# Hydrostratigraphic Modeling of Selected Sectors of Islamabad

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# ABSTRACT

Islamabad lies at the foothill of Margalla hills and adjacent to Rawalpindi. The study covers an area of approximately 76.87 square kilometers. The thesis presents the 3 dimensional models of the subsurface geological data obtained from borehole records. RockWorks v.2002 was used to model and create images describing the stratigraphy of the study area. Analysis of cross sections and three dimensional models created by RockWorks v.2002 allows texturally distinct hydrostratigraphic units to be identified. The study defines the hydrogeologic framework including mapping the extent and thickness of aquifer and confining units of groundwater system. The water flows from north to south as the topography changes from slopes to plane. Aquifer 3 of the study region was studied in detail and it porosity, permeability and moisture content were discussed. The eastern and western sides of the aquifer 3 has varying thickness, porosity, permeability and moisture content which can determine the more precise region for recharge and discharge.

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Aneeqa Abrar

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# 1. INTRODUCTION

Islamabad, the capital city of Pakistan, lies at the foothill of Margalla hills and adjacent to the ancient Gakhar city of Rawalpindi. The area of the city is approximately 906 square kilometers with an estimated population of 1.74 million in 2009. Geologically the area is uneven with elevation ranging from 1604 meters to 457 meters (Wikipedia).

Islamabad is located on Potwar Plateau and has been historically a part of crossroads of Punjab and Khyber Pakhtunkhwa. Islamabad was chosen as a new capital in 1958 by President Ayub Khan as it had a comparatively stable climate and had a central location on Grand Trunk Road which linked Punjab and Khyber Pakhtunkhwa. Also army headquarters was situated in Rawalpindi, its twin city.

Islamabad is the most peaceful and planned city of Pakistan. It is divided into eight (8) zones as shown in the following map. These zones have been divided as: Administrative Zone, Commercial District, Educational Sector, Industrial Sector, Diplomatic Enclave, Residential Areas, Rural Areas and Green Area.


**Figure 1: Location Map Showing Islamabad source: sheikh et.al (in press)**

## 1.1. Purpose and Scope of the Study

The study was carried out to delineate the subsurface hydrostratigraphic model and to generate a data base for the future research. The purpose of the study was to define the hydrogeologic framework including mapping the extent and thickness of aquifer and confining units of groundwater system.

The main objectives of the study are:

1. Characterization of the aquifer system of sectors F-8, F-10, G-7, G-8, G-9, G-10, H-8, H-9, I-8 and I-9 of Islamabad.
2. Computerization of older data.
3. Establish the correlation between lithologies.
4. Hydrostratigraphy was established.
5. Hydrostratigraphic model.
6. Spatial demarcation of aquifer system.
7. Identification of the prospective aquifer.
8. Prospective aquifer properties delineation.

The scope of the study includes regional geologic history of Islamabad, characteristics of hydrogeologic units, ground water levels and storage and recharge discharge of the delineated areas.

## 1.2. Previous Investigations

A reconnaissance of the study area was carried out by David Greenman, Z.U.Kidwai and Dr. N.R.Martin.

A comprehensive and scientific groundwater survey was carried out by WAPDA during the period 1963-66 and the results were summarized in the report 'Geohydrology of Federal Capital Area (Islamabad), West Pakistan'.

A report was prepared by Kazi Mujib Ashraf and Muhammad Hanif in 1980 which not only delineated the zones of potential groundwater development but also described the entire groundwater system of Islamabad Area as related to the geological and geographical settings.

Related studies have been carried out in other parts of the world as well. Examples of a few are as follow:

1. Three-Dimensional Geologic Framework Modeling of Faulted Hydrostratigraphic Units within the Edwards Aquifer, Northern Bexar County, Texas By Michael P. Pantea and James C. Cole.
2. Troy valley glacial aquifer: 3d hydrostratigraphic model aiding water management in southeastern Wisconsin, USA Kallina M. Dunkle, David M. Mickelson, Mary P. Anderson, and Michael N. Fienen.
3. Integrating borehole logs and aquifer tests in aquifer characterization by Fredrick L. Paillet and Ronald S. Reese.
4. Understanding wetland sub-surface hydrology using geologic and isotopic signatures by P. K. Sikdar and P. Sahu.

5. Regional hydrostratigraphy and groundwater flow modeling in the arsenic-affected areas of the western Bengal basin, West Bengal, India by Abhijit Mukherjee & Alan E. Fryar & Paul D. Howell.

## 1.3. Location

The study area is 14 km Northeast of Rawalpindi on the North Eastern Potwar Plateau of province of Punjab. Islamabad is situated between $33^{o}29'$ – $33^{o}49'$ North to $72^{o}50'$ - $72^{o}24'$ East at approximately 1663 feet (507 meters) above mean sea level (Wikipedia).

## 1.4. Climate and Rainfall

The climate of Islamabad is continental with extreme temperatures accompanied by a monsoon season (July and August) followed by mild and wet winters. The temperature varies from $-3.9^{o}C$ in January to $46.1^{o}C$ in June. In April the temperature ranges from $15^{o}C$ to $30^{o}C$. Islamabad gets appreciable rain both in summer and winter due to its closeness to the hills (Wikipedia).

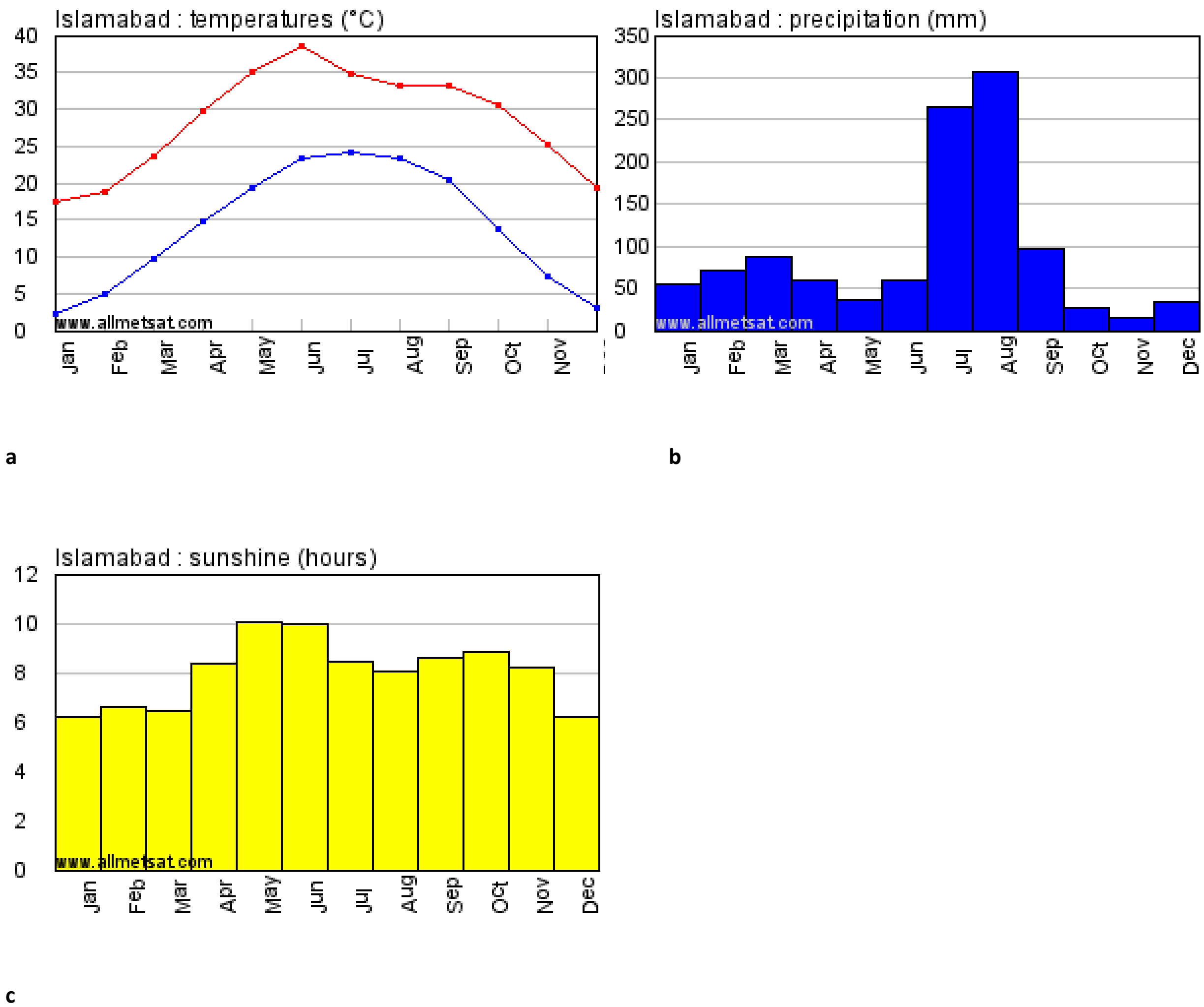


**Figure 2: (a) Monthly average of the minimum and maximum daily temperatures. (b) Monthly Average Precipitation. (c) Monthly average number of hours of sunshine per day. Source: http://en.allmetsat.com/climate/asia.php?code=41571**

| Months | Temperature ($C^0$) | | Precipitation (mm) |
|---|---|---|---|
| | Max Temp | Min Temp | |
| January | 15.89 | 3.18 | 93.74 |
| February | 17.62 | 5.22 | 134.66 |
| March | 22.29 | 9.63 | 156.46 |
| April | 28.09 | 14.15 | 111.14 |
| May | 33.10 | 18.27 | 79.12 |
| June | 37.57 | 22.14 | 103.31 |
| July | 34.79 | 22.79 | 327.61 |
| August | 33.77 | 22.44 | 249.24 |
| September | 33.33 | 19.38 | 108.05 |
| October | 29.85 | 13.63 | 51.04 |
| November | 23.91 | 7.83 | 35.44 |
| December | 17.70 | 4.00 | 76.86 |

*Source: District Census Report 1998, Population census Organization, Islamabad*

**Table 1: The Monthly Temperature and Precipitation of Islamabad.**

**Source:http://www.gisdevelopment.net/application/natural_hazards/floods/images/ma03032table2.gif**

## 1.5. Geography

The area of Islamabad is 906 square kilometers, with the Margalla Hills in the North and Northeast. 220 acres of the city consists of Margalla Hills National Park. Loi Bher Forest is situated along the Islamabad Highway, covering an area of 1087 acres.

## 1.6. Geographic Extension

Islamabad lies on the East of Khyber Pakhtunkhwa. Kotli Sattian, Murree and Kahuta are situated in the Northeast of Islamabad and the city is surrounded by Taxila and Attock district on the Northwest. In the South Rawalpindi, Gujar Khan and Rawat mark the boundary.

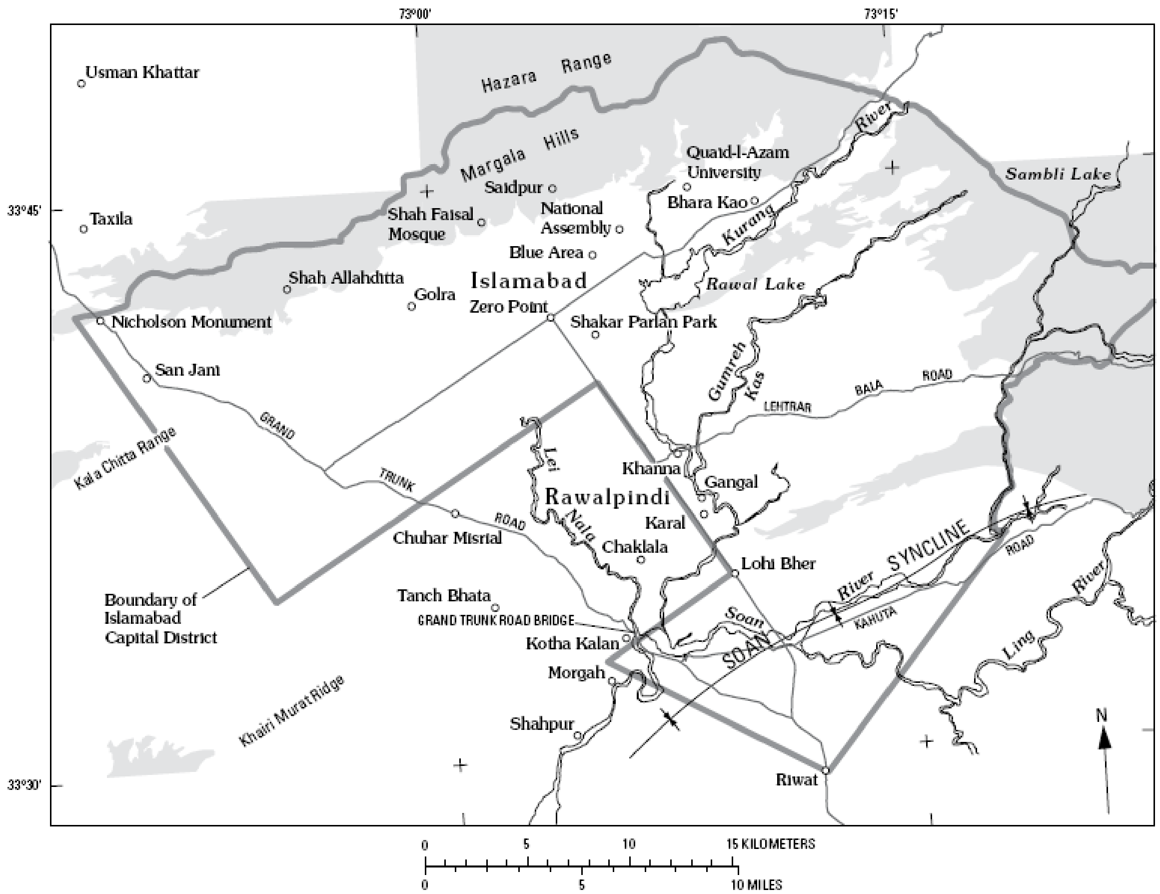


**Figure 3: Location Map of Islamabad showing geographical extents. Source: sheikh et.al (in press)**

## 1.7. Topography

The North of the city comprises of steeper hills of tertiary period. This area is composed of grey colored limestone with layers of shale. Towards the South, the land becomes planer and is composed of alluvium and gravel.

The topographic map shows the topography of the study region. The northern region which comprises of Margalla hills have a bit higher altitude than the southern region which can be clearly seen in the map. The lower region or zone 2 (which includes the sectors H-8, H-9, I-8 and I-9) have lower altitudes as compared to zone 1 (which includes the sectors F-8, F-10, G-7, G-8, G-9 and G-10) which have high altitudes due to closeness of the hills. The map shows the gradual change in the topography of the study area.

