the groundwater of Dhaka City is free from arsenic contamination, it excludes the hazards quantification of arsenic. Based on the available data no significance hazard other than pathogen was found. But there is provision for further inclusion of hazards if any other hazards is deemed significant.

3.2.3 Exposure Assessment

The purpose of exposure assessment is to estimate the dose of hazard consumed by the consumers. In this study the following scenarios were considered:

The study was done in dry season where there is water crisis in many places of Dhaka and the outbreak of waterborne disease was prevailing. This was gathered especially from the print and electronic media coverage on water crisis and deteriorating water quality. During the rest of the year, more or less steady state condition prevails with respect to water quality. For the purpose of this study only the worst condition prevailing during the dry season was considered.

There are several steps involved in exposure assessment of pathogens. The various steps demonstrate the pathways of pathogens from sewage to consumption by consumers. The steps for exposure assessment are as follows:

1. Pathogen concentration in fresh sewage.
2. Mixing of sewage with drinking water through leakages, especially during low pressure condition or interruption of supply in case of intermittent supply.
3. Transportation of pathogens, survival in water against the residual chlorine level.

4. Addition of extra pathogens at supply end due to unsanitary condition and unhygienic practices.

5. Pathogen concentration in water sources at the point of consumption, and

6. Volume of water consumed without boiling.

In this study, only the last three steps of pathogen exposure assessment were considered. Unsanitary condition in the vicinity of water point was studied by a standard sanitary inspection form prepared in light of WHO recommended format (WHO, 2004). Faecal coliform concentration of water was tested. E-Coli count in water was estimated based on the test ratio found in this study (Appendix D). Later on, other indicator pathogens as representatives of virus, bacteria and protozoa were estimated based on established ratio found in different studies.

Faecal Coliform Concentration

In this study, Faecal coliform (FC) presence in drinking water is assumed to be the only parameter as a microbial input in the model. In a previous study conducted by ITN-BUET (ITN-BUET, 2004; ITN-BUET, 2005), Thermo-tolerant Coliform (TTC) was taken as one of the inputs of risk model. But in this study FC was chosen for ease in the detection of coliform colony. TTC coliform colonies are yellowish in color. On pink Lauryl Sulfate broth those are often difficult to detect. This also happens due to their very resemblance to other colorless and pinkish colonies. On the contrary, deep blue colonies of FC on light blue MFC broth are easily detectable.

For pathogens, the median, upper confidence level (UCL: 95^{th} percentile), Lower Confidence Level (LCL: 5^{th} percentile) concentrations of the faecal coliform (FC) were used as model inputs and these were derived from samples colleted from different water points in different socio-economic settings and then fitted into a standard log-normal distribution curve. The various water supply points were chosen based on field survey. The basic pattern of urban water supply scenario is unique. For example, water is collected from groundwater or surface water source, treated with addition of chlorine and then supplied to community by a distribution network. Depending on extent of command area, the distribution line could be long with chances of having leaks. Also there are illegal connections, especially in slums. In many cases, flexible rubber pipe is used to collect water from DWASA main line. In some low-income and slum areas, handpump is directly connected with DWASA line. Typically there are conventional house connections with or without temporary storage facility. Temporary water storage facility can be overhead or underground reservoir or both.

Estimation of E-Coli

Some of the water samples were tested for E-Coil and thereby the ratio of E-Coli and FC count was set as 50%. In ITN-APSU model (ITN-BUET, 2004; ITN-BUET, 2005), the ratio, of E-Coli and TTC was 0.85. But in this study the ratio of E-Coli and FC was fixed based on the experimental data. No other corrections were applied to allow for laboratory or sampling error. An uncertainty in the model arises since only faecal coliform data are available to assess risk burden. This leads to an assumption of relationship between concentration of faecal indicator bacteria and faecal-oral gastrointestinal pathogens. These ratios are based on previous studies and described below in brief.

Ratio of E-Coli: Pathogens

Pathogens and E-Coli monitoring in raw sewage provides an indication of the ratio of pathogens to E-Coli that might be expected in human faecal matter deposited in the land, in water and in latrines. Therefore, in predicting pathogens based on E-Coli and pathogens ratio, available reports on sewage quality monitoring were assessed.

For viral pathogens, the ratio between total enteroviruses measured in sewage and indicator E-Coil in Melbourne, Australia was assumed to be representative of the ratio between E-Coli and Rotavirus. Raw sewage data show a ratio between E-Coli and rotavirus of 1: 1.1×10^5 (Stevens et al., 2004), although more locally relevant data would be more appropriate.

For bacterial pathogens, the ratio between salmonella measured in sewage and indicator E-Coil was assumed to be representative of the ratio between indicator FC and ETEC. Data from long term sewage monitoring of Melbourne, Australia show a ratio of E-Coli and ETEC 1: 1.5×10^5 (Stevens et al., 2004).

Similarly ratio between E-Coli and Cryptosporidium was selected 1: 6.2×10^6, considering their ratio to be representative of E-Coli and Giardia whose data are available from long term sewage data in Melbourne, Australia. (Stevens et al., 2004).

But in Bangladesh, pathogen concentrations may be higher than those in Australia. This is based on the following observation. Stool specimens from 1 in 50 hospitalized patients were analyzed to test for the presence of a limited number of important pathogens (ICDDRB, 2003). Results indicate that approximately 10% of samples are positive for rotavirus and similar portion are positive for Shigella. In contrast, pathogen prevalence in stools from 18- month prospective epidemiological study in Melbourne, Australia found presence of rotavirus in only 1.4% of faecal samples. This is an indication that in developing countries, the numbers of pathogens will be more compared to that in a developed country. So, in this study E-Coli: pathogens ratios for virus, bacterial and protozoan model reference pathogens were set at 10^5, 10^5 and 10^6, respectively. This is in line with the ITN-APSU study (ITN-BUET, 2004; 2005).

Volume of Water Consumed

The volume of water consumed was another important parameter which can affect the overall assessment. Watanabe et al. (2004) analyzed water consumption in two rural areas of Bangladesh. An Average of 3.1 liter /day was estimated. There was neither any significant difference between males and females water consumption nor between two communities of different villages. This is reasonably consistent with those of Milton et al. (2004), who estimated a mean direct water consumption of 3.53 l/day. Based on the above estimation ITN APSU model used a water consumption value of 2.91 L/day. In this study the volume of water consumed was set at 3.0 liter /day in accordance with all previous studies.

3.2.4 Dose Response Assessment and DALYs

Dose-response assessment involves predicting the probability of an adverse health-related outcome from an estimated dose of a hazardous agent. The outcome can be expressed in terms of infection, disease or as disability adjusted life years (DALYs). DALYs are preferred because they provide a single outcome parameter that can aggregate the many possible health outcomes arising from any or a range of single or multiple hazardous agents and via various exposure pathways. DALYs have been applied in this study because:

1. The promotion of health-based targets in contemporary guidelines of World Health Organization (WHO 2004)
2. There can be a variety of heath outcomes from any one infectious agent, and
3. The presence of a variety harmful agents related to particular water supply options.

3.2.4.1 Disability Adjusted Life Years (DALYs)

DALY involves three different components to be considered (Deere and Davison, 2004):

1. Likelihood of infection or incidence of illness by pathogens or harmful chemicals
2. The severity of the infection or health hazard
3. Duration of exposure

For example, a specific type of pathogen (e.g., E-Coli), if ingested, can cause mild diarrhea with a probability of infection of 10^{-5} per person per year (from dose-response equation) with a severity of 0.3 (a value in between 1 and 0) and a duration of 5 days. Then the DALY score for the disease burden is: $10^{-5} \times 0.3 \times \frac{5}{365} = 4.1 \times 10^{-8}$ yrs/py (py = person × year)

The rotavirus, Cryptosporidium and E-Coli 0157, DALY disease burden estimates described by Havelaar and Melse (2003) were selected for viral, protozoan and bacterial disease, respectively. But in context of the scenario of our country some modifications were made in the original prescribed data shown by Havelaar and Melse (2003). They have been described in the following sections.

Life-Expectancy

The life expectancy of Bangladesh at birth in 1999 was stated as 60.8 for males and 59.6 for females (BBS, 2004). Average life expectancies at birth of 62 years was therefore applied for both sexes in this study to incorporate a slight increase since 1999 which gave slightly different DALY values from those proposed by Havelaar and Melse (2003), who used a life expectancy at birth of around 80 years.

Background Level of Immunity

The background level of immunity to the viral, bacterial and protozoan reference pathogens were assumed to be relatively high due to the high background levels of diseases borne by hygiene-related and other routes of transmission. For viral reference pathogens, it was assumed that those older than one year were immune and then remain immune due to repeated asymptomatic re-infection and exposure. Therefore, a susceptible fraction in the general population of only 1.6 % was adopted, tenfold lower than the 17% proposed by Havelaar and Melse (2003). For the protozoan and bacterial reference pathogens the assumptions on background immunity of Havelaar and Melse (2003) based on developed world data were arbitrarily reduced by 10 fold to give a susceptible fraction of 7.1% and 9%, respectively. The tenfold difference may be reasonably good because for example Shigella and vibrio cholerae have been virtually eliminated from developed countries (Hellard et al., 2001) but that they are routinely isolated in Bangladesh in around 10% hospitalized patients whose stools are sampled regardless of condition (ICDDRB, 2003).

Probability of Death

The probability of death per symptomatic case (CFR) for the viral and bacterial pathogens was set at 0.23%, a figure based on the 1991 BBS census for hospitalized deaths from diarrhea. About 532,000 people were hospitalized in that year and 1250 people died. (0.23%). Hospitalized cases may be an over estimation of symptomatic cases but once hospitalized better treatment can reduce the probability of death making an underestimation of CFR. These two factors may balance out and 0.23% is reasonably consistent with the 0.6% and 0.4% CFR estimates by Havelaar and Melse (2003) for the developing world. The generally less severe protozoan pathogens were assumed to be less fatal with CFR of 0.01% being applied according to Havlaar and Melse (2003).

In summary, the DALYs per microbial infection applied in this study were 2.4×10^{-3} for virus, 1.3×10^{-2} for bacteria and 1.4×10^{-4} for protozoa.

3.2.4.2 Dose Response Assessment

The dose-response relationships for the model reference pathogens were based on reported human feeding trial (HFT) data as follows. For 'virus' the rotavirus model of Gerba et al. (1996) was applied with P_{inf} (Probability of infection for dose of one) of 27% and an ID_{50} (the dose leading to a probability of infection of 50%) of 6. This model was selected for the viral model reference pathogen since it was based on rotavirus, which is an endemic and routinely surveyed bacterial infection in Bangladesh. (ICDDRB, 2003), with the beta-Poisson being selected because it has been corroborated and widely used since being proposed by Gerba et al. (1996).

Dose-response equation for virus: Probability of infection, $P(\text{inf}) = 1 - \left(1 + \frac{dose}{b}\right)^{-a}$

Where, dose-response parameter a = 0.26 and b=0.42, dose in pfu/pd, pfu= plaque forming unit, pd= person-day. P(inf) in infections/day.

For bacterium, the Shigella dysenteriae model of Holcomb et al. (1999) was applied with a P_{inf} of 1 % and an ID_{50} of 219. This model was selected for bacterial model reference pathogen since it was based on Shigella, which is an endemic and routinely surveyed bacterial infection in Bangladesh. (ICDDRB, 2003). The Weibull-gamma relationship was selected since it provided the smallest overestimate at below-threshold doses from the acceptable-fitting infection models.

Dose-response equation for bacteria: Probability of infection, $P(\text{inf}) = 1 - \left(1 + dose^{x} / b\right)^{-e}$
This is a Weibull-gamma model. And the parameters x = 1.08, b = 22.5, e = 0.25, dose in cfu/pd, and P(inf) is in inf/day.

For protozoan the 'unknown strain' model for cryptosporidium pavum of Messner et al. (2001) was applied leading to P_{inf} of 2.8 % and an ID_{50} of 25. This model was selected for the protozoan model reference pathogen since it was based on cryptosporidium, a more environmentally mobile, persistent and infectious pathogen than the alternatives Giardia and Entameoba.

Dose-response equation for protozoa: Probability of infection, $P(\text{inf}) = 1 - e^{\left(-\frac{dose}{k}\right)}$ Here, k= dose-response parameter for protozoa = 35.2

The daily dose of pathogens consumed was converted to a daily probability of infection according to these dose-response relationships to give an infection endpoint prediction for each pathogen. The daily probability of infection was converted to an annual infection as described by Teunis et al. (1997), which provided the input to the calculation of DALY. According to this

Annual probability of infection $P_{annual} = 1-\{1-P\ (inf)\}^{365}$

3.2.5 Risk Characterization

Water Quality Health Index and Water Health Index

To simplify the reporting, the total DALY scores were normalized to give water quality health index (WQHI) scores. This involved normalizing the total DALY score for any particular value of input [FC] against a range with upper and lower limits. There are many ways of doing this. For example, one may compare the results with guideline values as follows.

The Lower Total DALY limit (LTDL) for the best water quality (given a WQHI score of 100%) could be defined as that which satisfies the Bangladesh guidelines for dinking water quality. Any water with water quality parameters exceeding the standards would give a score less than 100%. In the original model as arsenic was also considered, the minimum value of arsenic estimate LTDL may be set at the Bangladesh drinking water standard of 50 μg/l or a more stringent value of 1 μg/l, which is the WHO guideline value.

On the other hand, the Upper Total DALY limit (UTDL), for the worst water quality (given a WQHI score of 0%) could be the worst water quality observed in a particular data set or an arbitrary value. For example a FC value of 10,000 cfu/100 ml and an arsenic concentration of 1000 μg/l.

The water quality health index was calculated as follows:

To determine the DALY score for the LTDL, the model was run with 0 values for both FC and hazardous chemical (here As). In determining the DALY score for UTDL, the model was run with arsenic concentration of 1000 μg/l and FC concentration of 10,000 / 100 ml as inputs.

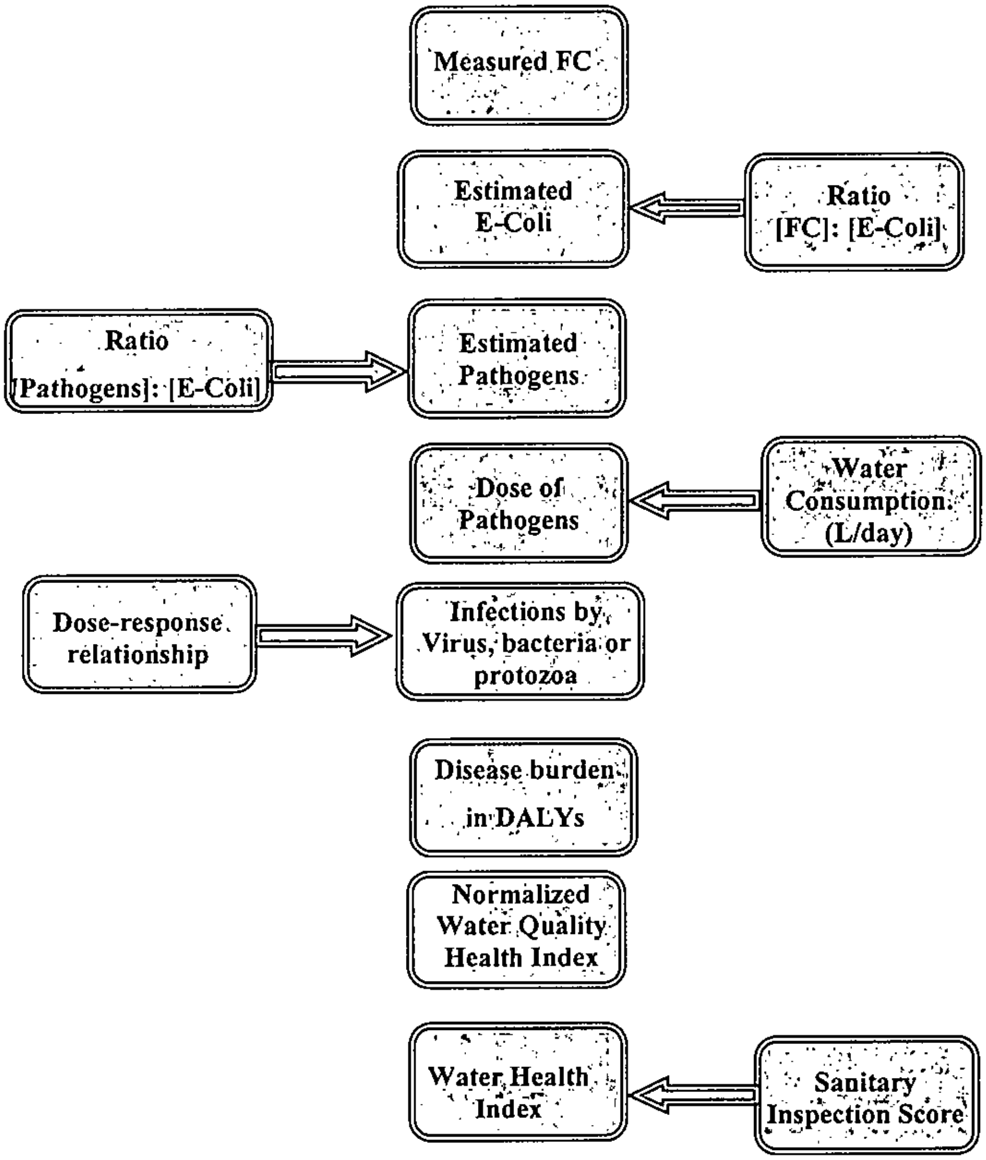

Fig. 3.1: Process Diagram of Quantitative Health Risk Model

For further simplifying the reporting by both Sanitary Inspection Score and WQHI scores a Water Health Index (WHI) was determined. This involved taking the average of the WQHI and 100 minus the SI score.

