# Hydrostratigraphy and Aquifer Piezometry of Dhaka City

A project by:

Mohammad Abdul Hoque

In partial fulfillment of the requirement for the Post Graduate Diploma in Water Resources Development



October 2004

**Institute of Water and Flood Management**
**Bangladesh University of Engineering and Technology**
**Dhaka 1000, Bangladesh**

# Bangladesh University of Engineering and Technology
# Institute of Water and Flood Management

The project titled 'Hydrostratigraphy and Aquifer Piezometry of Dhaka City' submitted by Mohammad Abdul Hoque, Roll no. DF 0328021, Session: April2003-March 2004, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Post Graduate Diploma in Water Resources Development on 31October 2004.

BOARD OF EXAMINERS

..........................................
Dr. M. Mozzammel Hoque
Professor
IWFM, BUET

Chairman

..........................................
Dr. Sayed Mahibuddin Ahmed
Professor
IWFM, BUET

Member

..........................................
Dr. Abul Fazal M. Saleh
Professor
IWFM, BUET

Member

# CANDIDATE'S DECLARATION

It is hereby declared that this project or any part of it has not been submitted elsewhere for the award of any degree or diploma.

..............................................
Mohammad Abdul Hoque

*Dedicated to "the friends of water & environment"*

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF ABBREVIATIONS

| | |
|---|---|
| BUET | Bangladesh University of Engineering and Technology |
| BWDB | Bangladesh Water Development Board |
| cps | counts per second |
| DTW | Deep Tube Well |
| DWASA | Dhaka Water Supply and Sewerage Authority |
| EM | Electro Magnetic |
| EPC | Engineering and Planning Consultants |
| ft | feet |
| gpd/ft | gallon per day/feet |
| gpm | gallon per minute |
| GPS | Global Positioning System |
| IWFM | Institute of Water and Flood Management |
| l/s/m | liter/second/meter |
| m | meter |
| $m^3$ | cubic meter |
| MMP | M. Macdonald and Partners |
| MSL | Mean Sea Level |
| n | number of sample |
| NE | North East |
| O H | Oxygen Hydrogen |
| PW | Production Well |
| RG | Robertson Geo-logging |
| $R^2$ | Co-efficient of correlation |
| SE | South East |
| 3 D | 3 Dimensional |

# ACKNOWLEDGEMENT

I specially acknowledge and express my gratitude to my project supervisor Dr. M Mozzammel Hoque, Professor, IWFM, BUET for his friendly co-operation, providing me the guidelines, and valuable suggestions through out the period of research work and during the preparing of the project paper.

I am very grateful to the members of the exam committee Professor Dr. Sayed Mahibuddin Ahmed and Professor Dr. Abul Fazal M. Saleh, IWFM, BUET for their review and valuable suggestions in improving the project paper.

I am very grateful to Dr. Alexander van Geen, Doherty Senior Research Scientist, Lamont-Doherty Earth Observatory, New York, USA and Dr. Kazi Matin Ahmed, Professor, Department of Geology, Uinversity of Dhaka for their kind permission to use the geophysical logger. I would like to thanks again Dr. Ahmed for his co-operation and suggestions throughout the research period. I am also very grateful to Professor Dr. Aftab Alam Khan and Professor Dr. A. S. M. Woobadullah of the same institute for their valuable suggestions and co-operation during the research period.

Discussion with many people has enriched my conceptions and knowledge about the Dhaka groundwater system. It is my pleaser to acknowledge Dave Clark of USGS, S. H. Baksh of DWASA, Anwar Zahid of BWDB for their enlighten discussions.

I like to express my gratefulness to Razib Mostafa, M. Shamsudduha, Md. Shahadat Hossain, and Tariqul Islam for their helps in the field and inspirations & warm company during the research.

I have the opportunity to put into words my immense love and 'appreciations to my wife for her endless love, encouragement, and inspirations without which I find everything unfinished and barren.

I am very happy to express my appreciation to the DWASA, and BWDB for their data support. The research is supported by the IWFM, BUET.

9 November 2004 Mohammad Abdul Hoque

# ABSTRACT

Dhaka, the capital of Bangladesh, has one of the fastest urban growth rates among the developing countries. Groundwater of Dhaka city occurs in the Dupi Tila sandy aquifer of Plio-Pleistocene age and almost only source of potable water in the city. Abstraction by water wells is the main discharge and causing dewatering of the aquifer. The research is aimed to understand the hydrostratigraphy and piezometry of the depleted aquifer.

Present study has used lithological and geophysical resistivity log information to build hydrostratigraphy of the area. Dhaka WASA groundwater abstraction and well design information, and BWDB Groundwater level data have been used to reconstruct the piezometry of the aquifer.

A thick column of unconsolidated sediments composed of sands, silts and clays build the hydrostratigraphy of the region and provisionally subdivided into 7 units up to a depth of 450m. These units organized into three aquifers system separated by clay-silt dominated horizons. The average thickness of the first aquifer ranges from 100-150m while second aquifer ranges from 50-100m. A thick clay layer of 37-128m is followed by the second aquifer and capping the third aquifer of uniform thickness (~40m). Third aquifer is based by another clay dominated layer.

Long term hydrographs from the different parts of the city specify the increasing trend of drop in water level throughout the city ($R^2$=0.75-0.94, n=12). Groundwater abstraction in the city has increased more than 1200% from 1970 to 2003. This increased abstraction causing sharp drop of water level throughout the city and excessive high rate of production in the south-central and south-western region formed cones of depression

The Hydrostratigraphy and piezometry of the first aquifer indicate higher vulnerability of groundwater in the central city area. Information on quality and quantity of water in the lower aquifers (second and third aquifer) are still inadequate. Resource assessment of the lower aquifers require adequate hydrogeological data to establish system geometry and continuity, aquifer transmissivity, and areas and rate of annual recharge to consider the lower aquifers' as potential groundwater source. To meet the present crisis of potable water abstraction has to be under taken from the peripheral region of the city. For long-term sustainable solution peri-urban well-fields have to be established and conjunctive use of groundwater and surface water should be adopted.

# Chapter One
# Introduction



## 1.1 Background

Dhaka, the capital city of Bangladesh, located in the central part of the country on the river Buriganga. It covers an area of greater than 250sqkm and home to more than ten million people. 84.33% of the municipal water supply for the domestic use comes mostly from groundwater. A small fraction (15.67%) is collected from the surface water (WASA, 2003).

The hydrodynamics of the study area is characterized by a large number of interconnecting rivers and multiple aquifer system. Hydrostratigraphically groundwater of Dhaka city occurs in the Dupi Tila sandy aquifer of Plio-Pleistocene age overlain by thick sequence of Madhupur clay. In some places the Dupi Tila sands are exposed along the river sections of the surrounding riverbeds (Ahmed et al., 1999; MMP/HTS, 1992). From the geologic point of view these rivers are flowing along the margin of the elevated terrace surrounding the city area over the downthrown block enhancing the opportunity to recharge the aquifer.

Systematic groundwater development started in Dhaka city from 1949 and available records show that groundwater abstraction in the city has increased more than 700% from 1960 to 1995 (Ahmed et al., 1998). Long-term hydrographs of Dhaka city show a continuous decline in the water level with little or even no fluctuation, indicative of an overexploited aquifer and the rate of decline ranges between 0.75m/y and 1.5m/y at different observation locations within the city (Ahmed et al., 1998). Large-scale abstraction has resulted in an extensive cone of depression in the central part of the City. There are number of urbanization practice significantly reduce the recharge in the aquifer. The steep piezometric gradient close to the rivers demonstrate that the periphery of the city area is replenished by the leakage induced from the rivers (BUET, 2000; Darling et al, 2002).

Large-scale abstractions always bring changes in the natural system of the aquifer and also in the environment (e.g. Chawala, 1994; Eisen and Anderson, 1980; Ford and Tellam, 1994; Somasundaram et al., 1993). The Dupi Tila, the main aquifer in Dhaka city area hydrostatically had become unconfined across the southern half of the metropolitan from its initial confined nature. The water quality is in the state of degraded due to overexploitation (Ahmed et al., 1995; Ahmed et al., 1998; Ahmed et al., 1999; Morris, et. al., 2003). To meet the ever-increasing demand of the city dwellers, WASA has undertaken a program for abstraction of more groundwater from the aquifer beneath the city. Presently, Dhaka WASA producing 1160.21 Million Litres of groundwater per Day as urban water supply through 389 DTW (WASA, 2003). It is an urgent need to study the hydrostratigraphy and consequence piezometric response to the recharge mechanism before dewatering the aquifers

The overview can be summarized as following:

- Groundwater of Dhaka city occurs in the Dupi Tila sandy aquifer of Plio-Pleistocene age overlain by thick sequence of Madhupur clay.
- Dhaka is mostly dependent on the groundwater for urban water supply.
- Groundwater abstraction exceeds recharge and in corollary, extensive areas of the aquifer beneath the central Dhaka are experiencing substantial dewatering.
- Deterioration of groundwater quality would result from the overexploitation.
- The current understanding of the groundwater system and the lack of research make competent management of the resources very difficult.

**1.2 Objectives**

The research is carried out with a view to the following objectives:

- to understand the hydrostratigraphy, and
- to evaluate the piezometry of the overexploited Dhaka urban aquifer.

# Chapter two

# Description of the study area

Dhaka, the capital city of Bangladesh, is the study area for the research project. It lies between 23°40″N-23°54″N latitude and from 90°20″E-90°31″E longitude. In the current study main thrust is given only within the metropolitan area and in some cases environs control were also taken into consideration (Figure 2.1). It is separated from the environs by the Tongi Khal in the North, the Buriganga River in the south & southeast, the Balu River in the east and Turag in the west.

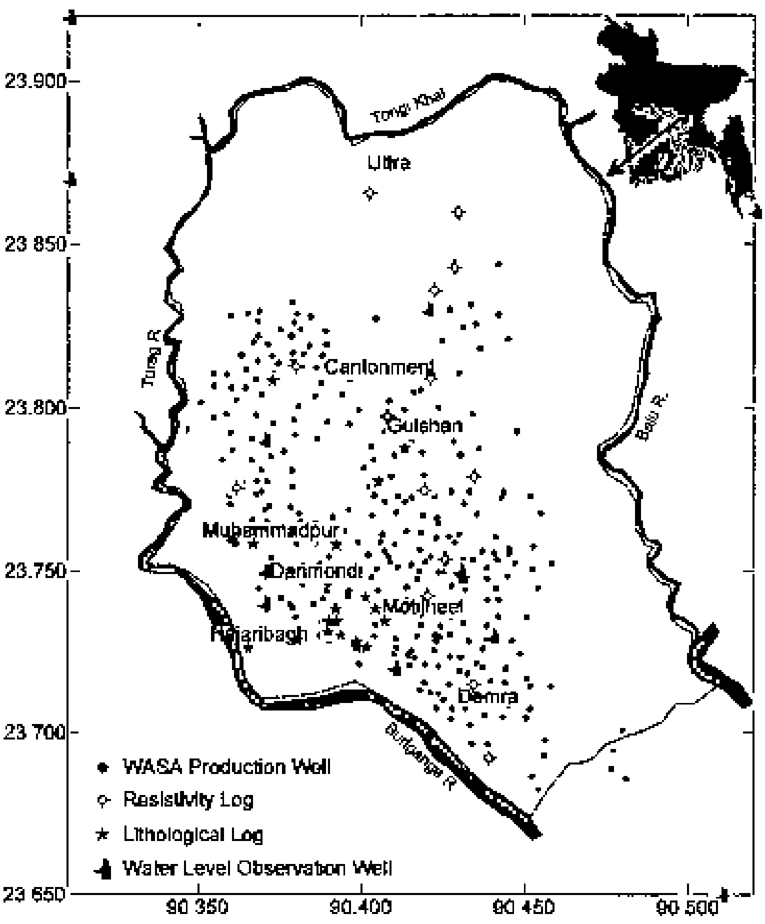



**Figure 2.1:** Location of the study area Dhaka-Capital of Bangladesh with different types of data points' location used in this study

### 2.1 Topography and Surface Geology

The area of the city is 250 square km and has a population of more than ten million. The city has a history of 300 years and over this time the city has expanded from 1.5 sq km to the present size.

The city area, the central part of the Dhaka district is occupied by the southern half of the Madhupur Tract. The rest of the area is covered by the floodplains of the Jamuna, Padma, and Meghan rivers.

Madhupur clay, weathered product of Pleistocene deposits forms the surface of the Madhupur tract, which stands higher than the surrounding floodplain (Figure 2.2). There is a great difference in the elevation throughout the Dhaka city. The outcome of the elevation differences is reflected by the distinct landforms: high lands, low lands, and abandoned channels and depressions. The surface elevation of the area ranges from 1.5 to 15m (Figure 2.2). The ground surface (~60% of the total city area) elevation of the low lands and abandoned channels & depressions is varying from 1.5 to 3.5 meters, which is conducive to monsoon flooding hence potential source of vertical recharge. In terms of surface exposure of the rock unit: Pleistocene old alluvium occupies the dissected uplands, and new alluvium of recent river born deposits covers the low-lying floodplains. The differential elevation, landform and distribution of geologic units terminated into a corrugated topography.

Four rivers the Buriganga, Turag, Balu and the Tongi Khal surround the Dhaka city. Hydro-dynamically the area is well linked with the surrounding big rivers by the interconnecting streams, streamlets, retention lakes & ponds and canals. Like other parts of the country the climate of the Dhaka city is characterized by tropical monsoon climate. The long term mean annual rainfall for Dhaka is over 2000 mm. about 80-90 % of this occurs during monsoon

### 2.2 Geology and Stratigraphy

Tectonics and structural framework of the Bengal Basin bears the features of juxtapose active and passive margin setting (Hoque and Khan. 2001). Active margin comprises part of the deep basinal area along with its folded eastern fringe, wherein the platform extensional western part is the passive margin. The Pleistocene uplifted blocks characterized the surficial geology of the passive margin. Geologically, the Dhaka city is situated in the Pleistocene uplifted block (Madhupur Tract) within the passive margin surrounded by subsiding floodplains (Miah and Bazlee, 1968). The area is characterized by numbers of faults terminating and delineating different blocks. They are NW-SE trending Padma fault, Kartoya-Banar fault, Tista-Old Brahmaputra fault, N-S trending Dubri-Jamuna-Madhupur fault (WASA, 1991; Khandoker, 1987) controlling the tectonics of Dhaka and its environs. The geo-tectonics and its structural arrangement in the area control the geology-stratigraphy and hydrogeology of the area. Stratigraphically, the area is characterized by an unconsolidated sequence of fluio-deltaic deposits of Plio-Pleistocene age. A generalized stratigraphy for Dhaka region is given in Table 2.1.

The Madhupur and/or Floodplain clay materials overlying the unconsolidated fluvio-deltaic sediments of many hundreds of meters usually composed of gravels, sands, silts and clays. This underlying unconsolidated layer is acting as the main aquifer for the Dhaka city and known to be a part of Dupi Tila formation. It can be opined from the EPC & MMP (1991) cross-sections that the extent of unconsolidated aquifer materials is terminated by the faults and the Dhaka seems to be popped up as a horst block. The rivers and stream networks flowing through this fault system could cut Dupi Tila sands and can play a significant role in the hydrodynamic restoration.

