HYDROGEOPHYSICAL AND ENVIRONMENTAL SCIENCE CONSULTANTS (HESC) NTN-1287293-8

E-MAIL: hesc97@gmail.com (Off) 051-8733819, (Res)230557
fz97@hotmail.com www.hesc.com.pk Mobile: 0300-9502376

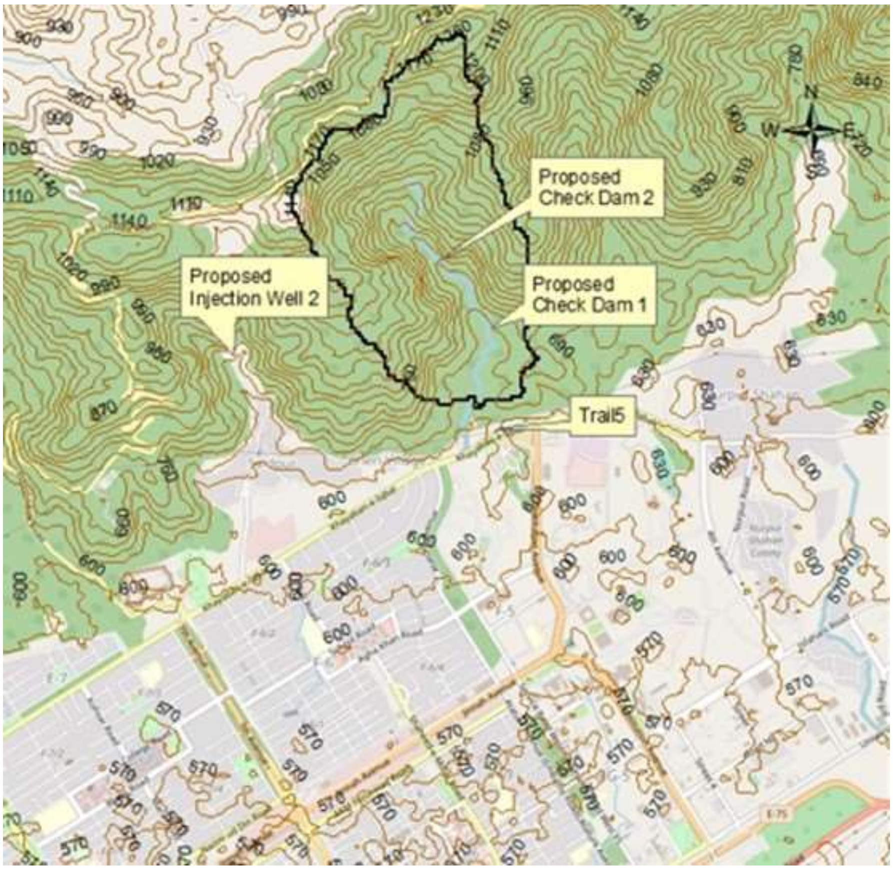
Specialized in:

Electrical Resistivity Survey, Well-logging, Seismic and gravity survey, Groundwater Resource Evaluation, Environmental Impact Assessment (EIA), Industrial Disposal Waste Site Assessment / Soak Pit & Injection Well, Soil Investigation, Water Well Drilling, Numerical Groundwater Flow and Transport Modeling, Air Plume Modeling Simulation of Industrial Pollution.

#131, St. 52, G-14/4, Islamabad - Pakistan

17, Dec, 2018

A Report on
Artificial Aquifers Recharge by involving Check Dams Site Selection / Rehabilitation and Dug Wells appropriate Placement in the middle Himalayas along Main Boundary Thrust Fault (MBT) Islamabad (Capital)



For

Nestle Pakistan Ltd.
Islamabad factory
Plot# 32, Street#3, Sector I-10/3,
Industrial Area, Islamabad, Pakistan

14 Dec, 2018

Contents

1. GENERAL

Present study is carried out to find the potential sites for check dams and injection wells to enhance the recharge to groundwater system in Potowar Aquifers, Islamabad. Check Dam is referred to a small dam constructed across a rain waterway track to store the run-off water to be used for recharging the underlying aquifer regimes. While injection wells directly inject the rainwater to the underlying aquifers with the support of a recharging well. The water is diverted to the injection well from a small artificial storage that is stored during rainfall-runoff water. It is likely to be mentioned that existing aquifers of Rawalpindi and Islamabad are superseding the safe-limit by excessive pumping of water wells and therefore the hydrologic budget / balance between the annual recharge and discharge is never met thereby creating a drawdown scenario in the levels of water wells. As a matter of fact, at some locations the pre-established pump-set depth of water wells have now been increased to maintain the reasonable water column. If this tendency of pumping is being continued on a same pace there is a likelihood that aquifers may run out of water within 1 decade or so. However, a numerical groundwater flow modeling study by Visual Modflow or any other suitable software would suffice the tentative establishment of the dry-out-aquifer scenario.

Present study is carried out primarily in Main Boundary Thrust fault (MBT), Margalla hills and Rose and Jasmine Garden to determine the suitable sites for check dams and injection wells. Figure 1.1 shows location of study area and its terrain and accessibility.

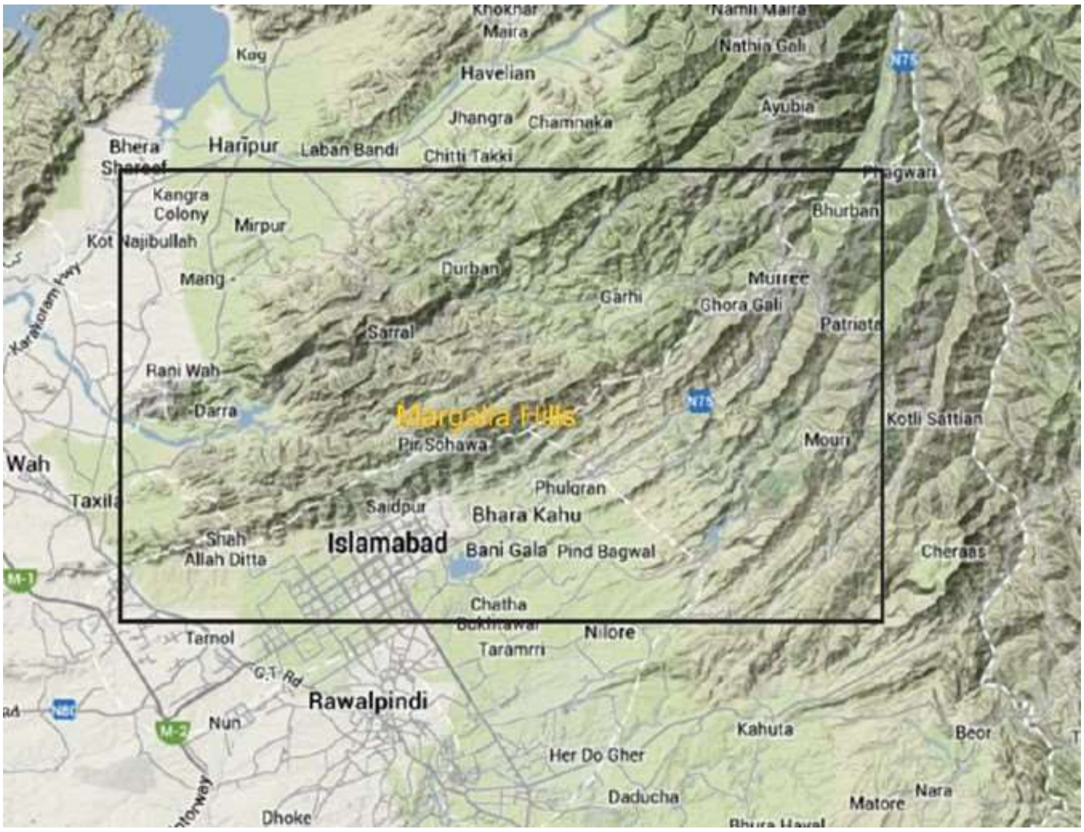


Figure 1.1 Location of study area showing terrain and accessibility.

2. METHODOLOGY

Two techniques involving check dams recharging system and a battery of dug wells/injection wells artificial recharge could be effectively used to replenish the underlying aquifers on short-term and long-term basis. A typical diagram of recharging check dams from hillside is shown in Figure 1.2. In this diagram, Type I dams would be constructed on the streams / nullahs in the hills, where they would catch storm runoff and release it to recharge wells or toward the recharge zone. Several studies have determined that Type I dams may be large and expensive and would inundate large areas during rainy times. (Source: http://www.edwardsaquifer.net/recharge.html). Type II dams would be constructed on the recharge zone itself and would stop water as it runs off the plateau, allowing more time for it to go into the ground. Best sites for recharge check dams will be identified with the field reconnaissance survey and GIS/Satellite data and historic record of flows in channels.

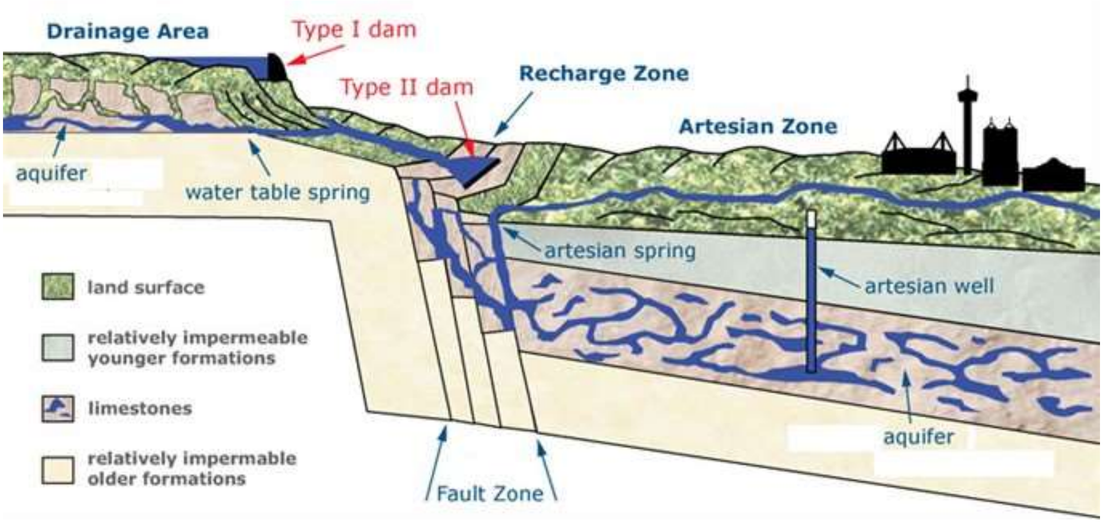


Figure 1.2 Typical diagram of recharging check dams.
(modified from http://www.edwardsaquifer.net/recharge.html)

The option of refilling, depleting aquifers with injection or percolation wells has become more important due to shortage of groundwater in our major cities such as Islamabad. Recharge wells, have the advantage of aquifer recharge and instantaneous supply of potable water at the same time. They can utilize existing infrastructure and require very little effort for the modification and operation. The area around the well acts as funnel. If this area is maintained well, the water will require little purification before it enters the groundwater body (source: Wikipedia 2018). A typical section of recharging dug well is shown in Figure 1.3.

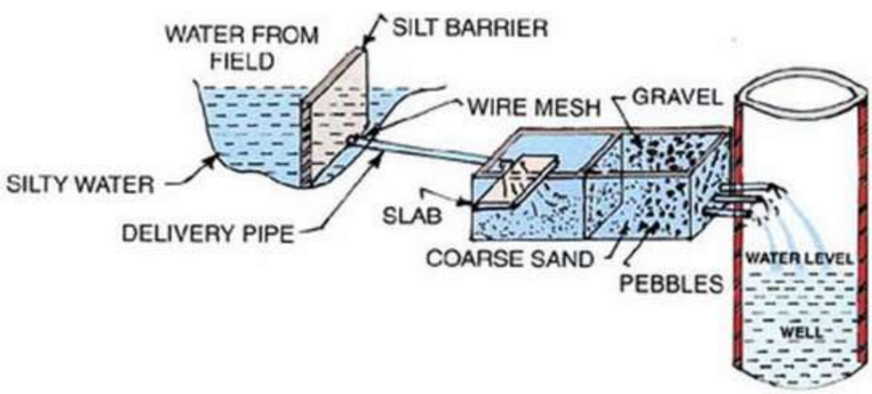


Figure 1.3 System of recharge well
(Source: http://hindi.indiawaterportal.org/node/54366

Margalla hills have numerous streams which carry appreciable runoff and it can be stored in check dams and later can be used for recharging the groundwater body in Islamabad city. **Figure 1.4** shows the drainage areas in Margalla hills, a source of surface runoff for groundwater recharge. These drainage areas will be marked on the map and their surface runoff available for recharge is calculated.

The Margalla Hills is part of the Himalayan foothills located within the Margalla Hills National Park, north of Islamabad, Pakistan. The Margalla range has an area of 12,605 hectares. The hills are a part of Murree hills. It is a range with many valleys as well as high mountains. The formation of the Margalla Hills dates to the Miocene epoch. The dominant limestone of the Margalla is mixed with sandstone and occasional minor beds of shale. (Source: Post-Earthquake explorations of human remains in Margalla hills project) (Wikipedia 2018)

3. OBJECTIVE

The objective of the project is to select the most appropriate locations for inducing artificial recharge into groundwater aquifers regimes by means of checks Dams and Dug/ Injection wells.

Main Boundary Thrust (MBT) Fault area along Trail 5 can be used along minor fractures for this objective. From reconnaissance survey along Trail 5, it is revealed that 5 minor check dams have already been existed that are in bad shape. If they are considered to be appropriate and capable of recharging they would be recommended for repair/rehabilitation and appropriate maintenance.

Trail 3 will also be used simultaneously for locating check dams sites or rehabilitation of existing sites.

Drainage areas in Margalla hills, a source of surface runoff for groundwater recharge are shown in Figure 1.4.

Figure 4.4 Drainage areas in Margalla hills, a source of surface runoff for groundwater recharge. Source: https://en.wikipedia.org/wiki/Margalla_Hills

Areas around Faisal Mosque, Shah Allah Ditta Cave, and Jasmine Garden etc will be used for selection of Dug Wells/injection wells.

Tectonically disintegrated areas where fractures / crevices tend to exist due to MBT are very vulnerable to explore for induced recharge for the following:

i. Select at least 5 dams which have the highest infiltration potentialities,
ii. Evaluate the additional volumes that can be infiltrated after repairing/cleaning the dams vs existing situation,
iii. Design a monitoring system that enables to demonstrate the efficiency of the enhanced recharge.
iv. Intensive induced recharge through dug/injection well may create impact on the aquifer should be immediate but extension around the injection point in the form of inverse (upward) cone of depression might be limited
v. Construct pilot dug/injection well and monitor impact over a 12 months period
vi. Piezometers to be constructed in the vicinity and further area to monitor the rise in water level for at least 12 months period
vii. Alternatively, assess current condition of Jasmine Garden well and evaluate impact on aquifer
viii. Map of existing percolation dams with color coding according to their respective infiltration capacities
ix. Map of potential areas where to create injection wells according to infiltration capacities, accessibilities, proximity of water source, impact on aquifer, relevance for local population
x. Origin and quality of the water source: for the check-dams it will be run-off water that may contain a lot of suspended solids. For the dug-wells, is it rainfall water or waste water?
xi. Tentative operation/maintenance program and cost to keep the systems in good working conditions
xii. For both systems, a cross-section showing clearly the infiltration mechanism and the impacted aquifer

4. SCOPE OF WORK

The work consists of field investigations within Islamabad MBT boundary on the existing hydrogeological conditions. The probable sites should be ranked based on the given criteria by the detail characterization of the sites including fracturing, water quality (TDS), Hydraulic conductivity (K) and porosity (Ø) etc.

5. DATA COLLECTION

Reliable data collection, procurement from industries and its proper utilization is the backbone of appropriating locating the dug wells site for inducing recharge and or rehabilitation of existing Check Dams along Trail 5 and Trail 3 or proposing new sites where substratum hydraulic conductivity (K) of the material is good enough to take in infiltrating water through the different horizons of soil profile within the top portion of zone of aeration (unsaturated zone).

Hydraulic characteristics (Transmissivity T and Storativity S), and hydraulic conductivity K are mandatory features to be used for locating a new source recharging area. Such information will lead towards identifying a successful location on priorities where Nestle Pakistan Ltd may be able to demonstrate these activities of recharging the aquifer system in collaboration with CDA followed by our advice of consultants would may turn into a best practice of making a balance between the recharging and discharging components.

