GROUNDWATER POLLUTION FROM ON-SITE SANITATION IN DHAKA, BANGLADESH

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GROUNDWATER POLLUTION FROM ON-SITE SANITATION IN DHAKA, BANGLADESH

by

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Engineering

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ABSTRACT

This study looked into the risk of groundwater pollution from on-site sanitation in Dhaka, Bangladesh. A sizable proportion of the city population do not have access to adequate water supply. Groundwater is the major source of potable water for domestic use. Safe excreta disposal facilities are also very limited in the area.

This study ~~also~~ evaluated the extent of groundwater pollution in relation to on-site sanitation systems in the project area. Groundwater quality was monitored at selected points for specified time at regular interval. Later the data were analysed for identifying the probable sources of the pollutants; and investigating the factors controlling their movement in the soil-water system. In addition, the present water supply, sanitation, and health status of the area ~~has al~~so been reviewed.

The results ~~from the experiments~~ indicated the presence of pollutants of fecal origin, such as fecal coliform, bacteriophage, and nitrate, in almost all the samples analysed. The extensive use of unsewered disposal system has been identified as the major source of pollutants. The hydrogeologic condition was found to be unsuitable for the traditional methods of on-site sanitation. Routine monitoring and detailed study has to be carried out for having a clear view of the potential of groundwater pollution by on-site sanitation facilities in the study area.

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LIST OF ABBREVIATIONS

DMC	Dhaka Municipal Corporation
DPHE	Department of Public Health Engineering Government of Bangladesh
EPA	Environment Protection Agency, USA
ICDDR	International Center for Diarrhoeal Disease Research, Dhaka, Bangladesh
SWT	Static Water Table
WASA	Water Supply and Sewerage Authority Dhaka, Bangladesh
WHO	World Health Organization

I INTRODUCTION

1.1 General

Groundwater is one of the major sources of water for potable use. In many places groundwater is extracted for irrigation and other purposes as well. There has been a marked increase in the development of groundwater resources over the last two decades. In many developing countries, apparent high cost involved in the construction, maintenance, and operation of surface water treatment facilities have forced them to use groundwater as the source for municipal and rural water supply schemes. Initially this practice was encouraged and funded by local and international agencies. On the other hand, the pace of development in safe excreta disposal facilities was not evenly coupled. As a result the groundwater is becoming polluted to a level that is no more safe unless some large scale treatment is done. So the use of groundwater is also becoming a costly affair.

Problem of groundwater contamination have never received much attention because they are usually local in nature, and the effects are hidden from view. Protection of groundwater resources from all types of pollutants is an essential part of any program involving the solution of environmental problems. In many ways, the correction of groundwater quality degradation is considerably more complex than in the case of surface water.

A discussion of the impact of groundwater contamination in any region takes on many aspects including:

(1) The important role of groundwater as a water supply source.

(2) The hidden and often misunderstood nature of groundwater pollution and the resulting health and other hazards.

(3) The dependence of groundwater quality on surface water quality, depending on local soil conditions.

(4) The problems involved in monitoring groundwater quality.

(5) The technical difficulties and high costs associated with the investigation, control, and correction of groundwater pollution, if possible at all.

1.2 Major Pollutants from On-site Sanitation

Pollutants resulting from the on-site sanitation facilities that might contaminate groundwater may be broadly classified as pathogenic microorganisms, and chemical substances, e.g. nitrate, chloride. Essentially, these two classes of pollutants are also related to human wastes. Tab. 1.1 summarises the diseases and their causative agents which might be spread through fecally contaminated groundwater.

1.2.1 Pathogen Transmission

Four types of pathogens can normally be found in human excreta. These are eggs of helminths (worms), protozoa, bacteria, and viruses. A large number of pathogens may be excreted by each individual, the exact number may vary slightly between various age groups. Fecal matter on an average contain 10^9 bacteria/g (not necessarily pathogenic), and in the excreta of infected individuals as high as 10^6 viruses/g.

Tab. 1.1 The diseases and their agents which might be spread by fecally contaminated groundwater (LEWIS et al., 1982)

Diseases	Pathogens
a) Viral diseases:	
Infectious hepatitis	Hepatitis A virus
Poliomyalitis	Poliovirus
Diarrhoeal diseases	Rotavirus, norwalk agent, other viruses
Varied symptoms and diseases	
b) Bacterial diseases:	
Cholera	Vibrio cholera
Typhoid fever	Salmonella typhi
Paratyphoid fever	Salmonella paratyphi
Bacillary dysentery	Shigella spp.
Diarrhoeal diseases	Enterotoxigenic E. Coli Enteroinvasive E. Coli Enteropathogenic E. Coli Campylobacter petus spp. jejuni

Bacteria and viruses may be transported with percolating effluent into the groundwater, and those organisms may be ingested causing infection. However, excreted viruses and bacteria are transmitted in many other routes, such as contaminated food, fingers, or flies. Whether or not an individual will become infected will depend on the concentration and persistence of pathogen. Bacteria, unlike viruses are able to multiply outside their host (FEACHEM et al., 1982).

1.2.2 Nitrate-related Diseases

The extensive use of on-site sanitation may lead to elevated concentration of nitrate in the underlying groundwater. Two diseases have been associated with consumption of water containing high nitrate concentration. Methaemoglobinaemia, which infects mainly children, and carcinogenesis.

(a) Methaemoglobinaemia

This is a disease primarily infecting young infants. In 1977 a WHO European Working Group on health hazards from drinking water proposed the adoption of 11.3 mg NO_3-N/l as the maximum acceptable concentration for infants, and of 22.6 mg NO_3-N/l as the maximum for the population as a whole (WHO, 1977), to safeguard against this disease. The potential health implications for infants ingesting excessive quantities of nitrate is a topic of continuing medical attention (WINDLE-TYLOR, 1974; SHUVAL and GREUNER, 1977; WHO, 1978; FRASER and CHILVERS, 1981).

(b) Carcinogenesis

Recently there has been increasing interest in the cancer risk associated with elevated quantities of nitrate in drinking water. Nitrites can react with amines and amides to form nitrosamines and nitrosamides. Most N-nitroso compounds tested have proved to be carcinogenic in a wide range of animal species, and most were mutagenic. The epidemological evidence suggests that high nitrate ingestion may be a contributing factor to cancer.

1.3 Objectives, Scopes, and Limitations of the Study

1.3.1 Objectives

Given the hazards caused by groundwater pollution, in this study, attempt has been made to relate this pollution to on-site sanitation. The study area chosen for this study is located in a developing country where people are dependent mostly on the traditional water supply and sanitation systems. Groundwater is the principal source for potable water and on-site sanitation is widely practiced for sewage disposal.

The principal objective of this study is to assess on-site sanitation as a potential source of pollutants contaminating the groundwater resources of the study area. The present situation with respect to water supply, sanitation, and health has also been reviewed.

1.3.2 Scopes

The existing water supply, sanitation, and public health status of the study area has been thoroughly reviewed. This review is based on the reports gathered from various organizations.

Groundwater and soil samples were collected from as many as 16 boreholes located at eight different locations of the study area, two at each location. In addition water samples from intake sources were also collected. The boreholes were drilled at specified distances from a representative on-site sanitation facility at each sampling location. The samples were tested for various chemical and microbiological parameters including nitrate-N, fecal coliform, and bacteriophage, the

presence of any or all of these in the sample indicate fecal contamination which might have its origin at some on-site sanitation facility. The groundwater quality from each borehole was monitored for one and half month period at two weeks interval between each observation. The aim was to detect any significant change in the quality during the sampling period. Hydrogeologic condition of the study area has also been studied, because the movement of pollutants in groundwater depends very much on the soil type and stratifications.

1.3.3 Limitations

Time and instrumentation were the major limitations for this study. From each location samples were collected thrice at 14 days interval. Hand-driven augers were used for drilling the boreholes. The experimental results from this study would be useful for a general understanding of the situation. For a detailed study longer time and sophisticated instruments will be necessary.

II LITERATURE REVIEW

2.1 Factors Affecting Pathogen Movement

The unsaturated zone is the most important line of defense against fecal contamination of aquifers. Maximization of effluent residence time in the unsaturated zone is, therefore, the key factor affecting removal and elimination of bacteria and viruses.

2.1.1 Filtration

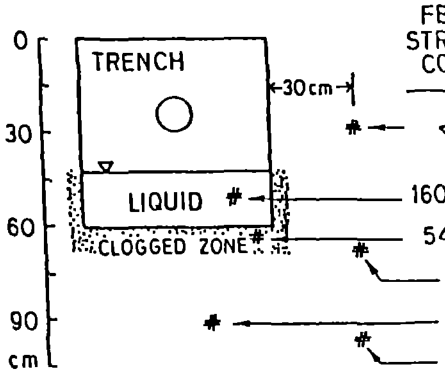
Filtration of bacteria at the infiltration surface appears to be the main mechanism limiting their movement through soil. It has been shown that filtration is most effective at the surface of the organic mat of the clogged zone. For instance, ZIEBELL et al. (1975) found that the bacterial population below and to the side of a septic tank seepage bed was considerably reduced to about the level of the population in a control soil sample. This abrupt drop occurred within 30 cm of the clogged zone (Fig. 2.1). CALDWELL and PARR (1937) also noted that with a newly constructed latrine penetrating the water table, fecal coliforms were detected 10 m away. However, after clogging (3 months) pollutant dispersion was considerably curtailed. KRONE et al. (1958) investigated E. Coli removal in sand columns, and found that the effluent concentration of bacteria gradually rose and then declined which suggested that accumulating bacteria at the soil surface enhanced the straining mechanism. BUTLER et al. (1954) studied the penetration of coliform bacteria in sandy soils used to dispose off settled sewage. Measurements showed that there was a dramatic reduction in coliforms in the first 50 mm of soil, but that a subsequent build-up of bacteria occurred at lower level.

The effect of temperature on the efficiency, drainage and maturation of slow filters suggested by POYNTER and SLADE (1977) that the removal of bacteria and viruses is essentially a biological process.

2.1.2 Adsorption

Unlike bacteria, viruses are very small and removal appears to be dependent entirely on adsorption. BURGE and ENKIRI (1978) studied the adsorption of bacteriophage Ø X-174 on five different soils in laboratory batch experiments. Good correlation was found between adsorption rates and cation exchange capacity, specific surface area and concentration of organic matter. A negative correlation was found between the rate and pH. A study by GREEN and CLIVER (1975) suggests that to enhance virus removal large hydraulic surges, or very uneven distribution of the waste should be avoided, because the virus detention within the soil was found to be affected by the degree of saturation of the pores. GOLDSHMID et al. (1973) investigated the adsorption capacity of E. Coli and found that bacteria removal was better with tap water than with distilled water.

ABSORPTION FIELD CROSS SECTION



BACTERIA / 100 ml OR PER 100 g OF SOIL

FECAL STREPTO-COCCI	FECAL COLI-FORMS	TOTAL COLI-FORMS	TOTAL BACTERIA × 10⁷
<200	<200	<600	0.6
160,000	1,900,000	5,700,000	3.0
54,000	4,000,000	23,000,000	4,400
<200	17,000	23,000	6.7
<200	<200	<600	3.7
<200	700	1,800	2.8

Fig. 2.1 Cross-section of an absorption field in Plainfield loamy sand with bacterial counts at various locations (ZIEBELL et al., 1975)

LANDRY et al. (1979) have demonstrated desorption of viruses. They observed that flooding soil columns with deionized water caused virus desorption and increased their movement through the columns. They also observed that different strains of viruses have varying adsorptive properties. A study by LANCE and GERBA (1980) on the factors affecting the rate and depth of virus penetration revealed that virus adsorption in soil is increased above some breakpoint velocity, whereas flow rate changes above and below the breakpoint do not affect virus adsorption. It was postulated that the velocity of water movement through the soil may be the most important factor affecting the depth of penetration. This suggests that adsorption may not be an important factor of removal in the saturated zone, specially in formations where groundwater velocities are high. Another study by WELLINGS et al. (1974) showed that the phenomena of desorption with decrease in ionic strength has practical implications for groundwater pollution. Previously adsorbed bacteria and viruses could be desorbed by heavy rains. MARTIN and NOONAN (1977) also observed that rainfalls of greater than 50 mm resulted in bacterial contamination of groundwater. Later BARREL and ROWLAND (1979) confirmed these findings by attributing the cause of massive increase in fecal coliforms (5.0×10^5/100 ml) in Gambian village well waters to the onset of rains which flushed the fecal material into the groundwater.

2.2 Factors Affecting Pathogen Survival

2.2.1 Survival in Soils

(a) Viruses

Different studies by GERBA et al. (1975) and BITTON et al. (1979) have shown that the nature of soils can affect virus survival

characteristics. HURST (1979)found that virus survival increased with the degree of viral adsorption to the soil. Hence, soils which are most effective in removing viruses would also enable them persist for the largest periods. DUBOISE et al. (1976) showed that anaerobic condition led to a reduction in activation.

LEFLER and KOTT (1974) and YEAGER and O'BRIEN (1979) in separate studies found that survival of poliovirus depended on temperature. In an accompanying study on the nature of virus inactivation YEAGER and O'BRIEN (1979) concluded that loss of infectivity was due to irreversible damage to the viruses. KESWICK and GERBA (1980) evaluated the factors controlling virus survival and found that inactivation was much more rapid near the surface. This is due to the detrimental effect of soil microorganisms, evaporation, and higher temperatures close to the surface. Thus, virus survival is expected to increase with depth of penetration.

(b) Bacteria

KLIGLER (1921) investigated the survival of Salmonella typhi and Shigella dysenteriae in different soil types at room temperatures. He found that in moist soils some bacteria survived for 70 days, although 90% died within 30 days. MIRZOEV (1968) showed that low temperatures (down to -45°C) were favorable for the survival of Shigella dysenteriae, and he was able to detect them 135 days after they had been added to the soil. KIBBEY et al. (1978) found that die-off rate varied between the different soils, but were generally largest in soils maintained under cool, moist conditions.

This finding was confirmed by BOUMA et al. (1972) in field studies on pollutant movement beneath septic tank disposal fields. DAZZO et al. (1973) recorded the time for 90% reduction of E. Coli as 8.5 days in soils receiving 50 mm of cow manure slurry per week and 4 days in soils receiving no manure. Finally, MARTIN and NOONAN (1977) found that fecal coliform and fecal streptococci were reduced by 90% in 28 and 22 days respectively at depths of 0-100 mm, but 182 and 25 days respectively at 100-200 mm depth in silt loam.

2.2.2 Survival in Groundwater (saturated zone)

(a) Viruses

Field studies by WELLINGS et al. (1975) suggest enteroviruses can survive for at least 28 days in groundwater. AKIN et al. (1971) found that between 2 and 100 days are required for various members of the enteric family to lose 99.9% of their initial infectivity when suspended in different surface waters at 20°C. Similar observations have been reported in more recent investigations (NIEMI, 1976; O'BRIEN and NEWMAN, 1977; YEAGER and O'BRIEN, 1979). From these data it appears that temperature is the single most important factor in die-off, and 99% reduction may be expected at 20°C within about 10 days although a few enteroviruses may survive for many months.

Several workers (CUBBAGE et al., 1979; KATZNELSON, 1978; YOUNG

and SHARP, 1977) have noted that the observed loss of infectivity of viruses in water may be due in part to genuine damage to the virus, and in part to an artefact caused by many viruses aggregating and simulating a single infectious particle.

(b) Bacteria

MITCHELL and CHAMBERLAIN (1978) surveyed published data on the survival of indicator organisms in a variety of freshwater bodies and found that bacterial die-off generally follows first order kinetics, although a significant increase in coliforms is often observed in the first few kilometers from the outfall. Experiments conducted in New Zealand (MARTIN and NOONAN, 1977; and PYLE and THORPE, 1979) found that hydrogen sulfide resistant strain of E. Coli survived for 4 days at 11°C and 2.2 days at 15.5°C. Investigations on antibiotic resistant E. Coli indicated that even after 32 days quite large number survived (HAGEDORN et al., 1978). GELDREICH et al. (1968) found that fecal streptococci often persist longer than fecal coliforms.

2.3 Field Investigations of Pollutant Movement

2.3.1 Bacteria in the Saturated Zone

CALDWELL and PARR (1937) measured pollution travel from a 5.1 m bored hole latrine in shallow (3.6 m) perched water table located in a coarse sandy stratum. A conclusion of this study was that the clogging process was an important defence mechanism limiting the extent of bacterial penetration. A parallel study (CALDWELL, 1937) was conducted using a nearby dug pit latrine and it was found that the clogging process was not as effective with this type of latrine, possibly due to the greater volume per depth of penetration. Fecal coliforms were detected 18 m away from the pit due to higher groundwater flow velocity which contradicts with a later study (CALDWELL, 1938) where no fecal contamination was found 3 m away after the pit was enveloped by a layer of fine sand (0.25 mm).

Based upon these findings a distance of 15 m was generally accepted as a safe distance of separation. But investigations by other researchers (DAPPERT, 1932; and PYLE et al., 1979) indicated that the distance upto which bacteria can travel depends on soil condition. The longest distance reported was 920 m in coarse alluvial gravels. Pollutants may be transported along preferential paths at velocities very much in excess of the average groundwater flow velocity. For instance, ALLEN and MORRISON (1973) injected bacterial tracer organisms (Bacillus steorothermophilus) into a borehole penetrating the water table in fissured bed rock. The tracer organism was detected in a well 29 m within 24 hours, although it could not be detected in two wells as close as 6 m and 16 m from the site.

2.3.2 Bacteria in the Unsaturated Zone

KLIGLER (1921) was one of the earliest researchers to investigate the relationship between pit latrines and the spread of

waterborne infectious diseases. He concluded that pit latrines and septic privies, if properly constructed, are unlikely to cause the spread of bacterial intestine infections. BAARS (1957) investigated dispersion from a pit latrine at a camping site in the Netherlands and he found that bacteria may penetrate some distance into soil. The conclusions that can be drawn from these early studies is that at least 2 m of sandy soil is required beneath a pit latrine to prevent pollution of any underlying water.

A more recent study (SCALF et al., 1977) concluded that soils in many areas are not suitable for conventional septic tank soil absorption system, such as the areas where groundwater table is high. There are many reported instances of groundwater contamination due to high water table (SRIDHAR and PILLAI, 1973; BRANDES, 1974; BINNIE and PARTNERS, 1975; SCALF et al., 1977; RAHE et al., 1978).

2.3.3 Movement of Viruses

Little data exist on virus contamination of groundwater from on-site sanitation. Virus determination are expensive, requires specialized laboratory facilities and highly trained personnel. Furthermore, methods are only available for less than half of all the viruses known to be present in human wastes (KESWICK and GERBA, 1980), for example, it is still not possible to detect Hepatitis A virus.

In the past demonstration of viruses in potable groundwater supplies were essentially confined to those sources where an outbreak of illness had occurred. For example, NEFFE and STOKES (1945) described an extensive outbreak of infectious hepatitis at a summer camp in the USA. An epidemic of the same disease was contributed to contamination of well water by septic tank effluents in Posen, Michigan, USA (VOGT, 1961). VAN der VELDE (1973) isolated poliovirus from a well responsible for a gastroenteritis outbreak in Michigan. Also, WELLINGS et al., (1975) detected poliovirus in water collected 3 m below a cypress dome receiving secondary sewage effluent. A recent study in Israel (MARZOUK et al., 1979) indicated that 20% of 99 shallow groundwater samples (3 m) analysed conatined enteric viruses.

Viruses are much smaller than bacteria and removal is dependent almost entirely on adsorption, thus, of all the pathogens present in sewage, viruses are the most likely to find their way into groundwater during land application (GERBA, 1979). WELLINGS et al. (1974) recovered viruses from groundwater after spray irrigation of secondary sewage effluent onto a sandy soil. In contrast, GILBERT et al. (1976) did not recover any viruses in groundwater samples collected 6 m beneath sewage spreading basins composed of fine loamy sand underlaid by coarser sand.

VAUGHN et al. (1978) conducted a survey of human virus occurrence in groundwater recharged with sewage effluent, virus concentrations between 0-2.8 pfu/l (plaque forming units) were reported in 20 - 33% of 40 liter samples collected. EDWORTHY et al. (1978) recovered viruses in groundwater 15 m beneath a sewage effluent and disposal site. Virus concentrations were 63 pfu/l at the groundwater

table, but zero in boreholes 100 m away.

2.4 Nitrate Pollution of Groundwater

Nitrates in soil and groundwater result from the microbial degredation of organic nitrogenous material such as protein to ammonium ions which are then biologically oxidized to nitrite and nitrate, in a two step process.

$$2NH_4^+ + 2OH^- + 3O_2 = 2NO_2^- + 2H^+ + 4H_2O \quad ...(1)$$

$$2NO_2^- + O_2 = 2NO_3^- \quad ...(2)$$

These two reactions are carried out by different bacteria: reaction (1) by Nitrosomonas, and reaction (2) by Nitrobacter; and both organisms are aerobic chemolithotrophs. Higher plants assimilate nitrite from the soil after reducing the nitrate to nitrite, and this reaction is catalyzed by the enzyme nitrate reductase. Bacteria can also reduce nitrate to nitrite. However, nitrite is easily oxidized to nitrate, the concentration of nitrites in surface water is usually very low (generally less than 0.3 mg NO_3-N/l).

WOODWARD et al. (1961) attributed the cause of groundwater nitrate pollution in unsewered areas of Minnesota to the widespread use of septic tanks and seepage pits. In a detailed literature review PATTERSON et al. (1971) concluded that the consistently poor performance of septic tanks led to recommendations that other waste disposal methods be used in densely populated areas if extensive groundwater pollution problems were to be avoided. BROOKS and CECH (1979) found that nitrate contamination of groundwater was widespread in rural areas of Texas, the principal source being septic tanks.

WALKER et al. (1973) calculated that in Wisconsin, USA, the average nitrogen input reaching the groundwater per year was 7.5 kg for a family of four people discharging septic tank effluent in sandy soils. His data suggested that the only active mechanism of lowering the nitrate content was by dilution with uncontaminated groundwater. HUTTON et al. (1976) attributed widespread and severe nitrate contamination of shallow village groundwater supplies in eastern Botswana to pollution emanating from pit latrines. LEWIS et al. (1980) conducted a hydrogeological study in the vicinity of a severely polluted water supply borehole which had nitrate concentration in excess of 135 mg NO_3-N/l. The results of this study show that pit latrines caused a major build-up of nitrogenous material in the surrounding soil and withered rock, from where nitrate is leached intermittently by infiltrating rainfall.

Data collected by COOK and DAS (1980) in a case study of groundwater pollution in Central India clearly shows a nitrate plume emanating from a village with many on-site sanitation units in operation. Thus it is apparent that nitrate contamination of shallow groundwater is likely to be a problem where the density of on-site

sanitation facilities is high, and where nitrogen removal and groundwater recharge is moderate to low.

LEWIS et al. (1980) observed that nitrate-rich polluted groundwater also had elevated concentrations of calcium and magnesium, i.e. increased hardness. A similar phenomena was evident in the data collected by COOK and DAS (1980). This is thought to be caused by the process of nitrification which produces hydrogen ions which are able to dissolve more carbonate material present in the soil (ANDREOLI et al., 1979).

III PROFILE OF THE STUDY AREA

3.1 Introduction

Dhaka, the capital of Bangladesh has been chosen as the area for this study. According to the 1981 census the total population of the metropolitan area was 3,458,602 within an area of 145 km^2 (Bangladesh Population Census, 1981, Preliminary Report). The population density is 23,852 per km^2 which is one of the highest in the world. The total number of households is 457,293.

Dhaka is extremely flat with ground elevations ranging from 4 to 9 m above mean sea level. During the monsoon season, over half the

Table 3.1 Rainfall at Dhaka

Year	Month	Rainfall (mm)
1981	July	356
	August	187
	September	320
	October	82
	November	9
	December	35
1982	January	0
	February	15
	March	81
	April	104
	May	154
	June	514

Source: Climatological Division, Bangladesh Meteorological Department.

study area is inundated for extended periods. The rainfall data recorded during the period from July 1981 to June 1982 is presented in Tab. 3.1. The climate is tropical with moderately warm temperatures, high humidity, and high annual rainfall. The lowest temperature occurs in January when overnight lows of 7-10°C are common. The highest temperatures are recorded in April or May when daytime temperature may reach 37-40°C. Daily temperature ranges are on the order of 20°C in winter and 30°C in summer.

3.2 Geologic Overview

Delta building is active in Bangladesh today as a continuing geologic process that commenced many millions of years ago in Pleistocene time. The result has been an accumulation of sediments estimated to be upto 3500 m thick. This great delta, comprising most of

Bangladesh, was formed as a series of smaller deltas accumulating at the mouth of channels. As the channel shifts, another small delta forms, commonly overlapping the previous small deltas. The delta complex gradually fills seaward in the bay, creating a large fan-shaped area.