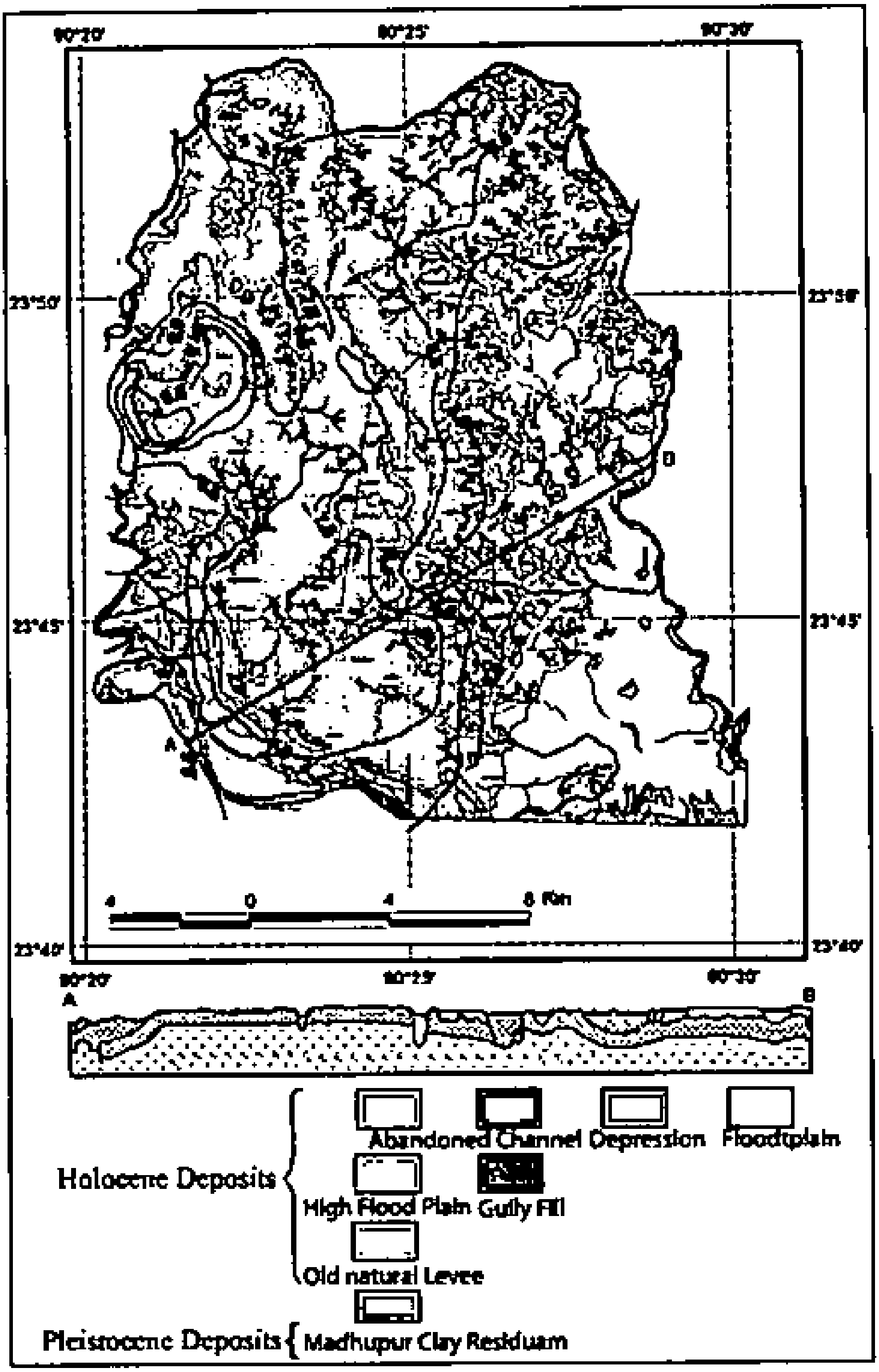



**Figure 2.2**: General geological map of the Dhaka city (modified after WASA, 1991) showing the exposed rock units along with the elevation contour overlay. The distribution of the geological units corresponds to the elevation clusters of the city.

**Table 2.1:** Stratigraphy of Dhaka city region (Modified after Morris, et al., 2000)

| Stratigraphic Age | Stratigraphic Name | Lithology | Thickness (m) | Function in Aquifer system |
|---|---|---|---|---|
| | | ***The Floodplain Area*** | | |
| Holocene | Floodplain | Alluvial silt, Sand & Clay | 6-15. | Upper aquitard |
| Late Pleistocene to Holocene | Dhamrai Formation | Alluvial Sand | 100-200. | Potential aquifer |
| Pre-Pleistocene | Not Named | Unknown | - | |
| | | ***The Madhupur Tract Area*** | | |
| Recent | Lowland Alluvium | Swamp, Lavee, and Riverbed sediments | 0-5 | Upper aquitard |
| Holocene | Bashabo Formation | Sand (discontinuous) | 3-25 | Aquifer |
| Pleistocene | Madhupur Clay formation | Silty Clay member, Fluvio-deltaic sand. | 6-25 | Upper aquitard |
| Plio-Pleistocene | Dupi Tila formation | Dupitila Clay stones Fluvio-deltaic sands. | 100-180 | Potential Aquifer |
| Miocene | Girujan Clay | Bluish clay | 50-100 | Known lower aquitard |

### 2.3 Hydrogeology

*2.3.1 Aquifer Geology*

Like the geology and stratigraphy of Dhaka, the hydrostratigraphy is poorly defined but undoubtedly distinct. Alam (1983) subdivided the vertical profile of Dhaka subsurface into four zones: Upper zone (0-10m, composed of finer materials) capping the aquifer, Middle zone-I (10-55m, composed of medium sands, silts and clays) potential for shallow well development, Middle zone –II (55-160m, composed of coarse sand and gravel) potential aquifer, Lower zone (160-200m, composed of dominantly clay and traces of finer particles like fine sand, silt) acting as aquitard. Analysis of the bore-hole logs indicates the continuity of geologic strata through out the area in a similar homogeneous sequence. The average thickness of the main aquifer ranges from 50-180 meters. In two deep boring at Gulshan and Sher-e-Bangla Nagar a continuous sequence of clay bed occurs below 165m depth. These logs also reveal the existence of suitable (yet to unveil) aquifer below the clay layer. The upper clay cap increases northwards and decreases south and southwestward, the average clay capping ranges 10 to 15m in thickness. An upper clay deposit to a depth of 10 to 50m confines Dhaka aquifer's water. The principal aquifer is semi-confined (leaky) throughout the study area.

*2.3.2 Aquifer Hydrology*

Abstraction by water wells is the main discharge. There is also base flow to rivers. Systematic groundwater development started in Dhaka city in 1949 and available records show that groundwater abstraction in the city has increased more than several hundreds time from the 1960 to date. Dhaka WASA is tapping water between 50-220m of the aquifer materials. Now it is producing 1160.21 million litres of groundwater per day as urban water supply through 389 DTW (WASA, 2003). Eitherway, there are hundreds of private tube wells abstracting water from the same aquifer.

The aquifer is in direct hydraulic connection with Buriganga River and other regional streams. These rivers could have a significant role in the aquifer recharge. But the aquifer is being recharged mainly from two known sources: direct infiltration and deep percolation of rainwater. Leakage from water mains in the range of 25-35% comes as an urban recharge (Rahman. 2003).

The aquifer is similar in nature and gross characteristics. But there exist some internal variation in layering, grain size, and material sorting. The variations in the aquifer materials resulted in different hydraulic properties. The generalized hydraulic properties of the aquifer based on the information gathered to date are shown in the Table 2.2.

The quality of the water in the northern part of the city is very good. There are some pollution in the industrial area and also being recharged from polluted river water The actual salinity is within the range of Bangladesh standard.

**Table 2.2:** Aquifer properties (Source: Alam, 1983)

| **Properties** | **Value Range** |
|---|---|
| Transmissibility | 25000-150000 gpd/ft |
| Permeability | 300-600 gpd/sq. ft |
| Well capacity ranges | 900-1350 gpm |
| Specific capacity ranges | 15-35 gpm/ft |
| Storage Co-efficient | 0.0005 |

# Chapter Three

# Methodology and Approach

To accomplish the objectives three tasks have been implemented. They are:

**3.1 Desk study and literature review**

Research on hydrogeology and aquifer condition of the study area is very scanty. Eitherway, the aquifer has been under utilization for the last 60 years. Detailed study on aquifer condition has never been carried out in the area. Several workers did some fragmentary works on the different hydrogeological aspect of the area, e. g., Alam, 1983; BWDB, 1991; MMP/HTS, 1992; Chowdhury, 1993; Ahmed et al., 1995; Majumder, 1996; Hasan, et al., 1998; Ahmed et al., 1998; Ahmed et al., 1999; Shams, 1999; BUET, 2000; Darling et al., 2002; Morris, et. al., 2003, Rahman, 2003; Hossain, et al., 2003; and routine publications of Dhaka WASA. A large number of reading materials are available on the utilization of urban aquifer, environment and groundwater management (e.g. Chawala, 1994; Eisen and Anderson, 1980; Ford and Tellam, 1994; Somasundaram et al., 1993). Based on these a review of the present research aspect has cited at the beginning of this report.

Desk study and Literature surveys disclose that the present study requires data of two different domains. These are borehole data for hydro-stratigraphic reconstruction and water level & groundwater abstraction data for piezometric analysis of the aquifer. The stratigraphic reconstruction has been done using both lithological and geophysical borehole data for the maximum spatial coverage. Data on different aspect of the DWASA well design has also been used for the piezometric calculation. Topographic relief and general geologic & hydro-geologic data have also been used in the present work.

**3.2 Data collection and geo-referencing**

The present work collected the data on borehole lithology, geophysical logs (resistivity), groundwater abstraction, WASA well design parameters, and groundwater level/ piezometric head (Figure 2.1) recorded by WASA and BWDB respectively. Moreover, some borehole lithological information was also collected from University of Dhaka. For spatial treatment but most of the WASA well data has no geo-reference but a map with the location of the wells is available. A 12 channel *Garmin*® Hand GPS was used to take some of the data points and with respect to those data points, other points were digitized for a complete geo-referenced data base. Same GPS unit was used to find the location of the lithologic log location depending on the physical address.

**3.3 Data Analysis**

***3.3.1 Hydrostratigraphic Assembling***

The sources of sediments and changes in mode of deposition have resulted in the great variation in the lateral and vertical continuity of the lithologic layers and hence stratigraphic horizons. Coarse textured lithologic layers contain water while fine textured lithologic units overlying or in between the coarse texrured layers acting as dividing means. In aquifer system they are known as aquifer contains water and aquitard turn away water. Depending on the position of these horizons the aquifer could be confined or unconfined (Todd, 1995). Hydrostratigraphy is the means to the 3-D geometric reconstruction of the aquifer texture and hydraulic conductivity of the hydrologic system.

To evaluate the hydrostratigraphy of Dhaka city lithologic logs and geophysical logs (mainly resistivity logs) were collected & collated and analyzed. The data points cover the central Dhaka city region. The geophysical logs are available for the middle part of the city and lithological data are available for the Central and western part of the metropolitan area. Eitherway, layering information comes together from the logs to establish the hydrostratigraphy of the region.

*3 3.1 1Lithologic logs*

Lithologic logs are the record of vertical rock units of a particular place. More than 50 lithologic logs were visually analyzed and 11 logs (Appendix-1) were treated in 3D environment using RockWorks 2000®. The selection was based on prior consideration upon the coherence & consistency of the information and even distribution of logs throughout the area. The layering information on the sand and clay horizons has been used in the hydrostratigraphic reconstruction To have an idea of the lower horizons nine dominant lthological record logs (about 450 meter) of BWDB from the different part of the city (Appendix- 2) were analyzed

*3 3.1.2 Geophysical Logging*

Geophysical logs are of different types and give much more detailed picture of the subsurface and expensive as well. One test hole in the University of Dhaka campus has been logged (Figure3.1) for natural gamma and induction EM conductivity (reverse of resistivity) up to a depth of 270 meters using a out of the ordinary type of slim hole logger (1.125 inches in diameter) of Robertson Geologging Limited (Robertson Geologging Ltd., 2000).

Numbers of geophysical logs are available in DWASA data depository in hard copy format. These logs could be useful to identify lithology irrespective of formation water. In case of Dhaka aquifer as long as there is no record of salt water bearing formation, only resistivity logs were used to identify the sand and clay horizons for hydro-startigraphic reconstruction.

Resistivity is the electrical resistance of a specific amount of material. The resistivity log is a measurement of formation's resistivity that is its resistance to the passage of an electric current (e. g. Keller and Frischknecht, 1966; Rider, 1986). Resistivity depends on porosity and nature of the interstitial fluid. It is seen that resistivity increases logarithmically whence porosity decreases. Normally, the sand is more resistive than clay. Resistivity of sandy layer with fresh water is more than salt water.

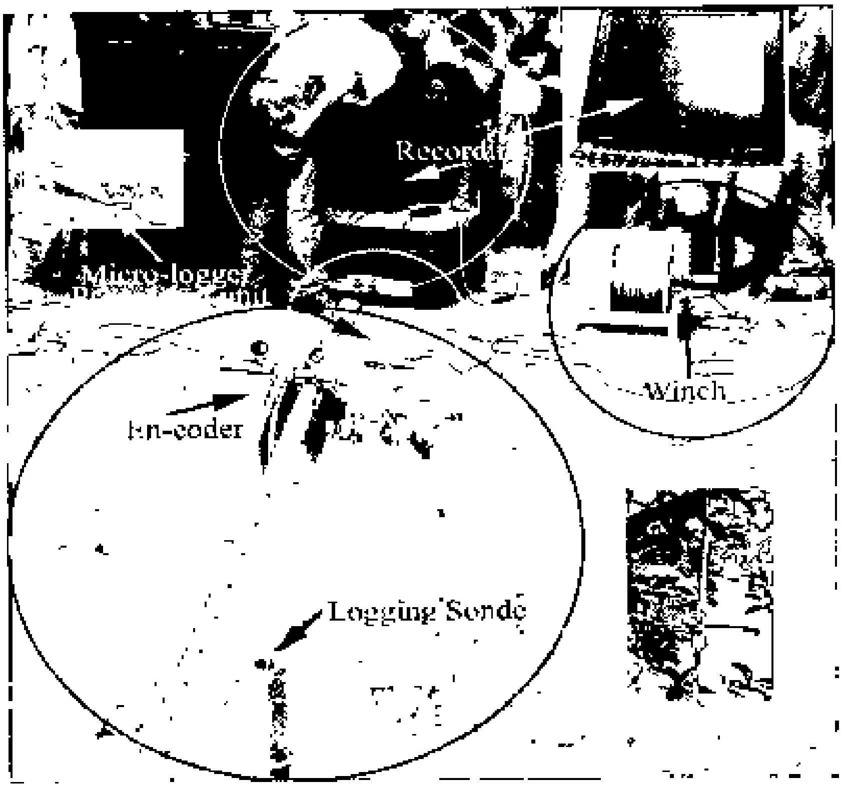



**Figure 3.1:** Geophysical logging effort at University of Dhaka.

The sensitivity of the resistivity logs to suitable lithological changes is the basis for their use in hydrostratigrapgic evaluation. Ideally, sensitivity of logs is sensitive to vertical changes than lateral changes. The hard copy logs were converted into digital format (Appendix-3). In all the logs highest resistivity value came for same aquifer and aquifer material. The distinctive shapes, trends, abrupt breaks, curve amplitude, frequency or peaks have been identified for 100% changes of the resistivity values with respect to the highest values of the individual. Then the peaks have used to correlate the layers. Geophysical log data were treated in 3D environment using RockWorks 2002®.

### *3.3.2 Piezometric Reconstruction*

Piezometry of an aquifer is controlled by the balance among recharge to, storage in, and discharge from an aquifer. Physical properties, such as the porosity, permeability, and thickness of the rocks or sediments that compose the aquifer affect this balance. Piezometric reconstruction of the study area has been done using the 12-observation stations (Appendix-4) data form Dhaka region centering metropolitan area by Surfer 8.04® (surface mapping & computing software) and Microsoft spreadsheet program (Excel). It should be mentioned here that BWDB has changed their monitoring bores ID from the previous as shown in Appendix-4. For grid data generation Radial Basis Function geo-statistical method was adopted for the water level data analyses. Radial Basis Function interpolation is a diverse group of data interpolation methods (e.g. Franke, 1982). Quality of the data from the metropolitan stations might not be good as the density of the DWASA production very high. Due to this high density pumped wells all or some of those observation wells might be in the interference of the production well. The correction of the data is very complicated and to some extent impossible. Here those data have been used as individual station to analyze the falling trend (Figure 4.13) and to statistical reconstruction of the surfaces of the over time.

Three hundred eighty nine DWASA production wells' data (no of wells, length of pump housing, discharge, and total depth) has been incorporated in the study to unveil the reason behind the nature & variability of piezometric surface with time. These data were analyzed statistically by Microsoft spreadsheet program (Excel) and Surfer 8.04® in different time interval to compare and depict the stress effects of the water withdrawal. In all the cases of WASA data analyses Linear Kriging statistical (e.g. Cressie, 1990) method has been used for grid data generation.

# Chapter Four
# Results and Discussion

The hydrogeology of the study area is simple and homogeneous. However, until date, hydrogeology of this area on a large scale is not understood very well due to lack of sufficient drilling, testing and monitoring data. As a part of groundwater exploration, development and substantial monitoring activities develop a better understanding of the hydrogeology of the area. Bore water level monitoring of system helps to understand the water table fluctuations, surface water and groundwater interactions, regional and local impacts of groundwater abstraction and dewatering related to mining, and water balance of the system. The lack of monitoring bores in the deeper part of hydrogeologic regime enables to determine the hydrostratigraphy & piezometric heads and groundwater patterns within deeper levels of subsurface. This chapter discusses various results and findings on the hydrostratigraphy and piezometry from the different analyses up to a depth of 150-180m and in some cases 450m for hydrostratigraphic investigation.