To enable ready comparison with risk estimates given in this study, the WHO reference level of risk (WHO, 2004) is noted to equate to 10^{-3} or 0.001 DALYs per 1000 ppy. This reference value is approximately 10,000 fold less than that or the LTDL DALY. This is because of the fact that LTDL considers value of FC and As just below practically possible estimate of FC and arsenic (0.5 ppb of and 0.5 cfu/100 ml of FC). Since LTDL represented the highest water quality assessed, all the assessed options were at least at 10,000 fold higher risk than WHO reference level. The overall risk model can be shown by the Fig. 3.1.

Chapter 4

HEALTH RISK ASSESSMENT IN SELECTED COMMUNITIES OF DHAKA CITY

4.1 INTRODUCTION

Water Supply in Dhaka city, both in quality and quality, is a matter of significant concern for city dwellers and the water supply authority. DWASA cannot keep pace with the ever increasing city population and their increasing water demand. Inadequate supply and poor quality of supply water are common phenomenon in day-to-day life. Outbreak of waterborne disease is reported to increase, especially in the dry season, when both quality and quantity of supply deteriorate.

Urban water supply pattern also varies in different socio-economic settings. Slum areas have community based water supply system. Illegal house connection and shallow tubewell are two distinct supply options in urban slum areas.

Low-income communities usually have some form of individual connection, but usually do not have temporary storage facilities like overhead or underground water tank. So, they are deprived of a continuous supply of water. On the other hand, rich or middle-income communities usually live in buildings with flat rooftop with overhead reservoir. They have some form of reservoir like underground or overhead tank or both. Therefore, they usually feel less water scarcity problem in comparison to low-income communities.

As water supply patterns vary, the risk pathways near water points also vary. For example, when water is collected from a remote water point through flexible/ PVC pipe that runs over a wasteland or dumping site, there are additional risks of contamination in addition to the risk in the distribution network. Lack of hygiene practice is another major issue, adding further risk.

This study was performed with a view to assess the risk of water supply in some selected communities of Dhaka city. For all selected communities, quality of water and sanitary condition of water points were evaluated. A questionnaire survey was also carried out to assess health and sanitary condition. Finally the data were used in a risk model to assess potential health risk burden.

4.2 METHODOLOGIES

In this study health risk resulting from water supply was assessed for selected low-income, slum and middle and high income communities. This section provides a description of the methodologies used in the study to assess water quality, sanitary integrity and risk burden from water supply.

4.2.1 Selection of Communities

The method of selection of water points was primarily based on reconnaissance survey conducted in Hazaribagh and Mirpur areas. The objective of this survey was to assess the possible water supply patterns and the socio-economic settings. In this survey no water samples were collected. Different slums, low income community areas and some residential buildings were visited. Local people were interviewed to collect their viewpoints on these issues. The following conclusions were made from this survey:

1. Water supply pattern in slum areas is mainly of two types:
    a. Community type DWASA supply and
    b. Shallow tubewell.

Community type standpoints have different patterns like

- Simple house connection where all communities collect water
- Flexible pipe carrying water from nearest legal water point
- Handpump fitted with WASA main line, and
- Conventional public stand post with platform and drains. Some of them have a reservoir to temporarily store water during non-supply hours.

A good number of shallow tubewells were also seen in slum areas primarily installed by different NGOs.

2. The definition of low income community in this study was made based on water supply pattern and house type. Low-income community has individual water supply systems like that of middle and high income communities. The difference is that very few low-income communities have their own reservoir i.e. overhead or underground tank. Low-income communities normally live in tin-shed house. So, they have to suffer from scarcity of water during non-supply hours. Low income communities usually do not boil water prior to drinking, mainly due to scarcity or high cost of fuel.

3. Middle and high income communities have been defined as those living in buildings with flat roof, often more than one storey. These houses have own underground and overhead reservoirs with pumps. So, the availability of water is ensured. They usually have available energy (e.g., gas connections) and better health awareness. So boiling is a common practice among them.

Sampling Points and Size

The study aims at assessing health risk in slum, low-income and middle/high income communities from water supply. Newspaper articles, information from television channels and public opinions were valuable information sources in choosing the sampling points. Sampling points were selected from 4 metropolitan thanas of Dhaka City as follows:

1. Mirpur
2. Mohammadpur
3. Tejgaon, and
4. Sabujbagh

Since the population of the city is very large, a statistically representative sample size would also be very large and therefore beyond the scope of the present research. In this study, a total of 80 water points were selected as follows:

a. Slum Community: 39 points (49%)
b. Low-income Community: 27 points (34%)
c. Middle/high income community: 14 points (17%)

4.2.2 Hazards Identification

While visiting a specific water point, the potential hazards pathways were identified. A hazard identification tool named *Sanitary Inspection Survey* was used for this purpose. Sanitary inspection forms were prepared in light of the WHO guidelines for drinking Water Quality (WHO, 2004)and adapted for the local condition of water supply pattern for urban areas. During initial reconnaissance survey the survey tool was tested and reviewed.

Sanitary Inspection (SI) uses observation to assess the sanitary integrity and potential hazards in the environment that may affect water quality, especially microbial quality. It is usually exercised in conjunction with microbial analysis to understand the potential causes of contamination and to develop control measures to improve microbial water quality.

In formulating a unique sanitary risk inspection tool, various aspects were considered. As the water supply patters in urban area varies considerably it is wise to use different SI forms for different water supply points. The diversified water supply patterns in Dhaka city were grouped into four general categories as shown in Table 4.1 and different sanitary inspection tools were used for different water supply options. The different SI risk forms are presented in Appendix A.

Table 4.1 Water supply options found in the study areas

Gr. No.	Description	Community Using Water Points
1	Piped Water Supply with reservoir (OHR/UGR)	Middle/High Income Community
2	Piped Water Supply without reservoir	Low Income /Slum Community
3	Hand pump Connected to supply line	Low Income /Slum Community
4	Shallow Hand Tubewell	Slum Community

OHR= Over Head Reservoir, UGR = Under Ground Reservoir

4.2.3 Assessment of Water Quality

Assessing water quality was a major task of this study. Water quality parameters were selected primarily for inputs in the health risk model as well as for aesthetic acceptability of water and to establish the causes of water quality deterioration. Some aesthetic parameters like colour, odour and presence of dirt/insect were based on observation and questionnaire survey. Test for bacteriological quality of water was the major part of this assessment. In addition, physical parameters like pH, turbidity, TDS were tested to assess the suitability of water for drinking purpose. Some chemical parameters like nitrate, ammonia were also tested to check for the compliance with Bangladesh standard and the WHO guideline values and to identify the contamination pathways. For example, a high concentration of Nitrate would be an indication of pollution by sewage. Moreover, to assess the adequacy of disinfection total chlorine concentration at supply end was examined. The tested parameters are listed in Table 4.2

Table 4.2 Water quality parameters tested in the study

Parameters Type	Parameters	Method of Testing
Aesthetic Parameters	Color Odor Turbidity Presence of Dirt	Field Observation and Questionnaire
Physical Parameters	pH Turbidity TDS	pH Meter (HACH) Turbidity Meter (HACH) Conductivity Meter (Wagtech)
Microbial Parameters	FC E-Coli	Membrane Filtration and incubation in MFC both media. Membrane Filtration and incubation in M-Coli blue media
Treatment Indicators	Chlorine	Spectrophotometer
Other Chemicals	Ammonia Nitrate	Spectrophotometer (HACH, DR4000)

4.2.4 Manifestation of Waterborne Diseases

An important part of this study was to assess the occurrence of waterborne diseases during the last one year. The objective of this study was to compare the model prediction of the incidences of selected waterborne diseases with the corresponding values obtained from the questionnaire survey. During the questionnaire survey, the consumers were asked regarding the incidences of waterborne diseases during last one year.

This is a subjective approach because in most cases a correct answer is based on the judgment of the respondent. Also very few medical diagnoses are actually done to identify the type of waterborne diseases especially for the slum and low-income communities. On the other hand, some feel shy to tell about the waterborne diseases particularly among the middle/high income community. So the information gained from this questionnaire was more or less subjective/indicative in nature.

Another paradox of this study was the overlap of water supply coverage. People especially workers or service holders drink water from their service places, restaurants and from many other locations. The working places may be hygienically more vulnerable than their household installations. It will be very complicated if all the sources of water consumption patterns have to be considered. Hence this overlap of water consumption was not considered in this study.

In addition to the incidence of waterborne disease, information on the frequency and severity of disease were also sought from the consumers during the questionnaire survey. The focus of waterborne disease was on such common diseases like Diarrhoea, Dysentery, Typhoid, Hepatitis and Skin Diseases. The questionnaire used to collect information on waterborne diseases is shown in Appendix B.

4.2.5 Estimation of Health Risk Burden

Finally quantitative health risk burden was assessed. As discussed in Chapter 3, the risk estimation is based on microbial and chemical concentration in drinking water (exposure assessment), and the impact of their presence on human health found by dose-response relationship. Lastly various outcomes of diseases are combined together by a common parameter called DALY. The primary tool of the risk assessment was a QHRA tool developed by International Training Network Centre, BUET in association with Water Future, Australia as an outcome of a project titled 'Risk Assessment of Arsenic Mitigation Options (RAAMO)'. The original version of this model has been developed for arsenic affected areas in rural areas. Therefore, for this study some modifications were made. Table illustrates these modifications.

Table 4.3 Modifications made in the risk model of RAAMO

Model Elements	RAAMO Study	This Study	Remarks
Input	TTC and Arsenic	FC	As DWASA water supply in Dhaka is free of arsenic
Output	Microbial as well as arsenicosis and cancer DALY	Microbial DALY	As arsenic was not considered
E-Coli: TTC/FC	0.85	0.50	From experimental data
Model objective	Compare arsenic Mitigation options	Compare risk burden among different community as well as among different urban water supply patterns.	

4.3 RESULTS AND DISCUSSIONS

4.3.1 Water Supply Pattern

This study shows that water supply in slum areas are principally based on handpump operated water collection system (59%). Of the handpumps, about half are connected with DWASA line and the rest are conventional shallow hand tubewell. Most of these STW are installed by NGOs. There are also a good number of house connections (41%), but most of them are illegal. In this case, water is collected from any nearby water point of WASA by flexible rubber, PVC or GI pipe. It also includes some conventional public standposts. Nevertheless almost all the options like house-connection without reservoir or handpumps are community type and modified variety of public stand-post. These illegal connections are prevalent in slum areas which have been sparsely developed and unauthorized.

Low income community has water supply options similar to that of slum people, but the only exception is that these options are not community type. Hand-pump (about 48%) connected with WASA mainline and house connections without any underground or overhead reservoir (about 41%) are two major water supply options for low-income community.

Middle/high income communities have house connections with overhead and underground reservoir system. Table 4.4 shows the water supply pattern found in the study. Fig 4.1a and 4.1b graphically show the water supply pattern in slum and low-income community, respectively.

Table 4.4 Water Supply Pattern among Different Communities

Water Supply Pattern	Total	Slum Area	Low Income Area	Middle/high income area
Piped water supply with reservoir (OHR/UGR)	18	1	3	14
Piped water supply without reservoir	26	15	11	0
Hand pump connected to supply line	24	11	13	0
Shallow Hand Tubewell	12	12	0	0
Total	80	39	27	14

4.3.2 Boiling of Water

In the context of water supply in Dhaka city, due to risk of outbreaks of waterborne disease people often boil the supply water prior to drinking. But boiling practice depends on the availability of fuel. In middle and high income community areas, natural gas is available. But in slum and low-income areas there are very few gas connections. Also the awareness among consumers plays a significant role in making the decision of boiling. In table 4.5 the boiling practice of drinking water is summarized. It shows that majority of households (75%) in the middle/high income community boil water, while the figure is nil for slum community. About 44% of households of low-income community, surveyed in this study, boil water for drinking purpose.

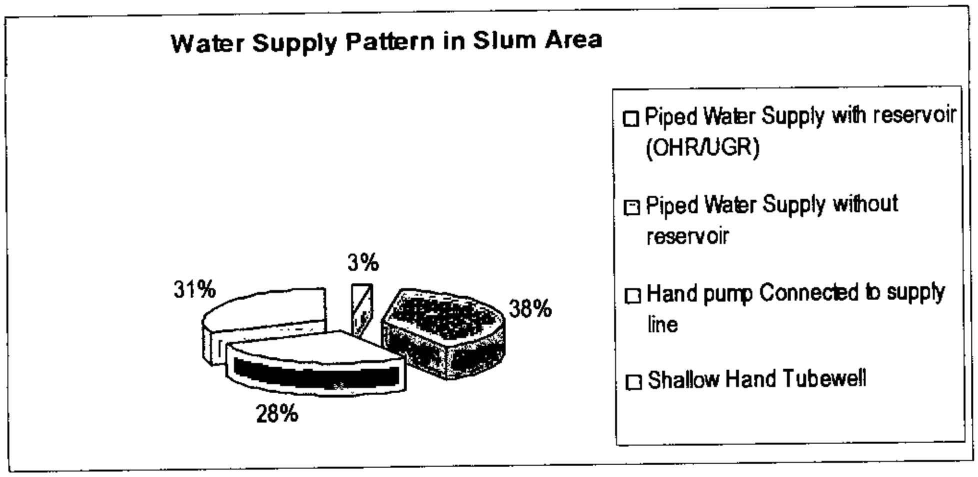

Fig. 4.1a: Water supply pattern in slum areas found in the study

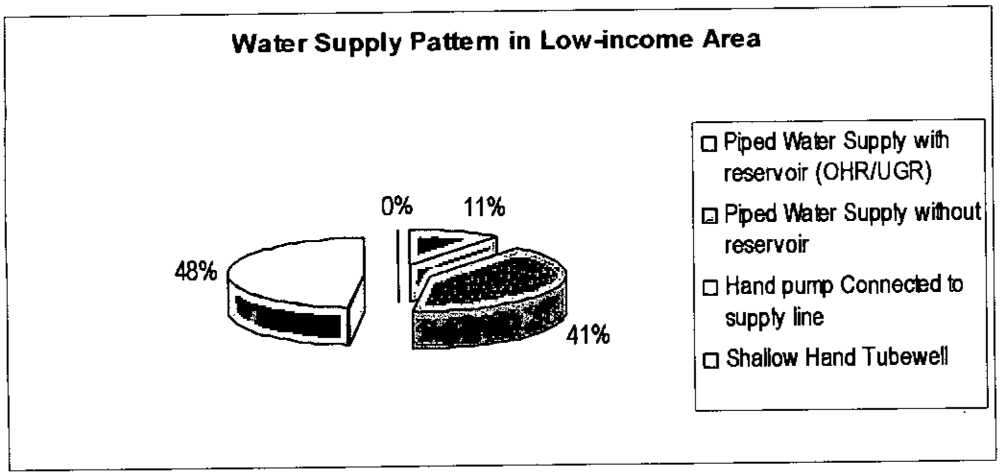

Fig. 4.1b: Water supply patter in low income areas found in the study

Table 4.5 Boiling practice of drinking water

Area Type	Total HH surveyed	% HH practicing boiling of water (%)
Slum community	39	0 (0%)
Low-income community	27	12 (44%)
Middle/high income community	14	11 (79%)

4.3.3 Sanitary Condition

As described earlier, the sanitary condition in the vicinity of the water supply point can alter the microbiological condition of the water. This is more applicable for the water supply system other than piped water supply like dug well, deep or shallow tubewell where water is extracted from the ground near the water point. In case of piped water supply where water is carried to supply point through long distribution network, the unseen leakages in the pipelines often cause contamination of water and deteriorate the microbiological quality of the water. Nevertheless good sanitary condition of the water supply point is important to obstruct additional risk.