The delta buildinng process consists of three dipositional sub-environments: (a) bottom off-shore, (b) deltaic near-shore. and (c) flood plain.

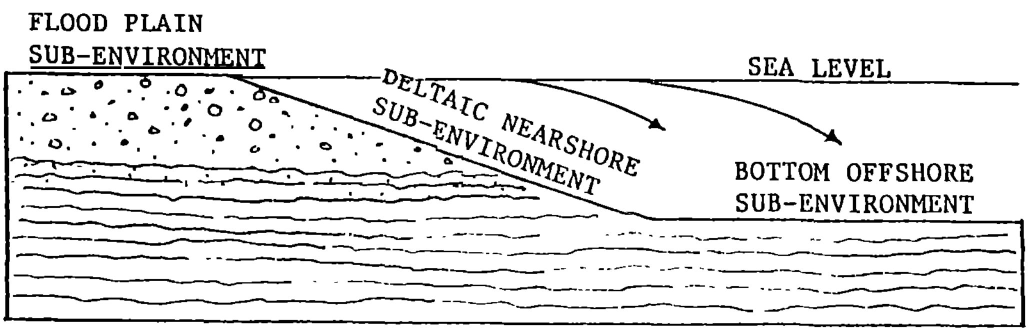


Fig. 3.1 Delta depositional sub-environments

Bottom off-shore sub-environment occurs in standing water of variable depth. Fine sediments, which remain suspended in water for a long period, will ultimately flocculate, settle to the bottom and accumulate there. Silt and clay layers are characteristic of these deposits.

Deltaic near-shore sub-environment occurs in turbulent water condition, where sand and gravel, carried in suspension and as bedload, will drop out when the moving water enters the standing water of the bay and dissipates its energy.

Flood plain sub-environment occurs by the accumulation of the sediments from bottom off-shore and deltaic near-shore, gradually building the delta seaward. Erosion and rediposition of the sediments by the meandering and shifting channel system constantly modify these sediments.

3.3 Hydrogeologic Condition

There is one principle aquifer at Dhaka. The base of this aquifer is at a depth of about 130 to 150 m. Generally this persistent layer becomes somewhat coarser with depth, and contains medium and coarse-grained sand with gravel. The deeper portions tend to be the most productive parts of the aquifer. The sequence of sediments is overlain primarily by clay, silt and fine sand, which is considered flood plain in origin. The thickness of flood plain sediments in Dhaka varies from 6 to 12 m.

The hydrogeologic condition of Dhaka metropolitan area can be

summarized as shown in Tab. 3.2. The best information about this topic is probably the one in the Water Resources Report prepared by RMP/MONTGOMERY in 1981 which states after investigating the well logs from more than 125 WASA production wells at Dhaka that the overlying aquitard in this area is 6 to 9 m thick and in some areas upto 15 m thick. The aquitard in Mirpur is generally found thicker than in the other areas. Typically, the aquitard is described as clay, silt, silty clay, plastic, hard, and at times, sandy, or with sand, particularly fine sand. The sediments comprising the aquitard are variable laterally and vertically, resulting in a range of permiabilities. Vertical permiability and leakage is quite significant in this area. This is probably due to the generally thinner nature of the aquitard and possibly fewer total restrictive layers.

Below the aquitard and upto depths of 30 to 45 m, the aquifer is predominantly fine sand with layers of medium sand and clay. Below, this the prime aquifer is present and is predominantly layered medium and coarse sand, with some layers of fine to medium sand, silty and gravelly layers.

Tab. 3.2 Dhaka hydrogeologic condition

Depth (m)	Sediments	Environment
0-6	Clay, silt, very fine sand	Flood plain
6-60	Firm sand, generally layered	Deltaic near-shore
60-130	Layered medium-coarse sand, gravel, trace fine sand	Deltaic near-shore
130-360	Silt, clay, sand layers	Bottom off-shore
360-450	Fine sand	Bottom off-shore

Source: Draft Final Report on Water Resources in Dhaka metropolitan area (RMP/MONTGOMERY, 1981)

At approximately 135 to 150 m depth, many well logs indicate a persistence silt or clay layer, while others show fine sand, suggesting a general change to finer material. Dhaka WASA wells utilize the aquifer between 60 and 120 m depth.

3.4 Sampling Locations

In order to have an idea about the extent of groundwater pollution, groundwater and soil samples were collected from different areas of the city and then those samples were tested in the laboratory for selected parameters. The sampling locations are shown in Fig. 3.2. Some photographs showing the physical condition of the sampling locations are presented in Appendix E.

3.4.1 Selection Criteria

The sampling locations were chosen on the basis of the water supply and sanitary condition, the living standard of the people, and the general topography of the area. Most of the sites selected are very densely populated and low-lying. The people are in the low to middle income group. Some of the locations are outside the WASA service area, this means these locations do not have any access to the water supply and sanitation facilities as it is available in the other areas.

Two terminologies are used in the following paragraphs in describing the water wells, these are hand-pumped wells and production wells. A "hand-pumped well" is normally drilled upto a depth not more than 30 m and in most of the cases is installed privately in areas which do not have access to the city water distribution network, or as a supplemental source in areas where supply from the distribution network is not adequate. The term "production well" is used here to describe the water production wells of the Water Supply and Sewerage Authority (WASA). These wells are generally more than 90 m deep.

3.4.2 Description of the Locations

(a) Location 1 - Mohakhali

Most of the houses in this area are within the water distribution network of WASA. But there are some areas which have no water or sewer connection as well. The sampling site chosen in this area was a place near a student hostel which houses nearly 200 students of a Paramedical Institute. The sewage from this hostel is being discharged into a nearby septic tank. This hostel has got tap water supply, and it has also got a hand-pumped well for emergency supply which is located at a distance 48 m from the septic tank. The reported depth of the well is around 30 m from the surface.

(b) Location 2 - Kachukhet

This whole area is outside the sewerage network of WASA and very densely populated. Most of the houses are connected with water supply network. But the supply is not continuous, so there are many underground reservoirs at individual households where water is stored during the supply hours and then pumped to the roof-top tanks. The underground reservoirs are made of simple brickwork and in many places the protective cement lining inside the tank is absent. One such reservoir was considered as the intake source for this study. This particular reservoir was found to be in a very unhygienic condition. At the time when first round of sample was collected the inspection hole was found partially covered but later this was corrected by the owner of the plot. Inside inspection of the reservoir showed many cracks on the wall with clear sign of water infiltrating from outside through the cracks. This reservoir is serving as the water storage for about 30 people who use septic tank for disposing their sewage. The septic tank is located only at a distance of 7 m from the reservoir.

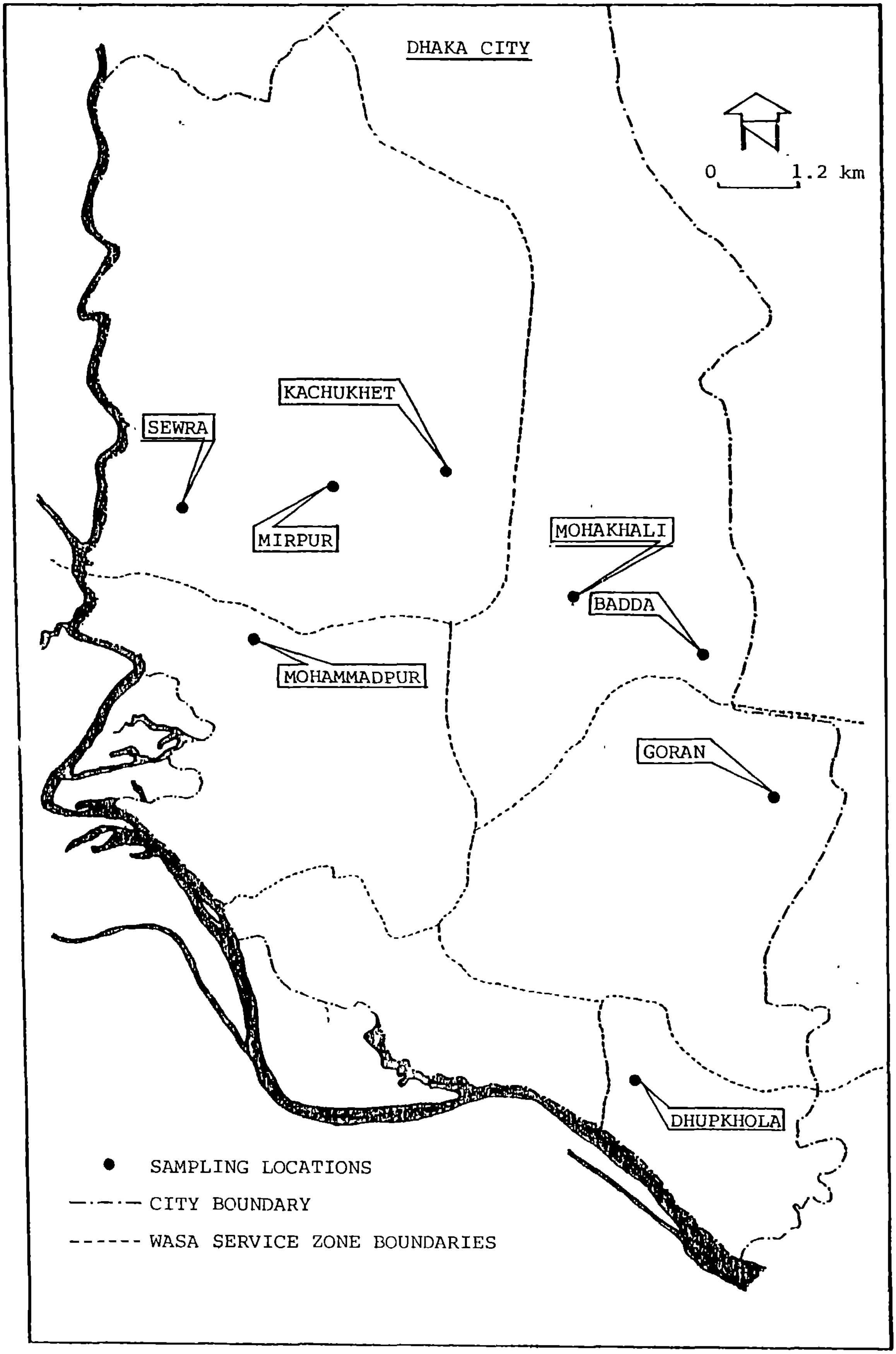


Fig. 3.2 Location of sampling stations

(c) Location 3 - Mirpur

This area is located at the northeastern part of the city with no sewerage system. The water supply network also have not reached the whole area. The sampling site selected is located in a slum area where most of the inhabitants are day labourers. Around 50 persons are residing in this area who use pit latrine for sewage disposal. The drinking water is collected from a nearby public standpost where water is supplied twice-a-day; once in the morning and once in the evening.

(d) Location 4 - Sewra

This is also an unsewered area. People is dependent on on-site sanitation system for sewage disposal. Pit latrines and septic tanks are the most common methods. A pit latrine site was selected as the sampling point which is located at a distance 12 m from the nearest water production well. Apart from this pit latrine there were signs of indiscriminate defecation at a small ditch not far from the production well.

(e) Location 5 - Badda

The boreholes were drilled near a pit latrine which has around 25 users. This entire locality is outside the WASA service area because of some administrative problems. The city authority has a plan to build a satellite town in this area in a near future, so they are not allowing any new house to be constructed in this locality, as such those who have illegally constructed new houses or have been residing there for long time have no access to water or sewer lines, which will be available only after a master plan to develop this area is worked out. The population of this area is well over 5000 (estimated). This vast population are using hand-pumped well for water supply and pit latrines or septic tanks for sewage disposal. The water intake source at the sampling station was only 17 m away from a pit latrine.

(f) Location 6 - Mohammadpur

The sampling site for this area was selected inside a refugee camp for stranded Pakistanis. Hundreds of people are staying here in an area of about 2.5 km^2. There are many pit latrines inside the compound taking care of the sewage in this locality. There are also hand-pumped wells for water supply. Both the pit latrines and the wells are not properly maintained, in addition indiscriminate defecation all around by young children is very common. Diarrhoeal disease is very common among the infants in this area. The boreholes were drilled near two pit latrines which are situated at 28 m distance from the nearest intake well.

(g) Location 7 - Dhupkhola

This area is located in the older part of the city. Though the sewerage system in this area was constructed a long time ago but still the majority of the population are using pit latrine and aqua privy for sewage disposal. There are also many bucket latrines in this area. Boreholes were made near a pit latrine which is serving around 20

persons. Samples were also taken from a production well at a distance 6 m from the pit latrine.

(h) Location 8 - Goran

This is one of the very low-lying areas in the city. The population belongs to the lower medium class. Like in many other locations, the city sewerage system do not serve the whole area. People in such areas are dependent on on-site sanitation. For this study a "katcha latrine" (Section 4.2.3) site was chosen as the sampling station. This particular latrine has 10 users and is located at a distance of 24 m from a hand-pumped well which is the source of water for this locality.

IV REVIEW OF PRESENT STATUS

4.1 Water Supply Status

The city of Dhaka has an extensive water supply system, supplied mainly from groundwater sources. From theoretical point it appears that the water supply system is hydraulically and physically sound with adequate water production, distribution, and storage capacity to meet the needs of the population. But in reality the situation is something different due to various reasons. Interestingly, some small areas which are well within the service area of WASA have no access to this facility; the population in such areas obtains water from communal hand-pumped shallow wells and raw surface sources.

Tab. 4.1 Status of the water supply system of WASA as of March 1986

1. Tubewells in Operation		114
2. Water Production		
Tubewells	4.25 m^3/s	
Surface Water	0.26 m^3/s	
Total		4.51 m^3/s
3. Water Mains		992 km
4. House Connections		89,828
5. Public Standpost		954
6. Overhead Reservoirs		30
7. Surface Water Treatment Plant		1

Source: Monthly Management Information Report, March 1986 Planning and Evaluation Cell, WASA Dhaka.

4.1.1 Groundwater Occurrence and Movement

Accumulation of sediments in the deltaic depositional environment has resulted in an extensive aquifer system overlain by variable thickness of silt, sand and clay sediments. Naturally occurring high static water levels in the low elevation flat lands have resulted in both locally confined, and leaky aquifer condition.

Continuous groundwater withdrawl in the past has reduced groundwater levels in the metropolitan area to elevation below local confining layer. Groundwater extraction for municipal purpose in the city area and irrigation in the surrounding country-side have imposed a depression in the natural piezometric surface. As a result, the historic or virgin direction of groundwater movement has been modified. The static water level in some of WASA wells recorded once in a month from July to December 1984 is shown in Tab. 4.2.

The principal source of groundwater is the percolation of abundant rainfall which occurs each year during the monsoon months of

April to September. The precipitation enters the aquifers by vertical seepage through the overlying confining layer and the extensive river system. Recent studies indicate that fairly direct vertical recharge is occurring in the study area.

Tab. 4.2 Static water level in some WASA wells (the elevations are in meters with respect to mean sea level)

Wells	Jyl 84	Aug 84	Sept 84	Oct 84	Nov 84	Dec 84
Mirpur II	-2.1	-1.9	-1.7	-2.4	-2.8	-2.7
Mirpur XII	+0.3	+0.6	+1.0	-0.3	-0.8	-1.0
Bangla Col.	+0.1	+0.4	+0.8	+0.4	+0.3	+0.1
Laleswarai	-3.3	-3.2	-3.3	-4.1	-4.3	-4.4
Hazaribagh	-1.9	-1.6	-1.4	-1.7	-2.0	-2.5
Gulshan V	-1.5	-1.1	-1.2	-1.9	-3.2	-3.6
Saidabad II	-5.6	-5.4	-6.4	-6.9	-7.3	-7.9
Nawabpur	-4.8	-4.4	-5.4	-6.5	-6.7	-7.0
I.G. Bagan	-2.6	-2.4	-2.7	-2.9	-3.6	-3.5
Nawabganj	-2.4	-2.2	-2.2	-2.6	-3.9	-4.1

Source: Draft Final Report on Water Resources in Dhaka metropolitan area (RMP/MONTGOMERY, 1981)

Aquifer tests carried out by WASA and other organizations suggest that the confining layer in the metropolitan Dhaka has vertical permiabilities ranging from 0.60 to 0.08 m^3/m^2-d under a uniform gradient. The confining layer is generally 6 to 12 meter thick, with some areas upto 15 meter thick.

Report by PARSONS (1979) indicate that the groundwater in Dhaka has been derived from (i) vertical seepage through the overlying confining layer, (ii) horizontal recharge from the regional aquifer, and (iii) changes in storage with the overlying aquitard and aquifer.

4.1.2 Water Well Conditions

(a) WASA Wells:

Dhaka WASA began installing water wells in 1949. For the next 10 years they installed an average of one well per year. Since 1959, WASA has been installing wells at an average rate of 3.25 wells per year. The design history of WASA wells over the past 35 years has developed in response to gradually increasing municipal demand for the easily obtained groundwater and the increasing stress on the aquifer supplying the groundwater. A summary on the depths of wells, pump chambers, and screens yearwise are presented in a tabular form (Tab. 4.3).

(b) Privately Owned Wells:

This include both deep wells and shallow wells. The

characteristics of deep wells are almost the same as that of WASA wells. Such wells are quite large in number (exact figure is not available) and are scattered throughout the metropolitan area, e.g. Cantonment, Dhaka Medical College Campus, Road Research Laboratory Compound etc.

Tab. 4.3 Summary of Dhaka WASA well installations (RMP/MONTGOMERY 1981)

Period	Well Depth (m)	Pump Chamber Dia (mm)	Pump Chamber Depth (m)	Screen Length (m)	Screen Material	Specific Cap. (l/s/m)
1949-59	65-105	300	18-20	20-30	Brass	5
1959-69	70-135	350	27-34	30-45	Brass	6
1969-74	100-140	400	37	50	Stainless Steel	6
1974-present	120-150	400	43	50	Stainless Steel	5

In addition to the deep wells there are numerous shallow wells serving as water source for quite a substantial number of residents in the city, specially in the areas which have not been served by WASA. One such locality is Badda. The citizens of this area are entirely dependent on hand-pumped shallow wells for their water supply. These wells are generally 15 to 30 m deep, operated manually. The well sites are not properly maintained, even in most cases they are constructed very close to pit latrines or other kind of sewage disposal sites. Notable among other areas having shallow wells for water supply are the two refugee camps - one at Mohammadpur and the other at Mirpur, some part of Kachukhet, Sewra, Mohakhali, and old part of the city.

4.1.3 Groundwater Quality

The expanded use of groundwater for water supply is significantly affected by the quality of the raw water produced. Available data indicate that groundwater in the Dhaka metropolitan area has generally met drinking water standards established by Bangladesh Water Pollution Control Board as shown in Tab. 4.4 except for the microbiological part. Tab. 4.5 presents the results of an area-wide reconnaissance survey completed in May 1980 by RMP/MONTGOMERY for Water Resources Report. As shown on Tab. 4.5, groundwater samples obtained during May 13-14, 1980 run contained significant numbers of coliforms. These bacteria are presumed to originate from domestic or municipal sewage effluents which have locally degraded groundwater supplies (RMP/MONTGOMERY, 1980). The report further suggested that treatment to reduce or eliminate bacterial concentration is absolutely essential before the water is suitable for drinking water sources, and unless precludes further groundwater exploitation. It also mentioned that nitrate and bacterial concentrations in groundwater should be monitored continuously because of the high potential for contamination by the percolation of domestic and municipal wastewaters.

Data about the quality of groundwater from 105 production wells of WASA are shown in Tab. B.5 (Appendix B). The samples were collected and tested in September 1985. This water quality survey is carried out by WASA once in every year as a routine program.

Tab. 4.4 Bangladesh drinking water standards

Parameter	Unit	Allowable Level
Turbidity	NTU	25
Color	Std. Unit	30
Odor		unobjectionable
Total Dissolved Solids	mg/l	1500
Chloride	mg/l	600
Iron	mg/l	1
Manganese	mg/l	0.5
Zinc	mg/l	15
Copper	mg/l	1.5
Sulfate	mg/l	400
pH		6.5 - 9.2
Total Hardness (as $CaCO_3$)	mg/l	250
Fluoride	mg/l	1
Nitrate	mg/l	45
Phenols		0.002
Cyanide	mg/l	0.2
Hexavalent Chromium	mg/l	0.05
Lead	mg/l	0.05
Cadmium	mg/l	0.01
E. Coli	nos./100 ml	nil

Tab. 4.5 Groundwater quality survey results (RMP/MONTGOMERY 1981)

Groundwater Samples (May 13-14, 1980)

Sampling Well	Conductivity µ-S/cm	pH	Turbidity NTU	Nitrate-N mg/l	Iron mg/l	Chloride mg/l	Coliforms nos./100 ml
Mirpur II	159	6.2	0.21	0.35	0.13	8.0	1300
Asad Gate	155	6.6	0.09	1.30	0.28	15.0	930
Mohakhali	227	6.7	0.14	1.40	0.22	10.0	890
Khilgaon	229	6.9	1.80	0.22	1.20	12.0	310
Fakirapool	308	7.0	0.28	2.30	0.24	21.0	180
Hazaribagh	495	6.7	0.87	4.10	0.31	42.0	0
Joydevpur	411	7.2	0.38	<0.05	0.02	7.0	1600
Millbarrack	217	6.8	0.18	<0.05	0.25	12.0	310

The conclusion that can be arrived at with this data is that the groundwater available in the area is slightly acidic with average hardness around 115 mg/l. The chloride content was found to be as high as 175 mg/l in few cases indicating the chances of pollution by fecal matters and it might also contain high concentration of nitrate due to this reason. The average electrical conductivity was over 270µ-S/cm. The electrical conductivity is sometimes considered as an indirect method of determining the concentration of Total Dissolved Solids (TDS). So the groundwater of Dhaka is expected to have high TDS meaning the presence of varieties of chemicals in dissolved form.

4.2 Private and Municipal Sanitation Systems

Dhaka WASA maintains a piped sewerage system which serves a smaller percentage of the total city population. City residents who do not have access to public waterborne sewerage facilities rely on several alternative sanitation systems (Tab. 4.7). Some of these were widely used and some, such as the Vietnamese composting privy, are used on a small scale.

4.2.1 Septic Tanks

Septic tanks are used for wastewater disposal in some parts of the Dhaka metropolitan area, particularly in the more affluent sections of Dhanmondi, Banani, and Gulshan.

Because septic tank receives all liquid wastes from a household, they offer a level of service more comparable to conventional sewers than other on-site sanitation systems. Therefore, septic tanks are attractive in less densely populated areas with houses on large plots having permeable soils and no flooding. In Gulshan, septic tank system have been used successfully, due in part to the relatively high soil permiability and large plot sizes in the area. In areas having less permeable soil. existing septic tank systems frequently overflow from the seepage pit or leach on the field at the surrounding ground surface. The exact number of septic tanks now in operation is not available. But it can be reasonably estimated that about 63 percent of households in Dhaka city uses this method (Tab. 4.6).

4.2.2 Pit Latrines

Thousands of pit latrines have introduced in Bangladesh during the past several years through the efforts of the Department of Public Health Engineering (DPHE) and various international assistance agencies. These latrines are principally used in rural village areas where these have been well accepted by the people.

Several type of pit latrines are presently in use in the Dhaka area. The simplest type consists of a circular pit dug in the ground and covered by a concrete slab with a whole for direct discharge of excreta into the pit. A modification of the simple pit latrine provides ventilation to the pit in order to reduce odors and fly breeding. A more common modification, promoted extensively by the DPHE, uses a simple pour/flush water seal to eliminate odor and fly problems (HUSSAIN, 1980). The water-seal latrine may be located directly over a pit, or it may be offset several feet so that excreta and flushing water flow through a small pipe to one or two pits. In the study area, perforated concrete rings generally used to line the pits to prevent the sides from caving in.

Within the study area, pit latrines of both the simple and water-seal types that have been in operation longer than one or two years were observed to have overflowed because of the build up of solid matters. The most extreme case observed was in the Jurain area, where a

simple pit latrine was desludged monthly during the monsoon season and bimonthly during the dry season to prevent it from overflowing (RMP/MONTGOMERY, 1981). The failure of pit latrines in the Dhaka area is due to clogging of the surrounding soil, which prevents the seepage of liquid out of the pit. In the study area, most soils are fine-textured, tending to encourage rapid clogging. A related problem occurs during the monsoon season, when surface soils may be saturated with water, particularly in low-lying areas only a few feet may seep into the pit from the surrounding soil, thus reducing the effective volume of the pit. A survey of the pit latrines in one area reported that 20 percent were not in use, and 30 percent of the remainder were not operating satisfactorily.

Tab. 4.6 House-wise survey on water and sewer connection in Dhaka

Survey conducted from 1 to 23 August 1984.