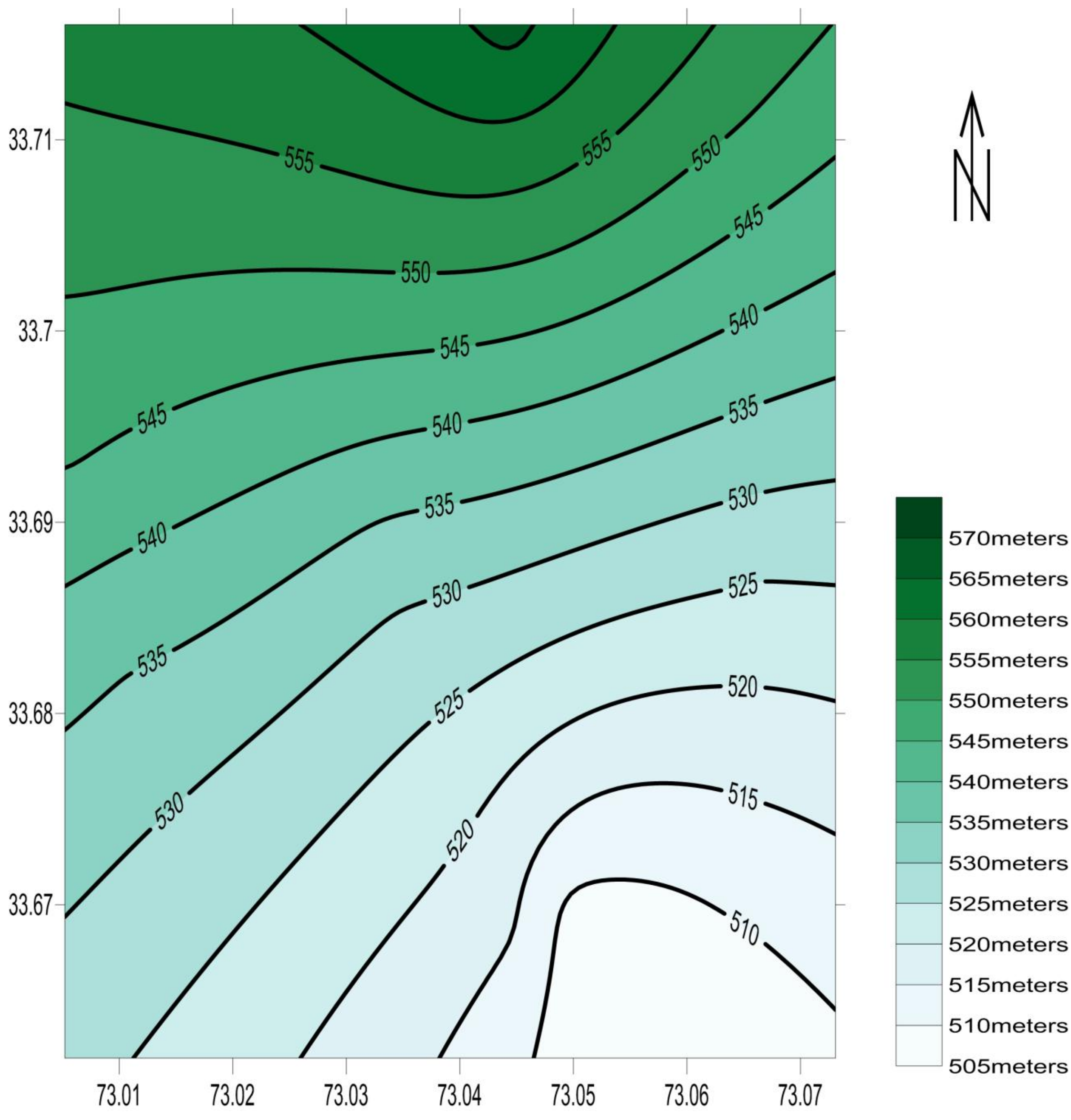


**Figure 4: Topographic Map of the Study Area. Contour Interval= 5 meters.**

## 1.8. Hydrogeology

Hydrogeologically, the study area is situated on the Soan river basin which forms a part of Indo-Gangetic synclinorium. The area is mainly drained by Soan River and Kurang River and the perennial streams emerging from Margalla hills are Gumrah Kas, Tanawala Kas, Bedarwali Kas and Lei Nala. The three artificial reservoirs which regulate the drainage system of Islamabad are Rawal, Simli and Khanpur Dam. The Soan and Kurang Rivers are the main streams draining the area. Their primary tributaries are the Ling River, draining northwestward into the Soan; Gumreh Kas, draining westward into the Kurang from the area between the Kurang and Soan; and Lei Nala, draining southward into the Soan from the mountain front and urban areas. The Kurang and Soan Rivers are dammed at Rawal and Sambli Lakes, respectively, to supply water for the urban area (Sheikh et.al, in press).

## 1.9. Stratigraphy

The rocks found in this area are mostly of sedimentary origin; limestone, shale and dolomitize limestone being the main constituent. These rocks belong mainly to Eocene and Paleocene ages. The major Formations which come under these ages are Margalla Formation, Patala Formation, Hangu Formation, Lockhart Formation and Kawagarh Formation. The table below summarizes the stratigraphy found in this region.

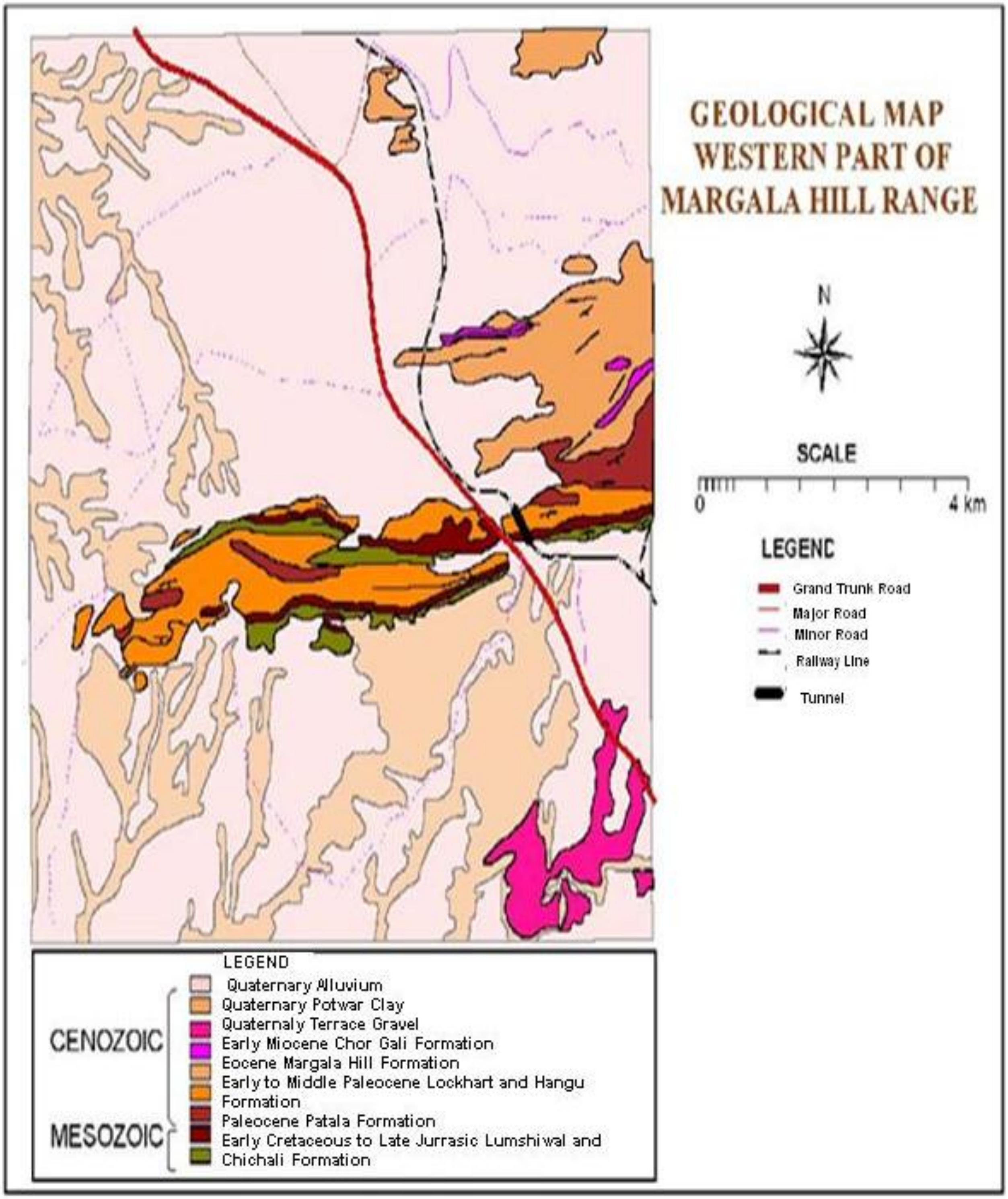


**Figure 5: Map showing stratigraphy of the study area source: modified from Latif**

| AGE | FORMATION | DESCRIPTION |
|---|---|---|

| | | |
|---|---|---|
| Pleistocene | Lei Conglomerates | Carbonate-cemented cobble conglomerate consisting of sub-angular limestone clasts intercalated with and grading laterally into weakly consolidated silt, sand, and clay. |
| Pleistocene | Soan | Conglomerate and subordinate inter beds of sandstone, siltstone, and clay stone. |
| Pliocene | Dhok Pathan | Light gray, fine to medium grained, medium bedded and cross-bedded sandstone. |
| Miocene | Nagri | Gray, greenish gray, and brownish gray; medium to coarse grained, thick bedded; cross-bedded; and calcareous. |
| Miocene | Chinji | Brick red, friable, hard, and intercalated clay stone with dark gray to brownish gray and cross-bedded sandstone. |
| Miocene | Murree | Sandy shale, siltstone, sandstone, conglomerate, fossiliferous limestone at the base. |
| Early-middle Eocene | Kuldana | Variegated, multicolored and maroon to magenta silt and shale, and yellowish to bluish grey, marly well banked limestone and cellular limestone. |
| Early Eocene | Chorgali | Alternating well banked limestone and brownish to greenish marl. The limestone has chert lenses in places. |
| Early Eocene | Margalla hills limestone | Well banked, usually dark grey but light grey weathering limestone, occasionally nodular, massive and cliff-forming. |
| Late Paleocene | Patala | Medium to dark brown shale with marly limestone layers. |
| Middle Paleocene | Lockhart | Well banked, usually dark grey and dark grey weathering limestone, occasionally nodular inliers; massive and cliff-forming; caves. |
| Early Paleocene | Hangu | Oxidized sandstone, while clay, iron-crusts, rusty weathering limestone, pisolitic gossans. |
| Early-middle Cretaceous | Kawagarh | Dark brown weathering limestone, partly dolomitic. |
| Early Cretaceous | Lumshiwal | Dark brown weathering thickly banked sandstone of dark grey to black color with an occasional greenish tint, glauconitic. |
| Late Cretaceous | Chichali | Black shale, thinly bedded, brown, often rusty, weathering. |
| Middle- Late Jurassic | Samana Suk | Well banked limestone, partly oolitic, often rich in fossils, yellowish tints, partly dolomitic. |

**Table 2: Stratigraphy of the study region, their age and description**

## 1.10. Geological Structures

Main boundary thrust (MBT)

It is a long feature extending for several hundred kilometers (about 270 km) along the Himalayan front. West of the Hazara- Kashmir syntaxes, it takes several bends and is concealed under the alluvial sediments at many places and therefore its structural continuity cannot be established. It passes at a close distance of about 1 km from Margalla hills and is the main fault present in the area of study (Ahmed, 2005).

Margalla Hill Anticlinorium

The major regional structure is the anticlinorium that extends over entire Kala Chitta and Margalla Range. It is known as anticlinorium because the major regional anticline of the area underwent a series of further deformations that created further folds on the existing anticline. Therefore the region under the observation underwent great deformation. It is built by multivergent folds of Margalla hill limestone and Lockhart limestone (Ahmed, 2005).

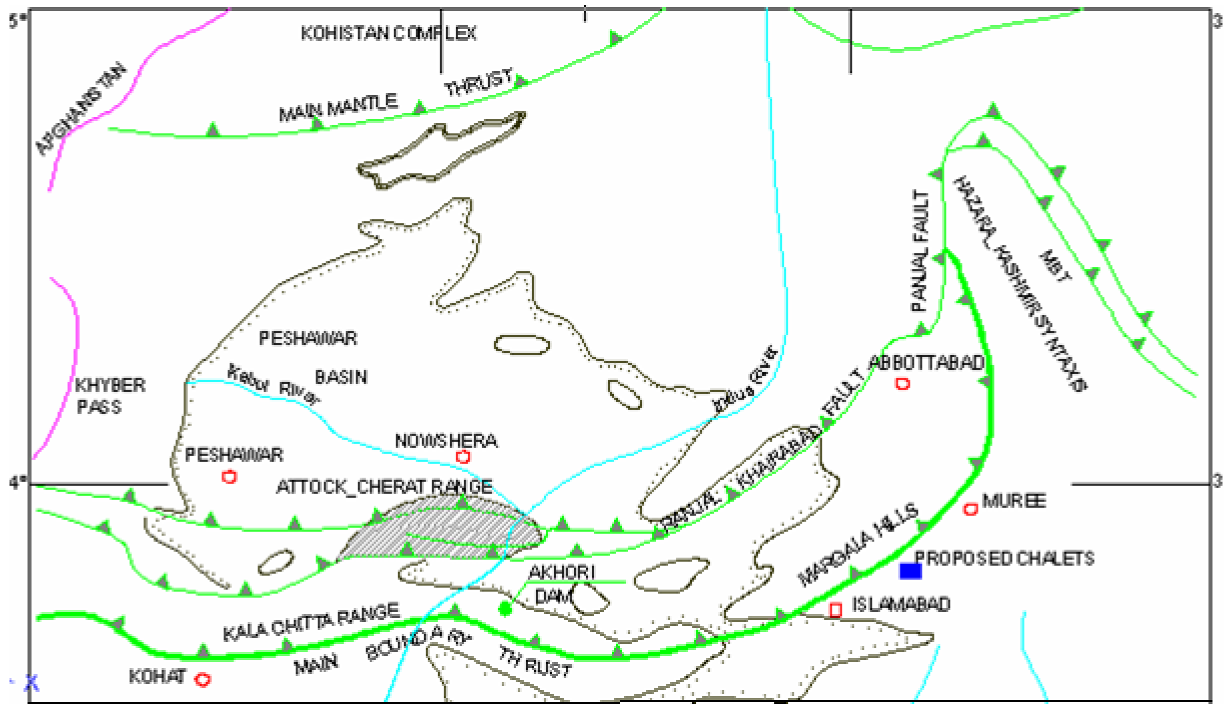


**Figure 6: Tectonic Feature of the Study Area source: Ahmed (2005)**

## 1.11. Tectonic Settings

Areas in Margalla hills are an intensely deformed and tectonised belt which along-with the Attock-Cherat range and Kala Cheta range represents the uplifted Southern margin of Peshawar basin. It is part of active Himalayan fore land – fold and thrust belt region in the collision zone between Indo-Pakistan and Eurasian plates. The plate boundary is characterized both by northward under thrusting plate margin and southward abduction of upper crustal rocks and sediments.

This has resulted in dramatic horizontal tectonics and crustal shortening since initial collision of the Indian Plate with the Kohistan Island Arc in latest Cretaceous to middle Eocene developing local micro faults and thrusts. Continental thrust transferred or distributed southward to a zone of weakness defined as Main Boundary Thrust (MBT) that also represents the frontal thrust of Margalla Hills and Kala Chitta. However, the deformation within these hills fold and thrust belt predates its thrusting to south over Kohat-Potwar plateaus (Ahmad, 2005).

## 2. METHODOLOGY

The methodology of the study has been described below in detail. The flowchart below outlines the method applied to establish the hydrostratigraphic model of the study area.

