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Hydrostratigraphy and Properties of Aquifer Materials in Dhaka University Campus

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Abstract

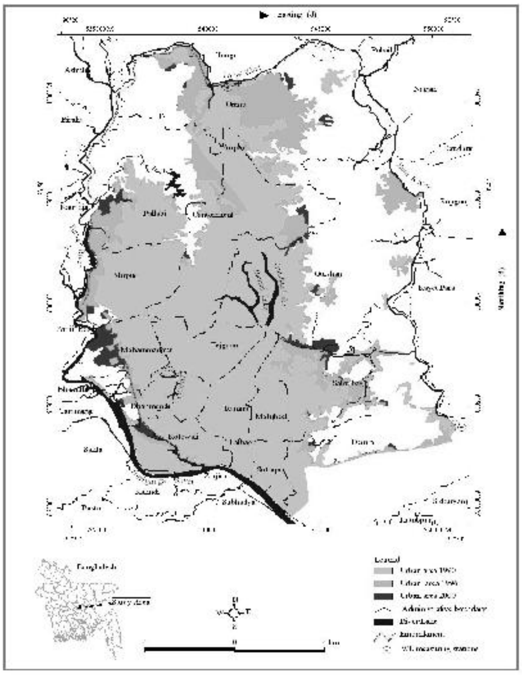
The reconstruction of hydrostratigraphy by subsurface panel diagrams and 3D block diagrams reveals that three aquifer units exist in the Dhaka University campus up to the investigated depth of 304 m. Most of the tubewells of Dhaka University Campus are tapping water from the upper aquifer system. The present groundwater table in the study area is 42m below the surface. The hydrographs show a continuous declining trend of groundwater table. The average rate of groundwater declination is 2m/year in the study area. The comparative hydrograph of surface and groundwater shows that the groundwater in the upper aquifer and surface water of the Buriganga river are interconnected. The regional groundwater flow shows a radial pattern concentrated to the center of the city. The aquifer properties i.e. hydraulic conductivity and transmissivity values of the aquifer sediments are estimated as 16.15 m/day and 1534 m^2/day for the upper or first aquifer and 5.25 m/day and 131.25 m^2/day for the second aquifer, respectively. The hydraulic conductivity of the third aquifer is 7.6m/day. The values of uniformity co-efficient of the first aquifer ranges from 1.38 to 2.18, second aquifer from 1.3 to 2.3 and third aquifer from 1.8 to 2.64 which indicates all samples are well sorted. To avoid further deterioration of aquifer condition and combat the situation, especially the continuous groundwater head declination, urgent action plan is required without further delay.

Key words: Hydrosrtatigraphy, Aquifer properties, Dhaka University campus.

I. Introduction

In recent years development of groundwater resource of the country are facing questions about the sustainability. The sustainability of groundwater resource is a function of many factors, including depletion of storage, reduction in stream flow, reduction of recharge area, potential loss of wetland and riparian ecosystem[1]. Each groundwater system and development situation is unique and requires an analysis adjusted to the nature of the existing water issues.

Dhaka is traditionally dependent on groundwater of Dupi Tila aquifer for drinking water supply. In addition, most of the industries and bigger user groups are utilizing groundwater for their need by sinking their own tubewells. The Dupi Tila aquifer, lying underneath the Madhupur Clay has been providing about 82% of the total supply of good quality water in Dhaka city[2]. Considering the approaching population of 10 million, about 1.6 Mm^3 (million m^3) of water is required every day to fulfill the demand of city dwellers. Compared to the over exploitation of groundwater, the renewable recharge to aquifer is very negligible. The rechargeable surface area is decreasing day by day due to construction of buildings, roads and concrete pavements as well as unplanned urbanization. Besides, 6 to10m thick compact upper clay layer in the subsurface, which is about 40m in the eastern part, is also responsible for almost no vertical recharge though the average annual rainfall in the city area is about 1800 mm. As a result, the lowering trend of groundwater level during last 32 years is 20 to 30 m with an average decline of more than 1m per year without replenishing water table that causes groundwater mining in the city area[3].



