DETERIORATION OF STORED DOMESTIC WATER

QUALITY AND DIARRHOEA IN ZENU

BY

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DECLARATION

This thesis is the candidate's own work produced from research undertaken under supervision.

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ABSTRACT

300 selected households were visited in Zenu, a peri-urban town in the Tema municipality of the Greater Accra Region of Ghana from July to October 2001. Data was collected on the water related practices and diarrhoea recall by the administration of a simple questionnaire. A total of 293 completed responses were obtained.

There were three main sources of water in the town; direct pipe (pipeborne), stored treated water (tank) and dam water. Though majority of households used the tank water only, about 35% of households used a combination of the available water sources i.e. potable and unpotable or unimproved sources. The information obtained on diarrhoea prevalence and drinking water storage shows that the use of unimproved drinking water sources; use of storage vessels for other household activities and the period of replenishment was associated with diarrhoea. Storage of water per se was however not found to be associated with diarrhoea.

In order to establish the deterioration of stored water quality in the home, water samples were collected from representative households for each of the drinking water sources; direct tap water, stored tank water or dam water. Cultures for coliform bacteria were done using *E. coli* as the main outcome indicator of contamination of stored water. The count in samples with organisms was used as an index of contamination.

Apart from the direct tap water collected at source, coliforms were found in all the samples from the source to the consumer level. The levels of contamination also increased from the source to the consumer level giving evidence for contamination in the home.

The evidence of contamination of domestic stored water together with the need to store water in the home suggests that residents should pay more attention to personal hygiene practices in their homes.

ABBREVIATIONS AND ACRONYMS

AIDS: Acquired Immunodeficiency Syndrome

BOD: Biochemical oxygen demand

CDD: Control of Diarrhoeal Diseases.

CSD: (UN) Commission on Sustainable Development.

CSIR: Council for Scientific and Industrial Research

DALY: Disability-adjusted life year

ECETOC: European Chemical Industry Ecology and Toxicology Centre

FAO: Food and Agriculture Organization of the United Nations

FC: Faecal coliform

GEMS: Global Environmental Monitoring System. (UNEP/WHO)

GWSS: Ghana Water Supply and Sanitation

HESD: Health and Environment in Sustainable Development

IDWSSD: International Drinking Water Supply and Sanitation Decade

ILEC: International Lake Environment Committee

IPCS: International Programme on Chemical Safety (UNEP, ILO, WHO)

IRC: International Rainwater Centre

IRCSA: International Rainwater Catchment Systems Association

PHC: Primary Health Care

POP: Persistent Organic Pollutants

TC: Total coliforms

UN: United Nations

CHAPTER 1

1.0 INTRODUCTION

1.1 GLOBAL WATER SITUATION

About 1.3 billion people in the developing world lack access to clean and plentiful water. Water quantity is as important as water quality (Verweij et al., 1991, Gilman et al., 1993, Huttly et al., 1990). Washing hands after defecation and before preparing food is of particular importance in reducing disease transmission (Pinfold et al., 1990), but without abundant water in or near the home, hygiene becomes difficult or impossible. The lack of water supply and sanitation is the primary reason diseases transmitted via faeces are so common in developing countries. The most important of these diseases, diarrhoea and intestinal worm infections account for an annual burden of 117 million Disability-adjusted life years (DALYs) or 10% of the total burden of disease in developing countries (World Bank,1993).

In addition, an inadequate water supply increases the risk of schistosomiasis, skin and eye infections, and guinea worm diseases (Cheesebrough, 1984). Those who are ill cannot work productively while those who are well waste time and energy in daily search for water. Women spend an average of three hours a day on the single task of fetching water (World Watch, 1984).

Half a century of efforts by the World Health Organization (WHO), the United Nation Children's Fund (UNICEF) and other international Organizations to improve water and sanitation conditions around the world have contributed to global awareness, the establishment of international programmes and the strengthening of national institutions. In the 1990s this afforded improved water supply for more than 800 million people and sanitation for around 750 million people. However, despite the intensive efforts of many institutions at the national and international levels, nearly 1.1 billion people still remain without access to improved sources of water, and about 2.4 billion have no access to any form of improved sources of water services. As a result, 2.2 million people in developing countries, mostly children, die every year from diseases associated with lack of safe drinking water, inadequate sanitation and poor hygiene.

Access to safe water and to sanitary means of excreta disposal are universal needs and, indeed, basic human rights (Gleick, 1999). They are essential elements of human development and poverty alleviation and constitute an indispensable component of Primary Health Care (PHC). There is evidence that provision of adequate sanitation services, safe water supply, and hygiene education represents an effective health intervention that reduces the mortality caused by diarrhoea disease by an average of 65% and the related morbidity by 26% (WHO/UNICEF/WSSCC, 2000). Inadequate sanitation, hygiene and water result not only in more sickness and death, but also in higher health costs, lower worker productivity, waste of time and energy in daily search for water, lower school enrolment and retention rates of girls and perhaps most importantly, the denial of the rights of all people to live in dignity (World Watch, 1984).

1.2 RESEARCH PROBLEM

1.2.1 Background and rationale

Access to safe water remains an urgent human need in many countries. Lack of safe water causes tremendous human suffering resulting from water related diseases. The problem is compounded in some places by growing water scarcity, which makes it difficult to meet increasing demand except at escalating cost (World Bank, 1992).

The most widespread contamination of water is from disease-bearing human wastes, usually detected by measuring faecal coliform levels. Lack of access to clean water and sanitation has serious effects on the health of about 3 billion people in developing countries. Food that is prepared with contaminated water is often contaminated with diarrhoea causing pathogens (Esrey and Feachem, 1989). There are 900 million cases of diarrhoea diseases every year, (WHO, 2000 a), which cause the deaths of many more than 3 million children; 2 million of these deaths could be prevented if adequate sanitation and clean water are available. 200 million suffer from schistosomiasis while 900 million people are infected from hookworm. Cholera, typhoid, and paratyphoid also continue to have their toll on human welfare (World Bank,1992). Much of the human distress could be alleviated by the provision of clean water and sanitation.

With industrial development and inevitable urbanisation, access to water supply has barely kept pace with population growth. Many cities have over-grown their capacity to provide adequate, sustainable water supplies, due to over population. At least 170 million people in urban areas still lack a source of potable water near their homes. In many suburban areas, households in areas unserved by the municipal water system buy water from private vendors, at prices several times greater than the charges for households, which are supplied by the municipal water system (Caincross & Kinnear, 1992). This limits the amount of water they use for domestic purposes. Even where there is official access or municipal water supply, water shortages and intermittent supplies have led to the use of storage systems which pollute the water in many homes.

Although access to potable water has rapidly increased in the rural areas more than 855 million people are still without safe water (World Bank, 1992). The rural poor rely directly on rivers, lakes and unprotected shallow wells for their water needs. Serious ill health can be caused by water supplies becoming contaminated from faeces being passed or washed into these rivers, streams or pools, or being allowed to seep into wells or boreholes.

Conceding that water quality deterioration is 'inevitable' during distribution (Cheesbrough,1984), further deterioration is expected during handling before consumption. In this way many of those who officially have access to potable water still drink polluted water. This is usually due to the container used to fetch, store and dip for use. It may also depend on the behavioural practices of the consumers.

Faeces contain large numbers of organisms including, *Escherichia coli, Streptococcus faecalis*, and *Clostridium perfringens*. The presence of normal faecal organisms could be tested to determine faecal pollution of a water supply and the possibility that it contains enteric pathogens, which are dangerous to health. The test for normal faecal organisms as indicators of faecal pollution is a reliable way to determine whether water is bacteriologically safe to drink. The reasoning is that, if no normal faecal bacteria are detected in a water sample, it is probable that enteric pathogens are also absent and vice versa.

1.2.2 Research questions

- Is water reaching the consumer at an acceptable quality?
- Is the source of water associated with diarrhoea?
- Do storage practices affect the quality of the water consumed?
- What are the existing water storage practices?
- Are the storage practices associated with diarrhoea?
- Does the water quality deteriorate after it has been stored in the home?

1.2.3 Objectives

- **General objective**

To describe the water storage related practices which affect domestic drinking water quality and their association with diarrhoea in Zenu.

- **Specific objectives**
  - To investigate the quality of domestic stored drinking water in Zenu
  - To find out whether water is reaching the consumer at an acceptable quality,
  - To find evidence of deterioration (faecal coliforms) of stored drinking water quality in the home,
  - To identify the water storage related practices and their association with diarrhoea.

1.2.4 Hypotheses

- There is no difference between the quality of water at source and at the storage and consumer levels.
- The water storage practices are not associated with diarrhoea.

1.2.5 Conceptual frame work

The conceptual frame work which identifies the variables and their operational definitions are provided in Appendices 1 and 2.

1.2.6 The study area

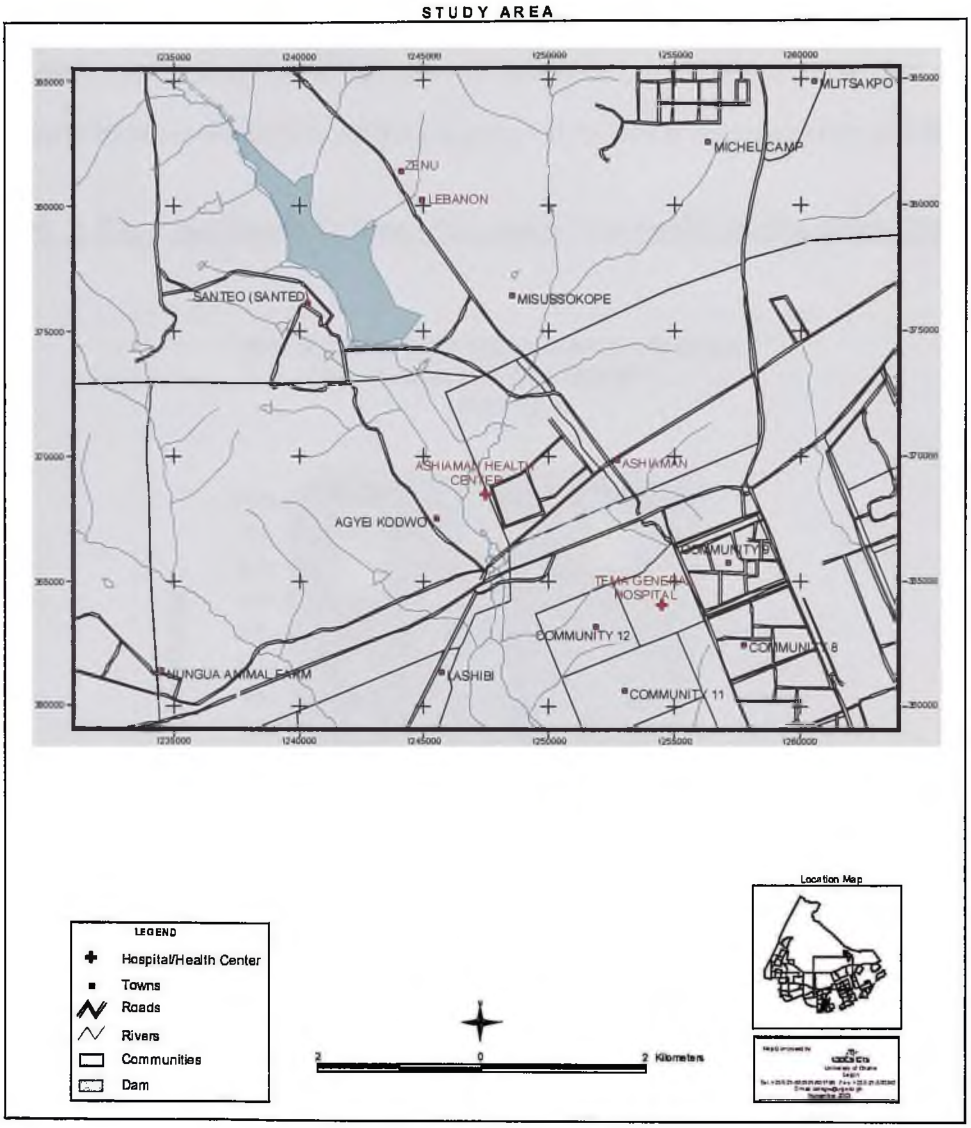
Zenu is situated in the southern plains of Ghana. It is a sub-urban town in the Tema municipality. It is about 10 kilometres from The Tema township (Fig.1). It has a growing population of about 3 thousand.

The inhabitants are mainly farmers. The town is unserved (not connected to the chlorinated water distribution system). The inhabitants rely both on chlorinated and dam water for drinking. An earth dam has been constructed across the Gworwulu River for an irrigation project. The dam water is used for other household purposes such as washing of clothes and utensils and bathing. There are no wells or boreholes.

Chlorinated water is brought in by water tankers, which are emptied and stored in reservoirs or tanks for sale to the inhabitants. Those who live close to Lebanon, a neighbouring settlement which is served, purchase tap water directly from connected homes. Whatever their source of drinking water, households bring water to their homes and store them in containers reserved for drinking water. While working on the farm, the dam water is used both for cooking and drinking.

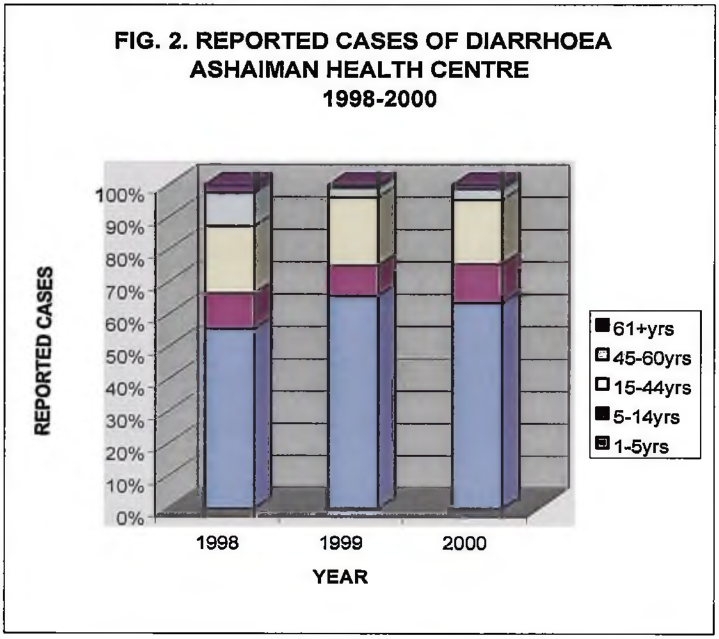
There are no public toilets in the town and very few homes have toilet facilities. The people practice "free ranging" (using nearby bush and land areas as toilet) along the banks of the dam. This practice together with the run off of agricultural chemicals

Fig. 1. Map of the study area.



form the main sources of pollution of the water. The water is also used for bathing and washing. There is also no clinic in the town. The people of Zenu use the Ashaiman Health Centre or the Tema General Hospital. Both facilities are geographically accessible. Diarrhoea ranks 4th among diseases reported at the Ashaiman Health Centre. All age groups are affected. Children under five years contribute between 55-65% of all the reported cases Table 1(Appendix 3) and Fig. 2.

Fig. 2. Reported Cases Of Diarrhoea, Ashaiman Health Centre,1998-2000.



Source: Ashaiman Health Centre, Records Department

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 GLOBAL WATER REQUIREMENTS

Clean water is an absolute prerequisite for healthy living. Yet for a large percentage of the world's population, water supplies are neither safe nor adequate.

The "basic needs" concept was among the concepts introduced during the 1977 UN Water Conference in, Argentina. It states that "... *all peoples, whatever their stage of development and their social and economic conditions, have the right to have access to drinking water in quantities and of a quality equal to their basic needs*" (UN, 1997). This concept was strongly reaffirmed during the Earth Summit and expanded to include ecological water needs: "*in developing and using water resources, priority has to be given to the satisfaction of basic needs and the safeguarding of ecosystems*" (UN, 1993).

A basic water requirement standard of 50 litres per person per day is adequate for meeting four basic human needs: drinking-water for survival, water for human hygiene, water for sanitation services, and modest quantities of water for household food preparation needs (UN, 1997, 1993; Gleick, 1996). This requirement is independent of the individual's economic, social or political status.

2.2 WATER SCARCITY

The definition for water scarcity is based on an index of vulnerability. A country is considered to be suffering from water scarcity if its annual per capita water availability is 1 000 m^3 or less (Falkenmark et al., 1989).

Water scarcity is mostly a local problem. It is caused by uneven distribution of water sources, misuse, poor management and population growth. It is becoming a problem of regional and even sub-continental proportions, as seen in large parts of Northern Africa, Central Asia and Southern India. Over 1000 million people (one-fifth of the global population) do not have access to adequate supply of safe water for household consumption (WHO/UNICEF, 1996).

About 20 countries are more or less suffering severely from water scarcity. This number is expected to have risen by 2050 (Gleick, 1993) because water availability in many of the countries already suffering from water scarcity is expected to decline further (Engelman & Le Roy, 1995).

2.2.1 The Water Decade

1981-1990 a period of ten years, was set aside as the International Drinking Water Supply and Sanitation Decade, (IDWSSD). It was a period of accelerated and concerted effort to expand water supply and sanitation services to the unserved and under-served poor populations. The primary goal was attainment of full access to water supply and to sanitation by all inhabitants in the developing countries by the year 1990. The aim was to control and prevent water and sanitation related diseases in order to promote health and socio-economic growth. The goal of Universal Access to Safe Water and Sanitation by the year 2000 was adopted to promote the survival, protection and development of children at the World Summit for Children in 1990.

Dr. Halfdan Mahler, then Director General of WHO, pointed out that since 80 per cent of all diseases are linked with unsafe water,*'the number of water taps per 100,000* *population is a better indicator of health than the number of hospital beds".* Access to piped water or nearby standpipe is therefore used as an indicator of health in smaller cities (UNCHS,1996).

Despite its major accomplishments (WHO,1988) and the investment of $134,000 million, more than 1,200 million people (30 per cent of the developing world's population) still lacked access to safe water and some 1,800 million (over 40%) were still without adequate sanitation (Bland, 1993). The number of urban residents without water had also not been reduced (World Bank, 1993). Thus the Water Decade, ended without reaching its declared goal of providing all people with safe drinking water and proper sanitation (Diamant, 1992).