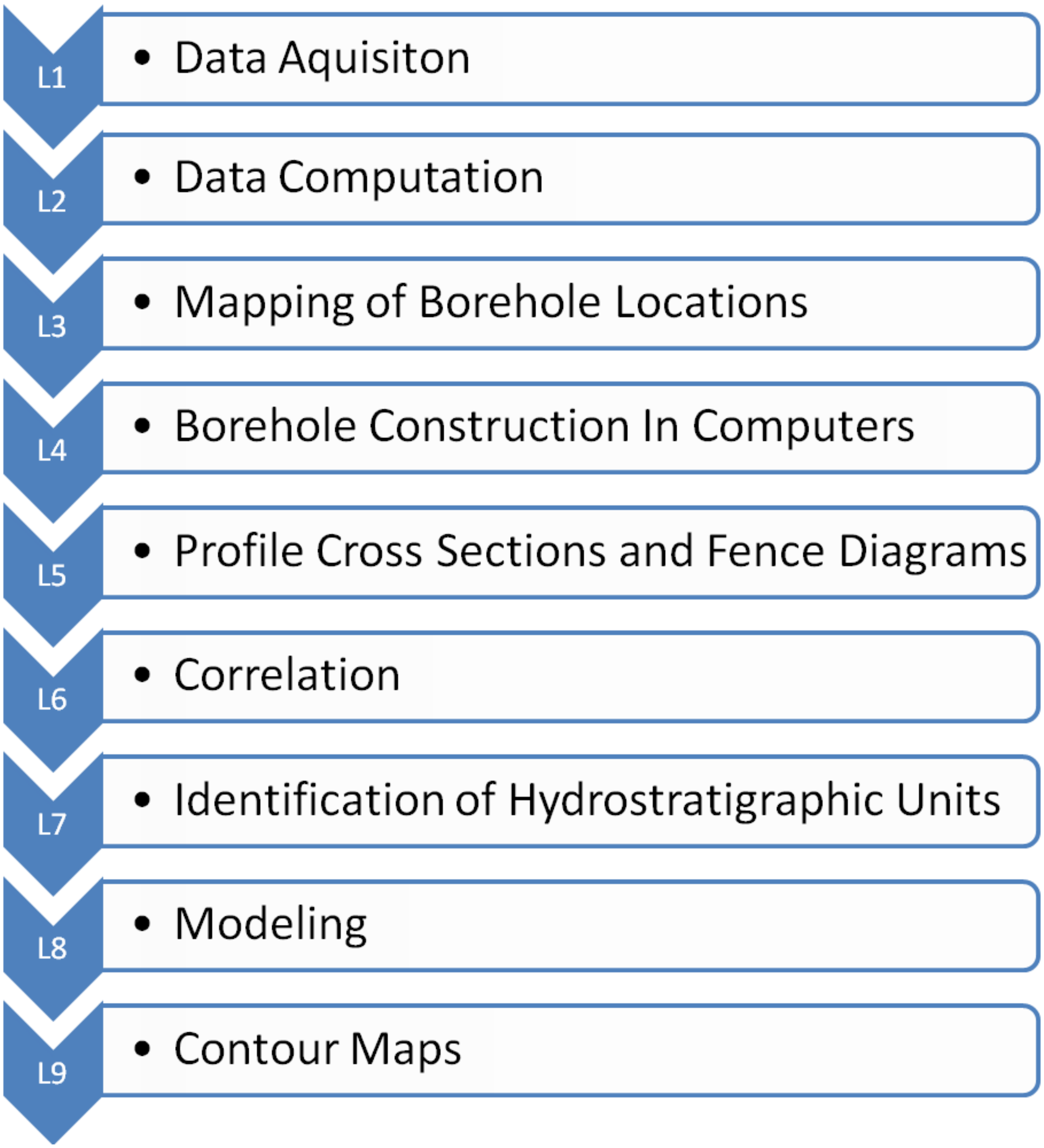


**Figure 7: Flowchart Summarizing Methodology**

### 2.1.1. Data Acquisition and Computation

Subsurface geological data used to create the three dimensional images presented in the thesis was obtained from the G.W.I report of Kazi Mujib Ashraf and Muhammad Hanif (October 1980). The area covered by the 12 boreholes was almost 76.87 square kilometers. Depth to water level was also obtained from the report.

Borehole locations, the altitude of the surface and geographic coordinates were established from Google Earth. The location coordinates were converted to the degree decimal and incorporated into the RockWorks v.2002. Then the built-in feature in the software was used to convert these degree decimals into Easting and Northing of each borehole.

The borehole location was then plotted on a geo-rectified satellite image of the study area. The borehole data consisted of basic lithology description, which mainly consisted of sand gravel clay and shale, and the depth at which the textural characteristics changes, recorded by the well driller.

This data was entered into an excel spread sheet and reformatted for entry into RockWorks v.2002, the software package used to model and create 3 dimensional images of the subsurface stratigraphy. Data describing the sediment texture and depth below the surface were manually entered into the software. The data was entered in the borehole manager which stores data for each borehole in a Microsoft Access database (MDB) file.

| Test Hole | Longitude | Degree Decimal | Latitude | Degree Decimal | Elevation (in meters) | Depth (in meters) |
|---|---|---|---|---|---|---|
| **1** | 73°2'1.71'' | 73.0338 | 33°41'15.13" | 33.6875 | 531.875999 | 124.6631 |
| **7** | 73°2'37.76" | 73.0438 | 33°40'8.18" | 33.6689 | 516.331199 | 118.2623 |
| **9** | 73°4'23.11" | 73.0730 | 33°39'43.15" | 33.6619 | 509.015999 | 109.1183 |
| **10** | 73°2'55.76" | 73.04882 | 33°41'48.39" | 33.6967 | 540.410399 | 121.9199 |
| **11** | 73°3'24.9" | 73.0569 | 33°39'50.34" | 33.6639 | 505.358399 | 119.7863 |
| **12** | 73°2'59.9" | 73.0499 | 33°40'9.9" | 33.6694 | 508.406399 | 125.8823 |
| **13** | 73°2'39.75" | 73.0443 | 33°42'57.66" | 33.7160 | 566.623199 | 125.8823 |
| **16** | 73°4'0.07" | 73.0666 | 33°40'35.77" | 33.6766 | 516.026399 | 122.8343 |
| **17** | 73°3'52.66" | 73.06462 | 33°42'44/67" | 33.7124 | 551.383199 | 135.6359 |
| **18** | 73°4'0.31" | 73.0667 | 33°41'11.36" | 33.6864 | 524.560799 | 140.2079 |
| **20** | 73°0'36.2" | 73.0100 | 33°41'1.09" | 33.6836 | 536.143199 | 94.48799 |
| **21** | 73°0'18.75" | 73.00520 | 33°41'38.06" | 33.6939 | 545.896799 | 121.9199 |

**Table 3: General Information of the Boreholes**

## 2.2. Plotting Borehole Locations Using ArcGIS

A geo-referenced satellite image of the study area was digitized using ArcMap v.9.2.The basic features identified were roads, parks, residential areas, lake and streams.

After the hydrogeological information was obtained the data was displayed on the GIS system. The 3 dimensional data was displayed as a map of GIS system by exporting xyz data set. The geographic coordinate system used was WGS 84. To minimize the distortion, the data was projected to Universal Transverse Mercator (UTM 1984), Zone 43 North.

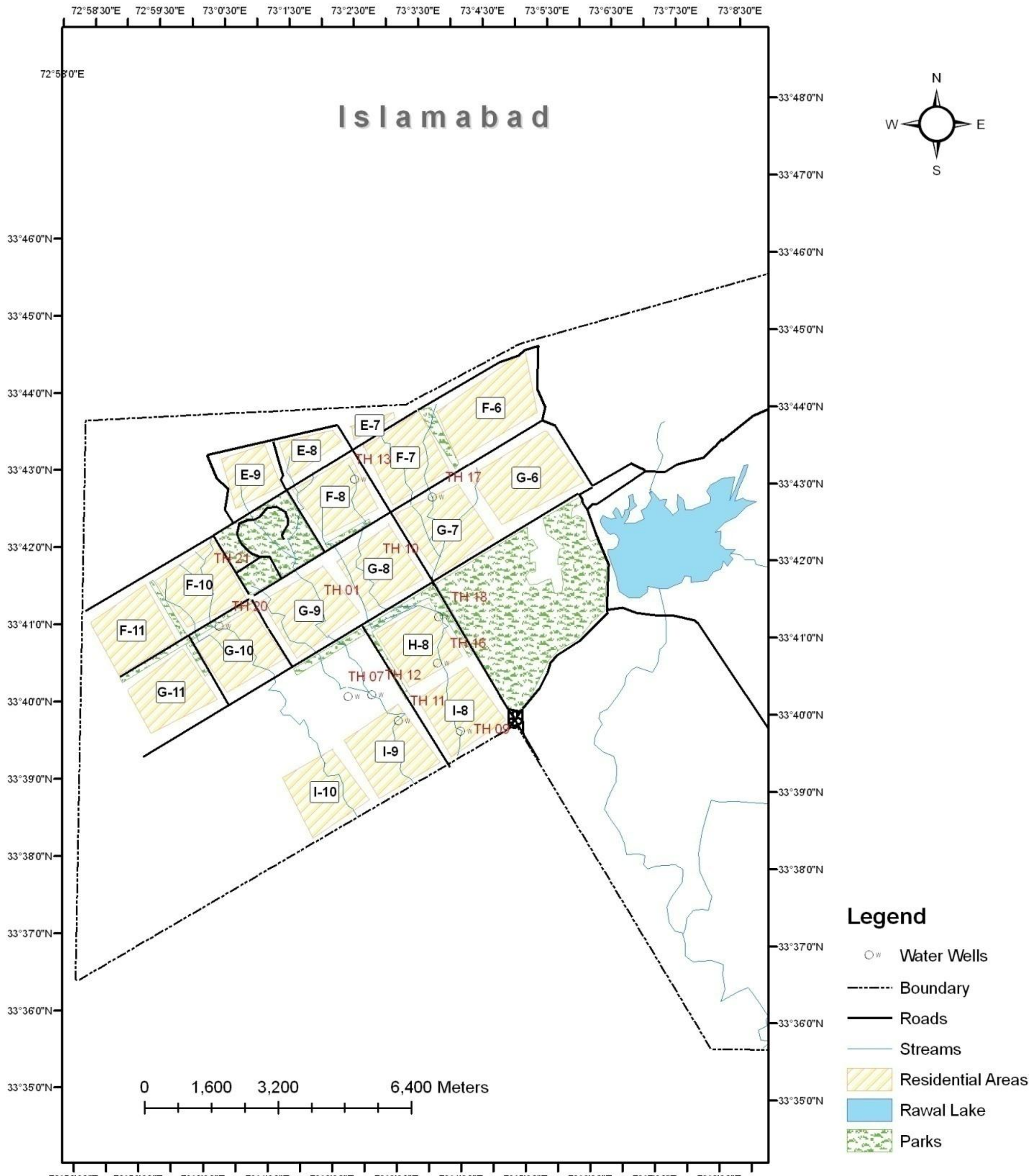


**Figure 8: Map showing borehole locations**

## 2.3. Correlation and Lithological Logs

The initial step in 3 dimensional subsurface modeling is the identification of geological units. The 2 dimensional lithological logs, showing observed rock types, was generated using RockWorks v.2002. The software has a built-in database for lithology types.

These lithology logs were then used to prepare a number of 2 dimensional geological profiles and 3 dimensional fence diagrams. The software created a solid model of 50 x 50 x 50 nodes in size. The lithoblending algorithm assigns lithology to nodes lying between wells and hence establishes 2 dimensional profile slices. The 3 dimensional fence diagrams created can be viewed from any angle or orientation.

The profile slices and the fence diagrams were then appended with the 2 dimensional and 3 dimensional multiple logs respectively. The images were exported in JPEG format. The correlation was done manually and very comprehensively.

Limitation: The 3 dimensional images do not give an entirely accurate representation of subsurface geological conditions and hence RockWorks v.2002 extrapolates the mapping of the subsurface lithological units.

## 2.4. Hydrostratigraphic Modeling

Hydrostratigraphic model depends on hydrogeological and stratigraphic data. Individual lithological units were identified on the basis of 3 dimensional models. Stratigraphic units consist of one or more lithological units that are closely associated in vertical succession and have similar characteristics.

After correlation and determination of stratigraphy of individual boreholes, hydrostratigraphic logs were made. The 3 dimensional structural elevation maps were established using the known well location and lithological data to determine the elevation points on the surface of each unit. These known points then create a grid model of the entire surface of each unit using the Inverse-Distance gridding method.

The hydrostratigraphic model was then established which created a solid model of 50 x 50 x 50 nodes size. The software created a grid model of each stratigraphic surface and base and inserts them into the solid model.

RockWorks v.2002 creates isopach maps using grid model of the elevation at the top and base of a selected stratigraphic unit and a 2 dimensional contour map is generated.

## 2.5. Contour Maps using Surfer

To create contour maps a xyz data file is first created in excel spreadsheet as shown below. Surfer 9 requires the use of decimal degree Latitude (Y) and Longitude (X) values when using Latitude Surfer and Longitude values. The software then creates a gridding file. The gridding method used was Kriging. The contour maps were then generated for elevation, porosity, permeability and water table.

| Stratigraphy | Depth (feet) | | Porosity (%) | Permeability (ft/sec) | Moisture Content (%) |
|---|---|---|---|---|---|
| **Aquifer 2** | 66 | 180 | 38.17 | 0.000223 | 5.0933 |
| **Aquifer 3** | 180 | 250 | 37.54 | 0.000339 | 7.5191 |
| **Aquifer 4** | 250 | 450 | 37.99 | 0.000278 | 7.9617 |

**Table 4: General Information of Aquifers**

| Test Hole | Longitude | Latitude | Elevation (meters) | Water Lever (meters) | Head in Meters |
|---|---|---|---|---|---|
| **TH-01** | 73.03381 | 33.68754 | 531.876 | 10.0584 | 521.8175992 |
| **TH-07** | 73.04382 | 33.66894 | 516.3312 | 4.572 | 511.7591992 |
| **TH-09** | 73.07309 | 33.66199 | 509.016 | 10.668 | 498.3479992 |
| **TH-10** | 73.04882 | 33.69678 | 540.4104 | 9.144 | 531.2663992 |
| **TH-11** | 73.05692 | 33.66398 | 505.3584 | 9.144 | 496.2143992 |
| **TH-12** | 73.04997 | 33.66942 | 508.4064 | 2.7432 | 505.6631992 |
| **TH-13** | 73.04438 | 33.71602 | 566.6232 | 11.2776 | 555.3455992 |
| **TH-16** | 73.06669 | 33.6766 | 516.0264 | 16.4592 | 499.5671992 |
| **TH-17** | 73.06463 | 33.71241 | 551.3832 | 6.096 | 545.2871992 |
| **TH-18** | 73.06675 | 33.68649 | 524.5608 | 19.5072 | 505.0535992 |
| **TH-20** | 73.01006 | 33.68364 | 536.1432 | 1.8288 | 534.3143992 |
| **TH-21** | 73.00521 | 33.69391 | 545.8968 | 2.7432 | 543.1535992 |

**Table 5: Water Level of the Boreholes**

# 3. MODEL CONSTRUCTION

## 3.1. Aquifer and Types of Aquifers

All the water below the ground surface is groundwater. Groundwater is found in a variety of rock types ranging from ancient crystalline basement rocks that store minor amount of water to alluvial plain sediments that store enormous volumes of water.

Aquifer is a water bearing formation that is capable of serving as a groundwater reservoir supplying enough water to satisfy a particular demand. Formations which store economically sufficient amount of water are:

1. Unconsolidated gravels, sands and alluvium
2. Lake sediments
3. Limestone with cavities
4. Granites and marbles with fissures and cracks
5. Weathered gneisses and schist
6. Slates

According to Theis, some characteristics of an ideal aquifer are as follows:

1. It is homogenous and extends horizontally in all directions beyond the area of interest.
2. Thickness is uniform
3. Permeability in horizontal and vertical direction is same.
4. Water is instantaneously released from storage when the head is reduced.

An aquitard is geological formation which does not transmit water at economically feasible rates for example clay lenses interbedded with sand.

An aquiclude is a geological formation which does not transmit groundwater shale being an example.

An aquifudge formation does not contain any interconnected openings hence can neither absorb nor transmit water for example basalt and granites.