Area	Number of Houses Surveyed	Water Supply		Sewage Disposal		
		WASA Supply	Own Supply	Katcha Latrine	Septic Tank	WASA Sewer
Badda	110	0	110	21	89	0
Baridhara	9	0	9	9	0	0
Dhanmondi	21	21	0	0	21	0
Dhania	11	1	10	5	6	0
Goran	117	115	2	57	60	0
Ibrahimpur	27	11	16	3	1	23
Islambagh	61	54	7	37	34	0
Jatrabari	128	98	30	33	95	0
Jigatola	65	60	5	18	47	0
Kafrul	15	11	4	4	11	0
Madartek	65	44	21	35	28	4
Mirpur	124	88	36	22	102	0
Moghbàzar	50	50	0	18	32	0
Mohakhali	43	37	6	18	25	0
Mohammadpur	29	29	0	0	29	0
Nakhalpara	6	6	0	0	6	0
Pallabi	70	61	9	26	44	0
Rahmatganj	17	4	13	11	6	0
Rampura	15	14	1	7	8	0
Shajahanpur	25	25	0	8	17	0
Shajadpur	31	0	31	31	0	0
Tejgaon	30	30	0	9	21	0
Total	1069	759	310	372	672	27

Source: Report on house-wise survey on water and sewer connections, Planning and Design (Sewerage) Division, WASA

4.2.3 Bucket Latrines

It has been estimated that nightsoil collection with bucket latrines is used by 12 percent of Dhaka population for excreta disposal (HUSSAIN, 1980). Nightsoil collection is also used in surrounding areas such as Narayanganj. This system, described by Hussain as the invention of "some evil genius," involves the direct discharge of excreta into a bucket or small container that is then emptied. In general, bucket latrine systems have not been found to provide excreta disposal in a sanitary manner because of the danger of contamination during transport and disposal of the nightsoil and because of the difficulty of cleaning the buckets effectively.

4.2.4 Katcha Latrines

The "katcha" latrine consists of a temporary structure of bamboo posts and sack-cloth to provide privacy, both bamboo logs to support the user and separate him from the discharged excreta. Katcha latrines are common in low-lying areas around Dhaka, where excreta are directly discharged into surrounding canals. The ground surface or small pits may also serve as the disposal area. An estimated 20 percent of the city population uses some form of katcha latrine.

Katcha latrines have also been widely used as a temporary sanitation method in unauthorized hutments. However, the katcha latrines used at present in the study area do not generally provide an effective barrier to contamination by excreta.

4.2.5 Public Toilets

Public latrine facilities are used in various places within the study area. Some of the facilities have deteriorated into extremely unsanitary conditions and are not well accepted by the general public. In contrast, a number of emergency public toilets have been installed successfully by international volunteer organizations (OXFAM and CONCERN) the resettlement camps at Mirpur, Tongi, and Demra. These facilities provide simple stalls for defecation and water for ablution; the wastes are treated in temporary treatment units and then discharged to a nearby waterway. The success of these units appears to be due to the provision of a full-time attendant who cleans and maintains the facility and ensures proper flushing of the stalls. Although the discharge of partially treated wastewater to surface drainage ditches is a potential sanitary hazard, the units at the resettlement camps represent a significant improvement in providing excreta disposal as a temporary measure.

4.2.6 Vietnamese Double-vault Composting Previes

Within the study area, composting previes have been used only on a very small scale as part of experimental programs, such as at the People's Health Center in Savar and the resettlement camp at Duttapara. The type they have been using is known as the Vietnamese Double-vault.

On the present small scale, the Vietnamese double-vault appears to be successful, inasmuch as existing units are used and maintained properly. Their use is restricted to areas where kitchen ash and organic mulch material are readily obtainable and where the composted material is easily disposed off. One household in Duttapara reported having to obtain kitchen ash from neighbors to meet the needs of the composting privy.

4.2.7 Waste Disposal on Open Areas

This is very common in the areas where the people are in the low income category, Use of open areas for human waste disposal constitute the most serious threat to both surface and groundwater as well as it creates nuisance in the surrounding neighborhood. In one study it was found that about 25 percent of people from the low income groups in Mirpur area use open areas for human waste disposal. Approximately 75 percent people in the same area use some form of facility which is mainly open pits, and 80 percent of these are used under some shared arrangement (STEARNS, 1986).

4.3 Incidence of Waterborne Diseases

It is extremely difficult to identify the source of various diarrhoeal and dysentery-type disorders, but bad water supply and the unsanitary handling of food and utensils are often the predominant causes. Some statistics are available on possible waterborne diseases in Dhaka through International Center for Diarrhoeal Disease Research (ICDDR) hospital, however, the statistics cover only those infected persons that have visited the facility. The number of unreported cases may be higher than this number. Tab. 4.7 details the visits, and deaths

Tab. 4.7 Visits and deaths in ICDDR hospital in Dhaka.

	1983	1984	1985
Number of diagnosed cases			
Diarrhoea	56,116	51,688	43,175
Dysentery	11,815	18,056	11,539
Others	3,179	4,086	2,636
Total visits	71,650	73,850	57,350
Number of deaths (attributed to)			
Diarrhoea	249	211	123
Dysentery	73	77	72
Others	176	214	158
Total deaths	496	502	353

experienced at the hospital over the past three years. Tab. 4.8 summarizes the number of visits on a monthly basis during 1985 when the city had a mild epidemic of diarrhoeal diseases including cholera.

The overall national health statistics estimates that young suffer disproportionately from diseases, especially those suspected of waterborne origins. Sever dysentery is the major cause of death in young children. Estimates of infant mortality for live births are 150 per 1000. Based on the mortality statistics for cholera, typhoid, diarrhoea, and dysentery compiled at the ICDDR hospital in Dhaka, the average person in Dhaka has one chance in thirty of dying of these maladies during his life time. This is based only on those deaths known to the ICDDR facility. In adults, the debilitating effects of these diseases impact their productivity, physical well-being, and financial status.

Month-wise distribution of visits by persons infected by diarrhoea and dysentery over the last three years is shown in Fig. 4.1. As is seen from the graph the number of patients is comparatively high during the months of March, April, and May. This coincides with the beginning of the rainy season. Possibly desorption of the bacteria and viruses from the soil due to the flushing effect by heavy down pour allows them (the pathogens) to contaminate the water sources.

Tab. 4.8 Patient diagnosis and mortality in 1985 in ICDDR hospital, Dhaka

Month	Total Visits	Visits			Deaths			Total Deaths
		Diarrhoea	Dysentery	Others	Diarrhoea	Dysentery	Others	
January	3750	2888	694	168	10	4	8	22
February	2925	2341	466	118	7	0	9	16
March	5650	4552	723	375	12	3	20	35
April	7325	5803	1197	325	23	7	23	53
May	6225	4592	1372	271	13	9	21	43
June	4950	3680	1057	213	8	5	17	30
July	4150	2848	1118	184	7	3	11	21
August	3925	2934	8238	168	6	8	11	25
September	3950	2793	9408	217	6	7	6	19
October	4050	2775	1035	240	7	8	12	27
November	4800	3565	1093	142	5	8	8	21
December	5650	4404	1031	215	19	10	12	41
Total	57350	43175	11539	2636	123	72	158	353

Cholera is an ideal indicator of pollution and related to waterborne diseases because the ailment is readily identifiable. The geographic locations around Dhaka, where cholera victims lived during the period as shown in Tab. 4.8, could be related to sever water pollution; deaths attributed to cholera during this period was 3.4 percent of the total deaths due to various types of waterborne diseases. Rate for cholera was higher than average during 1985 in Dhaka, and outbreaks in other areas of Bangladesh suggest this was a widespread phenomenon.

Shigellosis continued to be epidemic in Bangladesh with high fatality rate among children (GLIMPSE, 1986). Specially worrisome is the acquisition by the epidemic strain to stand against nearly all clinically useful antibiotics. Shigellae are much more dangerous than

cholera. Among the diarrhoea producing organisms they are by far the biggest cause of malnutrition and death in Dhaka. In many other developing countries, the shigallae are the major cause of deadly epidemics, for instance, in 1984, shigellosis killed thousands in India's West Bengal state adjacent to Bangladesh.

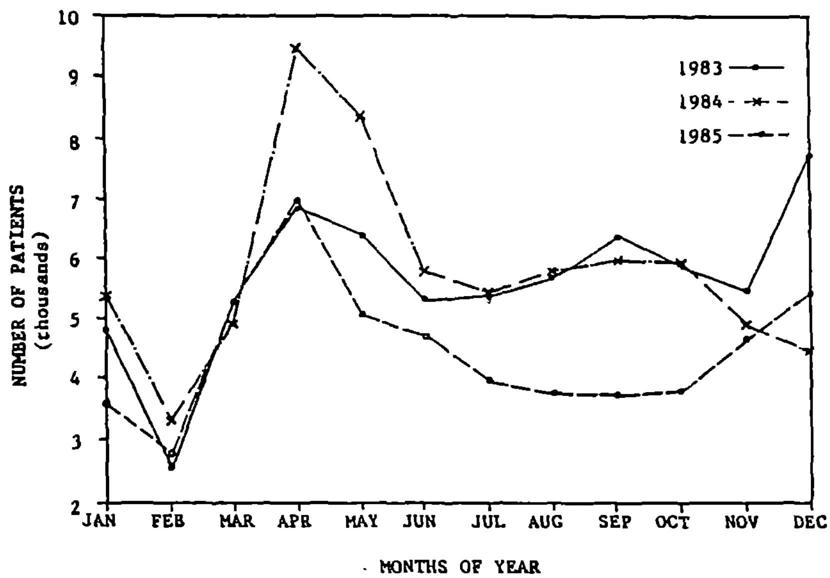


Fig. 4.1 Month-wise distribution of diarrhoea patients visited ICDDR hospital in Dhaka

Among the other waterborne diseases, infectious hepatitis, poliomyalitis, amoebiasis, typhoid, and paratyphoid frequently outbreaks in the study area (RMP/MONTGOMERY, 1981). No data could be found on the number of infected persons or the mortality due to those diseases. It can be conservatively assumed that the number of affected persons and the mortality rate due to these diseases as the same as that mentioned for cholera and other diarrhoeal diseases.

4.3.1 Protection and Prevention

The hospital and clinical facilities in Dhaka and nationwide are inadequate to provide even minimal medical assistance, and many years may pass before adequate facilities are available. The reduction of disease through safe water supply and sanitary waste disposal would relieve some of the pressures for expanded medical facilities.

KHAN (1981) investigated the effect of use of covered latrines and the source of water supply in the incidence of cholera. All cholera cases from three different refugee camps were recorded as shown in Tab. 4.9. The major differences in the camps were the presence of piped water supply and sewer connected latrine in Geneva Camp; and hand-pumped tubewells , ponds and pit latrines at the other two. In the camp with sanitation facilities (camp A), the rate of cholera was 1.61/1000. In the two camps (camp B and C) without such facilities, the rate were 3.95 and 4.29/1000 respectively. These rates were half during the following year in the same areas after the camps were removed.

Tab. 4.9 Hospitalisation rates of cholera cases from three refugee camps in Dhaka in 1974 (KHAN 1981)

Camp	Sanitation Facility	Population	Cholera Cases	Cholera Rate/1000
A. Geneva	Sewer line	49675	80	1.61
B. Kamalapur	Pit latrine	11375	45	3.95
C. Kataban	Pit latrine	12112	52	4.29

Tab. 4.10 Secondary infection rate (per 100 contact) of Shigellae spp. by water sources and places of defecation (KHAN and SHAHIDULLAH, 1980)

	Shig. Dysenteriae Type 1	Shigella Flexnari
A. Water source		
Dug well	28.2	23.8
Tap Water	12.0	17.7
B. Place of defecation		
Open latrine	23.5	21.4
Closed latrine	12.9	20.0

KHAN and SHAHIDULLAH (1980) demonstrated the pattern of association of water used either from dug wells or tap supply; and the use of closed versus open latrines by the members of the affected families; with the spread of shigellosis as shown in Tab. 4.10. Families infected with Shigella dysenteriae type 1 who used water from both open and closed sources had a secondary infection rate of 28.2 percent as compared to 12.0 percent among users of closed water sources. The families infected with Shigella flexnari, the users of water from mixed sources had a higher rate when compared to users of water from closed sources. Again, those who used open latrines had a higher attack rate than users of closed latrines.

V METHODOLOGY

The field investigation for this study was carried out in two ways, namely, data collection and experimental investigation.

5.1 Data Collection

Data which could be related directly with the topic under discussion are very scarce. But quite a plentiful data are available on the individual aspects, such as geology, hydrology, well conditions, sanitation, public health etc. of the study area. Such data were collected mainly from the reports prepared by by various government offices, and were presented while discussing the present status of water supply, sanitation, and public health in the study area, in the preceeding chapter.

5.2 Laboratory Analysis of Samples

This included experiments at the field level of groundwater and soil samples for detecting the presence of pollutants there. A total of eight sampling stations were established for monitoring the groundwater quality over a period of one and half month. It is to be mentioned here that the results of these experiments reflect only the conditions of the site from where the sample was collected. The results could be used as proofs that the groundwater resources at the study area are at a high risk and, as it will be discussed later, the results of the experiments call for a comprehensive study to assess the risk of spread of pollutions from on-site sanitation practices in particular, for formulating a guideline to save and protect the health and well-being of the citizens.

5.3 Sampling Techniques

At each location, one on-site sanitation site was selected as the sampling station. Two boreholes, one at 5 m distance and another at 10 m distance from the disposal site, were drilled at each station. Groundwater sample were collected from 1 m, 2 m, and 3 m depth from each borehole and the soil from the surface of the boreholes were also collected for analysis. In addition, water samples were also collected from the intake sources such as deep and shallow wells, and temporary under ground reservoirs nearest to the sampling locations.

Each borehole was 12 cm in diameter, and were drilled by a hand-driven auger. After drilling each meter of depth the drilling was stopped for some time to allow water to rise. A suction machine was used to pump out the initially rising water in order to have a representative sample of that depth. A 500 cm^3 sampling bottle, wrapped at its mouth with nylon net to prevent entrance of lumps of soils from the sides of the borehole, was placed in the hole and let it fill with water. About

1000 cm^3 of samples was collected from each depth.

Samples were collected from eight boreholes at four locations each week. The sampling dates of each location are shown in Tab. 5.1. Samples were collected thrice from each borehole during the sampling period at a regular interval. Sampling at Mohakhali and Kachukhet stations only was carried out for the fourth time. Some illustrations showing the sample collection procedure and the physical condition of the locations are presented in Appendix E.

Tab. 5.1 Sample collection schedule

Sampling Station	First Sampling	Second Sampling	Third Sampling	Fourth Sampling
Mohakhali Kachukhet	Oct. 19	Nov. 2	Nov. 16	Nov. 30
Mirpur Sewra	Oct. 22	Nov. 5	Nov. 19	
Badda Mohammadpur	Oct. 26	Nov. 9	Nov. 23	
Dhupkhola Goran	Oct. 29	Nov. 12	Nov. 26	

5.4 Analytical Techniques

The sample collected from the field were analyzed in the laboratory for various physical, chemical, and microbiological parameters.

5.4.1 Physical Parameters

The physical parameters monitored during the sampling period were temperature, turbidity, and electrical conductivity, and for the measurement of their values normal laboratory instruments such as thermometer, Hach turbidimeter, and conductivity meter was used.

5.4.2 Chemical Parameters

(a) pH

The pH was measured at the laboratory within an hour after the sample was collected. A pH meter was used for this purpose.

(b) Total Hardness

The total hardness of each sample was found out using the EDTA titrimetric approach as described in the "Standard Methods." The unit of expression is mg/l as $CaCO_3$.

(c) Nitrate-Nitrogen

The method used for determining the nitrate-N concentration was Sodium Salicylate Colorimetric method (RENEAU, 1978). This method of NO_3-N determination is quite new in which 10 ml of sample was mixed with 1 ml of 0.5% sodium salicylate solution and then allowed to dry at a constant temperature of 105°C. The dried sample was cooled down before adding 1 ml of concentrated H_2SO_4. The dried pellet has to go completely in solution at this stage, and then 8 ml of deionized water was added to this solution. After the solution has cooled down, 7 ml of 30% NaOH solution was added and the whole solution was transferred to a 25 ml volumetric flask. Finally the flask was filled with 2.5% NaOH solution upto the mark. The absorbance was measured by a photometer at 420 nm. Standard curves was used to find the concentration corresponding to the absorbance of a particular sample. The results are reported in mg-N/l. This method is suitable for measuring very low concentrations and is not affected by the presence of iron or chlorine.

5.4.3 Microbiological Parameters

(a) Fecal Coliform

Membrane filter technique was adopted for determining the number of fecal coliforms present in the sample. The presence of fecal coliforms indicate that fecal contamination of water has occurred, so pathogens may also be present.

The procedure described in the "Standard Methods" has been followed except that instead of using absorbent pad 20 ml of M-Fc broth with 1.5% bacto-agar has been used as the media. The results are expressed as nos./100 ml of sample.

(b) Bacteriophage

The analysis for bacteriophage was done using Plate Count technique which is almost similar to MPN method used for bacterial analysis. <u>E. Coli B</u> (Israel strain) was used as the host cell for phage assay. The host cell culture was prepared in the following way : 10-12 ml of McConkey agar was poured on a petri dish, when the agar has solidified after approximately 30 minutes the host cell was added to the media by wire loop and incubated at 37°C overnight. The young <u>E. Coli B</u> was then inoculated in phage broth and incubated at 37°C for 3-4 hours before using it with the sample. The phage broth consisted of 0.8% nutrient broth, 0.5% NaCl, 0.02% $MgSO_4(7H_2O)$, 0.005% $MnSO_4$ $(4H_2O)$, and 0.15% glucose. The pH was kept to 7.2. The phage agar and top agar consisted of the same constituents as phage broth except additional 0.6% and 1.1% bacto-agar respectively.

The phage broth was inoculated with 0.3-0.4 ml of young E. Coli B, 0.2-0.3 ml $CaCl_2$ (sterilized 0.1 M $CaCl_2,2H_2O$) solution, and 1.0 ml of diluted or undiluted sample, mixed thoroughly and incubated at 37°C for 24 hours. Three tubes were inoculated per dilution. For diluting the sample phage broth was used. After incubation the sample from each tube was transferred to a petri dish overlaid by melted top agar. Haemotocrite tubes were used for delivering the sample from the test tube to the plate. After incubating again for 24 hours at 37°C the number of clear zones were recorded and the MPN table was used to find the corresponding value indicating the number of bacteriophages present in 100 ml sample.

5.4.4 Soil Analysis

The grain size distribution of the soil collected from each borehole was found out by hydrometer analysis method. The average size of the soil grains at each borehole was calculated from the grain size distribution curves (Appendix C). The soil from each borehole was analyzed for grain size distribution in order to find out the average size of the soil grains. In addition, soil at each borehole is also classified by their physical appearance.

5.5 Groundwater Level Observation

The groundwater level at each borehole during the time of sampling was also recorded. For this purpose a chalked steel tape was lowered some distance into the water; the depth of water table was then calculated from the total length minus the wetted length.

5.6 Data Compilation

The raw data from the experiments were entered in tables as shown in Appendix A. These data were then rearranged several times to suit the application of various statistical procedures. One such arrangement is shown in Appendix B, this particular arrangement was made in order to find out the pattern of change in concentration of selected parameters with depth and distance.

VI RESULTS AND DISCUSSION

6.1 Occurrence of Groundwater Contamination

Pollutants of fecal origin have been detected in almost all the groundwater and soil samples analysed with varied concentrations depending on the distance of the sampling points from the on-site sanitation schemes and the depth below the surface. Figures in Appendix D show concentrations of NO_3-N, fecal coliform, and bacteriophage found at different locations during the sampling time. The presence of these three parameters in the samples can be attributed to the poorly managed sanitation system and their faulty construction disregarding the local soil condition. The figures in Appendix D also indicates that the concentration did not change significantly with time, as well as some relationship between the concentration, and the depth and distance from where the samples were collected. The concentrations in the samples collected from water intake sources (e.g. deep and hand-pumped wells, underground reservoirs etc.), located at various distances from the nearest on-site sanitation facility at each location was also found significantly high, specially in the numbers of fecal coliforms present. Quite large numbers of coliforms were also detected in the samples collected from a groundwater source as deep as 113 m. WASA statistics on groundwater quality also indicates their presence in many of their production wells (Tab. 4.5). The effect of each individual parameter on groundwater contamination are being studied in greater detail in the following sub-sections. Attempt has also been made to identify their sources, and the role of these sources in nurturing and spreading the pollutants from on-site sanitation schemes in the study area.

6.1.1 Temperature and pH

During the sampling period the groundwater temperature lied in the range between 25.8 to 27.9°C. It has already been established that temperature has a great influence on the survival of pathogenic microorganisms. The experimental results validate this influence. It is a general belief that higher temperature gives shorter survival time for enteric microorganisms. Average groundwater temperature during the sampling period was 26.7°C which is sufficiently high to kill most of the enteric organisms within a very short period. The presence of fecal coliform in considerably high concentration even at such condition clearly demonstrates the potentiality of the nearby on-site sanitation schemes in contaminating the groundwater, because such schemes are possibly acting as the source of nutrients and energy (substrate) for the whole bacterial population in enough quantities which is giving them better survival capability and increased growth rate offsetting the effect of temperature.

The pH value has an important role in nitrification and pathogen survival. It has been reported that a pH range of 6 to 8 is favorable for nitrification to proceed smoothly (ALEXANDER, 1965). The pH value of the groundwater samples ranged between 5.7 and 7.5. In most

cases the value was below 6.8. The high nitrate concentration in groundwater could be attributed to this favorable pH range.

The low pH range may also be the cause of greater concentration of bacteriophage in the soil samples than in the groundwater samples from the boreholes, because at a lower pH condition the virus particles become more positively charged and then it can be easily adsorbed by the fine grains of soil.

6.1.2 Turbidity and Electrical Conductivity

The turbidity of groundwater samples from boreholes was found to be higher than those from intake sources (Appendix A). The high turbidity in groundwater samples could be related with the presence of increased amount of fecal coliforms which might be one of the components of the suspension.

High electrical conductivity of the groundwater samples both from boreholes and intake sources indicate the presence of higher concentration of total dissolved solids.

6.1.3 Hardness

Analysis of the available data (Appendix B) on WASA production well water quality gave an average value of 115 mg/l for hardness; the lowest and highest values being 31 and 249 mg/l respectively. Out of a total of 105 samples; 52 had values higher than 100 mg/l. The Dhaka groundwater can be classified as moderately hard. High chloride concentration in the production wells (Appendix B) is an indication that the chloride salts are also contributing to the total hardness of groundwater in study area. It was found during the experiments that most of the groundwater samples have high electrical conductivity; high conductivity means more solids in water in dissolved form, and in this case the predominant metals might be ferrous or manganous which imparts hardness like carbonates and bicarbonates. The ability to dissolve is gained in the soil where carbon dioxide is released by bacterial action makes the water highly charged as evidenced by high conductivity values, and at such condition basic metallic ions can be easily dissolved. The bacteria, which may also contain some pathogens, might have its source at the sanitation sites.

6.1.4 Nitrate-N

Significant concentrations of NO_3-N was detected in all groundwater and soil samples. Nitrate concentration was found to be higher on the surface than at depths below the surface. This finding suggests that the nitrification process could be taking place on the surface where all NH_4-N are being converted to NO_3-N. Below the surface, denitrification process is converting the nitrate to its original form; thereby reducing the overall nitrate concentration in the groundwater. But the existing data (Tab. 4.5) on the well water quality indicates presence of nitrate even at a considerable depth below the surface. This

may be attributed to the leaky condition of the upper confining layer which does not allow complete denitrification of all the nitrate and at the same time the group of bacteria which are responsible for denitrification may not be present in sufficient numbers to convert all nitrate, so it is very likely that the excess amount of nitrate can easily move to a considerable depth with the groundwater.

The tables containing the results of experiments (Appendix A) indicate clearly that in most of the cases when an increase in nitrate concentration was observed it was associated with an increased value of hardness. This may also have been caused by the process of nitrification which produces hydrogen ions that are able to dissolve more carbonate material in the soil.

No major agricultural lands are there in the study area where fertilizers are being used, which is supposed to be one of the major sources of nitrate in soil water, hence in this case, excess nitrate concentration clearly indicates that it is drawn from sanitation sources. Least of this part being derived from leaky sewers and waste treatment lagoons, the major part being derived from the on-site sanitation schemes. Though the concentration in most of the cases was below the WHO recommended level of 22 mg-N/l yet continuous monitoring is necessary to prevent any build-up in concentration in future. US EPA recommends a NO_3 concentration of 10 mg-N/l as the safe limit for the public water supplies.