2.3 WATER ACCESS

Access can be defined in terms of the number of people who have access to sufficient quantities of safe drinking water for meeting basic personal health and hygiene needs. It is a human right under international law (Gleick, 1999).

The number of people without access to safe water (i.e. unserved) dropped from around 1600 million in 1990 to around 1 100 million in 1994 (WHO/UNICEF, 1996). 18% of the world's population lack access to improved water services (WHO, 2000 b). More than 800 million of those unserved live in rural areas. At the same time, the number of urban unserved is actually rising sharply in developing countries due to rapid urbanisation, much of which is occurring in peri-urban and slum areas. Although per capita water availability is being reduced continuously due to increasing population density, and water scarcity looms in many regions, urban water utilities have been able to achieve at least partial coverage. In Ghana, 87% of the urban population are served while 13% are unserved. The corresponding rural figures are 49 and 51% respectively (GWSS, 2001).

2.3.1 Access and equity

Although the global number of people without safe water supply dropped by around 470 million during 1990-1994 (WHO/UNICEF, 1996) these figures mask regional variations. There is no equitable distribution of water supply sources between countries, as well as between rich and poor populations and rural and urban areas within countries (Briscoe et al., 1990). The approximate consumption per person per day is 12 litres for individuals with no tap or nearby standpipe, while people in industrialised areas use 22 litres each time a toilet is flushed (World Watch, 1984).

Disparity between and within countries and regions also exists. Variations within countries show that urban areas generally have higher coverage than rural areas. Even within areas, inequitable distribution can be very marked (Briscoe et al., 1990). In cities water is often supplied to districts whose populations can pay for services. In poorer areas however, thousands of people may only have access to standpipes which are poorly and/or intermittently supplied and at which they must queue for long periods or even worse, they may have to buy water of doubtful quality from private vendors at prices that may be 10 to 20 times higher than average inner city water tariffs (WHO,1997a; World Bank, 1992). The unit cost of vended water is always much higher than that of water from a piped city supply. Families spend 10-20% of income to buy water for household needs (Cairncross and Kinnear, 1992; World Bank, 1992). The health consequences resulting from the deprivation caused by this inequity are the effects of drinking contaminated water, water acting as breeding grounds for vectors of disease and diseases caused by lack of washing.

2.3.2 Access and Quantity

The quantity of water people use depends on their ease of access. People use large quantities of water for hygiene if they have a house or yard connection. Consumption, however drops when water must be carried for more than a few minutes from the source to the house (Cairncross, 1990).

Fig. 3. Carrying water from the source to the house

Fig. 4. Water access and quantity

Source: WHO Poster – Improving water, Sanitation and Hygiene Reduces Water Related Disease.

The amount of water consumed largely depends on whether water has to be carried to the house (UNDP, 1985) (Fig. 4). The use of water for hygiene increases only when availability rises to about 50l/capita/day and generally depends on getting the water delivered to the house (World Bank, 1992). With drought, floods and conflict imposing their own pressures, African countries have faced difficult times throughout the IDWSSD to date.

2.3.3 Access and Quality

Contamination of distribution pipelines due to intermittent supply, low water pressure in the distribution network, inadequate wastewater collection systems and leaking pipes are also common problems in developing countries. If contaminated water penetrates distribution mains, water that has already been treated and disinfected may become re-contaminated (Fig. 5). The costs of compensating for poor water quality are great. Families in the lowest quartile and squatter settlements spend 11 and 29% respectively of average household income to boil their drinking water while middle class members spend on more expensive mineral water (World Bank, 1992).

Fig. 5. Penetration of contaminated water into distribution mains

2.3.4 Sustaining Access

Access to water needs to be sustained. Water supply sustainability involves:

- Ensuring the continuous availability of sufficient quantities of water of acceptable quality,
- Applying sound management practices,
- Appropriate technologies,
- Full-cost accounting, and
- Effective maintenance of facilities and equipment (WHO, 1997a).

The management of water supply and sanitation systems is often poor in developing countries. This results in interruptions in the provision of services and sometimes in the complete collapse of systems. In such situations, users may be obliged to resort to traditional water sources by building in-house storage facilities, sinking wells or by installing booster pumps which can draw contaminated ground water into the distribution system People also collect water in larger quantities and store it for longer periods (WHO, 1997a). Individuals who use public taps make fewer trips and collect more at each trip. Those with house connections fill basins and baths with water for use during the periods when supply is off. These are practices which promote contamination of the water before it is used and increase water-borne disease transmission. They also provide new breeding sites for the mosquito species *Aedes aegypti,* the major vector of epidemic yellow fever and dengue (Cairncross and Feachem,1993).

2.3.5 Access and Waste

Unaccounted for water is another major water supply problem. In many large developing country cities it has been reported as amounting to more than 50% of supplies. Most of this water is lost through leaking pipes or overflowing service reservoirs after abstraction, pumping or treatment, or during distribution. Those who suffer most from this inefficiency are populations living in impoverished, outlying urban (peri-urban) areas. However, if measures to ensure the sustainability and Organization of facilities were implemented, extension of coverage to the fringe and poor areas of large cities would be possible.

Improved access has direct economic benefits. It reduces the water fetching time by 20% and improves family well being. The time saved could be used to cultivate crops, trade, care for children or even take a rest. It also brings about considerable improvements in health. At the same time, the need to expand treatment and distribution facilities would be minimised, in effect releasing resources for other development activities.

2.4 WATER QUALITY

Adequate supply of safe drinking water is universally recognised as a basic human need. Yet more than 1000 million people do not have ready access to an adequate and safe water supply, and a variety of physical, chemical and biological agents make many water sources unwholesome and unhealthy. Health hazards in the aquatic environment and waterborne epidemics are mostly due to inadequate or even incompetent management of water resources. Adverse natural conditions are sometimes causative factors. They include areas where the natural geochemical composition of water supplies can lead to severe health impairments.

Differences in water related problems exist between the developed and developing countries. While developed countries are mostly concerned with chemical pollution, the developing countries tend to suffer water pollution problems caused by contamination of watercourses with bacteria, parasites and a host of microbial disease vectors.

Developed countries are however not protected from communicable diseases. General mobility and tourist travel render populations of these countries vulnerable to all sorts of biologically transmitted diseases, including waterborne (and food borne) gastrointestinal disorders. Recent outbreaks of *Cryptosporidium,* the largest documented outbreak of waterborne disease in the USA, affecting entire cities, have caused considerable alarm at many waterworks in North America and Europe (Mackenzie et al., 1994; Solo-Gabriele & Neumeister, 1996).

At the rural level, although some water sources such as boreholes in rural African areas deliver safe drinking water, there is a daily consumption of water polluted by faecal bacteria. Contamination occurs during transport, storage and domestic allocation of water. This is directly attributed to ignorance of the rules of hygiene (Empereur-Bissonnet et al, 1992).

Recent concern of many developing countries about water quality goes beyond microbes. Chemical pollution of water sources, for instance, is increasing with industrialisation and because of widespread use of agricultural chemicals. This, problem is most pronounced, in the newly industrialising countries and in countries in economic transition where the traditional problems of domestic sewage collection, treatment and disposal have not yet been resolved because the creation and maintenance of sanitation infrastructure have not kept pace with industrial and urban development. Investments in drinking water supply, treatment works and distribution networks have also not matched population growth (Diamant, 1992), while socio-economic development, and industrial expansion has been accompanied by inadequately treated or uncontrolled discharge of wastewater. Consumers are therefore not protected sufficiently from both microbial and chemical water contamination. Safe water supplies for all populations can only be guaranteed when access, equity and sustainability are assured.

Serious health threats can arise if polluted water is used as drinking water (World Bank, 1992), for bathing or washing (Sinha et al., 1991, Saliba and Helmer, 1990, Cheung et al., 1990), for food processing (Esrey et al., 1989) or for irrigation of edible crops (Gustafson, 1995).

2.4.1 Chemicals in drinking water

Chemical standards for drinking water are of secondary consideration since chemical contaminants are not usually associated with acute effects (WHO, 1993 a). There are a few chemical constituents of water which lead to acute health problems. These however, pose health problems only through "massive accidental" contamination of a water supply or after prolonged exposure. Even in such situations the associated unacceptable taste, odour and appearance make it undrinkable. The water is therefore rejected for drinking and the health problems are usually avoided or minimised. The main chemical constituents which have the ability to cause adverse health problems do so after prolonged periods of exposure. They have cumulative toxic properties and are usually inorganic substances (Fawell, 1993).

Both naturally occurring and man-made chemical substances in drinking water can have serious effects on health (Moore et al., 1993). A variety of acute and chronic health effects have been reported. Different gastro-intestinal disturbances, hypertension and so on may be caused by the magnitude of total mineralization, content of sulphates, bicarbonates, potassium, sodium (Gig Sanit,1992). Examples of the chemical substances include Fluoride (IPCS, 1984), Arsenic (Brown and Jackson, 1995; WHO, 2001 a; WHO, 1999; Bagla & Kaiser, 1996; Hopenhayn-Rich et al., 1996; WHO, 1996a), Lead (IPCS, 1995), Nitrates (ECETOC, 1988).

2.4.2 Pathogens in drinking-water

Pathogenic agents have several properties that distinguish them from chemical pollutants:

- Pathogens are discrete and not in solution.
- Pathogens are often clumped or adherent to suspended solids in water, so that the likelihood of acquiring an infective dose cannot be predicted from their average concentration in water.
- The likelihood of a successful challenge by a pathogen, resulting in infection, depends upon the invasiveness and virulence of the pathogen, as well as upon the immunity of the individual.
- Pathogens multiply in their host when infection is established. Certain pathogenic bacteria are also able to multiply in food or beverages prepared with contaminated water which increases the chances of infection.
- Unlike many chemical agents, the dose response of pathogens is not cumulative (WHO, 1993a).

They are grouped as follows:

a) Orally transmitted infections of high priority.

These are pathogens that present a serious risk of disease whenever present in drinking-water. They include *Salmonella* spp., pathogenic *Escherichia coli, Vibrio cholerae,* many viruses, and the parasites; *Giardia* spp., *Cryptosporidium* spp., *Entamoeba histolytica*, and *Dracunculus medinensis.*

b) Opportunistic and other water-associated pathogens

Opportunistic pathogens are naturally present in the environment. Though not formally regarded as pathogens, they are able to cause disease in people with impaired local or general defence mechanisms, such as the elderly or the very young, patients with burns or extensive wounds, those undergoing immunosuppressive therapy, or those with acquired immunodeficiency syndrome (AIDS). Examples of such agents are *Pseudomonas aeruginosa* and species of *Flavobacterium, Acinetobacter, Klebsiella, Serratia, Aeromonas*, and certain "slow-growing" mycobacteria.

c) Toxins

Blooms of *Cyanobacteria* (commonly called blue-green algae) which occur in lakes and reservoirs used for potable supply can produce three types of toxins depending on the species. These are Hepatotoxins, Neurotoxins, and Lipopolysaccharides.

d) Nuisance organisms

Nuisance organisms include different types of organisms that have no public health significance but which are undesirable because they produce turbidity, taste and odour, or because they appear as visible animal life in water. In addition to being aesthetically objectionable, they indicate that water treatment and the state of maintenance and repair of the system are defective. Examples include Seasonal blooms of cyanobacteria and other algae in reservoirs and in river waters.

2.4.3 Health indicators of water pollution / contamination

The lack of improved domestic water supply leads to disease through two principal transmission routes, waterborne and water washed. Waterborne disease transmission occurs by drinking contaminated water. They include those transmitted by the faecal-oral route including diarrhoea, typhoid (WHO, 2001b, c, d), viral hepatitis A, cholera, dysentery and dracunculiasis (Guinea worm disease).

Water washed disease occurs when there is a lack of sufficient quantities of water for washing and personal hygiene. When there is not enough water, people cannot keep their hands, bodies and domestic environments clean and hygienic. Without enough water, skin and eye infections (including trachoma) are easily spread, as are the faecal-oral diseases. Diarrhoea is the most important public health problem affected by water and sanitation and can be both waterborne and water washed. Adequate quantities of safe water and good sanitation facilities are necessary conditions for healthy living, but their impact will depend upon how they are used. Three key hygiene behaviours are of greatest likely benefit; hand washing with soap (or ash or other aid), safe disposal of faeces and safe water handling and storage.

The major water and excreta-related diseases used as health impact indicators in the evaluation of drinking water and sanitation include diarrhoea diseases, soil-transmitted nematode infections, Trachoma, Guinea worm and schistosomiasis (Huttly, 1990; Huttly et al., 1990).

- **Intestinal worms -** Intestinal worms which infect about 10% of the population of the developing world (Murray & Lopez 1996a) can also be controlled by better sanitation hygiene and water supply (Chan, 1997). Approximately 1,000 million people are infected with *Ascaris lumbricoides,* 900 million with hookworms and 500 million with *Trichuris trichiura*.

- **Trachoma** - About 600 million people are at risk from trachoma while it has caused blindness in 6 million people. Good personal and environmental hygiene has been proven to be successful in controlling trachoma. Encouraging the washing of children's faces, improved access to water, and proper disposal of human and animal waste has been shown to decrease the number of trachoma infections in communities (WHO, 2001a). Esrey et al.,(1991) found that providing adequate supplies of water reduced the median infection rate by 25%.

- **Schistosomiasis -** This disease is found in 76 countries, kills about 200,000 thousand every year and debilitates another 200 million (Bland, 1993), putting a serious brake on each county's economic advancement. A well designed water and sanitation intervention could reduce the burden by 77% (Esrey et al., 1991).

- **Guinea worm -** It is estimated that 10 million people are infected with Guinea worm each year. It prevents the infected persons from working or from attending school. The disease therefore has effects on health, agriculture and education (Bland, 1993).

The direct effects of improved water and sanitation services on health are most clearly seen in the case of water-related diseases, which arise from the ingestion of pathogens from contaminated water or food, and from exposure to insects or other vectors associated with water. Access to sustainable safe drinking water and sanitation services for populations currently at risk would result in: 200 million fewer diarrhoea episodes, 2.1 million fewer deaths caused by diarrhoea, 76000 fewer dracunculiasis cases, 150 million fewer schistosomiasis cases and 75 million fewer trachoma cases (Esrey et al., 1991).

- **Diarrhoea** - Diarrhoea is the passage of loose or liquid stools more frequently than is normal for the individual (WHO, 2000a). Primarily, diarrhoea is a symptom of gastrointestinal infection caused by a host of bacterial, viral and parasitic organisms most of which can be spread by contaminated water. The diarrhoea diseases of main concern are cholera, typhoid fever, paratyphoid fever, *Salmonella, Shigella*, giardiasis, non-human *Escherichia coli* infection and a variety of other diseases caused by bacteria, parasites and viruses. The specific pathogens of greatest importance to public health vary according to the geographic setting and age of the patient. Thus rotavirus is a significant cause of severe diarrhoea in children under two years of age in developing countries, while *Salmonella* and *Campylobacter* infections are significant in developed countries (Martines, Phillips & Feachem, 1993).

Children under 5 experience an average of 3.4 episodes of diarrhoea per year and a diarrhoea mortality rate estimated at 12 per 1,000, leading to 4 million diarrhoea-associated deaths per year. Diarrhoea may also be associated with a sizeable proportion of adult deaths. Thus the largest public health impact of drinking unsafe water is diarrhoea disease (UNICEF, 1999).

About 4 billion cases of diarrhoea occur each year. Globally, deaths due to diarrhoea are estimated between 2.2 and 3 million (Murray & Lopez 1996a; WHO, 1996a). Most of the deaths occur among children under the age of five years who are at highest risk (WHO, 2001b). Diarrhoeal diseases can also be fatal among the elderly and frail (Huttly, 1990). Diarrhoea causes 4% of all deaths and 5% of health loss to disability, (WHO, 1997a). The poorest countries suffer from per capita DALYs that are about 200 times higher than those of the richest countries. Diarrhoeal diseases account for 12% of the global total YLL and 8% of the global total DALY (Murray & Lopez, 1996b).

Though diarrhoea occurs world-wide, the disease is 5 to 6 times more common in developing countries (WHO, 1997a). Diarrhoea is therefore a rare occurrence for most people who live in developed countries where basic sanitation is available, access to safe water is high and personal and domestic hygiene is relatively good. The disease is however widespread throughout the developing world where sanitation services are least developed and poverty most deeply embedded. These regions of the world suffer the highest morbidity and mortality due to diarrhoeal diseases. In Southeast Asia and Africa, diarrhoea is responsible for as much as 8.5% and 7.7% of all deaths respectively. These diarrhoea incidences could be reduced by 25% to 33% by water, sanitation and hygiene interventions (Esrey and Potash 1991).

An episode of diarrhoea may last a few days, or several weeks, as in persistent diarrhoea. Depending on the type of infection (Cairncross, 1987), the diarrhoea may be watery as in cholera or bloody in the case of dysentery. Cholera and dysentery cause severe, sometimes life-threatening forms of diarrhoea. Severe diarrhoea may be life threatening due to fluid loss in watery diarrhoea, particularly in infants and young children, the malnourished and people with impaired immunity. The impact of repeated or persistent diarrhoea on nutrition and the effect of malnutrition on susceptibility to infectious diarrhoea can be linked in a vicious cycle amongst children, especially in developing countries.

Approximately 90% of the diarrhoeal disease burden is related to the environmental factors of poor sanitation and lack of access to clean water and safe food (Murray & Lopez, 1996a). World-wide, around 1.1 billion people lack access to improved water sources and 2.4 billion have no basic sanitation. Poor water supply and sanitation have a high health toll. Diarrhoea is more common when there is a shortage of clean water for drinking, cooking and cleaning and basic lack of hygiene is important in prevention (WHO, 2001e). Water contaminated with human faeces from municipal sewage, septic tanks and latrines is of special concern. Animal faeces also contain micro-organisms that can cause diarrhoea.

Diarrhoea can also spread from person to person, aggravated by poor personal hygiene. Food is another major cause of diarrhoea when it is prepared or stored in unhygienic conditions. Water can contaminate food during irrigation, and fish and seafood from polluted water may also contribute to the disease. Diarrhoea is also associated with other infections such as malaria and measles. Chemical irritation of the gut or non-infectious bowel disease can also result in diarrhoea. The key measures to reduce the number of cases of diarrhoea include access to safe drinking water, improved sanitation, good personal and food hygiene and Health Education about how infections spread.