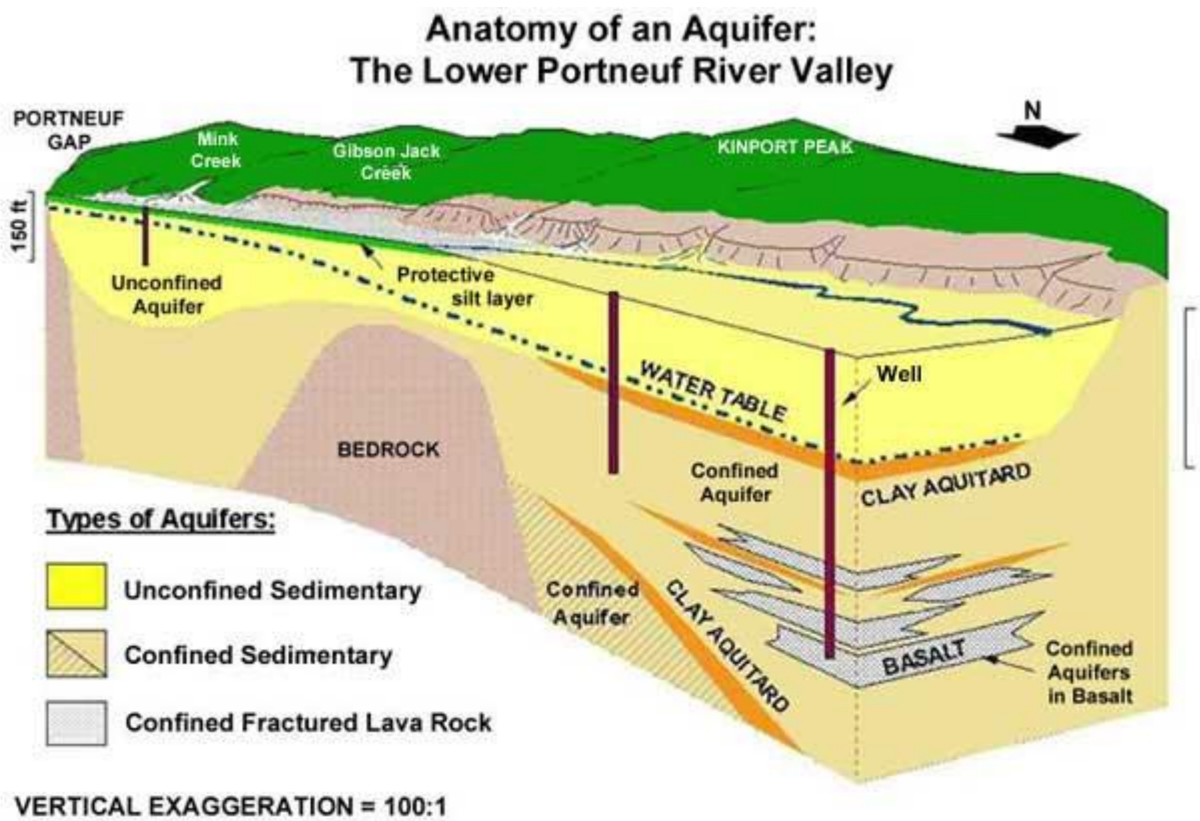


**Figure 9: Aquifer and Aquitard shown source: http://imnh.isu.edu/digitalatlas/hydr/concepts/gwater/aquifer.htm**

The main types of aquifers are described below.

Confined Aquifer:

A formation that contains water bounded above and below by impermeable beds or by beds of distinctly lower permeability than that of the water-bearing Formation itself. The piezometric pressure or head is sufficient to cause the water within the Formation to rise above the confining layer.

Unconfined Aquifer:

Groundwater not contained under pressure beneath relatively impermeable sediments or rocks and is exposed to the atmosphere through openings in the overlying soils or in the vadose zone. The water table is the upper boundary of the zone of saturation in which the absolute pressure equals the atmospheric pressure and the pressure due to the water equals zero.

Perched Aquifer:

Groundwater contained in a formation that is unconfined and opens to the overlying unsaturated zone but is separated from an underlying main body of groundwater by an unsaturated zone.

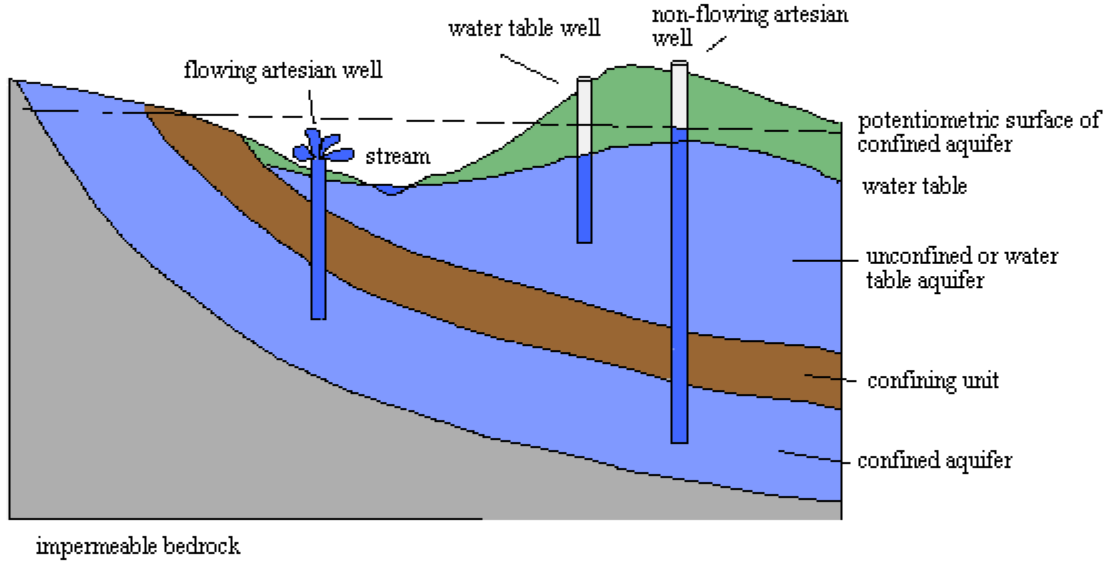


**Figure 10: Unconfined and Confined Aquifers source: http://www.purdue.edu/envirosoft/groundwater/src/geo3.htm**

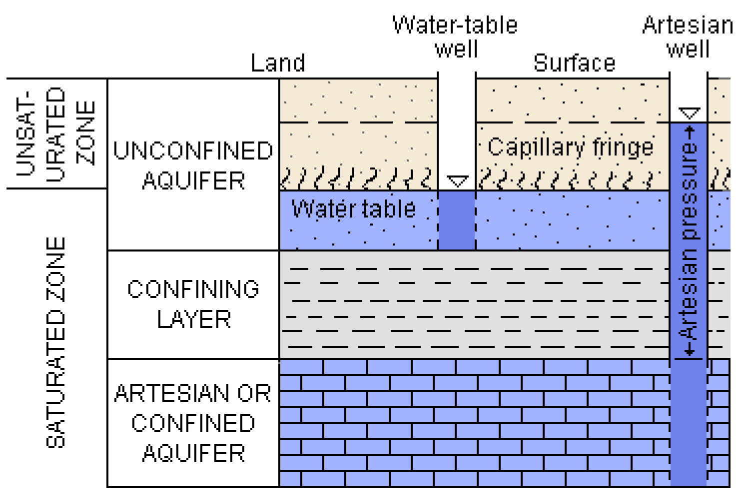


**Figure 11: Water Tables of the unconfined and Confined Aquifers**

**Source: http://www.purdue.edu/envirosoft/groundwater/src/geo3.htm**

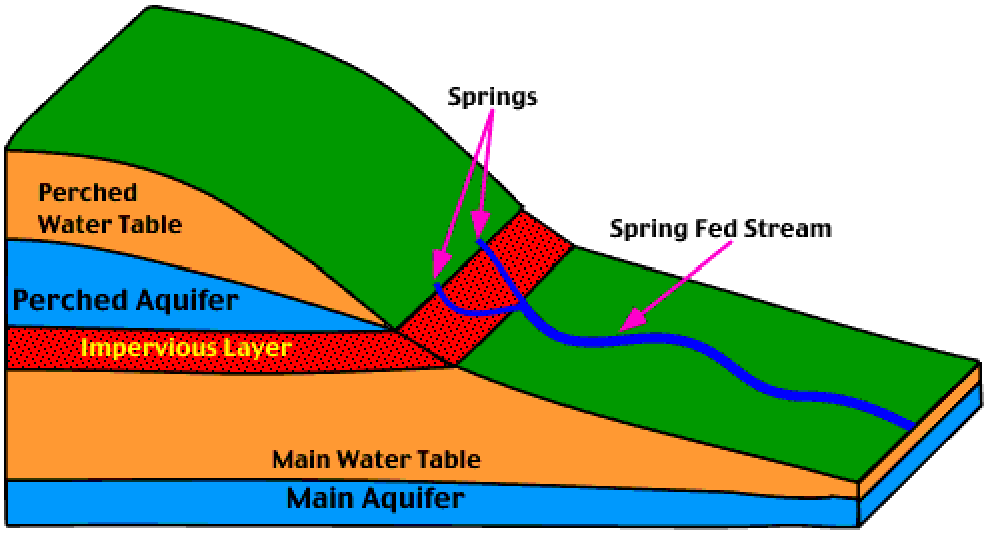


**Figure 12: Perched Aquifer source: physicalgeography.net**

## 3.2. Hydrostratigraphy and Hydrostratigraphic Modeling

Hydrostratigraphy involves combining or separation of units with similar hydraulic conductivities into aquifers or confining layers. The hydrostratigraphic boundary may not correlate with the formation boundary; this may result in several geologic formations being combined into a single hydrostratigraphic unit such as an aquifer.

Hydrostratigraphy along with geologic layers and lithological descriptions builds a conceptual model; a hypothesis for how a system or process operates. A conceptual model is a pictorial representation of the groundwater flow system incorporating all available geological and hydrogeological data into a simplified block diagram or cross section (Anderson and Woessner, 1992). In the first phase of the conceptual model a geological framework is defined which includes thickness, continuity, lithology and structure of any aquifer and confining units. The data is usually obtained from a variety of sources; geological maps and borehole logs. After the establishment of geological framework the hydrological framework is defined, this involves identifying boundaries of hydrological system and hydrostratigraphic units.

A 'model' is a term used for the description of the system under study. Modeling is a process of mathematically analyzing the mechanisms and controls of groundwater systems. Models help to understand the subsurface fluid flow and fluid related mass transformation flow. It is a framework that explains responses of subsurface systems to variations in both existing and potential new stresses for example pumping out contaminated groundwater or returning treated groundwater to the surface.

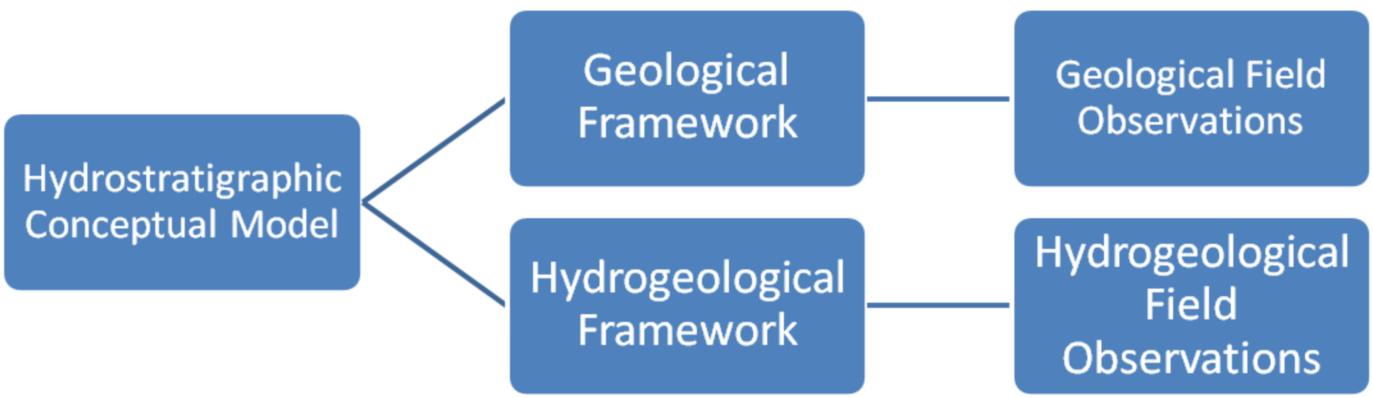


**Figure 13: Flowchart Summarizing the Establishment of Hydrostratigraphic Conceptual Model.**

## 3.3. 3 Dimensional Lithostratigraphic Correlations

The study area was divided into two zones as shown in the figure 14 each consisting of six (6) boreholes whose data was obtained from Ashraf and Hanif' G.W.I report (1980). The lithologic logs were constructed using the data in the report.

The area was divided into zones with respect to the closeness of boreholes. The reason for dividing the study area in such a manner was to establish an easier approach for correlation. The closer wells were correlated first, and then the zonal correlation was done followed by correlation of the entire study area to establish the hydrostratigraphy of the region.

Zone 1 covered the sectors F-8, F-10, G-7, G-8, G-9 and G-10 with one well situated in each sector while zone 2 covered H-8, H-9, I-8 and I-9 sectors of Islamabad. The H-8 and H-9 sectors comprised of two boreholes each while I-8 and I-9 had one well each.

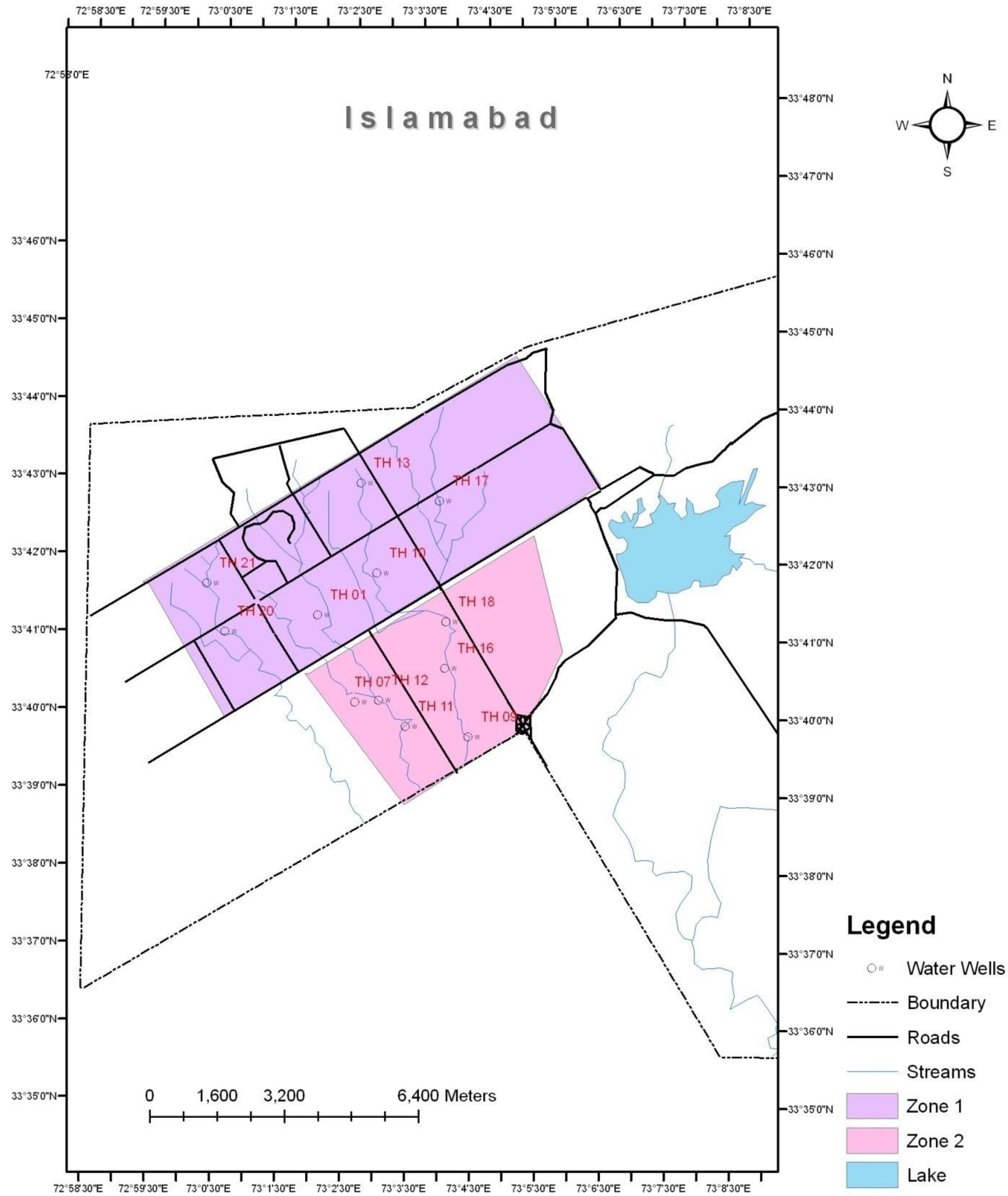


**Figure 14: Map Showing the 2 Zones of the Study Area**

The lithologic logs contained lithologic information that was used to help correlates between the sections. The individual logs described the lithology of their respective areas. The following characteristics were observed:

1. The depth of lithologic logs ranged from 94 meters to 140 meters.
2. They were distributed throughout the Islamabad covering an area of approximately 76.87 square kilometers.
3. The lithologic logs consist of three major types of sediments: gravel, sand and clay. Shale lenses were found in a few borehole logs.
4. The thorough examination of the twelve (12) borehole logs revealed large amounts of gravels present throughout overlain by clay.