Sanitary risk inspection is also a tool to guide the water user in setting possible control measures to exclude extra microbial risk. Sanitary Inspection form has simple yes/no type questions which reveals the potential risk of a particular supply system. A 'yes' answer to a question means presence of risk and constitutes a score. . The more the potential risks (i.e., 'yes' answers) the more will be the score. Comparison of sanitary risk values for different options depicts the potential hazard pathways of a faulty system. All Sanitary Inspection (SI) forms (see Appendix A) used in this study had ten questions. Hence a score of 10 constitutes the maximum risk and a score of 0 (zero) indicates no potential risk. Figure 4.2 presents median values of sanitary risk score for different water supply surveyed.

It can be seen from the figure that house connection without any reservoir has potentially high hazard pathways. Many of these systems are illegal and use flexible rubber pipe or PVC pipe and collect water from distant water point. It was observed during the study that many of these systems have leaks in pipe. Moreover, as these systems predominate in slum or low-income community areas the unhygienic surroundings of the areas contributed to the higher risk sore.

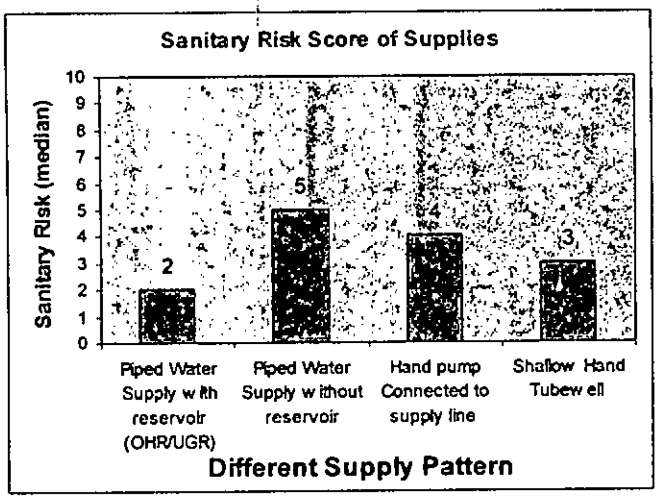

Fig. 4.2: Sanitary risks in different water supply options

As good hygiene practice contributes to good sanitary condition. The SI risk among different communities can be representative of the hygiene practices of users. Figure 4.3 shows sanitary risk score in the water supply options within different communities.

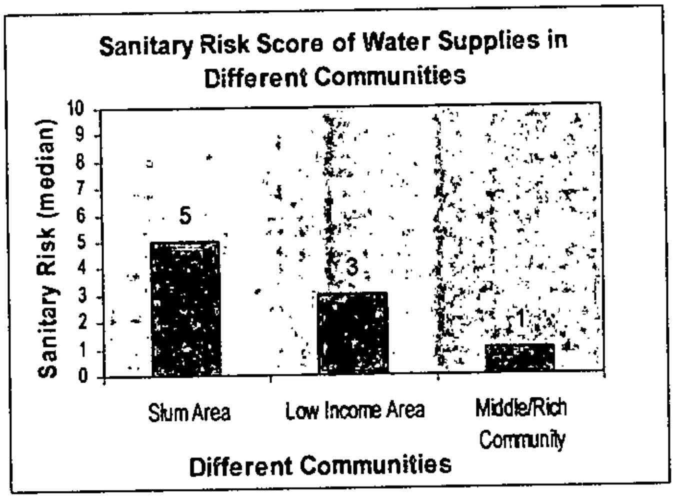

Figure 4.3 Sanitary risks in water options among different communities

It can be seen that in slum areas the potential hazards pathways are more compared to those in low-income or middle/high income areas. In slum areas, the unsanitary surroundings contributed the higher risk score.

4.3.4 Water Quality

4.3.4.1 Aesthetic Water Quality

Aesthetic water quality of the supply was assessed by physical observation and questionnaire. Figure 4.4 shows aesthetic qualities of water supplies. Sixty two percent of supplies under the study have odour problem. About half of them have this problem permanently. In other cases, this problem is occasional. Nineteen percent of supplies have temporary colour problem and 8% have permanent colour problem. About 23% of the consumers complained that their supplies have turbid water, but only 4% claimed this problem to be persistent.

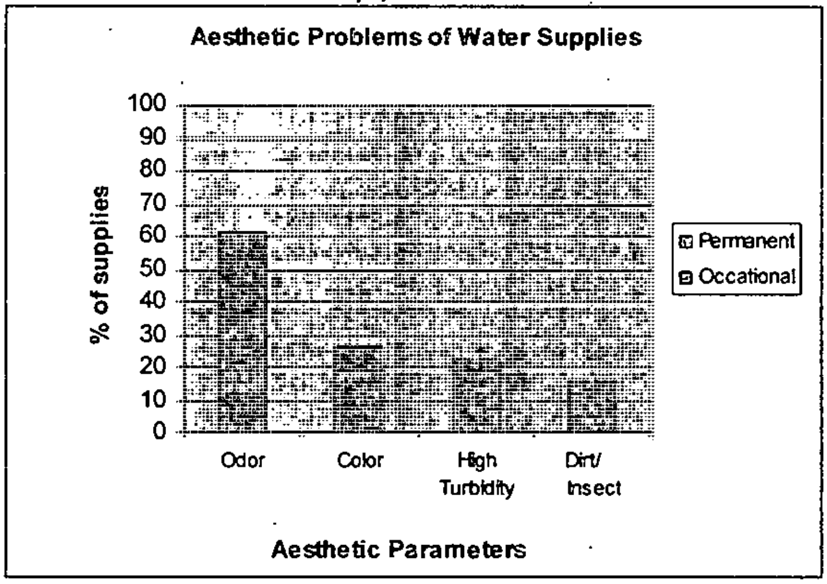

Fig. 4.4: Aesthetic problems of drinking water in different supplies under study

Majority of the respondents complained about the aesthetic problems especially odour and colour problems which typically occur during low-discharge condition. In some locations about 4% supplies have visible insects or mud in water, and 13% of supplies have this problem occasionally. Community-wise aesthetic problems are shown in Fig. 4.5a through 4.5c. These figures show that in low-income community supplies, aesthetic problems are more prevalent compared to other communities. In middle/high income communities, the colour, turbidity and presence of dirt or insects are only occasional problems.

In Fig. 4.6a through 4.6d, option-wise aesthetic problems are shown. These figures show that in piped water supplies without reservoir and hand-pump connected to supply line, aesthetic problems are more compared to other options. This reflects the poor aesthetic quality of major source of water for slum and low-income communities. Shallow hand tubewells in slum areas have the best aesthetic quality.

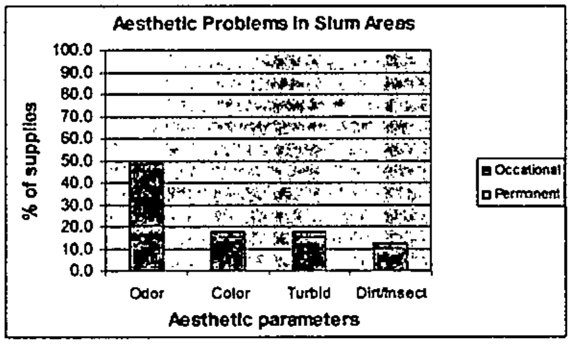

Fig. 4.5a: Aesthetic water quality problems in slum area

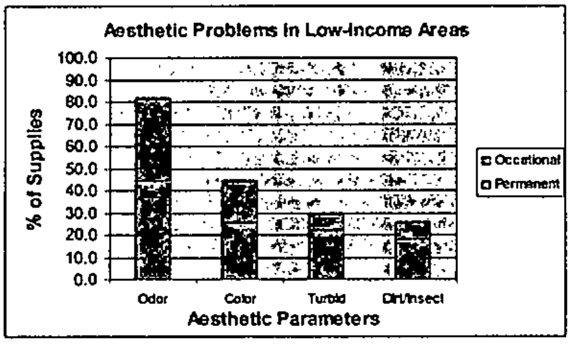

Fig. 4.5b: Aesthetic water quality problems in low income areas

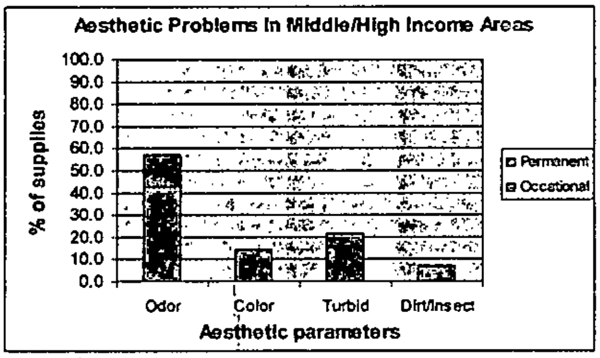

Fig. 4.5c: Aesthetic water quality problems in middle/high income areas

4.3.4.2 Physical Parameters

pH

The pH of the tested water samples varied from 6.0 to 8.5, nearly satisfying the Bangladesh Standard of 6.5 to 8.5. Sixteen samples (20%) have pH value below 6.5. The median value was 6.9 close to neutral value of 7. pH distribution of the water points are presented in Fig 4.7a and Fig. 4.7b.

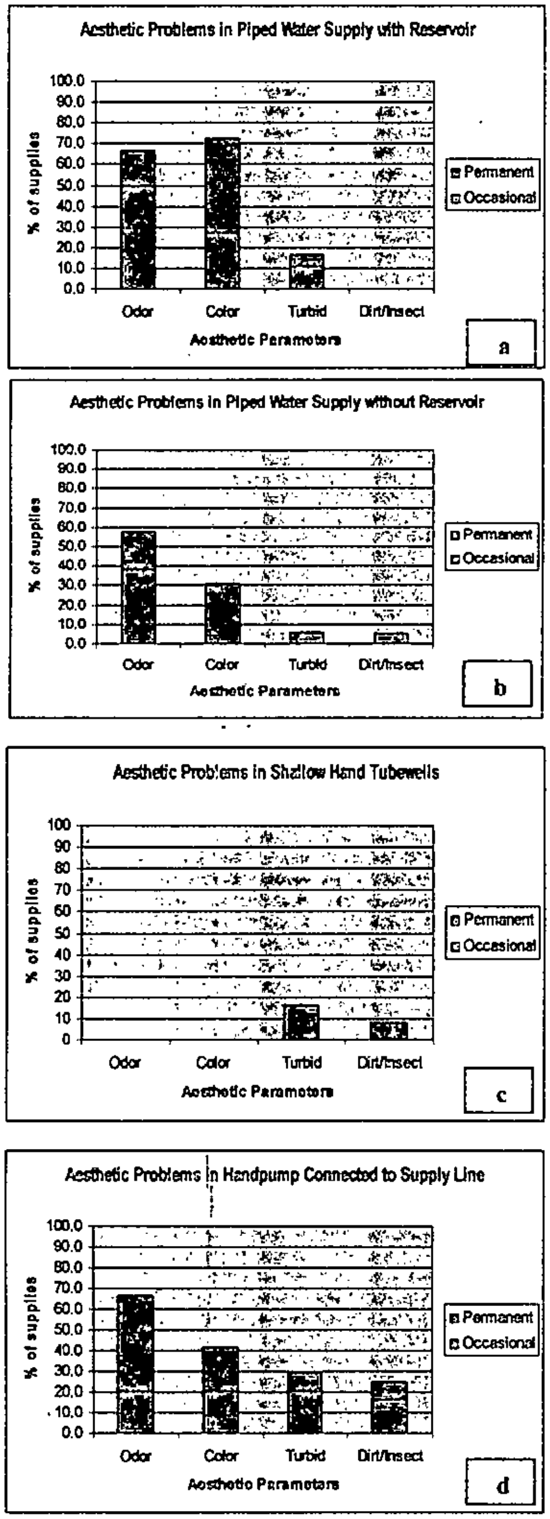

Fig. 4.6: Aesthetic problems in four different kinds of water supply options assessed in this study.

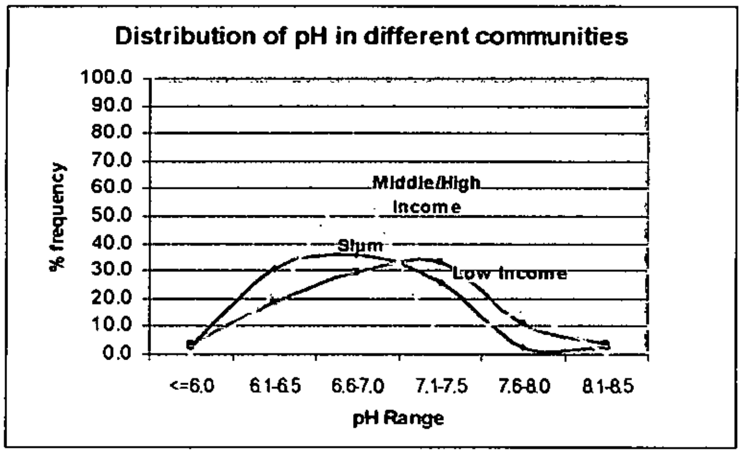

Figure 4.7a: Distribution of pH of water samples in different communities

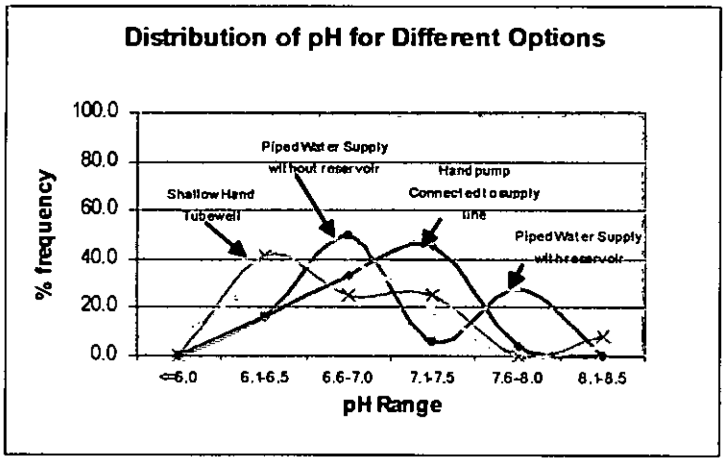

Figure 4.7b: Distribution of pH of water samples in different water supply options

Total Dissolved Solids

The total dissolved solids (TDS) concentrations in all water samples tested were within the Bangladesh Standard of 1000 mg/L, with a median value of 253 mg/L and maximum value of 459 mg/L.

Turbidity

Two respondents (one in slum area and 2 in low-income area) out of 80 complained that there supply water always have high turbidity problem. The test results also complied with their perception. The maximum value of turbidity was 83 NTU well above Bangladesh Standard of 10 NTU. Median value of turbidity was 0.81 NTU. Figure 4.8a shows community-wise distribution of turbidity in the tested water samples. It shows that the supplies within slum community have more turbidity compared to that of low income and middle/high income communities. Figure 4.8b shows distribution of turbidity of water samples in different water supply options.