Hydrological environmentally friendly study searching through the literature, reports and periodicals, water-table, elevation, latitude and longitude, groundwater quality, and aquifer type (confined or unconfined) and their thicknesses are essential for demarcation of a new suitable site.

6. HYDROLOGICAL ELEMENTS FOR THE GROUNDWATER RECHARGE STUDY

Following are the important hydrological elements for the study of groundwater recharge:

1. Precipitation
2. Air Temperature

3. Evaporation
4. Groundwater levels
5. Surface Geology
6. Subsurface Geology and Aquifer Strata
7. Tectonic Features/Faults Contributing Recharge to Groundwater
8. Topography, Slopes and Pervious Potential Recharge Zones
9. Land Use and Soil Type
10. Hydraulic Conductivity/Porosity of Aquifer Material
11. Existing Streams, Rivers and Lakes for recharge
12. Potential Sites for Check Dams for Recharging Aquifer
13. Design of Check Dams and Injection Wells

The above elements are studied in the following sections;

6.1 Precipitation

Precipitation is the main source of recharge to groundwater. Therefore more emphasis is made to find the ways to cater precipitation water to be used for groundwater recharge. Location of climate station with long term precipitation data is shown in Figure 6.1. These stations are maintained by Pakistan Meteorological Department (PMD)

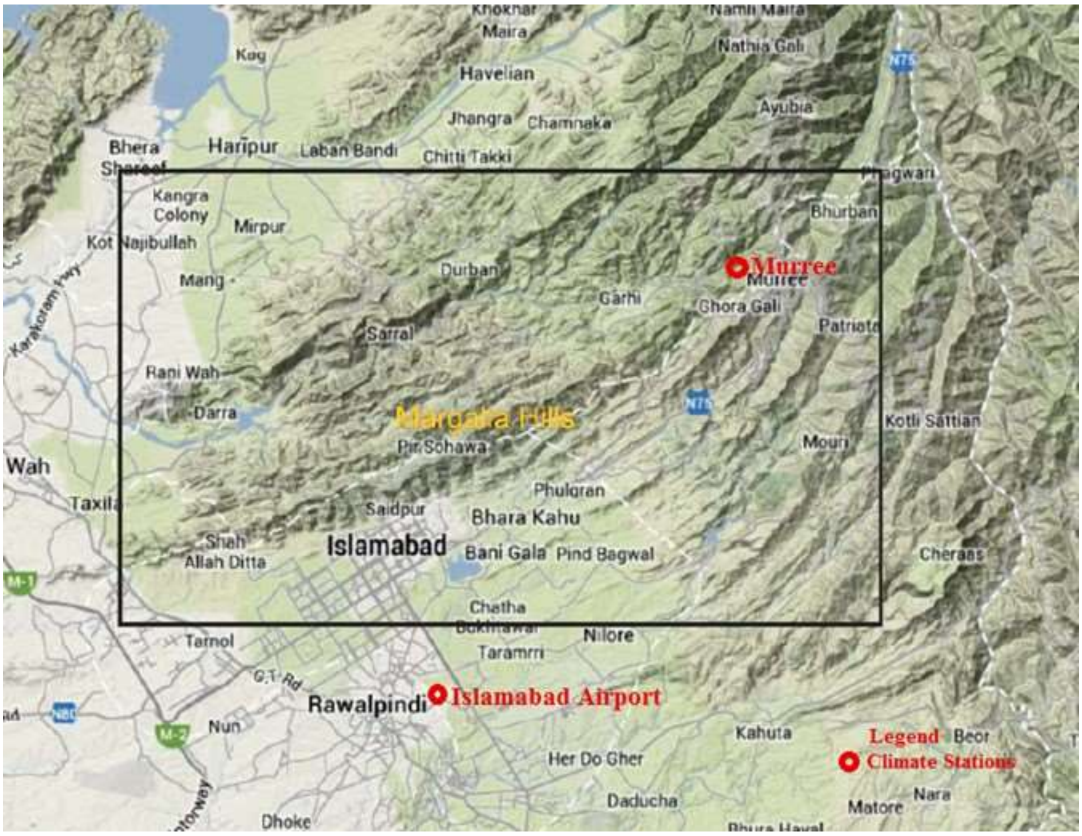


Figure 6.1 Location of climate stations with long term record (in red color)

Precipitation data is available for 58 years from 1959 to 2017 at Islamabad Airport station from PMD (Pakistan Meteorological Department). It reveals an annual average rainfall of 1175 mm. Minimum annual rainfall is 576 mm in year 2009 and maximum rainfall 1952 mm occurred in year 2013 (between period 1959 and 2017). Most of this precipitation occurs between June and October (826 mm). In this period (summer season), about 70 % of annual rainfall occurs. While between November and May, precipitation is about 350 mm (Table 4.1). Therefore area is located in a monsoonal climate zone with rainy hot summers and cool dry winters. The monsoon period usually starts in June, peak in August and end by September (see Figure 6.2). There is also a winter monsoon, much smaller than the one in summer, peaking in March. Long term annual precipitation at Islamabad airport station (1959-2017) is shown in Figure 6.3.

A record of a rainfall breaking 620 mm in just 10 hours occurs on July 2001.

Normal precipitation for 30 year period (1987-2017) is computed and shown in Figures 6.4 and 6.5, which shows the comparison of mean monthly precipitation at Islamabad airport station for 1959-1986 and 1987-2017 periods. It reveals that rainfall in 30y segment 1987-2017 is higher than the segment 1959-1986. It is also reconfirmed from Figure 6.6 that increasing trend in precipitation tends to prevail at Islamabad Airport (1959-2017). Moreover, rainfall projection up to 2040 as shown in Figure 6.7 also indicated increasing trend, which means that the chances of recharge and runoff are more as compared to previous years.

Table 4.1

Station Islamabad A.P (1959-2017)	
Period	**Rainfall mm**
Jun-Oct	826
Nov-May	350
Annual	1175

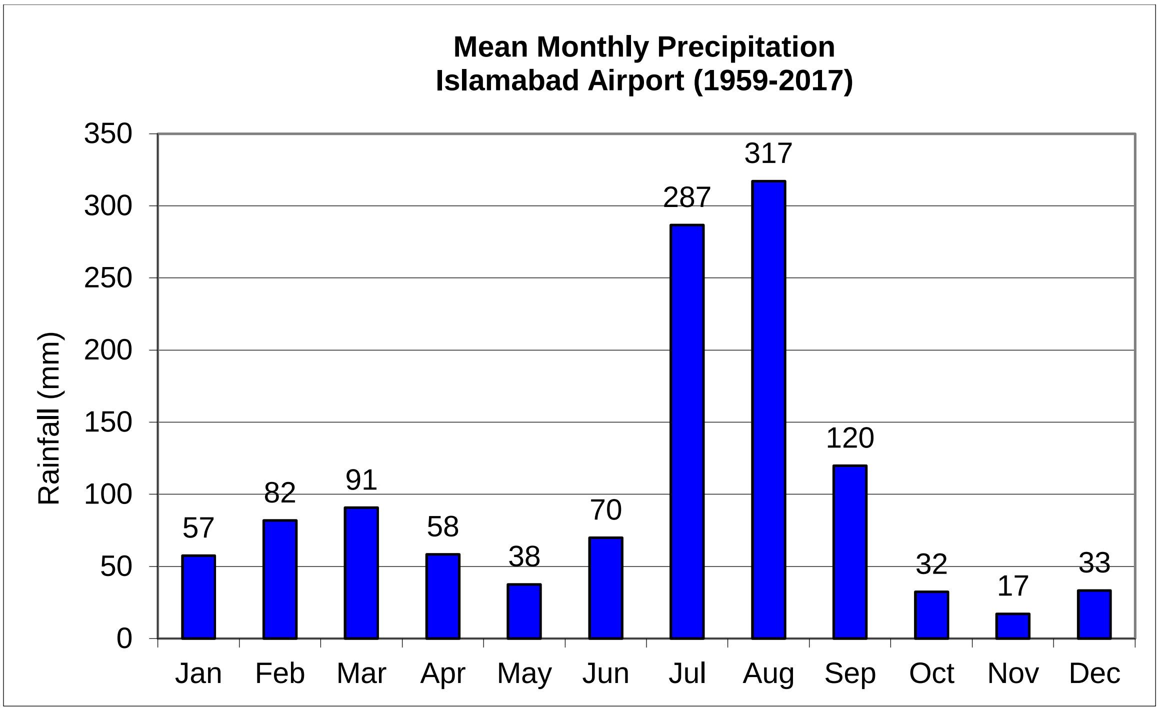


Figure 6.2 Mean Monthly Precipitations (1959-2017)

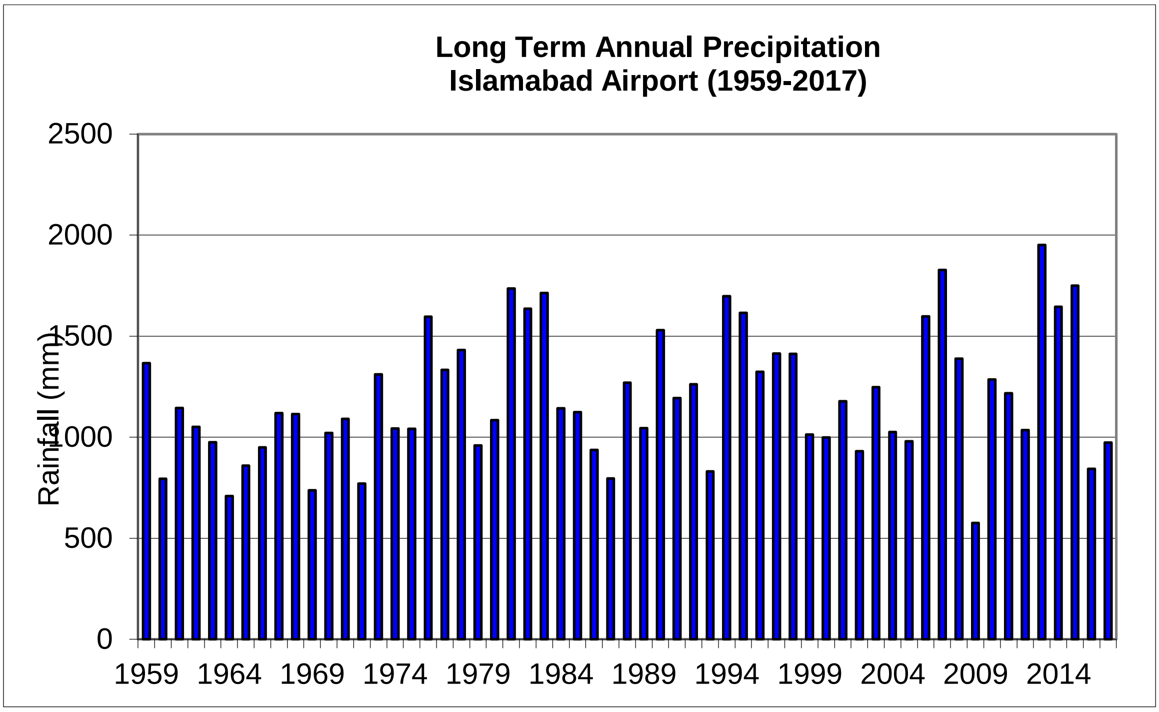


Figure 6.3 Long Term Annual Precipitation (1959-2017)

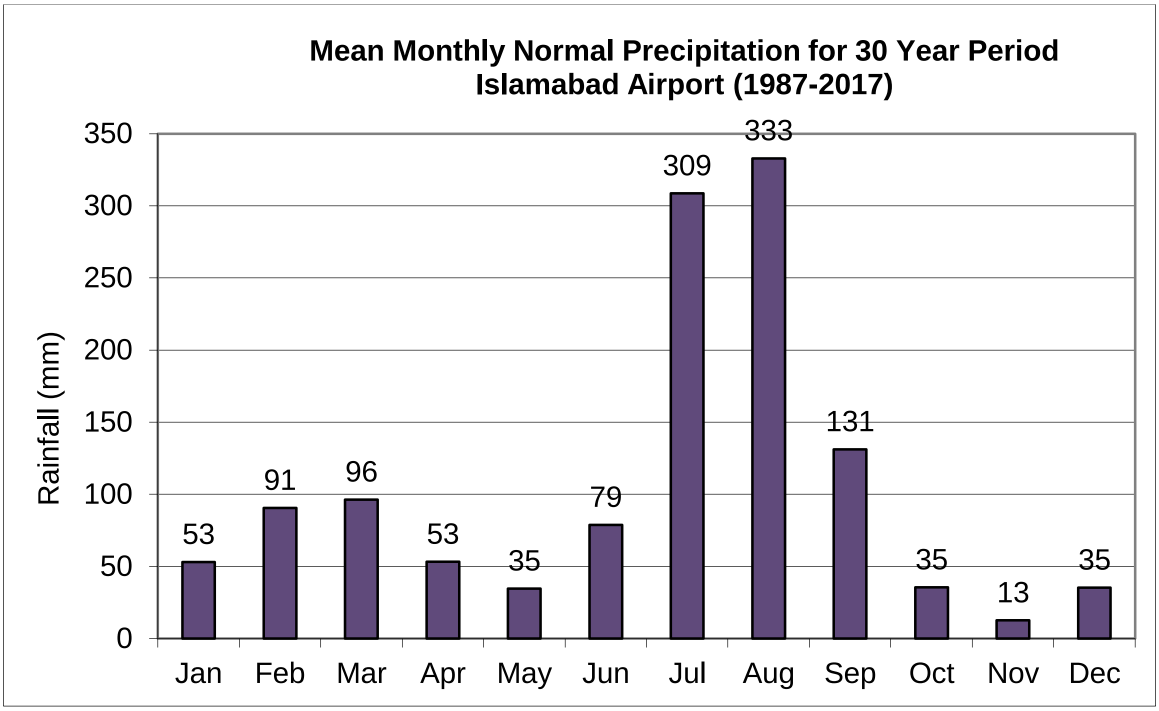


Figure 6.4 Mean Monthly Normal Precipitations (1987-2017)

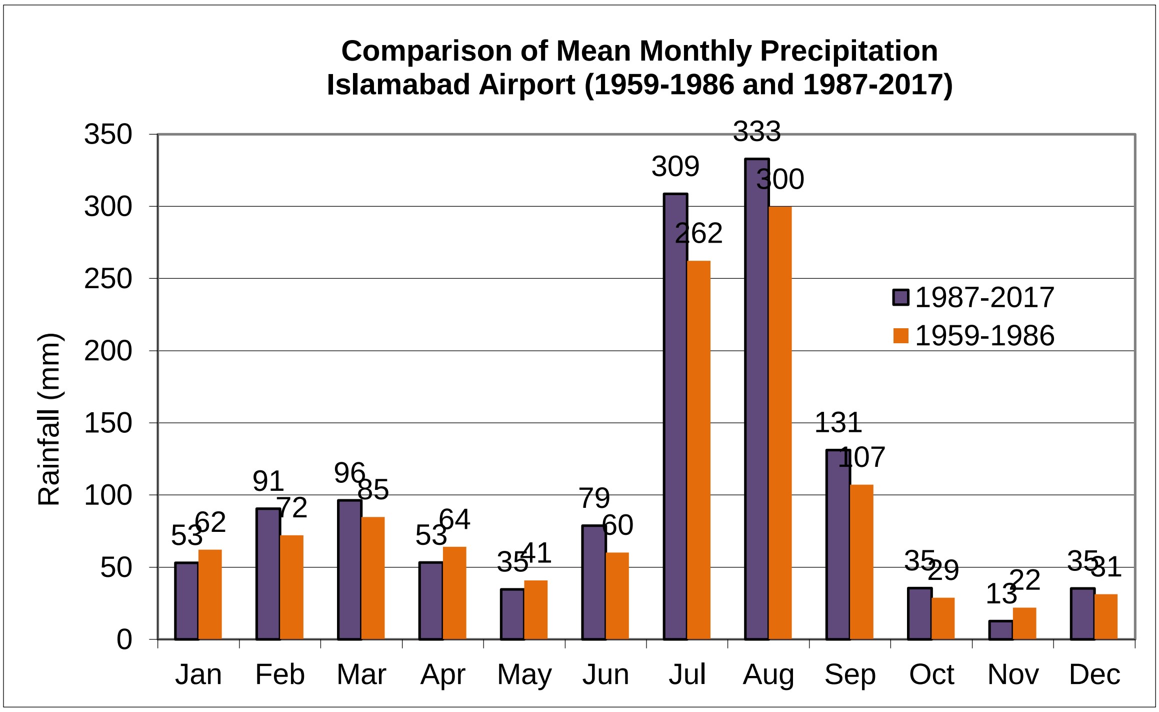


Figure 6.5 Comparison of Mean Monthly Precipitation Islamabad Airport (1959-1986 and 1987-2017)