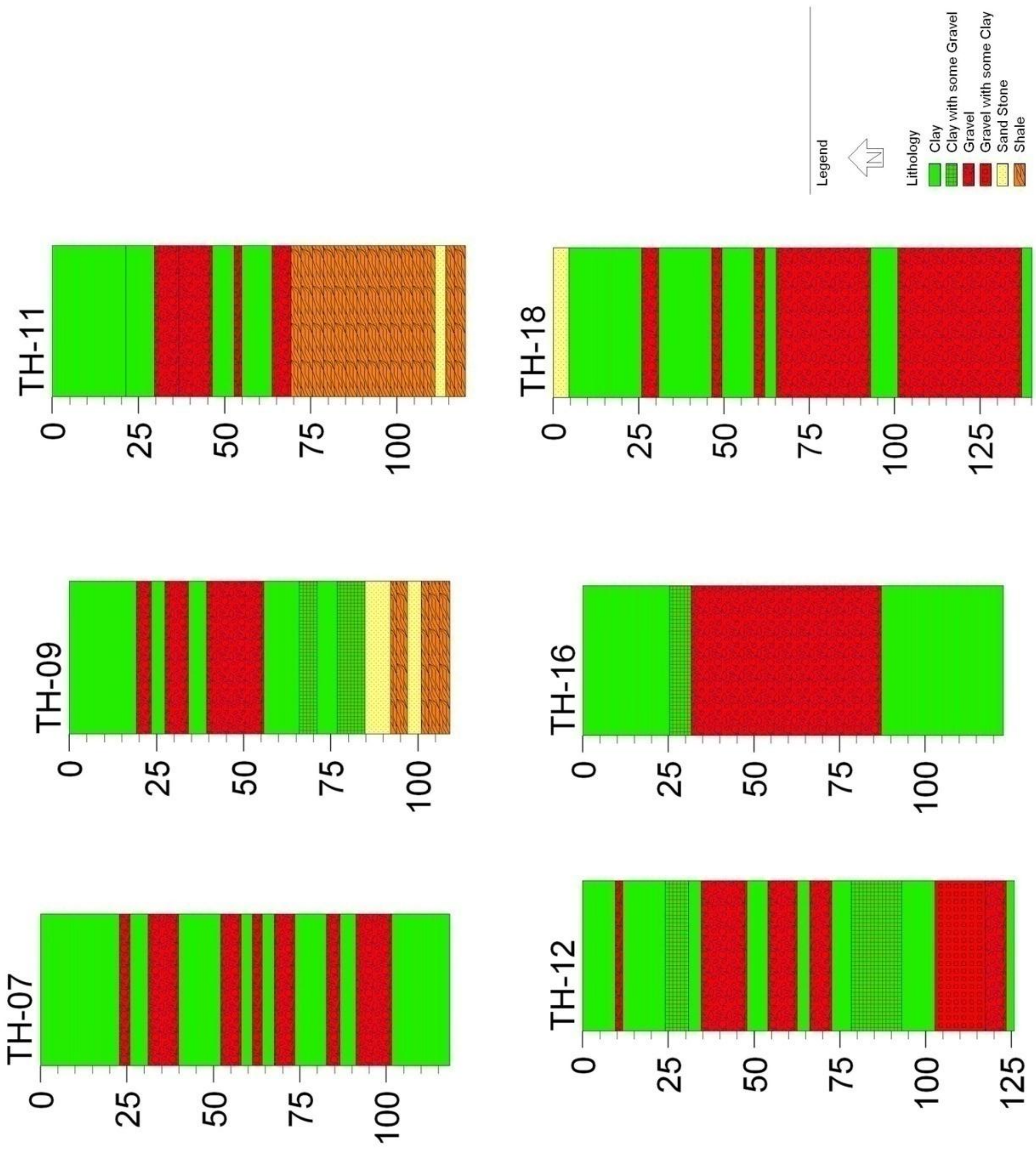


**Figure 15: Lithological Logs of Zone 1**

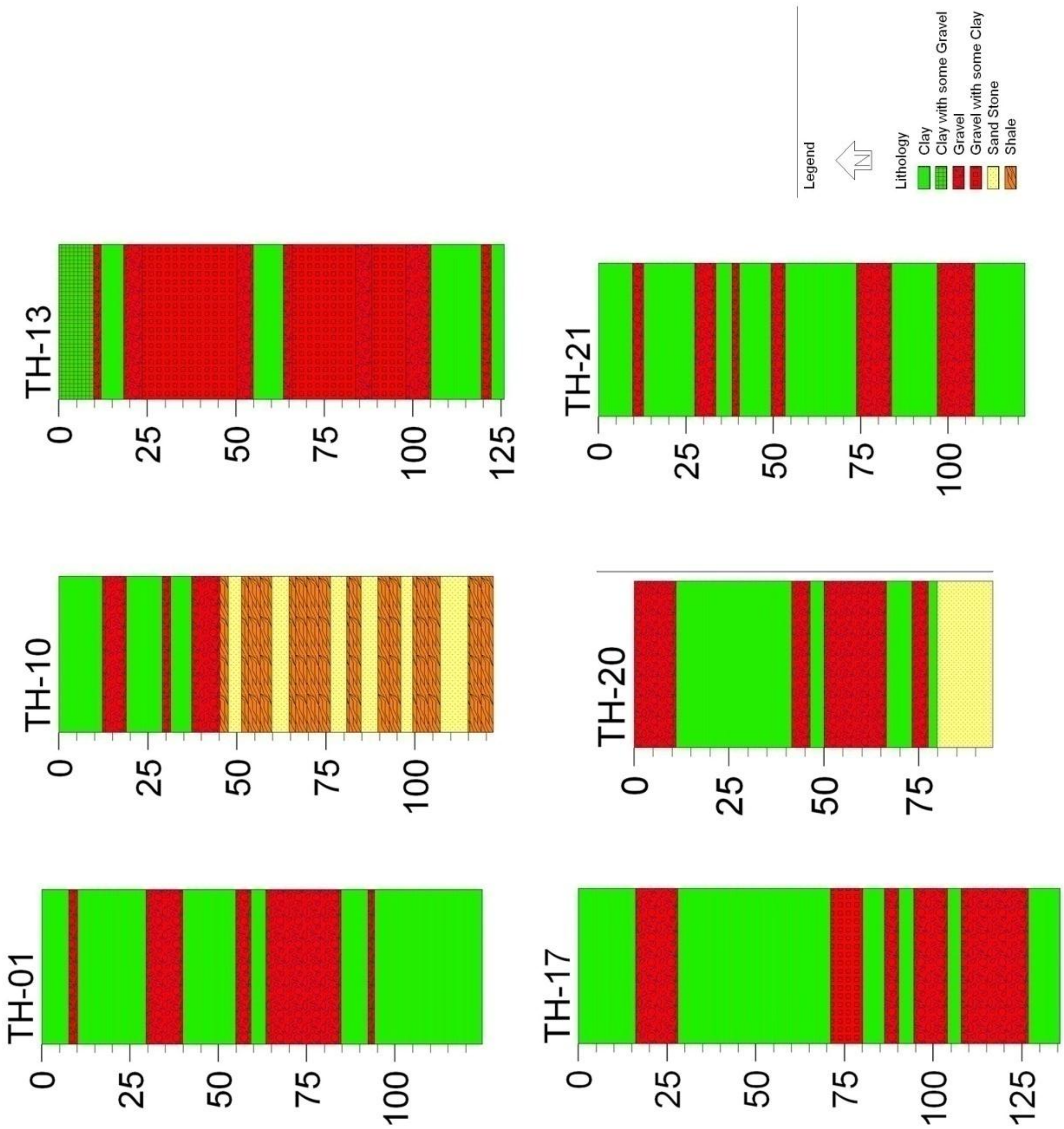


**Figure 16: Lithological Logs of Zone 2**

The geologic units shown in boreholes were reclassified into hydrostratigraphic units. Based on the acquired lithologic logs, a number of profile cross sections were prepared. The fence diagrams correlating lithologic logs were prepared, by aligning spatial position and then drawing lines between borehole logs that showed similar lithological characteristic, to obtain a view of the subsurface disposition of the sediments underlying the area. The corresponding lithologic logs were appended with the cross sections and the fence diagrams in order to correlate comprehensively. The fence diagram illustrated correlation between the borehole wells and the formation pinch outs and geological discontinuities.

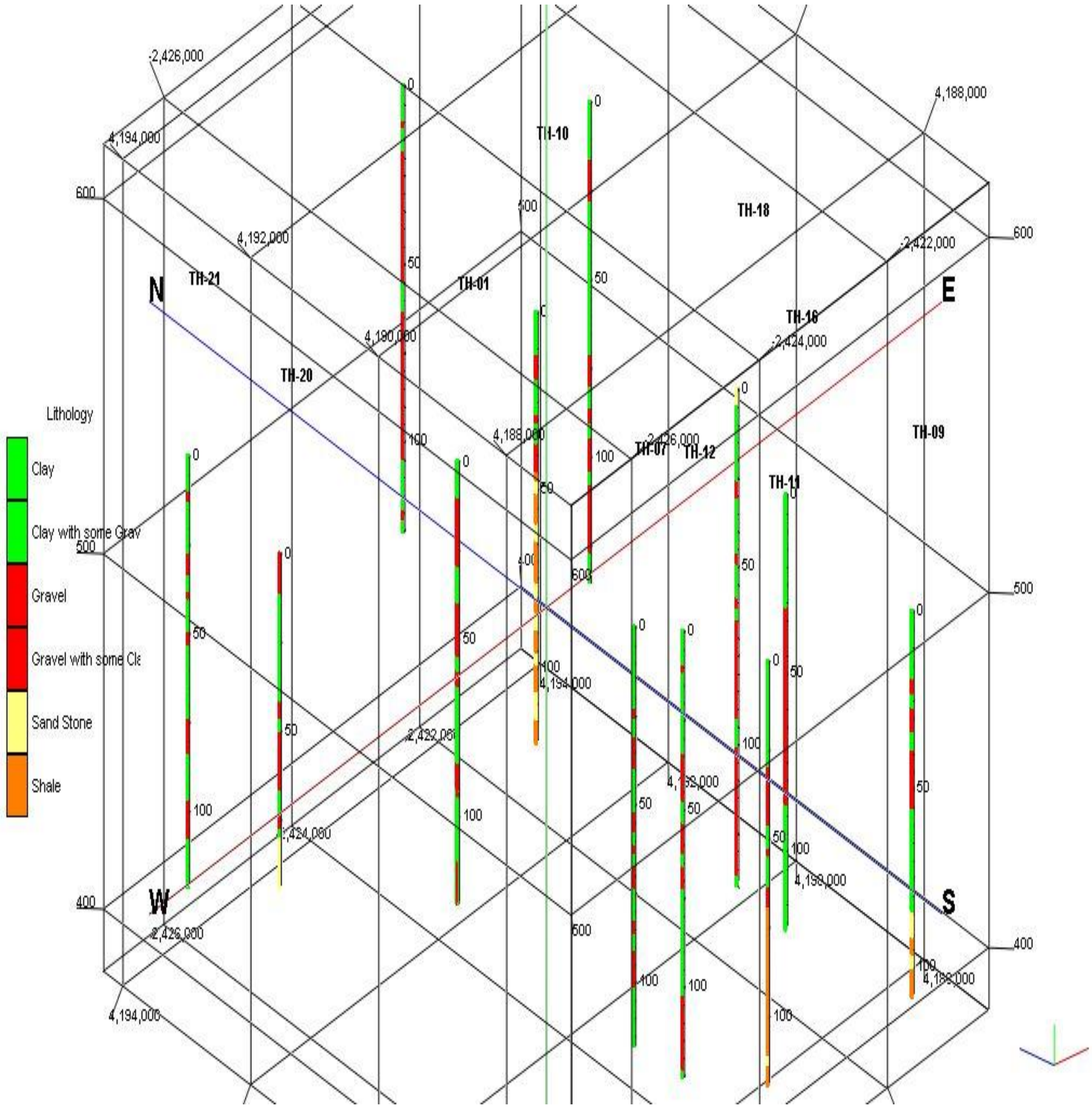


**Figure 17: 3 Dimensional Logs**

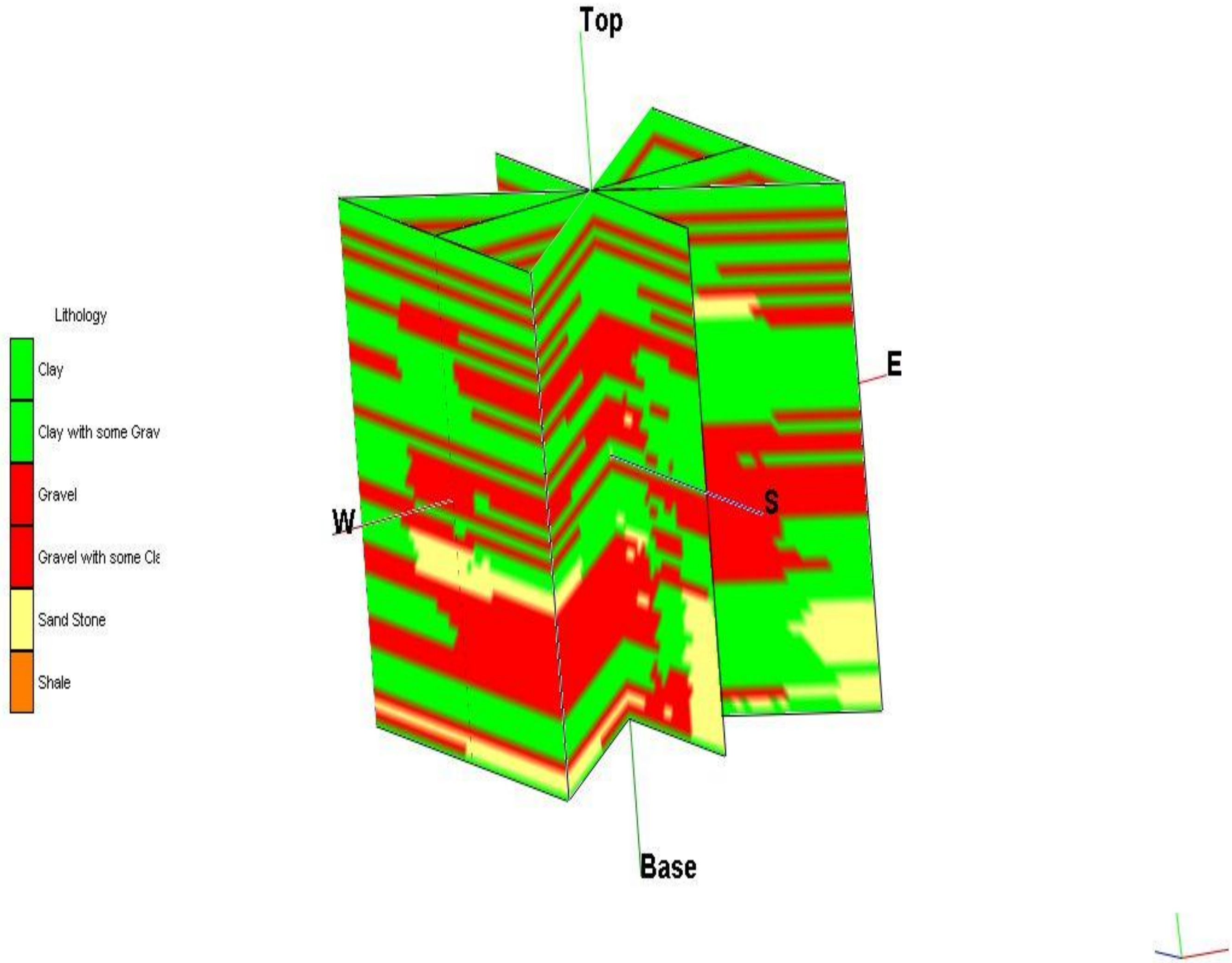


**Figure 18: Fence Diagram**

From the lithological logs, fence diagram and cross sections the following observations were made:

1. Gravels are quite common and sand is generally disseminated within the gravel lenses or constitutes a minor fraction of clay.
2. The gravel occurs in discontinuous lenses with clay. The gravel lenses are generally 1 to 15 meters thick and are composed of limestone and sandstone pebbles.
3. The gravels are predominantly composed of limestone pebbles. Some gravel beds contain a mixture of sand silt and clay.
4. The borehole logs which show an increase in total thickness of gravel layers are situated near perennial streams running through the study area.
5. The thickness of the alluvium ranges from a few meters to 150 meters as shown by the well logs.
6. In some areas where shale is identified with alternate beds of sandstones, they are overlain by thick alluvium materials.
7. The sector I-9, borehole number 11, encounters approximately 50 meters of shale. This is the only well which comprises of thick layer of shale. Borehole 10 encountered alternate layers of sandstone and shale.
8. The bed rock surface consists mostly of folded and faulted sandstone, clay and gravel. These rocks have been deformed and eroded into highly irregular surfaces.