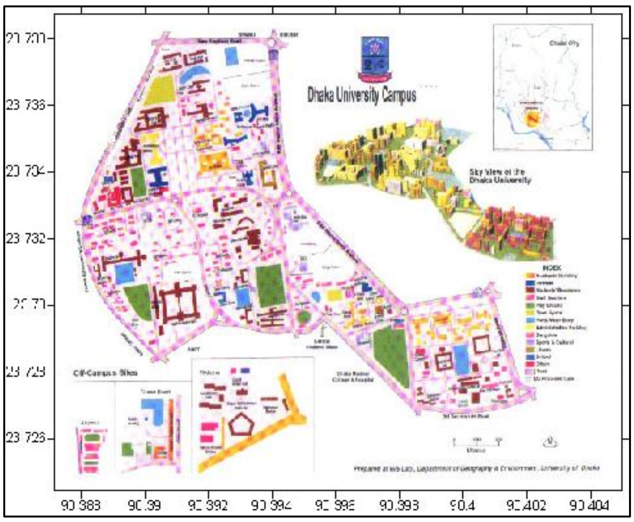


Fig. 1. Location map of the study area.

Dhaka University Campus, the study area, is located in the southern part of Dhaka city which lies between 23º47.5´N to 23º42´N latitude and 90º21´E to 90º25´E longitude. The area occupies about 256 acres or about 1.04 km^2 of land and belongs to Shahbagh Thana of Dhaka Metropolitan City (Figure 1). The objectives of this study were to reconstruct the hydrostratigraphy using the Rockworks software, to analyze the properties of the aquifer materials using the grain-size analysis method and to determine groundwater flow condition of Dhaka University Campus using the relevant softwares like Surfer, MS Excel and ArcGIS.

II. Methods and Materials

Literature survey and planning

As a part of literature survey, hydrogeological reports of different areas were studied for baseline ideas and planning[4,5,6]. For the general geological and hydrogeological knowledge, different reference books and existing report based on Dhaka geology are followed and studied[7,8,9]. Google Earth satellite image of the study area is visually studied for physiographic and topographic information of the study area. And also water supply and management related different reports and information were collected from internet browsing, journals and reports[10,11]. Going through all of the studies a detail planning of data collection was made.

Data collection

The data on borehole litholog were collected from engineering section (pump) of Dhaka University; rainfall, evaporation, surface water level (Balu, Turag, and Buriganga rivers), discharge and groundwater level data were procured from Bangladesh Water Development Board (BWDB). Data collected for the study area has been shown in Table 1.

Table 1. Different types of data of the study area[12,13].

Data Type	Data	Data Range	Data Source
Climatic	Rainfall	1997-2007	BWDB
	Evaporation	1997-2007	BWDB
Sedimentological	Bore logs	1997-2007	Engineering section, D.U.
Hydrological	River water level	1997-2007	BWDB
	Discharge	1997-2007	BWDB
Hydrogeological	Ground water level	1997-2007	BWDB

Samples for grain-size analysis were collected from a test-well drilled beside Shahidullah Hall Extension-2. The well was drilled to the depth of 1000 ft (304.8 m) and the samples were collected at 10 ft (3.048 m) interval. Grain-size analyses of all sand samples were carried out in the laboratory of Geology Department of Dhaka University. The depth ranges for the determination of the properties of aquifer materials of the study area were selected by observing subsurface panel diagram and 3D block diagrams by correlating all the available bore logs.

Data organization and processing

All the collected data were organized and analyzed by Excel spreadsheets. Then these data were imported to other computer program for processing and presentation. For example: litholog data were firstly organized by Excel spread sheets then imported to RockWorks 2004® for data processing and presentation as 3D block diagram, cross section and panel diagram. Similarly surface and groundwater data were organized and analyzed by Excel spreadsheets. Then these data were exported to Surfer 8.04 computer program to generate contour maps using normal krigging geostatistical method.

III. Results and Discussion

Climatic condition

The mean monthly rainfall (1998-2007) recorded in the study area ranges from 401.91 mm in September to 3.82 mm in January; mean annual rainfall (1998-2007) is 2084.00 mm. About 90% of the mean rainfalls in the study area is experienced during May to September (wet period) and the rest 10% during November to April (dry period). The annual average evaporation of the study area is 769 mm which is about 40% of total annual rainfall of the study area[12]. Thus the annual water balance of the area is 1601.75 mm which indicate humid tropical climate. The climatic stress period is from the months of November to March and the climatic surplus period is from April to October.

Groundwater flow

The groundwater (GW) hydrographs within Dhaka city show continuous declining pattern with no or very little fluctuations. The present groundwater table in the study area is 42m below the surface. The hydrograph shows a continuous declining trend of groundwater table (Figure 2a). The average rate of groundwater declination is 2m/year in the study area. The comparative hydrograph of ground- and surface water (SW), as shown in figure 2b, demonstrates an agreement of fluctuation which gives the impression that the groundwater in the upper aquifer and surface water of the Buriganga River are interconnected. Hence the upper aquifer of the study area gets replenished by the peripheral river.