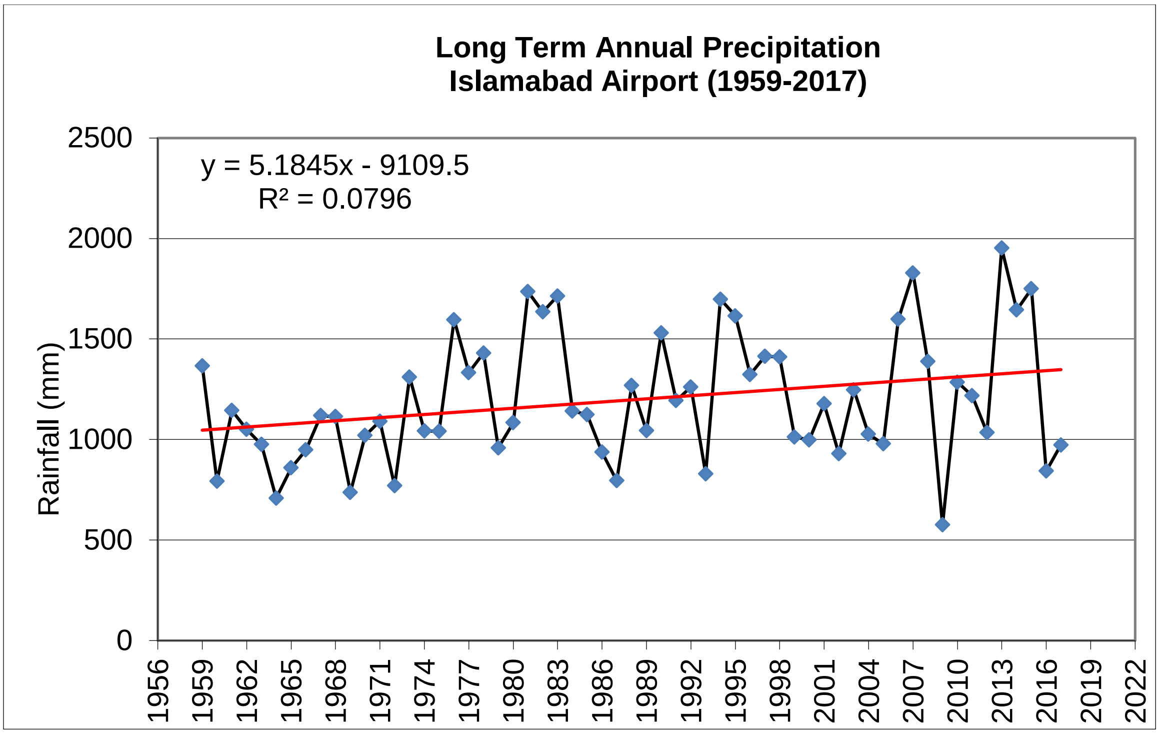


Figure 6.6 Increasing trend in precipitation Islamabad Airport (1959-2017)

Rainfall Projections

To find the impact of climate, rainfall was projected for next 40 years. (Source: Islamabad, Pakistan - Climate Change Vulnerability Assessment United Nations Human Settlements Program (UN-Habitat) First edition 2014)

Rainfall Projection shows a slight annual increase up to 2040. Projections also show increasing rainfall variability (Figure 6.7). The overall increase in average rainfall, with increasing urban growth, means that although urban flooding will be increased but it will also increase the recharge due to increase in runoff.

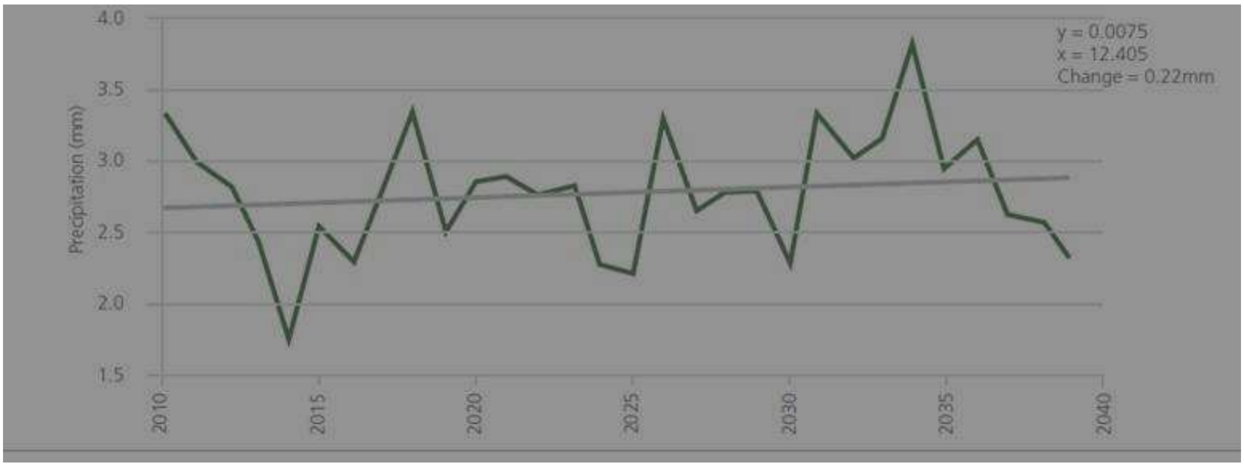


Figure 6.7 Projected increasing trend of precipitation for future years up to 2040

Source: Islamabad, Pakistan - Climate Change Vulnerability Assessment United Nations Human Settlements Program (UN-Habitat) First edition 2014

6.2 Air Temperature

In recharge process in a watershed, temperature plays an important role for the loss of water from reservoirs, ponds and soil moisture. In water balance calculation for recharge, temperature is an important element to estimate recharge. Mean monthly maximum and minimum temperature was computed with the help of recorded long term data 1959-2015 of Pakistan Meteorological Department (PMD) at Islamabad Airport station. Figure 6.8 shows mean monthly maximum and minimum temperature at Islamabad Airport. To understand the impact of climate change on hydrologic regime of the area, series of mean annual maximum temperature and mean annual minimum temperature were computed and trend line analysis was carried out. Increasing trend of temperature was observed from the two graphs (Figure 6.9 and 6.10). These preliminary results have shown the existence of impact/effect of climate change on hydrological regime in this area.

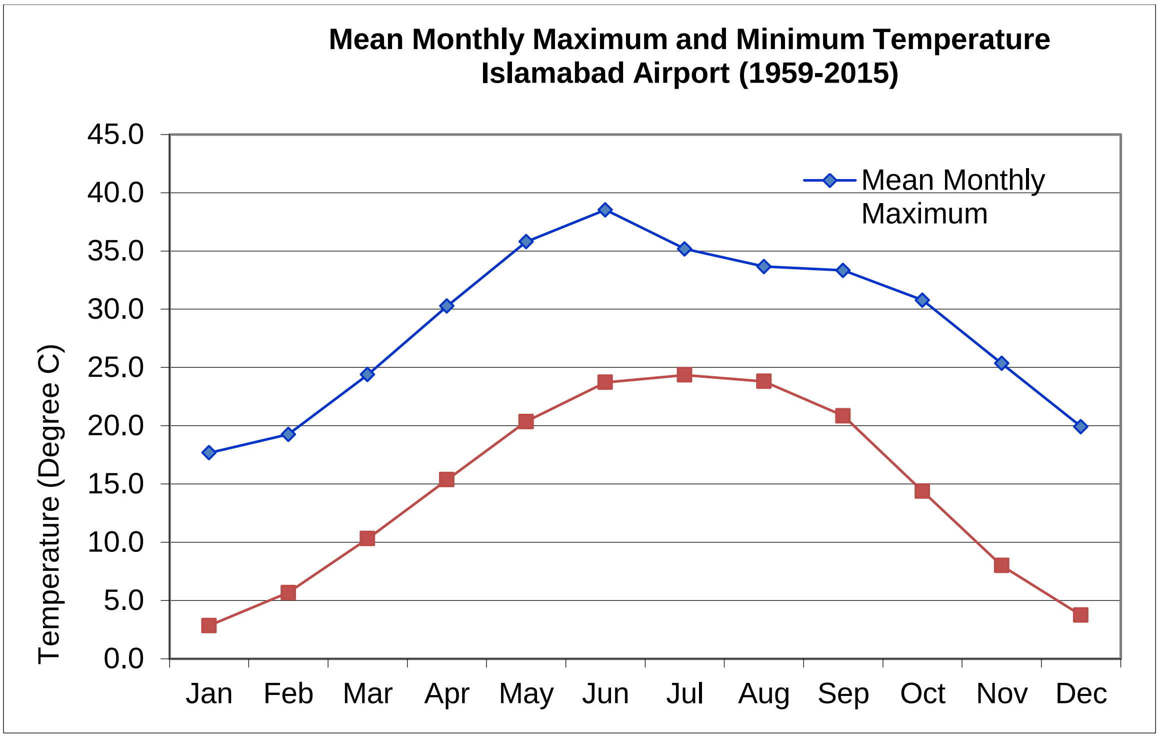


Figure 6.8 Mean Monthly Maximum and Minimum Temperature Islamabad Airport (1959-2015)

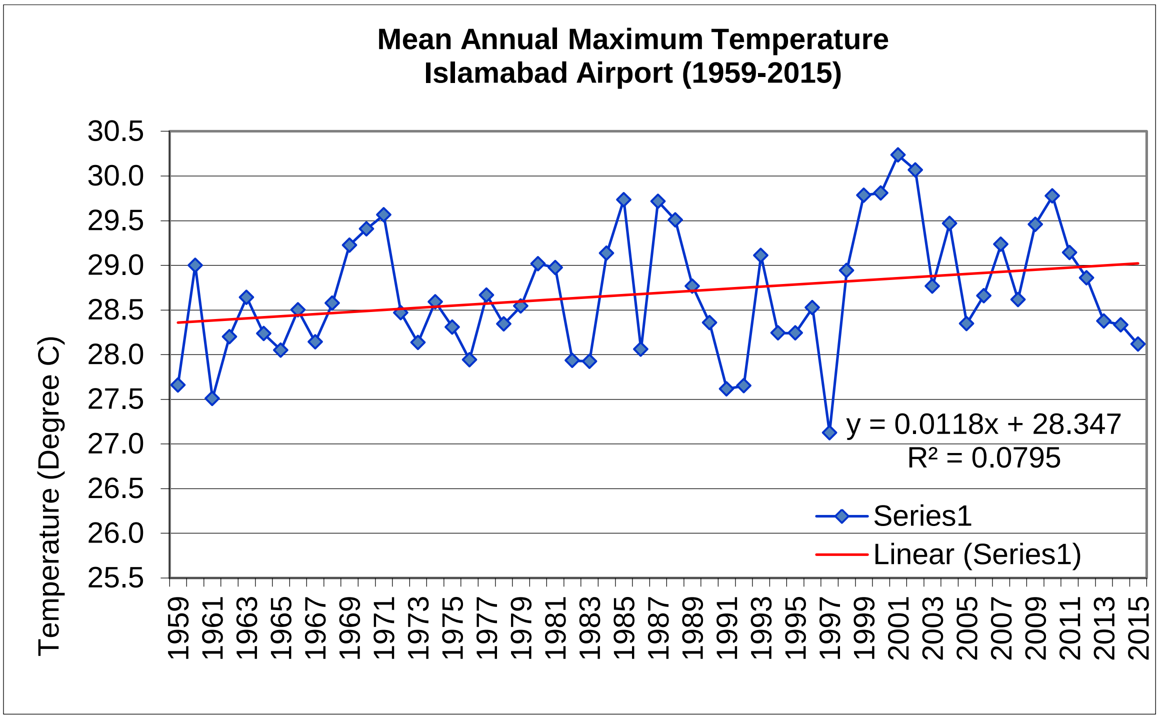


Figure 6.9 Increasing trend in maximum temperature, Islamabad Airport (1959-2017)

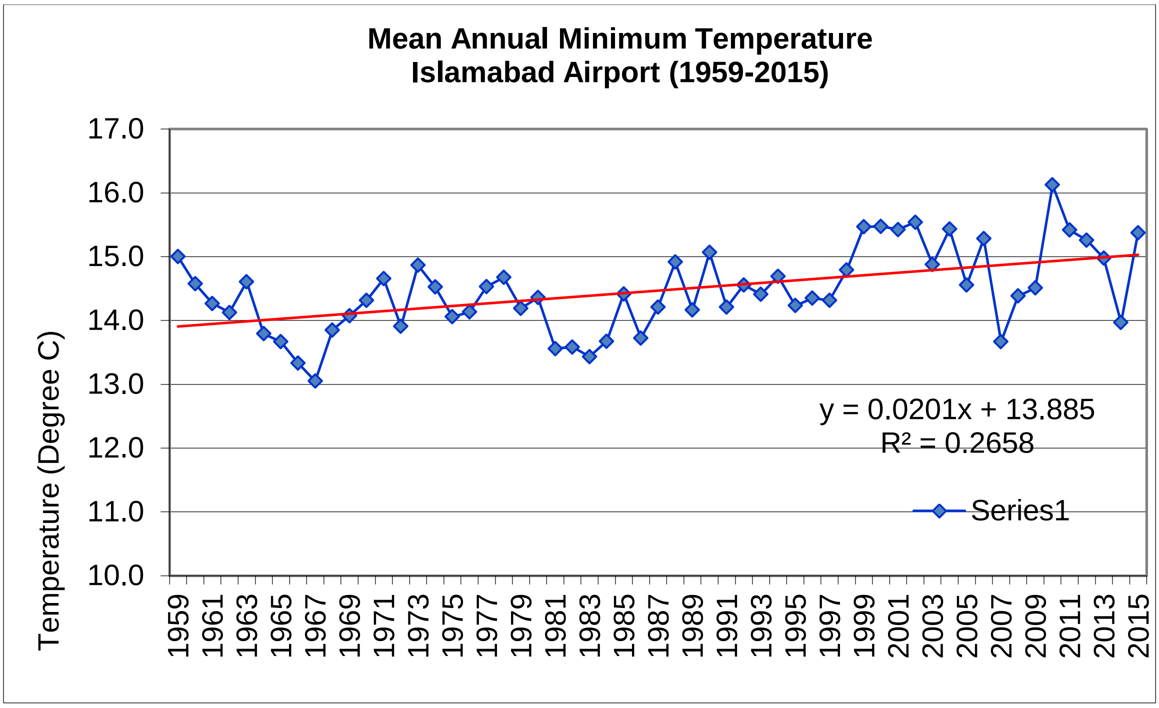


Figure 6.10 Increasing trend in minimum temperature, Islamabad Airport (1959-2017)

6.3 Evapotranspiration

Evapotranspiration plays an important role in term of water losses from rainfall which is the major source of recharge to groundwater in addition to the existing reservoirs/dams around the study area. Data have been obtained from Pakistan Meteorological Department (PMD) by HESC. A mean daily data of evapotranspiration is provided on a monthly basis from 2006 to 2015. Daily evapotranspiration varies between 0.9 mm and 6.8 mm corresponding to a mean annual evapotranspiration of 1283 mm (Table 6.2).

Table 6.2 Meteorological Data of Evapotranspiration (mm/day) Rawalpindi

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	1.3	2	3.4	5.7	6.6	5.2	2.7	2.6	4.3	4.8	3.4	2.1
2007	2	1.3	2.8	5.5	6.8	5.8	3.5	2.3	3.2	4.6	3.7	2.9
2008	2.2	1.6	2.4	5.1	6.2	5.3	4.1	2.6	3.7	3.9	3.9	3.1
2009	2.7	2.3	0.9	3.3	6	6.4	5.9	3.8	2.5	3.2	3.5	3.1
2010	3.2	2.3	2.4	3.2	6.7	6.1	5.5	3.4	2.3	2	3.4	3.2
2011	2.9	2.3	2.4	1.8	3.9	5.9	4.9	4.1	2.7	1.7	2.2	2.9
2012	2.7	2.7	2.7	1.9	2.7	4.6	5.7	4.7	3.2	1.6	1.7	2.3
2013	2.8	2.7	3.5	3.1	2.2	3.9	4.6	4	3.9	2.6	1.4	2.3
2014	2.4	3	3.3	3.2	2.5	2.1	4	5.4	4.2	2.9	1.2	1.3
2015	1.9	3.2	3.7	4.6	4.1	3.4	3.1	4.8	5.4	4	1.8	1.1

Source: Nestle water (2016) Islamabad water factory constructive critical review of hydrogeological reports.