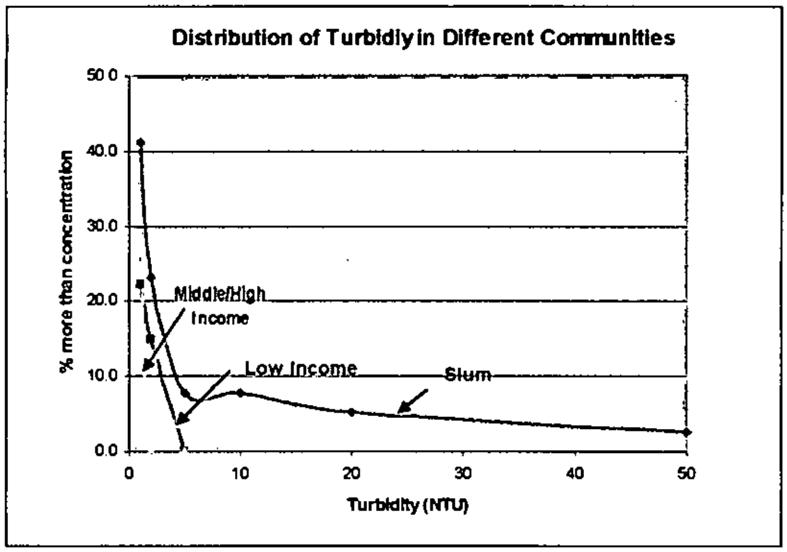

Figure 4.8a: Distribution of turbidity of water samples in different communities

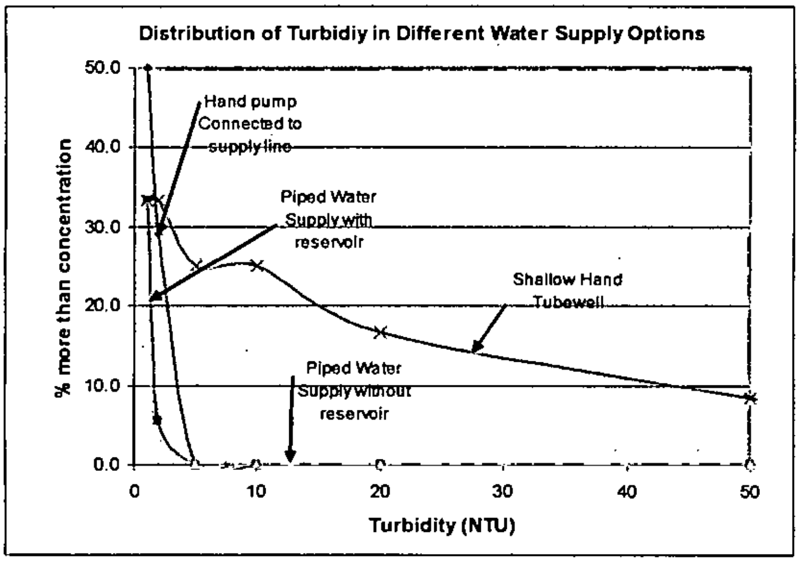

Figure 4.8b: Distribution of turbidity in different water supply options

4.3.4.3 Chemical parameters

Nitrate and Ammonia

None of the water samples had nitrate concentration exceeding the Bangladesh Standard of 10 mg/L. On the contrary, ammonia concentration of 25 (31% of total) samples exceeded Bangladesh Standard of 0.5 mg/L. Maximum value of ammonia was 2.9 mg/L and median value was 0.10 mg/L. Nineteen of the 25 supplies (76%) having high ammonia concentration also had complaints from users of having high odour problem. Figures 4.9 and 4.10 show nitrate and ammonia concentration, respectively.

There is no significant variation of nitrate concentration in water samples collected from different communities. In contrast to Nitrate, ammonia concentration shows marked difference. As shown in Fig. 4.10a, ammonia concentration in water samples of low income community areas are higher. Majority of the sampling points under Sabujbagh thana were supplied by Saidabad Surface Water Treatment Plant (SWTP), covering mainly low-income and slum communities. These water supplies showed high ammonia concentration. It is known that SWTP suffers from high ammonia concentration in treated water during the dry season (IWM-BUET, 2004). Slum communities also have a good number of water supplies from shallow tubewells, which typically contain very low ammonia. Figure 4.10b shows that among different supply options handpumps connected to supply line have relatively more ammonia concentration.

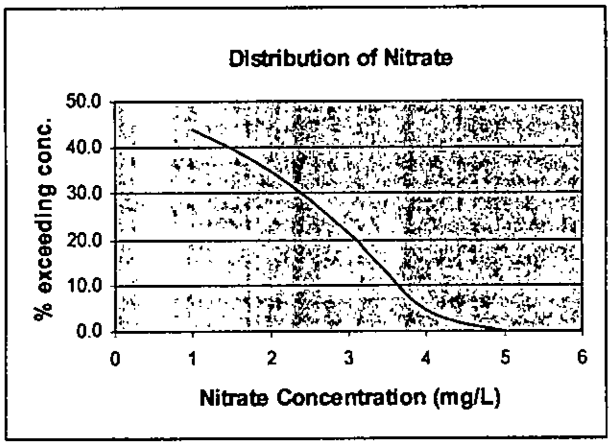

Fig. 4.9: Distribution of nitrate in water samples

Chlorine

The concentration of chlorine at delivery end was tested to check the adequacy of the chlorine level to safeguard against potential microbial contamination in the distribution network. If chlorine level is more than 0.05 mg/L for a contact period of 10-20 minutes, it would be effective in killing pathogen (Ahmed and Rahman, 2000). In this study it is found that about 50% (41 nos.) water points had this level of chlorine concentration at the delivery end. If we exclude the shallow tubewells from the total, the percentage of water points with sufficient chlorine becomes 60%.

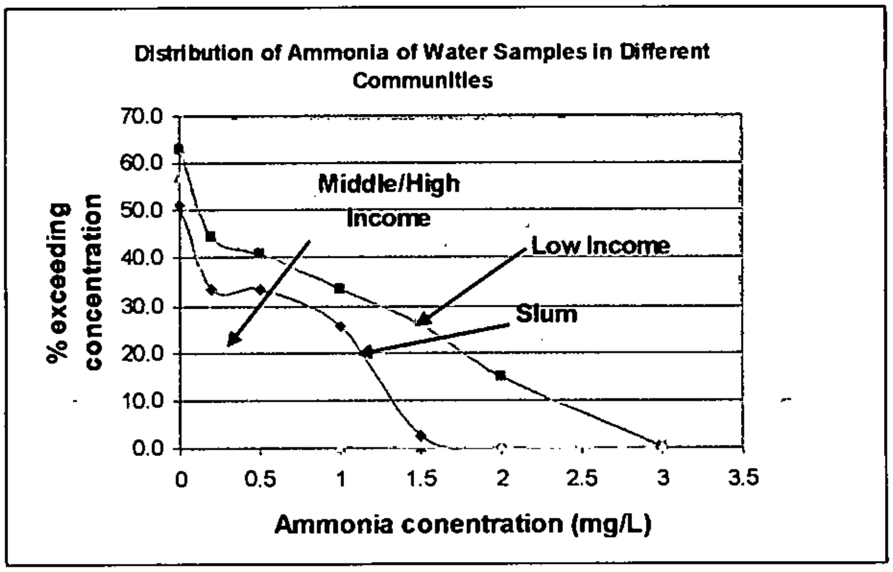

Figure 4.10a: Distribution of ammonia in water samples of different communities

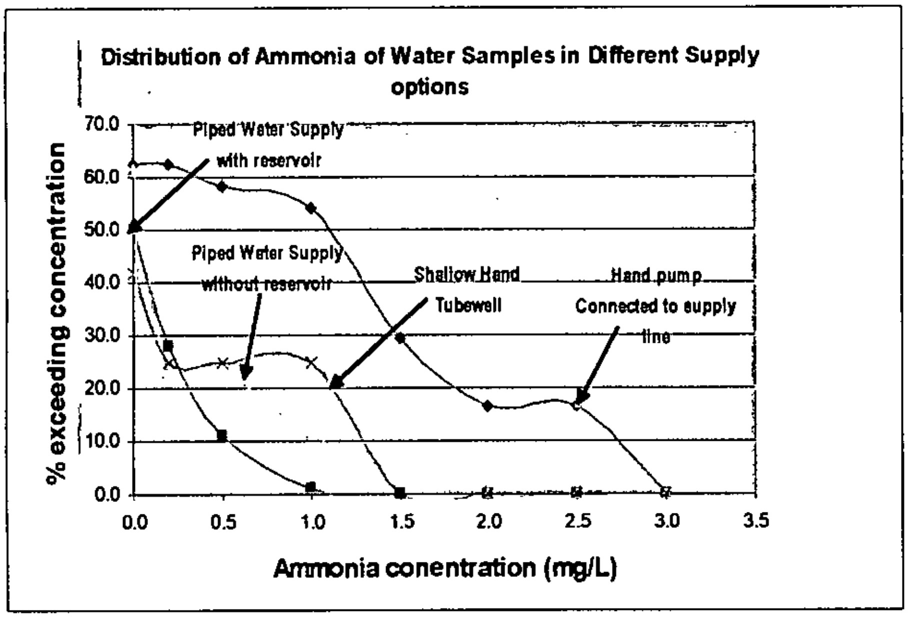

Figure 4.10b: Distribution of ammonia in water samples of different supply options

4.3.4.4 Microbiological Quality

The presence of faecal coliform (FC) was tested in water samples from all water points. Thirty seven (about 46%) of the total 80 supplies showed presence of FC. Table 4.6 shows the overall microbial status of different water supply options.

Table 4.6 Microbial status of different water supply options

	Piped Water Supply with reservoir	Piped Water Supply without reservoir	Hand pump Connected to supply line	Shallow Hand Tubewell
% having FC	67	50	54	42
Min	0	0	0	0
Mean	84	45	30	6
Median	31	1	1	0
Max	640	240	220	52

Figure 4.11 shows the presence of faecal coliform in different water supply options. It can be seen from the figure that piped water supply with reservoir have more bacteriological contamination compared to that having no reservoir. Also the contamination varies over a wide range. This is probably due to additional risk in the reservoir. The supplies where a hand pump is fitted with DWASA line are also microbiologically unsafe.

If we consider a particular level of contamination for example 100 FC counts, it can be seen that piped supply with reservoir have nearly 22 % points beyond this range. For piped water supply without reservoir this value is a little less (18 %). Handpump connected with WASA main have only 12 % supplies above this level. None of the shallow tubewells have that high level of microbial contamination.

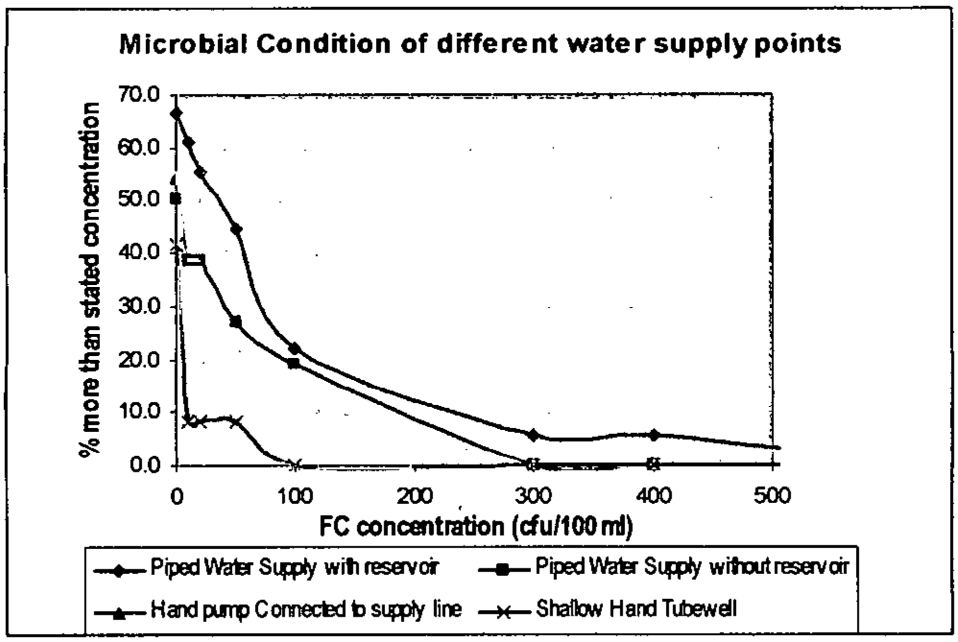

Fig. 4.11: Microbial water quality of different water supply pptions

In conclusion, very high level of microbial risk is obvious in conventional piped water supply of WASA compared to that of groundwater extracted by shallow tubewell. Among the three WASA supply systems, handpumps fitted with DWASA line suffer less from this problem. Because in case of hand pumps as water comes directly from WASA main, there are some residual chlorine level that reduces the microbial risk. Also there are few risk pathways. On the other hand, piped supply without reservoir mostly serves in slum and low-income areas where long flexible PVC pipes often carry water over wastelands and potential hazard pathways. In house connection with reservoir, if reservoirs are not frequently cleaned, this can cause deterioration of microbial water quality. In shallow tubewell, this problem is not very significant. The few problematic supplies in this category have unhygienic local condition (e.g., hanging latrine in close proximity).

Reasonably safe water in handpumps connected with supply line could be attributed to the level of chlorination. Chlorination is important for disinfection of pathogens and there is an inverse relationship with the chlorine value and FC count. Almost 71% handpumps found in this study have a total chlorine concentration more than 0.05 mg/L. In case of piped water without reservoir this value is 42% and with reservoir this value is 44%.

Community-wise FC count can give us a clear picture of the risk involved at the community level. Figure 4.10 shows community-wise FC distribution.

It can be seen from Figure 4.12 that that at a low level of contamination (FC<100), middle/high income community have more water points that are microbiologically unsafe, but at a higher level of contamination (FC >100), low income community have more water points that are unsafe.

But in contrast to this picture, low-income and slum people will be more vulnerable to water borne diseases, because boiling water is not a common practice among them due to shortage of fuel. On the other hand, middle/high income people compensate for the microbial hazards almost fully by boiling the water prior to drinking.

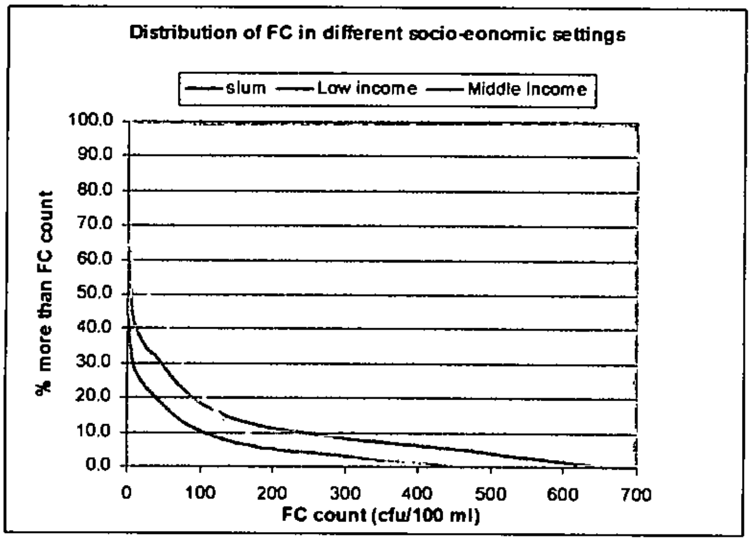

Fig. 4.12: Microbial water qualities of water supply in different communities

Attempts have also been made to find out the relationship of Sanitary Risk score with the faecal coliform count. Figure 4.13a through 4.13d show such relationships. It can be seen that there is no significant correlation with the sanitary condition of the water point and the FC count for piped water supply with and without reservoir.