6.1.5 Fecal Coliform

Fecal coliform is considered as an ideal indicator of fecal contamination, have been found to exist even in well waters drawn from depths of more than 100 m (Tab. 4.5) in the study area. Samples from both the boreholes; one being at 5 m distance and the other at 10 m distance from the on-site sanitation scheme at the sampling locations contained significantly large number of fecal coliforms. The early researchers have set a general safe distance of 7.5 m between a septic tank and an intake source. But the experiments showed that fecal coliforms are present in quite large numbers even at a distance of 10 m from the septic tanks and a depth of 3 m below the surface. This may be attributed to the improper maintenance and operation of the septic tanks or pit latrines, and also to the practice of waste disposal in open spaces which is very common in the study area; apart from other natural causes, e.g. soil condition, high groundwater level etc.

The results of the experiments indicated that the concentration of fecal coliforms have a decreasing tendency with depth, and the concentration on the surface in most of the cases was higher. As the wastewater moves downward, the bacteria is removed from the liquid phase by filtration, but the removal efficiency of the soil was found to be very less than it can be expected from this type of soil. This relatively large value may be due to the soil condition below the surface which possibly favors the regrowth of bacteria, and at the same time, less competition for nutrients at depths below the surface may be another contributing factor to this incidence.

Sources of fecal coliform in the samples are essentially related to the feces of all warm-blooded animals including human. The decreasing concentration of fecal coliform with distance from the on-site sanitation schemes at the sampling locations as found during the study suggest that such schemes are possibly acting as the major sources for this kind of pollution. As it has been already discussed in Sec. 4.2 a large percentage of the city population are using on-site sanitation method of domestic waste disposal so the risk of groundwater contamination from such sources is also high in this area, specially due to the existing hydrogeologic condition.

6.1.6 Bacteriophage

In the groundwater samples from boreholes the highest bacteriophage concentration was found to be 64/100 ml. No phage could be detected in the water samples collected from intake sources except one. Experimental values indicate that the virus concentration in the surface soil in most cases was higher than in the groundwater samples. In fact, due to very small size of virus particles it can be easily adsorbed by the soil grains. So the virus mainly concentrates on the soil phase. The soil grain size distribution of the study area (Tab. 6.1) shows that clay is predominant which is considered to have better sorption capacity.

Viruses adsorbed onto soil particles are not necessarily permanently immobilized. Adsorption is a reversible phenomena and viruses can become desorbed and thus can penetrate deeper into the soil. Heavy rains can disrobe viruses from the soil phase. This effect was observed in the samples collected on Nov. 19, 1986 from Mirpur and Sewra stations (Appendix A). Significantly large changes in viral population was detected in the groundwater samples as compared to the concentrations recorded during the other two observations at different times. These samples were collected about 6 hours after a long rainfall on the other night. Relatively higher incidence rate of waterborne diseases during the monsoon season in the study area (Tabs. 3.1 and 4.9) may be attributed to this phenomena.

Inactivation of viruses is greatly influenced by pH, it was found by earlier researchers that an increase in pH results in an increase in inactivation rate. The bacteriophage, as the name implies, is essentially a bacteria based virus, that is, it uses bacteria as the host cell. The origin of this kind of virus is from the feces of animals including human. So it can be concluded that the sources of bacteriophage in the samples were from the nearby sanitation units. Although virus could not be detected in the deep well waters during the sampling time but such a possibility cannot be completely ruled out. Once they enter the saturated zone viruses can be transported with groundwater flow for considerable distances and depth. SCHAUB and SORBER (1977) reported the presence of virus in wells 183 m deep. The experimental results indicate that the bacteriophage has already entered the groundwater in the study area, so it might some day appear in the deep well water.

6.2 Soil Condition

The grain size distribution curves (Appendix C) were plotted from the results of hydrometer analysis. From such curves the average size of the soil particles has been calculated. The results are shown in Tab. 6.1. As has already been mentioned in Chapter III, the overlying strata of Dhaka extending in average upto 6 m depth belongs to the flood plain sub-environment (Tab. 3.2); erosion and deposition is constantly

Tab. 6.1 Average size of soil grains and the type of soils at the sampling boreholes

Location	Borehole at 5 m distance		Borehole at 10 m distance	
	Average size (mm)	Soil Type	Average Size (mm)	Soil Type
Mohakhali	0.020	Brownish grey SILTY clay with trace fine sand	0.031	Reddish brown silt with clay and trace fine sand
Kachukhet	0.036	Light to reddish brown clayey SILT with trace fine sand	0.024	Light to reddish brown SILT with trace fine sand
Mirpur	0.014	Grey to light grey silty CLAY	0.014	Grey Silty CLAY
Sewra	0.044	Grey SILT with trace fine sand	0.038	Light grey SILT with traces of fine sand and clay
Badda	0.032	Reddish brown clayey SILT with trace fine sand	0.028	Reddish brown clayey SILT with trace fine sand
Mohammadpur	0.017	Dark grey silty CLAY with trace fine sand	0.026	Light grey silty CLAY
Dhupkhola	0.030	Light brown clayey SILT with trace fine sand	0.018	Reddish brown clayey SILT with trace fine sand
Goran	0.037	Light greyish brown clayey SILT with trace fine sand	0.030	Dark grey clayey SILT with trace organic matter

modifying the soil system in this strata. As a result the top soil consists of very fine grained particles which is generally classified as clayey silt. Due to this smaller sized soil particles the top soil of Dhaka has a very limited permiability. This is one of the reasons of failure of septic tank and pit latrine method of on-site waste disposal in this area. The high concentrations of fecal coliform, bacteriophage, and NO_3-N on the surface soil at all the sampling stations found during

the experiments as well as the necessity of frequent desludging of pit latrines (Sec. 4.2.2) to prevent it from overflowing validate this conclusion.

Normally the clayey soils can hold more moisture than other type of soils; as such this type of soil has very limited drainage capability. Due to this fact the pore clogging process occurs very quickly once the waste has been applied which ultimately leads to the system failure due to surfacing of effluent containing pathogens and objectionable chemicals, and possibly this is the reason for their presence in large concentrations in the samples. The high moisture content, as it can be expected for the type of soil prevailing in the study area gives greater survival time for the pathogens, this makes the situation even more worrisome.

The maximum nitrate-N concentration in the soil samples was found to be 24.9 mg/l. In most cases the nitrate concentration in the boreholes at a distance 5 m from the sanitation scheme was found to be higher than in the boreholes drilled at 10 m distance. This gives reason to believe that the sanitation sites in the study area have a key role in spreading nitrate into the groundwater system.

6.3 Groundwater Level Record

The overlying confining layer of Dhaka is often called "leaky" confining layer. The leaks are being attributed to the very high water levels at many points in the city due to low elevation of ground surface at those points. The sampling stations chosen for this study are located in such areas. The static water table record of the boreholes (Tab. 6.2) shows a minimum value of 0.12 m observed in one of the locations during the sampling period, and the available data from the previous observations (Tab. 4.2) indicate a minimum value of 0.1 m. It is very likely that the septic tank soak pits and the pit latrines at the sampling points are directly contaminating the groundwater because in many instances the depth of their bases are situated well below the water table. More worrisome is the fact that the number of such sanitation schemes are quite large in the study area. The preconditions for installing on-site sanitation systems have totally been ignored. The existing methods are not suitable for this area. The high groundwater level condition should be incorporated in the design of any on-site sanitation scheme for this area in future.

6.4 Effect of Depth and Distance

For understanding the general pattern of pollutant travel in both vertical and horizontal direction in the soil-water zone the results of the experiments were sorted according to the depth and distance from where they were collected. The average of the three values from three observations were calculated and the results were then arranged in the tables as shown in Appendix B (Tabs. B.1, B.2, B.3, and B.4). The values from these tables were then used for plotting concentration versus depth and distance graphs for selected parameters (viz. NO_3-N, fecal coliform, and bacteriophage).

Tab. 6.2 Static Water Table in Boreholes at the Sampling Locations During the Sampling Period

Location	Date	SWT at BH 1 (m)[a]	SWT at BH 2 (m)[b]
	1986		
Mohakhali	Oct 19	0.12	0.16
	Nov 2	0.14	0.17
	16	0.17	0.21
	30	0.15	0.18
Kachukhet	Oct 19	1.93	1.96
	Nov 2	1.97	2.09
	16	1.96	1.98
	30	2.08	2.14
Mirpur	Oct 22	0.38	0.35
	Nov 5	0.46	0.44
	19	0.27	0.21
Sewra	Oct 22	0.80	0.78
	Nov 5	0.75	0.71
	19	0.59	0.54
Badda	Oct 26	1.15	1.09
	Nov 9	1.28	1.25
	23	1.21	1.27
Mohammadpur	Oct 26	0.47	0.62
	Nov 9	0.38	0.58
	23	0.45	0.59
Dhupkhola	Oct 29	0.85	0.88
	Nov 12	0.79	0.78
	19	0.77	0.75
Goran	Oct 29	0.28	0.37
	Nov 12	0.31	0.38
	26	0.32	0.40

Note: a. BH 1 is at a distance 5 m from the on-site sanitation facility.
b. BH 2 is at a distance 10 m from the on-site sanitation facility.

6.4.1. Change in Pollutant Concentrations With Depth

The nitrate concentration profile (Fig. 6.1) shows that the concentration decreased with depth. This indicate that the nitrification rate decreases as the effluent moves deeper into the soil system. This is partly due to the anoxic condition that might be prevailing below the surface which favors denitrification, and also partly due to the dilution effect. A part of the nitrate formed on the surface by nitrification process can stay with groundwater in dissolved form which might be the reason for significant nitrate concentrations recorded in some well water samples.

The log values of average fecal coliform concentrations as shown in Fig. 6.2 indicate that no appreciable change in concentration took place upto a depth of 1 m. In case of the samples collected from the boreholes at 10 m distance from on-site schemes the rate of decrease in concentration with depth was even more slower at the first 1 m depth. All these indicate that the upper layer of the top soil has been clogged with filtered bacterial mass, and in this zone the bacterial population might increase if enough nutrients and substrates are available for their growth. The on-site sanitation facilities in the sampling location could be the possible source as no other kind of sources could be identified in the vicinity. From 1 m and upto a depth of 2 m the rate of decrease in concentration was comparatively higher, this rate was again dropped to a minimum value showing very little change in the gradient in both the curves. The intermediate range of the curves where the decreasing rate is higher could be attributed to the adsorption process which might be taking place simultaneously with the filtration resulting in a faster decrease of microbial population in the groundwater. The static water level in most of the sampling locations was located within 1 m below the surface, such a condition is favorable for bacterial survival as the water might contain enough nutrients to support their life system.

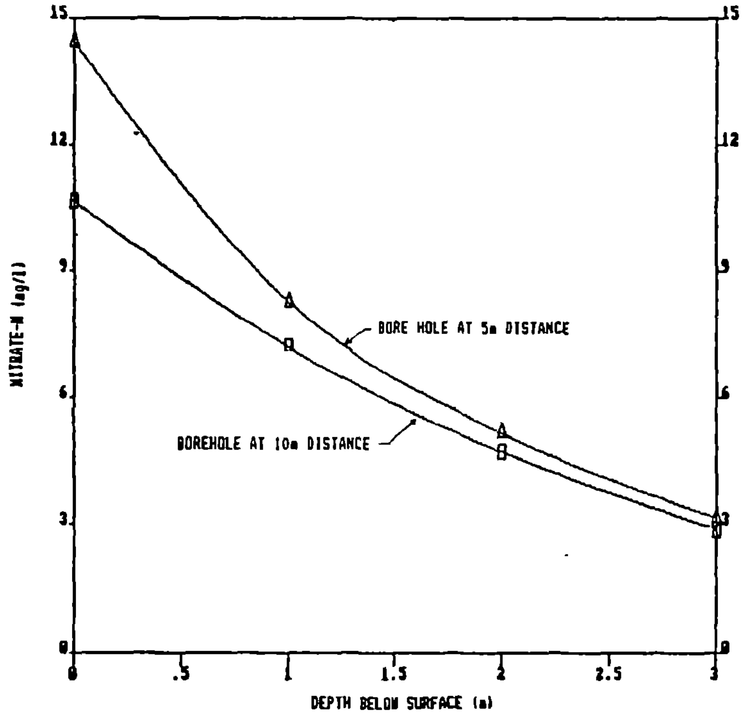


Fig. 6.1 Change in NO_3-N concentration with depth of penetration

Fig. 6.3 shows how the bacteriophage concentration was changing with depth. The nature of the curves is similar to the one showing changes in fecal coliform concentration. The phage concentration decreased slowly upto 1 m depth from the surface and then decreased sharply which might be due to adsorption mainly. The second line in the graph which represents the samples collected from 10 m distance from the on-site sanitation schemes indicates a very slow decreasing rate of

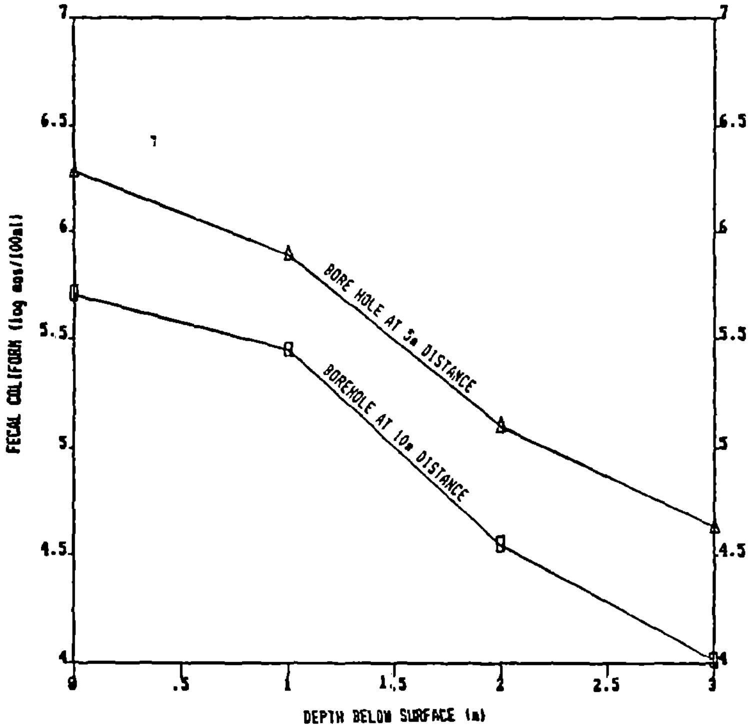


Fig. 6.2 Change in Fecal Coliform concentration with depth of penetration

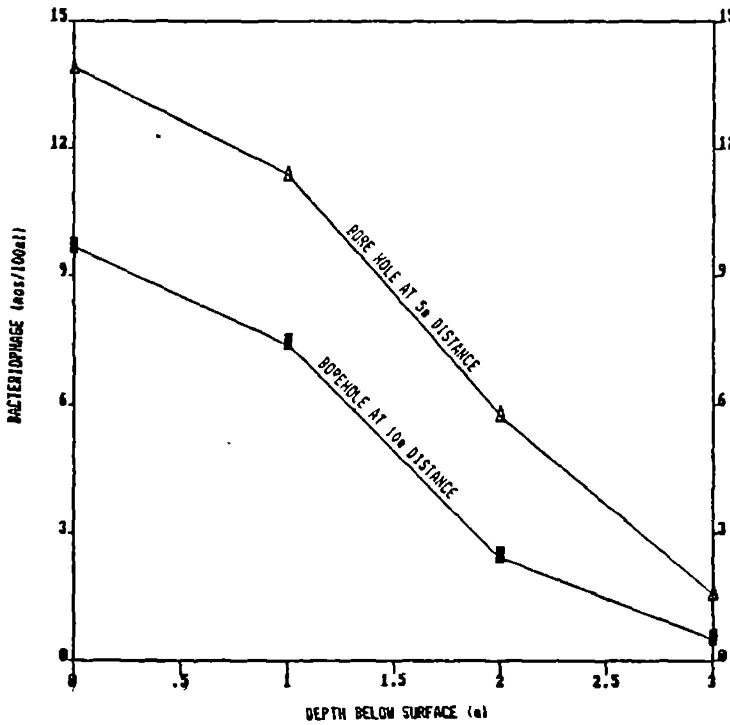


Fig. 6.3 Change in Bacteriophage concentration with depth of penetration

of phage concentration beyond 3 m depth. The possible explanation to this phenomena is that, the virus particles exist as cyst while living outside a host, and once these have entered the groundwater zone they can travel a long distance both vertically and horizontally depending on the soil condition. Dhaka hydrogeological condition seem to be of little problem for such a migration.

6.4.2 Change in Pollutant Concentrations With Distance

Concentration profiles of selected pollution parameters with distance were drawn in order to have a general idea about the effect of distance on their travel from the on-site sanitation schemes at the sampling locations. Average values of pollutant concentrations (Appendix B) were plotted against the distance of on-site sanitation units from the sampling boreholes.

The nitrate concentration decreased quite significantly with distance along the surface (Fig. 6.4). But at depths below the ground the distance had very negligible effect on the concentration. In case

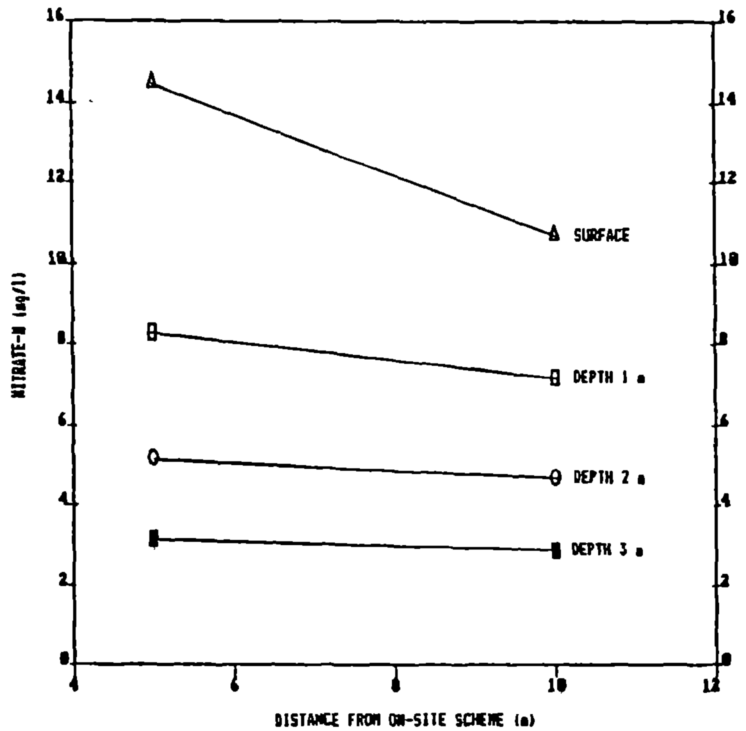


Fig. 6.4 Change in NO_3-N concentration with distance from on-site sanitation scheme

of fecal coliform concentration as shown in Fig. 6.5, the distance found to have an important role in the reduction of concentration but was effective only upto a depth of 2 m. Beyond this depth the concentration did not change appreciably with the distance. The bacteriophage concentration decreased with distance at a very faster rate in first 2 m depth and after that the rate was reduced but still was significant (Fig. 6.6).

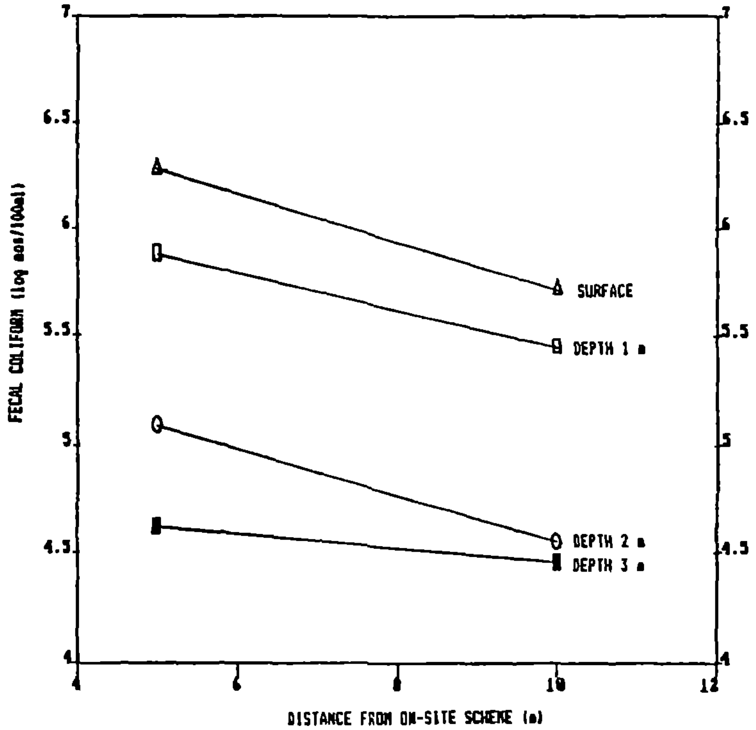


Fig. 6.5 Change in Fecal Coliform concentration with distance from on-site sanitation scheme

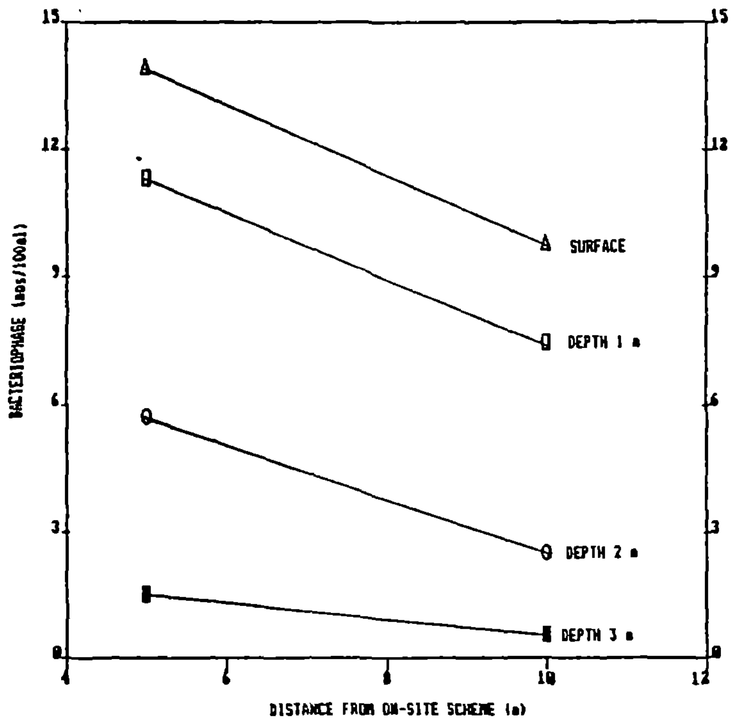


Fig. 6.6 Change in Bacteriophage concentration with distance from on-site sanitation scheme

From the discussion of the previous two sub-sections it is very clear that once the pollutants have reached the groundwater zone the effect of depth and distance on the concentration of the pollutants becomes minimum. All the samples for this study were collected from the places with a high groundwater level and with large number of on-site sanitation schemes which can be regarded as the cause and effect respectively of this situation.

6.5 Other Factors

Apart from the favorable geological condition there are other factors also which are contributing to the groundwater pollution from on-site sanitation in the area. The practice of defecation on open surface is an indication of people's lack of education on environment. Also the 'katcha latrine' method of on-site sanitation indicates the same thing. Fecal matters from such schemes can easily enter the groundwater system with the percolating water from the surface. So education is also an important factor related to the groundwater pollution from on-site sanitation in the study area.

VII CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The main objective of this study was to find out a relationship between on-site sanitation and groundwater pollution in Dhaka, Bangladesh. Apart from extensive data investigation, this study involved a large number of experiments with both groundwater and soil samples of the study area. Findings of this study can be summarized as follows:

(1) Both soil and groundwater samples collected from upto a distance of 10 m from on-site sanitation facility and upto 3 m depth below the surface found to contain pollutants of fecal origin in significant concentrations.

(2) Low level of groundwater table at some areas poses the greatest threat of providing easy access for these pollutants to contaminate the groundwater resources in the study area.

(3) Septic tank system which is considered as one of the safest modes of on-site sanitation, found to be a failure in the study area because of their poor maintenance.

(4) The hydrogeologic condition of the study area is found to be unsuitable for the types of on-site sanitation schemes now being used.

(5) Presence of pollutants of fecal origin in the groundwater samples demonstrate the most likelihood of spread of these from the on-site sanitation because such facilities were quite close to the sampling boreholes.

(6) The concentration of NO_3-N, fecal coliform, and bacteriophage showed a decreasing tendency with the depth of penetration. But it was found that the decreasing rate became smaller as the depth below the surface increased. This suggests that after reaching the groundwater table the effect of depth becomes negligible.

(7) It was found that the NO_3-N concentration on the surface decreased as the distance from the on-site sanitation scheme increased. But below surface the effect of distance was not that much significant.

(8) The study indicated that both fecal coliform and bacteriophage concentration decreased with the distance from the on-site sanitation facility. But still there numbers were quite significant even at 10 m distance from the on-site units. This suggests that the "safe" distance will be somewhat greater than 10 m in the study area.