6.4 Groundwater levels

Decline of Groundwater Level

Groundwater in Islamabad is being depleted on a gradual pace. Figure 6.11 shows decline of groundwater levels in Islamabad (1986-2015). This is linked to the unsustainable use of water, increased ground water extraction and reduced water percolation in soil due to urban expansion and increasing population. On average, groundwater is depleting at the rate of 1.7 meters per year. A maximum 20 meters drop in groundwater level was noticed in Gulshanabad Mohallah. The drop in groundwater level correlates positively with the density of the distribution of wells in the area. This not only makes groundwater harder to extract but also decreases the ability of ecosystems in and around Islamabad and the Islamabad Capital Territory to utilize groundwater for their survival. Source: UN-Habitat, 2014

To determine the future anticipated drawdown in groundwater levels, a best fit trend line was drawn through the recorded data. Figure 6.12 shows anticipated decline of groundwater levels in Islamabad up to 2025. It is inferred from the graph that approximately, the water table will be depleted up-to 46 m (151 feet) in 2025.

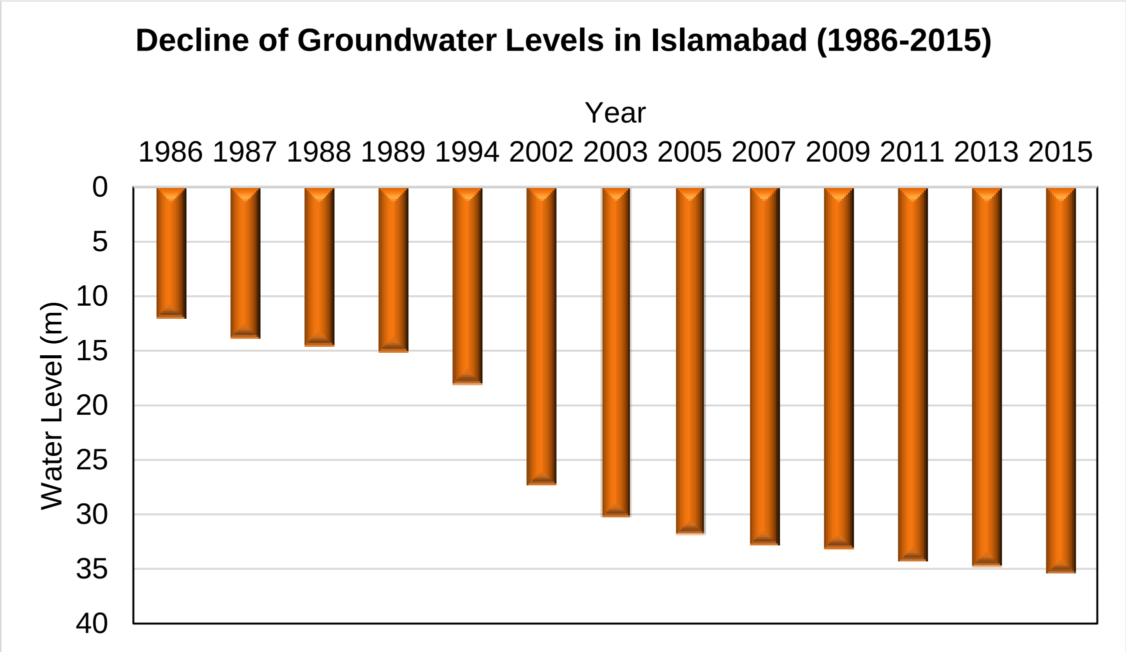


Figure 6.11 Declines of Groundwater Levels in Islamabad (1986-2015)

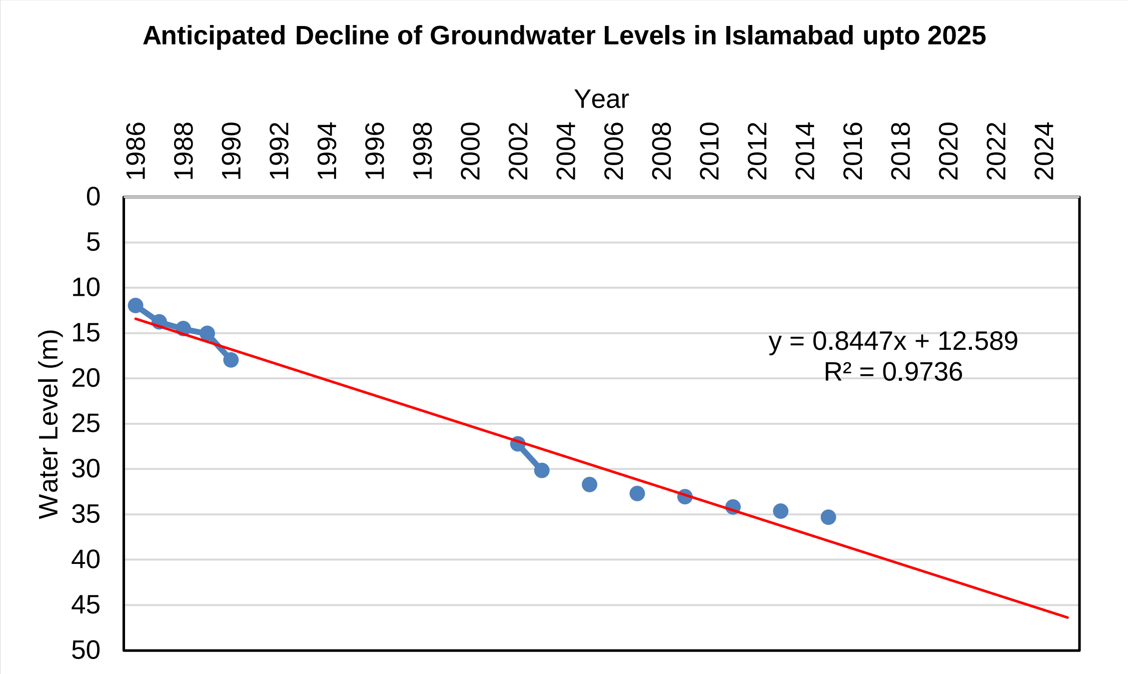


Figure 6.12 Anticipated Decline of Groundwater Levels in Islamabad up to 2025

6.5 Surface Geology

The study area is located in the Pothwar plateau of Pakistan. In the north and northeast, it is bounded by the Margalla and Murree hills, which are covered with mixed scrub and coniferous forest. The dominant formations (e.g., the Murree and Kamlial belonging to the Rawalpindi Group of Miocene age) are composed of sandstone, shale, and lenses of conglomerates. The Lei Nullah conglomerates of Quaternary age consist of poorly sorted pebbles and boulders mostly of Eocene limestone strata Allchin (1981).

6.6 Subsurface Geology and Aquifer Strata

The aquifers are mostly composed of gravels and boulders in the unconsolidated sediments of Pleistocene and Recent age. Alluvium (the channel-fill deposits) consists of dominantly silt and clay with subordinate amount of gravel and sand. The soils are mainly gravelly, medium to fine textured over calcareous material in the north and northeast and medium to coarse textured over sandstone in the south.

Stratigraphy and groundwater elevation in Islamabad/Rawalpindi area was discussed by Abbas et al. 2012. Figure 6.13 shows the line (DD') along which subsurface aquifer strata were drawn. Figure 6.14 shows ground surface (red line) and water table levels in 1998, 2003 and 2007. Local recharge from Lei nullah is obvious along cross section line DD' in Bangash colony near Bokra Road (Abbas et al., 2012)

The cross section (Figure 6.15) shows a thick clay layer sandwiched between first and second aquifer layer which are composed of boulder/gravel. *Thick clay layer could be one possible reason of fast depletion rate of water table in eastern locations along the Murree road.* (Abbas et al., 2012)

Hydrogeologic frame work of Islamabad/Rawalpindi area was studied by Ahmad et al. (2016). Their studies reveal that silt and clay dominate the subsurface lithology where boulder/gravel deposits are present in discontinuous layers with silty clay. The gravel beds are generally 1–20 m thick and are composed of limestone and sandstone pebbles mixed with sand.

Figure 6.13 Location of Section D-D' of subsurface x-section

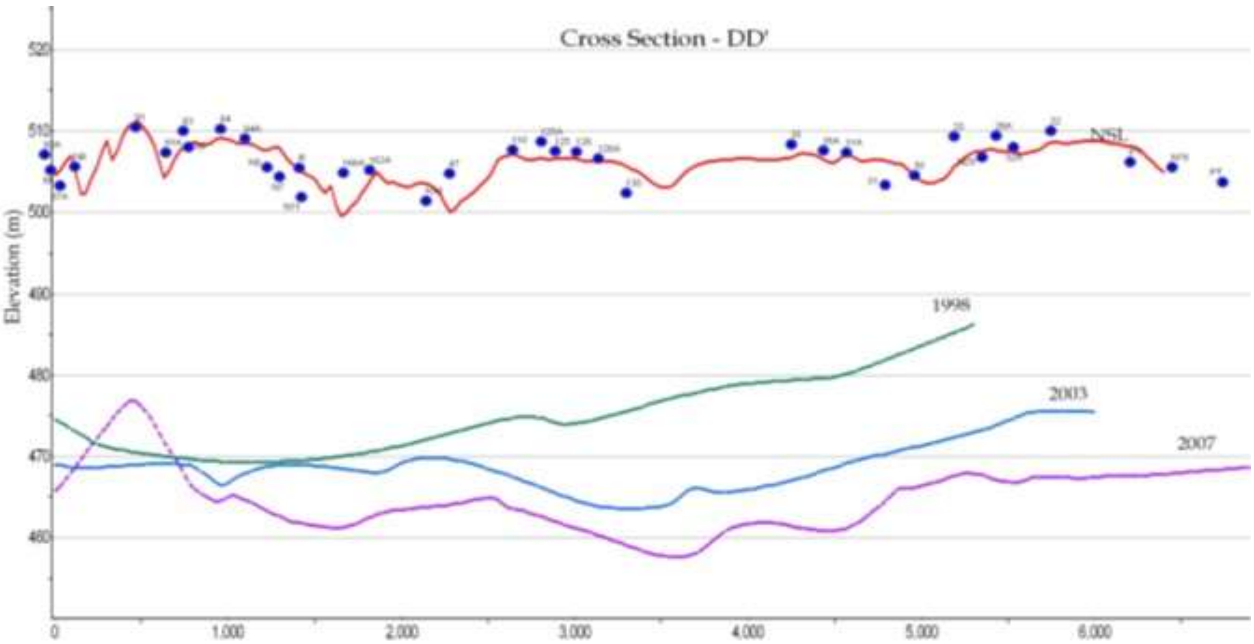


Figure 6.14 Ground surface (red line) and water table levels in 1998, 2003 and 2007 (Source: Abbas et al., 2012)

Subsurface Lithology

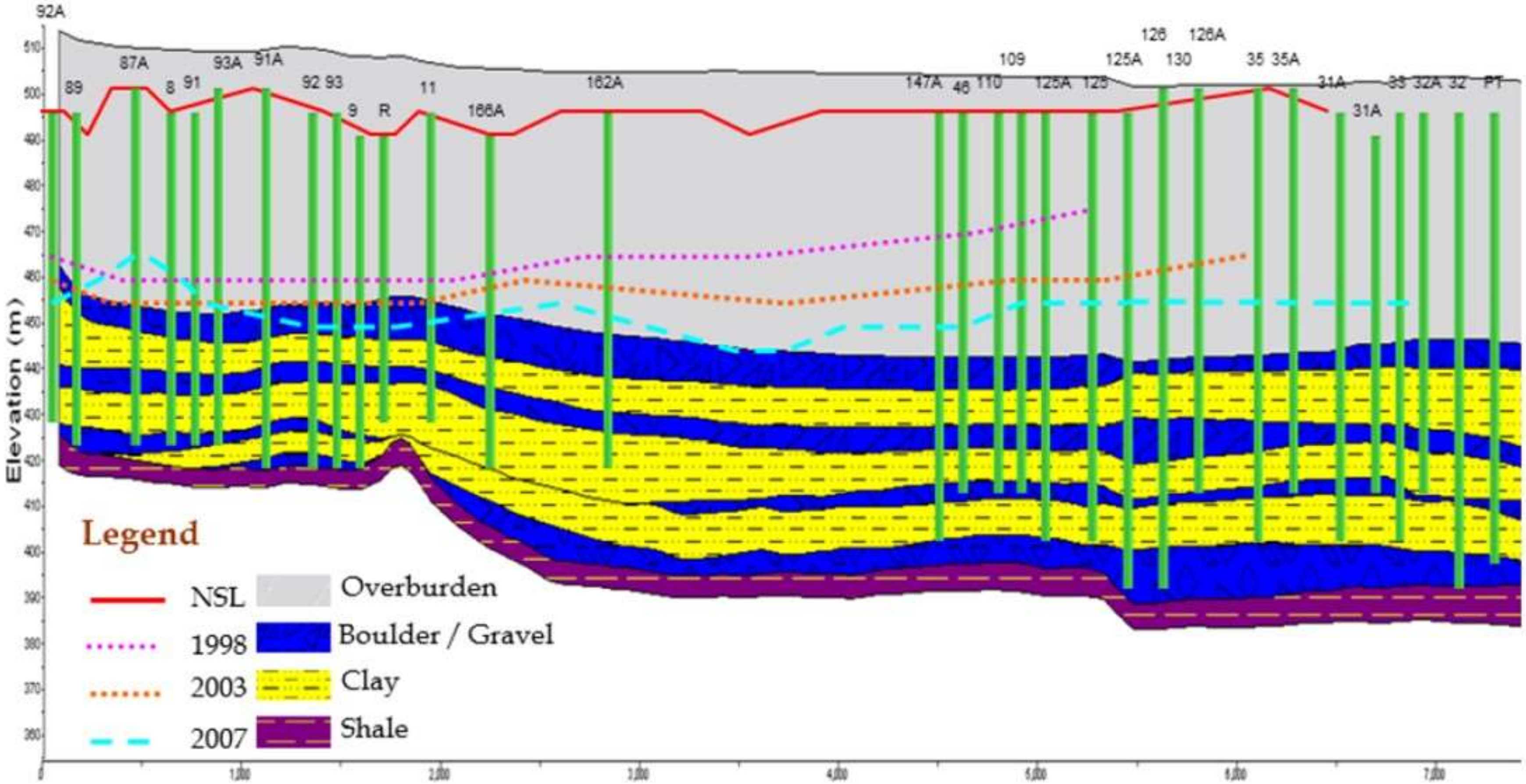


Figure 6.15 Stratigraphy and Groundwater Elevation along Cross Section (DD'), (Source: Abbas et al., 2012)

6.7 Tectonic Features/Faults and Stratigraphy

The information in this section is extracted from already published material (Ali, 2014). The geological structural of the study area is mainly controlled by the Main Boundary Thrust (MBT) (Figure 6.16). Ali 2014 carried out detailed study of geology/tectonic of Margalla hills. The fault plays an important role in the fracturing of the rocks and consequently a source of recharge to groundwater. After the Main Mantle Thrust (MMT), MBT is the major south verging thrust stretching in east-west direction starting from Afghanistan in the west and across Pakistan enters into India towards east. It occupies the topographic front of the southern Hill ranges of the Lesser Himalaya in North Pakistan and is found to be juxtaposing the Jurassic to Paleocene age platform strata of the Indian Shelf over the Miocene sediments of the Sub Himalaya derived mainly from the erosion of High Himalaya. The Main Boundary Thrust occupies the base of Margala Hills in the south (Figure 6.17). The hanging wall stratigraphy of MBT at Shah Alladitta is comprised of a thin succession of Samana Suk Formation overlain by Chichali, Lumshiwal, Kawagarh Formation which is unconformably overlain by the Hangu and Lockhart Formations of Paleocene age along the KT Boundary. The Paleocene sequence is in turn overlain by Margala Hill, Chorgali and Kuldana Formation of the Eocene age (Ali, 2014).