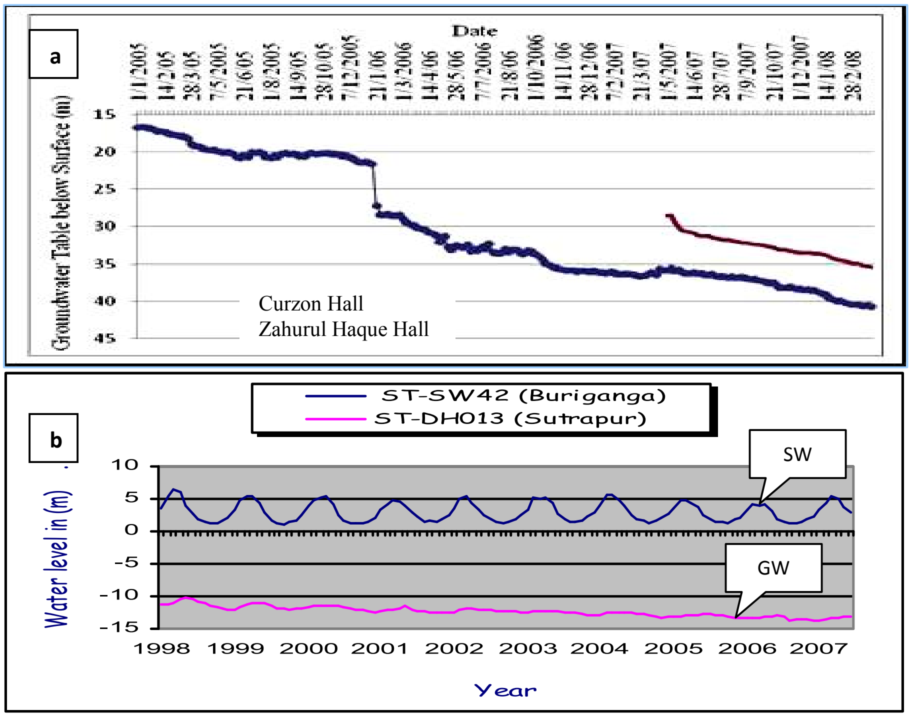


Fig. 2. Hydrographs of the study area: a) Groundwater head declination in Dhaka University Campus; b) Groundwater and surface water relationship in and around the study area.

The groundwater contour map of Dhaka city of the year 2007 shows that the flow of groundwater is radial in pattern, concentrated to the center of the city. T

he large cones of depressions are due to huge abstraction of water by nearby tubewells (Figs 3a and 3b). In wet period of the year 2007 the highest value of groundwater level (-13.14m) was in Sutrapur area and the lowest value was in Sabujbagh area (-27m), whereas in dry period the lowest value of groundwater level (-60.16m) was in Mirpur area and the highest value in Sutrapur area is about -13.68m.