The impact of a water, sanitation and hygiene education intervention project on diarrhoeal morbidity in children under 5 years old was evaluated in a rural area of Bangladesh (Aziz et al., 1990). The project showed a striking impact on the incidence of all cases of diarrhoea, including dysentery and persistent diarrhoea. By the end of the study period, children in the intervention area were experiencing 25% fewer episodes of diarrhoea than those in the control area. This impact was evident throughout the year, but particularly in the monsoon season, and in all age groups except those less than 6 months old. Within the intervention area, children from households living closer to hand pumps or where better sanitation habits were practised experienced lower rates of diarrhoea.

In 1991-1992, 17 states and territories in the United States of America reported 34 outbreaks associated with water intended for drinking which affected 17,464 people. A protozoan parasite (*Giardia lamblia* or *Cryptosporidium*) was identified as the etiologic agent for seven of the 11 outbreaks for which an agent was determined. Five (71%) of the outbreaks caused by protozoa were associated with a surface-influenced groundwater source. One outbreak of cryptosporidiosis was associated with filtered and chlorinated surface water. *Shigella sonnei* and hepatitis A virus were implicated in one outbreak each; both were linked to consumption of contaminated well water. Two outbreaks due to acute chemical poisoning were reported; one had an associated fatality. No etiology was established for 23 (68%) of the 34 outbreaks, including the largest one reported during this period, in which an estimated 9,847 persons using a filtered surface water supply developed gastro-enteritis (Moore et al., 1993).

Israel experienced a large number of waterborne disease outbreaks between 1975 and 1985, followed by a steep decline in the period 1986-92. The mandatory chlorination and more stringent water standards had impact on water quality and on waterborne disease outbreaks. This gave evidence which suggests that improving water quality may also be a factor in the changing patterns of some enteric diseases and the total burden of enteric disease (Tulchinsky et al., 1993).

- **Cholera -** Cholera is one of the most deadly diarrhoeal diseases. Cholera is only one of a great many waterborne or water-related illnesses. The diarrhoeal diseases alone kill about four million people each year, of whom 80 per cent are children (WHO, 2001d). In the middle of the last century, Snow's recognition of a link between faecal-contaminated water and cholera enabled him to undertake pioneering epidemiological research into the disease (Snow, 1849).

Cholera is caused by the bacterium *Vibrio cholerae*. It is known to be associated with the consumption of unboiled, unchlorinated drinking water (Swerdlow et al., 1992). People become infected after eating food or drinking water that has been contaminated by the faeces of infected persons. Raw or undercooked seafood may be a source of infection in areas where cholera is prevalent and sanitation is poor. Vegetables and fruit that have been washed with water contaminated by sewage may also transmit the infection if *V. cholerae* is present.

Cholera is an acute infection of the intestine, which begins suddenly with painless watery diarrhoea, nausea and vomiting. Most people who become infected have very mild diarrhoea or symptom-free infection. Malnourished people in particular experience more severe symptoms. Severe cholera cases present with profuse diarrhoea and vomiting. Severe, untreated cholera can lead to rapid dehydration and death. If untreated, 50% of people with severe cholera will die, but prompt and adequate treatment reduces this to less than 1% of cases.

Major health risks frequently arise where there are large concentrations of people with poor sanitation and unsafe drinking-water supplies (WHO, 1996b). These conditions often occur in refugee camps, and special vigilance is needed to avoid outbreaks of disease. Most of the 58057 cases of cholera reported in Zaire in 1994 occurred in refugee camps near the Rwandan border. A decrease to 553 cases in Zaire in 1995 reflected the stabilisation of refugee movement (WHO, 1996c).

Cholera cases and deaths were officially reported to WHO, in the year 2000, from 27 countries in Africa, 9 countries in Latin America, 13 countries in Asia, 2 countries in Europe, and 4 countries in Oceania. About 140,000 cases resulting in approximately 5000 deaths were officially notified to WHO. Africa accounted for 87% of these cases (WHO, 2000d). After almost a century of no reported cases of the disease, cholera reached Latin America in 1991; however, the number of cases reported has been steadily declining since 1995.

Cholera is a world-wide problem that can be prevented by ensuring that everyone has access to safe drinking water, adequate excreta disposal systems and good hygiene behaviours. The 1991 Latin American cholera epidemic demonstrated relationships between occurrence of cholera and lack of sanitation, lack of safe drinking water and poor food hygiene (Besser et al., 1995). Upon investigating the epidemic in Trujillo, the second largest city in Peru (Rodriguez, 1995), Trujillo's water supply was found to be unchlorinated and water contamination was common (Swerdlow et al., 1992). The management of drinking water therefore reduces cholera and other diarrhoeal diseases (Mouchet and Brengues, 1990).

2.5 WATER DISTRIBUTION AND POLLUTION

When water of excellent quality enters the distribution system, it may undergo some deterioration before it reaches the consumer's tap. Just as much deterioration may occur in the distribution of a chlorinated supply in which there is little or no residual chlorine in water reaching the consumer as in that of a non-chlorinated supply.

2.5.1 Chlorinated water distribution and pollution

Many possible factors can result in the sudden pollution of a water supply, which has previously passed all laboratory tests. Apart from the failure of the treatment processes, which could be very serious, there are many other possible faults. Coliform organisms may gain access to the water in the distribution system from booster pumps, from packing used in the jointing of mains, or from washers on service taps. In addition, contamination from outside may gain access to the water in the distribution system, for example, through cross-connections, back-siphoning, defective service reservoirs and water tanks, damaged or defective hydrants or washouts or through inexpert repairs of domestic plumbing systems (Figs. 6-9). Sudden deterioration of ground waters can occur through cess-pool leakage or the casual contamination of gathering grounds, where polluting material may then gain access through faults or fissures in the water-bearing strata.

Fig. 6. Contamination of chlorinated water at hydrant

Fig. 7. Contamination of chlorinated water through back-siphoning

Fig. 8. Contamination of chlorinated water through leakages

Fig. 9. Contamination of chlorinated water through defective reservoirs and tanks

Heavy rains following prolonged drought may aggravate the pollution of water sources, and even of service reservoirs in cases where the structure is faulty. Increased pumping from wells, as a result of prolonged drought and consequent greater demand may also lead to the pollution of previously satisfactory supplies. A drop in pressure in a leaky system when the supply is shut off can allow pollution from leaking sewers and drains. Where sewers exist, they can become blocked when the supply is off and so cause manholes to overflow with sewage when the supply returns.

Although organisms derived from the tap washers or the jointing material of mains may be of little or no sanitary significance, excreta contamination which gains access to the water in the distribution system is at least as potentially dangerous as the distribution of originally polluted and insufficiently treated water. The same premise applies to contamination from fetching into vessels, transportation, vessel transfer, storage and the final point to be consumed as a result of improper handling.

The greatest danger associated with drinking water is contamination by sewage or by human excrement. If such contamination has occurred recently, and if among the contributors there are active cases or carriers of such infectious diseases as typhoid, fever or dysentery the water may contain living micro organisms, which cause these diseases and the drinking of such water may result in fresh cases of disease. Sewage-polluted water may also contain the viruses of poliomyelitis, other viruses of the Enterovirus group, or the viruses of infectious hepatitis. Animals and birds, particularly seagulls, may carry human intestinal organisms pathogenic to man. Apart from the drinking of contaminated water, its use in the preparation of food especially those which do not require boiling, which may allow the multiplication of intestinal pathogens (Esrey et al., 1985).

Over burdening of the distribution system leads to intermittent or temporary cessation of supply of water. Its effect is that people collect water in larger quantities and store it for longer periods (Cairncross, 1992). Further, the consumer's water collection and storing behaviour to a great extent contributes to the final quality of the water consumed. This usually depends on the behaviour of the individuals fetching the water and the vessels used to collect the water. The transfer of water collected from public taps or outside the home also increases the chances of contamination (Pinfold, 1990). The risk of infection after exposure to treated waters containing varying levels of *Giardia* cysts have been demonstrated (Rose et al., 1991). Stored water quality was a function of water-related activities rather than quality at source. Likewise cross-contamination by water handling is the main mechanism of stored water pollution (Pinfold, 1990).

2.5.2 Distribution and pollution of unchlorinated water supply

a) Underground water

Water is derived from many sources in the rural areas. Almost all of which are untreated by disinfectants. The quality of the water also differs from one source to the other. It is however known that water of relatively high quality could be derived from the ground. Where water is obtained from a borehole or protected well i.e. free from harmful bacteria and faecal contamination from its zone of influence it is already filtered by the ground and is generally pure (Cairncross and Feachem, 1993; WHO, 1993b). Such water may however be polluted by surface water. In order to prevent this, wells should be grouted around the borehole and finished at the surface with a good platform with good drainage from the well. After all these precautions have been taken the water may quickly be polluted by the vessels used to draw the water, transport to the home and then by storage tanks and reservoirs.

The quality of water extracted from the ground varies with the seasons. Lowest *E. coli* counts are found during cold seasons in both protected and unprotected ground water sources while higher counts are found in the warmer and wetter months. The number of people who use a particular source also determines variations in the quality of water.

Sources of underground water pollution include the following:

- Locating or siting of the well too close to pit latrine, soak-away or refuse dumps whose influence may extend for 10m in a typical soil usually results in polluted ground water. In fissured strata such as limestone and fractured rock, water may flow in underground streams rather than seeping through the soil, and carry faecal material much ionger.
- Seepage water from the surface may enter through the top few meters of the well lining if it is insufficiently watertight near the surface.
- The quality of the water also varies from the type of water raising system used. The vessels used for drawing water can cause pollution of the well water no matter how often they are rinsed out. Water raised from a well with a hand pump is expected to contain fewer bacteria than a well fitted with a bucket and windlass. Even if a perfectly pure but untreated water source is drawn by using a hand pump, the level of contamination will rise as soon as water enters the

vessel used to carry water to the home. The level of contamination may further increase if the water is transferred from one vessel to another.

- Rubbish thrown down the well by children is a potential cause of contamination. It may also cause a reduction in the depth of the well or block it up.
- Surface water may be washed straight down the well if the ground surface has sunk as a result of inadequate lining.
- Spilt water splashed against feet can fall back into the well. This is important in the transmission of *Dracunculus medinensis* especially in the case of a shallow well.

b) Surface water

Usually, surface water has a very high bacterial contamination which is heavy with faecal bacteria. Other contaminants contributed from agricultural sources include nitrates, phosphates and pesticides. It is also more open to industrial contamination. Surface water in urban and peri-urban areas receive untreated wastes from industrial factories, untreated solid wastes and urban runoff resulting in very high Biochemical Oxygen Demand (BOD), organic compounds and trace metals (Johnston et al., 2001). In many cases surface water may be the only feasible water source in spite of the high risk of contamination. In such situations the water needs to undergo some form of low-cost, low-tech treatment in the home. These include boiling, slow-sand filtration and solar disinfection or SODIS. Others are chemical disinfection and cloth filtration (WHO, 1997b).

Solar disinfection is a new technology that uses clear bottles to purify water. When exposed to sunlight, the combination of ultraviolet radiation and high temperature destroy most pathogens. Although SODIS will not improve the chemical quality of water, it provides an inexpensive easy and efficient way to improve microbiological quality.

Bank infiltration, the practice of drawing water from shallow wells located close to the surface water body, may also purify the water. It improves both the chemical as well as microbiological quality of the water.

Ponds and other surface water sources used for domestic consumption should be protected as much as possible. Latrines should not be located near the water. Likewise there should be strict regulation about defecation near the water. Also people and animals should not bathe and wash clothes nearby. Communities must be responsible for the communities downstream who also use the water.

2.6 THE BACTERIOLOGICAL EXAMINATION OF WATER SUPPLIES

Bacteriology offers the most delicate test for the detection of recent and therefore potentially dangerous faecal pollution. The information obtained from bacteriological tests must be assessed in the light of thorough knowledge of the conditions at the sources of supply, throughout the stages of treatment to which the raw water may be subjected, and in the distribution system.

Drinking water microbiology has emerged from decades of relative complacency to recognise there can be major concerns with potable water quality (Geldreich, 1989). This awakening is a result of increased knowledge of new waterborne agents and resistance of some protozoan cysts to disinfection.

2.6.1 Indicators of faecal pollution

The organisms most commonly used as indicators of faecal pollution are the coliform group as a whole, and particularly *Escherichia coli.* The term "coliform organisms" refers to Gram-negative, oxidise-negative, non-sporing rods capable of growing aerobically on an agar medium containing bile salts and able to ferment lactose within 48 hours at 37° C with the production of both acid and gas.

a) *Escherichia coli*

Escherichia coli is a coliform organism. It is the most frequent type of coliform organism present in the human and animal intestine. It is up to 100 or even 1000 millions per gram of fresh faeces. Apart from excretal contamination, it is rarely found in soil, vegetation or water. It is capable of fermenting lactose with the production of acid and gas at both 37°C and 44°C in less than 48 hours, it produces indole in peptone water containing tryptophan, it is incapable of utilizing sodium citrate as its sole carbon, it is incapable of producing acetyl methyl carbine and gives a positive result in the methyl red test (WHO, 1993a).

The evaluation of four bacterial indicators of tropical drinking-water quality (faecal coliforms, *Escherichia coli,* enterococci and faecal streptococci) and their relationship to the prevalence of diarrhoeal disease show that *E. coli* and enterococci were better predictors than faecal coliforms of the risk of waterborne diarrhoeal disease. The methods to enumerate *E. coli* and enterococci were less subject to interference from the thermo-tolerant, non-faecal organisms that are indigenous to tropical waters (Moe et al 1991). Desmarchelier et al. (1992) also found the faecal coliform test was an excellent predictor of the presence of *E. coli* in these water samples. They also found the faecal coliform test was an excellent predictor of the presence of *E. coli* in these water samples, while the H_2S test was very inadequate.

Prospective epidemiological studies of beach water pollution were conducted in Hong Kong in the summers of 1986 and 1987 by Cheung et. al. (1990) and found *Escherichia coli* to be the best indicator of the health effects associated with swimming in the beaches of Hong Kong. It showed the highest correlation with combined swimming-associated gastro-enteritis and skin symptom rates when compared with other microbial indicators. A linear relationship between *E. coli* and the combined symptom rates was established.

b) Other Coliform Organisms

Coliform organisms other than *E. coli* also occur in the intestinal canal but their combined numbers seldom exceed one million organisms per gram, of fresh faeces. Outside the body, these coliform organisms have much greater powers of survival and do not appear to be strictly limited to faecal polluted sites. They are widely distributed in agricultural land where their presence cannot be dissociated from manure pollution. They can also be found in soil which appears to be unpolluted and which on examination is found to be free from *E. coli*. In such instances the numbers isolated are infinitely small seldom more than 100 organisms per gram of soil. Many samples of soil have been found to be completely free from coliform bacteria.

Small numbers of *E. coli* can be found from time to time in soil far removed from the possibility of faecal pollution by man or domestic animals. In such cases its presence is attributed to incidental pollution by wild animals or birds. Similar but more remote pollution explains the presence of other coliform organisms in apparently unpolluted sites.

Thus, so far as is known, the distribution of coliform organisms in nature suggests that they may all be primarily faecal organisms but that outside the body types other than *E. coli* have greater powers of survival and can multiply in certain circumstances.

- **Faecal streptococci**

Faecal streptococci regularly occur in faeces in varying numbers, they are usually considerably smaller than those of *E. coli.* The presence of faecal streptococci affords important confirmatory evidence of the faecal nature of the pollution when organisms of the coliform group but not *E. coli* are found in a water sample.

Kay et al. (1994) established relations between gastro-enteritis and microbiological water quality. However of a range of microbiological indicators assayed they found that only faecal streptococci concentration, measured at chest depth, showed a significant dose-response relation with gastro-enteritis. Adverse health effects were identified when faecal streptococci concentrations exceeded 32 per 100 ml. This relation was independent of non-water-related predictors of gastro-enteritis. Without suggesting that faecal streptococci caused the excess of gastrointestinal symptoms in sea bathers, they found them to be a better indicator of water quality than the traditional coliform counts.

- **Sulfite-reducing clostridia**

These are anaerobic, spore-forming organisms. The most characteristic, *Clostridium perfringens* is normally present in faeces, although in much smaller numbers than *E. coli*. However, they are not exclusively of faecal origin and can be derived from other environmental sources. Clostridia spores can survive in water much longer than organisms of the coliform group and will resist disinfection. Its presence in the absence of organisms of the coliform group suggests that the contamination is not recent. Because of their longevity, they are best regarded as indicating intermittent or remote contamination. Because they tend to survive and accumulate, they may be detected long after and far from the pollution and may give rise to false alarms.

- **Coliphages and other alternative indicators**

The bacteriophages have been proposed as indicators of water quality because of their similarity to human enteroviruses and their easy detection in water. They do not occur in high numbers in fresh human or animal faeces, but they are abundant in sewage. Their significance is as indicators of sewage contamination and, because of their greater persistence compared with bacterial indicators, as additional indicators of treatment efficiency or groundwater protection.

The bifid bacteria and the *Bacteroides fragilis* group are very numerous in faeces but have not been considered as suitable indicators of faecal pollution because they decay more rapidly in water than coliform bacteria and because the methods of examination are not very reliable and have not been standardised.

2.7 TESTS FOR WATER QUALITY

Water quality tests range from parasitological, planktonic and bacteriological examinations, to the determination of trace metals, pesticides, global radioactivity and toxicity tests (Abouzaid & Echihabi, 1995).

2.7.1 Water quality and the sanitary survey

It is a meaningful method, which ensures an overall improvement in rural water supplies such as open wells, bore holes, rain harvest water, rivers, lakes, dams and springs.

The sanitary survey includes an on-the-site inspection of the water supply system with particular attention to aspects of possible contamination. It checks for defects such as leaks in well linings and pipes, proximity of latrines, rubbish dumps and other sources of pollution (Morgan, 1990). It is very inexpensive, does not require specialised equipment and produces more reliable and informative results. Important aspects to inspect during the survey are;

- Location or siting of the water point
- Depth of water
- Distance from sources of contamination
- Sanitary protection of lining of well
- State of the slab and/or apron covering the water point
- Sealing of the pumping or water raising system
- Quality and length of the water run-off system
- Type and adequacy of waste disposal system (WHO, 1997b).