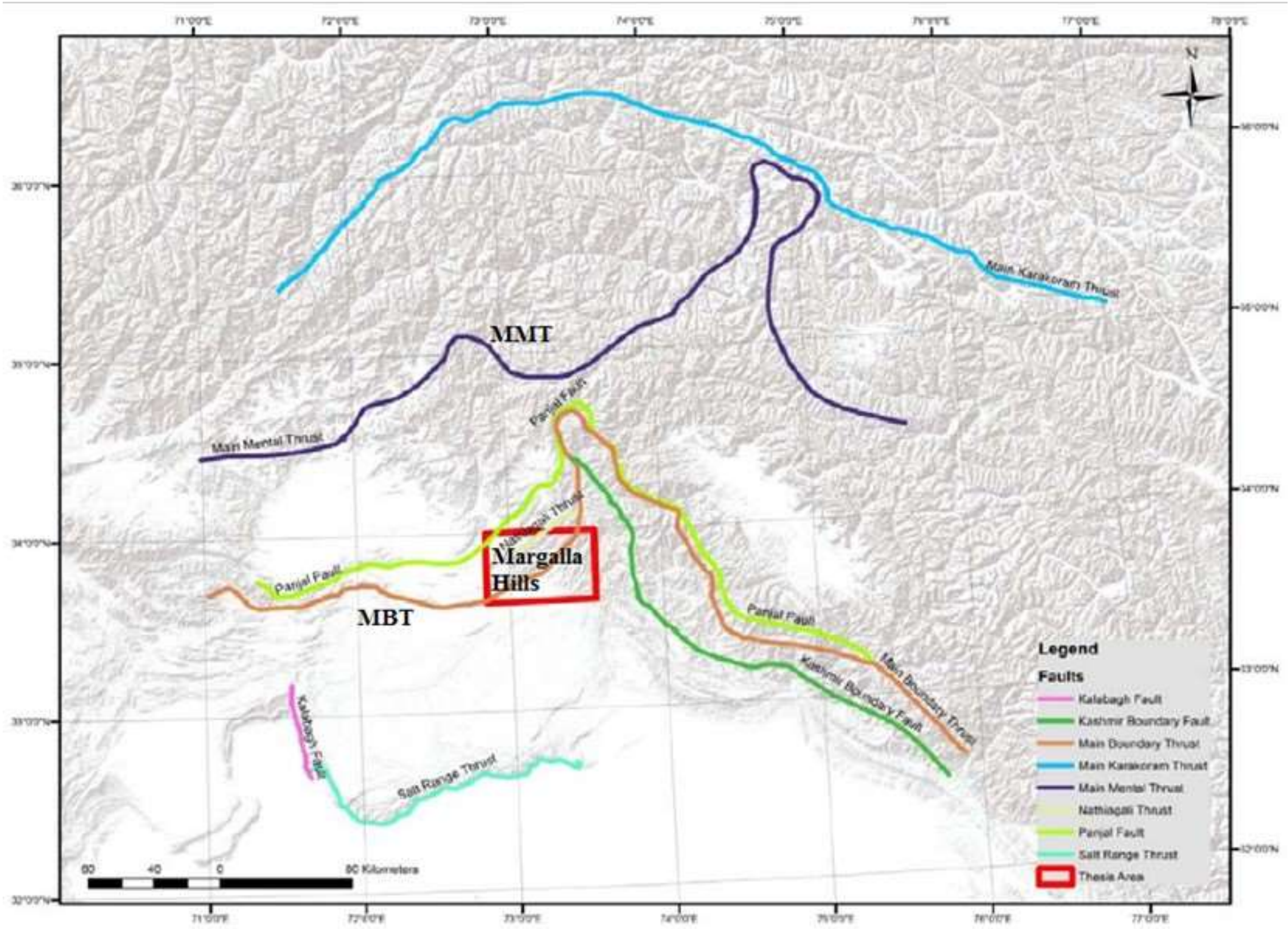


Figure 6.16 Tectonic features of the region, study area (source: Ali, 2014)

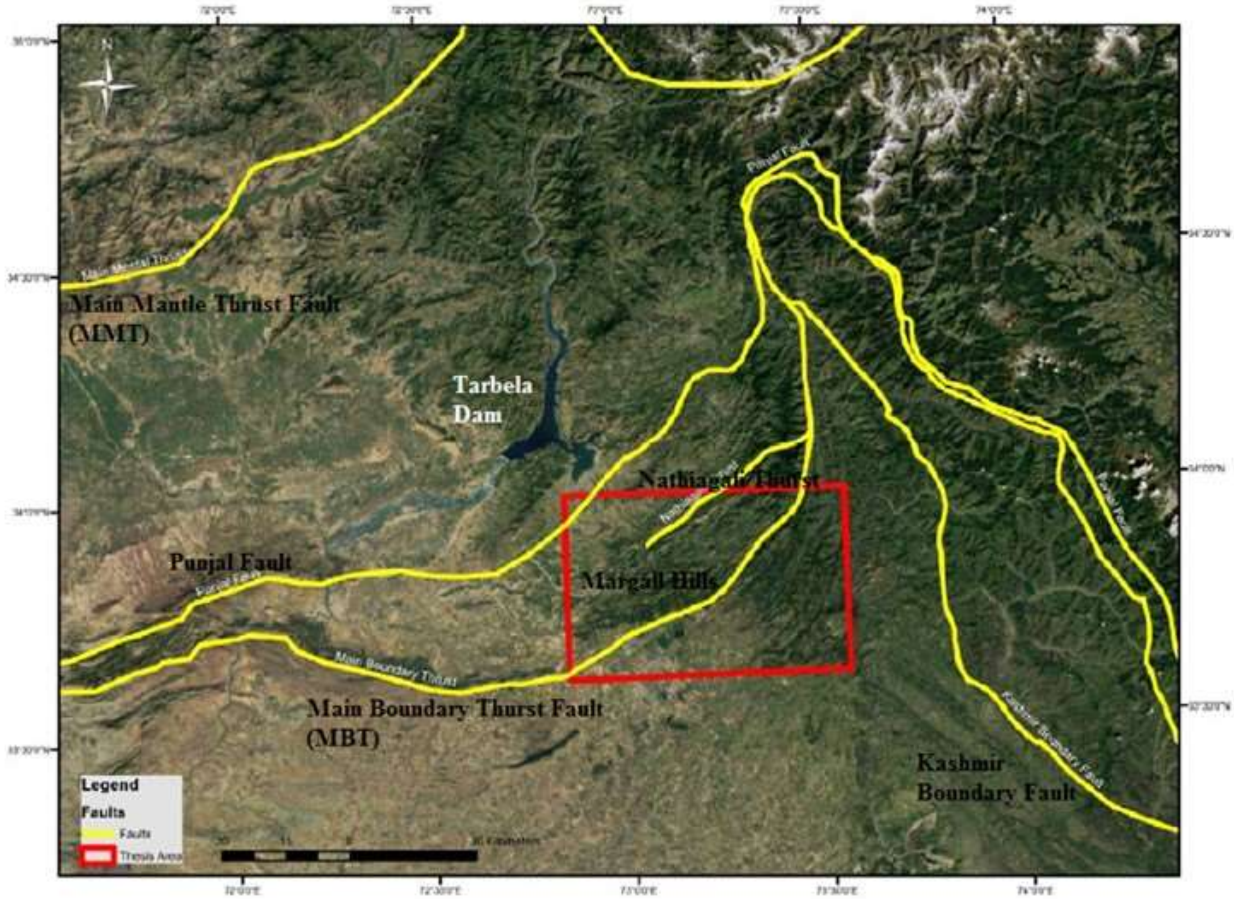


Figure 6.17 Land cover Google map and tectonic features of the region, study area (source: Ali, 2014)

6.8 Topography and Slopes

Topographic map with the help of 30m DEM (acquired from Earth Explorer using Aster data) is further constructed / prepared in ArcGIS and shown in Figure 6.18. The map shows the characteristics of slopes and facilitates in finding the direction of surface runoff. Highest elevation was observed at top of Margalla Hills. Figure 6.19 shows the topography in watershed area of Trail 5 in Margalla Hills. Topography of the area indicated that part of runoff from these small streams in Margalla hills may be used to cater rainfall/spring water to recharge depleting groundwater with the help of check dams. Therefore area at Trail 5 and adjacent Trail 3 was studied in details by field work, satellite data and processing in GIS. Maps showing topographic contours in Trail 5 and adjacent/nearby streams are shown in Figures 6.20 and 6.21.

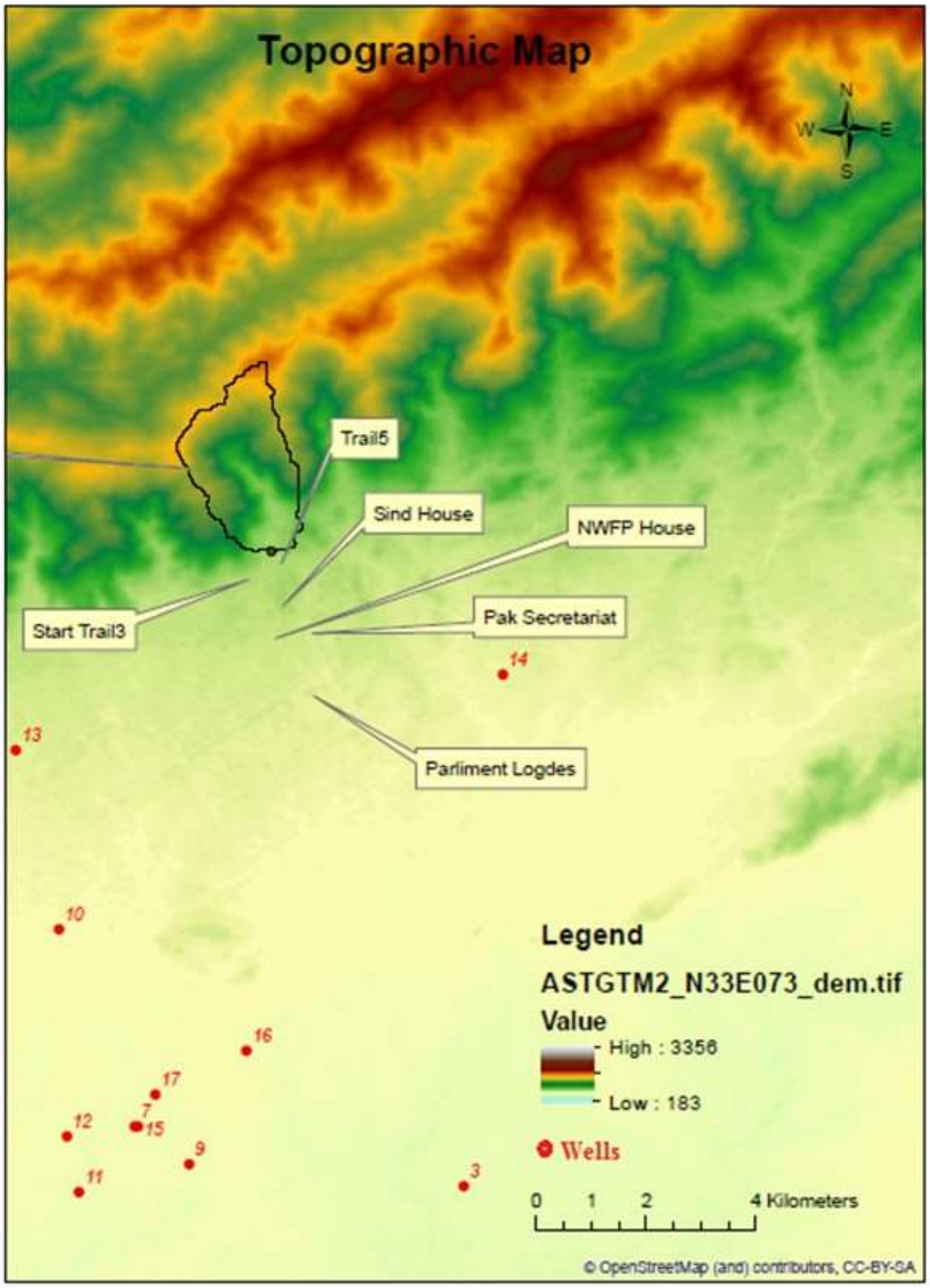


Figure 6.18 Map showing topography in the study area with the superimposition of watershed over Trails 5 and 3