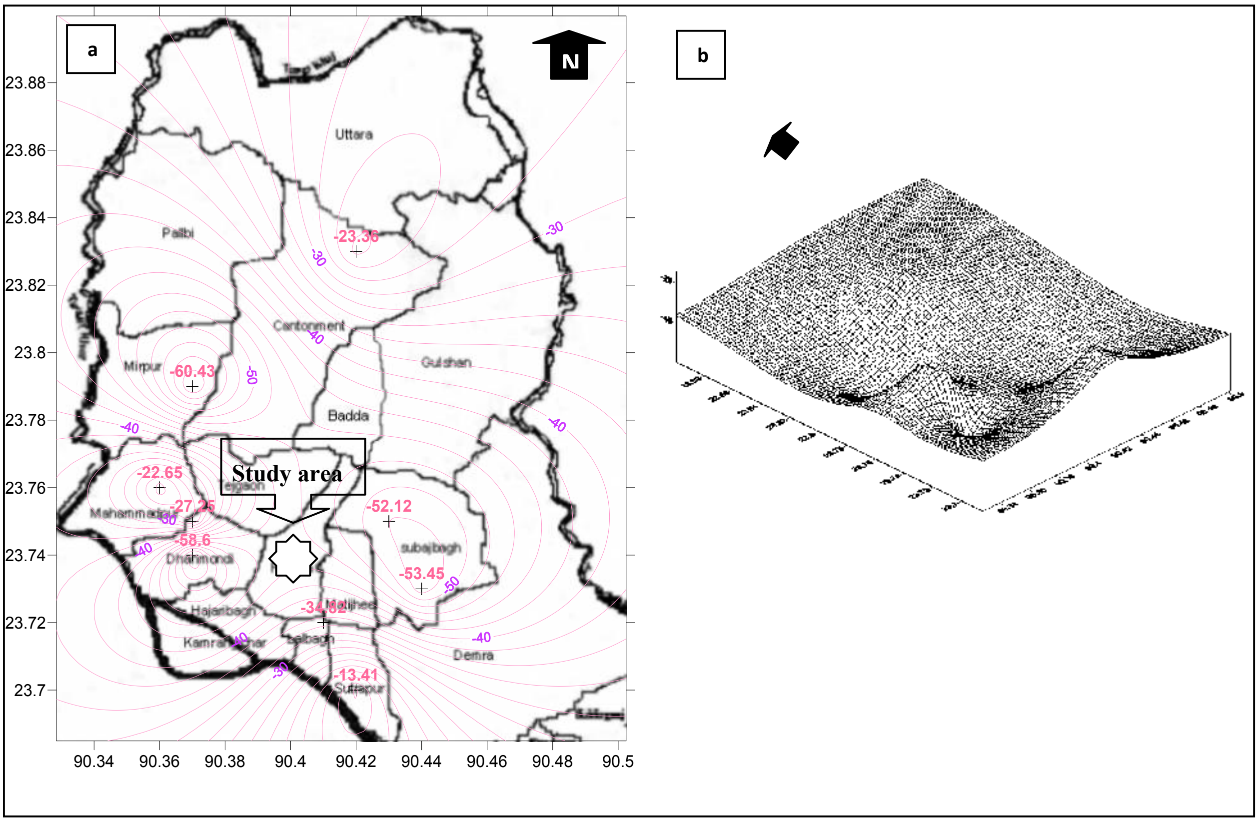


Fig. 3. a) Groundwater contour map; b) 3D impression of Dhaka City in wet period of the year 2007.

Hydrostratigraphy

The panel and 3D block diagram generated by Rockwork reveal that the uppermost clay layer is continuous throughout the study area except that in the south-eastern part (Figure 5). This is because the bore hole beside Shahidullah hall is just adjacent to the extension building and hence the uppermost clay layer might be cut out/removed during the construction of the building or may be the floodplain of Buriganga river is continuous up to this area. The thickness of the uppermost clay layer varies from 6 to 10 m. Figures 4, 5 and 6 depict the 3D view of all available logs, 3D block diagram and panel diagram of the study area, respectively.