(9) In many instances the distance between the on-site sanitation scheme and the water intake source (both deep and shallow wells) is found to be less than 10 m.

(10) Frequent outbreak of cholera, diarrhoea, jaundice, etc. all of which can be transmitted by fecal-oral route via water can be suspected to have originated from improper water supply and sanitation systems.

(11) Lack of education on hygiene was observed among the people in the study area. Defecation in open spaces can be stopped by providing proper health education.

7.2 Recommendations

(1) Before any comprehensive guidelines can be formulated for the safe separation of on-site sanitation schemes and groundwater supply installations, it is necessary to derive a classificatory system of hydrogeological environments in relation to pollution risk.

(2) Groundwater quality monitoring programs should be established wherever on-site sanitation and water supply wells are to exist side by side.

(3) Further research should be carried out to study the effect of various ranges of hydraulic loadings, the behavior of the pollutants in less favorable hydrogeological environments, and viral contamination of groundwaters.

(4) Further considerations also needs to be given to the implementation strategy of sanitation and water supply schemes.

(5) Establishment of routine monitoring programs and detailed field studies are required to extend the present state of knowledge regarding groundwater pollution and on-site sanitation systems.

(6) A safe on-site sanitation system suitable for the local environment has to be worked out. Adoptation of mound system of waste disposal seem to be an appropriate low cost option for the study area.

(7) Improvement and extension of present water supply network should be given priority.

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APPENDIX A

(Results of Experiments)

Tab. A.1 Results of analyses of groundwater samples collected from the sampling points at Mohakhali

Date	Dist.[a] m	Depth[b] m	Temp. °C	pH	Turbidity NTU	Nitrate-N mg-N/l	Hardness mg/l	Conductivity μS/cm	Fecal Coliform nos./100 ml	Bacteriophage nos./100 ml
19/10/86	48[c]	30	26.6	6.7	11	0.4	102	220	8.0×10^{1}	0
	5	0[d]				23.1			2.3×10^{4}	11
		1	26.2	6.8	44	13.6	82	180	1.5×10^{3}	7
		2	26.2	6.7	51	7.6	64	260	1.2×10^{4}	3
		3	26.3	6.8	30	3.6	72	275	4.0×10^{2}	0
	10	0[d]				12.3			1.4×10^{5}	5
		1	26.2	6.8	32	9.0	52	250	3.9×10^{4}	0
		2	26.3	6.7	46	6.2	54	240	1.8×10^{4}	0
		3	26.3	6.7	49	4.5	80	260	1.1×10^{3}	0
2/11/86	48[c]	30	26.7	6.5	5	1.9	107	310	2.1×10^{2}	0
	5	0[d]				18.9			3.5×10^{4}	9
		1	26.8	6.6	56	14.4	73	215	2.8×10^{3}	7
		2	26.9	6.7	58	7.7	56	250	4.1×10^{4}	0
		3	26.9	6.9	43	1.5	52	265	1.9×10^{4}	0
	10	0[d]				10.7			4.3×10^{2}	9
		1	26.7	6.8	41	6.9	51	310	3.1×10^{4}	0
		2	26.9	6.8	48	5.1	59	275	1.5×10^{4}	0
		3	26.8	6.8	46	3.3	48	280	1.3×10^{2}	0
16/11/86	48[c]	30	26.7	6.5	8	0.2	92	180	1.4×10^{2}	0
	5	0[d]				19.2			1.6×10^{2}	9
		1	26.7	6.8	51	6.8	76	190	2.7×10^{3}	7
		2	26.8	6.8	54	7.4	62	260	1.7×10^{4}	3
		3	27.0	6.9	45	2.2	51	280	2.1×10^{4}	0
	10	0[d]				13.6			2.2×10^{2}	4
		1	26.7	6.8	42	9.2	72	270	1.8×10^{3}	7
		2	26.8	7.0	44	7.4	63	255	2.1×10^{4}	0
		3	26.9	6.9	46	4.1	56	265	1.7×10^{4}	0
30/11/86	48[c]	30	26.4	6.6	10	0.1	84	210	0	0
	5	0[d]				17.1			2.1×10^{4}	9
		1	26.5	6.9	43	11.7	78	225	1.9×10^{3}	4
		2	26.6	6.9	47	6.4	55	290	4.7×10^{4}	0
		3	26.6	6.8	35	3.8	58	270	3.5×10^{4}	0
	10	0[d]				12.9			1.4×10^{2}	4
		1	26.5	6.9	38	11.7	83	210	2.5×10^{2}	0
		2	26.6	7.0	41	6.1	74	180	5.1×10^{2}	0
		3	26.6	6.9	40	3.8	62	320	4.6×10^{2}	0

Note: a. The distance from the nearest on-site sanitation facility.
b. Depth below the ground surface.
c. Distance of the nearest water intake source.
d. Soil sample, all counts should be read per 100 g of sample.

Tab. A.2 Results of analyses of groundwater samples collected from the sampling points at Kachukhet

Date	Dist.[a] m	Depth[b] m	Temp. °C	pH	Turbidity NTU	Nitrate-N mg-N/l	Hardness mg/l	Conductivity μS/cm	Fecal Coliform nos./100 ml	Bacteriophage nos./100 ml
19/10/86	7[c]	2.5	26.1	6.8	5	0	62	170	1.6×10^{2}	3
	5	0[d]				16.8			3.5×10^{4}	20
		1[d]				7.5			2.3×10^{4}	21
		2	26.2	6.7	45	8.4	84	260	1.8×10^{4}	9
		3	26.2	7.1	40	4.4	61	190	1.3×10^{4}	0
	10	0[d]				13.5			2.8×10^{3}	11
		1[d]				13.6			2.6×10^{3}	11
		2	26.2	6.6	58	7.4	68	280	1.2×10^{4}	4
		3	26.3	6.7	52	5.2	60	270	2.0×10^{3}	0
2/11/86	7[c]	2.5	25.8	6.9	6	0	66	180	5.2×10^{4}	3
	5	0[d]				19.2			5.7×10^{3}	15
		1[d]				14.7			1.4×10^{6}	21
		2	26.8	6.7	44	6.8	52	210	2.1×10^{3}	4
		3	26.9	6.9	38	4.1	56	235	1.7×10^{3}	3
	10	0[d]				11.8			3.7×10^{3}	11
		1[d]				8.7			1.9×10^{3}	7
		2[d]				6.9			2.5×10^{3}	3
		3	26.8	6.9	47	5.7	72	190	2.1×10^{3}	0
16/11/86	7[c]	2.5	26.2	6.8	12	0.2	73	210	1.4×10^{4}	0
	5	0[d]				15.3			2.7×10^{3}	15
		1[d]				11.8			4.6×10^{3}	7
		2	26.8	6.5	31	4.7	58	185	6.1×10^{4}	7
		3	26.6	6.6	34	6.8	69	250	4.9×10^{3}	0
	10	0[d]				15.9			1.8×10^{4}	11
		1[d]				12.4			4.7×10^{3}	9
		2	26.9	6.5	38	8.2	74	210	1.2×10^{4}	0
		3	26.8	6.5	44	7.2	56	245	1.8×10^{3}	0
30/11/86	7[c]	2.5	26.5	6.5	16	0	72	200	2.7×10^{4}	0
	5	0[d]				12.6			2.3×10^{3}	15
		1[d]				9.8			3.1×10^{4}	9
		2[d]				5.3			1.6×10^{2}	11
		3	26.6	6.8	27	4.2	74	340	1.8×10^{2}	0
	10	0[d]				11.4			4.1×10^{3}	9
		1[d]				8.6			2.8×10^{4}	4
		2[d]				4.4			3.6×10^{2}	0
		3	26.6	6.7	34	3.6	64	270	1.9×10^{2}	0

Notes a. The distance from the nearest on-site sanitation facility.
b. Depth below the ground surface.
c. Distance of the nearest water intake source.
d. Soil sample, all counts should be read per 100 g of sample.

Tab. A.3 Results of analyses of groundwater samples collected from the sampling points at Mirpur

Date	Dist.[a] m	Depth[b] m	Temp. °C	pH	Turbidity NTU	Nitrate-N mg-N/l	Hardness mg/l	Conductivity µS/cm	Fecal Coliform nos./100 ml	Bacteriophage nos./100 ml
22/10/86	23[c]	92	27.6	6.6	12	0.2	64	240	$2.1x10^3$	0
	5	0[d]				7 6			$2.2x10^5$	15
		1	27.2	7.3	48	5.8	81	450	$5.6x10^5$	7
		2	27.1	7.1	63	1.4	68	420	$4.1x10^4$	0
		3	27.2	7.1	79	0.3	72	580	$2.8x10^4$	0
	10	0[d]				6.8			$1.8x10^4$	7
		1	27.2	6.9	53	6.6	91	270	$5.0x10^5$	7
		2	27.2	7.1	77	4.6	68	360	$1.9x10^3$	0
		3	27.3	6.9	89	4.2	89	350	$4.2x10^2$	0
5/11/86	23[c]	92	27.7	6.6	7	0.4	71	220	$3.9x10^3$	0
	5	0[d]				11.8			$6.4x10^5$	15
		1	27.2	7.1	45	8.3	92	435	$1.8x10^6$	9
		2	27.3	7.3	67	3.7	84	470	$1.9x10^5$	0
		3	27.3	7.2	65	2.9	73	530	$5.3x10^4$	0
	10	0[d]				5.7			$2.7x10^5$	14
		1	27.2	7.1	52	5.1	71	250	$1.4x10^5$	11
		2	27.2	6.9	85	4.7	68	245	$3.7x10^4$	3
		3	27.4	6.9	79	3.1	62	310	$5.3x10^3$	0
19/11/86	23[c]	92	27.5	6.7	10	0	48	185	$5.1x10^3$	0
	5	0[d]				12.6			$4.7x10^6$	20
		1	26.6	6.8	68	7.2	66	380	$4.7x10^6$	64
		2	26.7	7.1	63	3.8	71	490	$2.5x10^4$	21
		3	26.7	7.4	77	0.9	58	620	$1.9x10^4$	20
	10	0[d]				2.4			$1.9x10^4$	15
		1	26.7	7.5	73	1.7	54	270	$3.8x10^5$	39
		2	26.7	7.6	88	0.9	53	310	$4.6x10^4$	11
		3	26.6	7.4	76	0	59	280	$2.2x10^4$	11

Note: a. The distance from the nearest on-site sanitation facility.
b. Depth below the ground surface.
c. Distance of the nearest water intake source.
d. Soil sample, all counts should be read per 100 g of sample.

Tab. A.4 Results of analyses of groundwater samples collected from the sampling points at Sewra

Date	Dist.[a] m	Depth[b] m	Temp. °C	pH	Turbidity NTU	Nitrate-N mg-N/l	Hardness mg/l	Conductivity µS/cm	Fecal Coliform nos./100 ml	Bacteriophage nos./100 ml
22/10/86	12[c]	113	27.4	6.8	5	0	69	310	$2.4x10^2$	0
	5	0[d]				17.1			$3.7x10^5$	15
		1	26.2	6.8	31	9.9	116	310	$4.1x10^5$	14
		2	26.3	6.8	43	6.4	110	270	$1.8x10^5$	9
		3	26.2	6.9	66	2.1	124	260	$2.2x10^4$	0
	10	0[d]				13.8			$2.4x10^5$	15
		1	26.2	6.9	98	8.6	142	700	$2.6x10^4$	3
		2	26.2	7.0	32	6.3	204	620	$1.7x10^4$	9
		3	26.2	6.8	39	3.2	168	600	$1.9x10^4$	3
5/11/86	12[c]	113	27.9	6.9	0	0.1	64	320	$8.2x10^1$	0
	5	0[d]				15.4			$2.9x10^5$	9
		1	26.5	6.7	34	8.3	112	295	$3.5x10^5$	9
		2	26.6	6.8	39	5.1	110	230	$5.6x10^4$	9
		3	26.6	6.8	67	3.2	118	280	$1.3x10^3$	0
	10	0[d]				14.6			$5.9x10^4$	15
		1	26.5	6.9	84	10.2	148	680	$1.3x10^5$	9
		2	26.6	6.9	46	7.1	186	590	$2.4x10^4$	0
		3	26.6	6.8	40	4.4	170	610	$3.0x10^3$	0
19/11/86	12[c]	113	27.3	6.8	4	1.1	86	350	$4.1x10^2$	0
	5	0[d]				5.9			$5.4x10^4$	39
		1	26.1	6.8	38	4.7	93	310	$1.8x10^5$	28
		2	26.1	6.9	40	2.3	88	290	$2.9x10^4$	11
		3	26.2	6.9	74	0.7	102	330	$5.8x10^3$	4
	10	0[d]				3.5			$2.8x10^4$	28
		1	26.0	6.9	96	4.1	108	610	$4.1x10^5$	20
		2	26.2	7.1	53	1.2	114	650	$1.5x10^4$	11
		3	26.2	7.2	58	0.2	142	655	$3.3x10^3$	0

Note: a. The distance from the nearest on-site sanitation facility.
b. Depth below the ground surface
c. Distance of the nearest water intake source.
d. Soil sample, all counts should be read per 100 g of sample.

Tab. A.5 Results of analyses of groundwater samples collected from the sampling points at Badda

Date	Dist.[a] m	Depth[b] m	Temp. °C	pH	Turbidity NTU	Nitrate-N mg-N/l	Hardness mg/l	Conductivity μS/cm	Fecal Coliform nos./100 ml	Bacteriophage nos./100 ml
26/10/86	17[c]	24	27.1	6.8	14	2.4	142	215	2.8×10^{2}	0
	5	0[d]				21.3			4.6×10^{4}	20
		1[d]				11.2			1.8×10^{4}	11
		2	27.0	6.8	71	9.2	120	410	3.8×10^{3}	11
		3	27.0	7.1	75	5.8	116	380	6.0×10^{2}	0
	10	0[d]				19.9			6.1×10^{3}	11
		1[d]				9.6			4.0×10^{3}	9
		2	27.0	6.9	78	6.0	104	280	2.1×10^{3}	0
		3	27.1	6.9	132	4.2	96	300	1.7×10^{2}	0
9/11/86	17[c]	24	26.8	6.7	10	0.9	125	270	3.9×10^{2}	0
	5	0[d]				24.9			1.3×10^{4}	21
		1[d]	26.5			12.6			3.6×10^{5}	11
		2	26.8	6.9	68	8.1	112	390	2.9×10^{4}	11
		3	26.9	7.1	72	4.7	106	400	1.2×10^{4}	4
	10	0[d]				18.6			2.5×10^{3}	15
		1[d]				9.1			4.7×10^{4}	4
		2	26.9	6.9	67	6.4	116	310	5.0×10^{3}	0
		3	26.9	6.8	94	3.7	102	290	2.8×10^{3}	0
23/11/86	17[c]	24	26.9	6.8	0	1.3	153	280	1.8×10^{3}	0
	5	0[d]				22.8			2.2×10^{4}	21
		1[d]				9.2			5.5×10^{5}	11
		2	26.5	6.9	76	8.4	112	370	4.7×10^{4}	9
		3	26.5	7.0	82	5.6	110	390	2.5×10^{4}	0
	10	0[d]				17.8			3.8×10^{3}	15
		1[d]				10.2			1.7×10^{4}	9
		2	26.5	7.0	69	5.8	112	325	5.8×10^{3}	4
		3	26.6	7.1	88	3.1	128	260	2.1×10^{2}	0

Note: a. The distance from the nearest on-site sanitation facility.
b. Depth below the ground surface.
c. Distance of the nearest water intake source.
d. Soil sample, all counts should be read per 100 g of sample.

Tab. A.6 Results of analyses of groundwater samples collected from the sampling points at Mohammadpur

Date	Dist.[a] m	Depth[b] m	Temp. °C	pH	Turbidity NTU	Nitrate-N mg-N/l	Hardness mg/l	Conductivity μS/cm	Fecal Coliform nos./100 ml	Bacteriophage nos./100 ml
26/10/86	28[c]	24	27.1	6.8	5	2.8	109	300	1.2×10^{3}	0
	5	0[d]				11.2			4.8×10^{6}	21
		1	27.1	6.8	26	6.4	162	700	2.3×10^{6}	14
		2	27.1	6.9	38	5.2	160	590	2.5×10^{5}	14
		3	27.2	7.1	28	4.8	152	280	3.8×10^{4}	7
	10	0[d]				8.6			3.2×10^{6}	11
		1	27.0	6.8	21	6.5	56	470	1.6×10^{5}	11
		2	27.1	7.1	34	4.8	58	510	3.6×10^{4}	9
		3	27.2	7.3	22	4.2	118	320	2.1×10^{4}	0
9/11/86	28[c]	24	27.0	6.7	0	0	98	285	1.5×10^{3}	0
	5	0[d]				12.3			3.3×10^{5}	15
		1	26.8	6.9	25	8.3	166	690	1.9×10^{6}	14
		2	26.8	7.2	34	5.8	158	615	2.7×10^{5}	7
		3	26.8	7.2	21	5.3	150	310	1.9×10^{5}	0
	10	0[d]				10.4			5.7×10^{5}	14
		1	26.8	6.9	24	5.4	58	500	3.8×10^{5}	11
		2	26.8	7.0	33	4.8	69	480	4.1×10^{4}	4
		3	27.0	7.3	25	4.7	92	320	2.5×10^{4}	0
23/11/86	28[c]	24	27.2	6.5	0	3.1	122	270	5.3×10^{2}	0
	5	0[d]				14.1			5.1×10^{5}	21
		1	26.5	6.8	33	8.7	172	610	3.1×10^{5}	15
		2	26.6	6.9	40	5.7	154	570	1.8×10^{5}	4
		3	26.6	7.2	37	5.5	158	320	1.8×10^{4}	0
	10	0[d]				11.0			1.8×10^{5}	11
		1	26.5	6.9	28	5.1	72	520	4.1×10^{5}	7
		2	26.6	6.9	36	4.9	63	310	2.3×10^{4}	4
		3	26.6	7.2	32	4.3	109	335	1.7×10^{4}	0

Note: a. The distance from the nearest on-site sanitation facility.
b. Depth below the ground surface.
c. Distance of the nearest water intake source.
d. Soil sample, all counts should be read per 100 g of sample.

Tab. A.7 Results of analyses of groundwater samples collected from the sampling points at Dhupkhola

Date	Dist.[a] m	Depth[b] m	Temp. °C	pH	Turbidity NTU	Nitrate-N mg-N/l	Hardness mg/l	Conductivity μS/cm	Fecal Coliform nos./100 ml	Bacteriophage nos./100 ml
29/10/86	16[c]	107	27.8	6.5	0	0.4	74	410	$2.5x10^1$	0
	5	0[d]				17.4			$3.1x10^6$	4
		1	27.0	5.5	48	12.2	82	460	$4.7x10^5$	4
		2	27.0	5.7	56	5.5	126	385	$1.8x10^5$	0
		3	27.1	6.1	52	4.2	114	370	$5.0x10^4$	0
	10	0[d]				12.4			$4.4x10^5$	4
		1	27.1	5.8	54	8.5	94	390	$1.3x10^5$	3
		2	27.1	6.3	36	4.7	112	325	$3.9x10^4$	0
		3	27.2	6.3	32	2.4	88	360	$2.1x10^3$	0
12/11/86	16[c]	107	27.7	6.3	0	0.6	132	370	$6.3x10^2$	0
	5	0[d]				10.2			$5.8x10^5$	9
		1	26.9	5.7	54	6.1	94	440	$2.6x10^5$	7
		2	27.0	5.8	59	4.8	117	410	$2.1x10^4$	0
		3	27.0	6.0	46	3.3	108	365	$1.9x10^4$	0
	10	0[d]				8.3			$2.7x10^6$	7
		1	27.1	5.9	48	5.7	107	360	$5.3x10^5$	0
		2	27.1	5.9	59	4.1	91	295	$1.8x10^5$	0
		3	27.1	6.2	34	2.5	84	340	$2.1x10^4$	0
26/11/86	16[c]	107	27.4	6.5	0	0	126	420	$2.2x10^2$	0
	5	0[d]				16.8			$1.8x10^6$	9
		1	26.5	5.7	56	10.6	112	475	$2.3x10^5$	4
		2	26.6	5.7	58	4.6	110	430	$1.5x10^4$	4
		3	26.6	5.9	48	1.8	124	310	$1.8x10^4$	0
	10	0[d]				8.8			$4.6x10^5$	4
		1	26.5	5.9	46	4.9	102	350	$3.7x10^5$	0
		2	26.4	5.7	62	3.8	108	280	$3.8x10^4$	0
		3	26.5	5.9	32	3.1	74	290	$1.5x10^4$	0

Note: a. The distance from the nearest on-site sanitation facility.
b. Depth below the ground surface.
c. Distance of the nearest water intake source.
d. Soil sample, all counts should be read per 100 g of sample.

Tab. A.8 Results of analyses of groundwater samples collected from the sampling points at Goran

Date	Dist.[a] m	Depth[b] m	Temp. °C	pH	Turbidity NTU	Nitrate-N mg-N/l	Hardness mg/l	Conductivity μS/cm	Fecal Coliform nos./100 ml	Bacteriophage nos./100 ml
29/10/86	19[c]	24	27.8	6.5	18	1.6	128	380	$1.5x10^3$	0
	5	0[d]				6.8			$1.4x10^5$	11
		1	27.1	6.8	41	2.9	110	475	$2.7x10^4$	3
		2	27.2	6.9	35	1.1	118	415	$5.3x10^5$	0
		3	27.2	6.8	32	0.8	121	380	$1.8x10^5$	0
	10	0[d]				7.2			$2.1x10^5$	3
		1	27.2	7.1	35	4.6	82	650	$4.5x10^5$	0
		2	27.2	6.9	28	1.8	78	685	$3.8x10^4$	0
		3	27.2	7.0	26	0.7	114	575	$1.5x10^4$	0
12/11/86	19[c]	24	27.9	6.6	9	1.3	120	410	$2.9x10^3$	0
	5	0[d]				3.9			$2.2x10^5$	11
		1	27.1	6.8	52	4.8	112	460	$1.8x10^6$	0
		2	27.1	7.1	38	1.4	114	470	$3.3x10^5$	0
		3	27.1	7.1	41	0.7	134	415	$2.4x10^5$	0
	10	0[d]				1.4			$2.8x10^5$	0
		1	27.2	6.9	38	0.8	84	580	$3.9x10^5$	0
		2	27.1	6.9	44	0.1	90	660	$2.6x10^4$	0
		3	27.2	7.1	40	0.1	98	610	$1.8x10^4$	0
26/11/86	19[c]	24	27.6	6.6	4	0.8	144	430	$4.2x10^2$	0
	5	0[d]				7.6			$3.0x10^5$	9
		1	26.6	6.5	68	3.1	107	420	$4.7x10^5$	0
		2	26.7	6.6	44	0.7	126	460	$1.9x10^5$	0
		3	26.6	6.8	38	0.1	128	430	$3.5x10^4$	0
	10	0[d]				6.5			$2.5x10^5$	4
		1	26.7	6.7	52	2.4	922	430	$1.7x10^6$	0
		2	26.7	6.8	48	0.7	96	610	$2.3x10^5$	0
		3	26.8	6.9	42	0.1	109	620	$3.1x10^4$	0

Note: a. The distance from the nearest on-site sanitation facility.
b. Depth below the ground surface.
c. Distance of the nearest water intake source.
d. Soil sample, all counts should be read per 100 g of sample.