Map Showing Topography, Trail 5

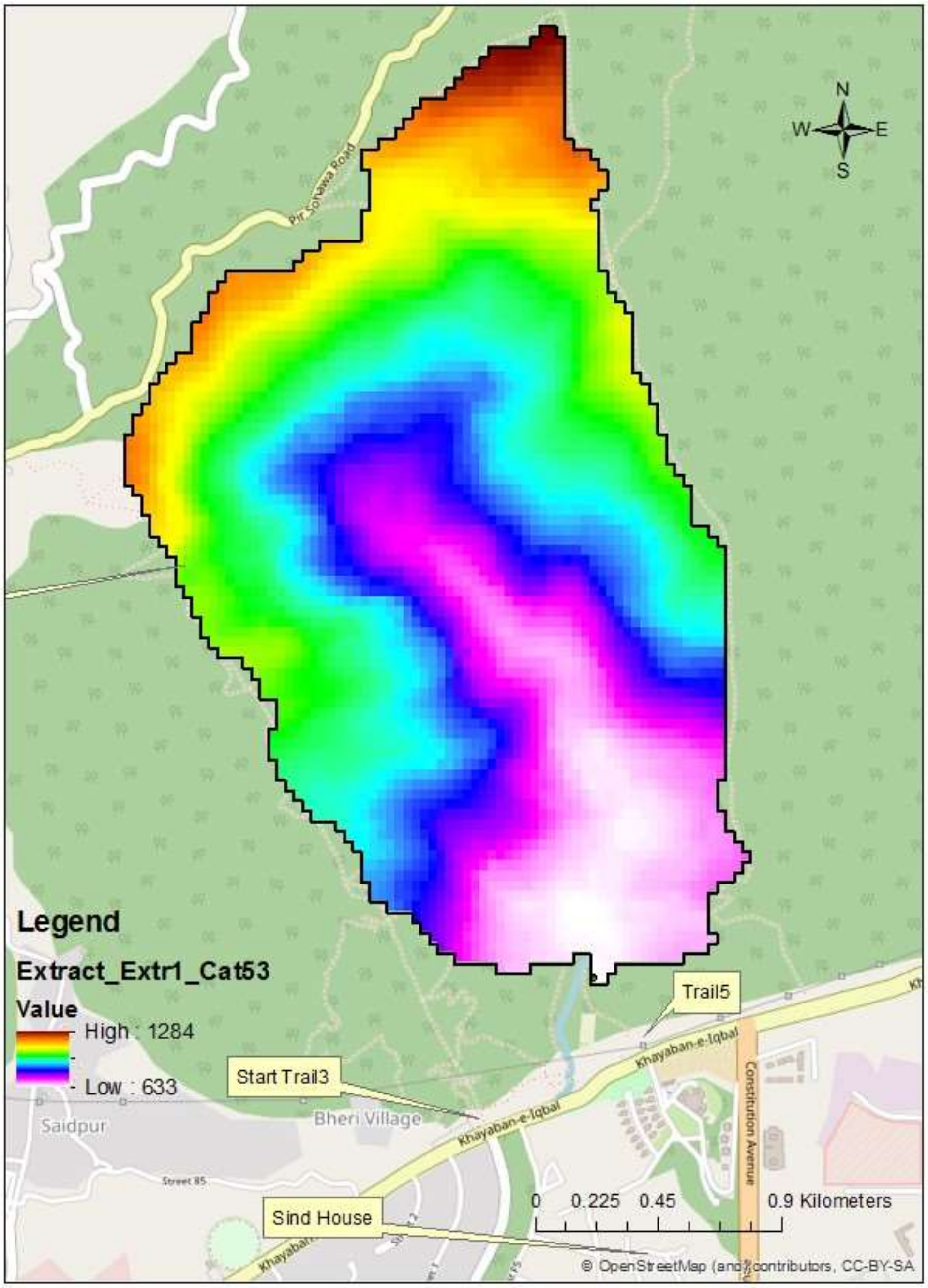


Figure 6.19. Map showing topography in watershed, Trail 5

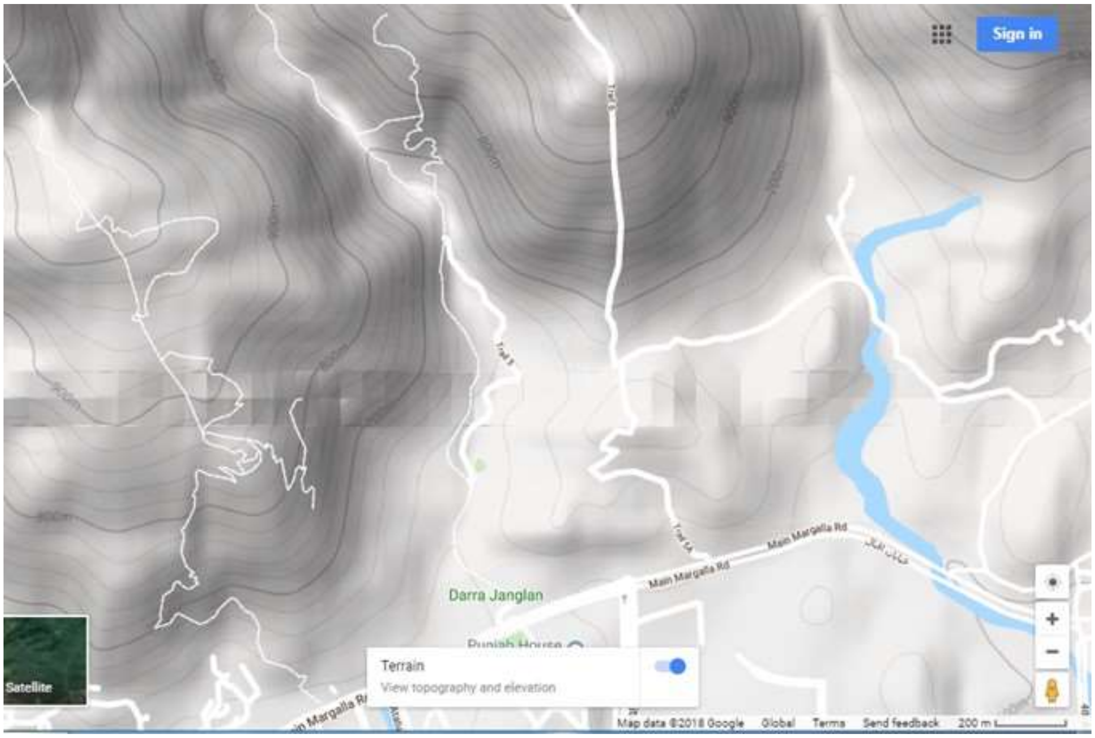


Figure 4.20. Map showing topographic contours, Trail 5 (source: Google 2018)

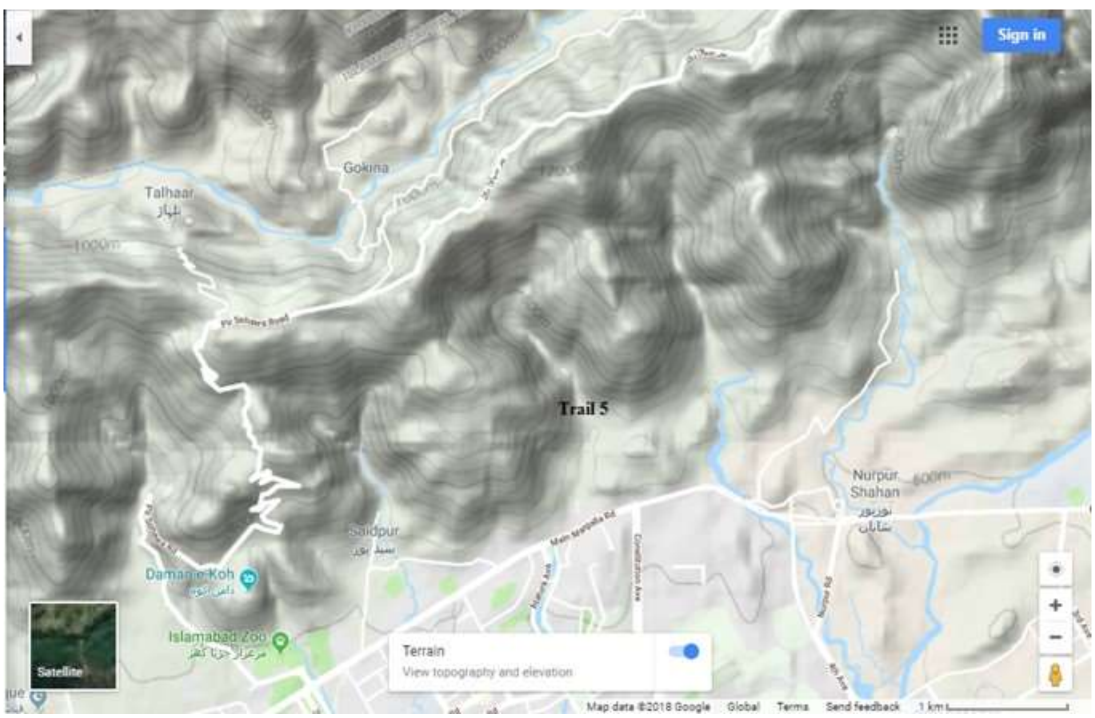


Figure 4.21. Map showing topographic contours, Trail 5 and adjacent streams (Source: Google 2018)

6.9 Physiography, Land Use and Soil Type

The following material is taken from previous published material (Ahmad at al. 2016, and JICA, 2003). On regional scale, the area may be divided into four physiographic zones.

- the Margalla Hills,
- the Higher Plain,
- the Lower plain,
- the Valley area.

Margalla hills are located in the North of the area. The dominant formations are composed of sandstone, shale, and lenses of conglomerates and are covered with permanent mixed scrub and coniferous forest. The ground elevation is up to 1240 m at the upstream end. There are three major tributaries of Lai Nullah namely Saidpur Kas, Tenawali Kas and Bedarawali Kas, which originate from the Margalla Hills forming a very steep channel bed slope of about 1/10.

The higher plain expands over the built-up area of Islamabad City with a gradual slope from North to South. Saidpur Kas, Tenawali Kas and Bedarawali Kas run southward in the plain and finally flow into Lai Nullah just upstream of Kattarian Bridge.

The lower plain extends over the upper part of the Rawalpindi area above Chaklala Bridge. This area is flatter than the upper Higher Plain and the lower Valley Area forming a bowl-shaped topography. Rawalpindi city area is covered with alluvium and eolian deposits and is part of dissected basin plain formed by Lai Nullah and its tributaries.

The valley area is located below Chaklala Bridge. The valley area, falling down to the Soan River is composed of gravel/boulder and sand/silt (JICA, 2003).

Soil Type

Alluvium (the channel-fill deposits) consists of dominantly silt and clay with subordinate amount of gravel and sand. The soils are mainly gravelly, medium to fine textured over calcareous material in the north and northeast and medium to coarse textured over sandstone in the south. Due to high urban sprawl, a major area has been converted into various degrees of built-up category (Ahmad at al. 2016). Land use maps are presented in section 7.

6.10 Hydraulic Conductivity/Porosity of Aquifer Material

Aquifer material is composed of gravel, sand, sandstone and limestone with clay layers. Typical values of specific yield of gravel, sand, sandstone and limestone are 19, 22, 18 and 6% respectively. Porosity varies between 6-22%. Hydraulic characteristics obtained from the analysis of pumping test data are provided in Table 6.1. The mean water table depth was 28 m.

Table 6.1 Hydraulic characteristics of the aquifer in the study area.

Test hole	**Easting**	**Northing**	**Transmis-sivity**	**Permeab-ility coeff.**	**Storage coeff.**	**Specific capacity**
			m2/s	**m/s**		**m3/day/m**
TH-1	3214782	1053687	1.50E-02	5.60E-04	7.00E-02	607
TH-6	3211368	1048417	3.60E-03	1.50E-04	2.00E-03	116
TH-8	3212866	1047817	1.40E-03	6.90E-05	2.00E-04	116
TH-9	3212299	1049052	1.30E-02	4.60E-04	5.00E-02	840
DW-02	Nestle Factory I-10/3		4.68E-03	4.92E-05	-	-
DW-03	Nestle Factory I-10/3		1.00E-03	5.90E-04	-	-

Source: Ahmad et al., 2016 and Nestle, 2018

6.11 Existing Streams, Rivers and Lakes for recharge

On regional scale the main perennial stream in the area is the Soan, whose primary tributaries are the Ling, Gumrah Kas, Korang, and Lei Nullah. Figure 6.22 shows stream network in Margalla hills and Islamabad. Table 6.2 gives the catchment areas of these streams. Three dams Simly, Khanpur and Rawal dams are supplying water in the area. (Figure 6.23). Figure 6.24 presents stream network in Trail 5 and adjacent area.

Table 6.2 Catchment areas of the streams located in Islamabad

Location of Confluence with Main Stream	No. and Name of Tributary		Catchment Area (km^2)
	No	Name	
Islamabad	-	Saidpur Kas	24.7
	-	Tenawali Kas (Including Kanitawali Kas as the secondary tributary)	39.7
	-	Bedarawali Kas (Including Johd Kas as the secondary tributary)	79.9
	Sub-total		144.3

Data Source: JICA 2003

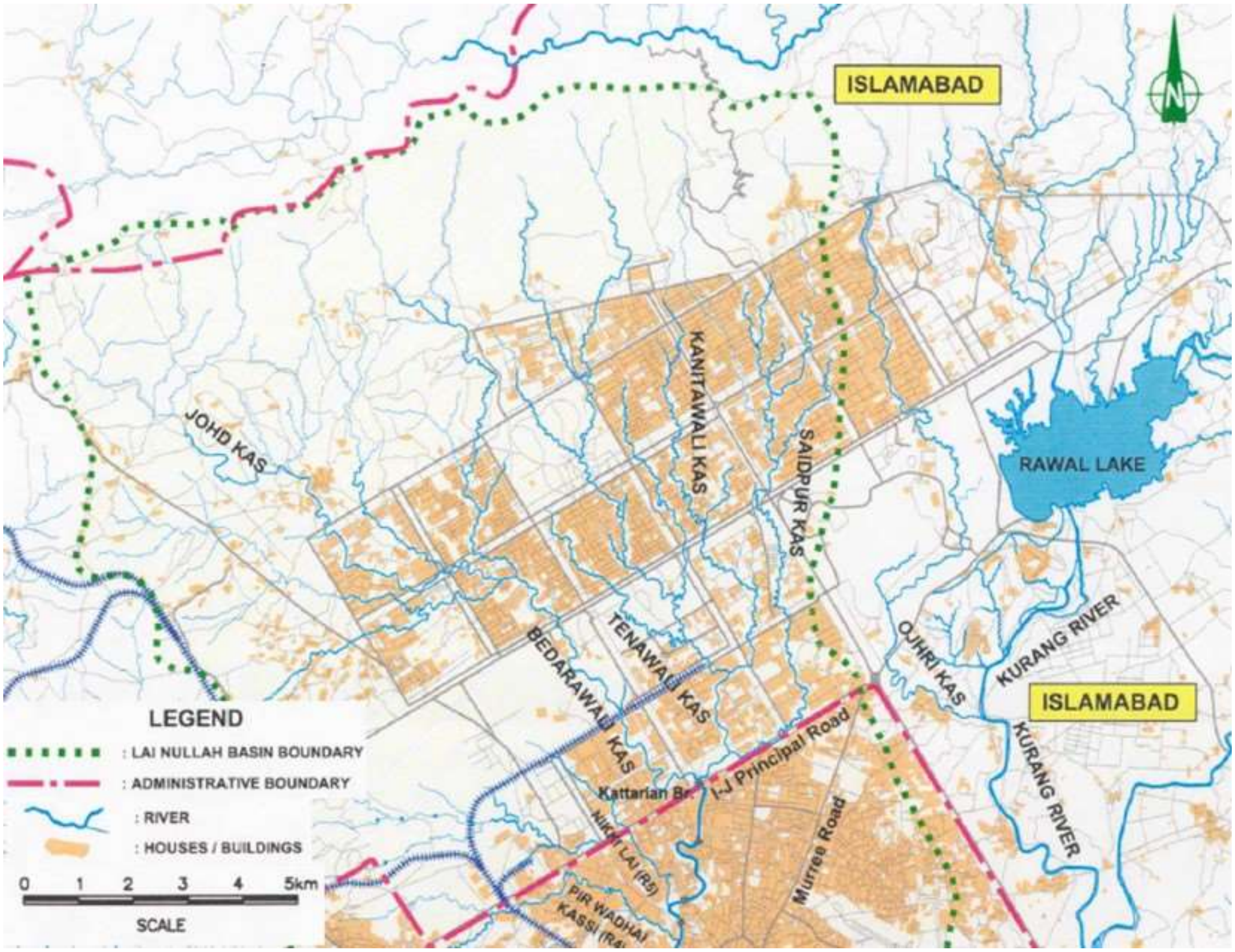


Figure 6.22 Stream network in Margalla hills and Islamabad. (map source: JICA, 2003)

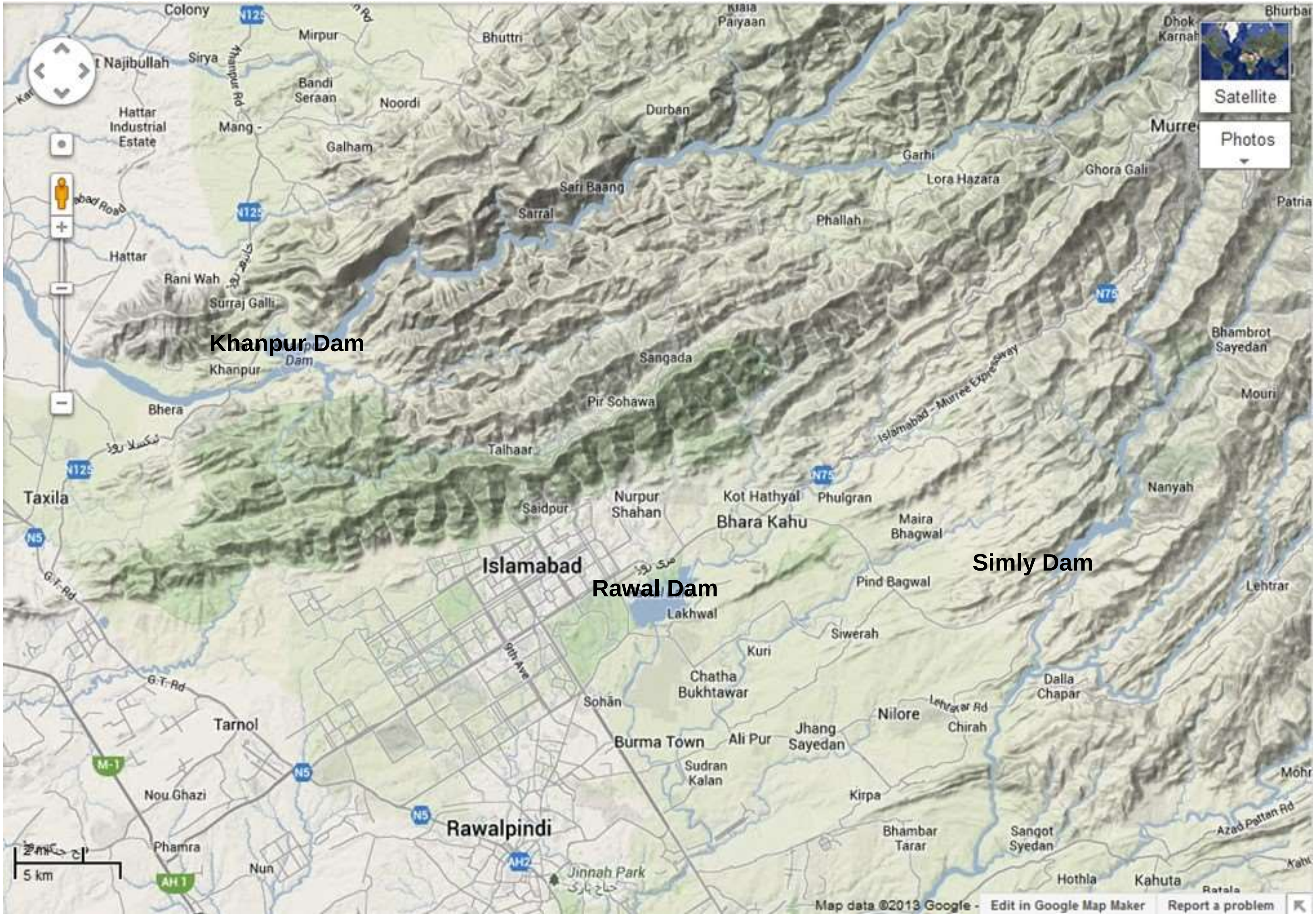


Figure 6.23 Location of Simly dam, Rawal dam and Khanpur Dam (water supply sources) in Islamabad. Map source: Google Maps