## 4.1 Results

### *4.1.1 Analysis of Lithologs*

Lithologs considered in this study range from 122 to 170m. Eleven lithological units were identified (Appendix-I) and those are mostly sands of different sizes and silt & clay. Subsurface of the area is more or less is homogeneous. Computer assisted regional Panel (Figure 4.1) and 3D block diagrams (Figure 4.2) were generated from the lithological data. Dots with locality name are the data points. Smaller number of data made the sub-surface picture generalized and simplified. However, the results of the litholog analyses are as follows:

a) diagrams reveal that the top most clay ranges from 6 to 9m in most of the places and extends up to 25m in Banani-Gulshan area of the city

b) the upper clay unit is followed by a thick sequence (ranges from 90 to 140m in thickness) of unconsolidated sands of varying sizes. The sequence is characterized by finer gain sediments in the upper portion and coarser sediments in the lower part of the sequence. Within this sequence lenses of silts and clay occasionally and locally appeared.

c) throughout the study area the striking horizon is resting vertically from 45 to 140m and is composed of medium to coarse sands and gravels. This zone is medium to highly permeable and highly potential for fresh water. The total volume of the silt-free fine to gravelliferrous sandy horizon in Dhaka city is estimated to be $5.5 \times 10^{12}$ $m^3$.

d) most of the lithologs encountered a clay horizon at a depth of 122 to 140m but in the south-eastern area the clay layer might be at higher depth. This clay horizon is separating sandy sequence from the lower one. None of the logs reached the bottom of the clay horizon.

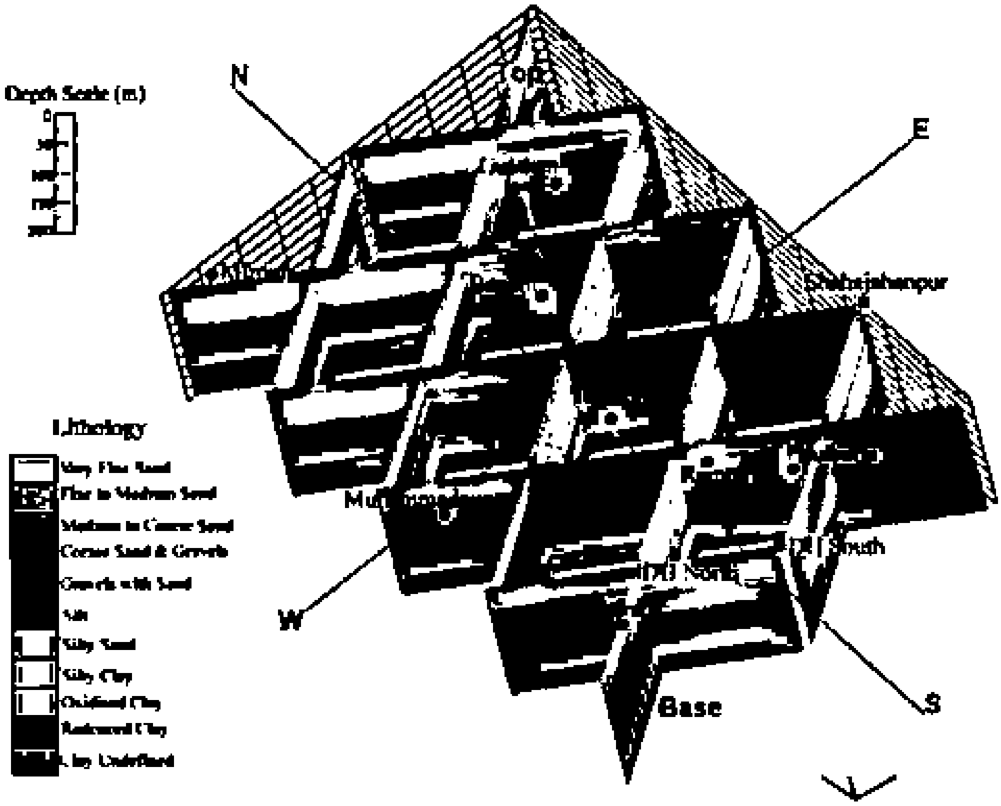



Figure 4.1: Regional subsurface (upto 180m) panel diagram of the Dhaka city.

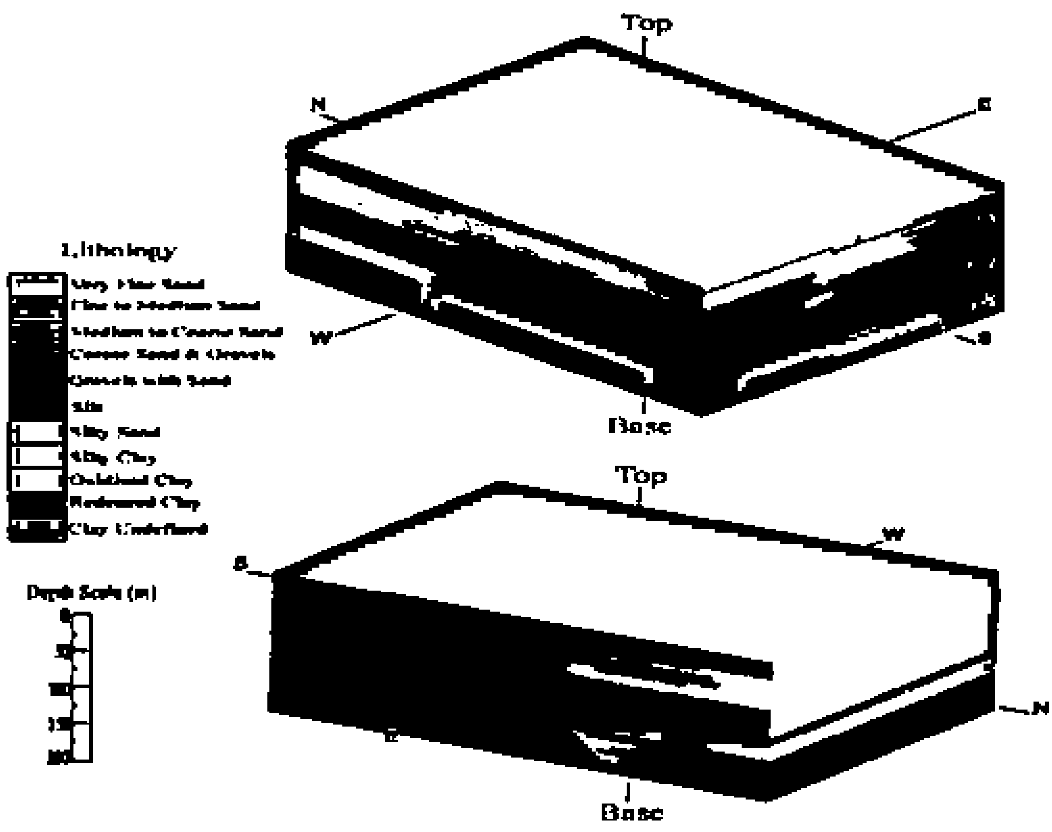



Figure 4.2: Three Dimensional lithologic block diagrams (upto 180 m): upper facing from southwest and lower facing from northeast.

Observation and analyses of the deep logs (Appendix-2) and computer assisted panel (Figure 4.3) gives an idea of the lower horizons and terminated into the following:

a) It is seen from the logs (Appendix-2) that upper 27m (~90 ft) is predominantly clay which is followed by three sandy horizons separated & Floored by clay-silt sequences of differing thicknesses.

b) Panel shows that the upper sandy horizon is separated from the second one by a 30m clay-silt unit while third one is separated by very thick clay-silt unit (about 120m) through out the area. Dots with locality name are the data points.

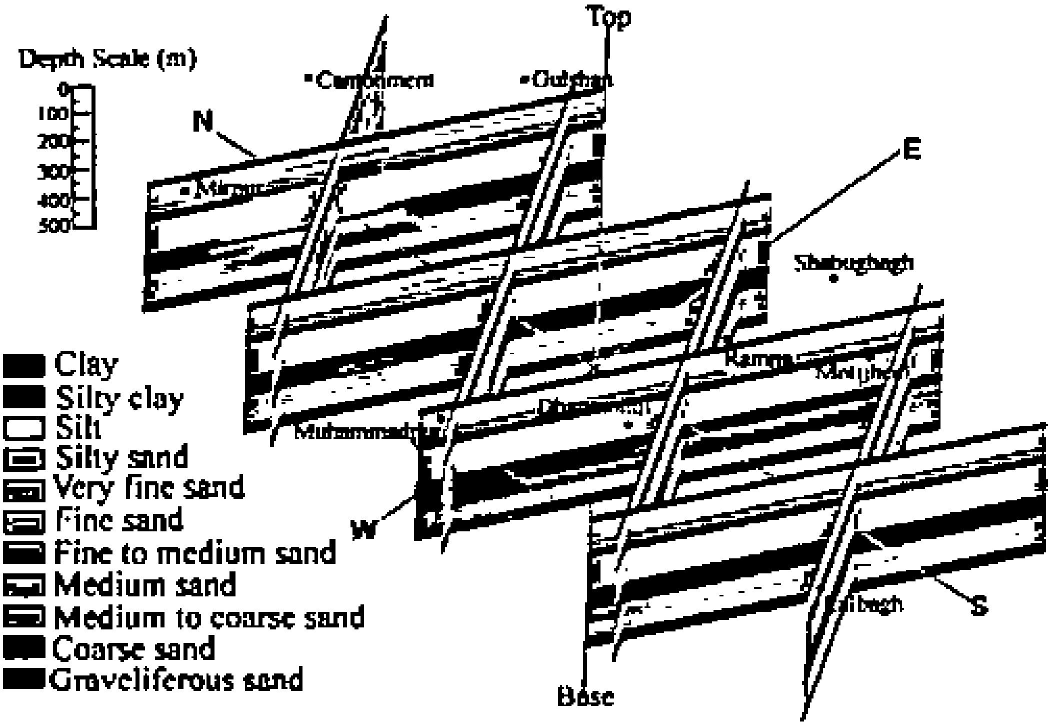



Figure 4.3: Regional subsurface panel (upto 450 m) of Dhaka city showing the dominant litho layer distribution.

#### *4.1.2 Analysis of Geophysical logs*

Composite log of natural gamma and EM conductivity clearly depicted the sub-surface main litho units in the University of Dhaka area (Figure 4.4). The lithological interpretation is mentioned into the log. Generally, conductivity is high for clay or finer units & sands with saline water, and low for sands or coarser units with fresh water. Natural gamma is low for sands or coarser units but high for clay or finer units (Rider, 1986). It is seen from the log that a 7-9 m thick clay or finer layer is followed by a 122-130 m thick sandy sequence with some minor clay units within it, which is underlain by about 30m thick clay or finer unit. Another sandy unit is found at a depth between 170 to 213m sandwiched clay units and the lower clay unit followed by another sandy or coarser unit at a depth 244m onward. These alternating litho-units are corresponding to the dominant lithological results discussed in section 4.1.1.

Usually, the resistivity log does not allow a first indication of lithology. However, the lithology of the area has been identified by observing the change in the resistivity log response. Individual logs (Appendix-3) response exhibit clay or finer horizon in the upper part of each logs indicated by the moderate to low resistivity. The middle part is sandy as it is moderate to high in resistivity indicate sandy horizon. Lower part again low in resistivity indicating clay-silt floored the middle sandy horizon.

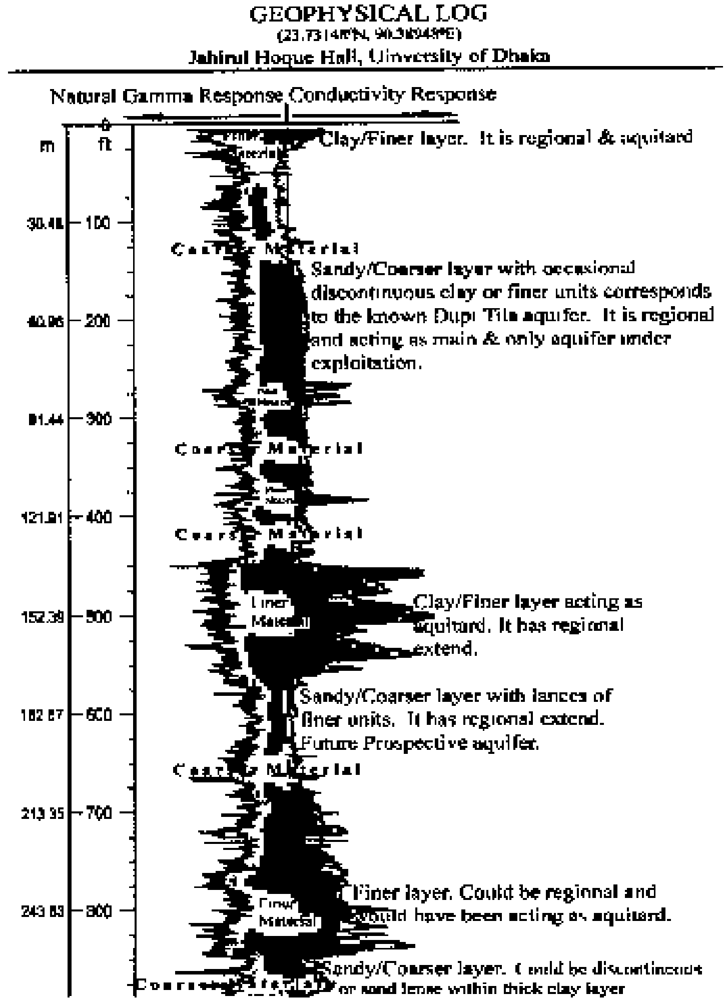



**Figure 4.4:** Composite log response for natural gamma (cps) and the induced Electro-Magnetic (EM) response of the University of Dhaka test hole.

Computer assisted regional Panel (Figure 4.5) and 3D block (Figure 4.6) diagrams were generated from the resistivity data to reconstruct the sub-surface picture up to a depth of 175 m. The results of the analyses are as follows:

a) Dots companioning the figure 4.5 representing locality name of the data points. The area is generally covered by a low to moderate resistive layer which corresponds to the clay or finer litho-unit. In the northwest of the area the surface resistivity is a bit higher indicating little coarser or silty clay at the surface. The thickness of the clay-silt layer changes from well to well and it is ranging from about 9 to 55 m. The maximum thickness of the clay-silt layer occurs in the Jurain (SE area of the city) and Kalachandpur (NE area of the city) area.