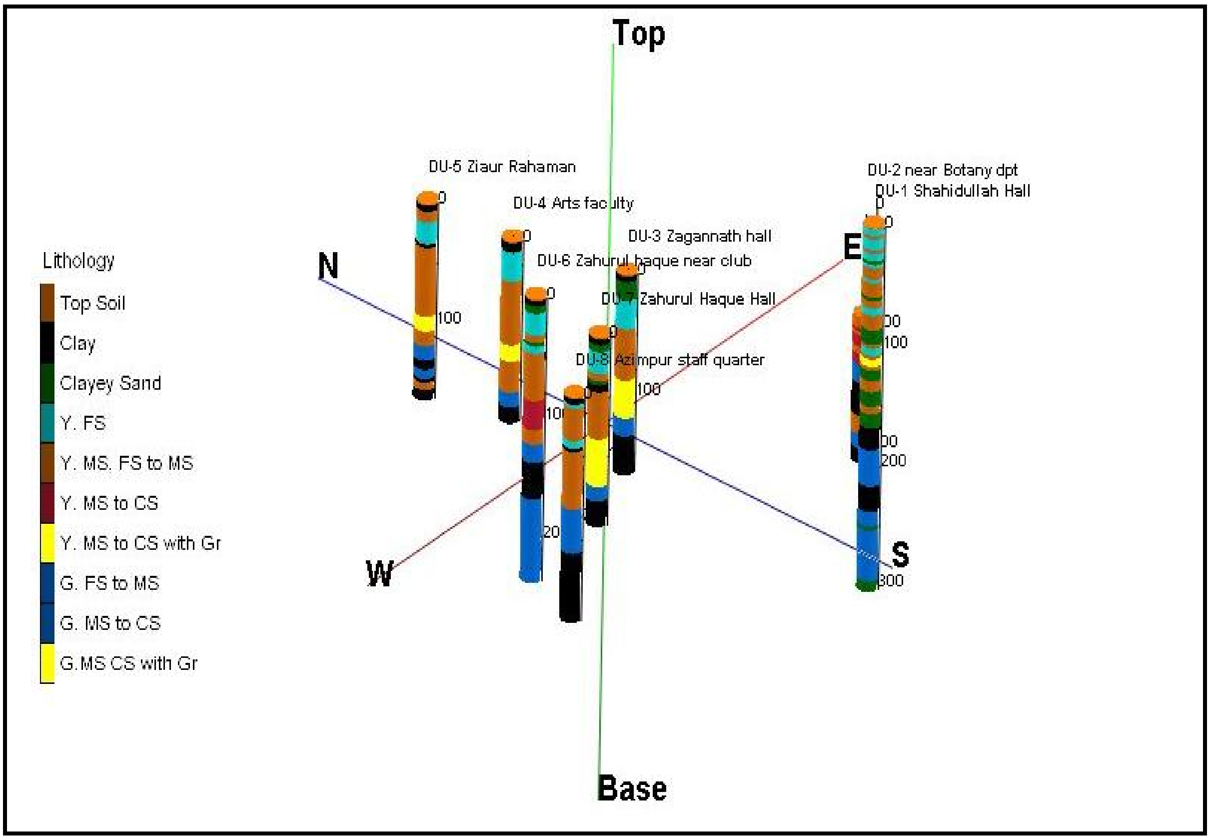


Fig. 4. Lithologs of the study area prepared by Rockwork ® 2004.

The upper clay layer is followed by a thick sequence of unconsolidated sands of varying sizes. The sand unit ranges from 45 to 160 m in thickness. The sequence is characterized by very fine to fine-grained sand, medium-grained sand, and medium to coarse-grained sand with gravel. The upper portion is characterized by very fine to fine-grained sediments and lower portion is characterized by medium to coarse-grained sediment with gravel. Within this sequence lenses of silt and clay occasionally appear.

Most of the logs encountered a clay horizon below the sand unit. This clay unit separates sandy sequence from the lower one. The thickness of the clay layer is higher in the south-western area than that in the north-eastern area particularly the northern area; the depth of this clay layer is higher to the north which is about 150m.

Most of the available logs are up to about 160 m in depth, so the deeper lithology could not be observed clearly. However, below the second clay layer a thin clean sand layer is present in the northern part of the area. This sand unit contains medium-grained sediment, which is followed by thin clay layer ranging in thickness from 15 to 30 m.