## 3.4. Hydrostratigraphic Framework

Hydrological framework defines the physical lithological and hydrological characteristics of the hydrogeologic units that compose the aquifer system. The hydrostratigraphic unit encompasses more than one lithology and hydrostratigraphic boundaries do not go through the middle of a lithological unit. A large scale hydrogeological model provides useful approach for studying the nature of fluid migration in sedimentary basins.

The lithological modeling suggests the presence of a very complex 3 dimensional hydrostratigraphic framework. The sediments were characterized as aquifers (sand and gravel), aquitard (clay) and aquiclude (shale).

The transmissibility of the aquifer, which is the rate at which water is transmitted through a unit width of aquifer under hydraulic gradient, is 75000 gallons-day/foot. The storage coefficient is from $7.5x10^{-3}$ to $2.7x10^{-5}$.

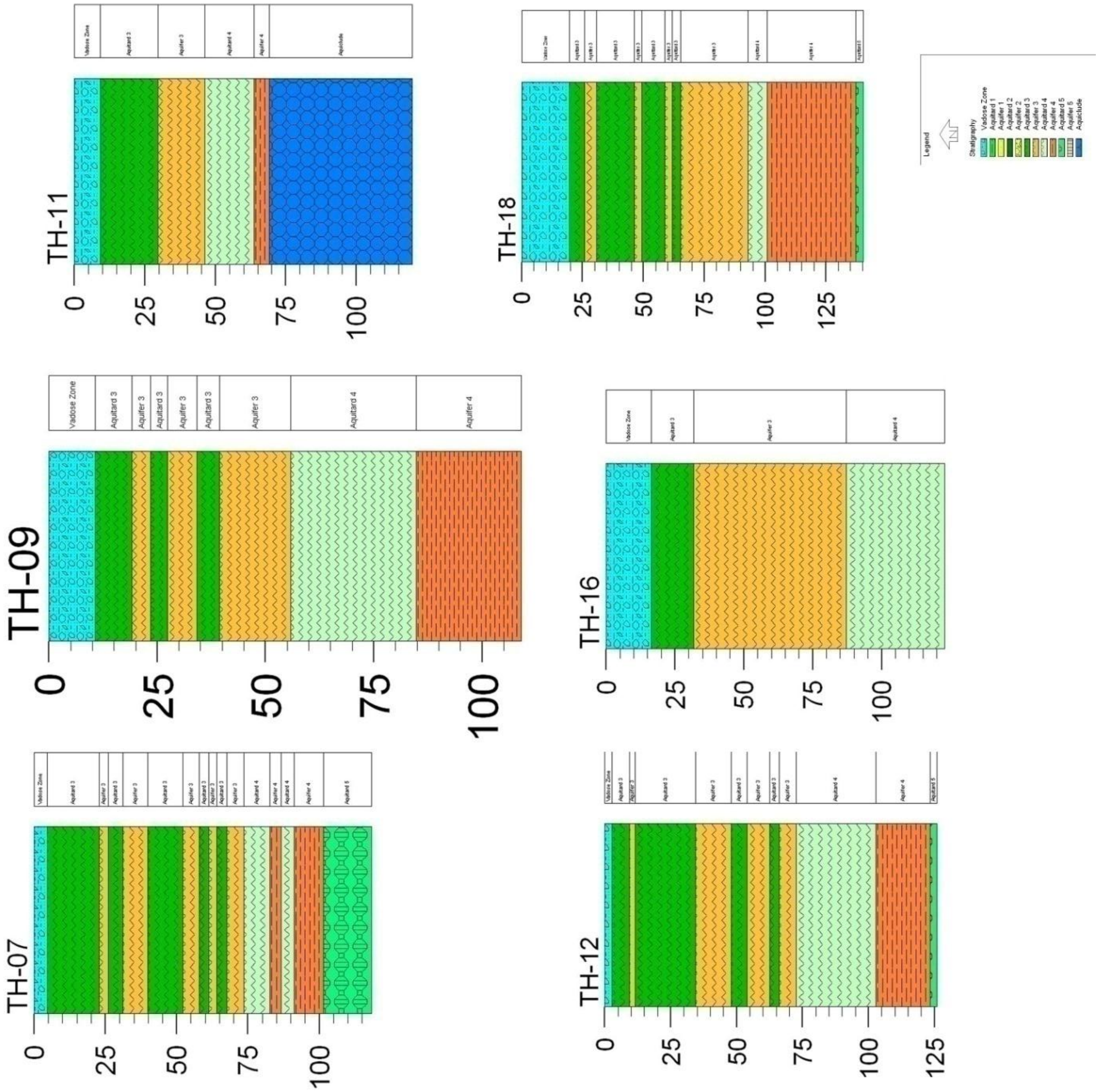


**Figure 19: Hydrostratigraphic Logs of Zone 1**

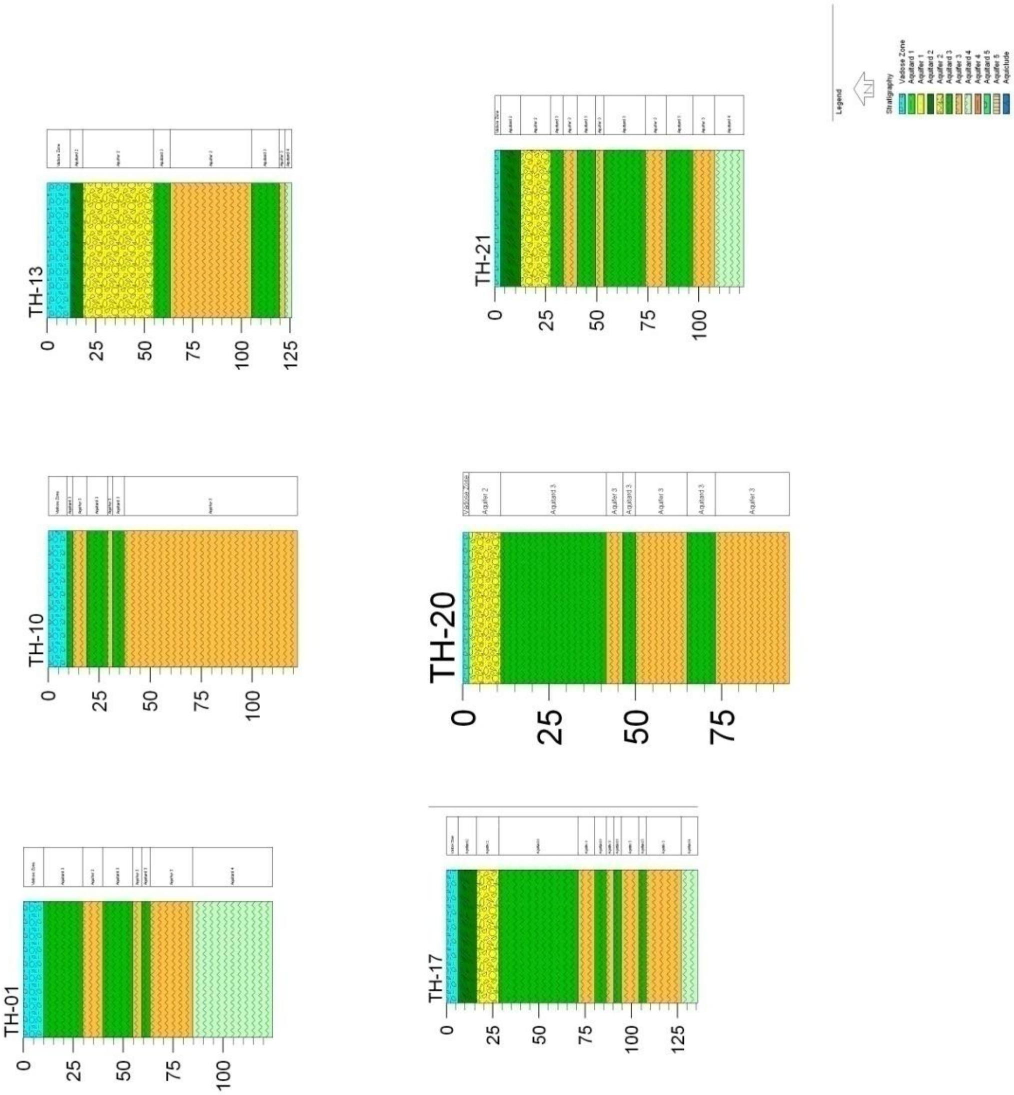


**Figure 20: Hydrostratigraphic logs of Zone 2**

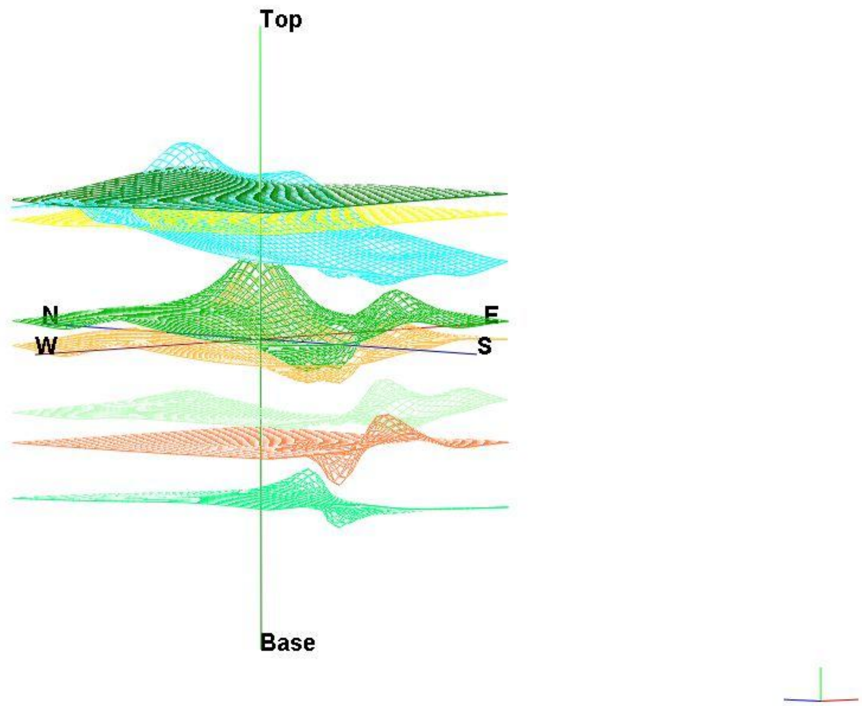


**Figure 21: Structural Elevation Model**

This 3 dimensional model represents the upper or lower surface elevations of all hydrostratigraphic units of the system.

1. Eight (8) distinct stratigraphic units were identified within the study area of Islamabad city.
2. Each unit is vertically separated layer. Each stratigraphic unit records deposition under different environment.
3. The study area comprises of four (4) aquifers which are mostly confined.
4. In several localities, aquifer 3 has been locally divided into multiple layers by the presence of discontinuous aquitards. The aquitards has divided the aquifer into multiple but connected layers.

5. The alluvium exists in semi consolidated and unconsolidated form and is mainly composed of the silt and clay with alternate layers of sand and gravel.
6. The alluvial sand and gravel is the most productive aquifer of the Islamabad region. The thickness and the areal extent of the individual strata vary within relatively short distance.
7. The aquifer 1 lies at a depth of 20 meters to 50 meters and consists mainly of gravel. It is a very narrow aquifer and is absent from most of the area. The absence of the aquifer is due to erosion of these layers.
8. The bends within the units are due to elevation differences. The thickness of each unit varies laterally throughout the study area.

# 4. RESULTS AND DISCUSSIONS

After the model had been constructed the next step was interpretation.

## 4.1. Aquifer Volumes

The model below gives an overall view of the hydrostratigraphic system of Islamabad area. The topmost layer is of vadose zone, followed by aquitards and aquifers. From this model the thickness of various aquifers were established.

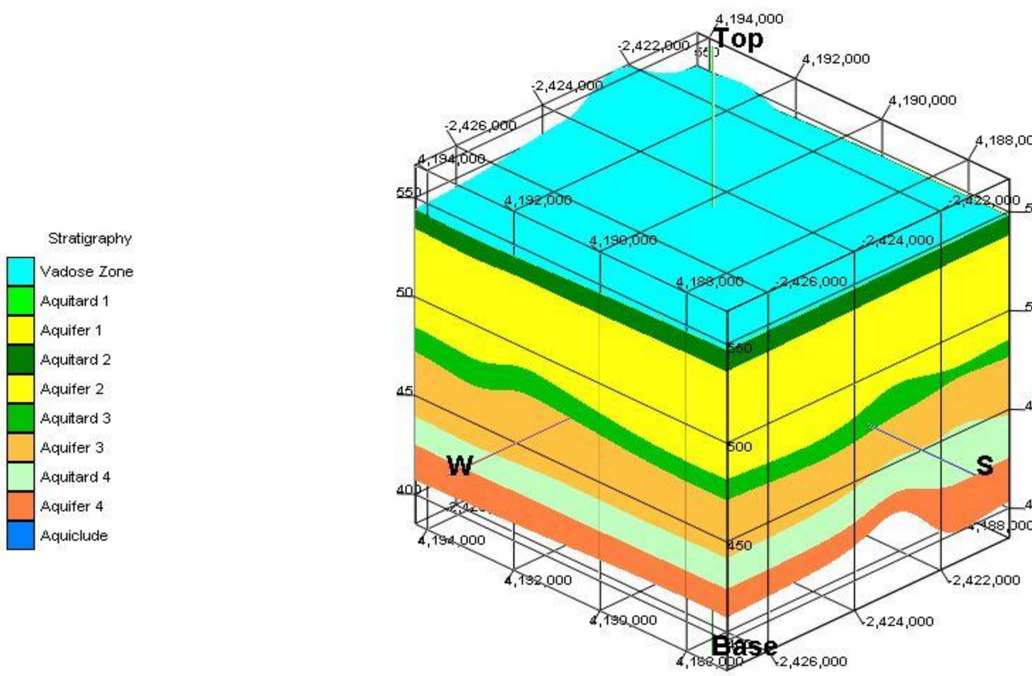


**Figure 22: Static Solid Model of the Hydrostratigraphic System**

| Aquifers | Volume ($m^3$) |
|---|---|
| 1 | 15841272 |
| 2 | 2571393281 |
| 3 | 769440822 |
| 4 | 3082063455 |

**Table 6: Volumes of aquifers**

As can be seen from the table and the model aquifer 4 has the most volume of 3082063455 $m^3$, followed by aquifer 2. Aquifer 1 has the least volume of 15841272 $m^3$.

## 4.2. Isopach Maps

Isopach maps show variations in stratigraphic thickness of formations. Isopach maps were made of aquifer 2, 3 and 4 which graphical represented the variation in thickness.

Spacing of the contours on map reflects the steepness of the slope. The equally spaced contour lines represent an inclined plane while concentric rings denote a domal or basinal feature.

The isopach map of aquifer 2 shows the variation in the thickness of the aquifer. The thickness varies from 8 meters to 38 meters. The aquifer is thickest in the centre as can be seen from the map. The isopach map was correlated with the topographic map and well stratigraphy. It was noted that the aquifer 2 was identified in 4 boreholes out of the 12 boreholes which were used for the research. These boreholes belonged to the northern region (or zone 1) of the study area, hence the isopach map was a clear reflection of the northern part of the aquifer system. It was assumed that the aquifer 2 was eroded from most of the study region. The correlation of the isopach map with the topographic map revealed that the aquifer thickness varied with the topographic thickness proportionally.