2.7.2 Bacteriological tests

The main methods used in the isolation of indicator organisms in water are the Membrane Filtration (MF) method, Multiple-Tube (MT) method, the Most Probable Number (MPN) method and presence-absence tests.

a) Membrane Filtration Technique

In this method, measured volumes of water are filtered through each of two sterile filter membranes so that all faecal coliform bacteria are retained on it. These are placed face upwards on an absorbent pad, saturated with a suitable growth medium in a Petri dish.

Both membranes are incubated for a preliminary period at a relatively low temperature, usually four hours at 30°C, and then changed to a higher temperature, one at 35° or 37°C and one at 44°C. During incubation each faecal coliform bacterium develops into a visible colony. Acid-producing colonies are counted after a total incubation time of 18 hours. The count per 100ml is then calculated (WHO, 1997 b).

b) The Tube Method

This is based on an indirect assessment of microbial density in the water sample. Reference is made to statistical tables to determine the MPN of organisms present in the original sample.

CHAPTER 3

3.0 METHODS AND MATERIALS

3.1 ENTRANCE INTO THE COMMUNITY

The community was approached through the Assemblyman to explain the purpose of the study and to learn about the community. He in turn introduced the traditional leaders group and the Unit Committee members. Indepth interviews were conducted with each of the groups. Information obtained was verified by confirmation with another group and also by direct observation. Permission to access the households was obtained from the traditional leaders. This was facilitated by the Assemblyman.

3.2 COLLECTION OF DATA

Information was collected by both qualitative and quantitative methods. Basic data about the community was collected from the Ashaiman Health Centre. Information provided by the records department on diarrhoea was analysed. Information was also collected from the District and Regional offices of the health services in Tema and Accra respectively.

3.2.1 Questionnaire

A conceptual frame work was developed from the research question and the hypothesis (Appendix 2). The variables and their relationship to the research question were identified. The operational and practical definitions were listed (Appendix 3).

A quantitative method was employed to collect data from the sample population. Two scheduled questionnaire were developed. One was designed to collect information on diarrhoea by recall and obtain information of water use and its related practices at the household level (Appendix 4).. The second questionnaire targeted the owners of the commercial water tanks. This was designed to collect information on the sanitary conditions of the water points (Appendix 5).

3.2.2 Questionnaire development and testing

The questionnaire were prepared by writing questions for each of the already identified variables. These were then tested in the field for reliability and validity using both qualitative and quantitative methods.

- **Qualitative method** - Eight community members were recruited to assist in locating the water points and to administer the questionnaire. These were mainly literate members of the Unit Ccommittee and school teachers who could speak the local language. The assistants went through a day's orientation during which the draft questionnaire was pre-tested. After adjusting and rewriting, another appointment was made with the recruits and the questionnaire was tested for the second time. Since the questionnaire was to be administered by interview, the variable definitions were explained and translated into the main local languages, Dangme and Twi to give uniform interpretation. This was followed by role-play.

- **Quantitative method** – The interviewers then went into the community and pre-tested the questionnaire in a total of 35 households. After the pre-testing the group met to discuss the results and the questionnaire was subsequently revised and finalized.

3.3 SAMPLE SIZE

The sample size was chosen to detect Odds Ratio (OR) of 2.0 at 5% level of significance. Using the proportion of the population exposed of 0.50 and a power of 95%, the sample size was obtained from the Cousens' table on diarrhoea studies (Cousens et al., 1988). This gave a sample size of 300 inclusive of 25% adjustment for confounding.

3.4 SELECTION OF SITES

Households were selected by systematic random sampling technique. A household was defined as members who shared a common drinking water container or vessel.

The administration of the questionnaire began from a home with a storage tank. From there every 2nd house and 2nd household was selected for interview. Subsequent selections were then made in the direction of the dam. The interviews were conducted in the evening when most household members and heads were available. Other members of the household contributed to the interview. Field management was done on a weekly basis.

A total of 293 completed responses were obtained. The results of the questionnaire were coded and initially stored into a data base using Epi Info software version 6.04 and then used to verify as well as describe and eyeball the data and for statistical analysis of associations between selected variables.

3.5 WATER ANALYSIS

A two-man team comprising the investigator and a technical assistant collected water samples for analysis in February 2002. Water samples were collected from the three identified sources and from household storage containers as well as the containers used to allocate and/or drink water. They were assisted by a member of the community who was involved in conducting the interview.

3.5.1 Sampling site selection

Six samples were collected from each of the identified water sources namely, treated water stored in tanks, treated water fetched directly from taps and dam water. This gave a total of 18 samples. For the selection of households, the total number of responses from the previous questionnaire, 293, was divided by 18 based on the availability of materials for the analysis. The number 16 was obtained. This was used as a guide in the random selection of households to be sampled. Every 16th household which stored water was selected from the data list until 6 households were obtained for each of the 3 drinking water sources. Ten households were selected for each source and the next on the list was used if the house was not located or members were absent.

3.5.2 Sampling for Bacteriological analysis

Water was collected into previously labelled sterile containers from the randomly selected homes, which used either direct pipe water, stored tank water or dam water as a source of drinking water. Precautionary measures for the collection of the samples were based on Cheesebrough (1984).

For each of the households water was collected from the source (level 1), storage container in the home (level 2), and the consumer dipper (cup or vessel used in the domestic allocation (level 3).

- **Sampling from a tap in a distribution system**

The following are the methods used to collect water samples from the taps;

- Splash attachments were removed where they existed. A clean cloth was used to wipe the outlet of any dirt.
- The tap was turned on at maximum flow and the water allowed to run for two minutes.
- Without adjusting the flow, the bottle was taken out and the cap unscrewed carefully by holding the protective cover.
- Holding the bottle cap face down, the open bottle was immediately held under the water jet and filled leaving a small air space.
- The cap was screwed and the foil protective cover was fixed in place by exerting pressure on it.

- **Sampling from the surface water (dam water)**

  After unscrewing the cap, the bottle was held by the lower part and submerged to a depth of about 20cm with the mouth facing slightly upwards and towards the current.

- **Sampling from a tank or household storage container/ vessel**
  - A clean weight was attached to the bottle by a piece of string.

- The bottle was lowered into the tank or vessel taking care so that it did not touch the walls.
- It was then immersed completely well below the surface and filled completely.
- The bottle was then removed and some water discarded to create air space before capping.

- **Storage and transportation**

Each sample collected was immediately placed in a light-proof insulated box containing ice-packs and transported to the laboratory for bacteriological analysis.

3.5.3 Bacteriological tests

- **Membrane filtration technique**

Two tests were performed on each of the water samples using the membrane filtration technique. These were Total Coliform (TC) and Faecal Coliform (FC) tests.

a) Total coliform determination

100 ml of the water sample was filtered through 0.45µ pore size, 47mm membrane filter (Millipore). The membrane filter was incubated on M. Endo les agar (Difco) at 37 ± 0.5°C for 16 – 18hrs for the determination of total coliform (Appendix 6).

b) Determination of faecal coliform bacteria

100 ml of water sample was filtered and incubated on M-FC agar (Difco) at 44 ± 0.5°C for 16-18 hrs for faecal coliform determination (Appendix 7).

Equipment

- Membrane filter forceps
- Petri dishes (60-mm diameter glass or disposable plastic)
- A membrane filtration unit (plastic) (Fig.10)
- 5ml or 10ml and 1ml serological "blow-out" pipettes
- Pipette suction pump
- Vacuum pump (manual)
- Bunsen burner
- Incubator
- Binocular wide field microscope

Consumables

- membrane filters (0.45µm pore size, 47mm diameter)
- Ethanol.
- Endo agar
- M-FC medium

Fig. 10. A membrane filtration unit

Procedure

1. The samples were removed from storage and brought to room temperature.
2. The porous plate of the filtration unit was burnt off in the Bunsen burner flame.
3. The membrane filter forceps were dipped in ethanol, and burnt off in the flame of the Bunsen burner. The sterile forceps were then used to transfer a sterile membrane filter onto the porous plate of the membrane filtration unit with the grid side up (Fig.11).
4. The metched funnel unit was carefully placed over the receptacle and locked in place (Fig. 10).
5. The required volume of the water sample was added to the membrane filtration unit by using the funnel measure or by means of a sterile pipette (Serial dilutions were prepared and used in the case of the dam water samples).
6. The sample was passed through the filter under partial vacuum The filtrate was then discarded.
7. The funnel was unlocked and removed.
8. Sterile forceps were used to remove the membrane filter onto a sterile Petri dish containing the appropriate growth medium (M. Endo les agar for coliforms and M-FC agar for faecal coliforms) by a rolling action, in order to prevent the formation of air bubbles between the membrane filter and the medium.
9. The Petri dishes were inverted and incubated at 35°C (± 0.5° C) and 44°C for 16–18 hours, for total and faecal coliform bacteria respectively.
10. After incubation typical coliform colonies were identified as colonies with pink to dark red colour with a metallic sheen (Fig.12) while blue colonies were identified as faecal coliforms (Fig. 13) . Colony counts were done with the aid of a colony counter (Fig. 14). Filters containing 20-80 coliform colonies were

counted. Each filter was counted three times and the mean count was recorded.

Fig. 11. Transfer of a sterile membrane filter onto the porous plate of the membrane filtration unit

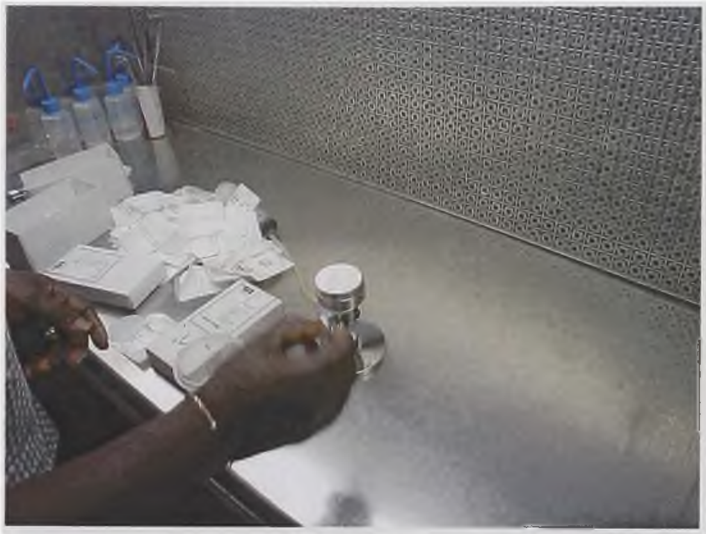


Fig. 12. Typical coliform colonies

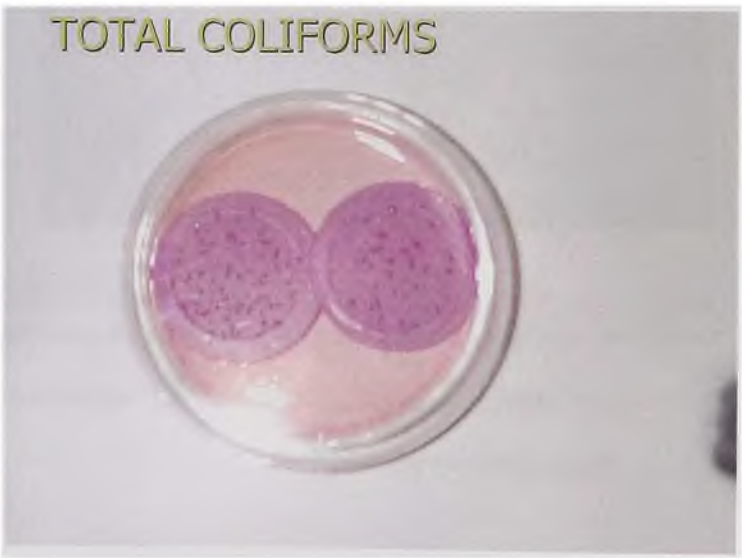


Fig.13. Faecal coliforms

Fig. 14. Colony counter

11. Coliform density was calculated per 100 ml of sample as follows:

$$\text{Total coliform colonies /100ml} = \frac{\text{coliform colonies counted} \times 100}{\text{Volume (ml) sample filtered}}$$

- **Standard Plate Count**

-Total heterotrophic bacteria determination (Fig.15)

1.0ml of water sample was used as inoculum on Nutrient Agar plates supplemented with 5% Yeast extract and incubated at 37 ± 0.5°C for 48 hrs. (Appendix 8).

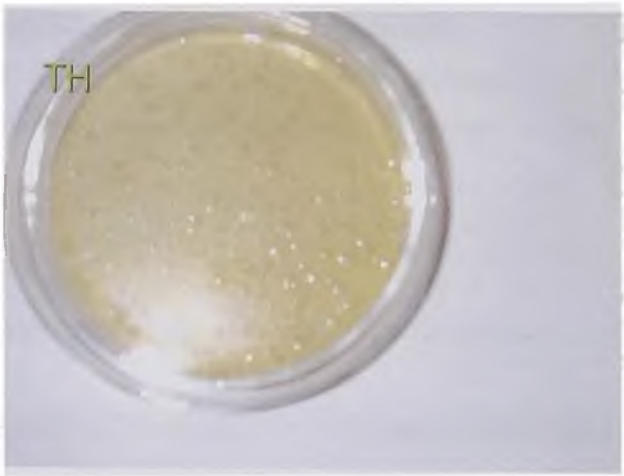
Equipment

- Petri dishes
- Pipettes
- Colony counter
- Water bath, 45° C
- Nutrient agar with 0.5% NaCl
- Phosphate buffer solution (10% peptone water)

Procedure

- The sample bottle was shaken
- Serial decimal dilutions (0.1, 0.01) of the sample were made with the buffer solution.
- 1ml of the sample was placed in the Petri dish.
- About 15ml of liquefied medium was added.
- The agar and sample were mixed thoroughly by clockwise and anti-clockwise rotations of the dish.
- The dish was left for a while until the agar had solidified.
- The Petri dish was incubated inverted at 37°C for 48 hours
- Counts were done with the aid of a colony counter as above.

Fig.15. Heterotrophic bacteria



CHAPTER 4

4.0 RESULTS

4.1 RESULTS AND ANALYSIS OF QUESTIONNARE

A total of 293 complete responses were obtained from the questionnaire administered to the systematically selected households in Zenu between July to October, 2001.

4.1.1 Water Storage

97.3% of households store water, while only 2.7% (8) respondents do not store water (Fig.16).

Fig. 16. Storage of water by households in Zenu

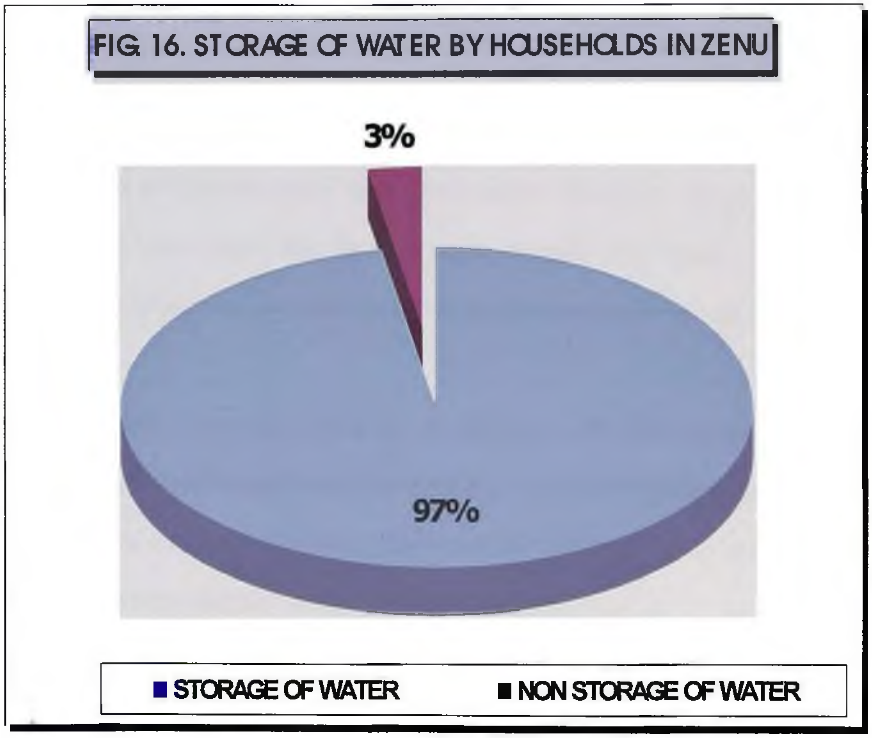


Table 2 shows the effect of water storage on diarrhoea.

Table 2. Water storage and diarrhoea

	Diarrhoea		
Store water	**+**	**-**	**Total**
+	28	255	283
-	1	7	8
Total	29	262	291

A single table analysis gave a p-value of 0.57 with the Fisher's exact test. The results indicate that storage of water is not associated with diarrhoea.

4.1.2 Types of water sources

Three main sources of drinking water were identified in the town. These were raw dam water, treated tank water and treated water directly from taps. Majority of households (62.8%) depended on tank stored water only as their source of drinking water, Fig.17.

Further, another 21.2% used tank water in combination with dam water, very few households 4.4% depended on dam water as their sole source of drinking water.

Only 1.7% used water drawn from nearby taps from the adjoining town, and 9.6% of households used both tap and dam water, Table 3, (Appendix 9).

Grouping the sources of drinking water into *improved* (tank only + tap only) and *unimproved* (dam only, dam + tap, tank + dam) sources of drinking water (Tables 4a, 4b) gave odds ratio OR = 2.95. This shows that those who drink unimproved water were about 3 times more likely to have diarrhoea than those who drink from improved sources.