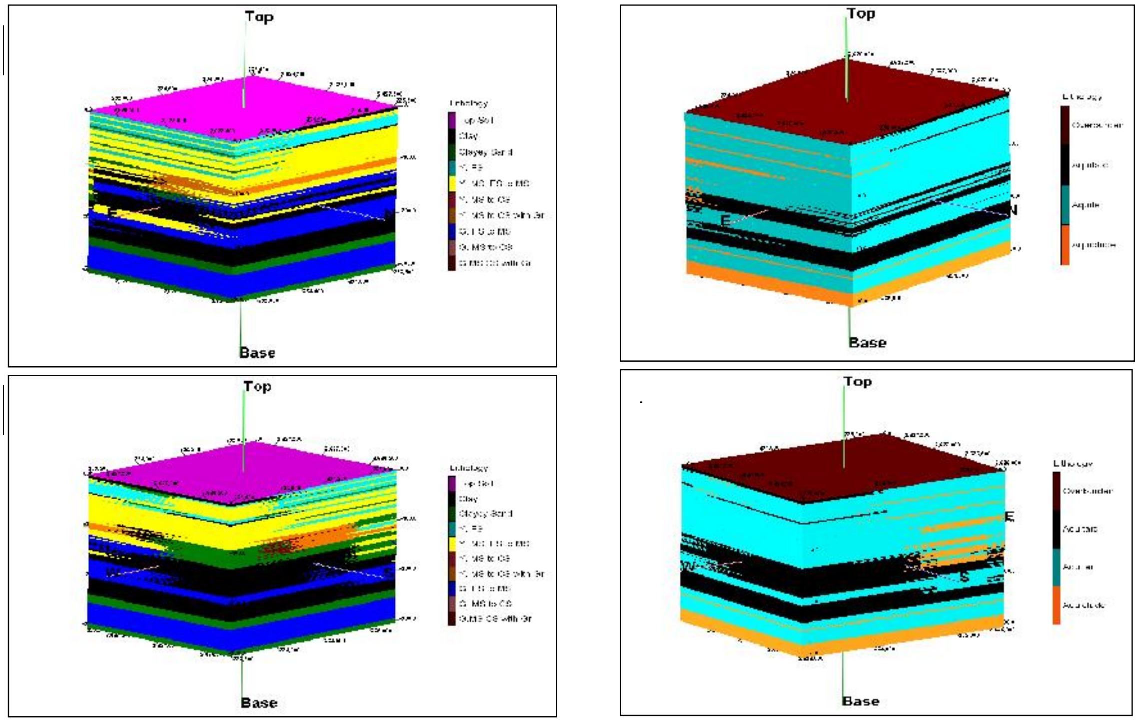


Fig. 5. 3D block diagram: a) northeastern lithostratigraphic view; b) northeastern hydrostratigraphic view; c) southwestern lithostratigraphic view; d) southwestern hydrostratigraphic view.

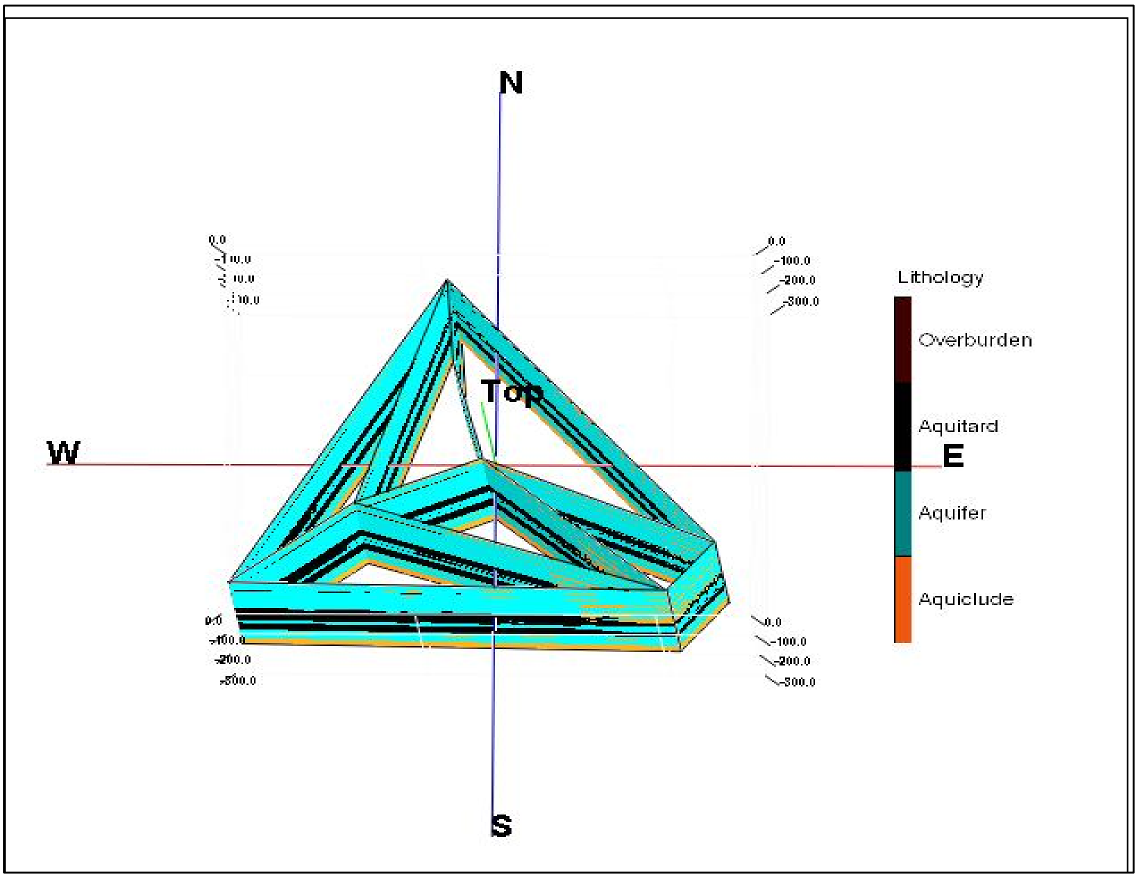


Fig. 6. Hydrostratigraphic panel diagram of the study area.