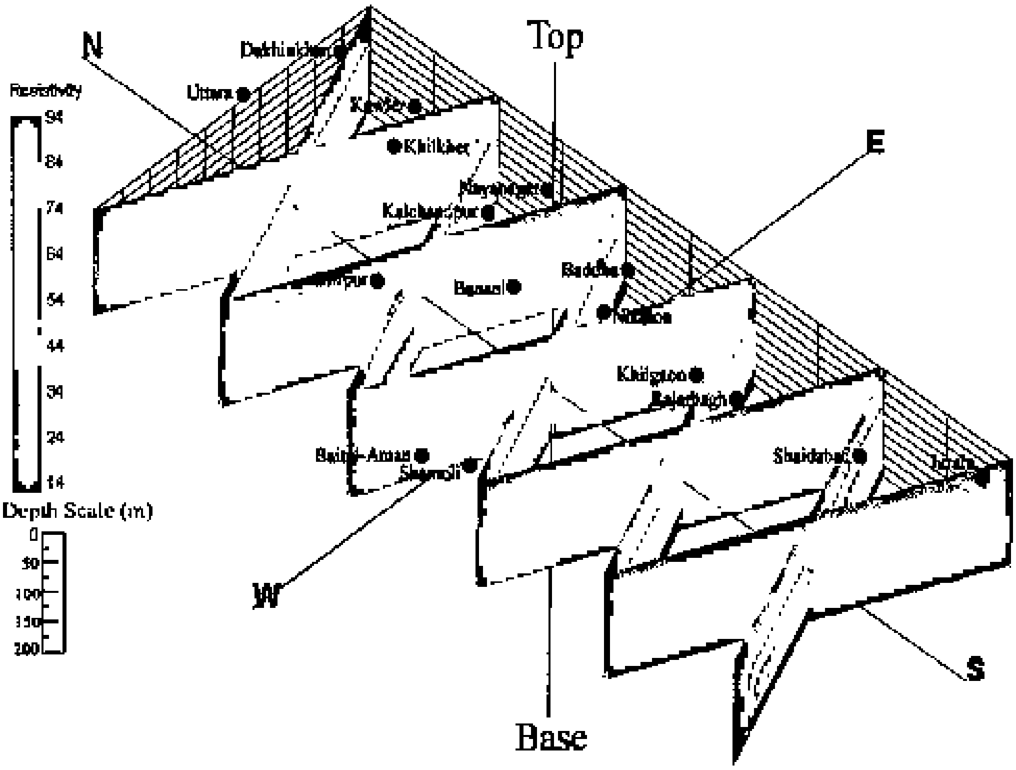



**Figure: 4.5:** Subsurface panel diagram (upto 175 m) showing the resistivity layering.

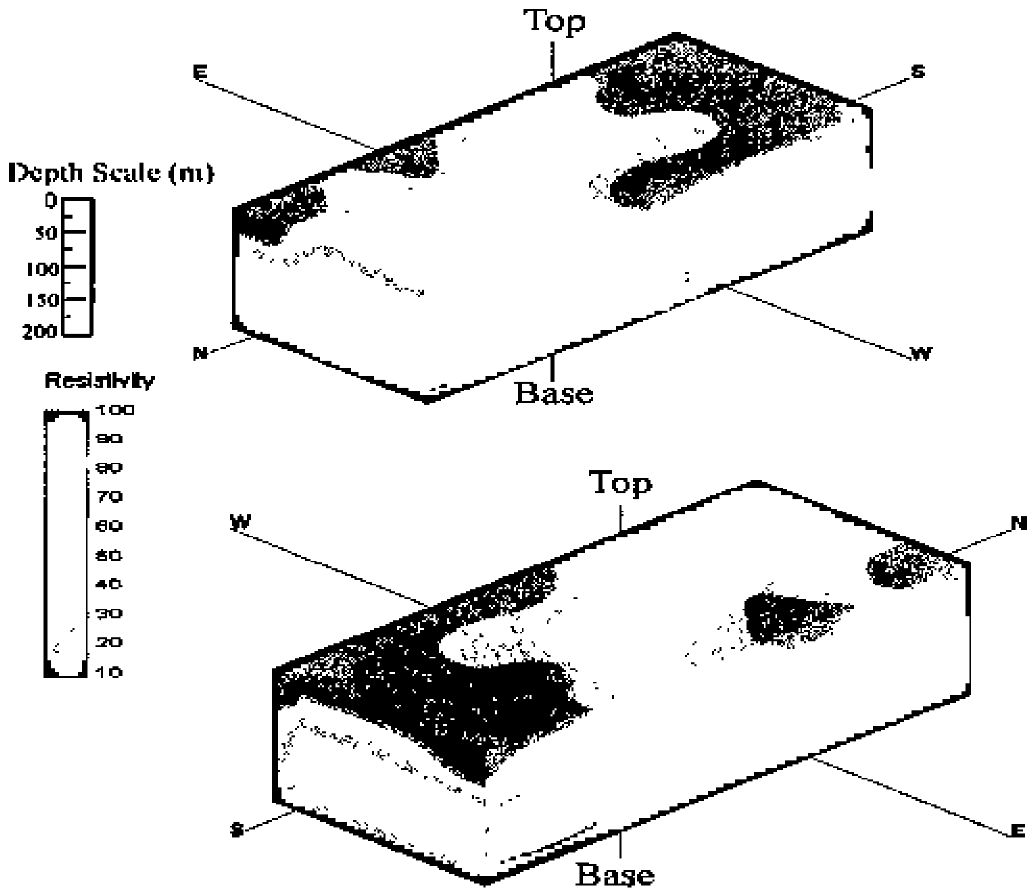



**Figure 4.6:** Resistivity block diagram (upto 175 m) of Dhaka city showing resistivity layering.

b) The upper low resistive layer is followed by a high resistive layer which occurs regionally and corresponds to the sandy horizon. The thickness of the layer varies from 75 m to more than 150 m. The thickness of the sandy horizon is maximum at Shamoli and minimum at Kalachandpur area of the city (Figure 4.5 and Appendix-3). Individual log (Figure 4.4 and Appendix-3) noticed some clay or finer lenses within the sandy horizon which are not occurring the regional scale as the data density is low. Resistivity of the logs falls (low to moderate) again in the vertical scale at a depth in between 110 m (Baitul Aman) and 170 m (Shamoli). This indicates the occurrence of clay-silt at that depth. Here high resistive layer is sandwiched by low resistive layers Inferred aquifer is sandwiched by aquitard. The depth of low resistive layer below the high resistive layer in the south eastern part of the city is not well represented as the data density is very low.

#### *4.1.3 Groundwater Abstraction Analysis*

A network of 389 (up to October 2003) deep tubewells of DWASA and more than 900 private tube wells have been withdrawing water from the subsurface of the city (Rahman, 2003). 84.33% of the municipal water supply for the domestic use comes mostly from groundwater. A small fraction (15.67%) is collected from the surface water, mostly from Sayedabad Surface Water Treatment Plant. Observation and analyses of the DWASA abstraction data and well data are pointed out as follows:

a) Groundwater abstraction by DWASA and private wells have been increasing with time (Figure 4.7) with an escalating trend ($R^2$=0.96, n=21). Volume of water withdrawal from the aquifer was in between 140-160 x $10^6$ $m^3$ up to 1989 and after 1990 drastically it increased from 264 x $10^6$ $m^3$ in 1990 to 592 x $10^6$ $m^3$ in the year 2003. The average daily groundwater abstraction has increased more than 1200% from the 1970 to 2003.DWASA has six revenue zones within the city and the abstraction scenario is almost same in all the zones except zone 2, where abstraction is steady over time (Figure 4.8).

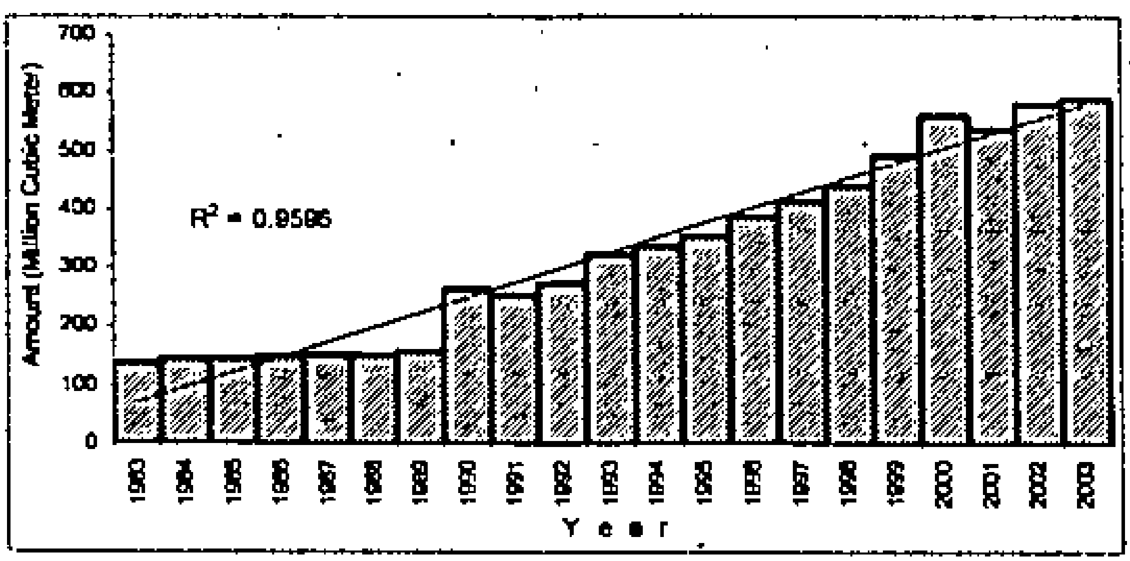



Figure 4.7: Increasing trend of total groundwater abstraction by WASA and privately own tube-wells in consecutive years.

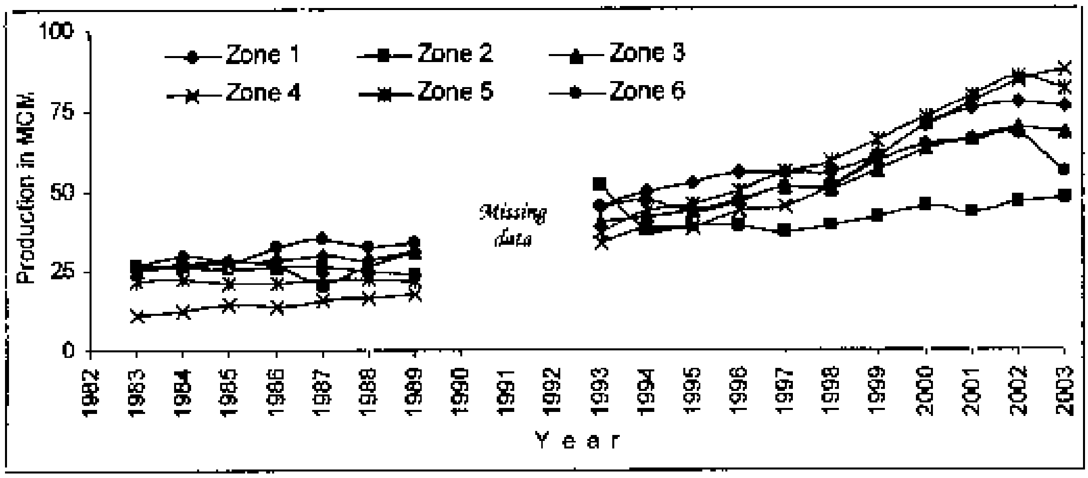
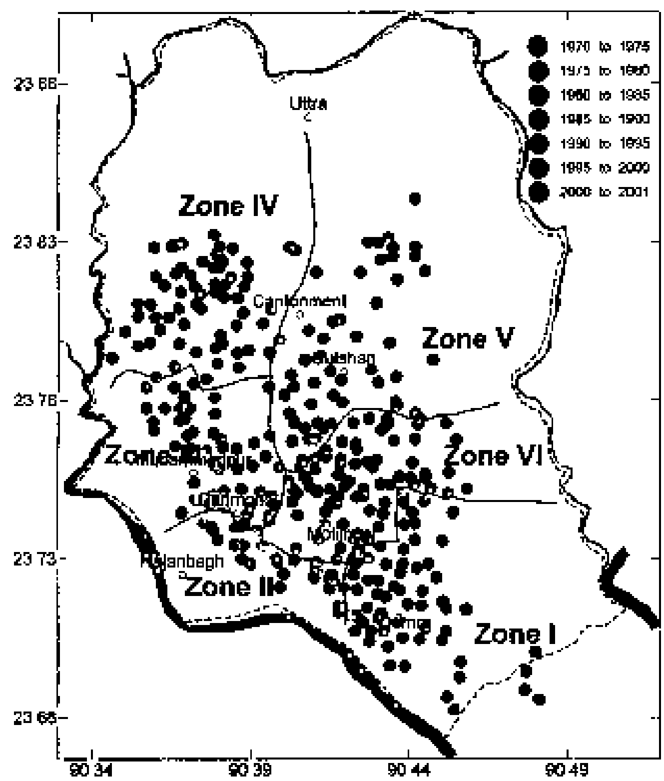



**Figure 4.8:** Increasing trend of groundwater abstraction in different DWASA revenue zones in different years.

b) DWASA has been increasing its production to keep track with the demand through installing deep tube wells. The change in number of tube wells is more than 700% from 1970 (no of PW 49) to 2003 (no of PW 389). The frequency of new tube wells installation increased after the 1990. Most of the production wells by DWASA have been sunken in the year between 1996 and 2000 (Figure 4.9 a &b).




| Year | No of wells |
|---|---|
| 1970-1975 | 2 |
| 1975-1980 | 2 |
| 1980-1985 | 7 |
| 1985-1990 | 17 |
| 1990-1995 | 54 |
| 1995-2000 | 178 |
| 2000-2001 | 69 |

**Figure 4.9a:** DWASA year wise production well installation scenario in Dhaka Metropolitan area.

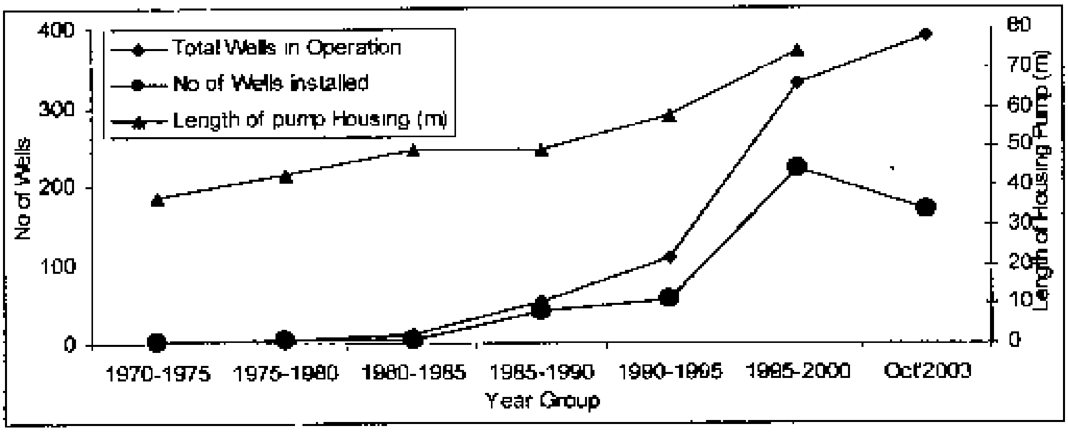
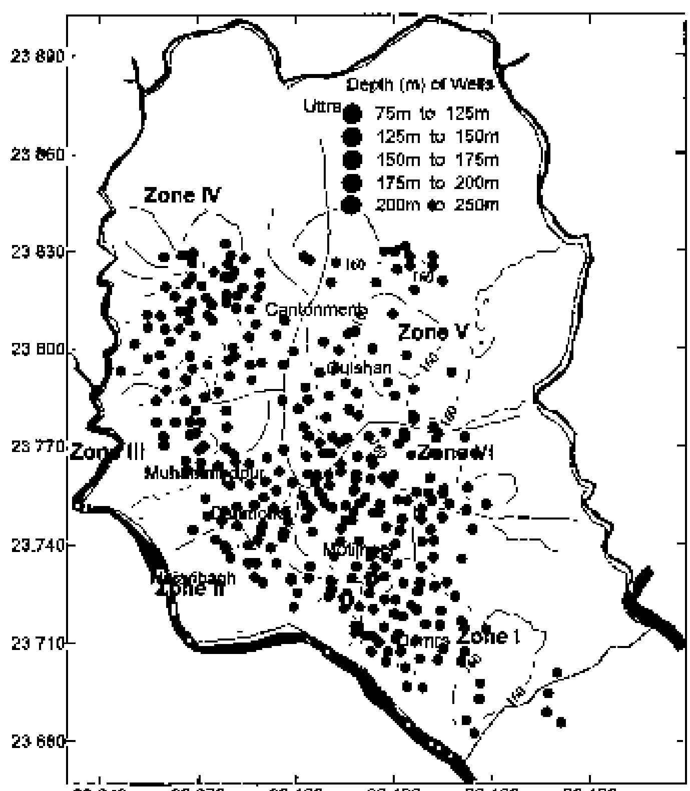



**Figure 4.9b:** Graph showing total wells in operation of DWASA in different year, number of wells installed, and increasing state of pump housing length with time.

b)DWASA is withdrawing water from a depth ranging from 75 to 200m below the ground surface with a definite trend of increasing depth towards the east of the city (Figure 4.10) as if keeping phase with the deepening of the aquifer. Depth of the DWASA production wells are well matched with the depth of the increasing clay layer's depth below the sandy horizon. In the figure 4.1 and 4.5 it is seen that the clay layer depth increasing towards south-east corner of the city. Depth distribution is also showing that WASA is withdrawing water from different depth horizon of the southern part of the city, which might have an influence on the water level cones.




| Depth Class (m) | No of wells |
|---|---|
| 75-125 | 44 |
| 125-150 | 132 |
| 150-175 | 139 |
| 175-200 | 28 |
| 200-250 | 0 |

**Figure 4.10:** Depth (in meter) distribution of the WASA production wells' screen in the city.

d) Spatial pattern of the specific capacity of the aquifer in the metropolitan area is diversified. In broad spectrum specific capacity is higher in the south-west part of the city (Figure 4.11). This implies the possibility of higher permeability of the aquifer materials in that part of the city. As the permeability data is not available surface could not constructed for the same. It can also be opined that the highest rate of production of the WASA wells would be in the southwest corner of the city area. Aquifer permeability and consequence high rate of abstraction might have a strong relation with the rapid falling of the water level in that part of the city.