Fig. 17. Sources Of Drinking Water In Zenu

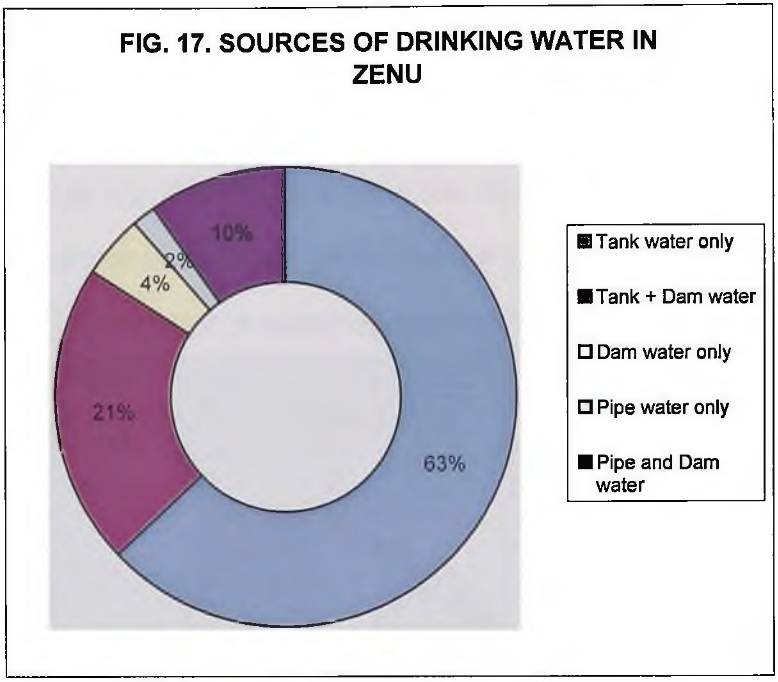


Table 4 a. Water sources and diarrhoea

Drinking water source	Diarrhoea +	Diarrhoea -	Total
Tank water only (1)	11	173	184
Dam water only* (2)	2	11	13
Tank and dam water*(3)	3	59	62
Pipe borne water (4)	1	4	5
Dam and pipe borne water* (5)	12	15	27
Total	29	262	291

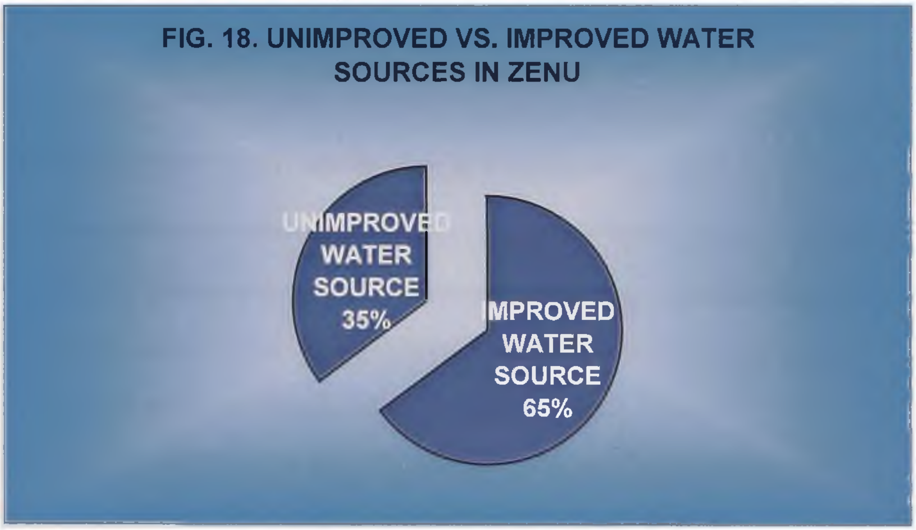
* Unimproved water source

Table 4b. Improved and unimproved water source vs. diarrhoea

Water Source	Diarrhoea +	-	Total
Improved	12	177	189
Unimproved	17	85	102
Total	29	262	291

This translates to mean that 65% of respondents use improved sources of drinking water while 35% use unimproved sources of drinking water Fig. 18.

Fig. 18. Unimproved vs improved water sources in Zenu



Chi square analysis of Table 4a shows an association between source of drinking water and diarrhoea (χ^2 = 41.84; p <0.000000). There is a very strong evidence that such an association exists. Further, analysis (Table 4b) shows that the storage of water from unimproved sources increases the risk of consumers to diarrhoea by three (OR = 2.96, χ^2 = 6.75, P = 0.006). This means that those who use unimproved stored water are more likely to have diarrhoea.

4.1.3 Diarrhoea.

9.9% of respondents have had diarrhoea in their homes in the past two weeks (Table 5).

Table 5. Diarrhoea frequency

Diarrhoea	Frequency	%
+	29	9.9%
-	263	90.1%
Total	292	100

4.1.4 Water treatment

About 10% of households treated their water by boiling before drinking. This practice cuts across all types of water sources with $\chi^2 = 4.19$; p =0.38 (Table 6). There is therefore no significance association between the types of drinking water sources and the practice of water treatment in the home. The likelihood of treating water at home does not depend on the source of water. The users of the different kinds of water are therefore equally likely to treat their water at home.

Table 6. Water treatment and drinking water source

	Drinking water source					
Water treatment	**1***	**2***	**3***	**4***	**5***	Total
+	19	3	4	1	2	29
	165	10	58	4	26	263
Total	184	13	62	5	28	292

Tank water only (1*), Dam water only (2*), Tank and dam water(3*), Pipe borne water (4*), Dam and pipe borne water (5*).

A single table analysis of water treatment and diarrhoea gave a p-value of 0.015. There is therefore a significant association between the treatment of water and diarrhoea. It appears that those who treat their water are rather getting more diarrhoea than those who do not treat their water (Table 7).

Table 7. Water treatment and diarrhoea

	Diarrhoea		
Water treatment	**+**	**-**	**Total**
+	7	22	29
-	22	241	263
Total	29	263	292

4.1.5 Replenishment of water

The mean period for topping up or replacement of drinking water in the various storage containers in the home is 3.4 days. About 44% of households changed or added fresh supplies by day 3 while 20.5% and 19.8% did so on the 2nd and 4th days respectively. 8.3% brought in fresh supplies weekly. The maximum and minimum periods were 14 days and one day respectively. Storing water for periods longer than 3 days does not put the consumer at risk (χ^2 = 2.95, p =0.084).

4.1.6 Vessels

Most households (76.4%) kept a vessel solely for storing drinking water, while 23.6% used such vessels for other household purposes (Table 8).

There was an association between the sole use of vessels for the storage of water and diarrhoea (χ^2 = 5.10, p = 0.023) as shown by Table 9.

Table 8. Vessel for water storage

Solely used for storage	Freq.	percent	Cum.
+	233	76.4%	76.4%
-	69	23.6%	100.0%
Total	292	100.0%	

Table 9. Water storage vessel and diarrhoea

	Diarrhoea		
Vessel solely used for storage	+	-	Total
+	16	205	221
-	12	57	69
Total	28	262	290

There was also no significant association between the use of other vessels for fetching water (transferring of drinking water into storage vessels) and diarrhoea (χ^2= 1.02, p = 0.311).

92.7% of the households visited had covers for the storage containers while 7.3% had no covers. Significant associations were not obtained for covering of vessels and diarrhoea (χ^2= 3.29, p = 0.069). The results are summarized in Table 10 (Appendix 10).

4.1.7 Commercial water storage tanks (Water survey)

Tank type - A total of 15 water storage tanks were counted at the study site. The details are presented in Table 11, (Appendix 11). 80% of the tanks were built from cement blocks (Fig. 19) while 20% were poly tanks (Fig. 20). They were all above ground. All the tanks had complete covers (Figs. 21, 22) Cracks were observed in 2 concrete tanks. One of the tanks had connected drains.

Fig. 19. Tank built from cement blocks

Fig. 20. Poly tanks above ground with tap outlet

Fig. 21. Tank with complete cover (sloped)

Fig. 22. Tank with complete cover (not sloped)

Environment - There were no latrines cattle kraals nor rubbish hips within site (< 30m)of the tanks. All the tanks were on dry ground (Figs 19, 20). None was found in a swampy area. 21% of the tanks were connected for rain harvesting.

Water drawing system – All the concrete tanks used a bucket drawing system while the rubber tanks used a tap outlet (Figs 20, 23). All the bucket system users had non-collapsible buckets made of plastic or aluminium (Fig. 24 a, b). The last time of cleaning the tanks from the time of the survey ranged from 3 days to a month.

Fig. 23. Tap outlet system

Fig. 24 a. Aluminium bucket drawing system

Fig. 24 b. Aluminium bucket drawing system

4.2 WATER ANALYSIS

Water samples were collected from household drinking water sources. These were 6 chlorinated (tap) water points, 6 stored chlorinated water points from tanks and 6 points of unchlorinated dam water. The samples were also taken from 3 levels. Level 1 was the source, level 2 the home storage container and level 3 the consumer or allocation level. The results of the water analysis are presented in Table 12 and 13 (Appendix 12 and 13).

E. coli was detected in 100% of all tank water and dam sources. Although the pipe water contained coliform and heterotrophic bacteria, it contained no *E. coli* at all the source points (level 1).

Figs. 18 and 19 show mean faecal coliform (FC) and total coliform counts (TC) respectively at the various sources and levels. Water type 1, tank water, was contaminated at all points; source, house storage and at the consumer level. The pipe borne water had zero FC count when the sample was collected directly from the tap but was contaminated at the storage level and subsequently at the consumer level. The dam water, contained FC at all levels and increased from source to the consumer level.

Statistical analysis of the faecal coliform counts showed significant differences between the counts at the various levels evidence of the difference between the water at the different levels. (Appendix 14).

Fig. 25. Mean faecal coliform count/100ml

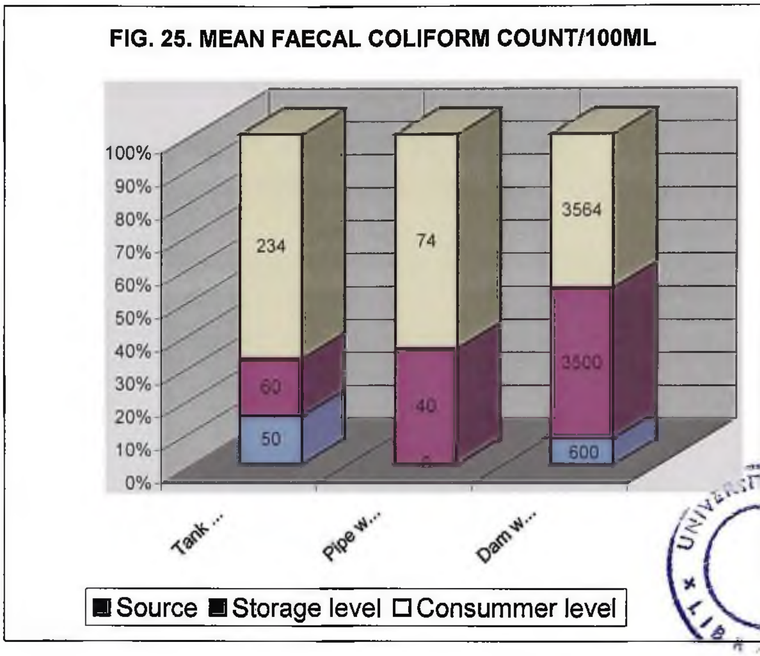
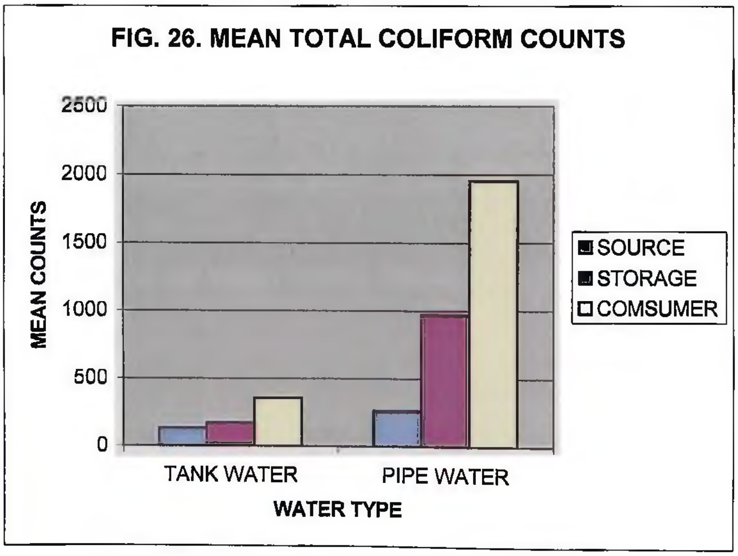


Fig. 26. Comparison of mean total coliform counts/100ml



The TC for tank and pipe borne water increased from source to the storage level and then to the consumer level, Fig. 26. The dam water showed the same trend in Fig. 27.

Fig. 27. Mean total plate counts – dam water

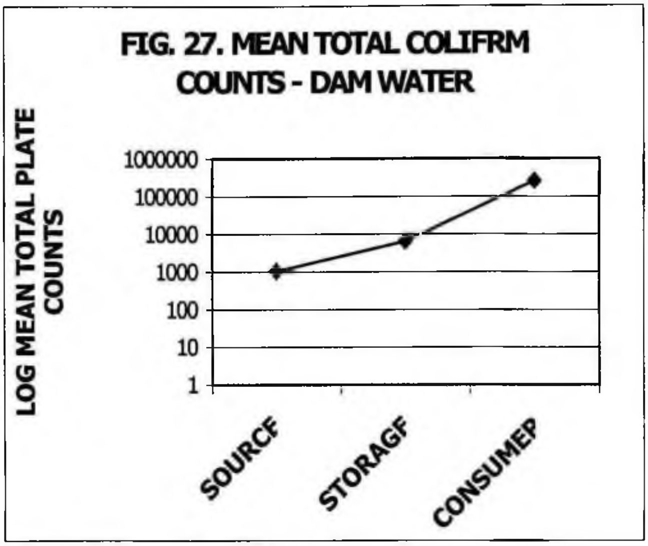
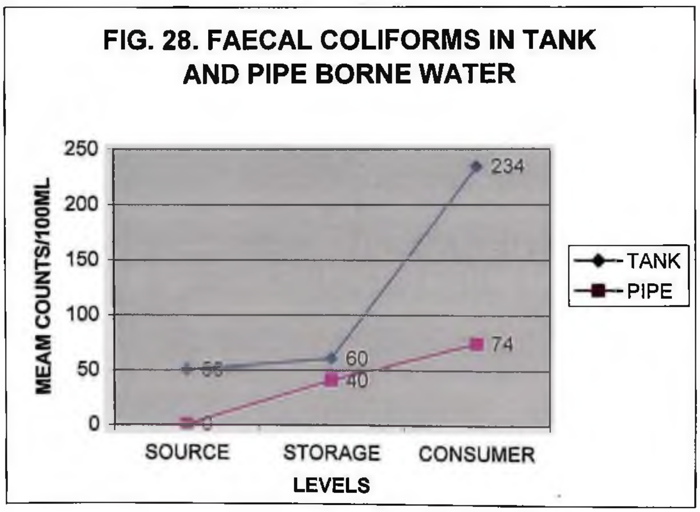


Fig. 28. compares faecal coliforms in chlorinated water supplies.

Fig. 28. Faecal coliforms in tank and pipeborne water



The main findings are listed as follows:

- 97% of the population store water (Fig. 16)
- There are three main sources of water used (Fig. 17)
- Diarrhoea prevalence was 10% (Table 5)
- 21% use a combination of water sources (Fig. 17, 18)
- Water source and diarrhoea are associated (Table 4 a, b)
- There was no association between the storage of water and diarrhoea (Table 2)
- Households who treated their water had more diarrhoea (Table 7)
- The sole use of vessels for storage reduces the risk of diarrhoea (Table 9)
- Water quality deteriorates at the household level. (Fig. 25, 26)

CHAPTER 5

5.0 DISCUSSION

5.1 WATER SOURCES

There were three main types of water sources used by households in the study area. While 63% and 2% depended solely on tank and pipe water respectively, about 31% used a combination of these two sources with the dam water (Fig. 17). Thus 65% of households used improved sources of water while 35% used unimproved sources (Table 4a and Fig.18). Analysis of the questionnaire showed that drinking from unimproved sources of water puts people at risk of diarrhoeal diseases. It showed a strong association between the type of drinking water source and diarrhoea (Section 4.1.2). This compares with the results of a similar study conducted in Sri Lanka where 60 and 30% of households used improved and unimproved sources of water respectively (Mertens et al., 1990).

The practice of households of the study site of supplementing their improved water source with water from the dam needs to be discouraged especially among households with younger children in order to derive the benefits of using improved water for drinking and cooking.

In a related study, Esrey et al., (1988) have shown that supplementing improved water with unimproved water reduced the benefits of the improved water source. They found that children of families who used improved water sources exclusively, for cooking and drinking grew 0.438cm and 235g more than those who supplemented the improved water with contaminated water for drinking and cooking. They explained the difference in growth to be due to lower rates of *Giardia lamblia*. Therefore health benefits are obtained upon the exclusive use of improved water sources. The improved water quality is a factor in the reduction of enteric diseases and enteric diseases burden (Tulchinsky, 1993). Further, the provision of improved water results in 17% reduction in diarrhoea incidence (Esrey et al., 1985).

On the contrary, Knight et al., (1992), found no association between water source and diarrhoea. The trend in associations with diarrhoea is shifting from improvements in water quality alone. There is therefore shifted emphasis from the relative importance of water quality and quantity in the transmission of diarrhoeal disease to "complex interrelationships" (Kolsky, 1993). Van Derslice and Briscoe, (1995) and Esrey, (1996), along the same thinking, reported that improved water quality has the greatest effect on diarrhoea together with improvements in sanitary conditions. A greater association with water availability rather than quality was suggested for rates in young children (Huttly et al., 1990).

5.2 STORAGE

The situation in Zenu, the study area, is that it is unserved. The results of the study show that majority of respondents (>97%) stored drinking water in vessels in their homes (Fig.16). The water quality analysis shows that stored water is contaminated in the home regardless of the water source. There was very strong evidence that an association existed between the type of drinking water source and diarrhoea. There was however no association between diarrhoea and storage of water (Verweij et al., 1991) (section 5.2.1).

The need to store drinking water in the house therefore arises from the lack of connection, availability and access to water (Besser et al.,1995) but people are not

5.2.1 Contamination during storage

The water analysis showed contamination of all the types of water at the storage level, (Fig. 25). Although there were no faecal coliforms in the pipe water samples taken directly from the tap, it was found to be contaminated with faecal coliforms in all the samples stored in the home. The commercial tank water was contaminated from all the sources, likewise the dam water. Thus 100% of all the stored samples were contaminated. Although storage itself does not cause contamination, it is the handling practices and other associated factors, possibly personal hygiene and sanitation, which bring about a deterioration in the water quality.