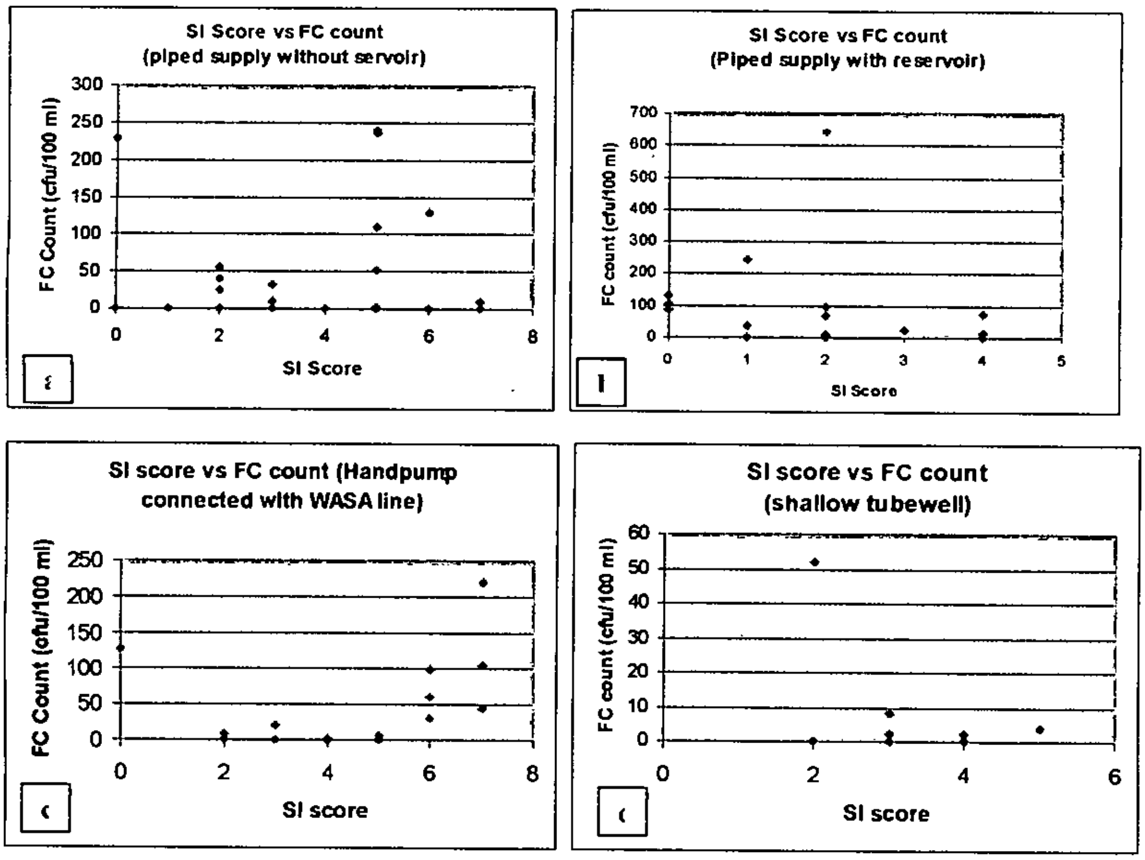

Figure 4.13: SI score vs. FC count in (a) piped water supply with reservoir, (b) piped water supply without reservoir, (c) hand-pump with WASA line, and (d) shallow tubewell

Nonetheless, in case of hand pump connected with WASA line and shallow tubewell there is one important thing to notice. In case of hand pump connected to WASA line, as sanitary score increases beyond 5 (high risk) the FC count also increases. Although this particular option has more chlorine concentration as discussed earlier, unsanitary condition in the surrounding probably makes the water contaminated.

Similarly shallow tubewell also supplies good quality water as long as sanitary condition in the vicinity of the tubewell remains good. Also unlike other options, shallow tubewells are not connected to long distribution networks vulnerable to pollution through leakage. So, sanitary condition of the surroundings often governs microbial contamination.

E-Coli

In addition to determining the above water quality parameters, some of the samples were tested for E-Coli with a view of using the E-Coli: FC value in the model. A total of 10 samples were tested and the average value of the ratio E-Coli: FC was found to be 0.5. Appendix C shows the E-Coli values of the samples tested.

4.3.5 Assessment of Risk Burden

In this study risk burden resulting from water supply was assessed for different communities using a risk model and the experimental results. The risk model is described briefly in the following sections. Detailed description of risk model is presented in chapter 3.

Input of risk Model

Inputs of a risk model can be mean or median values of Faecal Coliform Concentration. That is a sort of deterministic approach. But as there are many zero values for each type of water supply options, a median value would also be zero and it can significantly underestimate the effect. Hence in this study a probabilistic model is thought to be more realistic. Some other important issues related to the application of the risk model are given below.

1. Community-wise microbial data are fitted in a log-normal distribution curve. Median, lower confidence limit (5^{th} percentile) and upper confidence limit (95^{th} percentile)

values can be estimated from this log-normal distribution. But in this case median, log*a* and log*b* parameters are estimated for use as model input. The community responses like boiling practices were considered by substituting the FC values with zero in case the household boils water.

2. Per capita water consumption has been assumed to be 3 litre/day.

Fig. 4.14a) though 4.14c show community-wise log-normal distribution of FC. Table 4.7 summarizes the input parameters for different communities.

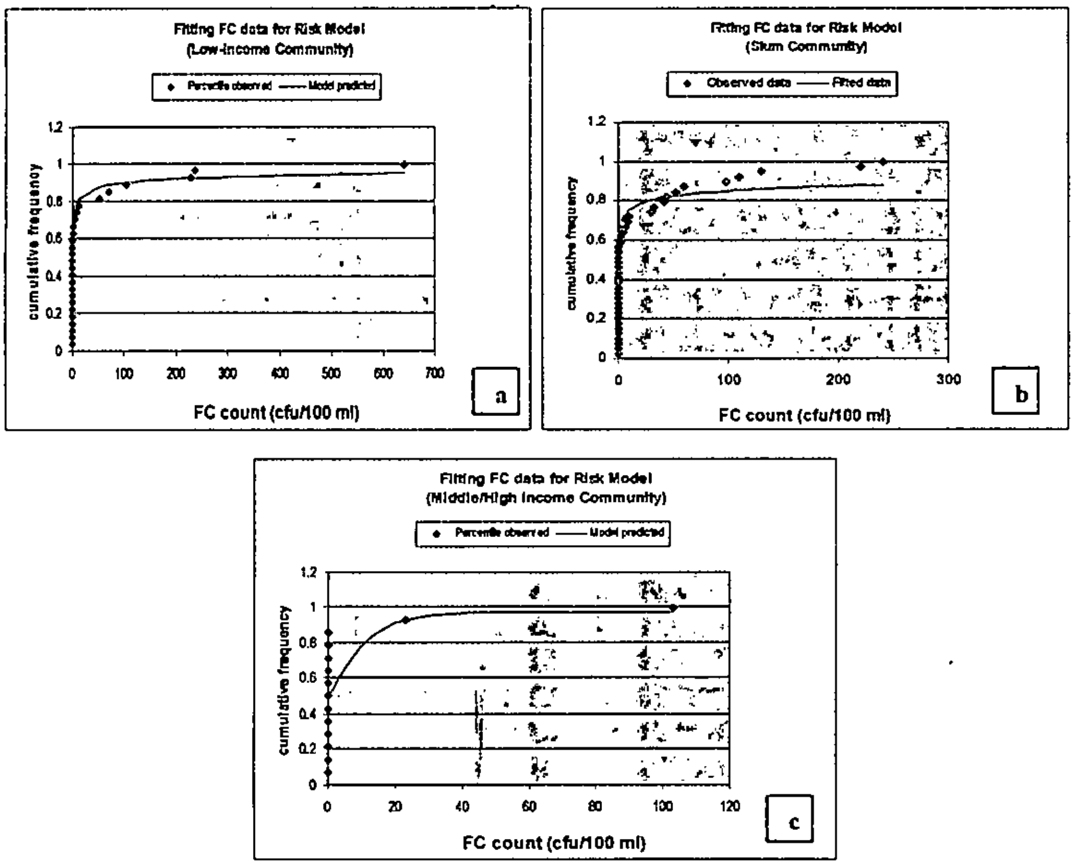

Fig. 4.14: Fitting of faecal coliform data in log-normal distribution for (a) slum community, (b) low income community and (c) middle/high income community

Table 4.7 Input of Health Risk Model (Community-wise)

Community Type	Median FC Value	Log a	Log b	Sanitary Risk Score (%)
Slum	0.1	-2.303	6.635	50
Low Income	0.1	-2.303	5.347	30
Middle/High Income	0.1	-2.303	3.711	10

Figure 4.15a though 4.15d show option-wise log-normal distribution of FC. Table 4.8 summarizes the input parameters for different water supply options.

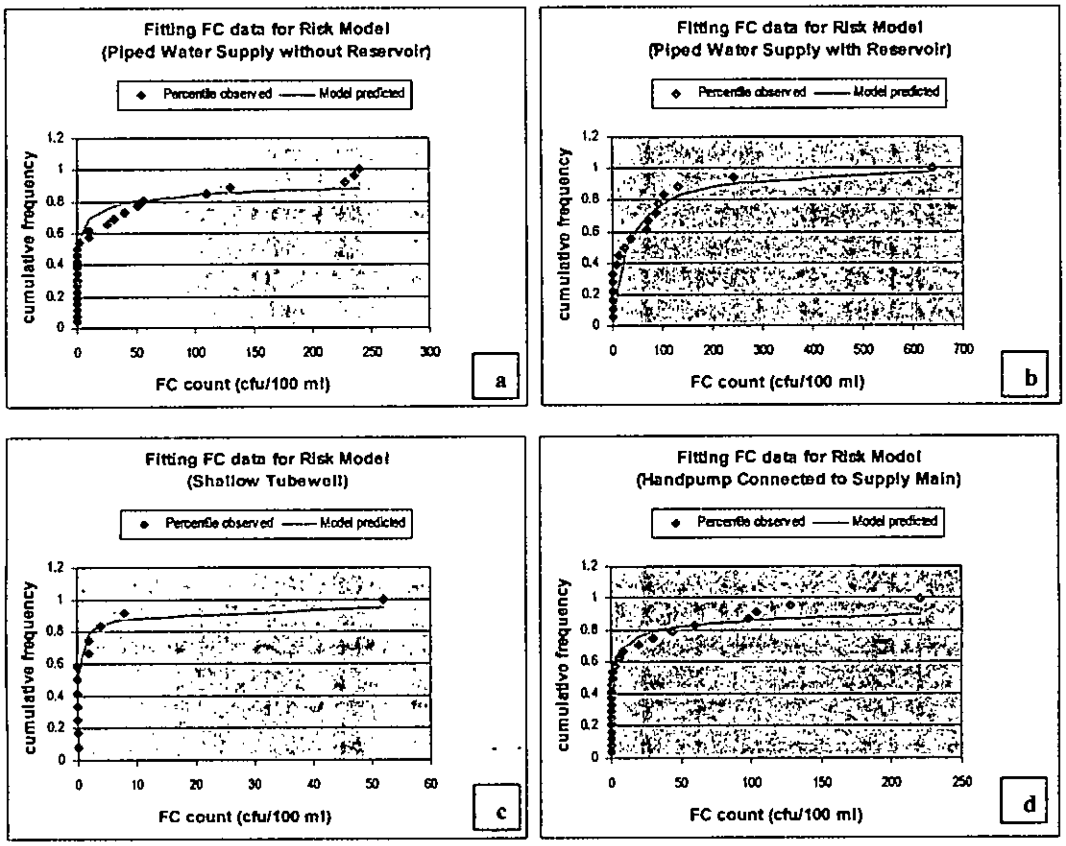

Figure 4.15: Fitting of FC data in log-normal distribution for (a) piped supply with reservoir, (b) piped water supply without reservoir, (c) hand-pump connected to supply line and (d) shallow tubewell

Table 4.8 Input of Health Risk Model (Option-wise)

Option Type	Median FC Value	Log a	Log b	Sanitary Risk Score (%)
Piped Water with Reservoir	30.5	3.418	1.574	20
Piped Water without Resevoir	1.05	0.0488	4.574	50
Handpump Conneted with Supply line	1	0	4.232	40
Shalow Tubwell	0.1	-2.303	3.813	30

Output of Risk Model

The output of the risk model is summarized in Tables 4.9a and 4.9b.

Table 4.9 (a) Risk burden of different communities

		Slum	Low Income	Middle/high Income
Total DALY (DALY/1,000 py)	LCL(5th percentile)	0.0001	0.0001	0.0001
	Median	0.0083	0.0083	0.0083
	UCL(95thPercentile)	15.914	15.5779	4.1141
Water Quality Health Index (%)	LCL(5th percentile)	100.0	100.0	100.0
	Median	100.0	100.0	100.0
	UCL(95thPercentile)	24.7	26.3	80.5
Water Health Index (%)	LCL(5th percentile)	75.0	85.0	95.0
	Median	75.0	85.0	95.0
	UCL(95thPercentile)	37.4	48.1	85.3

Table 4.9 (b) Risk burden of different water supply options

		Piped Water Supply with reservoir	Piped Water Supply without reservoir	Hand pump Connected to supply line	Shallow Hand Tubewell
Total DALY (DALY/1,000 py)	LCL(5th percentile)	0.0323	0.0001	0.0001	0.0001
	Median	1.6636	0.0854	0.0813	0.0083
	UCL(95thPercentile)	12.0561	15.901	15.7421	4.4744
Water Quality Health Index (%)	LCL(5th percentile)	99.8	100.0	100.0	100.0
	Median	92.1	99.6	99.6	100.0
	UCL(95thPercentile)	43.0	24.8	25.5	78.8
Water Health Index (%)	LCL(5th percentile)	89.9	75.0	80.0	85.0
	Median	86.1	74.8	79.8	85.0
	UCL(95thPercentile)	61.5	37.4	42.8	74.4

Figure 4.16 shows disease burden (model output) for different communities. It shows that at upper 95th percentile, both low-income and slum areas show significant increase of DALY value, while for middle/high income communities the value is relatively small.

As stated earlier, DALY calculated for microbial risk involves risk of different pathogens like virus, bacteria and protozoa. Figure 4.17 shows the break-up of different DALY component for different communities.

It can be seen from the figure that at upper confidence limit slum community has more risk burden of bacteria (84%) and then virus (15%). On the other hand for low income communities the percent DALY for bacteria is 84% and for virus, 15.3%. For high income communities the bacterial risk burden decreases and viral risk burden increases with percentage of burden 58% and 42%, respectively.

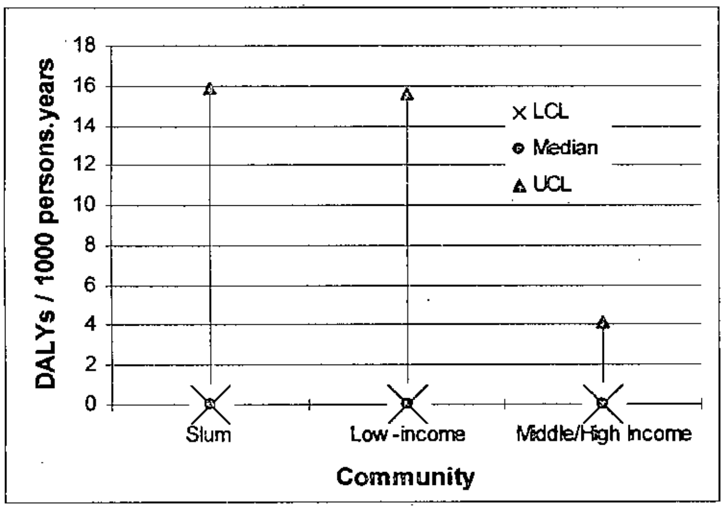

Fig. 4.16: Disease burden in DALY/ 1000 py at LCL, median and UCL among different communities

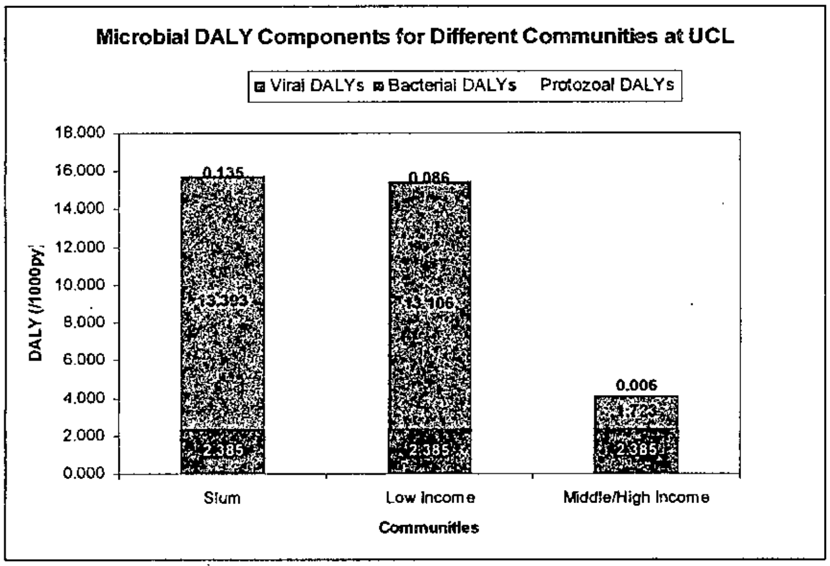

Fig. 4.17: Break-up of disease burden for different microbial risk at UCL among different communities

4.3.6 Analysis Overview

The risk model used in this study incorporated different dose-response equations and assumptions. It is necessary to provide a detailed description of the background mathematical operation. In the following section, detailed mathematical operations and assumptions involved in calculating DALY for water supply options in slum areas is given.