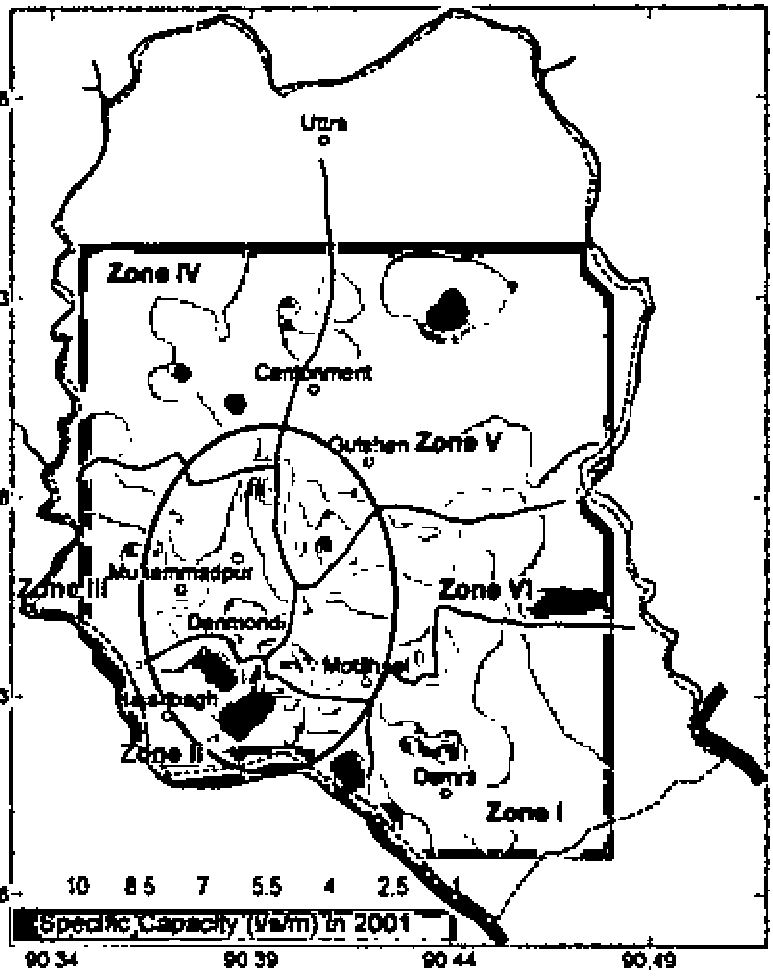



Figure 4.11: Surface construction of specific capacity of aquifer (assuming specific capacity remains constant over time).

#### *4.1.4 Water Level Analysis*

Groundwater level of the country (Figure 4.12) has a good relationship with the surface elevation & physiography (Morgan and McIntire, 1959) except the study area, where water level is deepest position in the country (35m+ below the Mean Sea Level [MSL]). This drop was analyzed for the study area by building long-term hydrograph and creating temporal contour surfaces for the water level.

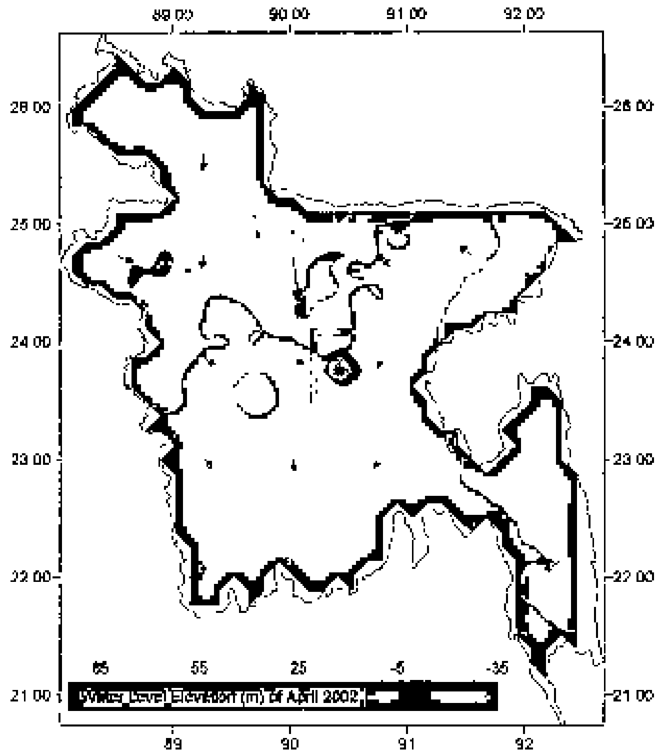



**Figure 4.12:** Groundwater level elevation surface of April 2002 indicate the lowest water level surface (boxed area) in Bangladesh is in Dhaka city area.

##### *4.1.4.1 Long-term hydrograph*

Hydrographs of water level monitoring bores have been analyzed to asses the changes in the water levels in the Dhaka city. Long term hydrographs (for the individual monitoring bores appendix-4) from the different part of the city (Figure 4.13) indicate the drop in water level is increasing very rapidly throughout the city. The observation wells are mostly screened below 30-45m (100-150ft) from the ground surface. Analysis of the hydrograph terminated in the following results:

a) The magnitude is varying from 5m above the MSL in 1969 to 54.21m below the MSL in 2003. The water level drop has increasing trend with time ($R^2$ values range from 0.75 to 0.94, n=12). The drop in water level is drastically increased after 1980s. In 2003 the spatial dimension of the water level is ranging from 12.86m at Jaganath Collage, Sutrapur to 54.21m at Dhanmondi below the MSL.

b) This huge depression is confined within the city area and can not be found to occur just out side the city for example Nawabganj School station at Nawabganj and Figure 4.12 for other parts of the country. Long-term hydrograph of this station also illustrating the seasonal fluctuation in the graph with no historical trend ($R^2 = 0.077$) while there is no depictable seasonal variation on the city area.

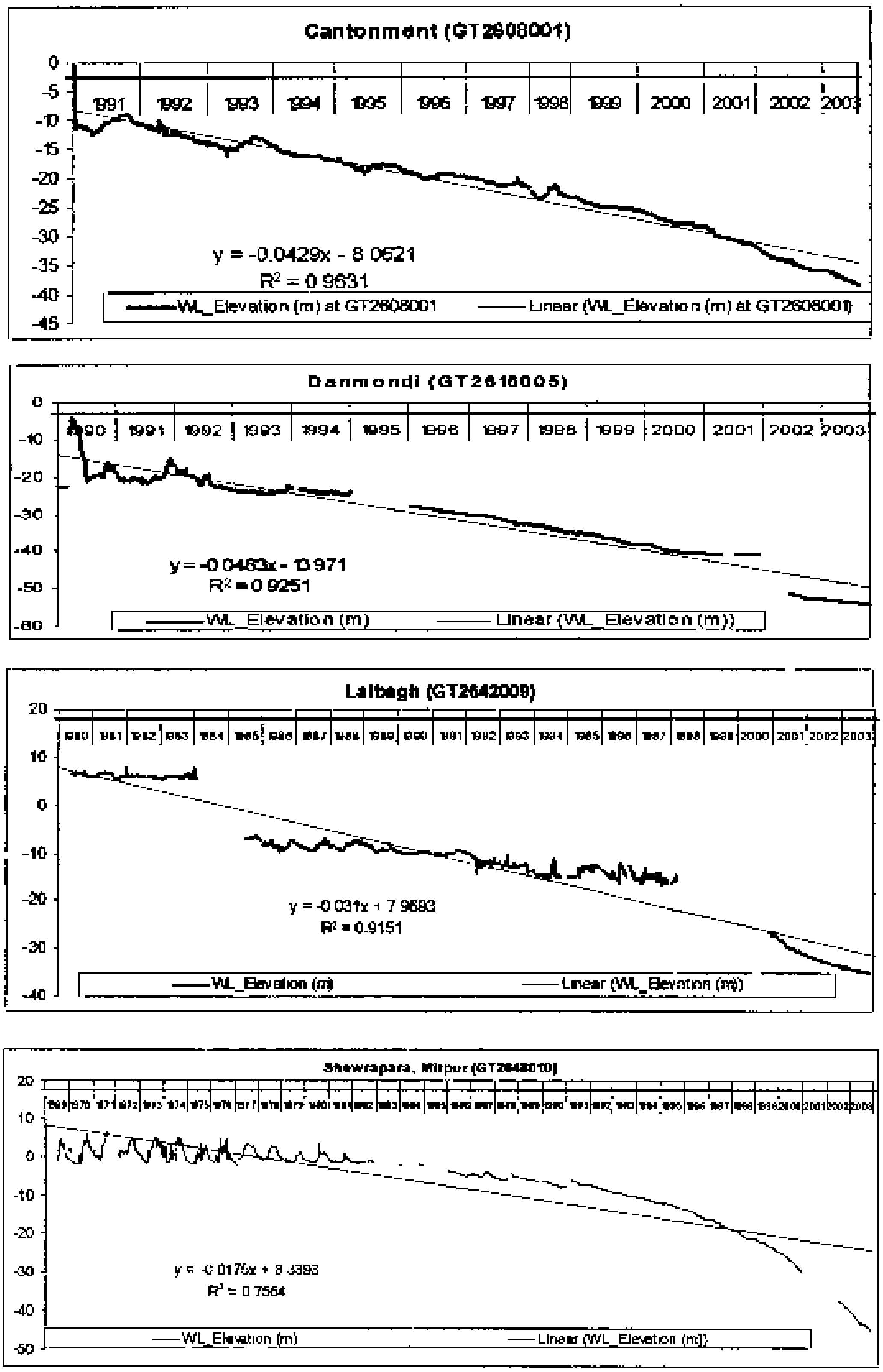



**Figure 4.13:** Long-term hydrographs for individual observation stations in Dhaka city.

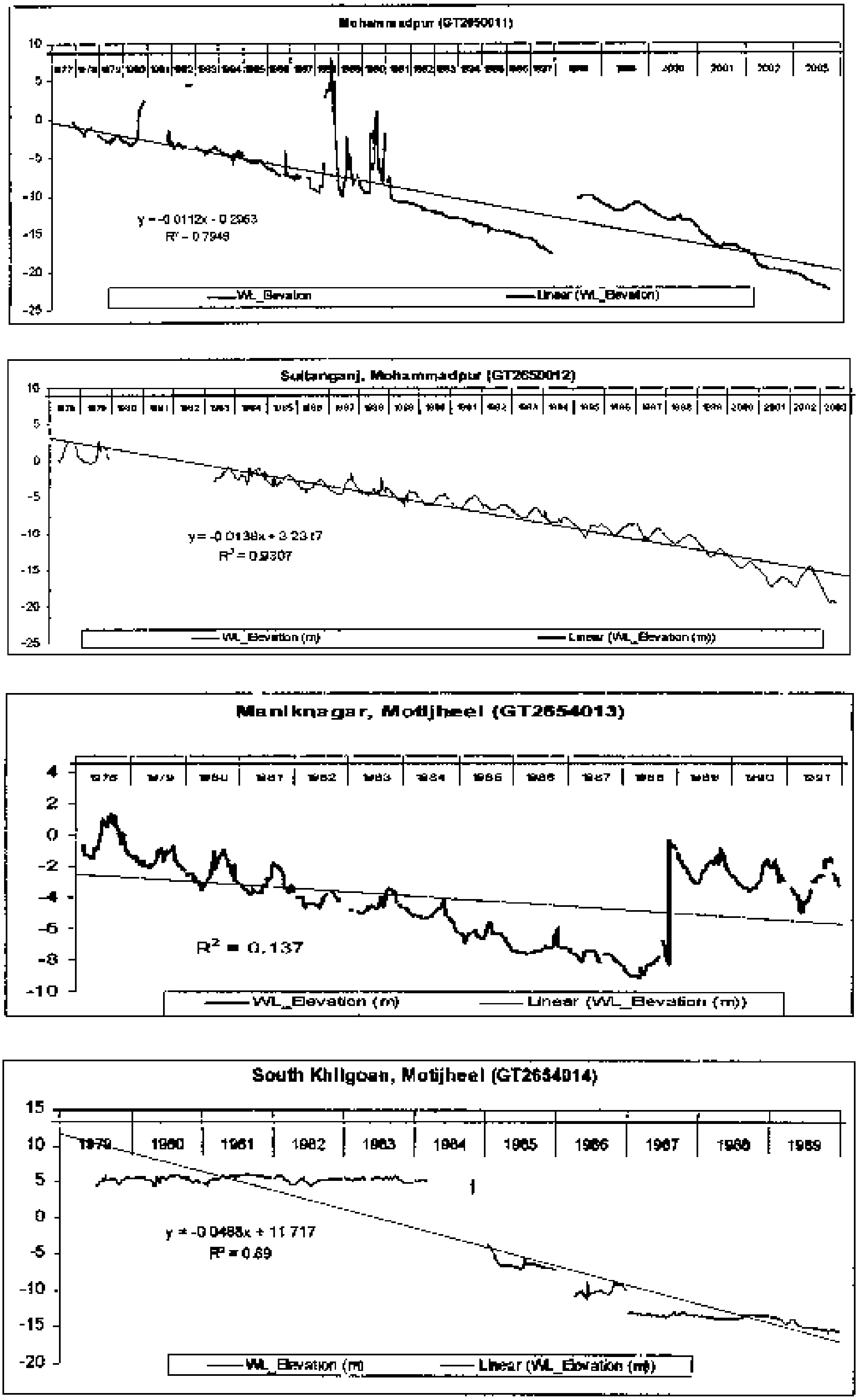



**Figure 4.13 (continued):** Long-term hydrographs for individual observation stations in Dhaka city.

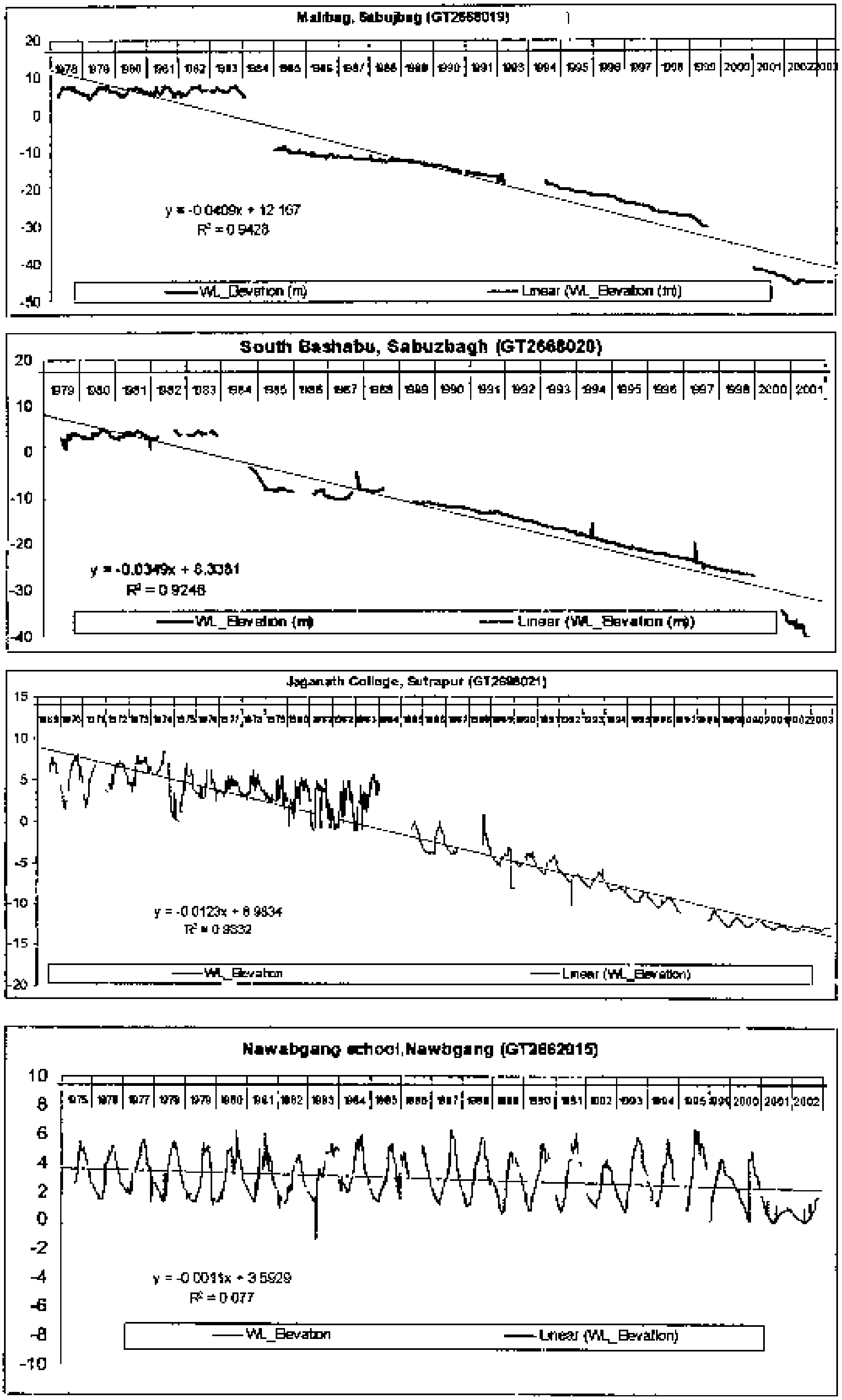



**Figure 4.13 (continued):** Long-term hydrographs for individual observation stations in Dhaka city.

c) The hydrographs show missing data (mostly during 1984) due to the change of observation well type from dug well to piezometer well. Eitherway, there is another prominent high jump in the water level observed during 1988 at Maniknagar and Muhammadpur which could be due to recharge of the aquifer by the 1988 big flood.

d) Long-term hydrographs also indicate that the water level in the dug wells in the Madhupur clay is much more above than the water level of piezometer wells in the Dupi Tila.