Map Showing Location and Stream Lines

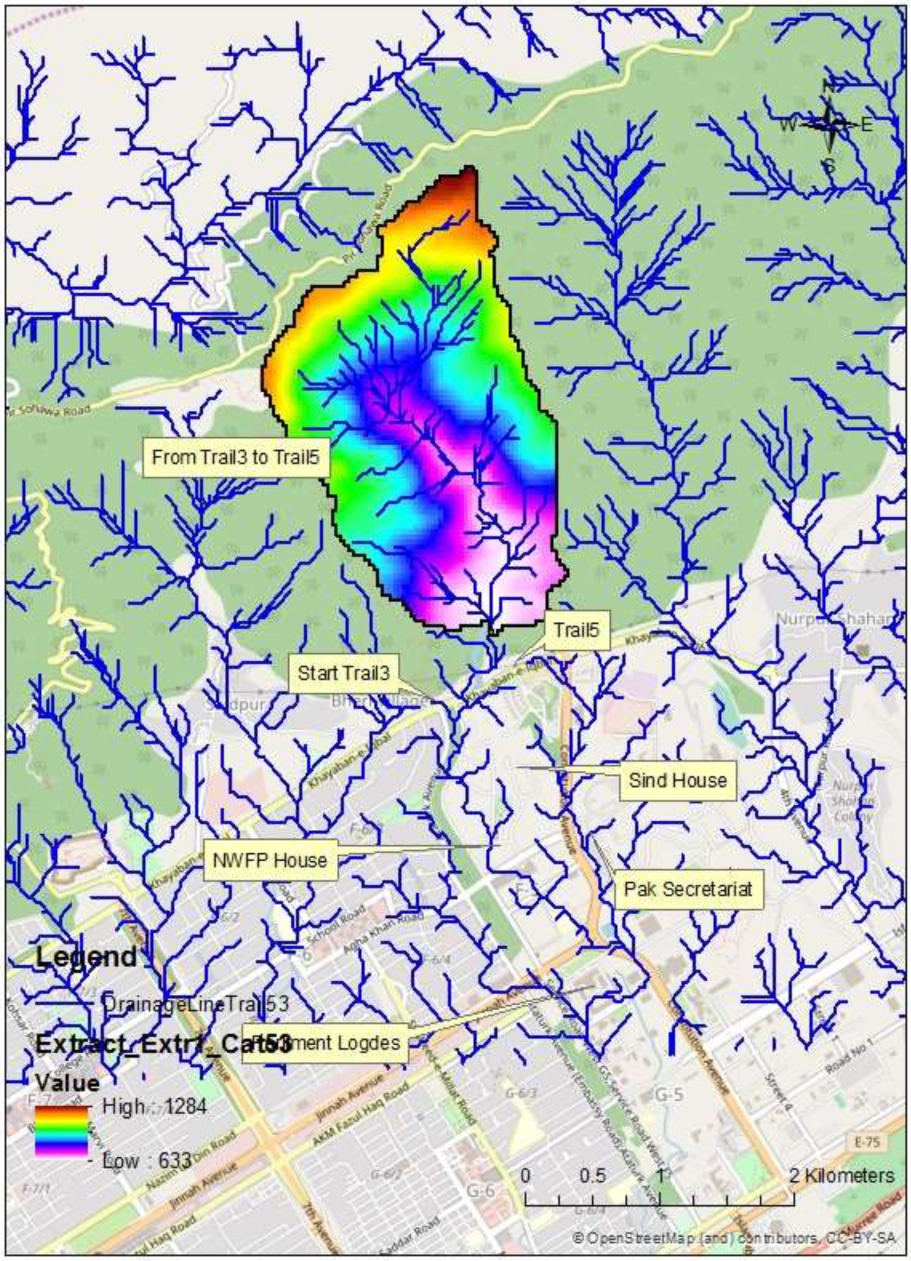


Figure 6.24 Stream network in Trail 5 and adjacent area

Zones of water supply in Islamabad as reported by CDA are divided into three parts (1) Simly zone, (2) Khanpur zone and (3) Tubewell zones. Zones of water supply are marked on Figure 6.25. (Source: CDA 2013). Supplies from Rawal Dam are not marked on the map as major part is given to Rawalpindi area.

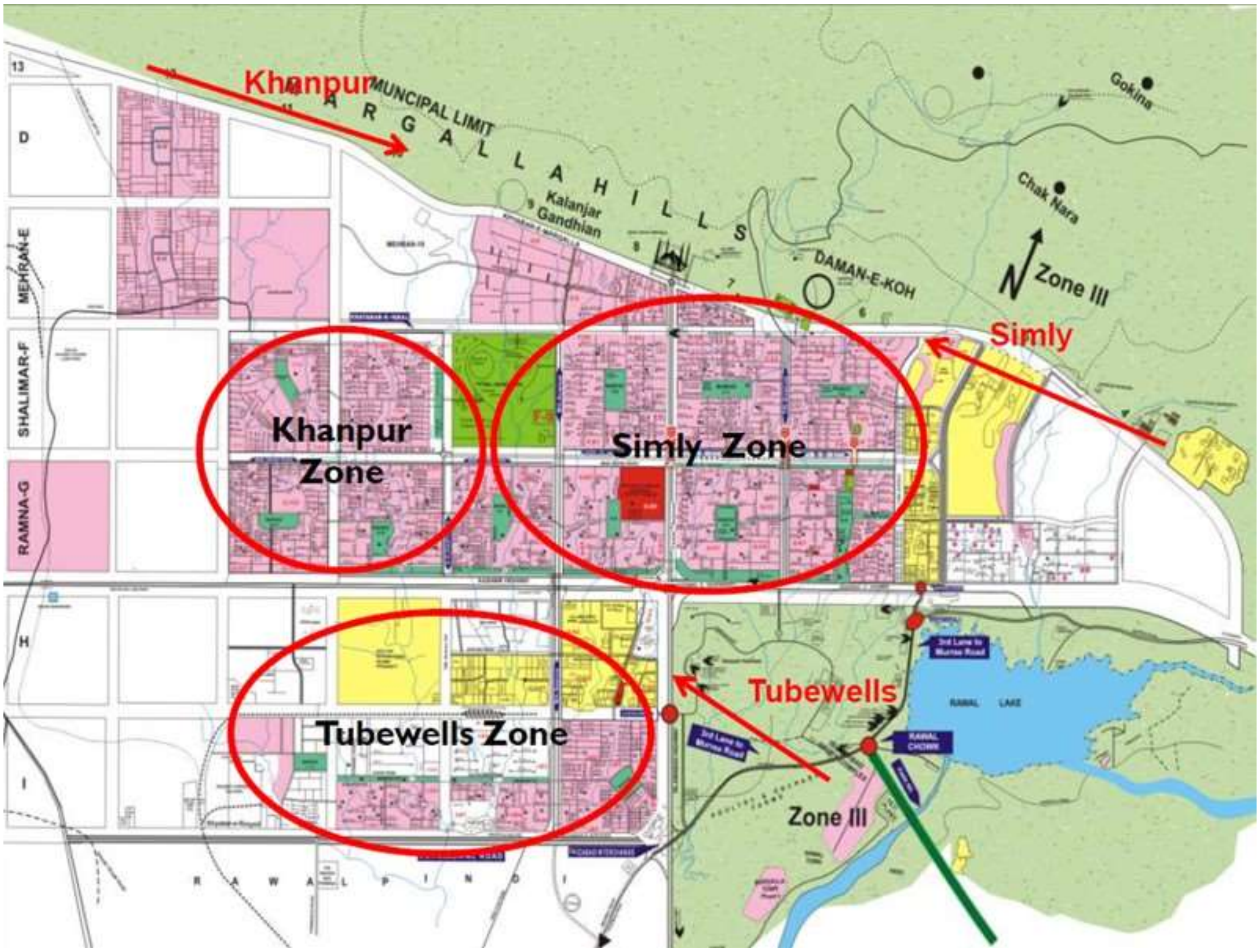


Figure 6.25 Zones of water supply in Islamabad as reported by CDA (Source: CDA 2013)

6.12 Potential Sites for Check Dams for Recharging Aquifer

The area was surveyed in detail to find potential sites for replenishment of aquifer. Reconnaissance survey in Trail 3 found that there is no suitable site in Trail 3 for check dams based in topographic condition in this area. Trail 5 was found more suitable for check dams to recharge the groundwater. Figure 7.1 shows the location of identified sites for check dams for future development of the area. Figure 6.26 shows the proposed check dam No.1. **Annexure-1** includes the data collected during present study.

(a) (b)

Figure 6.26 (a) Proposed check dam site 1, (b) Emerging point of nearby spring

7. Hydrological Design for Groundwater Recharge

7.1 Catchment Area

To find the water potential of the area, survey was carried out to select promising location for future groundwater development in the area. In Margalla Hills, Trail 5 was found promising for construction of check dams, which may be a good source to replenish the aquifer. Catchment area of the Trail 5 was determined with the help of GIS method using ArcGIS software. Figure 7.1 shows the catchment area with stream network and topography of the area. Catchment area of Trail 5 stream is worked out to be 3.303 km^2. Highest elevation towards north boundary of watershed is 1284 m AMSL, while lowest is 633 m AMSL towards south. The area along Trail 5 was surveyed in detail. Two check dams are proposed below the existing springs to cater more water for recharge (Figure 7.1). Figure 7.2 shows the location of springs, existing and proposed check dams in

Trail 5.

On regional scale, the area lies in Soan watershed which covers an area of about 1684 sq km with its longitude 72° 54~–73° 34~ E and latitude 33° 26~–33° 56~ N in the Pothwar plateau of Pakistan. In the north and northeast, it is bounded by the Margalla and Murree hills, which are covered with permanent mixed scrub and coniferous forest (Ahmad et al., 2016).

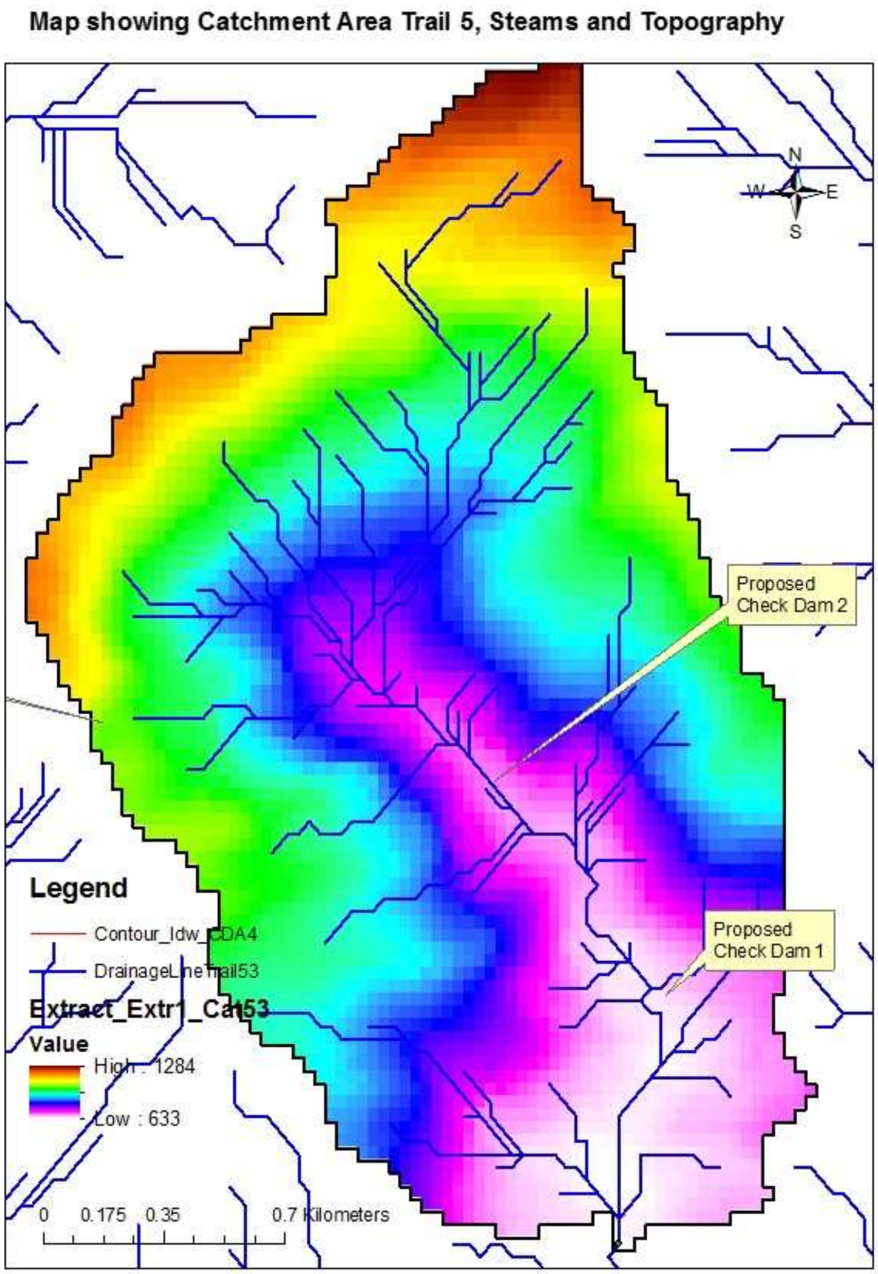


Figure 7.1 Catchment area of Trail 5

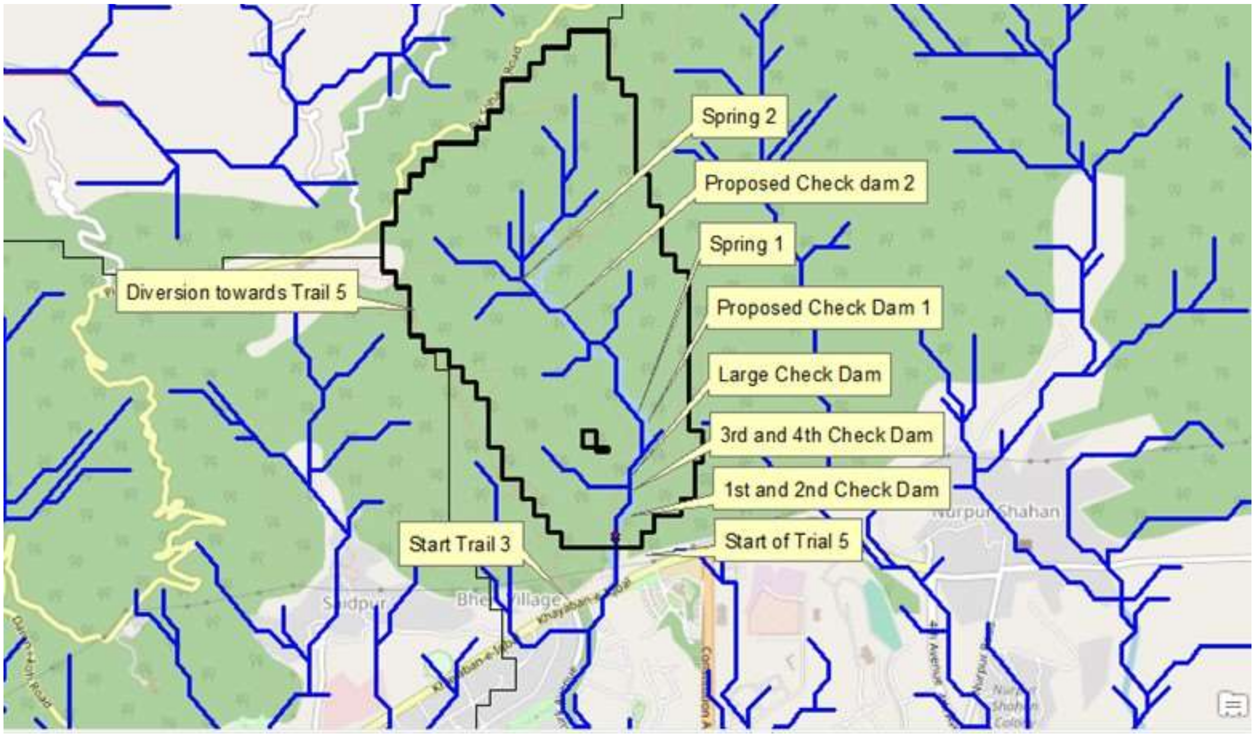


Figure 7.2 Location of springs, existing and proposed check dams in Trail 5

7.2 Estimation of Runoff

The main source of runoff in the area is the rainfall. Other factors, such as catchment area, slopes/topography, and land cover plays an important role for runoff generation. Therefore map of ground surface contours is prepared to mark the suitable locations for check dams / injection wells (Figure 7.3). To determine the runoff of trail 5 where check dams are proposed, map showing ground surface contours in catchment area of Trail 5 is prepared and presented in Figure 7.4.