The tank water can also be considered to be in storage. Assuming that uncontaminated water is delivered into the tank. There were two types of tanks; the concrete and the poly (rubber tanks). The rubber tanks had a tap delivery system (Fig. 23) while the concrete tanks used the bucket system (Fig. 23a). The vending activities expose the concrete tank water to contamination especially where the vessel used to draw the water is handled by contaminated hands before being lowered into the tank (Fig. 24b). Where the drawing vessel is kept when not in use as well as the type of drawing vessel used contributes to contamination of the vended water.

100% of the concrete water tanks used the non-collapsible bucket system (Table 11). These were kept on top of the tanks tied with a rope. The rope or parts of it lie on the roofing and may also be a source of contamination. In contrast to this, collapsible buckets usually hang in the tank and are less likely to be contaminated. Physical defects of the tanks though present were minimal. There were no drains, although a few of them had aprons, therefore the ground immediately surrounding the tanks was soaked wet. This is important where there are steps to climb to the opening where water is drawn. Water splashes on feet and legs may wash into the tank while drawing water from the top.

There were no latrines in the town thus the question of Minimum Safe Distance (MSD) does not apply here. This however does not rule out the practice of indiscriminate defecation close to the houses which may pose a danger to the water tanks. Although the tanks were well grouted it cannot be concluded that they were safe from faecal contamination from latrines or faecal matter. Other sources of possible contamination are mentioned in section 2.5.2. Although not investigated, the water tankers which deliver the water into the tanks may also be considered as a source of contamination. However, this being the case, there is increased contamination at the home levels.

Fig. 25 shows the mean faecal coliform counts for the different water types and contamination levels. The allocation or removal of water for consumption is another possible source of contamination. In the study community, this is usually by a cup. Where this cup is stored/kept, its other uses and mode and regularity of cleaning affect the quality of the stored water. During the collection of the samples for analysis, the cup was found either on top of the lid of the storage container or produced from somewhere in the house and dipped into the stored water.

The presence of other bacteria in the pipe water sample collected directly from the tap (Tables 12b & c) may be due to faults in the distribution system. This may be attributed to many possible factors (see Section 2.5.1).

Although the tap water delivers safe drinking water, further deterioration is expected during handling before consumption (Cheesebrough,1984). This compares with the findings of Gilman et al., (1993). They reported that more than 80% of the water stored by families had faecal coliforms. There is therefore a daily consumption of faecal bacteria from water stored in the home (Empereur-Bissonet et al., 1992). Likewise, Swerdlow et al., (1992) found evidence for the progressive contamination of water during distribution and storage in the home. They also reported that the highest faecal coliforms were found from the storage containers, especially from a household water storage container in which hands had been introduced. The contamination of previously treated water occurs during transportation and domestic allocation of water by contaminated hands (Empereur-Bissonet et al., 1992). Similarly, Pinfold, (1990) found cross contamination by water handling as the main mechanism of stored water contamination.

To support the hand contamination theory, Verweij et al., (1991) in an evaluation of the impact of the installation of a system of chlorinated drinking water on the water quality found that the water supply showed no contamination with coliforms even after storage. The odds ratio for drinking water from a household storage container was 0.77. Swerdlow et al., on the other hand obtained OR = 4.2. The stored water quality was a function of water related activities rather than quality at source. Since the hands are the most mobile part of the body, it is most probable that they may be responsible for carrying pathogenic organisms from contaminated places into the stored water (Morgan, 1990).

Investigation of contamination by hands has shown no significant difference in the proportion of low-income and high income mothers. The promotion of hand washing, particularly among young children reduces the incidence of diarrhoea by 14-48% (Feachem, 1984). Another study in the Philippines gives evidence for hand contamination among a high proportion of mothers and children (Hardon and Oosterberg, 1984). This makes washing of hands after using the toilet or changing little children very important in the reduction of diarrhoeal morbidity (Oyamede et al., 1980; Feachem, 1984).

Good hygienic measures to practice to reduce the health risks of stored water include

- careful storage of household water and regular cleaning of all household water – storage facilities;
- construction, proper use and the maintenance of latrines;
- regular hand-washing, especially after defecation and before eating or preparing food (Fig 29).
- careful storage and preparation of foods.

Fig. 29. Regular hand-washing, especially after defecation and before eating or preparing food

5.2.2 Vessels

Findings of the questionnaire showed an association between the sole use of vessels for drinking water storage (χ^2 =5.10, p = 0.02) and diarrhoea but there was no significant association obtained for the use of a transfer storage vessel for fetching water (χ^2 =1.02 p = 0.31) or covering the storage container (χ^2 =3.29, p = 0.06) and diarrhoea (Appendix 10). Therefore, it is important to maintain a vessel solely for the purpose of water storage in order to reduce or prevent diarrhoea while it is not so important to reserve the fetching vessel for fetching only. This is probably due to the short duration of the water in the fetching vessel as compared to the duration in the storage vessel. It may not also be practicable for rural households to maintain a vessel solely for fetching drinking water. This does not however rule out the possibility of the fetching vessel contaminating the water before storage.

The non-significance of covering of the storage vessel and diarrhoea is difficult to explain. It was expected that uncovered storage vessels would be more prone to contamination especially if there were little children in the house and if the storage containers were not kept out of their reach (Fig. 29).

Contamination of the water brought to the home is usually due to the container used to fetch, store and dip for use. The transfer of water collected from public taps or outside the home into other containers also increases the chances of contamination (Pinfold, 1990). Morgan, (1990) reported that the containers themselves may be the source of contamination and recommended that water containers should be used for no other purpose, be covered and kept out of the reach of children who may contaminate the water.

Fig. 30. Stored water within reach of children

The use of storage containers which are ineffective in maintaining water quality increase bacterial contamination of the water (Empereur-Bissonnet et al., 1992). In such containers, the level of contamination rises immediately the water enters the vessel in which it is carried to the home. Non-significant results were found for the type of storage container, fly covers and diarrhoea (Knight et al., 1992).

5.2.3 Duration of storage

The mean duration of water in storage was found to be 3.4 days. . The longer the water remains the more contaminated it becomes due to the introduction of contaminated hands and allocation vessels thereby increasing water-borne disease transmission. The results show non significant association between storage duration of more than 3 days and diarrhoea.

Longer periods of storage provide new breeding sites for the mosquito species *Aedes aegypti,* the major vector of epidemic yellow fever and dengue (Cairncross and Feachem,1993). In this community however, 97% of the households had fitted lids for their storage containers. No larvae were found in any of the water samples collected.

The frequency of replenishment may depend on other factors including size of the storage vessel, the number of household members and possibly the distance from the source where water is purchased or collected.

5.3 TREATMENT

10% of households treated their water before consumption. Treatment by boiling was the only method indicated. Boiling was practised by households who used all the different sources of water identified. The odds ratio for drinking boiled water was 3.49.

The results were unexpected since it is believed that the boiling of water should rather have a protective effect on health. It appears that other factors may apply here. If it is considered that the water was well boiled then the handling after boiling may be suspected to be unsatisfactory. This could increase the chances of recontamination. Treated water needs to be stored properly and handled hygienically to be protective.

Household treatment of water is recommended where local supplies are known to be contaminated or of doubtful quality to ensure that it is safe for consumption. It is not clear why users of water from improved source also treated their water at home.

In order to protect clean or treated water from recontamination, the precautions for important consideration include the location of the vessel, design of the storage vessel and removal of the water.

The storage vessel must be kept above ground level, out of access of children and accessible to users and refilling to minimise contact with hands. The design of the storage vessel must be such that it will reduce the risk of contamination with a tight fitting lid. It must also be able to withstand rough handling without cracking. The removal of the water from the storage container must be done hygienically with no contact between the hands and the water.

Water is commonly withdrawn with a cup (WHO, 1997b). The risk of contamination by hands while removing water by a cup is high. A better alternative is to use a ladle that is kept permanently in the container and used solely for that purpose. The ladle must be used to transfer water to a cup or other vessel and not used for directly drinking. The ladle must also not be held by the scoop (Fig. 31).

Fig. 31. Water withdrawal by a ladle.

5.4 INSPECTION OF WATER TANKS

The aspects of the water supply tanks inspected were to provide a complete knowledge of the state of the water points including possible pollution of the water in a storage tank or reservoir.

None of the tanks was sited in a swampy area or underground. This prevented polluted ground water from entering the tanks. Since there were hardly any latrines or soak-aways in the town, this did not pose a problem of faecal contamination. The danger here is the practice of indiscriminate defecation in the absence of latrines. This is more so where there are young children in the households which sell water.

Drawing water by the bucket system was good if the buckets were always left hanging in the well/tank. All the buckets used were non-collapsible. A collapsible bucket could not be put on the ground and therefore not become easily contaminated. The non collapsible buckets were however kept outside on top of the tanks or on the steps of the tank which made contamination easier.

The provision of permanent covers for all the wells prevented the accumulation of rubbish or wind blown dust. It also prevented the growth of algae and reduced evaporation. 20% of the tanks which received treated water were also connected to collect and store rain water from roof runoff. All the tanks had been recently cleaned.

The ideal water point should be sited on raised or elevated ground away from where water collects or accumulates in order to prevent both underground and surface contamination. It must be sited well away from latrines, cattle kraals and hollows in the ground. The outer covering, casing, should be finely plastered. It needs a strong and complete cover slab which is sloped to allow water to run to waste. Once a year cleaning is adequate if water that is run into the tank is clean (Cairncross and Feachem; 1993, WHO, 1997b). More frequent cleaning is required if the water supplied is not clean.

Rainwater harvesting is a well known technique that is practised in many rural areas and in places with intermittent water supply (IRC,1990; IRCSA, 2001). Since all harvester surfaces are exposed throughout the year, the collection area is prone to contamination (Thomas and Green,1999). Bacterial contamination can be minimised by collecting water from preferably a galvanised surface. The roofs must be periodically cleaned and not overhung by trees. Water can then be collected, after allowing about 10 to15 minutes runoff, through gutters into storage tanks. Water from such tanks can be considered safe for drinking even if low levels of bacteria are present (UNEP, 1983). They consistently have *E. coli* counts rarely exceeding 10 colonies/100ml water sample (Morgan,1990) and total coliform counts 25-75/100 ml on the average.

5.5 WATER ANALYSIS

The water quality study showed progressive contamination during distribution and storage in the home: faecal coliform counts were highest in water from household storage containers and lowest at the source of collection. This compares with the findings of (Swerdlow et al., 1992).

Water from the tap though without any faecal coliforms was contaminated at storage level in the home. Therefore though originally the consumer collected FC-free water, one ended up drinking contaminated water. Water is therefore contaminated in the home during storage.

The tank water which had previously been treated contained faecal coliforms at the point of sale. Tank water is contaminated during sales. All the concrete tanks were opened on top and a bucket tied with rope was lowered into the water. The buckets are kept on top of the tank where they are exposed to possible contamination from bird droppings and faecal soiled feet and/or slippers. Customers collected the bucket and straightened the rope by passing it through their hands before dipping the bucket (Fig. 24 a,b). Contamination of the water therefore occurs from the hands of the customers (Section 5.2.1). The water is further contaminated when it is being transferred into the customer's vessel by the hands. At home, the use of water by different people handling the dipper several times further contaminates the water. A cup that is contaminated by hands introduces faecal coliforms into the water.

Water from the dam is expected to have faecal coliforms at all sources; from birds and small animals and cattle. Humans who use the banks for sanitary purposes further contaminate the dam at Zenu.

In a similar study where water samples were taken from 151 wells, 44 taps supplying water from the treated municipal supply and 192 domestic stored water supplies. *E. coli* were detected in 20% of the samples (42% of wells, 7% of tap water and 6% of drinking water). Excellent correlation was found between the faecal coliform and *E.coli* counts for all sample types.

5.5.1 Counts

The Total coliform count (TC) for all the water sources was above 10/100ml of sample (Table 12). The mean counts ranged from 132/ml to hundreds of thousands from tank to dam water (Table 13). The pipe water had the least number of faecal coliforms ranging from 0 to 74/100ml of sample. Apart from the source sample, the counts at both the pipe storage and the consumer levels were not acceptable (Table 12) (Appendix 6).

The results form a presumptive membrane coliform count, and a presumptive membrane *E. coli* count. The presumption in this case is that the colonies are gas-producers as well as acid-producers, and in the case of *E. coli* at 44°C also indole-producers. This is liable to lead to an overestimation of the number of coliform organisms, but the error is on the side of safety and, moreover, the final result is obtained in a much shorter time than by the tube method.

In bacteriological examinations the presence of *E. coli* in a water sample indicates excretal pollution of either human or animal origin. High counts indicate heavy and recent pollution while, low counts indicate slight or relatively remote pollution. Since there is no satisfactory method for determining whether *E. coli* is of human or animal origin, its presence is always regarded as an indication of potentially dangerous pollution. Even in the presence of obvious animal sources of pollution one cannot be certain that human contamination has not also occurred. The faeces of birds, rodents and domestic animals may contain organisms of the salmonella group, including *Salmonella paratyphi B.* Reservoirs and upland surface waters are particularly liable to pollution of this nature.

The presence of *other* coliform organisms in a water sample, in the absence of *E. coli,* may be due to a variety of causes. The finding of coliform organisms in a water sample may indicate past excretal contamination at a time sufficiently remote to allow *E. coli* to die out. This contamination would have however be picked up, if frequent testing is carried out. It would also forecast the onset of more dangerous pollution in the future.

Coliform organisms other than *E. coli* can also occur in water sources as a result of contamination by soil washings or from growth on decaying vegetation, especially in warm weather. In wells, pollution of the shaft or adit may also be caused by the presence of old sacking, decaying wood-work or other material serving as a suitable growth medium. However the underground water itself may be quite pure. In distributed water, growth may occur on pump, gland or joint packing and on washers on taps and other fittings.

The presence of *any* coliform organisms in chlorinated water indicates either inadequate treatment or the access of undesirable material after treatment. Coliform organisms may accidentally gain access to the sample during collection, e.g. from the sampler's hands, the interior of an improperly sterilised tap or from a non-sterile sampling bottle.

It is more important to consider the quality of the water source serving a community. The objective is to get from bad quality (>1000feacal coliforms/100ml) to moderate quality (>10 faecal coliforms/100ml (World Bank, 1992).

According to the International Reference Centre for Community Water Supply and Sanitation, the levels of coliforms present in acceptable drinking water should be less than 10/100ml sample, and the number of faecal *E. coli* less than 2.5/100ml sample (Morgan, 1990). Water from a source that is found to be consistently well below standard (*E.coli* counts are several hundreds or even above 100 colonies/100ml sample) require closer inspection.

In a study by Moe et al., (1991), little difference was observed between the illness rates of children drinking good quality water (less than 1 *E. coli* per 100 ml) and those drinking moderately contaminated water (2-100 *E. coli* per 100 ml). Children drinking water with greater than 1000 *E. coli* per 100 ml had significantly higher rates of diarrhoeal disease than those drinking less contaminated water. This threshold effect suggests that in developing countries where the quality of drinking water is good or moderate other transmission routes of diarrhoeal disease may be more important; however, grossly contaminated water is a major source of exposure to faecal contamination and diarrhoeal pathogens.

5.6 DAM WATER

The use of surface waters from extremely polluted rivers generates a high hygienic risk and requires the sanitation of the rivers. The high number of existing protection zones in the catchment areas for drinking-water is a valuable precondition to ensure the hygienic safety of the drinking-water supply (Schlosser and Schulze,1991).

Usually, surface water has a very high bacterial contamination which is heavy with faecal bacteria. This is evidenced in the very high counts of faecal coliforms (Appendix 12). Other contaminants are contributed from agricultural source including nitrates, phosphates and pesticides which are washed from farms close to the water. Although the dam water is not the only available water source, it is happens to be the cheapest in spite of the high risk of contamination. Results show an association between the type of drinking water and diarrhoea. The odd ratio for drinking from the dam is 3. Treatment is usually by boiling to improve the microbiological quality. Other low-cost, low-tech treatment should include slow-sand filtration and SODIS (Letterman, 1999). Bank filtration may also be practised (Johnston et al; 2001).

Ponds and other surface water sources used for domestic consumption should be protected as much as possible. Although latrines are not located near the water there is no strict regulation about defecation near the water. Also, people and animals should not bathe and wash clothes nearby. Communities must be responsible for the communities downstream who also may use the water.

CHAPTER 6

6.0 CONCLUSION AND RECOMMENDATIONS

The effect of stored drinking water quality on diarrhoeal disease provides powerful confirmation of the importance of environmental factors on diarrhoea: The effects of water quality, source of water, and the sole use of vessel for water storage are strong, consistent, and statistically significant. Covering of the household storage vessels, use of other vessels instead of the storage vessel to fetch the water, the duration of storage and the practice of water storage were not associated with diarrhoea.

There was evidence of progressive contamination of water during storage in the home. The highest faecal coliform counts were found from the storage containers from which a daily consumption of faecal bacteria occurred (Empereur-Bissonet et al., 1992; Swerdlow et al.,1992).

According to Moe et al., (1991), there is no significant difference in the rates of diarrhoea between children who drank moderately contaminated water(1 and 2-200) faecal coliform couts/100ml water sample. Very high rates were found for drinking water with faecal coliform values above 1000/100 ml. Based upon these findings it may be concluded that there is no difference between the diarrhoea rates of pipe borne water and tank water users. The tank water supply level of 50/100 ml however needs careful examination (Morgan, 1990), Appendix 14.

The positive impact of improved water quality is greatest for families living under good sanitary conditions, with the effect statistically significant when sanitation is measured at the community level but not significant when sanitation is measured at the household level. Improving drinking water quality would have no effect in neighbourhoods with very poor environmental sanitation; however, in areas with better community sanitation, reducing the concentration of faecal coliforms by two orders of magnitude would lead to a 40 percent reduction in diarrhoea. Providing private excreta disposal would be expected to reduce diarrhoea by 42 percent, while eliminating excreta around the house would lead to a 30 percent reduction in diarrhoea. The findings suggest that improvements in both water supply and sanitation are necessary if infant health in developing countries is to be improved. They also imply that it is not epidemiological but behavioural, institutional, and economic factors that should correctly determine the priority of interventions (Van Derslice & Briscoe, 1995).