*4.1.4.2 Temporal contour surfaces of water level*

Linear drop is observed in the long-term hydrographs without any significant seasonal fluctuation; data of December Last week are used to construct 5 year temporal (1988 to 2002) water level elevation contour surfaces (Figure 4.14). Contour surfaces were constructed for the year 1988, 1993, 1998 and 2002. All the potentiometric surfaces are getting close to the centre of the city as the largest declines were concentrated in the city centre. The results may be summarized as follows:

a) 1988 potentiometric surface shows a huge cone of depression having a magnitude of 12m below the MSL at area close to Motijheel in the city with a bulge towards Dhanmondi.

b) The shape of the potentiometric surface remain same in 1993 but depth to the culmination changed to 22 m at Motijheel area below the MSL.

c) The contour shape and magnitude of the depression largely changed in the year in between 1993 and 1998. 1998's contour surface shows two cones of depression in the area close to Motijheel and Dhanmondi-Hazaribagh area. The magnitudes of the depressions are same and hit the highest point at about 31m below the MSL but the spatial dimension of Motijheel depression is larger than other one.

d) The scenario in 2002 is same as 1993 apart from the depth of the highest point of the cones. This time it is about 50m below the MSL.

e) It is estimated that from 1988 -1993 about $915 \times 10^6$ $m^3$ of the aquifer has dried in the central part of the city and this figure changed to $2050 \times 10^6$ $m^3$ in the year 2002.

f) All the temporal contours indicate radial flow of groundwater from the peripheral zone to the city centre.

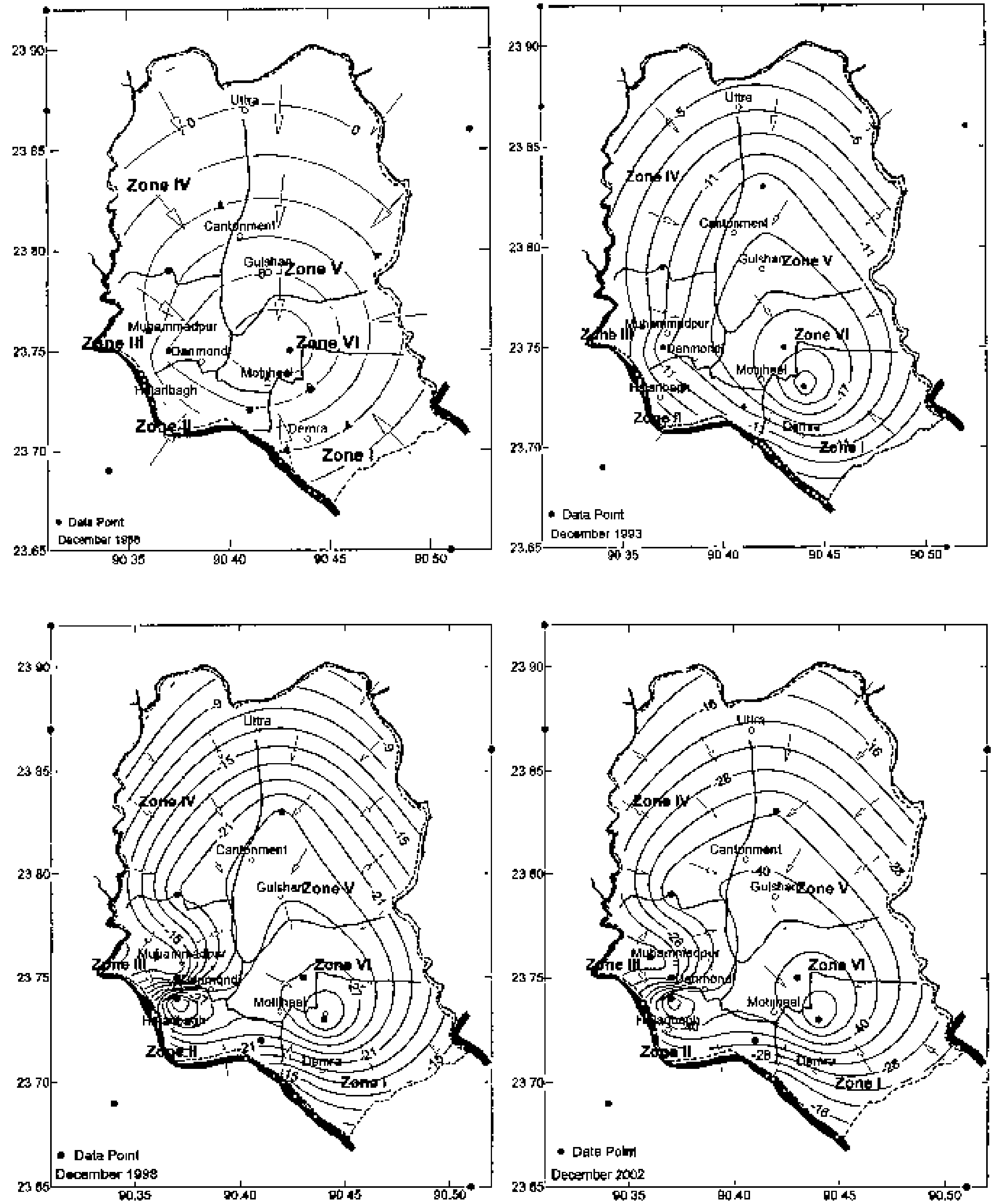



**Figure 4.14:** Water level contour surfaces showing the development and deepening of cones of depression in Dhaka city and graph showing the linear trend of drying up volume of aquifer

## 4.2 Discussion

### *4.2.1Assembling Hydrostratigraphy and Aquifer Delineation*

Lithological information extracted from geophysical logs and drilling time washed sample log is used to assemble the hydrostratigraphy of the region. Data quality is good and detailed up to a depth of 170 to 185m but hydrostratigraphy below this depth is assembled up from the limited number of dominant lithological logs.

The layered hydrostratigraphy of the region is mostly homogeneous and assemblage of sands, silts and clays. These unconsolidated sediments are of Mio-Pliocene age and have been provisionally subdivided into 7 hydrostratigraphic units (Figure 4.15) and therefore, three aquifers system from surface to 450m depth level (Table 4.1) separated by clay-silt dominated horizons. Aquifer system should be defined on the basis of hydraulic connectivity of lithostratigraphic sequences irrespective to thickness & discontinuous clay barriers. But due to lack of hydraulic connectivity data present work delineated the aquifers on the basis of sandy lithology separated from the other by clay barriers.

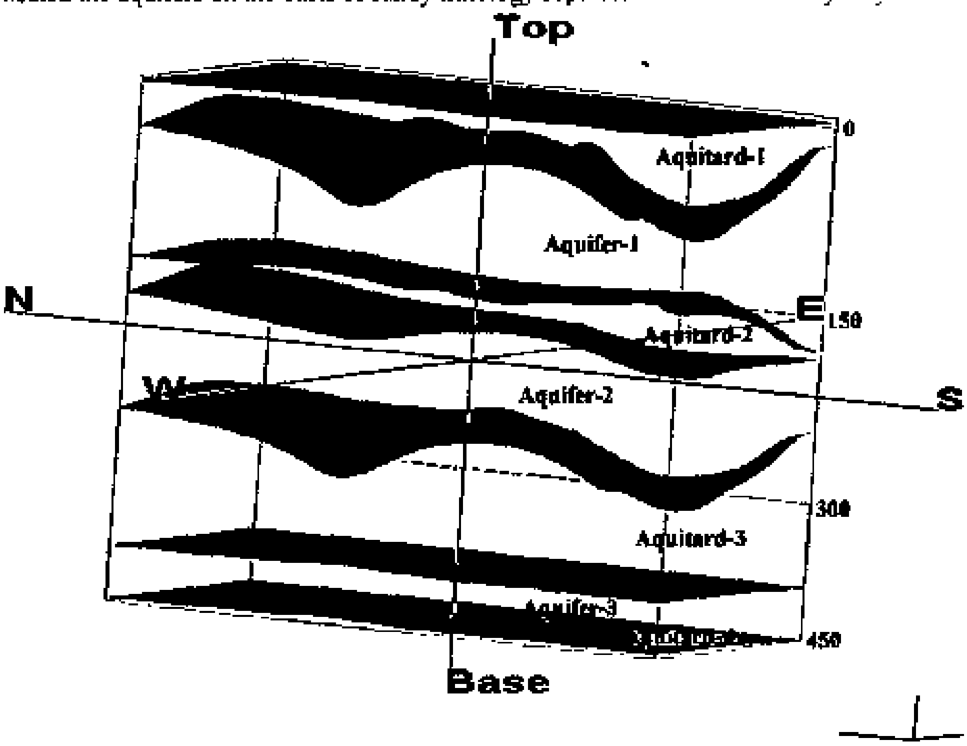



**Figure 4.15:** 3D geometric reconstruction of the aquifer texture in the study area.

The study area is skinned by the Madhupur residuum (Clay rich horizon) upto a depth of 55m and capping the first aquifer. Hydrostratigraphically the first aquifer is a confined aquifer (e.g. Tood, 1995) as it is caped by a clay-silt layer but hydrostatically it became unconfined (section 4.2.2) as the piezometric surface is below the capping clay layer and within the aquifer horizon. The aquifer horizon is composed of medium to coarse sand and gravel. Results of bore-hole log analyses indicate the continuity of geologic strata through out the area. However, the depth of the upper surface and the base of the first aquifer vary spatially from place to place (Figure 4.16). The average thickness of the main (first) aquifer ranges from 100-150m (Figure 4.17). Cones of depression (afore said in section 4.1.4.2) have a strong relation with the aquifer thickness. The aquifer thickness is grater in the region of the cones and the base of the aquifer (clay layer) is elevated from the nearby eastern region which might cause groundwater movement along the base towards eastern slopes of the aquifer. Either way, regional groundwater movement is depression induced in the shallower horizon of the aquifer (Figure 4.14). Conversely, WASA is abstracting water from the different horizon of the aquifer in this region due to the greater thickness of the aquifer.

**Table 4.1:** Summery of Hydrostratigraphic assemblages.

| Depth to base (m) | Dominant Lithology | Hydrostratigraphy | Aquifer Thickness (m) | Comments on Aquifer system |
|---|---|---|---|---|
| 10-50 | Clay-silt | First Aquitard | 100-150 | Hydrogeological characteristics and water resource is well defined but almost explored & exploited. Typical range of transmissivity is 500-2000m²day⁻¹. Overlying aquitard is much less permeable, typically ~0.01 -0.1 m day⁻¹ |
| 95-195 | Sand | First aquifer | | |
| 125-210 | Clay | Second Aquitard | 50-100 | Hypothetical, based on 9 dominant lithology logs. Water resource is not defined and almost unexplored & unexploited |
| 230-250 | Sand | Second Aquifer | | |
| 340-375 | Clay | Third Aquitard | ~40 | Hypothetical. Water resource is not defined totally unexplored & unexploited. Overlying aquitard thickness ranging 40-130m and might contain thin perched aquifer |
| 410-416 | Sand | Third Aquifer | | |
| >~410 | Clay | Fourth Aquitard | | |

The first aquifer is standing on about 30m thick clay-rich layer which is capping the second aquifer at a depth of about 170m. Thickness of the second aquifer ranges from 50 to 100m (Figure 4.17). The depth of water table in the second aquifer is 10.8m in the University of Dhaka campus (measured on 22 August 2004) and 11.60m in the Tejgaon area (Shamim Sher, personal communication). A very thick clay layer (ranging 40 to 130m) is followed by the second aquifer and capping the third aquifer of uniform thickness about 40m. Third aquifer is based by another clay dominated layer at a depth of about 420m. Piezometric head of the second aquifer indicating a good amount of groundwater storage in that aquifer. Geologic age and stratigraphic position of the second and third aquifer system is undefined due to lack of appropriate data set.

Very few data exist for the second and the third aquifer system and only very preliminary estimates of groundwater occurrence are available. Quality and quantity of water in the lower aquifers (second & third aquifer) cannot yet be established. Preliminary quality analyses of test well in University of Dhaka campus screened at second aquifer indicate the good quality of the water (Anwar Zahid, BWDB, personal communication). In the absence of adequate hydrogeological data it would not be prudent to consider the lower aquifers as potential sources of groundwater for the Dhaka city.

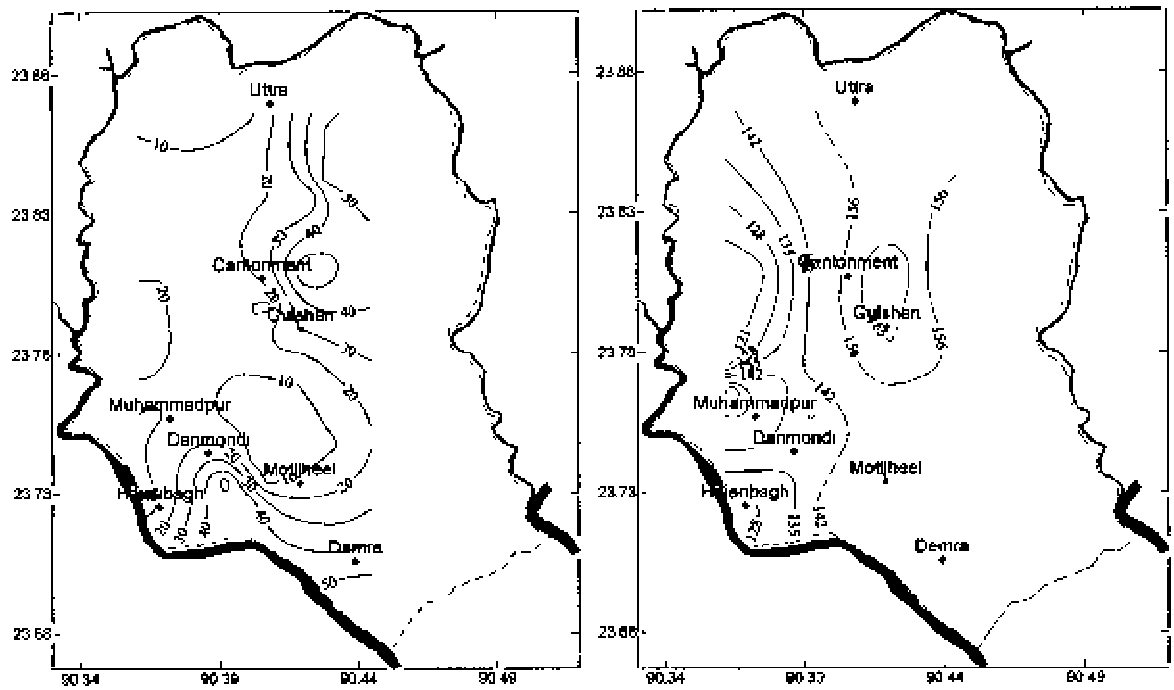



**Figure 4.16:** Surface map (m below the GL) of Top or base of first aquitard (left) and Base of (right) first aquifer in the study area.