Step 1: Estimation of viral, bacterial and protozoan dose

Operation	Basis	Example
Model Input	Median Value of FC in cfu/100 ml	For Slum areas, median value of FC = 0.1
Converting FC concentration in cfu/100ml into cfu/ litre	Multiply by 10	0.1*10 = 1 cfu/ litre
Estimation of E-Coli	E-Coli: FC = 0.5	E-Coli Concentration= 1* 0.5 = 0.5 cfu/litre
Estimation of Pathogens	E-Coli: pathogen ratio E-Coli: virus = $1*10^{-5}$ E-Coli: bacterium = $1*10^{-5}$ E-Coli: Protozoan = $1*10^{-6}$	Viral Conc. = $0.5/(1*10^{-5})$ = $5*10^{-6}$ pfu/ litre Bacterial Conc. = $5*10^{-6}$ cfu/ litre Protozoan Conc. = $5*10^{-7}$ oocysts/pd.
Estimation of dose (ingestion of pathogens/person-day)	Daily water consumption: 3 liter/day	Viral dose = $5*10^{-6}*3.0$ = $1.5*10^{-5}$ pfu/pd Bacterial dose = $1.5*10^{-5}$ cfu/pd Protozoan dose = $1.5*10^{-6}$ oocysts/pd

Step 2: Dose-response assessment

Operation	Dose-Response Equation	Example
Dose-response assessment for virus.	$P(\inf) = 1 - \left(1 + \frac{dose}{b}\right)^{-a}$ a = 0.26 and b = 0.42	P(inf) = $1-(1+1.5*10^{-5}/0.42)^{-0.26}$ $=9.29*10^{-6}$ infections/pd
Dose-response assessment for bacteria.	$P(\inf) = 1 - \left(1 + dose^{x} / b\right)^{-e}$ x = 1.08 b= 22.5 e= 0.25	P(inf) = $1-(1+(1.5*10^{-5})^{1.08}/22.5)^{-0.25}$ $=6.85*10^{-8}$ infections/pd
Dose-response assessment for protozoa.	$P(\inf) = 1 - e^{\left(-\frac{dose}{k}\right)}$ k= 35.2	P(inf) = $1 - e^{\frac{(-1.5*10^{-6})}{35.2}}$ $= 4.26*10^{-8}$ infections/pd
Estimating annual probability of infection for each type of Pathogens	$P(annual) = 1 - [1 - P(\inf)]^{365}$	P_{annual} for virus $=1-[1-9.29*10^{-6}]^{365} = 3.38*10^{-3}$ inf./py P_{annual} for bacteria= $2.5*10^{-5}$ inf./py P_{annual} for protozoa= $1.56*10^{-5}$ inf./py

Step 3: Estimating DALY

(a) Estimating viral DALY:

Operation	Basis	Example
Estimating viral DALY (individual DALY components)	Probability of illness given infection = 1.61%, Average Life expectancy = 62 years	
	Probability of Mild Diarrhoea given illness= 88%, severity = 0.1 and duration 7 days	DALY of mild diarrhoea per infection= 0.1*7/365=0.0019 yr
	Probability of Severe Diarrhoea given illness= 12%, severity = 0.23 and duration 7 days	DALY of severe diarrhoea per infection= 0.23*7/365=0.0044 yr
	Probability of Death given illness= 0.23%, severity = 1	DALY of death = 62 yr
Summing up individual DALY	Total viral DALY =Σ Individual DALYs* Probabilities in (%)	Total DALY per infection=1.61%(88%*0.0019 +12%*0.0044+0.23%*62) $=2.33*10^{-3}$ yr *Therefore, DALY for the estimated annual probability of infection (calculated in step 2) = $3.38*10^{-3}$ inf./py* $2.33*10^{-3}$ *1000 = 0.0078 DALY /1,000 py*

(b) Estimating bacterial DALY:

Operation	Basis	Example
Estimating bacterial DALY (individual DALY component)	Probability of illness given infection = 9 %, Average Life expectancy = 62 yrs	
	Probability of watery diarrhoea given illness= 53%, severity = 0.067 and duration 3.4 days	DALY of watery diarrhoea per infection =0.067*3.4/365 $=6.24*10^{-4}$ yr
	Probability of Severe Diarrhoea given illness= 47%, severity = 0.39 and duration 5.6 days	DALY of severe diarrhoea per infection=0.39*5.6/365 $=5.98*10^{-3}$ yr
	Probability of Death given illness=0.23%, severity = 1	DALY of death = 62 yr
	Probability of HUS given illness=0 %, duration of HUS[1]= 23 yrs and severity= 0.93 Probability of Death given HUS =17%, Lift lost due to death = 22.68 yrs DALY of death due to HUS = 22.68 yrs Probability of ESRD[2] given HUS =10% and	*Not Considered in this study (i.e. probability of HUS = 0%)*

Operation	Basis	Example
	DALY of ESRD = 8.7, Probability of Death given ESRD =25.2% [1] *Hemolytic Uremic Syndrome* [2] *End-Stage Renal Disease*	
Summing up individual DALY	Total bacterial DALY=Σ Individual DALYs*Probabilities in (%)	Total DALY per infection= 9.0%(53%*$6.24*10^{-4}$ +47%*$5.98*10^{-3}$ +0.23%*62) =0.013 yr/infection *Therefore, DALY for the estimated annual probability of infection (calculated in step 2)* = $2.5*10^{-5}$ *(inf./py)* * 0.013 *1000 = $3.25*10^{-4}$ *yr /1,000 py*

(c) Estimating protozoan DALY:

Operation	Basis	Example
Estimating protozoan DALY	Probability of watery diarrhoea given infection= 7.1%, severity = 0.067 and duration 7 days	DALY of watery diarrhoea per infection= 0.067*7/365=$1.28*10^{-3}$ yr
	Probability of Death given illness= 0.001%, severity = 1, life lost due to death 62 yrs	DALY of death = 62 yr
	Total protozoan DALY=Individual DALYs*Probabilities in (%)	Total DALY per infection=7.1%($1.28*10^{-3}$+ 0.001%*62)=$1.35*10^{-4}$ yr/inf. *Therefore, DALY for the estimated annual probability of infection (calculated in step 2)* = $1.56*10^{-5}$ *(inf./py)* * $1.35*10^{-4}$ *1000 = $2.1*10^{-6}$ *DALY /1,000 py*

Step 4: Estimating total microbial DALY, Calculating Water Quality and Water Health Index

Operation	Basis	Example
Estimating Total microbial DALY	Total microbial DALY = viral DALY+ bacterial DALY+ protozoan DALY	Total microbial DALY=*0.0078+$3.25*10^{-4}$+ $2.1*10^{-6}$=0.0082 DALY/1000 py*
Total DALY	As DWASA water supplies is free from arsenic a background arsenic concentration of 0.1ppb was set in the model which results in a very minimal DALY score (0.0001 DALY/100 py). Therefore, total DALY is the sum of these two components	Total DALY= 0.0083 DALY/1000 py

Operation	Basis	Example
Water Quality Health Index (WQHI)	Lower total DALY limit (LTDL)= 0.0001 DALY/1000 py/1000 py Upper total DALY limit (UTDL)= 21.1362 DALY/1000 py Setting WQHI 100 for lower total DALY limit and 0 for upper total DALY limit, WQHI for a DALY of x = $100*\left[1-\frac{(x-LTDL)}{(UTDL-LTDL)}\right]$	WQHI= $100*\left[1-\frac{(x-LTDL)}{(UTDL-LTDL)}\right]$ $=100*\left[1-\frac{(0.0083-0.0001)}{(21.1362-0.0001)}\right]$ $=99.96 \cong 100.0$
Water Health Index (WHI)	For a given WQHI and Sanitary Inspection Score WHI can be calculated as, WHI= $\frac{(100-\text{SI score})+\text{WQHI}}{2}=$	WHI= $\frac{(100-50)+100}{2}$ =75.0

4.3.7 Development of Nomograph for Estimating DALY

The Estimation of DALY for different pathogens (i.e. virus, bacteria and protozoa) involves use of available dose-response equations under different underlying assumptions. Nonetheless, a generic nomograph can be developed to find DALY values in a quicker way. Figures 4.18 (a) through 4.18 (c) show nomographs for calculating DALY values for virus, bacteria and protozoa, respectively. These graphs have been generated with the following set of assumptions:

1. Drinking Water Consumption has been taken as 3 liter/day
2. Ratios of E-Coli to virus, bacteria and protozoa have been taken as used in ITN-APSU model (i.e., step 3 of previous section).
3. The assumptions for calculating DALY values (i.e., probability of illness given infection, duration and severity) were also taken from ITN-APSU model.

E-Coli: FC ratio is an important variable affecting the DALY values significantly. So, these nomographs have taken the ratio E-Coli:FC as a variable, together with FC concentration.

3. The assumptions for calculating DALY values (i.e., probability of illness given infection, duration and severity) were also taken from ITN-APSU model.

E-Coli: FC ratio is an important variable affecting the DALY values significantly. So, these nomographs have taken the ratio E-Coli:FC as a variable, together with FC concentration.

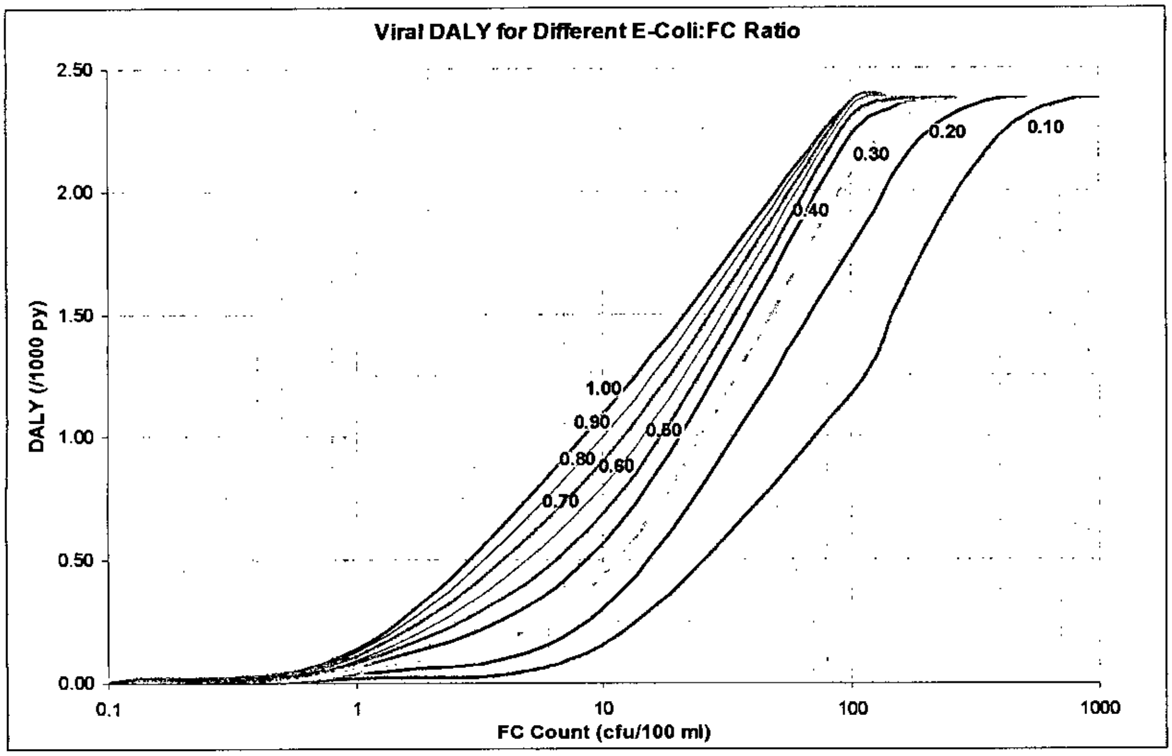

Fig. 4.18a: Nomograph for calculating viral DALY for different FC Count and E-Coli: FC ratio

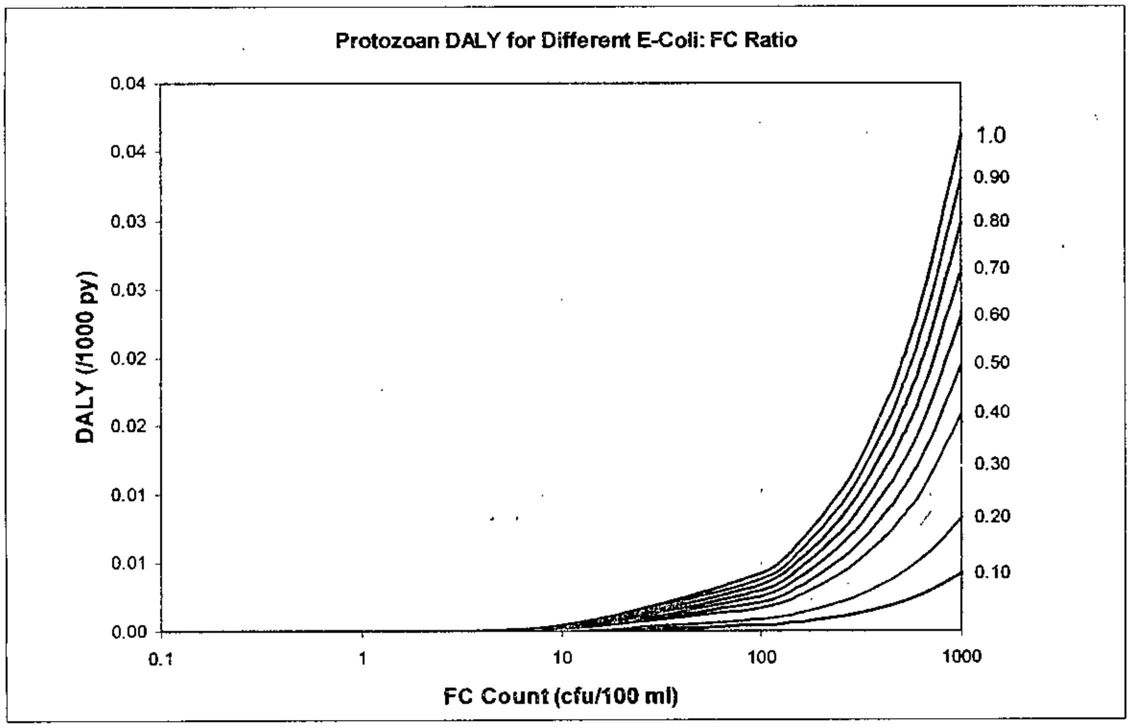

Fig. 4.18c: Nomograph for calculating protozoan DALY for different FC Count and E-Coli: FC Ratio

4.3.8 Manifestation of Disease Burden

An important task of the study was to assess the manifestation of waterborne disease by questionnaire survey. The individual households were asked for symptoms or incidence of waterborne disease for the last one year. The objective of this survey was to cross check the consistency of the risk burden estimation. This study has the following shortcomings:

1. The respondent's information may not be fairly accurate. Because in slum or low-income areas the diagnosis of disease are not done unless the patient is hospitalized. But the objective was to assess both the severe and mild cases.

2. The respondents may not drink water from their household water source alone. In urban context most of the consumers have to go their working places. So a significant portion of their ingested drinking water comes from other sources, the quality of which may be worse or better than the water supply option in question.