In view of the above, some fundamental ideas about the relative importance of water quality and quantity in the transmission of diarrhoeal disease have changed, and there is increased recognition of the complex interrelationships between interventions, hygiene behaviour and health (Kolsky, 1993).

Since contamination of water occurs in the home the following are being recommended to improve upon the stored domestic water quality:

- The concrete water tanks should preferably be fitted with taps since the number of users is high in order to reduce the potential for complex cross contamination (Fig. 31).
- Promote hygiene practices especially by using soap to wash hands after defecation (Fig. 28).

- Keeping storage containers out of reach of little children (Fig. 30).
- Removal of water from the storage containers should be done with a ladle that is stored in the water (Fig. 31).
- Increase in the frequency of changing the stored water.
- Keeping special vessels for water storage only
- Water which has been boiled or heated should be stored in the same container with a fitting lid
- Boiled water should also be consumed as soon as possible, preferably the same day

Fig. 32. A concrete water tank fitted with a tap

In order to derive the full benefits of using improved sources of water, community members should carry water to drink on the farm. If they must drink the dam water it is recommended that the water be treated conveniently by SODIS.

The community must take steps to provide latrines in the town to protect the dam and water tanks from faecal pollution. There must be strict laws about defecating close to the dam (Fig. 33).

Fig. 33. Defecation in bushes close to water source

REFERENCES

Abouzaid, H., and Echihabi, L. (1995). Drinking water quality and monitoring in north Africa: the Moroccan experience. *Sci. Total Environ* (NETHERLANDS), **171** (1-3) 29-34 ISSN: 0048-9697.

Aziz, K.M., Hoque, B. A., Hasan, K. Z., Patwary, M.Y., Huttly, S. R., Rahaman, M.M. and Feachem, R. G. (1990). Reduction in diarrhoeal diseases in children in rural Bangladesh by environmental and behavioural modifications. *Transactions of the Royal Society of Tropical Medicine and Hygiene,* **84** (3), 433-8 ISSN: 0035-9203.

Bagla, P. and Kaiser, J. (1996). India's spreading health crisis draws global arsenic experts. *Science*, **274**, 174-175.

Besser, R.E., Moscoso Rojas, B., Cabanillas Angulo, O., Gonzalez Venero, L., Minaya, Leon, P., Rodriguez Pajares M., Saldana Sevilla W., Seminario Carrasco J. L., Highsmith A. K. and Tauxe R. V. (1995). Prevention of cholera transmission: rapid evaluation of the quality of municipal water in Trujillo, Peru. *Bol Officinal Sanit Panam* (United STATES), **119** (3) 189-94 ISSN: 0080-0632.

Bland, J. (1993). The cost of dirty water. *People and the Planet,.* **2** (2), 8-9.

Briscoe, J., de Castro, P. F., Griffin, C., North, J. and Olsen, O. (1990). Toward equitable and sustainable rural water supplies: a contingent evaluation study in Brazil. *World Bank Economic Review,* **4** (2),115-134.

Brown, J. P. and Jackson, R. J. (1995). Water Pollution. In Stuarts et al., *Environmental Medicine.* Maple-Vail Book Mfg. Group. Mosby-Year book Inc. St. Louis Missouri. pp. 479-487.

Cairncross, S. (1987). Ingested dose and diarrhoea transmission routes. *American Journal of Epidemiology.* **125** (5), 921-5.

Cairncross, S. (1990). Health aspects of water and sanitation. In: Kerr C, ed. *Community health and sanitation*. Intermediate Technology Publications. London.

Cairncross, S. (1992). *Sanitation and water supply: Practical Lessons from the decade*. The World Bank. Washington DC.

Cairncross, S. and Kinnear, J. (1992). Elasticity of demand for water purchased from vendors in the squatter areas of Khartoum, Sudan. *Social Science and Medicine.* **34** (2), 183-9.

Cairncross, S. and Feachem, R. (1993). *Environmental health engineering in the tropics (2nd Edition).* John Wiley & Sons Ltd. Sussex. England.

Chan, M.S. (1997). The global burden of intestinal nematode infections – fifty years on. *Parasitology Today.* **13**(11), 438-443.

Cheesebrough, M. (1984). *Medical laboratory manual for tropical countries.* Volume II: Microbiology. Tropical Health Technology/Butterworth-Heineman Ltd. Oxford. pp. 206-220.

Cheung, W.H., Chang, K.C., Hung, R.P. and Kleevens, J.W. (1990). Health effects of beach water pollution in Hong Kong. *Epidemiol Infect* (ENGLAND) **105** (1), pp.139-62.

Cousens, S.N., Feachem, R.G., Kirkwood, B., Mertens, T.E. and Smith, P.G. (1988). *Case-control studies of childhood Diarrhoea: II Sample size*. Diarrhoea Diseases control Programme. CDD/EDP/88.3. WHO, Geneva.

Desmarchelier, P. Lew, A., Caique, W. Knight, S. Toodayan, W. Isa, A.R. and Barnes, A. (1992). An evaluation of the hydrogen sulphide water screening test and coliform counts for water quality assessment in rural Malaysia. *Transactions of the Royal Society of Tropical Medicine and Hygiene.* **86** (4), pp.448-50.

Diamant, B.Z. (1992). Assessment and evaluation of the international water decade. *Jr. Soc. Health* (ENGLAND).**112** (4), pp. 183-8.

ECETOC (1988). *Nitrate and drinking-water.* ECETOC technical Report No. **27**. Brussels

Empereur-Bissonnet, P., Salzman, V. and Monjour, L. (1992). Application of a new transport and storage material for improving the quality of drinking water in rural African areas. *Bull Soc Pathol Exot* (FRANCE) **85** (5), pp.390-4

Engleman. R. and Le Roy, P. (1995). *Sustaining water: an update.* Population Action International. Washington, DC.

Esrey, S. A., Feachem, R.G. and Hughes, J. M., (1985). Interventions for the control of diarrhoeal diseases among young children: Improving water supply and excreta disposal facilities. *Bulletin of the World Health Organization*, **63,** pp. 757-772.

Esrey, S. A., Habicht, J. P., Latham, M. C., Sisler, D. G. and Casella, G. (1988). Drinking water source, diarrhoeal morbidity, and child growth in villages with both traditional and improved water supplies in rural Lesotho, southern Africa. *American Journal of Public Health*. **78** (11), pp.145-5.

Esrey, S. A., Collet, J., Miliotis, M. D., Koornhof, H. J. and Makhale, P. (1989). The risk of infection from *Giardia lamblia* due to drinking water supply, use of water and latrines among preschool children in rural Lesotho. *International Journal of Epidemiology*. (1), 248-53.

Esrey, S. A. and Feachem, R.G. (1989). *Interventions for the control of diarrhoeal diseases among young children: promotion of food hygiene.* WHO/CDD/89.30. WHO, Geneva.

Esrey, S.A. and Potash J. B. (1991). Effects of improved water supply and sanitation on ascariasis, diarrhoea, dracunculiasis, hookworm infection, schistosomiasis and trachoma. *Bulletin of the World Health Organization*, **69**(5), 609 -621.

Esrey, S.A. (1996). Water, wastes and well-being; a multicountry study. *American Journal of Epidemiology* **143** (6), pp. 608-23.

Falkenmark, M., Lundqvist, J. and Widstrand, C. (1989). Macro-scale approaches: aspects of vulnerability in semi-arid development. *Natural Resources Forum*, **13** (4), 258-267.

Fawell, J. K. (1993). The impact of inorganic chemicals on water quality and health. *Ann Inst Super Sanita* (ITALY). **29** (2), pp. 293-303.

Feachem, R.G. (1984). Interventions for the control of diarrhoeal diseases in children: Supplementary feeding programmes. *Bulletin of the World Health Organization.* **62,** 467-476.

Fernandez Gomez, J. al-Kassam Mukdise, A., Perez Martinez, L., Santos Diez, M. L., Aguado Carmona, P. and Diez Gonzalez, I. (1993). Water pollution and its impact in the Basic Health Area of Cistierna. *Aten Primaria* (SPAIN) **12** (2), pp.79-80, 82-4.

Galal-Gorchev, H., Ozolins, G. and Bonnefoy, X. (1993). Revision of the WHO guidelines for drinking water quality. *Ann Inst Superior di Sanita* (ITALY). **29** (2), pp. 335-45.

Geldreich, E. E. (1989). Drinkiing water microbiology new directions toward water quality enhancement. *International Journal of Food Microbiology* (NETHERLANDS). **9** (4), pp. 295-312.

Gig Sanit (1992). Chemical composition of the drinking water and the health of the population. (1) pp.13-5 (abstract).

Gilman, R.H., Marquis, G. S., Ventura, G., Campos, M., Spira, W. and Diaz, F. (1993). Water cost and availability: key determinants of family hygiene in a Peruvian shantytown. *American Journal of Public Health.* **83** (11), pp.1554-8.

Gleick, P.H. (1993). *Water in crisis: a guide to the world's fresh water resources.* New York/Oxford, Oxford university Press.

Gleick, P.H. (1996). Basic water requirements for human activities: meeting basic needs. *Water International*, **21**, 83.

Gleick, P.H. (1999). The human right to water. *Water Policy.* **1**(5), 487-503.

Gustafson D. I. (1995). Use of computer models to assess agricultural chemicals via drinking water *Sci. Environ* . **171** (1-3), 35-42.

GWSS, (2001). Ghana Water Supply and Sanitation. Fact sheet, 2001.

Hardon, A. and Oosterberg, E.(1984). *Food contamination in relation to diarrhoea: A study in a rural village in the Philippines.* Amsterdam Royal Tropical Institute, Mimeograph 1.

Hopenhayn-Rich, C., Biggs, M. L., Fuchs, A., Bergoglio, R., Tello, E.E., Nicolli, H. and Smith, A.H. (1996). Bladder cancer mortality associated with arsenic in drinking water in Argentina. *Epidemiology* . **8** (3),334.

Huttly, S.R. (1990). The impact of inadequate sanitary conditions on health in developing countries. *World Health Stats Q* (SWITZERLAND) **43** (3), pp.118-26.

Huttly, S.R., Blum, D., Kirkwood, B.R., Emeh, R.N., Okeke, N., Ajala, M., Smith, G.S., Carson, D.C., Dosunmu-Ogunbi, O. and Feachem, R.G. (1990). The Imo State (Nigeria) Drinking Water Supply and Sanitation Project, 2. Impact on dracunculiasis, diarrhoea and nutritional status. *Transactions of the Royal Society of Topical Medicine and Hygiene.* **84** (2) pp.316-21.

IPCS, (1984). Fluorine and fluorides. *Environmental health criteria.* **36**. WHO, Geneva.

IPCS, (1995). Inorganic lead. *Environmental health criteria.* ***165***. WHO, Geneva.

IRC, (1990). Water harvesting in five African countries. *IRC international Water and Sanitation Centre,* **14**.

IRCSA, (2001). International rainwater catchment systems association. http://www.ircsa.org/.

Johnston, R., Heijnen, H., Wurel, P. (2001). *Safe water technology.* Final Draft (unpublished)

Kay, D., Fleisher, J. M., Salmon, R.L., Jones, F. Wyer, M.D., Godfree, A. F., Zelenauch-Jacquotte, Z. and Shore, R. (1994). Predicting likelihood of gastroenteritis from sea bathing: results from randomized exposure. *Lancet* **344** (8927), pp. 905-9.

Knight, S.M., Toodayan, W., Caique, W.C., Kyi, W., Barnes, A. and Desmarchelier, P (1992). Risk factors for the transmission of diarrhoea in children: a case-control study in rural Malaysia. *International Journal of Epidemiology.* **21** (4), pp. 812-8.

Kolsky, P. J. (1993). Diarrhoeal disease: current concepts and future challenges. Water, sanitation and diarrhoea: the limits of understanding. *Transactions of the Royal Society of Topical Medicine and Hygiene.* **87** Suppl. 3 pp. 43-6.

Letterman, A. (1999). *Water quality and treatment: a handbook of community water supplies.* American Waterworks Association, McGraw-Hill, New York.

MacKenzie, W. R. et al. (1994). A massive outbreak on Milwaukee of cryptosporidium infection transmitted through the public water supply. *New England Journal of Medicine*, **331**, pp. 161-167.

Martines, J., Phillips, M. and Feachem, G. A (1993). Diarrhoeal diseases. In D.T. Jamison et al., (Eds.). *Disease control priorities in developing countries.* New York, Oxford University Press.

Mertens, T. E., Fernando M. A., Marshall T. F., Kirkwood B. R., Caincross S., and Radalowicz (1990). Determinants of water quality, availability and use in Kurunegala, Sri Lanka. *Tropical Medicine and Parasitoogy,* **41** (1) : 89-97.

Moe, C. L., Sobsey, M. D., Samsa, G. P. and Mesolo, V. (1991). Bacterial indicators of risk of diarrhoeal disease from drinking-water in the Philippines. *Bulletin of the World Health Organization.* **69** (3) pp. 305-17.

Moore, A. C., Herwaldt, B. L., Craun, G. F., Calderon, R. L; Highsmith, A. K. and Juranek, D. D (1993). Surveillance for waterborne disease outbreaks. *MMWR CDC Surveill Summ.* **42** (5), pp. 1-22.

Morgan, P. (1990). *Rural water supplies and sanitation. A text from Zimbabwe's Blair Research Laboratory.* Macmillan Education Ltd. London and Basingstoke. pp. 225-255.

Mouchet, J. and Brengues, J. (1990). Agriculture-health interface in the field of epidemiology of vector-borne diseases and the control of vectors. *Bulletin Soc Pathol Exot* (FRANCE) **83** (3), pp. 376-93.

Murray, C. J. L. and Lopez, A. D, (Eds.). (1996 a). Global burden of disease and injury. In: *Global health statistics.* Cambridge, MA, Harvard School of Public Health. (Series Vol. 2).

Murray, C. J. L., Lopez A. D.(Eds.). (1996 b). *The global burden of disease: a comprehensive assessment of mortality and disability from disease, injuries and risk factors in 1990 and projected to 2020.* Harvard School of Public Health. Harvard University Press.

Oyemade, A., Omokhodion, F. O., Olawayi, J. F., Sridhar M. K. C. and Olaseha, I. O. (1980). Environmental and personal hygiene practices. Risk factors for diarrhoea among children of market women. *Diarrhoea Dialogue Online.* Issue **3** pp. 4,5.

Pinfold, J. V. (1990). Faecal contamination of water and fingertip-rinses as a method for evaluating the effect of low-cost water supply and sanitation activities on faeco-oral disease transmission. II. A hygiene intervention study in rural north-east Thailand. *Epidemiol Infect* (ENGLAND).**105** (2), pp. 377-89.

Rodriguez Pajares, M., Saldana Sevilla, W., Seminario Carrasco, J. L., Highsmith, A.K. and Tauxe, R. V. (1995). Prevention of cholera transmission: rapid evaluation of the quality of municipal water in Trujillo, Peru. *Bol Oficina Sanit Panam* (UNITED STATES). **119** (3), pp.189-94.

Rose, J.B., Haas, C. N. and Regli, S. (1991). Risk assessment and control of waterborne giardiasis. *American Journal of Public Health.* **81**(6), pp.709-13.

Saliba, L. J. and Helmer, (1990). Health Risks associated with pollution of coastal bathing waters. *World Health Stat Q* (SWITZERLAND) **43** (3) pp.177-87.

Satterthwaite, D. (1993). Securing water for the cities. *People and the Planet* (vol. 2) **2** p. 13.

Schlosser, F.U. and Schulze, E. (1991). The hygienic situation of the central drinking water supply in the former East Germany--an evaluation of the annual reports on water hygiene from 1984 to 1989. *Zentralbl Hyg Umweltmed* (GERMANY).**192** (4), pp. 287-323. (abstract).

Sinha, A. K., Pande, D. P., Srivastava, R. K., Srivastava, P., Srivastava, K. N., Kumor, A. and Trpathi, A.(1991). *Sci Total Environ* (NETHERLANDS). **101** (3) pp.275-80.

Snow, J.C (1849). On the pathology and mode of communication of cholera. *London Medical Gazette*, **9**: pp.745-753; 923-949.

Solo-Gabriele, H. and Neumeister, S. (1996). US outbreaks of cryptosporidiosis. *Journal of the American Waterworks Association,* Sept: pp. 76-86.

Swerdlow, D. L., Mintz, E. D., Rodriguez, M., Tejada, E., Ocampo, C., Espejo, L., Greene, K. D., Saldana, W., Seminario, L., and Tauxe, R. V. (1992). Waterborne transmission of epidemic cholera in Trujillo, Peru: lessons for a continent at risk. *Lancet* **340** (8810) pp. 28-33.

Thomas, P. and Green, G. (1993). Rainwater quality from different roof catchments. *Water Science and Technology*, **28** (3-5), pp.291-299.

Tulchinsky, T. H., Burla, E., Halperin, R., Bonn, J. and Ostroy, P. (1993). Water quality, waterborne disease and enteric disease in Israel, 1976-92. *Israel Journal of Medical Science* **29** (12) pp.783-90.

UN (1993). *Agenda 21: The United Nations programme of action from Rio.* New York, UN.

UN (1997). *Report on the United Nations water conference, Brazil,* 14-25. New York, UN (E/CONF. 70/29).

UNDP (1985). *Is there a better way?* UNDP division of Information, New York.

UNEP (1983). *Rain and storm water harvesting: a report by the United Nations environment programme,* Cassell Tycooly, Dublin.

UNICEF (1999). *Facts for life.* United Nations Children's Fund. New York.

UNCHS, (1996). *An urbanising world: global report on human settlements.* Oxford University Press, Oxford.

Van Derslice, J. and Briscoe, J. (1995). Environmental interventions in developing countries: interactions and their implications. *American Journal of Epidemiology.* **142** (2), p.227.

Verweij, P. E., van Egmond, M., Bac, D. J., van der Schroeff, J. G. and Mouton, R. P. (1991). Hygiene, skin infections and types of water supply in Venda, South Africa. *Transactions of the Royal Society of Tropical Medicine and Hygiene.* **85** (5) pp.681-4.