APPENDIX B

(Additional Tables)

Tab. B.1 Average and variance of observed concentrations of selected parameters collected from a depth of 0m

Location	Distance m	Nitrate mg/l Mean	Nitrate mg/l Var	Fec. Colif. nos/100 ml Mean	Fec. Colif. nos/100 ml Var	Bacteriophage nos/100ml Mean	Bacteriophage nos/100ml Var
Mohakhali	5	19.58	6.38	2.01E+04	1.93E+08	9.50	1.00
Kachukhet	5	15.98	7.64	9.02E+06	3.00E+14	16.25	6.25
Mirpur	5	10.67	7.21	1.85E+06	6.12E+12	16.67	8.33
Sewra	5	12.80	36.43	2.38E+05	2.69E+10	21.00	2.52
Badda	5	23.00	3.27	2.70E+04	2.91E+08	10.67	0.33
Mohammadp	5	12.57	2.12	1.88E+06	6.40E+12	19.00	12.00
Dhupkhola	5	14.80	15.96	1.83E+06	1.59E+12	7.33	8.33
Goran	5	6.10	3.79	2.20E+05	6.40E+09	10.33	1.33
Average		14.44		1.89E+06		13.84	
Variance		24.02		7.92E+12		21.91	
Mohakhali	10	12.88	4.16	5.50E+03	3.37E+07	5.25	6.25
Kachukhet	10	13.15	4.19	7.15E+05	5.26E+11	10.50	1.00
Mirpur	10	4.97	5.24	7.29E+05	1.04E+12	12.00	19.00
Sewra	10	10.63	38.32	1.09E+05	1.31E+10	19.33	56.33
Badda	10	18.77	1.12	4.15E+03	3.32E+06	13.67	5.33
Mohammadp	10	10.00	1.56	1.31E+07	2.69E+12	9.67	26.33
Dhupkhola	10	9.83	5.00	1.20E+06	1.69E+12	5.00	3.00
Goran	10	5.03	10.02	2.47E+07	1.23E+09	2.33	4.33
Average		10.66		5.07E+05		9.72	
Variance		17.76		7.23E+13		26.33	

Tab. B.2 Average and variance of observed concentrations of selected parameters collected from a depth of 1m

Location	Distance m	Nitrate mg/l Mean	Nitrate mg/l Var	Fec. Colif. nos/100 ml Mean	Fec. Colif. nos/100 ml Var	Bacteriophage nos/100ml Mean	Bacteriophage nos/100ml Var
Mohakhali	5	11.63	11.63	1.89E+05	1.50E+10	6.25	2.25
Kachukhet	5	10.95	9.34	5.30E+05	3.67E+11	14.50	57
Mirpur	5	7.1	1.57	9.63E+05	5.25E+11	26.67	1046.33
Sewra	5	7.63	7.09	1.54E+06	4.91E+12	17.00	97
Badda	5	11	2.92	3.09E+05	7.27E+10	11.00	0
Mohammadp	5	7.8	1.51	1.50E+06	1.10E+12	14.33	0.33
Dhupkhola	5	6.37	3.57	3.43E+05	4.05E+10	1.00	3
Goran	5	3.6	1.09	9.33E+05	5.64E+11	0.00	0
Average		8.26		7.88E+05		11.34	
Variance		6.67		2.5E+11		68.44	
Mohakhali	10	9.2	3.86	2.26E+04	2.55E+08	2.75	11.58
Kachukhet	10	10.83	6.55	2.35E+05	3.46E+10	7.75	8.91
Mirpur	10	4.47	6.3	3.40E+05	3.36E+10	19.00	304
Sewra	10	7.63	10	1.49E+05	5.09E+10	10.67	74.33
Badda	10	9.63	0.3	2.27E+04	4.86E+08	7.33	8.33
Mohammadp	10	6.67	0.54	3.17E+05	1.86E+10	11.00	0
Dhupkhola	10	6.37	0.57	3.43E+05	4.05E+10	1.00	3
Goran	10	2.67	4.05	8.47E+05	5.47E+11	0.00	0
Average		7.18		2.85E+05		7.44	
Variance		6.53		6.0E+10		34.46	

Tab. B.3 Average and variance of observed concentrations of selected parameters collected from a depth of 2m

Location \ Distance m		Nitrate mg/l		Fec. Colif. nos/100 ml		Bacteriophage nos/100ml	
		Mean	Var	Mean	Var	Mean	Var
Mohakhali	5	7.33	0.41	2.92E+04	3.00E+08	1.50	3
Kachukhet	5	6.3	2.74	1.13E+05	9.67E+09	7.75	8.92
Mirpur	5	2.97	1.84	8.53E+04	8.28E+09	7.00	147
Sewra	5	4.6	4.39	8.83E+04	6.48E+09	9.67	1.33
Badda	5	8.57	0.32	2.66E+04	4.71E+08	10.33	1.33
Mohammadp	5	5.56	0.1	2.33E+05	2.23E+08	8.33	26.33
Dhupkhola	5	4.97	0.22	7.00E+04	8.76E+09	1.33	5.33
Goran	5	1.07	0.12	3.50E+05	2.92E+10	0.00	0
Average		5.17		1.24E+05		5.74	
Variance		4.96		1.1E+10		14.90	
Mohakhali	10	6.78	1.79	1.47E+04	4.76E+08	0.00	0
Kachukhet	10	6.73	2.69	7.53E+03	2.69E+07	1.75	4.25
Mirpur	10	3.4	4.69	2.83E+04	5.43E+08	4.67	32.33
Sewra	10	4.87	10.24	1.87E+04	2.23E+07	6.67	34.33
Badda	10	6.07	0.09	4.30E+03	3.79E+06	1.33	5.33
Mohammadp	10	4.83	0	3.33E+04	8.63E+07	5.67	8.33
Dhupkhola	10	4.2	0.21	8.56E+04	6.67E+09	0.00	0
Goran	10	0.87	0.74	9.80E+04	1.31E+10	0.00	0
Average		4.72		3.63E+04		2.51	
Variance		3.37		1.1E+09		6.60	

Tab. B.4 Average and variance of observed concentrations of selected parameters collected from a depth of 3m

Location \ Distance m		Nitrate mg/l		Fec. Colif. nos/100 ml		Bacteriophage nos/100ml	
		Mean	Var	Mean	Var	Mean	Var
Mohakhali	5	2.78	1.23	1.98E+04	1.60E+08	0.00	0
Kachukhet	5	4.88	1.66	5.35E+03	2.82E+07	0.75	2.25
Mirpur	5	1.37	1.85	3.33E+04	3.10E+08	6.67	133.33
Sewra	5	2	1.57	9.37E+03	1.06E+08	1.33	5.33
Badda	5	5.37	0.34	1.25E+04	1.49E+08	1.33	5.33
Mohammadp	5	5.2	0.13	8.20E+04	8.85E+09	2.33	16.33
Dhupkhola	5	3.1	1.47	2.90E+04	3.31E+08	0.00	0
Goran	5	0.53	0.14	1.52E+05	1.10E+10	0.00	0
Average		3.15		4.29E+04		1.55	
Variance		2.95		2.2E+09		4.35	
Mohakhali	10	3.93	0.26	6.00E+03	5.63E+07	0.00	0
Kachukhet	10	5.43	2.2	1.95E+03	1.67E+03	0.00	0
Mirpur	10	2.43	4.74	9.24E+03	1.28E+08	3.67	40.33
Sewra	10	2.6	4.68	8.43E+03	8.37E+07	1.00	3
Badda	10	3.67	0.3	1.06E+03	2.27E+06	0.00	0
Mohammadp	10	4.37	0.08	2.23E+04	2.13E+07	0.00	0
Dhupkhola	10	2.67	0.14	1.27E+04	9.33E+07	0.00	0
Goran	10	0.3	0.12	2.13E+04	7.23E+07	0.00	0
Average		2.88		1.04E+04		0.58	
Variance		2.09		5.63E+07		1.47	

Tab. B.5 Water Quality Survey Results of WASA Production Wells

Sampling Period: September 1985

Well Location	Conductivity µ-S/cm	Chloride mg/l	pH	Hardness mg/l
1. Mirpur II	245	32	6.8	62
2. Mirpur XI	247	38	6.8	72
3. Mirpur X	210	30	6.9	73
4. Mirpur II	260	32	6.8	40
5. Dhakeswari	420	115	6.5	180
6. I.G. Bagan	245	26	6.6	75
7. Mirpur VI	215	39	6.8	61
8. Laxmibazar	210	70	6.7	160
9. Abul Hasnat Road	200	140	6.7	255
10. Dhanmondi VI	275	75	6.7	118
11. Bonogram II	210	156	6.9	94
12. Gandaria II	270	38	6.6	75
13. J.N. College II	525	139	6.9	220
14. Kawran Bazar	260	29	6.3	155
15. Rayer Bazar	285	73	6.8	144
16. Lichubagan II	340	53	6.5	100
17. Bashaboo II	185	68	6.7	120
18. Peelkhana II	450	125	6.6	219
19. Tejgaon VIII	195	72	6.7	82
20. Khilgaon III	300	83	6.9	110
21. Elephant Road	360	69	6.7	113
22. Mohakhali I	210	76	6.9	99
23. Banani III	190	26	6.9	72
24. Mohammadpur VI	275	49	6.8	105
25. Dhaka Water Works	235	38	6.6	96
26. Kakrail	315	53	6.5	90
27. Shahjahanpur II	390	50	6.7	87
28. Bara Moghbazar II	285	33	6.5	159
29. Dhanmondi VIII	315	93	7.0	145
30. Gulshan V	195	20	6.7	89
31. Agamashi Lane	235	142	6.9	249
32. Mirpur XII	275	43	6.9	70
33. Mirpur VII	295	30	6.7	85
34. Nawabganj II	335	160	6.7	246
35. High Court	300	50	6.9	78
36. Mohammadpur VIII	325	40	7.0	69
37. Zikatola	300	174	6.9	205
38. Green Road III	310	34	6.5	95
39. Rajarbagh II	350	50	6.4	70
40. Lalmatia II	285	36	6.7	125

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Well Location	Conductivity µ-S/cm	Chloride mg/l	pH	Hardness mg/l
41. Hatkhola	185	40	6.6	96
42. Azimpur VI	400	80	6.8	200
43. Tejgaon VIII	185	40	6.6	80
44. Hazaribagh II	255	72	6.8	146
45. Nawabpur	320	40	7.0	78
46. Millbarrack	260	26	6.8	69
47. Dayaganj	285	78	6.8	120
48. Bangladesh Math	205	130	6.6	215
49. Armanitola Math	215	92	6.8	170
50. Lalmatia IV	270	32	6.7	125
51. Shyamoli	315	36	6.9	80
52. Rahmatullah High School	225	118	6.7	221
53. Khilgaon IV	290	81	6.3	132
54. Banani IV	155	23	6.8	65
55. Peelkhana III	600	140	6.4	225
56. Green Road IV	290	82	6.7	169
57. Maniknagar	200	40	6.3	110
58. S.D. Park II	325	88	6.6	199
59. Bijoynagar III	275	58	6.6	105
60. Mitford III	195	76	6.7	162
61. Azimpur III	380	95	6.6	193
62. Khilgaon V	245	86	6.4	97
63. Hazaribagh III	240	105	6.9	196
64. Laleswarai	205	26	6.5	60
65. Indira Road	325	41	6.6	93
66. Farashganj II	420	62	6.8	125
67. Dhupkhola	300	45	6.5	73
68. Bangla College	220	56	6.6	63
69. Laboratory School	240	68	6.5	104
70. Pallabi II	250	29	6.8	83
71. Saidabad II	265	76	6.8	105
72. Sukrabad II	320	29	6.8	133
73. Fakirapool II	340	53	6.7	112
74. Dhania	310	85	6.6	80
75. Fulbaria III	285	139	6.8	200
76. Jurain	305	23	6.5	31
77. Baldha Grarden	280	110	6.6	79
78. Sangsad Bhaban II	200	51	6.9	86
79. Goran	190	28	6.5	82
80. Sewra	325	29	6.8	70
81. D.O.H.S. (Mohakhali)	175	76	6.8	76
82. Modhubagh	260	24	6.8	90
83. Simpson Road	300	60	6.8	126
84. Bakshibazar	270	96	6.6	175
85. Kallyanpur	270	35	6.9	73
86. Uttara II	180	44	6.7	92
87. Senpara	295	40	6.6	76

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Well Location	Conductivity µ-S/cm	Chloride mg/l	pH	Hardness mg/l
88. Pagla	350	49	7.0	80
89. Mirpur XIV	220	32	6.6	79
90. Motijheel	310	39	6.0	101
91. Rajarbagh II	400	54	6.2	91
92. Malibagh	295	55	6.9	90
93. Mughdapara	240	40	6.9	79
94. Narinda II	295	68	6.7	149
95. F.D.C.	275	27	6.7	160
96. Gandaria	265	59	6.5	102
97. Madartek	190	29	7.0	89
98. Mohakhali	205	36	6.8	73
99. Asad Gate	265	46	6.6	76
100. Uttara I	185	52	6.8	102
101. Zymkhana	340	60	6.7	169
102. Gulshan IV	190	27	6.8	61
103. Elephant Road II	325	69	6.8	103
104. Banga Bhaban	220	151	6.7	107
105. Medical College	310	93	6.9	192

Source: Report on groundwater data collection witnin Dhaka city, AHMED (1986)

APPENDIX C

(Grain Size Distribution Curves)

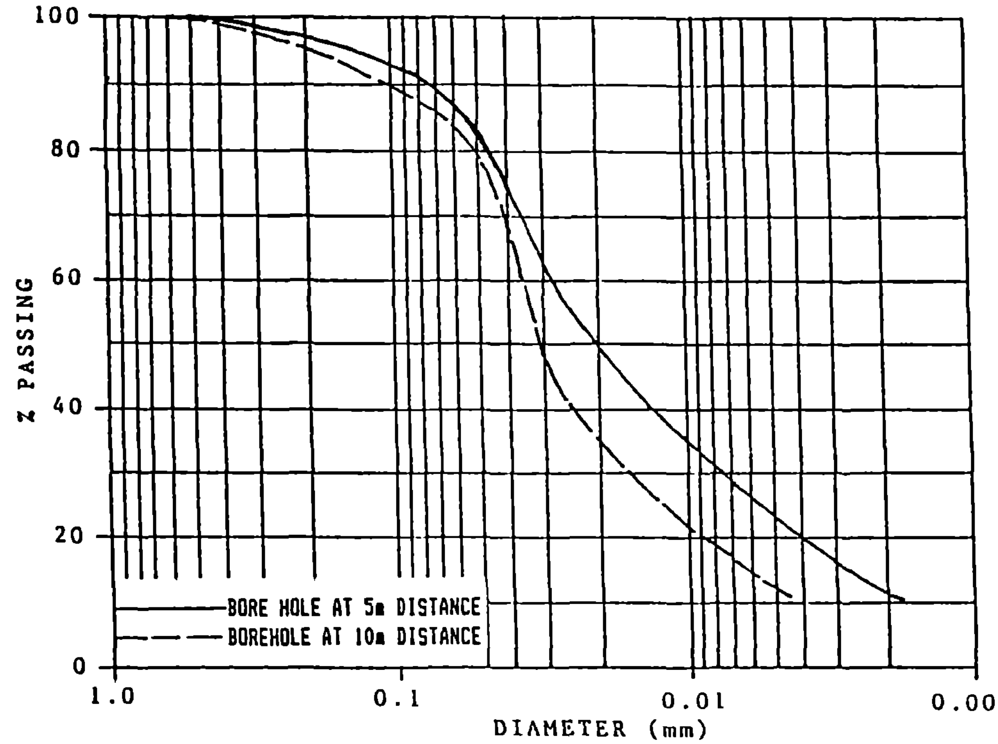

Fig. C.1 Grain size distribution of the soil samples collected from the sampling boreholes at Mohakhali

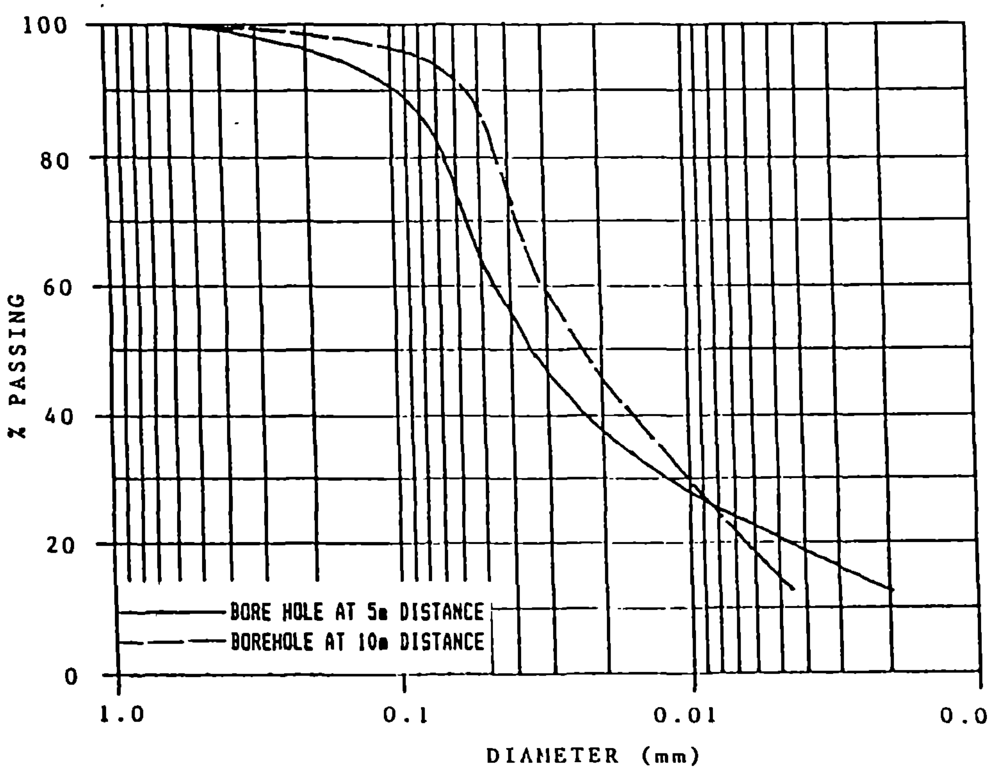

Fig. C.2 Grain size distribution of the soil samples collected from the sampling boreholes at Kachukhet

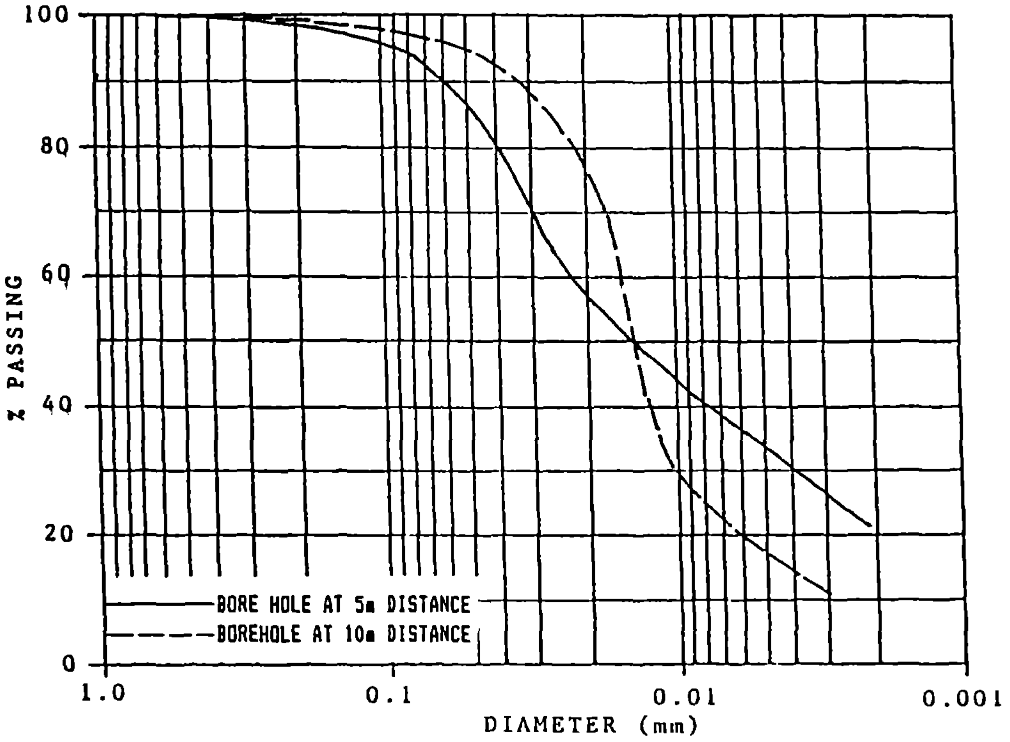

Fig. C.3 Grain size distribution of the soil samples collected from the sampling boreholes at Mirpur

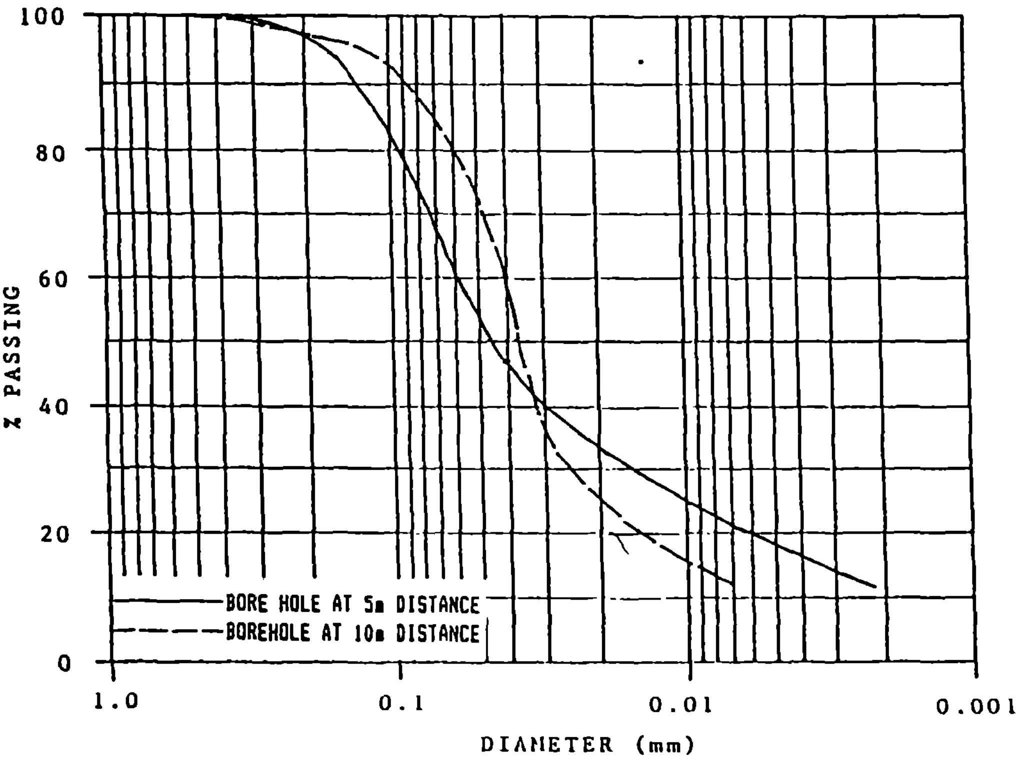

Fig. C.4 Grain size distribution of the soil samples collected from the sampling boreholes at Sewra

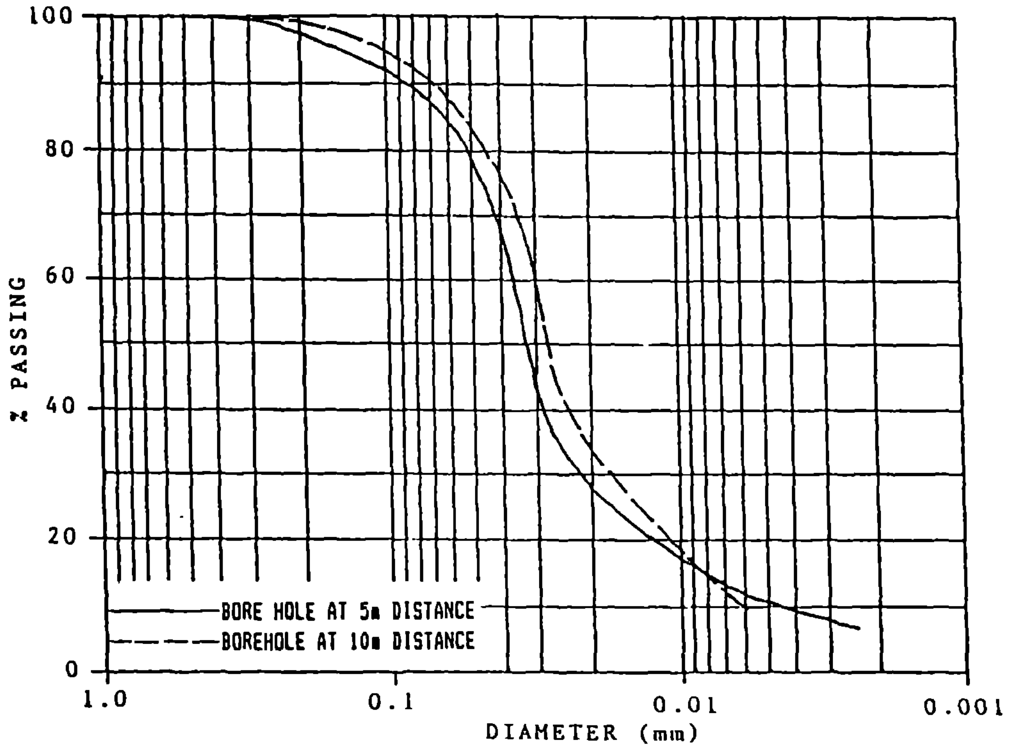

Fig. C.5 Grain size distribution of the soil samples collected from the sampling boreholes at Badda