Isopach map of aquifer 3 describes the thickness of the entire aquifer more comprehensively. The maximum thickness of this aquifer is 60 meters while minimum is almost 5 meters. When the boreholes locations were identified on this map it was noted that again the thickness varied along with topographic thickness; the aquifer being thickest in the northern part of the study region and thinnest in the southern part.

The isopach map of aquifer 4 reflected the southern part of the study area as this aquifer was identified in the wells of zone 2. The thickness variation is from 4 meters to 38 meters. The gradual change in the thickness of the aquifer refers to the change in topography of the region. The slightly higher regions have thicker aquifer while slightly lower regions have thinner aquifer.

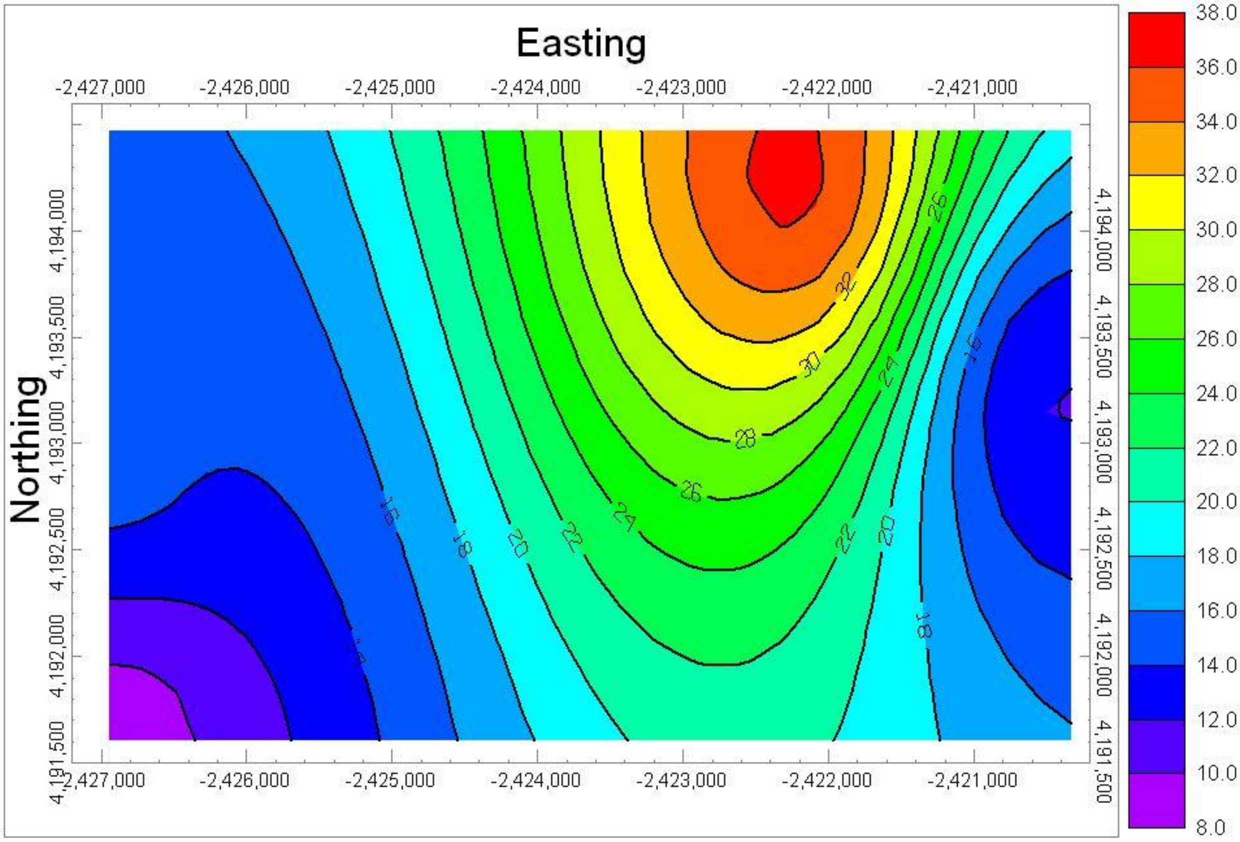


**Figure 23: Isopach Map of Aquifer 2. Contour interval= 2. Contour values in meters.**

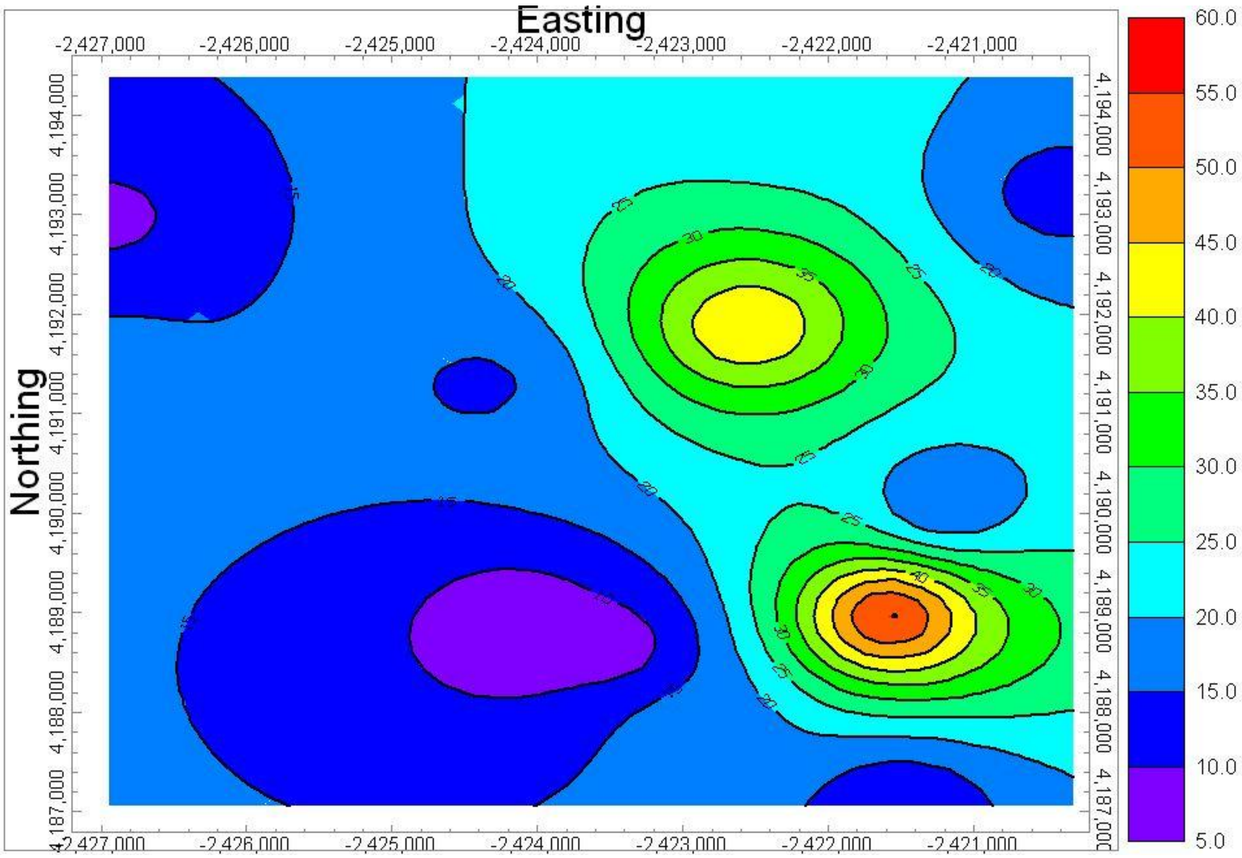


**Figure 24: Isopach Map of Aquifer 3. Contour interval= 5. Contour values in meters.**

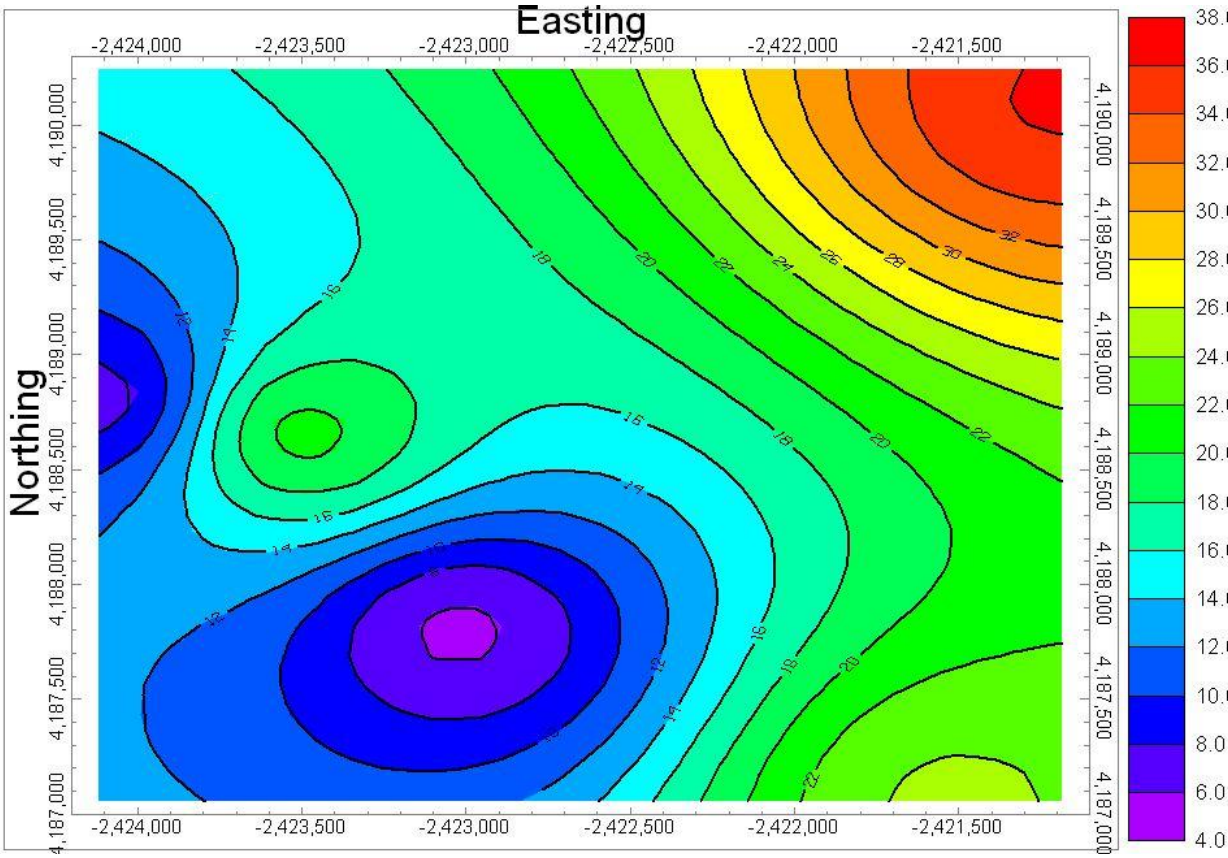


**Figure 25: Isopach Map of Aquifer 4. Contour interval= 2. Contour values in meters.**

## 4.3. Potentiometric Maps

A potentiometric surface map is a contour map that represents the top of the ground water surface in an aquifer. The contour lines illustrate the potentiometric surface much like the contour lines of a topographic map represent a visual model of the ground surface. A potentiometric surface map is very similar to a water table map in that both show the horizontal direction and gradient of ground water flow. However, a water table map shows the level of saturation in an unconfined aquifer. The potentiometric surface is generally not the physical top of the water table but is a representation of the potential energy that is available to move the ground water in a confined aquifer. A confined aquifer is totally saturated and is bounded by less permeable formations, top and bottom.

Water level data was available for all the wells used in the study. These wells were not uniformly distributed across the region or amongst the aquifer layers identified in the research. Most of the water level data were for aquifer 3.

From the map the water flow identified was from North to South. When correlated with the topographic map it was noted that this was directly related to the topography of the region.

Recharge areas are those where the water enters the aquifer while discharge areas are those where the water leaves the aquifer. Geological strata are not perfectly horizontal. At some point the lithological unit that comprises the confined aquifer is exposed to the surface. This is the aquifer's recharge zone. Discharge areas are the opposite of recharge areas. They are the locations at which ground water leaves the aquifer and flows to the surface. Ground water discharge occurs where the water table or potentiometric surface intersects the land surface. Where this happens, springs or seeps are found.

The northern region of the city mainly recharges the aquifer systems. The recharge area is not covered in the study region but from the flow which is from North to South it can be predicted that the recharge area is somewhere in the Northern region. Islamabad receives rainfall throughout the year which contributes to the recharge of the aquifer system. Recharge rates in an aquifer depend upon the amount of local precipitation, the ability of surface deposits to allow water to filter through, and the rate at which water moves through the aquifer. Surface water can enter an aquifer only as fast as water within the aquifer moves away from the recharge zone.

The tube wells are the main source for the discharge of the water from the aquifer system. Also the perennial streams distributed throughout the region are also contributed vastly to recharge and discharge of the aquifer system.

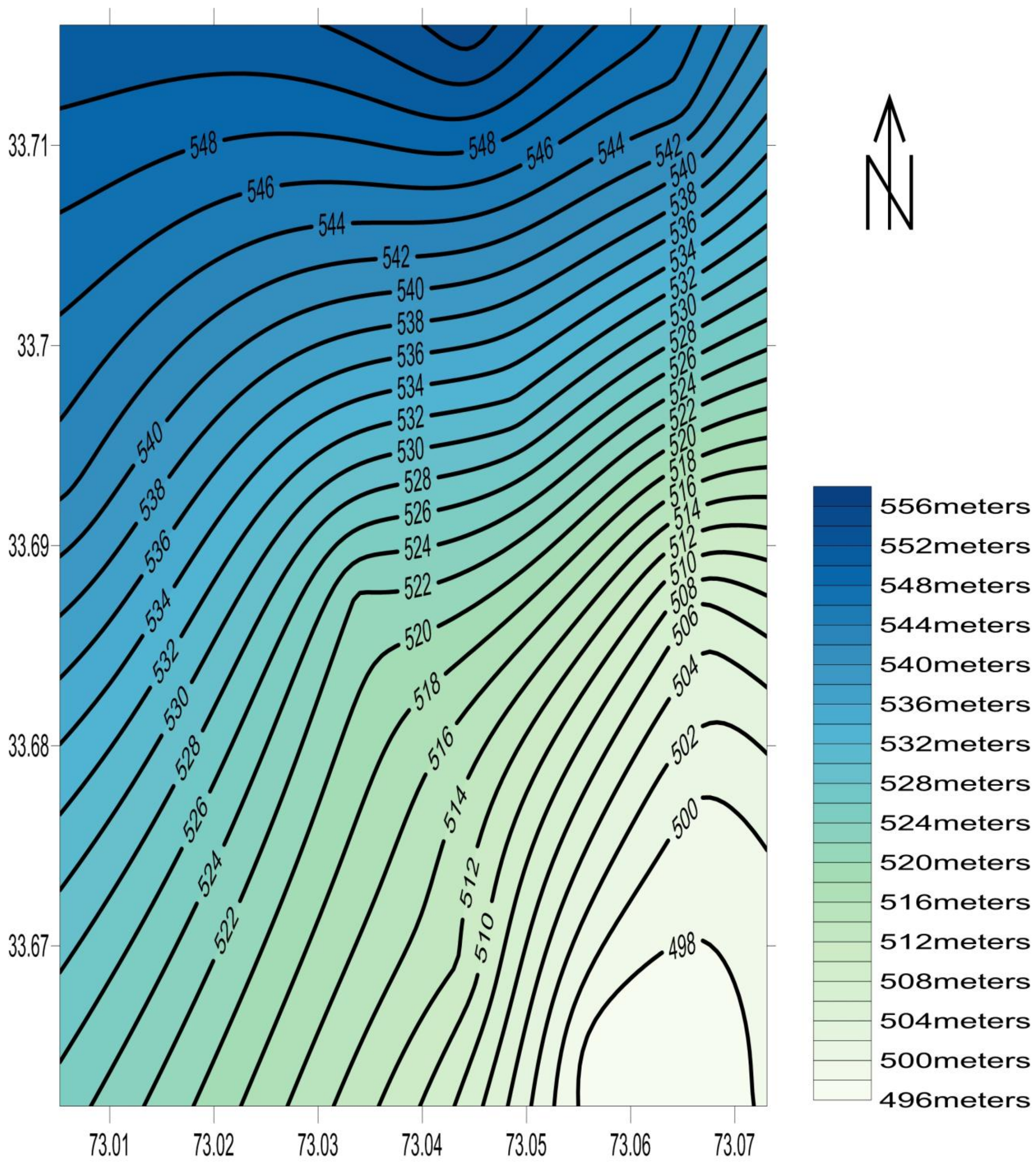


**Figure 26: Potentiometric Contour Map. Contour Interval= 2 meters.**

## 4.4. Porosity, Permeability and Moisture Content Maps

Porosity is a measure of how much of a rock is open space. This space can be between grains or within cracks or cavities of the rock. Permeability is a measure of the ease with which a fluid (water in this case) can move through a porous rock.