The uppermost clay layer serves as first aquitard varying in thickness from 6 to 9.5 m. Below this layer a thick sequence of sand layer serves as aquifer which is 110 to 140 m in thickness. Occasionally, beneath the clay unit a sequence of mixed sand silt and clay can be observed which is termed as aquiclude. Following the thick sequence of sand, the second aquitard was encountered at a depth of 130 to 150 m which varies in thickness from 6 to 30 m in the area. The second aquifer starts from 140 to 180 m depth and the thickness ranges from 10 to 30m. The third aquitard starts from 200 to 215 m depth in the area and the thickness was found to be about 25 m in Shahidullah Hall log. The third aquifer or the lower Dupi Tila aquifer starts at a depth of 240 m in Shahidullah Hall log. The thickness can not be determined because the lower aquitard was not encountered by any available log in the area. Therefore, from these figures three aquifers of the study area can be identified: *upper aquifer* (110 to 140m thick), 2) *middle aquifer* (10m to 30m) and 3) *lower aquifer* (thickness can not be determined).

Properties of aquifer materials

For the determination of the properties of aquifer materials, the grain-size analysis data were plotted on a grain-size distribution curve by using simple Excel spread sheet chart option, and the values of D_{10}, D_{25}, D_{50}, D_{60} and D_{75} were measured. Data were arranged like that in Table 2. The cumulative weight retained, cumulative weight retained percentage and percent of passing were calculated and grain-size distribution curve was plotted following the diameter of grain or grain size vs percent of passing. Grain size in logarithmic scale represents X-axis and percent of passing in normal scale represents Y-axis (Fig 7). The results obtained from grain-size analysis have been given in Table 3.

Table 2. Grain size analysis data of 240 to 250 ft (73.17-76.22 m) depth.

Depth of the Sample:240-250 ft				Weight of the sample: 100 gm	
Grain Size	Diameter (mm)	Weight retained (gm)	Cumulative wt. retained (gm)	Cumulative wt retained (%)	(%) Passing
V. coarse sand	1	0.715	0.715	0.715	99.285
Coarse sand	0.5	0.065	0.78	0.78	99.22
Medium sand	0.25	63.9	64.68	64.68	35.32
Fine sand	0.125	22.44	87.12	87.12	12.88
V. fine sand	0.063	8.24	95.36	95.36	4.64
Pan	0.03125	4.64	100	100	0

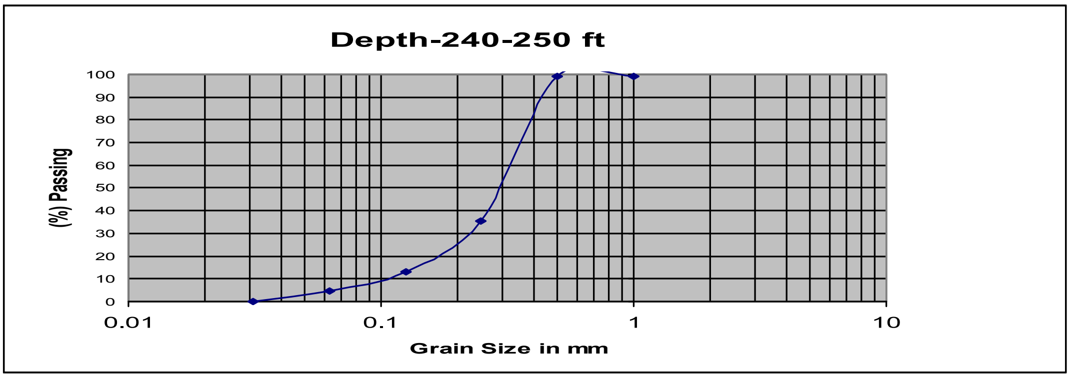


Fig. 7. Grain-size distribution curve of sample of depth range 240-250ft (73.17-76.22 m).

Table 3. Results from Grain-size Distribution Plot.

Depth	Es $=D_{10}$	D_{25}	Median= D_{50}	D_{60}	D_{75}
240-250ft	0.115	0.2	0.3	0.33	0.38

From the grain-size distribution curve the following properties were measured:
The uniformity co- efficient Cu= D_{60}/D_{10}
The sorting co efficient = D_{75}/D_{25}
The effective size Es = D_{10}
The median grain size = D_{50}

After calculating these parameters hydraulic conductivity and transmissivity values were determined.