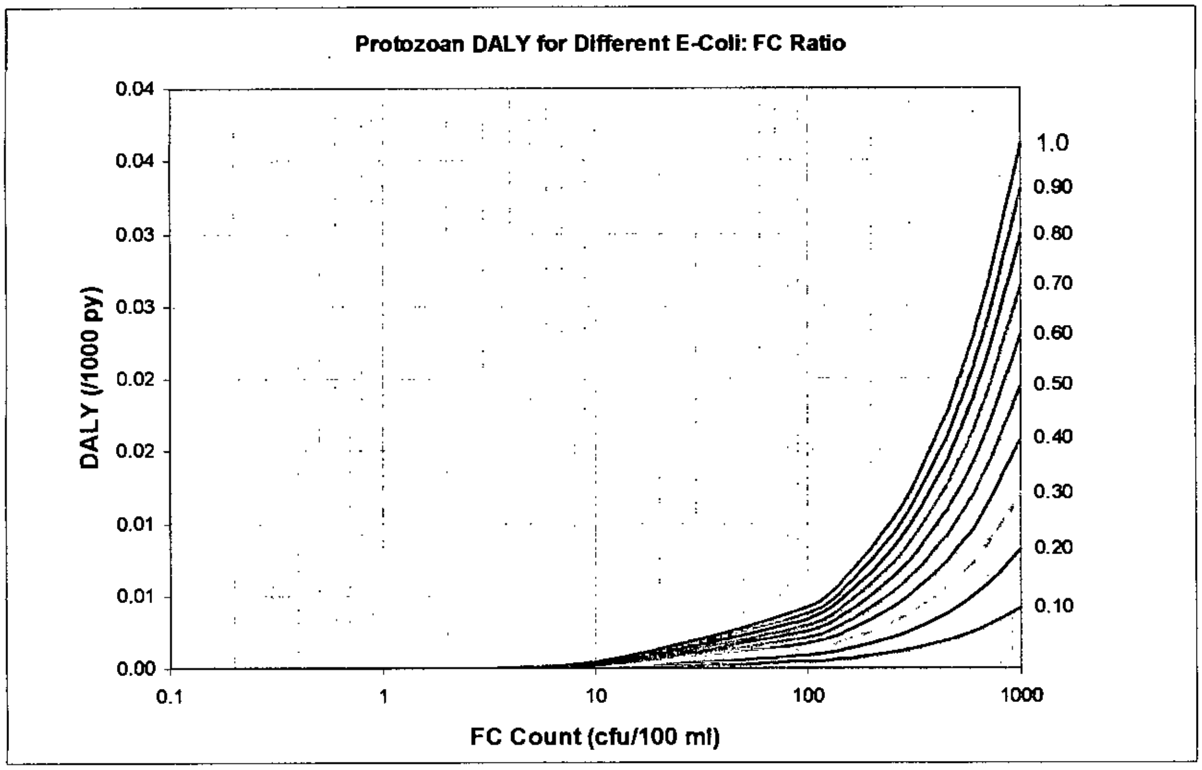

Fig. 4.18c: Nomograph for calculating protozoan DALY for different FC Count and E-Coli: FC Ratio

4.3.8 Manifestation of Disease Burden

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middle/high income people. Many complained skin irritations during bathing. Low income communities have the second highest percentage of skin diseases and slum people did not complain about this problem. This can be attributed to the fact that in overhead and underground reservoir there can be multiplication of micro-organisms responsible for skin diseases.

4.3.9 Estimation of Pathogenic Infections from Model

Now a comparison can be done between the actual prevalence and that predicted by dose-response equation. In doing this comparison, faecal coliform (FC) concentrations are divided into some class interval and median values and population exposed are calculated for each range from experimental data and survey results. Risk model is used to calculate the probability of viral, bacterial and protozoan infections for each median values. Probability of infection is multiplied by probability of illness given infection and then by population size. The individual incidences are summed up to figure out the number of predicted incidences. The model output is shown from Table 4.11 (a) through (c) for each community.

Table 4.11a: Estimation of viral, bacterial and protozoan prevalence from risk model (slum community)

FC Range	Median of Range (from data)	Population exposed	Model output			No. of predicted diarrhoeal incidences
			Annual Probability of Viral Infection	Annual Probability of Bacterial Infection	Annual Probability of Protozoan Infection	
0	0	1006	3.3E-05	1.7E-07	1.51E-07	0.00056
1-10	4	187	1.2E-01	1.3E-03	6.04E-04	0.39
11-50	37	232	7.0E-01	1.4E-02	5.57E-03	3.0
51-100	60	105	8.6E-01	2.4E-02	9.03E-03	1.75
101-300	175	21	1.0E+00	7.4E-02	2.61E-02	0.52
>300	--	--	--	--	--	--
Total	--	1551	--	--	--	5.66

Table 4.11b: Estimation of viral, bacterial and protozoan prevalence from risk model (low income community)

FC Range	Median of Range (from data)	Population exposed	Model output			No. of predicted diarrhoeal incidences
			Annual Probability of Viral Infection	Annual Probability of Bacterial Infection	Annual Probability of Protozoan Infection	
0	0	237	3.3E-05	1.7E-07	1.51E-07	0.00013
1-10	2.5	165	7.9E-02	7.8E-04	3.78E-04	0.23
11-50	12	6	3.3E-01	4.3E-03	1.81E-03	0.035
51-100	61	144	8.6E-01	2.4E-02	9.18E-03	2.40
101-300	228	58	8.5E-01	2.3E-02	8.728E-03	1.0
>300	640	8	1.0E+00	2.7E-01	9.221E-02	0.38
Total	--	1551	--	--	--	3.66

Table 4.11c: Estimation of viral, bacterial and protozoan incidences from risk model (middle/high income community)

FC Range	Median of Range (from data)	Population exposed	Model output			No. of predicted diarrhoeal incidences
			Annual Probability of Viral Infection	Annual Probability of Bacterial Infection	Annual Probability of Protozoan Infection	
0	0	189	3.3E-05	1.7E-07	1.51E-07	0.0001
1-10						
11-50	23	6	5.3E-01	8.6E-03	3.47E-03	0.06
51-100	103	20	9.6E-01	4.3E-02	1.545E-02	0.41
110-300	--	--	--	--	--	--
>300	--	--	--	--	--	--
Total	--	1551	--	--	--	0.47

A comparison of predicted infections of diarrhoea and dysentery by Risk Model and that by questionnaire survey is given in Table 4.12.

Table 4.12 Comparison of incidences of diarrhoeal diseases obtained from questionnaire survey with the corresponding values predicted by the risk model

Community	Population Exposed	Prevalence of Disease (by Risk Model)	Prevalence of Disease (by Questionnaire Survey)
Slum	1551	6	38
Low Income	618	4	56
Middle/High Income	215	1	4

Here, diarrhoea and dysentery are combined together as diarrhoeal incidences. It can be seen from Table 4.12 that the prevalence of diarrhoeal incidences as predicted by model is much less than the observed prevalence by questionnaire survey. This is probably due to the fact that there can be multiple sources of risk pathways contributing diarrhoeal diseases other than the water point in question. The consumers often drink water from other sources during their working hours. Also contaminated food is another source of diarrhoeal disease, the risk of which was not considered in the model.

4.3.10 Comparison of Risk Burden of Urban and Rural Water Supplies

A recent study conducted by ITN-BUET on "Risk Assessment of Arsenic Mitigation Options (RAAMO)" (ITN-BUET, 2004; 2005) provided valuable information of risk burden for rural water supplies in arsenic affected areas. Risk burden in rural water supplies can be compared with that of urban water supplies as found in this study. Fig 4.20 shows the comparative risk status of urban water supplies found in this study together with rural water supplies. Here DW, DTW and STW data are compared with four water supply options in urban areas found in this study. If we consider the 95th confidence level (UCL values), the DALY values for urban water supplies are higher in comparison to that for rural water supply. But if we consider median values both piped water supply with reservoir and DW in rural areas shows relatively higher DALY values compared to other options. But in urban areas where middle/high income communities, who are accustomed to boiling water prior to drinking will eventually get out of this risk. On the contrary DW users have more threat to their health. Among all water supply options, DTW in rural areas are the safest option, following STW in rural areas. Urban shallow tubewell operating mainly in slum areas have more DALY values compared to that of rural areas. This is due to more unsanitary surrounding in slum areas compared to village areas.

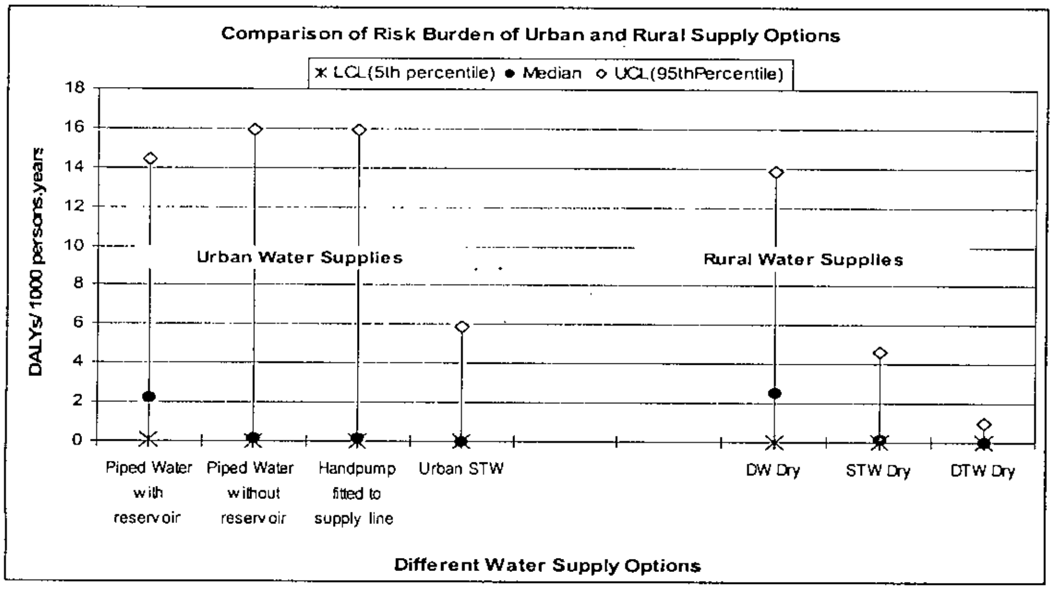

Fig. 4.20: DALY outputs of different water supply options in urban and rural areas

4.4 CONCLUSION

In the urban context though water supply options of middle/high income communities have more microbial contamination, boiling practice makes them safe from waterborne disease. As a result of this, risk burden in middle/high income communities are less than that of slum and low income communities. Risk model can simulate the prevalence of waterborne diseases provided that the background data of waterborne diseases include proper diagnoses. Disease burden of urban water supplies appear to be more than that of rural water supply options like, DTW or STW at upper confidence level. But for median and LCL, the DALY values are more or less the same. Deep tubewell in rural area have the lowest disease burden.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The major objective of this research work was to assess the health risk burden of water supply options in Dhaka city in various socio-economic settings. In order to do that sampling points were chosen based on a preliminary survey. Communities were divided into three distinct categories, namely slum, low-income and middle/high income community, based on water supply pattern and house type. Microbial as well as some physico-chemical water quality parameters were tested for a total of 80 water points covering all communities. Sanitary Inspection was carried out for each water point. Finally, microbial water quality data were used in a Health Risk Model tool to estimate the health risk burden. Major conclusions from this study are summarized below:

- Water supply in slum areas are principally based on handpump operated water collection system (59%), about half of which are connected with DWASA line and the remaining are shallow hand tubewell. There is also good number of house connections (41%), but most of them are illegal. Hand-pumps connected with WASA mainline (about 48%) and house connections without any underground or overhead reservoir (about 41%) are two major water supply options for low-income communities. Middle/high income communities have house connections with overhead and underground reservoir system.

- Majority of households (75%) in the middle/high income community boil water, while the figure is nil for the slum community. About 44% of households of low-income community, surveyed in this study, boil water for drinking purpose.

- From Sanitary Inspection (SI) survey, it appears that house connection without any reservoir has potentially high hazard pathways because of illegal and unsanitary methods of water collection. As these systems predominate in slum and low-income community areas, the unhygienic surroundings of the areas also contributed to the higher sanitary risk score. In slum areas, the unsanitary surroundings of water points contributed the higher sanitary risk.

- Sixty two percent of supplies under the study have odour problem. About half of them have this problem permanently. In other cases this problem is occasional. Nineteen percent of supplies have temporary colour problem, while 8% have permanent colour problem. About 23% of the consumer complained that they get turbid water, but only 4% claimed this problem to be persistent.

- Ammonia concentration of 31% of samples exceeded the Bangladesh Standard of 0.5 mg/L; 76% of these water point users also complained of having objectionable odour in water. Nitrate concentration of all the samples was within the Bangladesh drinking water standard. Ammonia concentrations in water samples of low income community areas were higher. A major portion of low-income community area under this study (Sabujbagh) is served by Saidabad surface water treatment plant, which is known to have high ammonia concentration during the dry season.

- About 50% of water points had desired residual chlorine concentration at the delivery end to combat risk of microbial contamination.

- About 46% of samples showed presence of FC. Among the supply systems, shallow tubewell suffers least from microbial contamination. Hand-pumps fitted with DWASA line also suffer less from this problem. This is probably because of the fact that here water comes directly from the WASA main, which contains some residual chlorine that acts against microbial contamination. Piped supply without reservoir mostly serves the slum and the low-income areas, where long, flexible, PVC pipes often carry water over wastelands, increasing the risk of microbial pollution. In house connection with reservoir, if reservoirs are not cleaned frequently this can cause deterioration of microbial water quality.

- No significant correlation was found between the sanitary condition of the water points and the FC count of water samples.

- Health risk burden assessment showed that at upper 95th percentile both low-income and slum areas have significantly high DALY values, while for middle/high income communities the value is relatively small. Median and lower 5th percentile values of DALY for all communities were similar and about 0.0083 DALY/ 1,000 py.

- Upper 95th percentile of DALY for both piped water supply without reservoir and hand-pump fitted to supply line were higher. These two options are widely used by slum and low-income communities. On the other hand, poor water quality of piped supply with reservoir, which is the primary supply source of middle/high income community, is more or less offset by boiling practices. This is why the community-wise DALY value for middle/high income communities are far less than that for slum or low-income communities.

- From questionnaire survey, higher prevalence of diarrhoea (8.5%) and typhoid (1.6%) was found to be common among low-income communities. Slum people reported slightly less prevalence of diarrhoea (2.1%) and typhoid (0.6%). Prevalence of hepatitis in both slum and low-income communities are almost similar (about 5.3%). Middle/high income communities did not report any incidence of typhoid, but reported nearly same prevalence of diarrhoeal disease as observed among slum communities.

- Prevalence of diarrhoeal incidences as predicted by model is much less than the observed prevalence obtained from the questionnaire survey. This is probably due to the fact that there can be multiple sources of risk pathways contributing to diarrhoeal diseases, other than the water point. People often drink water from other sources during their working hours. Also contaminated food is another source of diarrhoeal disease.

- A comparison of rural and urban water supplies shows higher health risk burden from urban water supply. Among all the water supply options, deep tubewell showed the lowest DALY values. Dugwells in rural areas appear to be the most risky option (having highest mean DALYs), while piped water supply with reservoir being the next. But unlike the users of dugwells in rural areas, middle to high income communities using piped water supply with reservoir usually boil their water which reduces the risk significantly.

5.2 RECOMMENDATIONS FOR FUTURE STUDY

- A suitable water safety plan can be developed and applied in the urban water supply system, based on the findings of this study.

- In this study, an outline to simulate the incidence of waterborne diseases using quantitative health risk model has been presented. But the method used for estimating the manifestation of disease was rather crude, i.e., by questionnaire survey. Proper diagnoses of waterborne diseases should be made for more accurate assessment of disease manifestation.

- In simulating the incidence of waterborne disease, the issue of water consumption by people from multiple sources (e.g., at home and at workplace) should be considered. Also a more accurate estimation of the quantity of water actually consumed by people should be made.

- Some of the assumptions in this model, especially different ratios like [E-Coli]: [FC] or [E-Coli]: [Index Pathogens] should be further checked by more extensive laboratory analysis.

- Prevalence of viral diarrhea was simulated with the health risk model. Viral hepatitis should also be considered in future study, as this seems to be a common waterborne disease in urban areas.