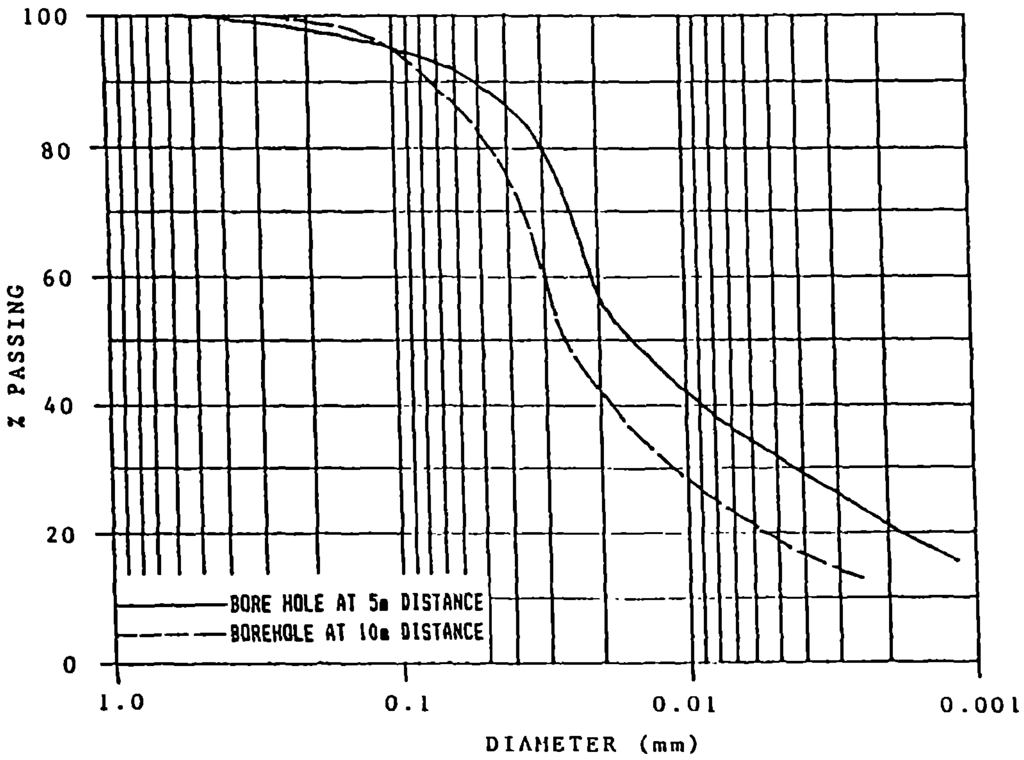

Fig. C.6 Grain size distribution of the soil samples collected from the sampling boreholes at Mohammadpur

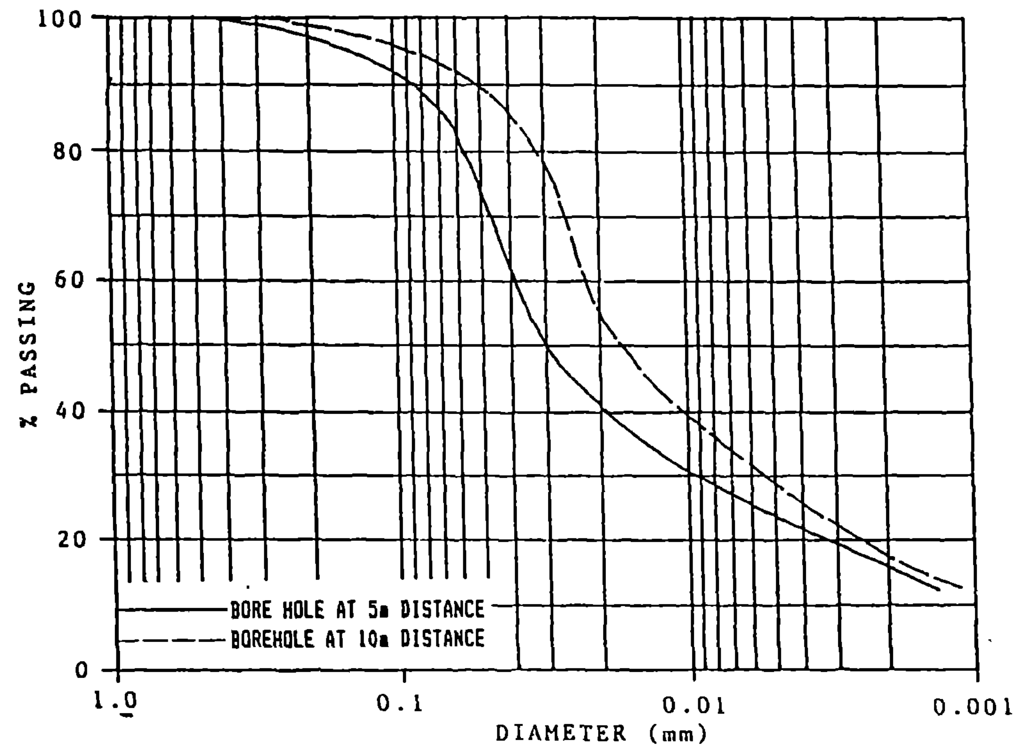

Fig. C.7 Grain size distribution of the soil samples collected from the sampling boreholes at Dhupkhola

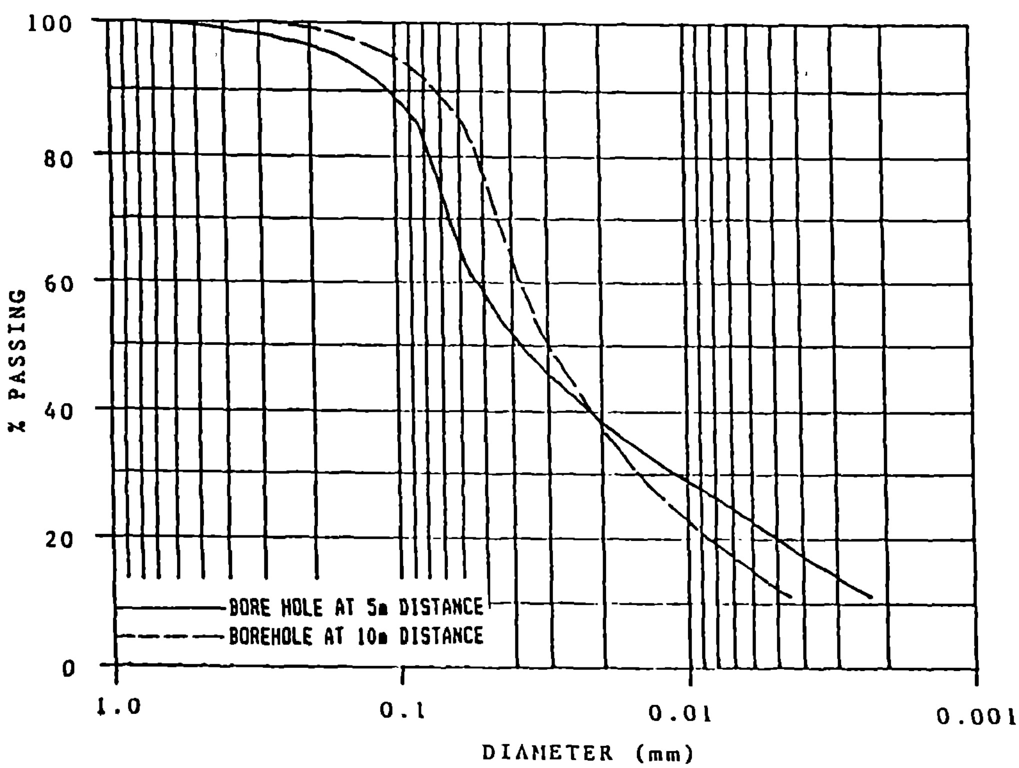

Fig. C.8 Grain size distribution of the soil samples collected from the sampling boreholes at Goran

APPENDIX D

(Additional Figures)

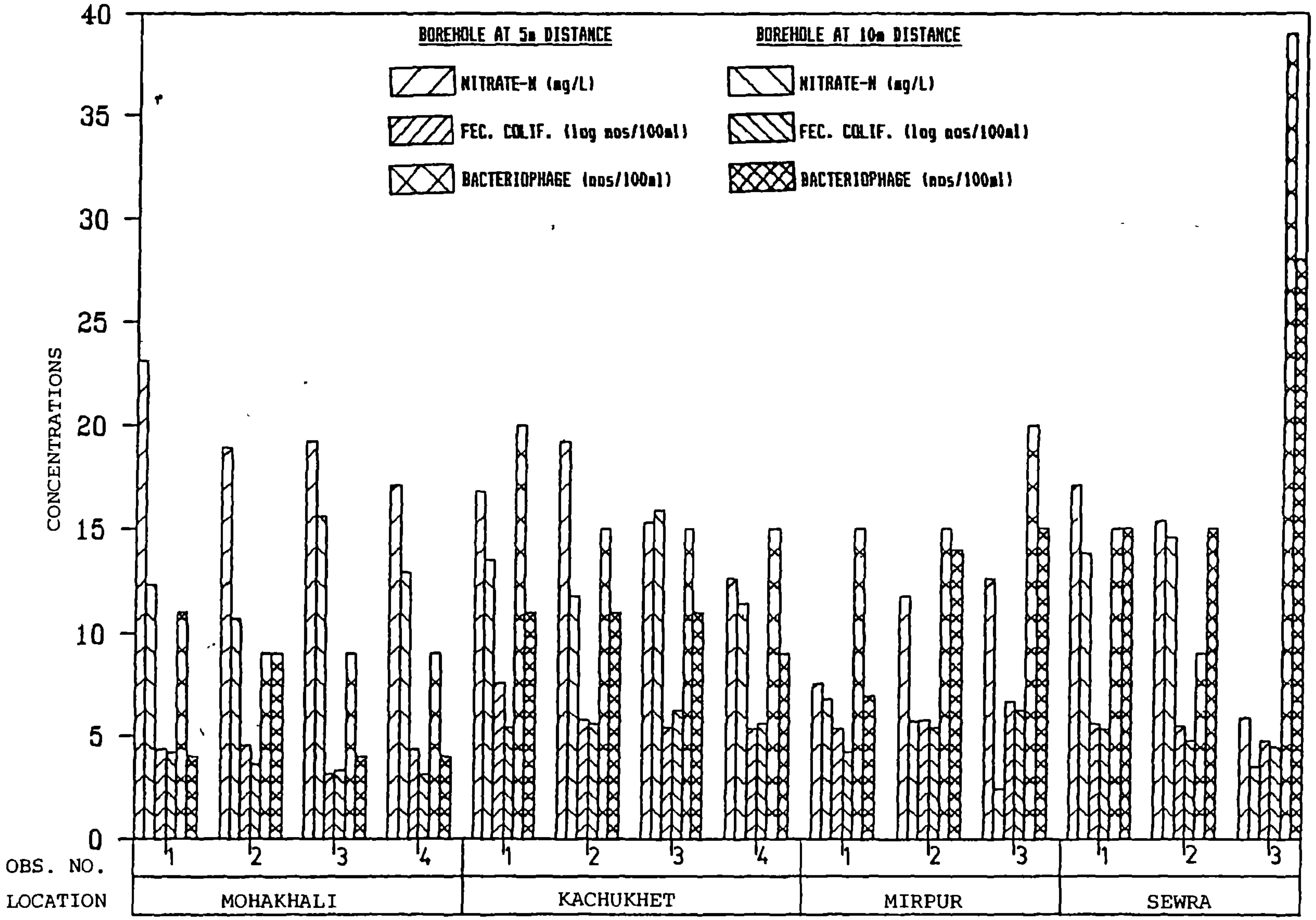

Fig. D.1 Change in concentration of pollutants of fecal origin in the soil samples collected from the surface of the boreholes at locations Mohakhali, Kachukhet, Mirpur, and Sewra

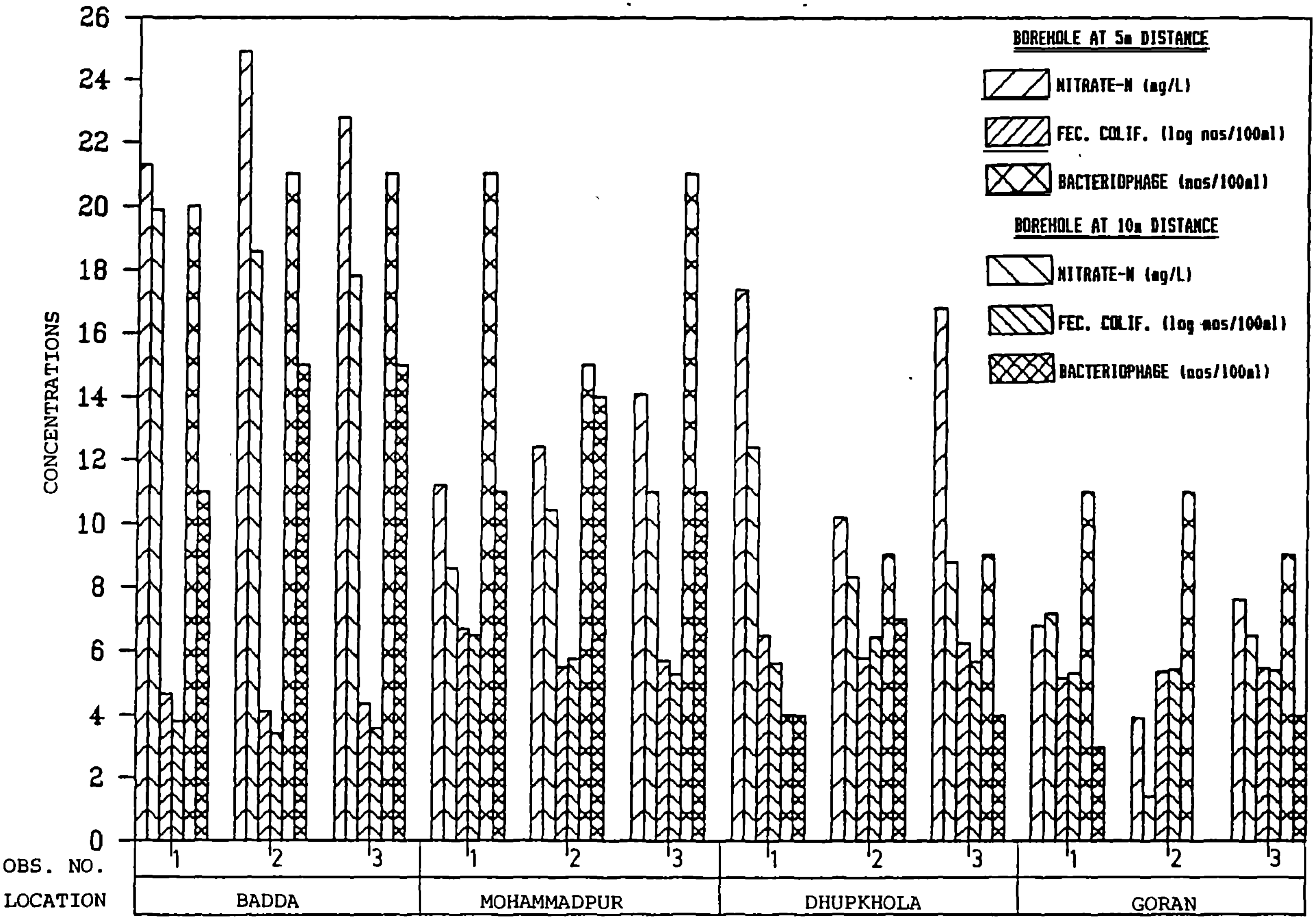

Fig. D.2 Change in concentration of pollutants of fecal origin in the soil samples collected from the surface of the boreholes at locations Badda, Mohammadpur, Dhupkhola, and Goran

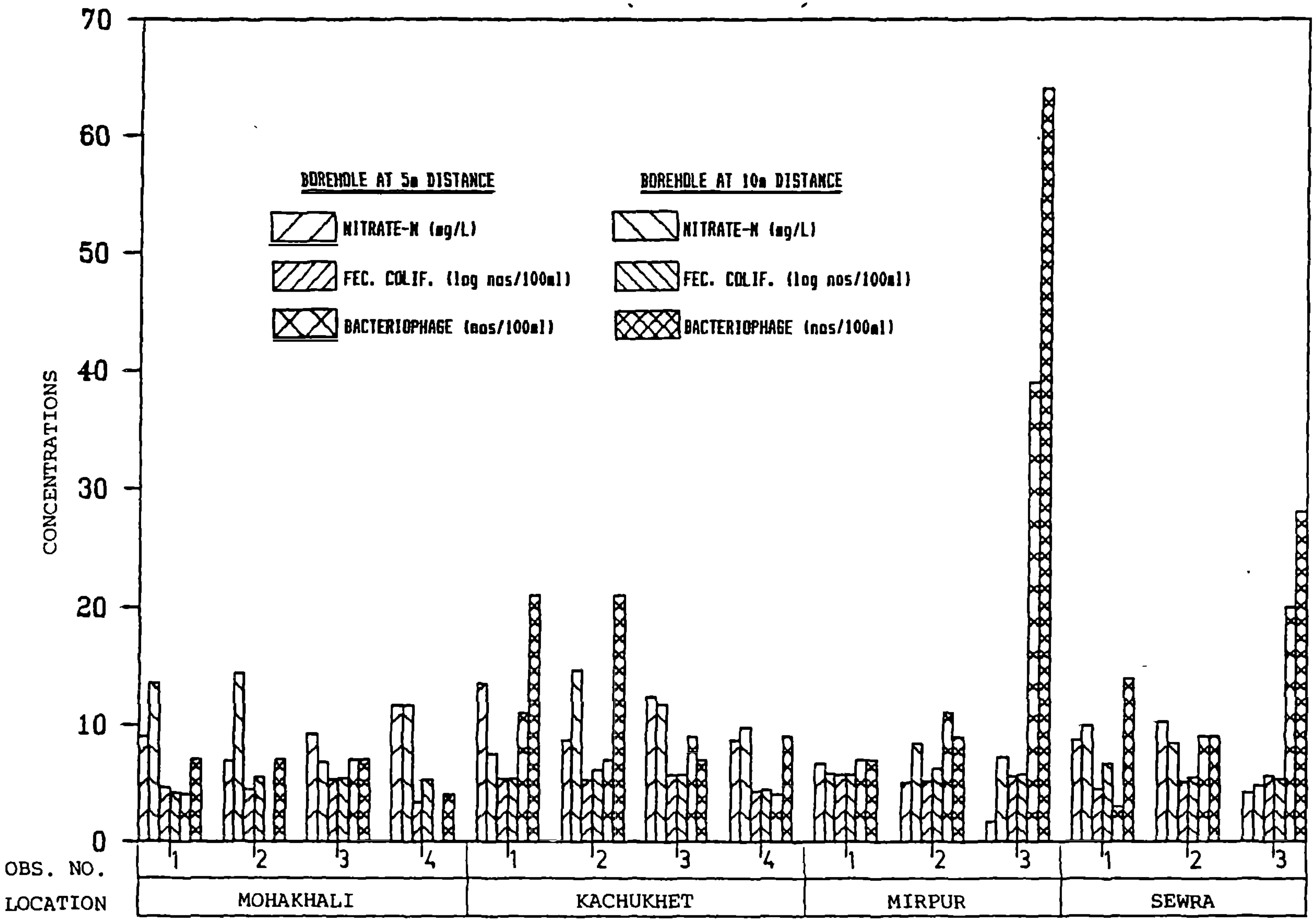

Fig. D.3 Change in concentration of pollutants of fecal origin in the groundwater samples collected from a depth of 1 m from the boreholes at locations Mohakhali, Kachukhet, Mirpur, and Sewra

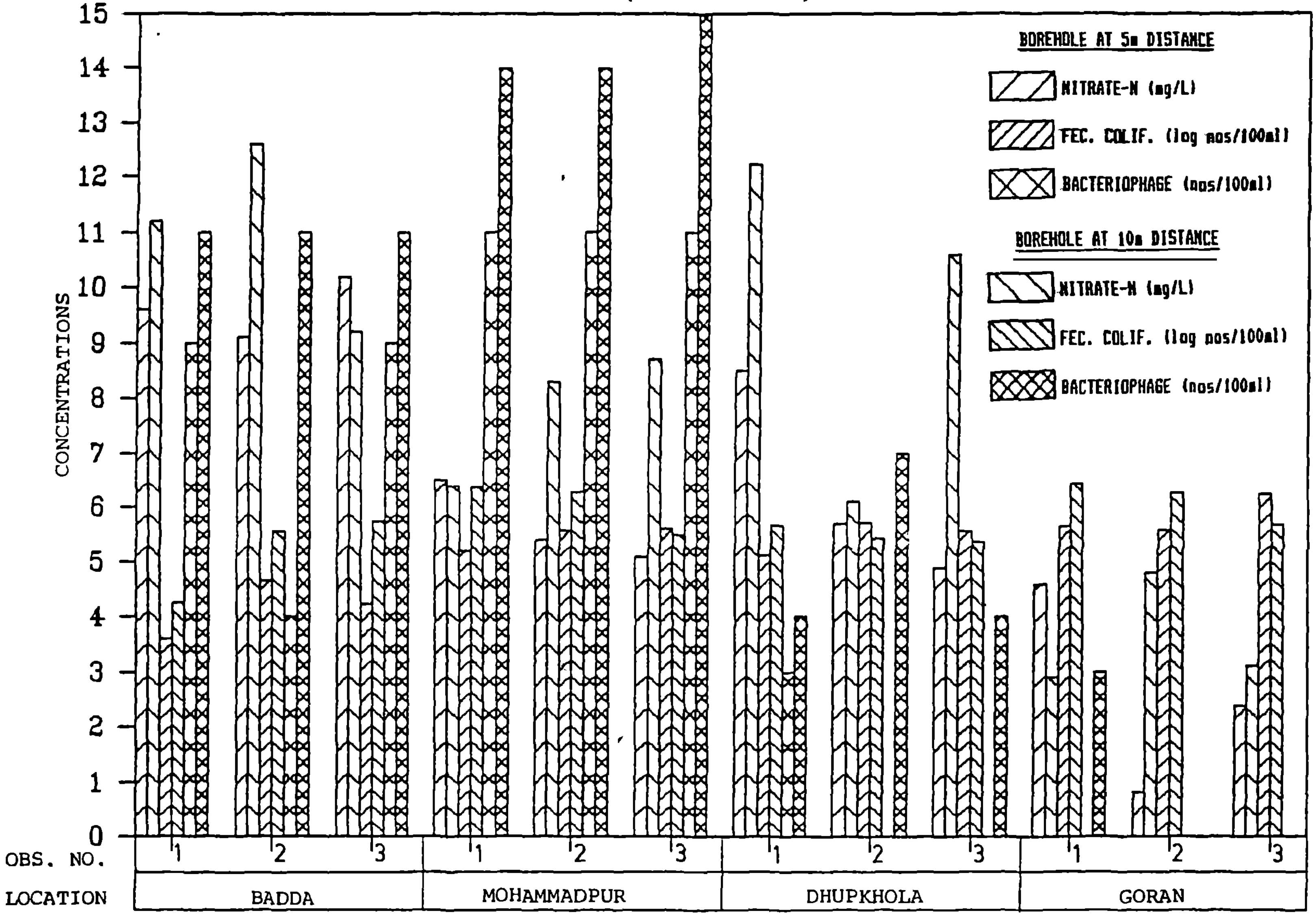

Fig. D.4 Change in concentration of pollutants of fecal origin in the groundwater samples collected from a depth of 1 m from the boreholes at locations Badda, Mohammadpur, Dhupkhola, and Goran