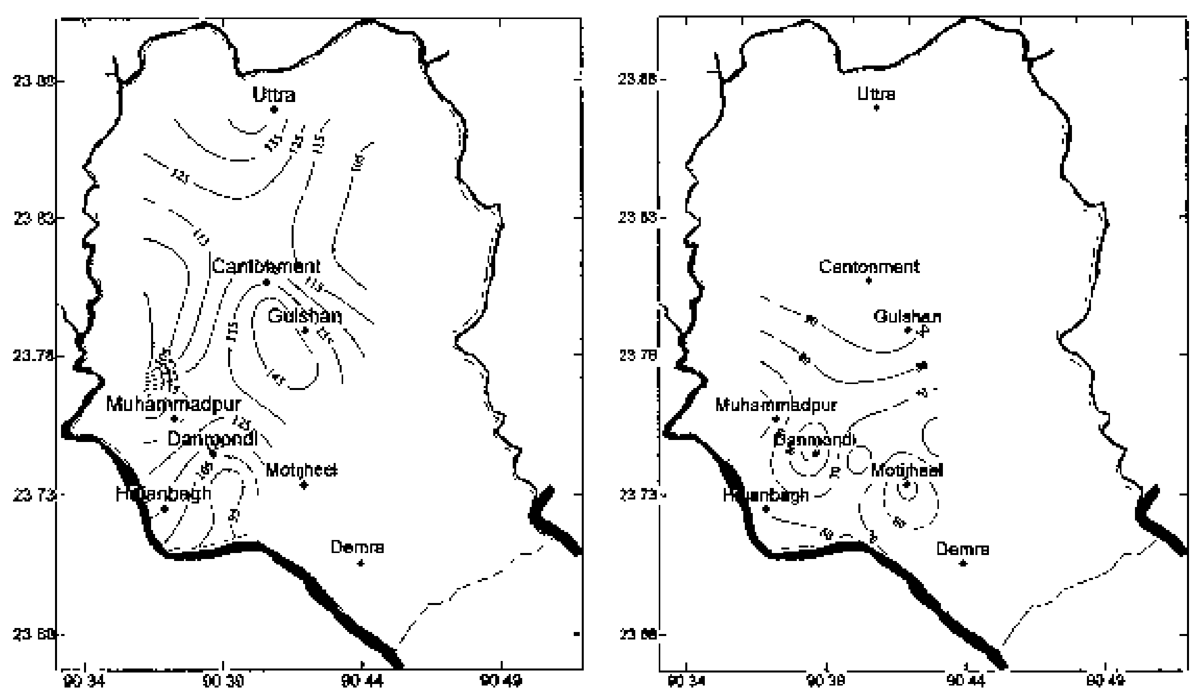



**Figure 4.17:** Thickness (m) of the first aquifer (left) and second aquifer (right) in different parts of the city.

#### *4.2.2 Piezometric Reconstruction*

The pattern of water-level change in Dhaka city from 1980s onward largely replicate the patterns of changes in the groundwater abstraction in the city (Figure 4.18). Large water-level declines have continued in south central and western parts of the city. Dhaka WASA has been abstracting water since the very beginning of 1980s from these regions (explained at section 4.1.4) which correspond to the increasing decline of water level in this region. The decline of water level is bi-directional i.e. it is declining vertically and extending spatially (explained at section 4.1.4) which is also positively related to DWASA's installation of more production wells and their spatial distribution. It is clear from the relationship is that water level in Dhaka city is directly related to DWASA abstraction and with time it is constantly dropping. The water Level in the aquifer is lowering as withdrawals exceeding recharge. Upper parts of the aquifer is already dewatered throughout the city except part of northeastern corner of the city as indicated in the temporal contour surfaces (Figure 4.14) and depth to base of first aquitard (Figure 4.16) due to continued abstraction of groundwater.

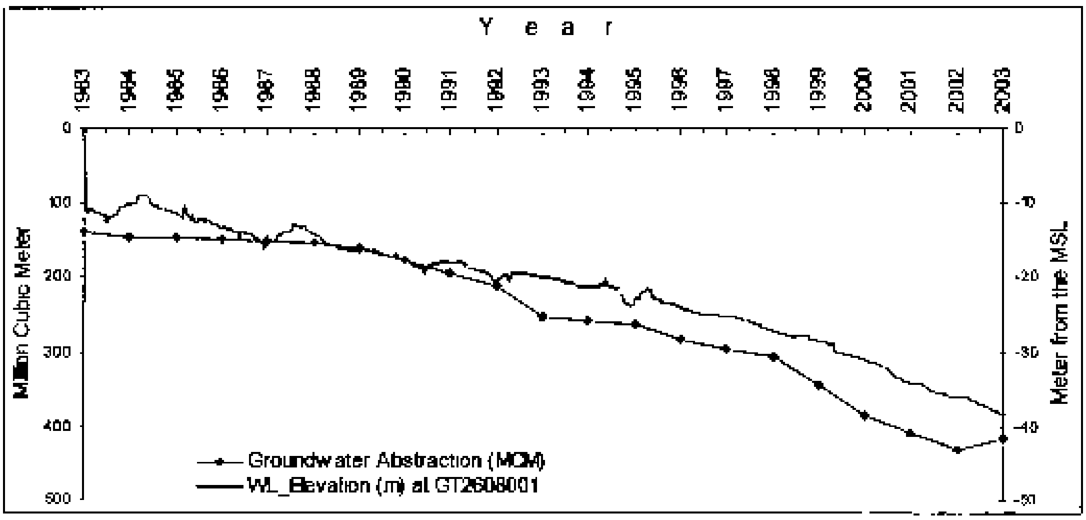



**Figure 4.18:** Relationship of groundwater abstraction and falling trend of water level in the city.

Excessive groundwater withdrawal in Dhaka city resulting into huge leakage type recharge from the surrounding rivers. O and H stable isotope study confirms the large scale leakage of river water in the first aquifer in Dhaka city and $^3H/^3He$ isotope validates the water at 75m in the university of Dhaka area is younger than 20 years indicating recharged water (Darling, et al, 2002). From the same study it can be opined that the flow pattern in the shallower horizon is greatly from the surrounding rivers towards the cones of depression while in the water in the deeper horizon is stable, slow-moving and very old. The gradient & permeability of the Madhupur residuum and underlying aquifer indicate leakage type significant vertical recharge of the aquifer (Ahmed, et al., 1995). Bangladesh Water Development Board (BWDB, 1991) quantify the DWASA withdrawal in terms of recharge as 47% of the withdrawal is dependent on vertical recharge, 47% comes from inflow from surrounding rivers and low-lying areas and remaining 6% of the withdrawal comes from storage causing permanent decline in the water level. Vertical recharge sources are the urban infrastructures via pipe leakage (mains water, sewers, storm drains), on-site sanitation, rainfall and pluvial drainage. With the progressive urbanization in Dhaka the vertical recharge and inflow from the surrounding is greatly reduced and the rate of water level drop is drastically increased in the recent years.

Hydrostratigraphically the aquifer is a confined aquifer as it is caped by a clay-silt layer and pre and early development hydrostatics of the aquifer was confined. Due to the increasing drop of water level the piezometric surface of the aquifer has fallen more than 50m over the last 3 decades in some parts of the city. Due to this drop of water level, the hydrostatics of the aquifer changed to that of unconfined aquifer (Figure 4.19).

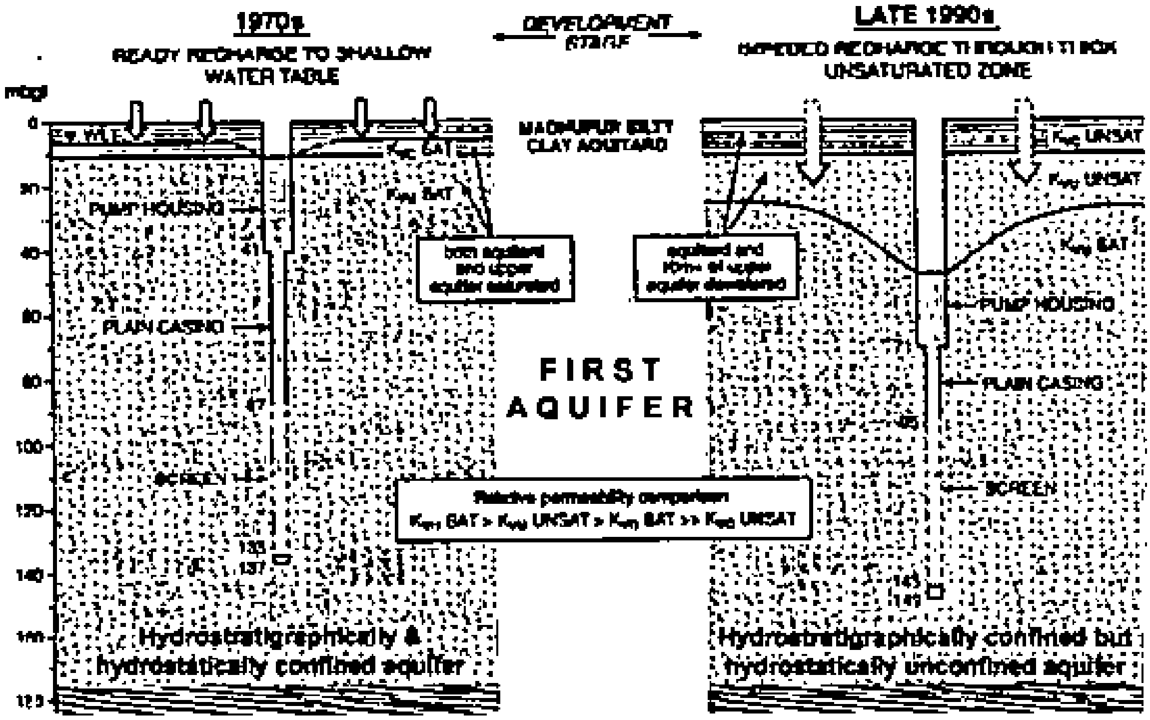



**Figure 4.19:** Hydrostatic response of the first aquifer to intensive abstraction (modified after Morris, et al., 2003).

The falling water level across the extensive part of the city in the first aquifer, leading to increased pumping costs through deepening of wells, and installation of longer, large diameter pump house and longer screen section (Morris, et al., 2003). Falling water level also causing abandonment of wells as the aquifer is dewatered and running-down of wells' productivity. Dewatering is declining the vertical recharge aptitude of the aquifer as the shallower horizon of the aquifer is getting unsaturated (Figure 4.19). If the water level goes down to 70 metres due to continuation of the present rate of extraction of ground water, a large number of WASA pumps will become inoperative. Dewatering is also creating conducive environment to land subsidence in the city through increasing inter-granular stress via rearrangement of the grains. The maximum subsidence of 17 to 27 mm in Dhaka city occurred near the New Airport and 11 to 63 mm at Mohakhali and Kamalapur area during the period between 1990 and 1999 (BUET, 2000).

A generalized model for hydrogeologic system of Dhaka city is conceived as in Figure 4.20 based on the hydrpstratigraphy, piezometry and recharge mechanism. This model needs further modification and enhancement through the improved data sets. There are not enough data sets to detail the second and third aquifer stated in the model.

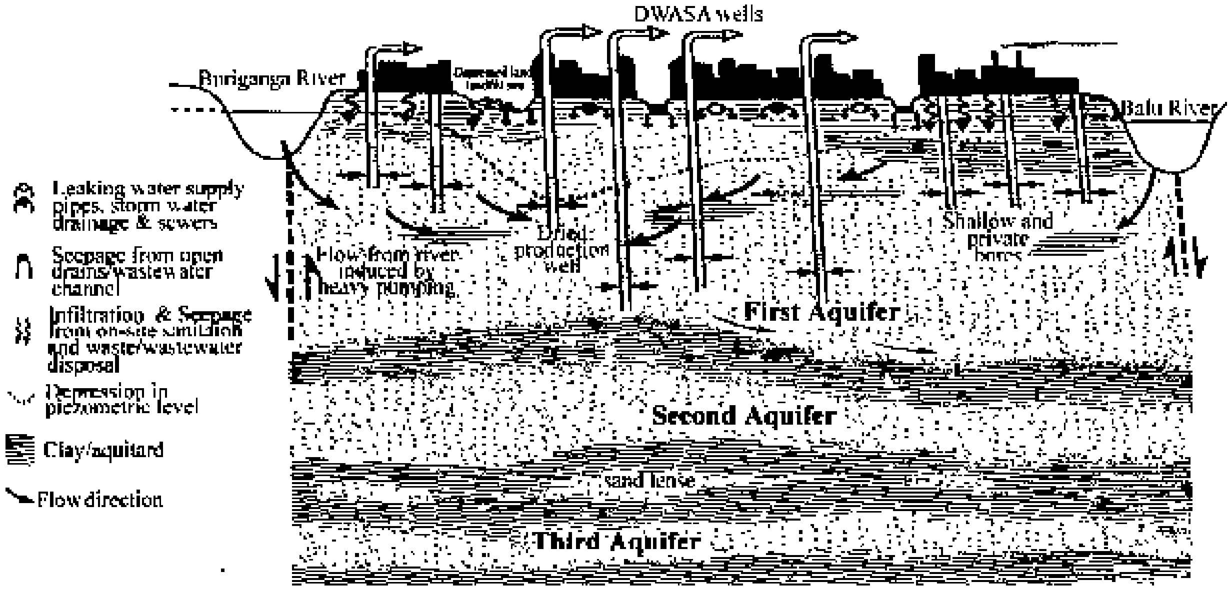



**Figure 4.20**: Hydrogeolgoic system of Dhaka city region up to a depth of 450 meter.

The Hydrostratigraphy and piezometry of the first aquifer indicate the higher vulnerability of groundwater in the central city area. Urgent need of potable water could be fulfilled from the peripheral region mostly from the northern and eastern area of the city.

# Chapter Five
# Conclusions and Recommendations

### 5.1 Conclusions

Dhaka is mostly dependent on the groundwater for urban water supply. Systematic groundwater development started in Dhaka city since 1949. Presently, Dhaka WASA producing 1160.21 Million Litres of groundwater per Day as urban water supply through 389 DTW. Abstraction by water wells is the main discharge. The study aimed to understand the hydrogeologic system of Dhaka city area. The present work collected data on lithology, geophysical logs (resistivity), groundwater abstraction & well design parameters data of the WASA, and Groundwater level/ piezometric head data recorded by different Government agencies. Resistivity logs and lithologs were used to identify the sand and clay horizons for hydrostratigraphic reconstruction. Water level monitoring of bores data and Dhaka WASA data sets used in developing an improved understanding of the piezometry of the aquifer. Based on the findings the following conclusion can be made:

1. These unconsolidated sediments are of Mio-Pliocene age and have been provisionally subdivided into 7 hydrostratigraphic units and therefore three aquifers system from surface to 450mt depth level separated by clay-silt dominated horizons.
2. The first aquifer horizon is composed of medium to coarse sand and gravel. The average thickness of the main aquifer ranges from 100-150 m. The first aquifer is standing on about 30m thick clay-rich layer which is capping the second aquifer at a depth of about 170 m.
3. Thickness of the second aquifer ranges from 50 to 100 m A very thick clay layer (ranging 36 to 128 m in thickness) is followed by the second aquifer and capping the third aquifer.
4. The thickness of the third aquifer is about 40m. Third aquifer is based by another clay dominated layer at a depth of about 420m.
5. Long term hydrographs from the different part of the city indicate the drop in water level is increasing very rapidly throughout the city. The magnitude is varying from 5m above the MSL in 1969 to 54.21m below the MSL in 2003. The water level drop has increasing trend with time ($R^2$=0 75-0 94).
6. The pattern of water-level change in Dhaka city from 1980s onward largely replicates the patterns of changes in the groundwater abstraction rate in the city. Groundwater abstraction in the city has increased more than 1200% from 1970 to 2003
7. The Hydrostratigraphy and piezometry of the first aquifer indicate the high vulnerability of groundwater abstraction from the central city area.
8. Quality and quantity of water in the lower aquifers (second & third aquifer) cannot yet be established. In the absence of adequate hydrogeological data it would not be wise to consider the lower aquifers as potential sources of groundwater for the Dhaka city.

**5.2 Recommendations**

To overcome the problems and strengthening the understanding of the hydrogeological system of the area following recommendations are made:

1. As soon as possible dependency on the groundwater for the urban use should be reduced and abstraction of groundwater from the central part should be stopped immediately. For the time being groundwater could be abstracted from the peripheral region of the city and for the long run strong suggestion goes for the peri-urban well-fields outside of the city.

2. Replenishment of the exhausted Dhaka aquifer is a natural emergency. Existing urban recharge can be supplemented by artificial recharge to mitigate excessive aquifer dewatering in Dhaka. It is highly recommended to be very care full and to carried out studies on the probable consequences (specially geochemical) before setup artificial recharge wells / other means

3. Abstraction of groundwater and surface water should have conjunctive base.

4. In the absence of adequate hydrogeological data it is recommend for not using the lower aquifers as potential sources of groundwater for the Dhaka city. Conversely, resource assessment of the lower aquifers sequence require sufficient data to establish system geometry and continuity, aquifer transmissivity, and areas & rate of annual recharge.

# References


Ahmed, K. M., Hassan, M. A. and Woobaidullah, A S. M. (1995), Hydrochemistry of the Dupi Tila aquifer, Dhaka city, Bangladesh, Acta Universitatis Carolinae Geologica, v. 39, p. 113-125.

Ahmed, K. M., Hassan, M. A., Sharif, S. U. and Hossain, K. S (1998), Effect of urbanisation on groundwater regime, Dhaka city, Bangladesh, Jour. Geol. Soc. of India, v. 52, p. 229-238.

Ahmed, K. M., Hassan, M. K., Burgess, W. G., Dottridge, J., Ravenscroft, P., van Wonderen, J. J. (1999), The Dupi Tila quifer of Dhaka, Bangladesh: Hydraulic and hydrochemical response to intensive exploitation, In: Chilton (ed.) Groundwater in the Urban Environment: Selected City Profiles, Balkema, Rotterdam.

Alam, M. (1983), Evaluation of ground water condition of Dhaka city, Unpublished MSc thesis, Department of Geology, University of Dhaka, Bangladesh, p.71

BUET (2000), Updating of existing groundwater and land subsidence project, Final report, Volume I. Department of Water Resources Engineering and Institute of Flood Control and Drainage Research, Bangladesh University of Engineering and Technology, Dhaka 1000. Bangladesh.