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Appendix A

Sample Sanitary Inspection forms

(Piped Water Supply with Reservoir)

Date of Survey:
Water Supply Option:
Community Type:
Water Point No:

Risk Questions

Risk Questions	**Risk**
1. Is there any hanging /pit latrine within 10 m of the water supply option?	Y/N
2. Is there any other source of faecal pollution 10 m of the water supply option?	Y/N
3. Is there any visible leak in the water supply system from street main to underground reservoir near the collection point?	Y/N
4. Is there any visible leak in the water supply system from UGR to OHR reservoir?	Y/N
5. Is the tap loose/ missing/faulty at the connection point?	Y/N
6. Is there any visible crack on the underground reservoir?	Y/N
7. Is the drainage system near the water points faulty inundating the area?	Y/N
8. Is there any way to contaminate the under ground reservoir from septic tank?	Y/N
9. Is there any collection of water on the under ground reservoir from faulty drainage?	Y/N
10. Is there visible sign of dirt, insects in the underground/ overhead reservoir?	Y/N
Total Score	

Sanitary Inspection forms

(Piped Water Supply without Reservoir)

Date of Survey:
Water Supply Option:
Community Type:
Water Point No:

Risk Questions	**Risk**
1. Is there any hanging /pit latrine within 10 m of the water supply option?	Y/N
2. Is there any other source of faecal pollution within 10 m of the water supply option?	Y/N
3. Is there any visible leak in the water supply system from street main to the collection point?	Y/N
4. If water is collected by flexible rubber, PVC pipes does it go over dirty areas (waste dump, wasteland etc)?	Y/N
5. Is the tap loose/ missing/faulty at the connection point?	Y/N
6. Is the drainage system near the water points faulty inundating the area?	Y/N
7. Is the platform slope not properly designed facilitating poor drainage?	Y/N
8. Are the water collecting containers seen dirty?	Y/N
9. Does the community lack hygiene practices?	Y/N
10. Do the people reserve water temporarily in containers like drums?	Y/N
Total Score	

Sanitary Inspection forms

(Handpump Connected to supply line/ STW)

Date of Survey:
Water Supply Option:
Community Type:
Water Point No:

Risk Questions	**Risk**
1. Is there any hanging /pit latrine within 10 m of the water supply option?	Y/N
2. Is there any other source of faecal pollution within 10 m of the water supply option?	Y/N
3. Are there cracks in the platform supporting infiltration of dirty water?	Y/N
4. Is the platform slope not properly designed facilitating poor drainage?	Y/N
5. Is the handpump loose at the connection point?	Y/N
6. Is the drainage system near the water points faulty inundating the area?	Y/N
7. Does the pump water go down and the community use dirty water for priming?	Y/N
8. Are the water collecting containers seen dirty?	Y/N
9. Does the community lack hygiene practices?	Y/N
10. Do the people reserve water temporarily in containers like drums?	Y/N
Total Score	

Appendix B

Questionnaire to assess the waterborne diseases

Date of Survey:
Water Supply Option:
Community Type:
Water Point No:

Fill out the waterborne diseases that were manifested in the past one year

	Total users	Person affected	Mild/severe	Possible Source
Diarrhea				
Dysentery				
Typhoid				
Jaundice				
Skin Diseases				

Appendix C

E-Coli Test Results

Cluster Name	**Ward Number**	**Water Point No.**	**FC**	**E-coli**	**Ratio E-Coli: FC**
Hazaribagh	48	60	220	114	0.518
Mohammadpur	47	61	130	130	1.000
Mohammadpur	47	64	60	60	1.000
Mohammadpur	46	67	98	31	0.316
Mohammadpur	46	68	640	168	0.263
Mohammadpur	46	69	92	25	0.272
Mohammadpur	46	70	132	47	0.356
Mohammadpur	46	74	52	22	0.423
Mohammadpur	46	77	70	38	0.543
Mohammadpur	46	80	104	30	0.288
				Average	**0.498**

Appendix D

Sanitary Score, Boiling Practices and Results of Testing (Physical and Chemical)

Cluster Name	Water Point	Com. Type	SI Score	Boil. Prac.	pH	Conductivity	Turbidity	NO3	NH3	Total Cl2	FC	E-coli
Mirpur	1	low income	2	y	6.3	240	0.61		0.1	0.025	26	
Mirpur	2	low income	2	y	8.5	280	0.81		0.1	0.025	56	
Mirpur	3	low income	1	y	6	290	0.86		0.1	0.025	0	
Mirpur	4	middle/high	0	y	6.3	260	0.83		0.1	0.025	86	
Mirpur	5	slum	2	n	7	250	1.38		0.1	0.025	41	
Mirpur	6	slum	3	n	6.6	230	0.57		0.1	0.025	32	
Mirpur	7	low income	0	y	7.1	260	0.61		0.1	0.025	0	
Mirpur	8	middle/high	0	n	6.6	250	1.23		0.1	0.025	103	
Mirpur	9	low income	5	n	7	250	0.4		0.1	0.025	52	
Mirpur	10	slum	5	n	6.7	240	0.64		0.1	0.25	0	
Mirpur	11	middle/high	1	y	6.9	250	0.5	0.13	0.01	0.25	0	

Cluster Name	Water Point	Com. Type	SI Score	Boil. Prac.	pH	Conductivity	Turbidity	NO3	NH3	Total Cl2	FC	E-coli
Mirpur	12	slum	5	n	6	210	0.82		0.05	0.25	0	
Mirpur	13	slum	5	n	6.2	220	0.81		0.1	0.25	0	
Mirpur	14	middle/high	1	n	6.4	260	1.14		0.1	0.25	0	
Sabujbagh	15	middle/high	1	y	7.8	425	1.52	4	0.34	0.08	38	
Sabujbagh	16	middle/high	2	y	7.8	275	0.54	0.4	0	0.02	68	
Sabujbagh	17	low income	3	y	7.2	270	0.6	0.3	0	0.02	20	
Sabujbagh	18	low income	3	n	7.6	460	1.3	3.7	1.64	2	0	
Sabujbagh	19	slum	4	n	7.8	510	4.02	3	0.63	0.1	0	
Sabujbagh	20	slum	4	n	7.5	410	1.39	3.6	1.14	1.07	0	
Tejgaon	21	slum	5	n	6.7	340	1.84	4.7	0	0.02	0	
Tejgaon	22	slum	3	n	6.5	350	1.88	4.3	0	0.02	0	
Tejgaon	23	slum	6	n	6.2	330	1.25	4.4	0	0.02	30	
Tejgaon	24	slum	6	n	6.2	330	0.98	3.4	0	0.03	0	

Cluster Name	Water Point	Com. Type	SI Score	Boil. Prac.	pH	Conductivity	Turbidity	NO3	NH3	Total Cl2	FC	E-coli
Tejgaon	25	slum	5	n	6.3	400	0.18	3.1	0	0.29	0	
Tejgaon	26	slum	7	n	6.3	400	0.91	2.7	0	0.32	0	
Tejgaon	27	slum	4	n	6.2	400	0.43	2.3	0	0.38	0	
Sabujbagh	28	low income	2	y	7.5	570	0.78	1.8	1.67	1.86	0	
Sabujbagh	29	low income	3	n	7.4	500	0.56	3.3	1.61	1.84	0	
Sabujbagh	30	low income	4	y	7.1	540	3.15	3.1	2.9	0.66	0	
Sabujbagh	31	low income	4	n	7.2	550	3.52	3.6	2.78	0.19	3	
Sabujbagh	32	low income	4	n	7.3	550	3.55	3.4	2.9	0.33	0	
Sabujbagh	33	low income	4	y	7.2	540	3.25	2.7	2.9	0.49	1	
Sabujbagh	34	middle/high	2	y	7.2	480	0.57	3.5	0.38	0.09	0	
Sabujbagh	35	middle/high	2	y	7	390	1.26	1.7	0.28	0.03	7	
Sabujbagh	36	middle/high	1	y	7	490	0.71	2.6	0.75	0.15	0	
Sabujbagh	37	slum	3	n	7	470	4.25	2.5	1.372	1.42	0	
Sabujbagh	38	slum	5	n	7.1	510	1.1	1.8	1.5	1.35	0	
Sabujbagh	39	slum	5	n	6.9	470	1.45	1.6	1.02	0.55	0	
Sabujbagh	40	slum	5	n	6.8	450	2.31	2.5	1.05	0.57	0	
Sabujbagh	41	slum	4	n	7	460	0.8	0.4	1.18	1.06	0	
Sabujbagh	42	slum	4	n	6.9	460	0.96	2.7	1.28	1.29	0	

Cluster Name	Water Point	Com. Type	SI Score	Boil. Prac.	pH	Conductivity	Turbidity	NO3	NH3	Total Cl2	FC	E-coli
Sabujbagh	43	low income	2	y	6.9	490	0.65	2.6	1.28	1.49	0	
Sabujbagh	44	low income	3	y	7.2	480	0.76	3.7	0.543	0.25	0	
Sabujbagh	45	middle/high	2	y	6.7	230	0.41	0.1	0	0.01	0	
Sabujbagh	46	middle/high	1	y	6.4	230	0.57	0	0	0.02	242	
Sabujbagh	47	middle/high	3	n	6.8	230	0.86	0.1	0	0.02	23	
Sabujbagh	48	low income	3	y	6.8	230	0.35	0	0	0.02	10	
Sabujbagh	49	low income	3	n	6.4	120	0.71	0.1	0	0.01	1	
Sabujbagh	50	low income	2	n	6.3	220	0.57	0.1	0	0.02	8	
Hazaribagh	51	slum	5	n	7.3	380	2.28	0.1	0.96	0.02	240	
Hazaribagh	52	slum	5	n	7.3	500	0.76	0.04	2	0.14	110	
Hazaribagh	53	low income	5	n	6.7	390	0.93	0.06	1.08	0.08	236	
Hazaribagh	54	low income	0	y	6.5	380	0.62	0.12	0.28	0.08	128	
Hazaribagh	55	low income	0	n	6.7	410	0.79	0.17	0.8	0.02	228	
Hazaribagh	56	slum	4	n	6.4	470	0.64	0.02	1.24	0.04	0	
Hazaribagh	57	slum	3	n	6.5	510	0.78	0.04	0.16	0.04	8	
Hazaribagh	58	slum	5	n	6.5	510	0.93	0.03	0.13	0.08	4	
Hazaribagh	59	slum	7	n	7.3	220	0.46	0.16	1.04	0.06	44	
Hazaribagh	60	slum	7	n	6.6	390	0.75	0.04	0.68	0.04	220	114
Mohamadpur	61	slum	6	n	7.19	379	0.62	0.9	0	0	130	130

Cluster Name	Water Point	Com. Type	SI Score	Boil. Prac.	pH	Conductivity	Turbidity	NO3	NH3	Total Cl2	FC	E-coli
Mohamadpur	62	slum	3	n	7.33	688	0.81	1.1	0	0.02	0	
Mohamadpur	63	slum	7	n	6.77	371	0.6	0.4	0	0	10	
Mohamadpur	64	slum	6	n	6.85	302	0.74	0.6	0	0	60	60
Mohamadpur	65	slum	4	n	6.5	447	0.61	0.5	0	0	2	
Mohamadpur	66	slum	3	n	7.02	416	83	0.3	0	0.04	0	
Mohamadpur	67	slum	6	n	6.76	254	2.58	0	0	0	98	31
Mohamadpur	68	low income	2	n	6.86	271	1.78	0.5	0	0	640	168
Mohamadpur	69	middle/high	2	y	6.97	268	0.6	0.5	0	0.01	92	25
Mohamadpur	70	middle/high	0	y	6.9	263	0.75	0.5	0	0.01	132	47
Mohamadpur	71	slum	2	n	6.56	596	15.1	0.2	0	0.02	0	
Mohamadpur	72	slum	3	n	6.46	403	25.1	0.3	0	0.17	0	
Mohamadpur	73	slum	3	n	8.21	343	3.65	1.3	0	0.03	2	
Mohamadpur	74	slum	2	n	7.34	535	0.66	0.4	0	0.11	52	22
Mohamadpur	75	low income	4	n	7.76	429	0.73	0.3	0	0.38	12	
Mohamadpur	76	low income	5	n	6.5	371	0.67	0	0	0.24	2	
Mohamadpur	77	low income	4	n	7.61	381	0.79	0.4	0	0.39	70	38
Mohamadpur	78	slum	5	n	7.34	373	0.91	0.4	0	0.2	6	
Mohamadpur	79	low income	4	n	6.88	372	0.59	0.5	0	0.32	0	
Mohamadpur	80	low income	7	n	6.98	373	0.86	0.5	0	0.17	104	30

Appendix E

Results of Manifestation of Waterborne Disease by Questionnaire Survey

Cluster Name	Water Point	Community Type	No. of family members/ users	Diarrhea	Dysentery	Typhoid	Jaundice	Skin Diseases	Sanitation System
Mirpur	1	low income	5					5	sanitary sewer
Mirpur	2	low income	6	1	1			1	sanitary sewer
Mirpur	3	low income	6					6	septic tank
Mirpur	4	middle/high	5						sanitary sewer
Mirpur	5	slum	6	1			2		pit latrine
Mirpur	6	slum	20			2	6	15	unsanitary
Mirpur	7	low income	7					1	septic tank
Mirpur	8	middle/high	20	2			5	25	
Mirpur	9	low income	60				1		unsanitary
Mirpur	10	slum	20						hanging
Mirpur	11	middle/high	10						sanitary sewer
Mirpur	12	slum	7				1		hanging
Mirpur	13	slum	25	10			4	4	unsanitary
Mirpur	14	middle/high							sanitary sewer
Sabujbagh	15	middle/high	8		1				sanitary sewer
Sabujbagh	16	middle/high	50	1					sanitary sewer
Sabujbagh	17	low income	16	1					sanitary sewer
Sabujbagh	18	low income	48	5					sanitary sewer
Sabujbagh	19	slum							hanging
Sabujbagh	20	slum	150	1			10	3	unsanitary

Cluster Name	Water Point	Community Type	No. of family members/ users	Diarrhea	Dysentery	Typhoid	Jaundice	Skin Diseases	Sanitation System
Tejgaon	21	slum	350				10		pit latrine
Tejgaon	22	slum					20		hanging
Tejgaon	23	slum	200	4				10	hanging
Tejgaon	24	slum	30				3	4	hanging
Tejgaon	25	slum	8	2	1				pit latrine
Tejgaon	26	slum	6						pit latrine
Tejgaon	27	slum							pit latrine
Sabujbagh	28	low income	5	2					septic tank
Sabujbagh	29	low income	6	3	1				septic tank
Sabujbagh	30	low income	20	2				15	septic tank
Sabujbagh	31	low income	30				7	4	sanitary sewer
Sabujbagh	32	low income	35	2		2	2	20	sanitary sewer
Sabujbagh	33	low income	30	7		6	4		sanitary sewer
Sabujbagh	34	middle/high	6				1		sanitary sewer
Sabujbagh	35	middle/high	60						sanitary sewer
Sabujbagh	36	middle/high	10						sanitary sewer
Sabujbagh	37	slum	16	5			3		pit latrine
Sabujbagh	38	slum	10	1					pit latrine
Sabujbagh	39	slum	30			3	2		hanging
Sabujbagh	40	slum	30			2	2		hanging
Sabujbagh	41	slum	90	5			4		pit latrine
Sabujbagh	42	slum	50						pit latrine
Sabujbagh	43	low income	5	1				1	sanitary sewer
Sabujbagh	44	low income	20	7					sanitary sewer
Sabujbagh	45	middle/high	10						sanitary sewer
Sabujbagh	46	middle/high	17				1		sanitary sewer
Sabujbagh	47	middle/high	6						sanitary sewer

Cluster Name	Water Point	Community Type	No. of family members/ users	Diarrhea	Dysentery	Typhoid	Jaundice	Skin Diseases	Sanitation System
Sabujbagh	48	low income	6						sanitary sewer
Sabujbagh	49	low income	50						sanitary sewer
Sabujbagh	50	low income	60						sanitary sewer
Hazaribagh	51	slum	4						pit latrine
Hazaribagh	52	slum	4						pit latrine
Hazaribagh	53	low income	3						unsanitary
Hazaribagh	54	low income	7						septic tank
Hazaribagh	55	low income	7				1		sanitary sewer
Hazaribagh	56	slum	6						hanging
Hazaribagh	57	slum							pit latrine
Hazaribagh	58	slum							pit latrine
Hazaribagh	59	slum	6		1				hanging
Hazaribagh	60	slum	5						hanging
Mohammadpur	61	slum	8				3		pit latrine
Mohammadpur	62	slum	12						pit latrine
Mohammadpur	63	slum	6				2		hanging
Mohammadpur	64	slum	10	2	3	2	3		hanging
Mohammadpur	65	slum	7						hanging
Mohammadpur	66	slum	8						hanging
Mohammadpur	67	slum	5	2					hanging
Mohammadpur	68	low income	8	3					hanging
Mohammadpur	69	middle/high	8						sanitary sewer
Mohammadpur	70	middle/high	5						sanitary sewer
Mohammadpur	71	slum	8						pit latrine
Mohammadpur	72	slum	150						pit latrine
Mohammadpur	73	slum	150						pit latrine
Mohammadpur	74	slum	90						pit latrine
Mohammadpur	75	low income	6	1	1				sanitary sewer
Mohammadpur	76	low income	25						sanitary sewer
Mohammadpur	77	low income	84						sanitary sewer
Mohammadpur	78	slum	24			1	6		unsanitary
Mohammadpur	79	low income	15			2	2		unsanitary

Cluster Name	Water Point	Community Type	No. of family members/ users	Diarrhea	Dysentery	Typhoid	Jaundice	Skin Diseases	Sanitation System
Mohammadpur	80	low income	48	18			16		unsanitary