The values of effective grain-size D_{10} for the first aquifer ranges from 0.09 to 0.231mm, the second aquifer ranges from 0.068 to 0.09 mm and for the third aquifer the range is 0.058 to 0.155 mm. The Median grain size D_{50} ranges from 0.21 to 0.34 mm, 0.19 to 0.295 mm and 0.175 to 0.33 mm for the first, second and third aquifer respectively, which indicates the aquifer materials are fine to medium and medium to coarse grained.

The sorting co-efficient (D_{75}/D_{25}) values range from 1.38 to 2.18 (first), 1.62 to 2.36 (second) and 1.73 to 2.64 (third).The values of uniformity co-efficient of the first aquifer ranges from 1.38 to 2.18; of the second aquifer ranges from 1.3 to 2.3 and that of third aquifer ranges from 1.8 to 2.64, which signify that all the samples are well-sorted (values less than 4 are well-sorted, and values greater than 6 are considered to be poorly sorted)[14].

Hydraulic conductivity

The hydraulic conductivity can be estimated for sandy materials where the effective grain size (D_{10}) is between 0.1 and 3.0 mm[15]. Here, D_{10} represents the smallest 10% of the sample. The effective grain-size is determined from a grain-size distribution plot. Although some of the D_{10} values of the samples are less than 0.1 mm, well-sorted samples may allow the calculation to be usable[9]. Grain-size plots are helpful in determining the sorting of a sample. The sorting is estimated with the uniformity co-efficient (Cu).

$Cu= D_{60}/D_{10}$

Hazen equation (1911) relating hydraulic conductivity to effective grain size and sorting co-efficient is

$$K= C (D_{10})^2$$

Where,

K = Hydraulic conductivity in cm/sec

D_{10} = effective grain size in cm

C = sorting and grain size co-efficient in (1/cm/sec)

The co-efficient C is assigned according to sorting and grain size. The grain-size is determined by evaluating the median grain-size (D_{50}) from grain-size distribution curve. As all the analyzed samples are fine to medium and medium to coarse grained and well-sorted, the value of the co-efficient is assigned as 90 cm/sec[15].

Converting the effective grain-size in cm and using a Hazen (1911) C factor 90 the hydraulic conductivity of the samples were calculated[15].

One of the examples of calculation of depth (240-250ft) (73.17-76.22 m) is given below:

$$K_{Hazen} = 90(0.015\ \text{cm})^2 = 13.22\times10^{-5}\text{cm/sec}\ (86400/1\text{day})(1\text{ft}/30.48\text{cm}) = 33.739\ \text{ft/day}$$

The hydraulic conductivity values of first aquifer range from 22.07 to 140.88 ft/day or 6.73 to 42.95 m/day; of the second aquifer range from 11.79 to 20.66ft/day or 3.59 to 6.30 m/day and that of the third aquifer range from 12.501 to 61.292 ft /day or 3.81 to 18.68184 m/day

Transmissivity

Transmissivity of the aquifer was calculated from the hydraulic conductivity value, as it is directly related to the hydraulic conductivity by the following relationship:

T = Kb

where,

K = Hydraulic conductivity

b = Saturated thickness

The common approach is to assume the saturated thickness (b) in an unconfined aquifer as the thickness of saturated materials from bedrock to the water table and in a confined aquifer b is simply the thickness of the aquifer between confining units[9]. Assuming the average thickness of the first aquifer is 140 m and the saturated thickness is 95 m, and the saturated thickness of the second aquifer is 25 m, the transmissivity values stand as below:

$T_{1st} = 16.146 \times 95 = 1533.91\ m^2/day$

$T_{2nd} = 5.25\times 25 = 131.25\ m^2/day$

The transmissivity value of the third aquifer can not be determined as the thickness of this aquifer is unknown.

IV. Conclusion

Though the properties of aquifer materials are favorable, groundwater head declination is a constraint to groundwater development in the area as the groundwater head in Dhaka University Campus has been declining alarmingly like other parts of Dhaka city. The ponds situated in the campus could be re-excavated to an optimum depth so that the aquifers get recharged. Besides, the system loss in the water supply system should be reduced to as minimum as possible and the provisions for rainwater harvesting should be exercised as soon as possible to meet the ever-growing demand of water thereby reducing the dependency on the groundwater. An integrated multidisciplinary holistic approach is urgently needed to get rid of this water-demand conundrum.

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(c) (d)