WHO, (1985). *Guidelines for drinking-water quality control in small community supplies.* WHO, Geneva.

WHO, (1988). *International Drinking water supply and sanitation decade – towards the targets (An overview of progress in the first five years of the IDWSSD).* WHO/CWS/88.2

WHO, (1993a). *Guidelines for drinking water quality.* Vol. 1, Geneva, World Health Organization.

WHO, (1993b). *Guidelines for drinking-water quality.* (vol.1). Recommendations WHO, Geneva.

WHO, (1996a). *WHO Guidelines for drinking-water quality.* (2^{nd} Ed.) Vol. 2. Health criteria and other supporting information. WHO, Geneva.

WHO, (1996b). Cholera and other epidemic diarrhoeal diseases control: fact sheets on environmental sanitation. World Health Organization. Geneva (unpublished document WHO/EOS/96.4).

WHO, (1996c). Cholera in 1995. *Weekly Epidemiological Record*, **21**, pp.157-163.

WHO, (1997a). *Sustainability of water supply and sanitation services. Health and environment in sustainable development. 5 Years after the earth summit.* pp.98-140. World Health Organization. Geneva.

WHO, (1997b). *Guidelines for drinking-water quality (2 Edtn.). Vol. 3. Surveillance and control of community supplies.* World Health Organization. Geneva.

WHO, (1999). *Arsenic in drinking water.* Geneva, World Health Organization, 1999 (Fact Sheet No. 210).

WHO, (2000a). *The world health report: making a difference.* Geneva, World Health Organization.

WHO, (2000b). *Global water ssupply and sanitation assessment 2000 Report.* Pg.1-7 (ISBN 92 4 156202 1) NLM Classification: WA 675. World Health Organization.

WHO, (2001a). Arsenic in drinking water. WHO Fact Sheet No. 210. Revised May 2001. *Bulletin of the World Health Organization,* **78**, (9):p.1096. WHO, Geneva. WHO/WSH/WWD/DFS.13.

WHO, (2001b). *Disease fact sheet: Diarrhoea.* WHO Geneva. WHO/WSH/WWD/DFS.09

WHO, (2001c). *Disease fact sheet: Typhoid and paratyphoid.* WHO/WSH/WWD/DFS.16.

WHO, (2001d). *Disease fact sheet: Cholera.* WHO/WSH/WWD/DFS.19.

WHO, (2001e). Water for health. Taking charge. WHO, Geneva

WHO/ UNICEF/ WSSCC, (2000). *Global water ssupply and ssanitation aassessment. 2000 Report.*

WHO/UNICEF, (1996). *Water supply and sanitation sector monitoring report: sector status, Dec. 1994.* Geneva. WHO (unpublished document WHO/EOS/96.15).

World Bank, (1992). *Sanitation and clean water.* World development rreport, 1992. Development and the eenvironment. World development indicators, pp. 98-100. World Bank, New York/Oxford Press.

World Bank, (1993). *Environmental influences on hhealth.* World development report,1993. Investing in health - World development indicators, pp. 90-93. World Bank, New York/Oxford Press.

World Watch, (1984). *Water: Rethinking management in an age of scarcity,* 62. The World Watch Institute. Washington.

APPENDICES

APPENDIX 1

TABLE 1. REPORTED CASES OF DIARRHOEA – ASHAIMAN HEALTH CENTRE 1998-2000

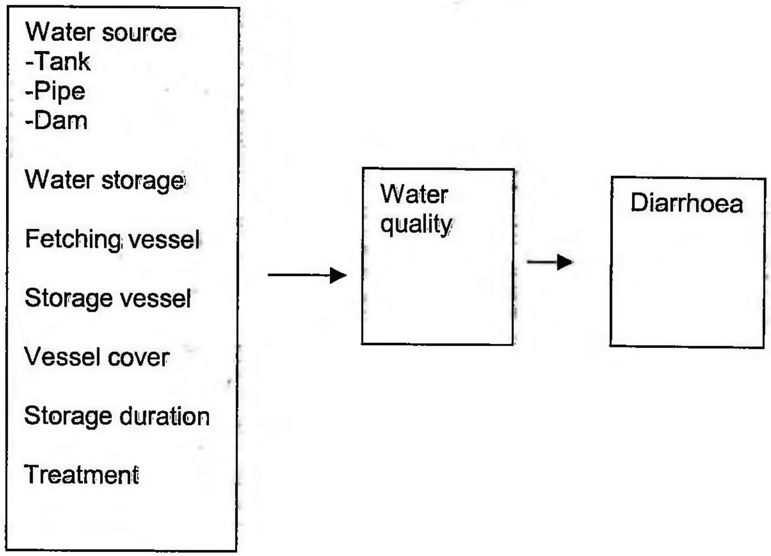
YEAR	1-5	5-14	15-44	45-60	61+	TOTAL
1998	436 (55.75%)	87 (11.0%)	163 (20.73%)	81 (10.30 %)	19 (2.41%)	786 100%
1999	484 (65.67%)	69 (9.36%)	156 (21.10%)	21 (2.84%)	7 (0.94%)	737 100%
2000	570 (63.54%)	108 (12.02%)	178 (19.84%)	30 (3.34%)	11 (1.22%)	897 100%

Source: Ashaiman Health Centre, Records Department.

APPENDIX 2

CONCEPTUAL FRAMEWORK

VARIABLES



APPENDIX 3

OPERATIONAL DEFINITIONS

Tank – concrete or rubber container which receives water from a water tanker truck and stores such water for sale.

Dam – surface water dammed for irrigation.

Pipe – water from the chlorinated water distribution system collected from a tap

Vessel – container used by household to store drinking water

Household – members of a family who drink from a common storage vessel

Diarrhoea – the passage of loose or liquid stools more frequently than is normal for the individual

APPENDIX 4

ZENU HOUSEHOLD WATER AND DIARRHOEA SURVEY

1. Area……………………….Name of Household……………………..

   Date………………Name of interviewer……………………………..

2. What is your source of drinking water?

   Tank water only ( )

   Dam water only ( )

   - Tank and dam water ( )

   Dam and pipe water ( )

   Pipe water only ( )

   Other……………….

3. Do you store your drinking water? (YES) (NO)
4. Is the vessel for storage solely used for storing the drinking water or used for other purposes (YES) (NO)
5. What do you use to fetch the drinking water?

   -Storage container ( ) -Other vessel ( )

6. May I see your drinking water storage container?

(Please check if the storage vessel has a cover and check the response). (YES) (NO)

7. What is the longest storage period before replenishment?……days

10. Do you treat your drinking water in some way? (YES) (NO)

(If yes state treatment method) ……………………………………

11. Has any one in the household had diarrhoea in the past two weeks?

(YES) (NO)

APPENDIX 5

ZENU HOUSEHOLD WATER AND DIARRHOEA SURVEY
(For tank storage only)

Name.. Area........................

Date..................Name of interviewer.................................

1.Type of tank

Block ( )

Rubber ( )

Aluminium ( )

2 Apron present (YES) (NO)

3. Covered completely ( )

Covered partially ( )

Not covered ( )

4. Cover sloped (YES) (NO)

5. Water outlet type

Bucket collapsible ( ) Bucket non-collapsible ( ) Tap ( )

5. Last time the tank was cleaned...........................months

6. Connected to rain water (YES) (NO)

7.Ground swampy (YES) (NO)

8.Distance from latrine (<30m) (>30m)

9. Cracks (YES) (NO)

10. Drains (YES) (NO)

FEACAL COLIFORM DETERMINATION

SAMPLE NO.

Source	Dilution	1	2	3	4	5	6
Tank 1	1	✔	✔	✔	✔	✔	✔
		✔	✔	✔	✔	✔	✔
Tank 2	1	✔	✔	✔	✔	✔	✔
		✔	✔	✔	✔	✔	✔
Tank 3	1	✔	✔	✔	✔	✔	✔
		✔	✔	✔	✔	✔	✔
Pipe 1	1	✔	✔	✔	✔	✔	✔
		✔	✔	✔	✔	✔	✔
Pipe 2	1	✔	✔	✔	✔	✔	✔
		✔	✔	✔	✔	✔	✔
Pipe 3	1	✔	✔	✔	✔	✔	✔
		✔	✔	✔	✔	✔	✔
Dam 1	1:10	✔	✔	✔	✔	✔	✔
	1:100	✔	✔	✔	✔	✔	✔
	1:1000	✔	✔	✔	✔	✔	✔
	1:10000	✔	✔	✔	✔	✔	✔
Dam 2	1:10	✔	✔	✔	✔	✔	✔
	1:100	✔	✔	✔	✔	✔	✔
	1:1000	✔	✔	✔	✔	✔	✔
	1:10000	✔	✔	✔	✔	✔	✔
Dam 3	1:10	✔	✔	✔	✔	✔	✔
	1:100	✔	✔	✔	✔	✔	✔
	1:1000	✔	✔	✔	✔	✔	✔
	1:10000	✔	✔	✔	✔	✔	✔

TOTAL COLIFORM DETERMINATION

SAMPLE NO.

Source	Dilution	1	2	3	4	5	6
Tank 1	1	✔	✔	✔	✔	✔	✔
		✔	✔	✔	✔	✔	✔
Tank 2	1	✔	✔	✔	✔	✔	✔
		✔	✔	✔	✔	✔	✔
Tank 3	1	✔	✔	✔	✔	✔	✔
		✔	✔	✔	✔	✔	✔
Pipe 1	1	✔	✔	✔	✔	✔	✔
		✔	✔	✔	✔	✔	✔
Pipe 2	1	✔	✔	✔	✔	✔	✔
		✔	✔	✔	✔	✔	✔
Pipe 3	1	✔	✔	✔	✔	✔	✔
		✔	✔	✔	✔	✔	✔
Dam 1	1:10	✔	✔	✔	✔	✔	✔
	1:100	✔	✔	✔	✔	✔	✔
	1:1000	✔	✔	✔	✔	✔	✔
	1:10000	✔	✔	✔	✔	✔	✔
Dam 2	1:10	✔	✔	✔	✔	✔	✔
	1:100	✔	✔	✔	✔	✔	✔
	1:1000	✔	✔	✔	✔	✔	✔
	1:10000	✔	✔	✔	✔	✔	✔
Dam 3	1:10	✔	✔	✔	✔	✔	✔
	1:100	✔	✔	✔	✔	✔	✔
	1:1000	✔	✔	✔	✔	✔	✔
	1:10000	✔	✔	✔	✔	✔	✔

APPENDIX 8

TOTAL HETEROTROPHIC BACTERIA DETERMINATION

SAMPLE NO.

Source	Dilution	1	2	3	4	5	6
Tank 1	1:10	✔	✔	✔	✔	✔	✔
		✔	✔	✔	✔	✔	✔
	1:100	✔	✔	✔	✔	✔	✔
		✔	✔	✔	✔	✔	✔
Tank 2	1:10	✔	✔	✔	✔	✔	✔
		✔	✔	✔	✔	✔	✔
	1:100	✔	✔	✔	✔	✔	✔
		✔	✔	✔	✔	✔	✔
Tank 3	1:10	✔	✔	✔	✔	✔	✔
		✔	✔	✔	✔	✔	✔
	1:100	✔	✔	✔	✔	✔	✔
		✔	✔	✔	✔	✔	✔
Pipe 1	1:10	✔	✔	✔	✔	✔	✔
		✔	✔	✔	✔	✔	✔
	1:100	✔	✔	✔	✔	✔	✔
		✔	✔	✔	✔	✔	✔
Pipe 2	1:10	✔	✔	✔	✔	✔	✔
		✔	✔	✔	✔	✔	✔
	1:100	✔	✔	✔	✔	✔	✔
		✔	✔	✔	✔	✔	✔
Pipe 3	1:10	✔	✔	✔	✔	✔	✔
		✔	✔	✔	✔	✔	✔
	1:100	✔	✔	✔	✔	✔	✔
		✔	✔	✔	✔	✔	✔

APPENDIX 8

TOTAL HETEROTROPHIC BACTERIA DETERMINATION
(contd.)

SAMPLE NO.

Source	Dilution	1	2	3	4	5	6
Dam 1	1:10	✔	✔	✔	✔	✔	✔
	1:100	✔	✔	✔	✔	✔	✔
	1:1000	✔	✔	✔	✔	✔	✔
	1:10000	✔	✔	✔	✔	✔	✔
Dam 2	1:10	✔	✔	✔	✔	✔	✔
	1:100	✔	✔	✔	✔	✔	✔
	1:1000	✔	✔	✔	✔	✔	✔
	1:10000	✔	✔	✔	✔	✔	✔
Dam 3	1:10	✔	✔	✔	✔	✔	✔
	1:100	✔	✔	✔	✔	✔	✔
	1:1000	✔	✔	✔	✔	✔	✔
	1:10000	✔	✔	✔	✔	✔	✔

Table 3. Frequency of household drinking water sources in Zenu.

Drinking water	Frequency	Percent	Cumulative
Tank water only	184	62.8%	62.8%
Dam water only	13	4.4%	67.2%
Tank + dam	62	21.2%	88.4%
Pipe water only	5	1.7%	90.1%
Pipe and dam	28	9.6%	99.7%
No response	1	0.3%	100%
Total	293	100.0%	

Table 10. Summary of analysis

VARIABLE	YES	NO	ASSOCIATION WITH DIARRHOEA	P-VALUE
Water storage	97%	2.7%	Not significant	0.57
Use of improved source	65%	35%	Highly significant	0.0000
Water treatment	10%	90%	Significant	0.015
Duration before replenishment less than 3 days	66.5%	33.5%	Not significant	0.084
Storage vessel solely used for water storage	76.4%	23.6%	Significant	0.023
Transfer of water into storage vessels	–	–	Not significant	0.311
Storage vessel covered	92.7%	7.35	Not significant	0.69
Water treatment / water source	–	–	Not significant	0.38

APPENDIX 11

TABLE 11. COMMERCIAL STORAGE TANK SURVEY

Type of tank	Block 80% (12/15)	Rubber 20% (3/15)	Aluminium 0
Ground	Swampy 0	Not swampy 100% (15/15)	
Apron	Present 73% (11/15)	Absent 27% (4/15)	
Slab cover	Complete 100% (15/15)	Partial 0	None 0
Slab slope	Sloped 20% (3/15)	Not sloped 80% (12/15)	
Distance from latrines etc.	Within site (< 30m) 0	Out of site (> 30m) 100%	None
Water outlet system	Bucket 80% (12/15)	Tap 20% (3/15)	Other 0
Type of bucket	Collapsible 0	Non collapsible 100% (12/12)	
Cracks	Present 17% (2/12)	Absent 83% (10/12)	
Connected to harvest rain water	Yes 21%	No 79%	
Drains	Absent 100% (15/15)	Present 0	

APPENDIX 12

COLONY COUNTS

TABLE 12a. FAECAL COLIFORMS

SAMPLE	1	2	3	4	5	6	MEAN
TANK1	46	48	52	40	60	54	50
TANK2	33	46	74	52	73	82	60
TANK3	205	225	201	275	253	245	234
PIPE1	0	0	0	0	0	0	0
PIPE2	28	32	45	37	42	56	40
PIPE3	84	63	79	90	57	71	74
DAM1	704	652	590	629	550	475	600
DAM2	3411	3941	2987	3581	3324	3756	3500
DAM3	3737	3666	3634	321	3615	3527	3564

TABLE 12b TOTAL HETEROTROPHIC BACTERIA

SAMPLE	1	2	3	4	5	6	MEAN
TANK1	22	55	42	29	35	39	37
TANK2	26	19	31	22	14	32	24
TANK3	69	59	55	70	65	60	63
PIPE1	3	2	1	5	3	4	3
PIPE2	8	12	14	22	14	20	15
PIPE 3	118	118	132	112	128	138	124
DAM1	397	360	353	374	382	354	370
DAM2	475	532	446	485	515	487	490
DAM3	492	515	509	486	526	532	510

TABLE 12c TOTAL COLIFORM COUNT

SAMPLE	1	2	3	4	5	6	MEAN
TANK1	121	127	137	129	135	143	132
TANK2	150	165	176	174	186	181	172
TANK3	195	272	37	408	432	186	355
PIPE1	280	233	282	275	267	245	264
PIPE2	1098	824	1033	1177	746	930	968
PIPE3	1366	1562	2196	1806	2050	2732	1952
DAM1	1232	1141	1033	1100	963	832	1050
DAM2	6432	7432	5633	6753	6268	7082	6600
DAM3	266780	261710	259430	244220	258070	251790	257000

APPENDIX 13

Table 13. MEAN COLONY COUNTS

SAMPLE	MEAN TOTAL COLIFORM COUNT / 100ML	MEAN FAECAL COLIFORM COUNT /100ML	MEAN TOTAL HETEROTROPHIC BACTERIA COUNT /ML
Tank (source)	132	50	37
Tank (Home storage)	172	60	24
Tank (consumer)	355	234	63
Pipe (source)	264	0	3
Pipe (Home storage)	968	40	15
Pipe (consumer)	1952	74	124
Dam (source)	1050	600	490
Dam (Home storage)	6600	3500	370
Dam (consumer)	257000	3600	510

FAECAL COLIFORM COUNT ANALYSIS

kwallis tnum,by(tank)

Test: Equality of populations (Kruskal-Wallis Test)

tank	_Obs	_RankSum
1	6	34.00
2	6	44.00
3	6	93.00

chi-squared = 11.661 with 2 d.f.
probability = 0.0029

. kwallis pnum,by(pipe)

Test: Equality of populations (Kruskal-Wallis Test)

pipe	_Obs	_RankSum
1	6	21.00
2	6	57.00
3	6	93.00

chi-squared = 15.158 with 2 d.f.
probability = 0.0005

. kwallis dnum,by(dam)

Test: Equality of populations (Kruskal-Wallis Test)

dam	_Obs	_RankSum
1	6	21.00
2	6	73.00
3	6	77.00

chi-squared = 11.415 with 2 d.f.
probability = 0.0033

APPENDIX 15

GUIDELINES FOR RURAL WATER QUALITY

E. coli count/100 ml sample	Remarks
1-10	satisfactory
11-50	Needs further testing
51+	Not satisfactory. Requires improvement