In saturated groundwater aquifers, all available pore spaces are filled with water. Above a capillary fringe, pore spaces have air in them too. Most soils have water content less than porosity, which is the definition of unsaturated conditions, and they make up the subject of vadose zone hydrogeology. The capillary fringe of the water table is the dividing line between saturated and unsaturated conditions. Water content in the capillary fringe decreases with increasing distance above the phreatic surface.

The porosity, permeability and moisture content of aquifer were mapped because this was the main aquifer present throughout the region.

The percentage of porosity of the aquifer increases from east to west, the maximum aquifer porosity being around 38%.

The permeability of the aquifer decreases from east to west, the permeability ranges varying from 0.0002 ft/sec to 0.0048 ft/sec.

The moisture content varies slightly throughout the aquifer. The western side has less moisture content as compared to the eastern side. The moisture content varies from 5% to 11%

When the porosity, permeability and moisture content were correlated with the isopach map it was noted that as the thickness changes from east to west, the porosity and permeability also varied. The thickness of the aquifer increases from east to west, the porosity also increases but the permeability decreases in this region. The stratigraphy of the region was then correlated with these maps and the following observations were made.

1. The presence of thin layers of gravel in the eastern side of the study area contributes to low porosity while the thin layers of clay causes the high permeability. Hence the water retention and specific yield is less and the recharge of the aquifer in this region is less but the flow of water is more when compared to the western side. The moisture content in the eastern region is more as the flow of water is easier.
2. The gravel layers in the western part is thicker than the eastern region hence the recharge is more effective. The clay layer also thickens, which compacts the gravels and reducing the permeability of the aquifer. The moisture content of the western region is less as the compaction of the gravels restricts the water movement.

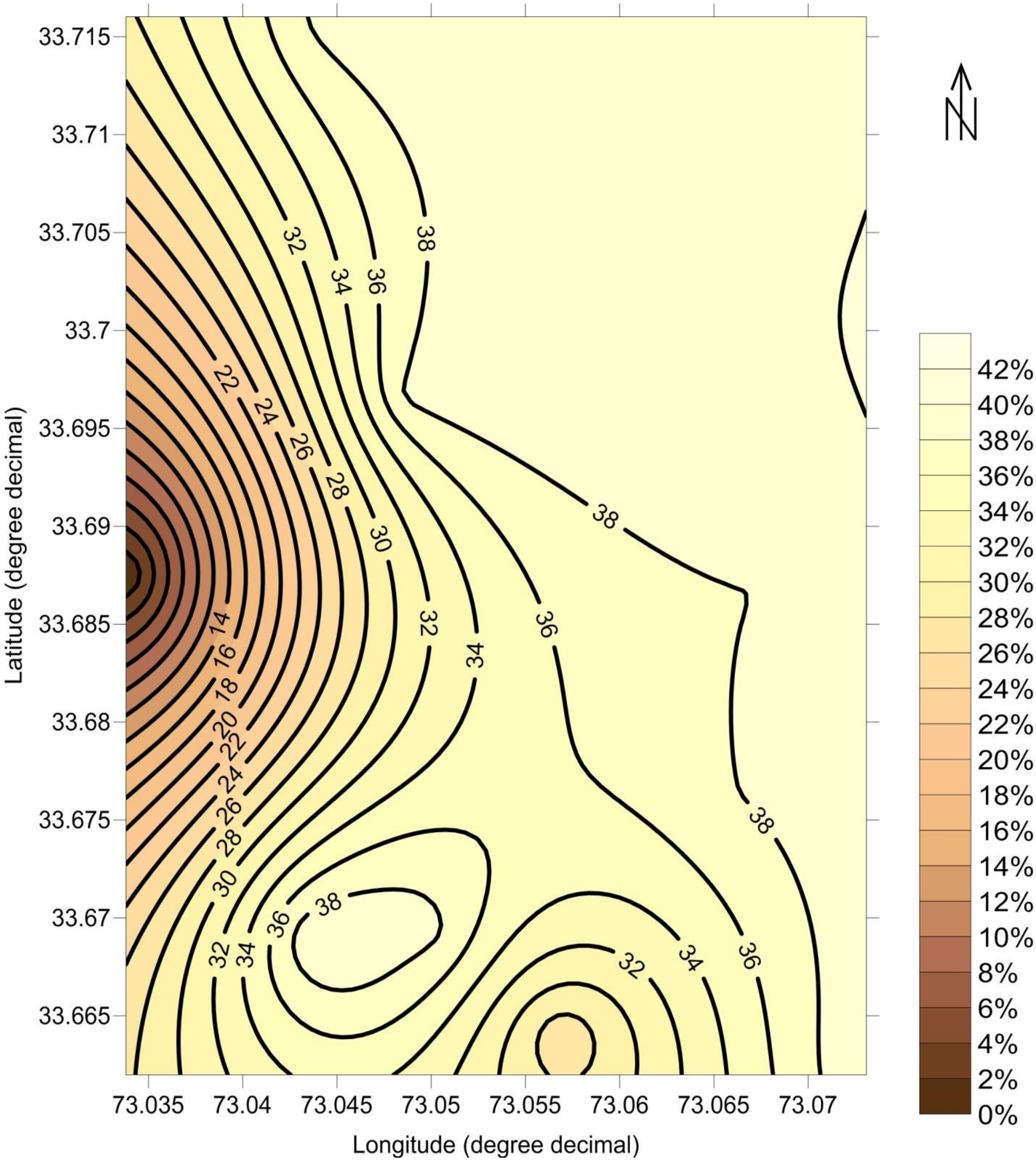


**Figure 27: Porosity Contour Map. Contour Interval= 2 meters.**

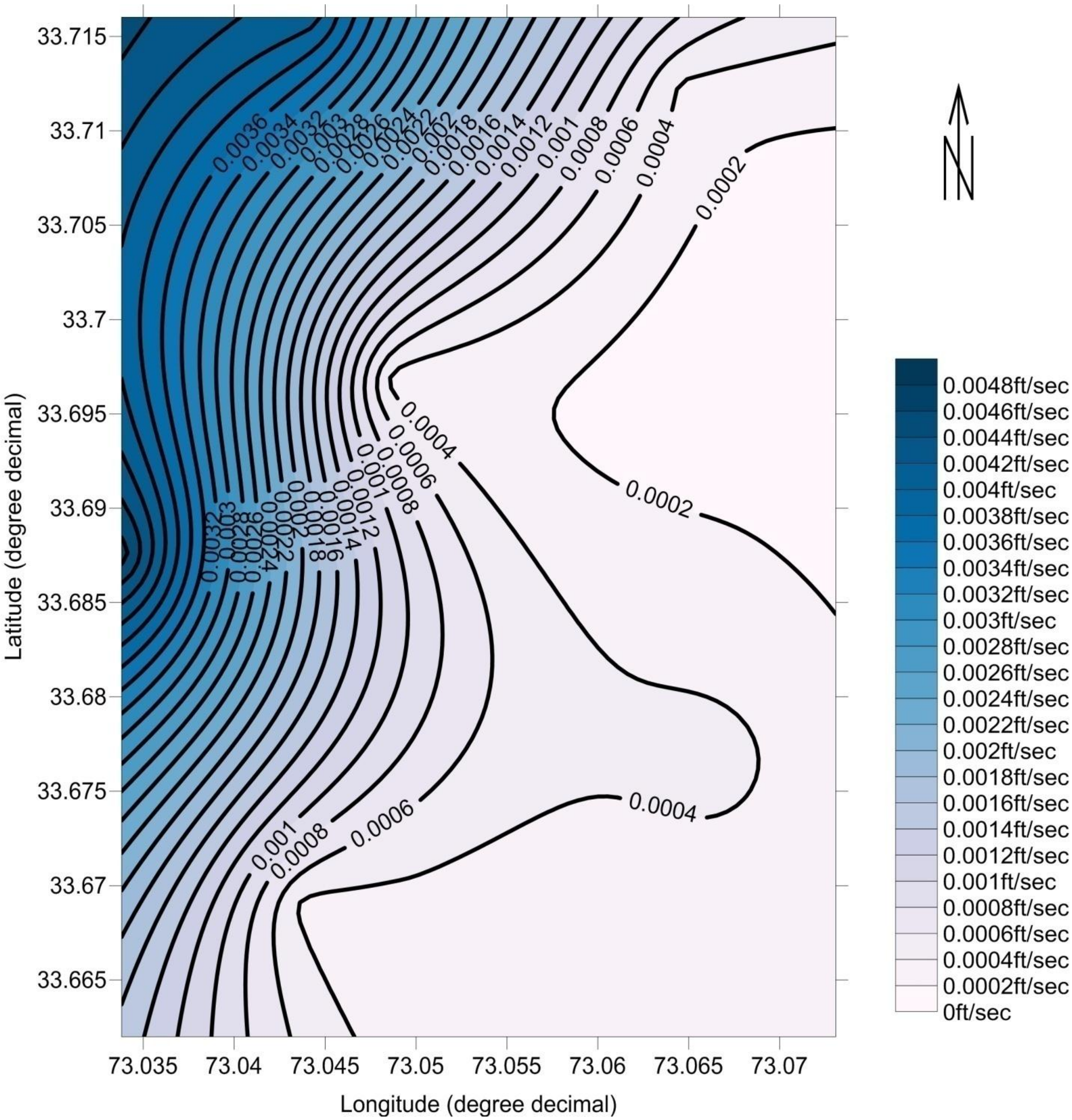


**Figure 28: Permeability Contour Map. Contour Interval= 0.0002 meters.**

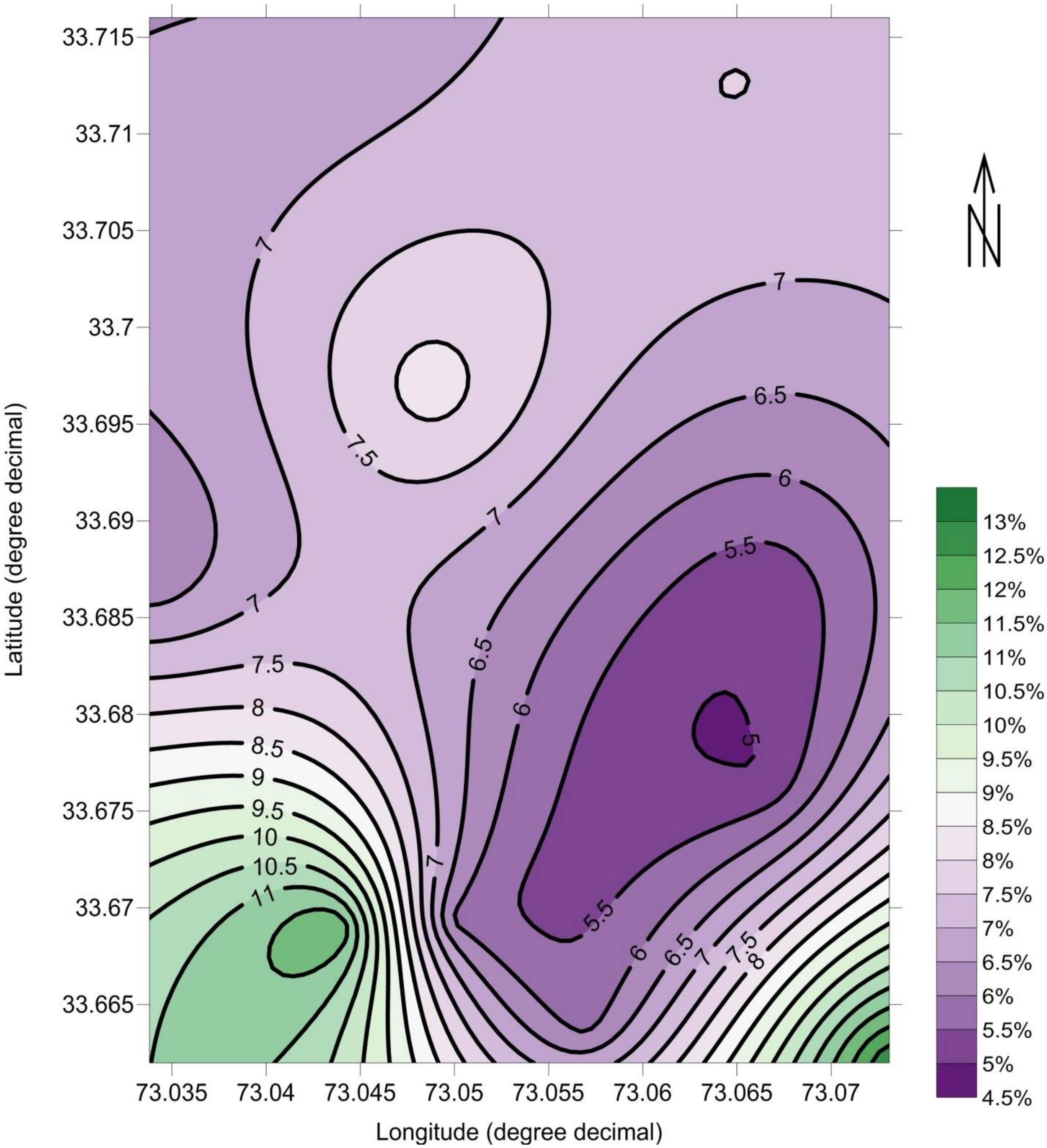


**Figure 29: Moisture Content Contour Map. Contour Interval= 0.5 meters.**

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# 5. CONCLUSION AND RECOMMENDATIONS

1. This study identifies the methods and tools that may be used to effectively visualize and analyze the subsurface characteristics and three dimensional aquifer systems.
2. The study includes regional geologic history of Islamabad, characteristics of hydrogeologic units, ground water levels and storage and recharge discharge of the delineated areas.
3. The methodology for conceptual model development, including stratigraphic and lithological interpretation is extensive but necessary. The model provides a basic understanding of the complex flow system and the interactions between various units.
4. Aquifer system of the Islamabad city was established using the hydrostratigraphic model.
5. Lithostratigraphic modeling indicates that the Islamabad city exhibits a multilayer system where aquifers are separated from each other by thick aquitards. Five (5) aquifers were identified out of which only aquifer three was widespread.
6. The potentiometric map was established and the flow of water was determined which was found to be dependent on the topography of the region.
7. The thickness of the aquifer three was approximately 760440822 $m^3$. The thickness of this aquifer increases from east to west.
8. The porosity permeability and moisture content also varies from east to west in aquifer 3. The relationship of porosity and permeability is inversely proportional in this aquifer i.e. as the porosity increases from east to west the permeability decreases. The moisture content decreases from east to west.

9. The recharge and discharge zones were also identified. the eastern side of the aquifer was more prone to discharge while the western side recharges more effectively.
10. Although aquifer 4 has a limited extent it can still be utilized for artificial recharge which will increase the water storage and reservoirs.

## 5.1. Recommendations

1. The population increase will lead to a very rapid depletion of aquifers.
2. There should be a regulation for the installment of private tube wells in capital territory.
3. The shallow parts of the aquifer may be utilized for artificial recharging.
4. The groundwater of this aquifer should be characterized chemically.

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