BWBD (1991), Effects of overwithdrawal of ground water in Dhaka city, BWDB water supply paper-519, Ground Water Circle-II. Bangladesh Water Development Board. Dhaka, Bangladesh, 14p.

Chawala, A. S. (1994), Effects of overexploitation of groundwater and remedial measures-a case study. Proc. Reginal Workshop on Environmental aspects of groundwater development. Kurukshetra. India, IV, p.19-31

Chowdhury, S. U. (1993), Evaluation of aquifer characteristics of the Dhaka city using geophysical wireline logs, Unpublished MSc thesis. Department of Geology. University of Dhaka, Bangladesh, p. 124.

Cressie, N. A. C. (1990), The Origins of Kriging, Mathematical Geology, v. 22, p. 239-252.

Darling, W. G., Burgess, W, G., and Hasa, M K , 2002, Isotopic evidence for induced river recharge to the Duti Tila aquifer in the Dhaka urban area, Bangladesh, In: The application of isotope techniques to the assessment of aquifer systems in major urban areas, TECDOC 1298, International Atomic Energy Agency, p. 95-107.

Eisen, C. and Anderson, M. P (1980), The effects of urbanisation of groundwater quality-a case study. Groundwater, v. 17(5), p. 456-462.

EPC/MMP, 1991, Dhaka region groundwater and subsidence study, Dhaka WASA, EPC in association with Sir MacDonald and Partners, Dhaka.

Ford, M. and Tellam, J. H. (1994), Source, type and extent of inorganic contamination within the Birmingham urban aquifer system, U.K.,Jour. Hydrology, v. 156, p. 101-135.

Franke, R. (1982), Scattered Data Interpolation: Test of Some Methods, Mathematics of Computations, v. 33, n. 157, p. 181-200.

Hasan, M. K., ahmed, K. M., Burgess, W. G., Dottridge, J., and Asaduzzaman, M. (1998), Limits on the sustainable development of the Dupi Tila aquifer, Bangladesh, In: Hydrogeology in a changing environment, Volume II, British Geological Society, p.186-194.

Hoque, M. A. and Khan, A. A. (2001), Seismicity and seismotectonics regionalization of the Bengal basin, Bangladesh. Bang. Jour. of Geology, Vol.20, p.77-86.

Hossain, A., Uddin, M. E., Zahid, A., and Deeba, F. (2003),Groundwater level in Dhaka city area with reference to declining trend, Presented in the workshop on 'Water Resources Management and Development in urban areas with special reference to Dhaka city', Goethe Institute, Dhaka, Sunday, September 14, 2003.

Kandoker, R. A. (1987), Origin of elevated Barind-Madhupur Areas, Bengal basin results of neotectonic activities, Bang. Jour. of Geology, vol. 6, p. 1-7.

Keller, G. V. and Frischknecht, F. C. (1966), Electrical Methods in Geophysical Prospecting, Pergamon Press, London.

Miah, M. M. and Bazlee, B. I. (1968), Some aspects of the Geo-morphology of the Madhupur Treat, Oriental Geographer, Dhaka p. 39-48.

MMP/HTS (1992), Natural Resources. Deep Tubewell II project. Final Report Supporting Volume 2.1, Gov. of Bangladesh

Mojumder, R. K. (1996), Hydrogeological investigations of the eastern part of Dhaka city using geophysical well logging, Unpublished MSc thesis, Department of Geological Sciences, Jahangirnagar University, Bangladesh, 170p.

Morgan, J. E. and McIntire, W. C. (1959), Quaternary Geology of Bengal Basin, East Pakistan and India, Geol. Soc. Amer. Bull., Vol. 70, pp.319-342.

Morris B L., O Dochartaigh B. E , Cunninggham J., Ahmed K. M., Hassan M. K., Seddique, A. A (2000), Groundwater Vulnerability and urban activity assessment : the Narayanganj Bangladesh case-study, BGS Technical Report WC/00/21

Morris, B. L., Seddique, A. A., and Ahmed. K. M. (2003). Response of the Dupi Tila aquifer to intensive pumping in Dhaka, Bangladesh, Hydrogeology Journal, vol. 11, p.496-503.

Rahman, A. T. M. A. (2003), Present status of surface water and groundwater condition in Dhaka city, Presented in the workshop on 'Water Resources Management and Development in urban areas with special reference to Dhaka city', Goethe Institute, Dhaka, Sunday. September 14, 2003.

Rider, M. H. (1986), The geological interpretation of well logs, John Wiley and Sons Inc., New York.

Robertson Geologging Ltd. (2000), Robertson Geologging Manual, Deganwy, Conwy, Gwynedd, LL31 9PX, U.K.

Shams, N., 1999, Urban Geology of Dhaka City for geohazard mitigation and development planning, Unpublished MSc thesis, Department of Geology, University of Dhaka, Bangladesh, p. 94.

Somasundaram, M. V., Ravindran, G., and Tellam, J. H. (1993), Groundwater polution of the Madras urban aquifer, India. Groundwater, v. 31, p. 4-11.

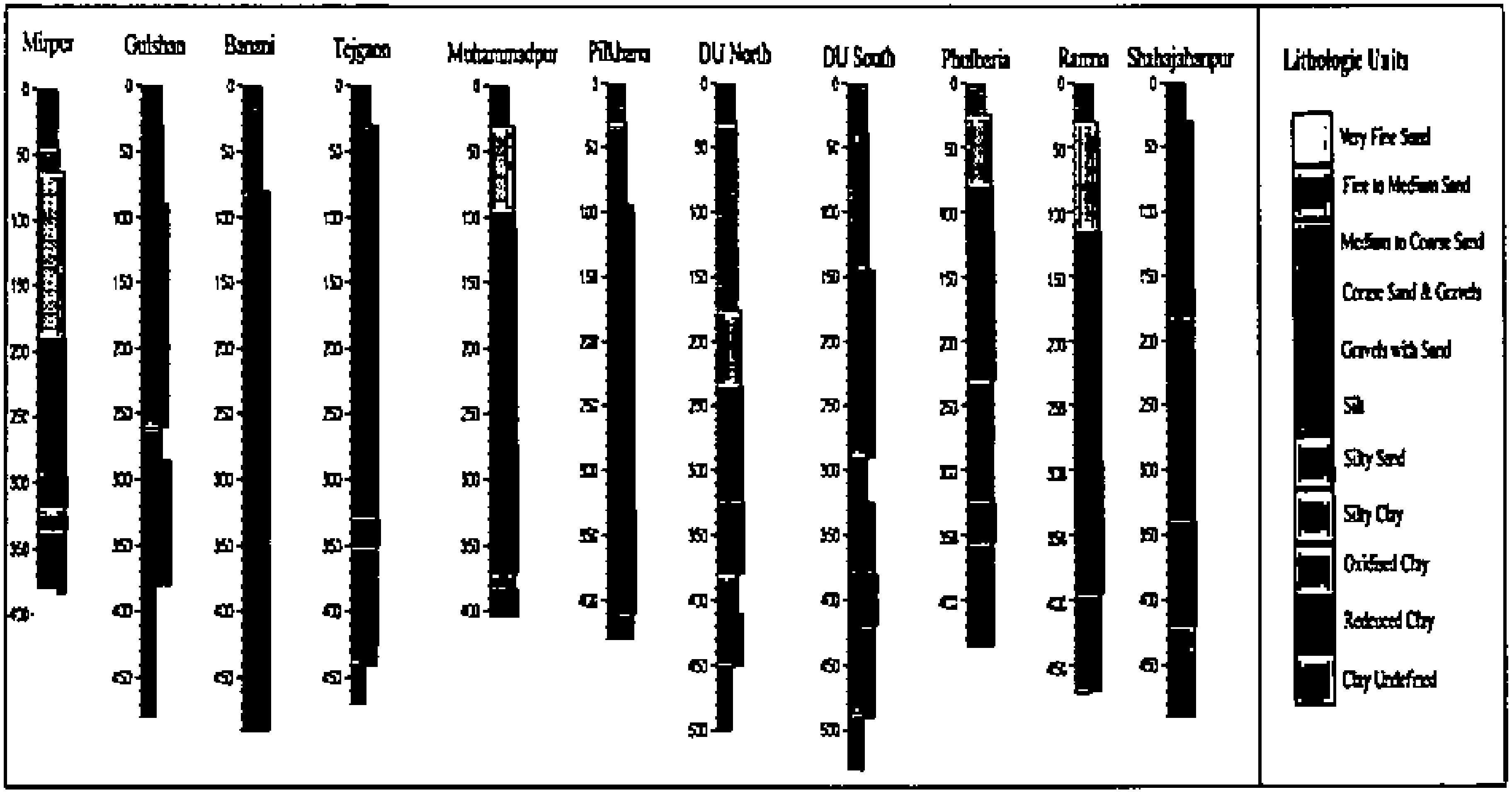
Tood, D. K. (1995), Groundwater hydrology, John Willy & Sons, Singapore, 535p.

WASA (1991), Dhaka regional groundwater and subsidence model, Dhaka Water Supply and Sewerage Authority.

WASA (2003), Management Information Report for the month of November 2003, Dhaka Water Supply and Sewerage Authority. Dhaka, Bangladesh.

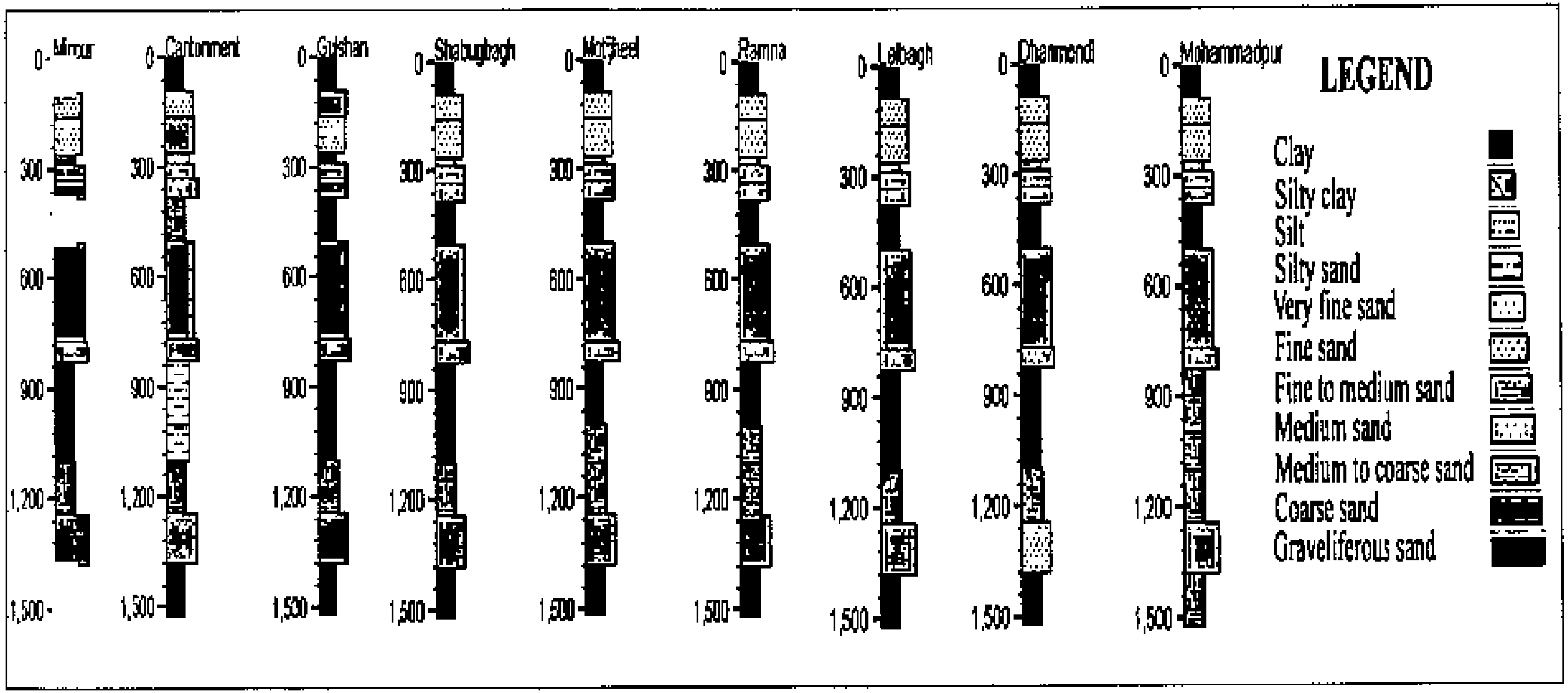
# Appendix - 1

Lithologs (depth in ft) used in the study (Shallowlog



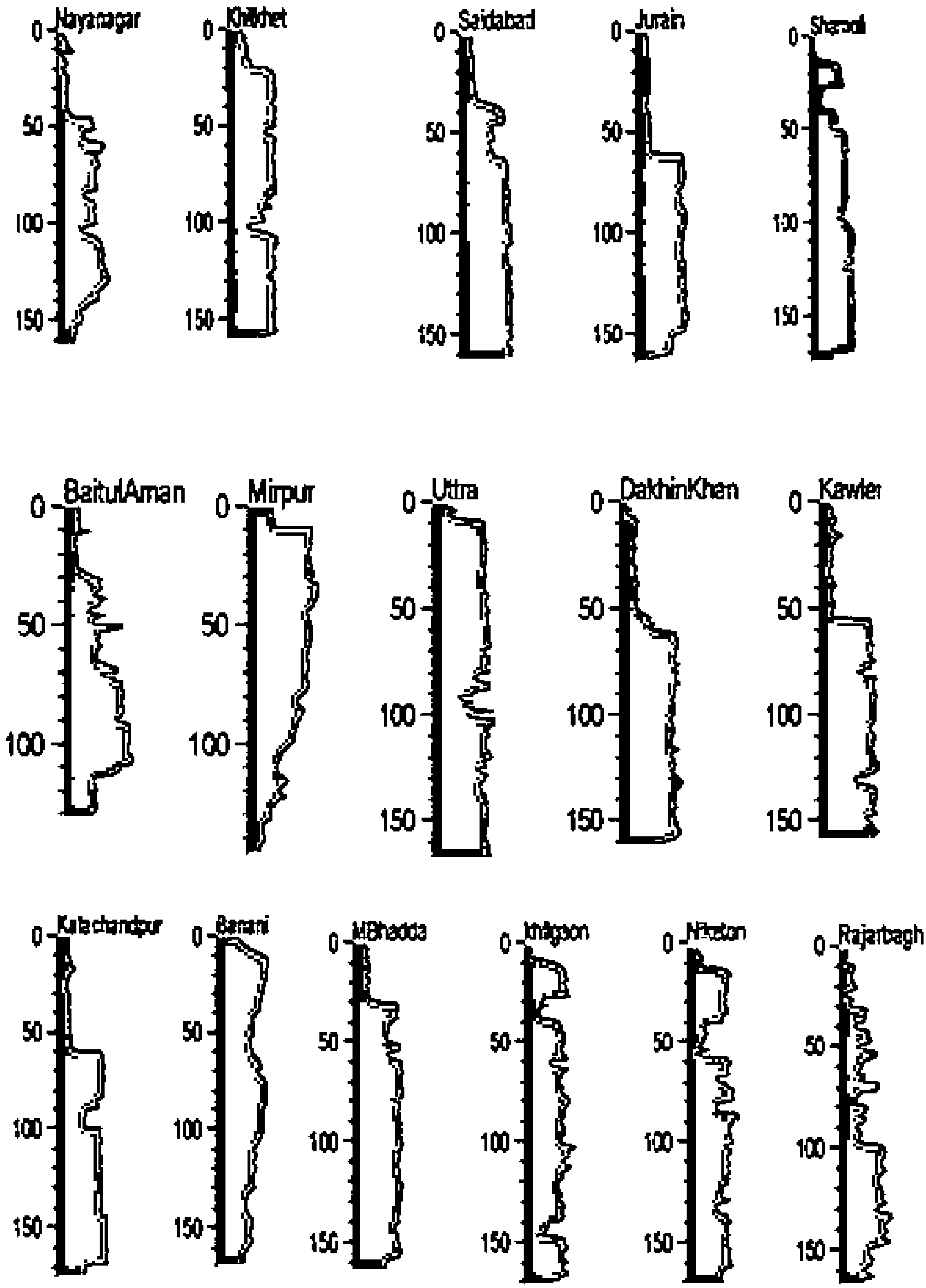
## Appendix-2

Lithologs (depth in ft) used in the study (Deep log)



# Appendix-3

Geophysical logs (depth in m) used in this study



# Appendix-4

Location of the BWDB water level monitoring stations