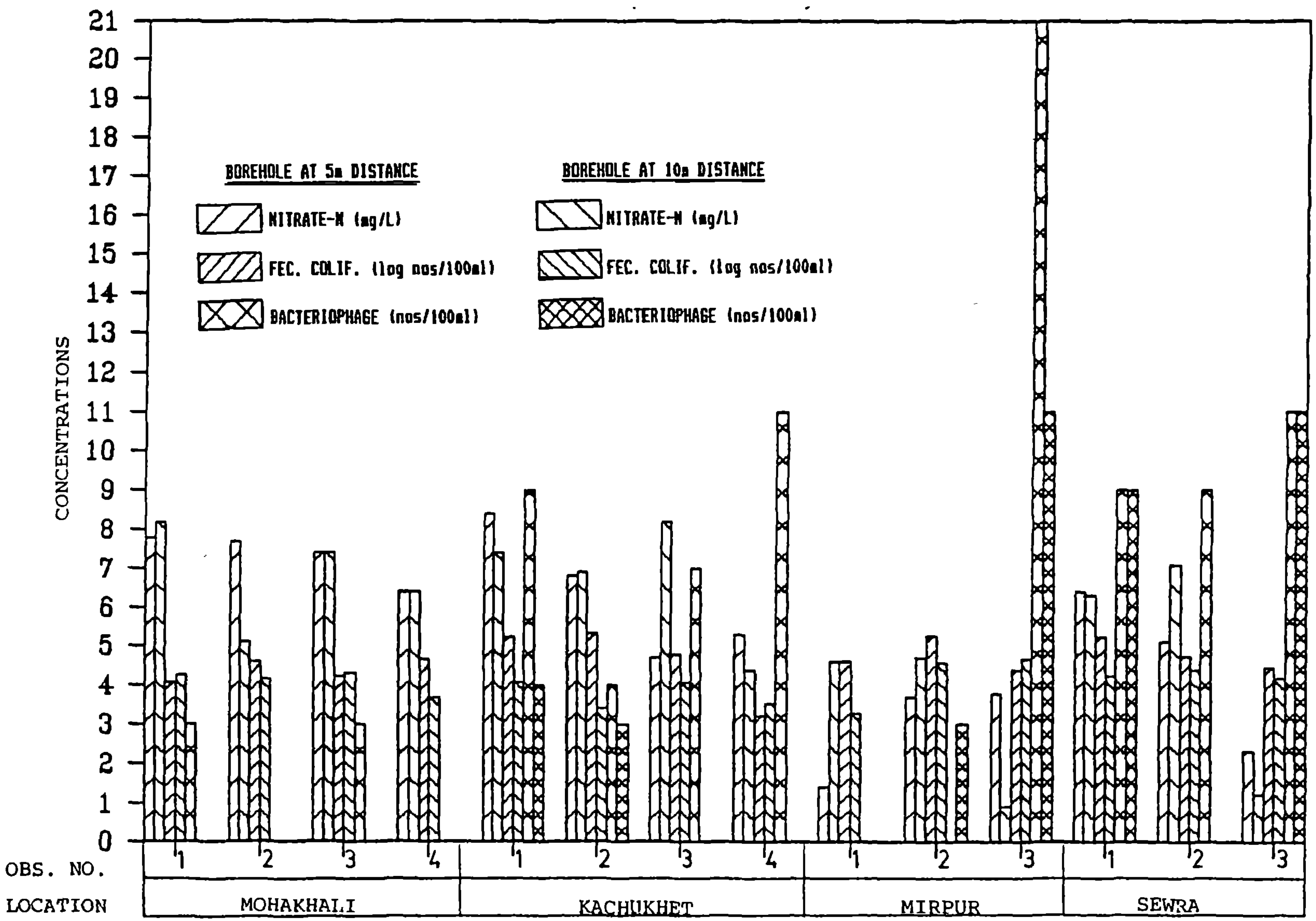

Fig. D.5 Change in concentration of pollutants of fecal origin in the groundwater samples collected from a depth of 2 m from the boreholes at locations Mohakhali, Kachukhet, Mirpur, and Sewra

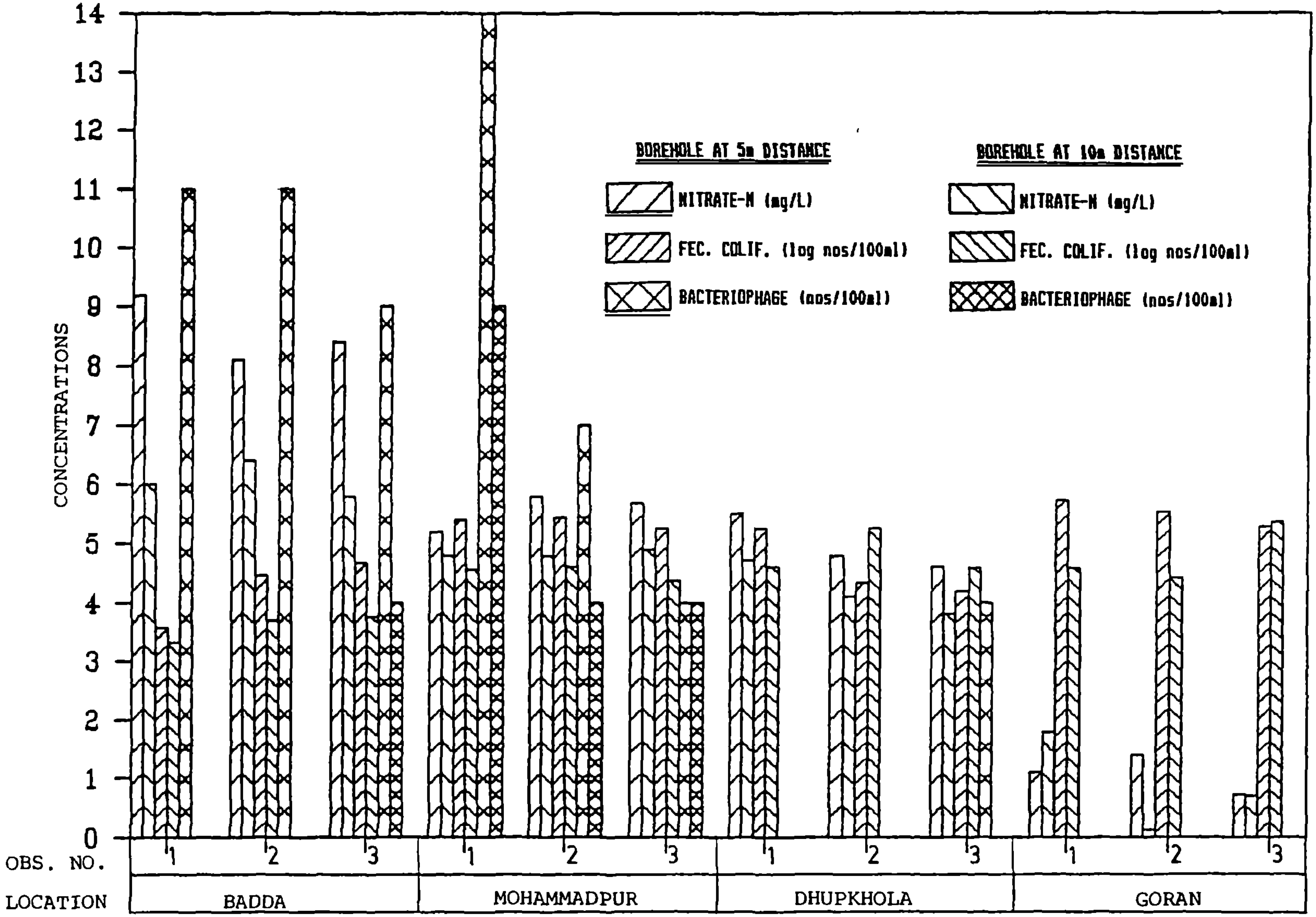

Fig. D.6 Change in concentration of pollutants of fecal origin in the groundwater samples collected from a depth of 2 m from the boreholes at locations Badda, Mohammadpur, Dhupkhola, and Goran

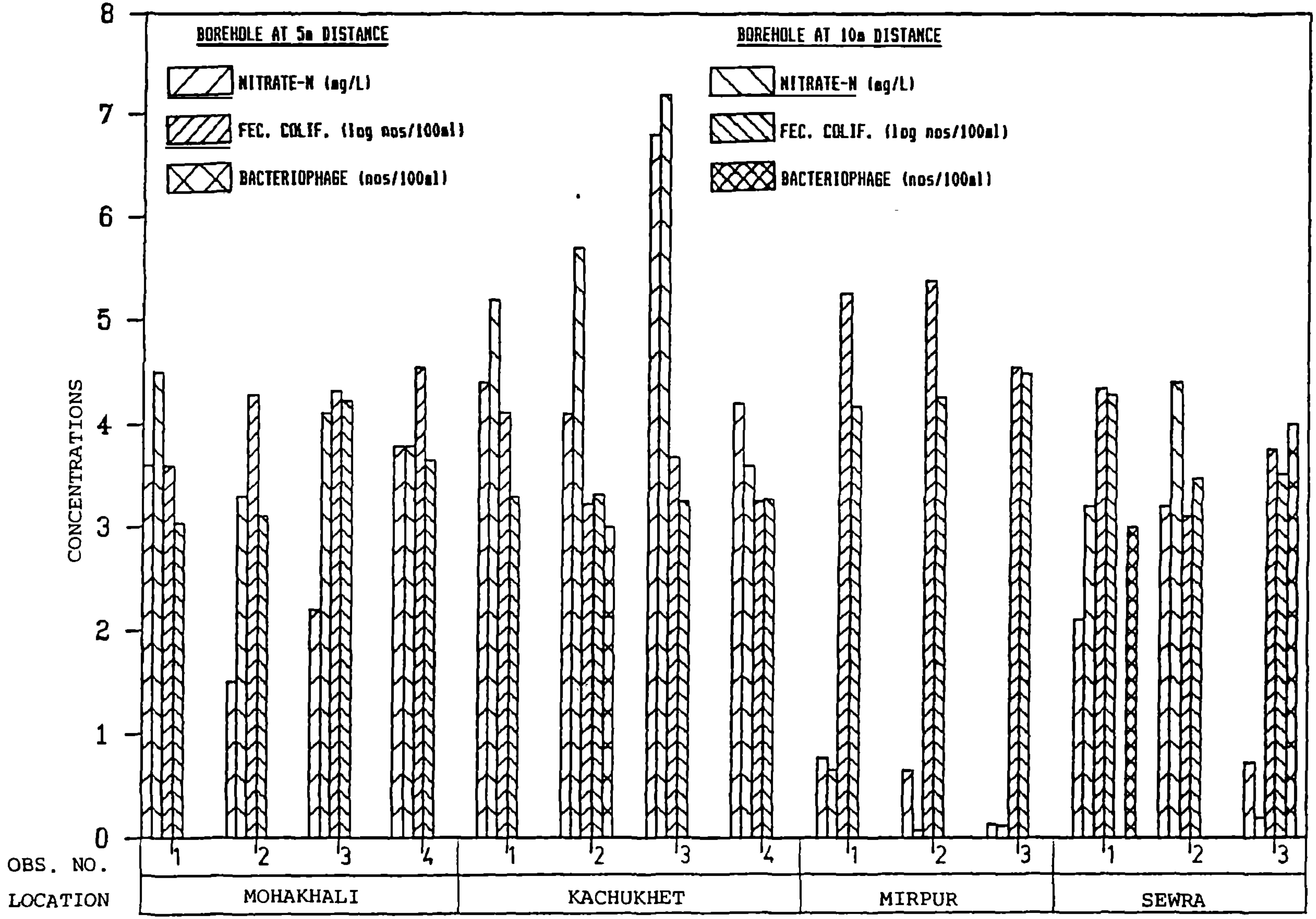

Fig. D.7 Change in concentration of pollutants of fecal origin in the groundwater samples collected from a depth of 3 m from the boreholes at locations Mohakhali, Kachukhet, Mirpur, and Sewra

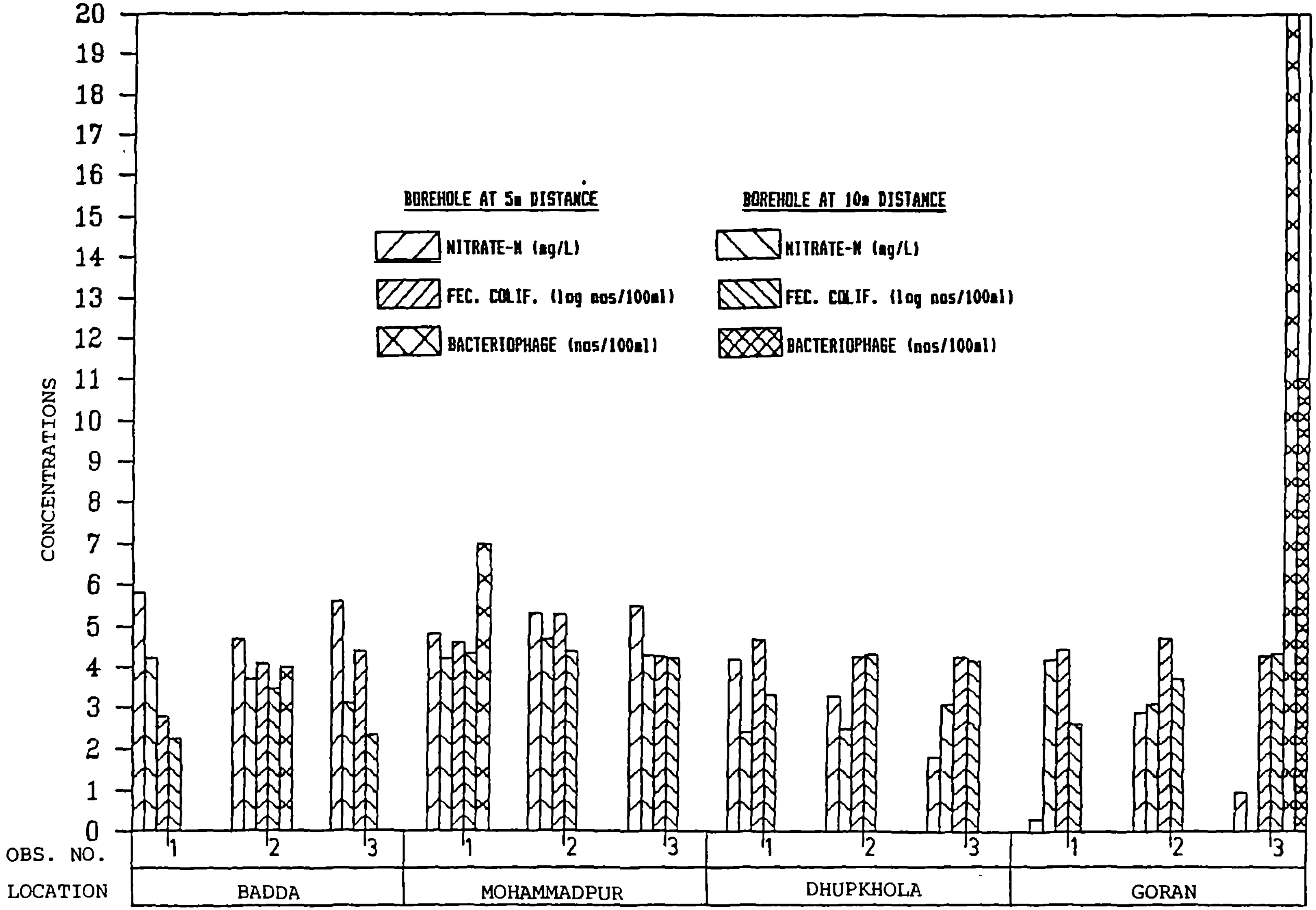

Fig. D.8 Change in concentration of pollutants of fecal origin in the groundwater samples collected from a depth of 3 m from the boreholes at locations Badda, Mohammadpur, Dhupkhola, and Goran

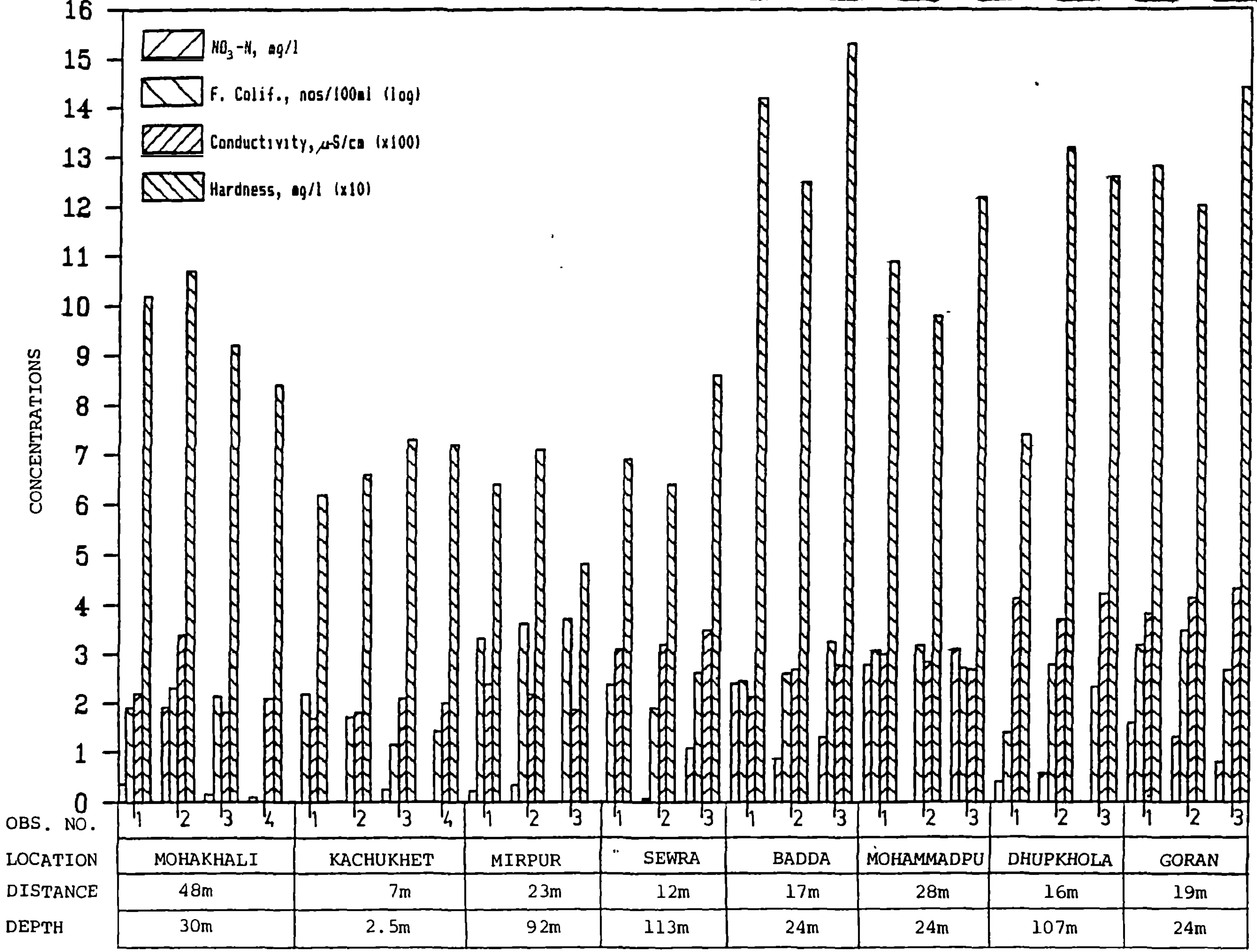

Fig. D.9 Change in concentration of selected parameters in the groundwater samples collected from the water intake sources nearest to the on-site schemes at the sampling locations

APPENDIX E

(Illustrations)

Fig. E.1 Drilling borehole near a septic tank

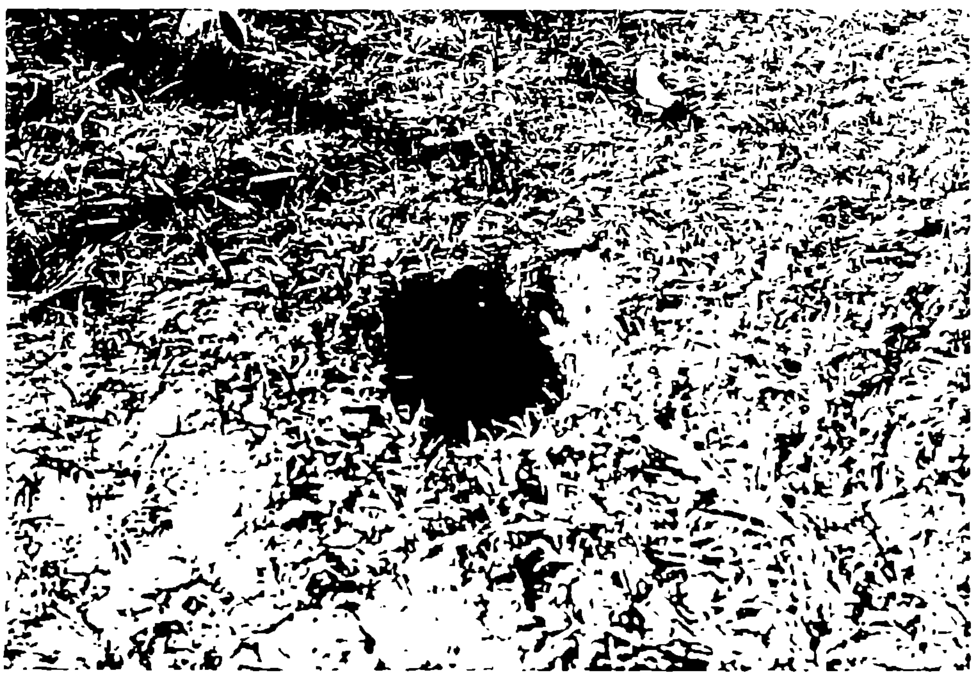

Fig. E.2 Borehole after drilling

Fig. E.3 A typical "katcha latrine"

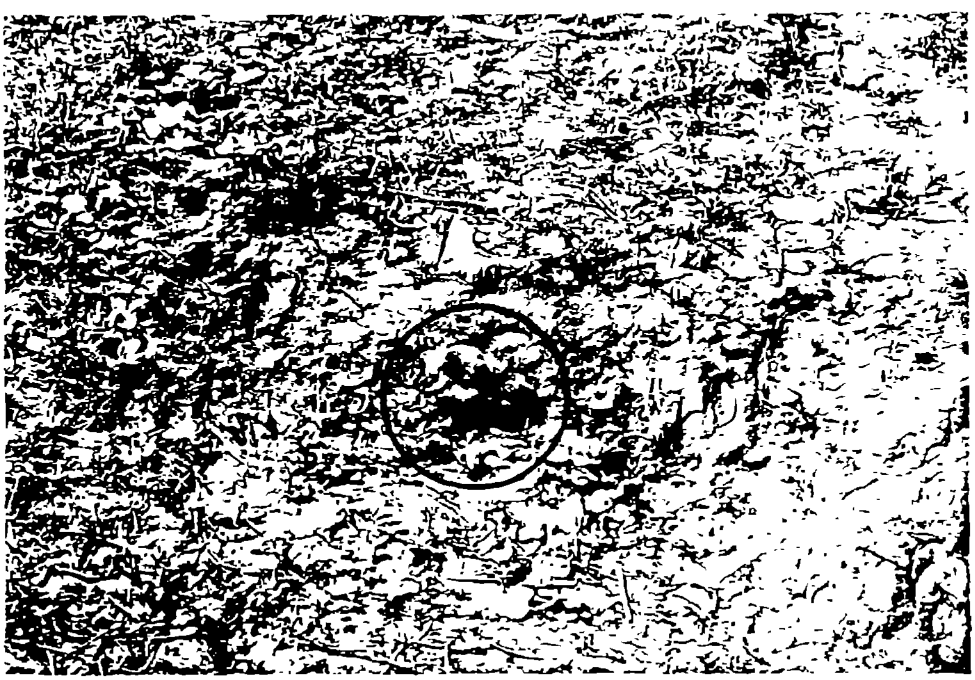

Fig. E.4 Defecation on open surface

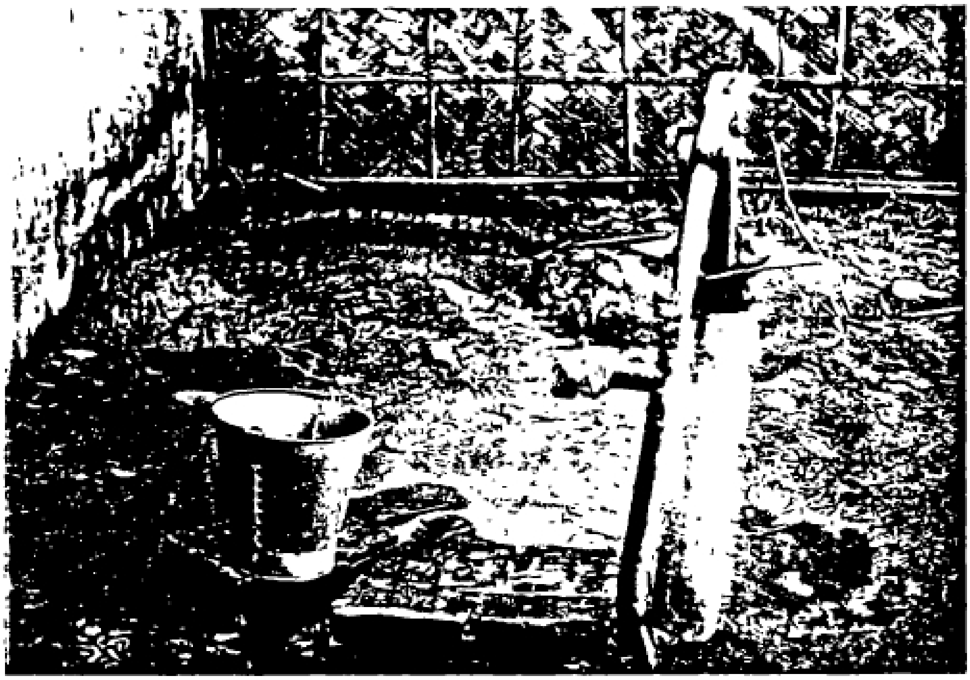

Fig. E.5 A typical hand-pumped well