Map showing Ground Surface Contours proposed Check Dams / Injection Wells

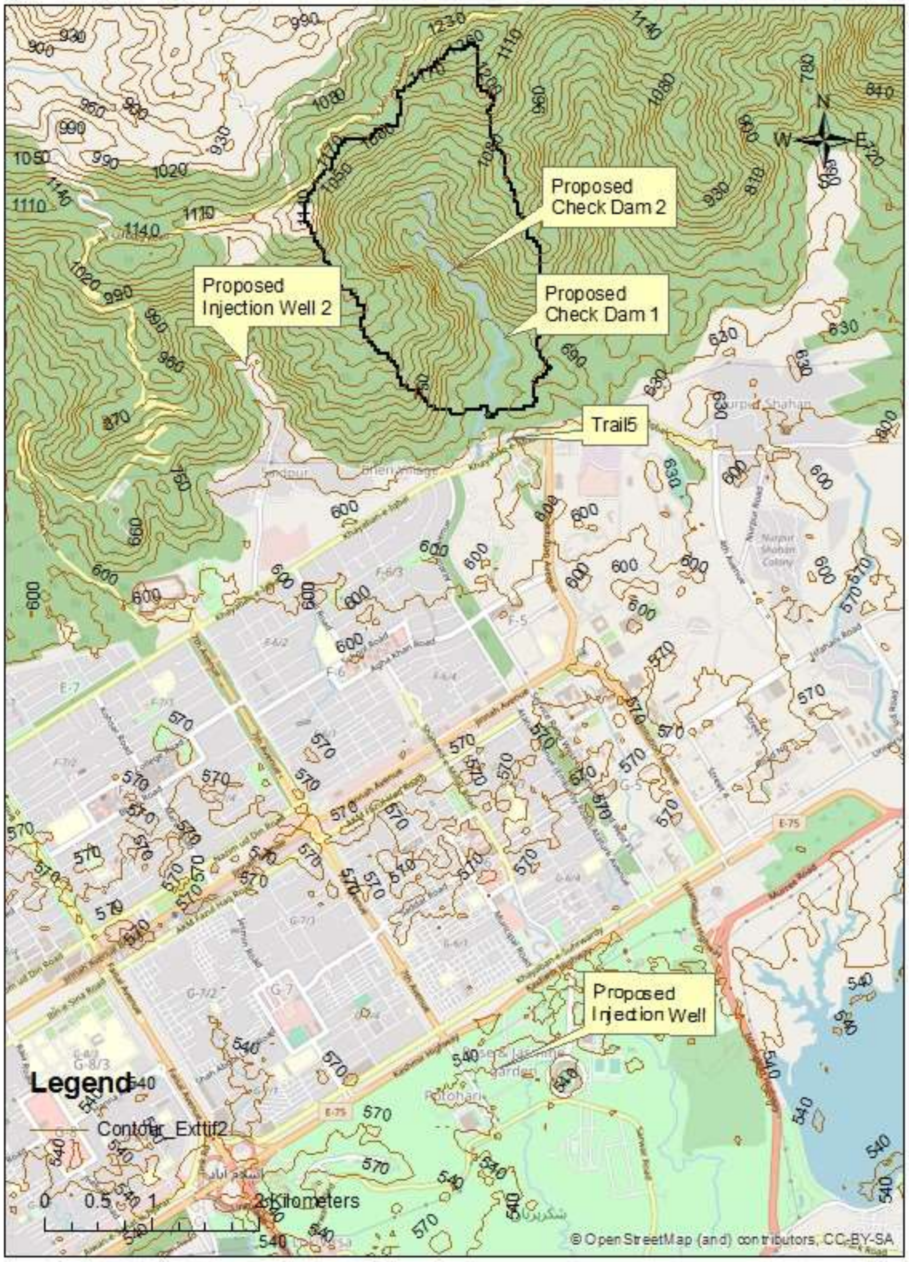


Figure 7.3 Ground surface contours and proposed check dams / injection wells (contour interval 30 m)

Map showing Ground Surface Contours and Stream network in Catchment Area Trail 5

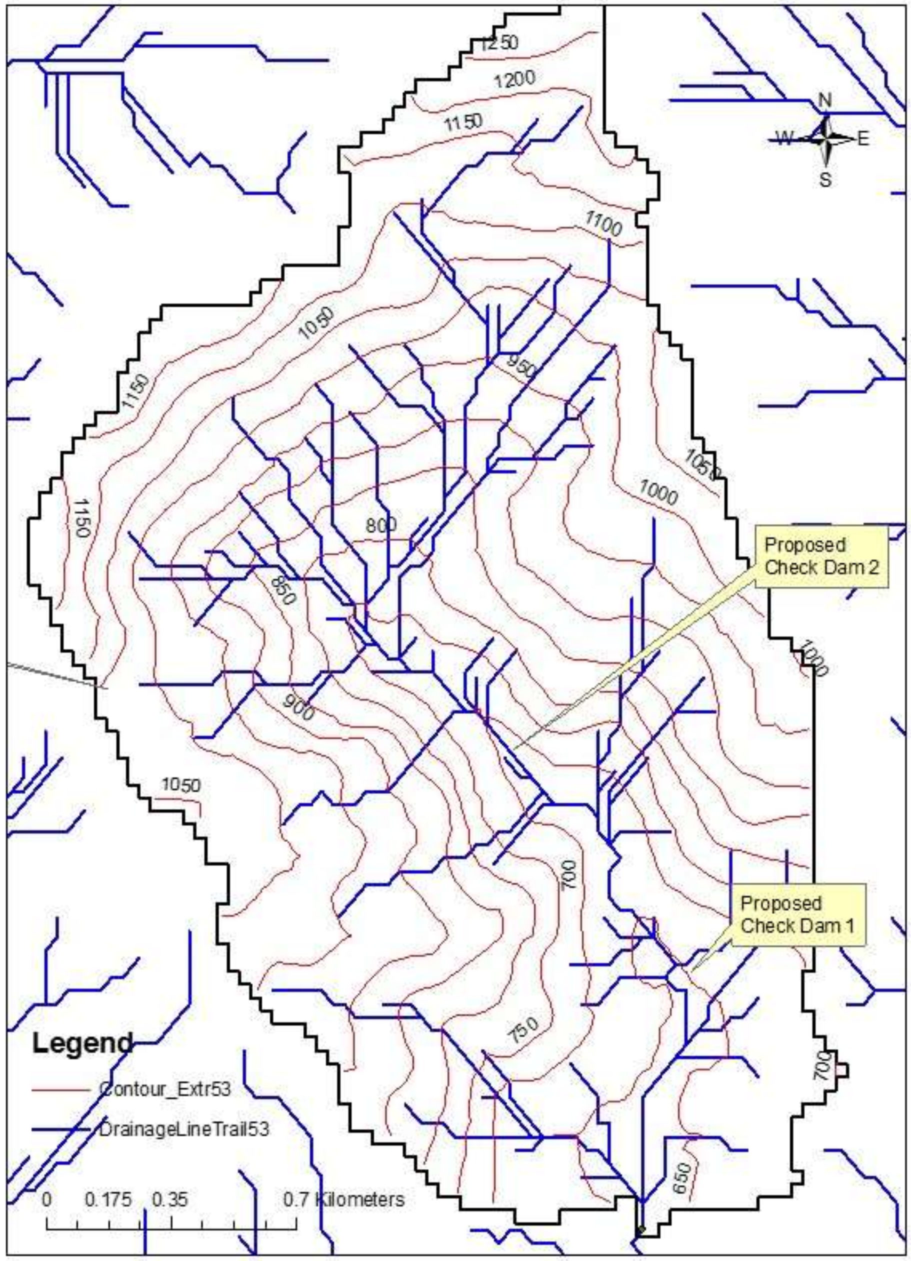


Figure 7.4 Ground surface contours in catchment area of Trail 5 (contour interval 50 m)

Runoff Estimation from Rainfall Data

Small Dam Organization (SMO) of Irrigation Department constructed a lot of small dams in Pothwar region. JICA with SMO developed empirical relationships in the area to determine runoff from rainfall data.

The equation is:

.

$$\mathbf{Q = C_1 (P + C_2)^{C3}}$$

Where: Q = Monthly runoff (mm)

P = Monthly rainfall (mm)

C_1, C_2 and C_3 are constants.

The traditional equation used by the SMO for various dams is as below:

$$\mathbf{Q = 0.00922 (P + 21.30)^{1.60}}$$

The method has been successfully used by Small Dam Organization (SDO) for the runoff estimation in Pothwar areas. The above method has therefore been employed to determine runoff for the areas of newly selected sites in this study. Rainfall data of Islamabad Airport station has been used. Monthly runoff over total area (908.5 sq km) of Islamabad region for the last 30 years (1988-2017) is computed and given in Table 7.1. Figure 7.5 shows mean monthly runoff in Islamabad due to rainfall. Average annual runoff for 1988-2017 (30 year period) comes to be 272619 Acre ft (243 MGD).

Monthly runoff in watershed area (3.3 sq km) of Trail 5 for the last 30 years (1988-2017) is computed and given in Table 7.2, which comes equal to 995 Acre ft (0.886 MGD).

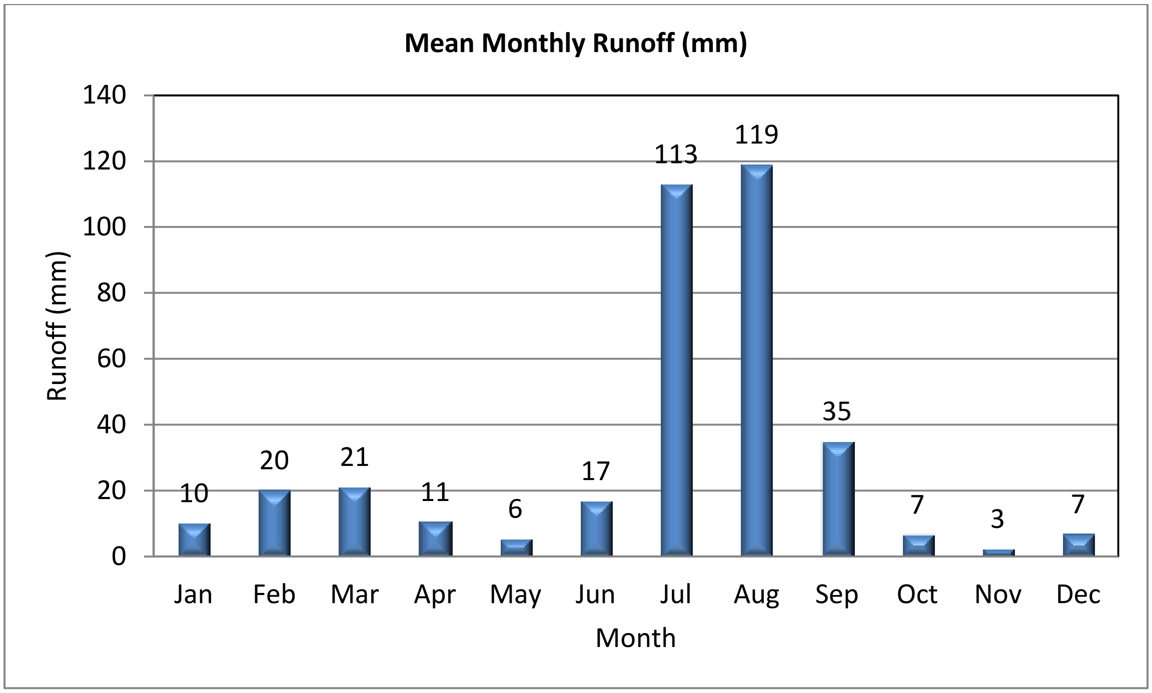


Figure 7.5 Mean monthly runoff in Islamabad from 30 year of rainfall data (1988-2017)

Table 7.1 Mean Monthly Runoff at Islamabad (1988-2017)

Month	(mm)	1000 x m^3	m^3/sec	Acre-ft	ft^3/sec
Jan	10.48	9500	3.547	7703	125
Feb	20.46	18548	6.925	15039	245
Mar	21.47	19464	7.267	15782	257
Apr	10.83	9818	3.666	7961	129
May	5.75	5209	1.945	4224	69
Jun	17.19	15583	5.818	12635	205
Jul	113.33	102734	38.357	83300	1355
Aug	119.29	108139	40.374	87683	1426
Sep	35.33	32023	11.956	25966	422
Oct	6.98	6329	2.363	5132	83
Nov	2.65	2406	0.898	1951	32
Dec	7.13	6468	2.415	5244	85
Annual	370.90	336221	10.461	272619	369

Table 7.2 Mean Monthly Runoff at Trail 5

Month	(mm)	1000 x m^3	m^3/sec	Acre-ft	ft^3/sec
Jan	10.48	34.7	0.013	28.1	0.46
Feb	20.46	67.7	0.025	54.9	0.89
Mar	21.47	71.0	0.027	57.6	0.94
Apr	10.83	35.8	0.013	29.0	0.47
May	5.75	19.0	0.007	15.4	0.25
Jun	17.19	56.8	0.021	46.1	0.75
Jul	113.33	374.8	0.140	303.9	4.94
Aug	119.29	394.5	0.147	319.9	5.20
Sep	35.33	116.8	0.044	94.7	1.54
Oct	6.98	23.1	0.009	18.7	0.30
Nov	2.65	8.8	0.003	7.1	0.12
Dec	7.13	23.6	0.009	19.1	0.31
Annual	370.90	1227	0.038	994.54	1.35

These results are compared with previous research conducted to evaluate a three year field data of rainfall-runoff and sediment load at Rawal sub-watershed (Strameel), Islamabad. In this work, the water samples were taken during the monsoon seasons of years 2006, 2007 and 2008. The total runoff was measured as 115, 191 and 241 mm during monsoon as per recorded events out of 282, 557 and 512 mm rainfall in 2006, 2007, and 2008 years respectively (Mangrio et al. 2011). Runoffs factors of present study are quite close to the runoff factors estimated by Mangrio et al. 2011. However minor difference is due to the difference in area and small sub watershed of Mangrio et al., 2011. In addition runoff factor in present study is 32% which is in lower side and therefore gives more conservative results as provided in Table 7.3.

Table 7.3 Comparison of runoff factors with present study and Mangrio 2011 study

	Present Study (Islamabad)			Mangrio et al. 2011 (Rawal Dam)		
Year	Monsoon Rainfall (mm)	Estimated Runoff (mm)	Runoff Factor	Monsoon Rainfall (mm)	Recorded Runoff (mm)	Runoff Factor
2006	974	373	0.38	282	115	0.41
2007	1155	419	0.36	557	191	0.34
2008	698	215	0.31	512	241	0.47
Average			0.35			0.41

Average runoff factor for whole year comes to be 28%. Results showed that plenty of rainwater in the form of runoff (average annual 243 MGD) is available in Islamabad and 0.88 MGD at Trail 5. This runoff can be saved/stored by using:

1. Check dams
2. Rainwater harvesting technique
3. Injection wells/ Dug wells

Runoff Estimation using HEC-HMS computer software

HEC-HMS computer software developed by US army corps of Engineers is a standard model for runoff simulation. Curve Number (CN) method of US SCS (Soil Conservation Services) /NRC is employed. CN is determined with the help of land use information of watershed and tables provided by NRC/SCS. Runoff (Q) is estimated in inches using the following equation, where P is rainfall in inches.

$$Q = \frac{(P - 0.2\,S)^2}{(P + 0.8\,S)}$$

$$S = \frac{1000}{CN} - 10$$

To determine the Curve Number of watershed, Land cover/ land use maps were prepared with the support of Satellite data. These maps are shown in Figure 7.6 and 7.7.

Map Showing Proposed Check Dams and Injection Wells

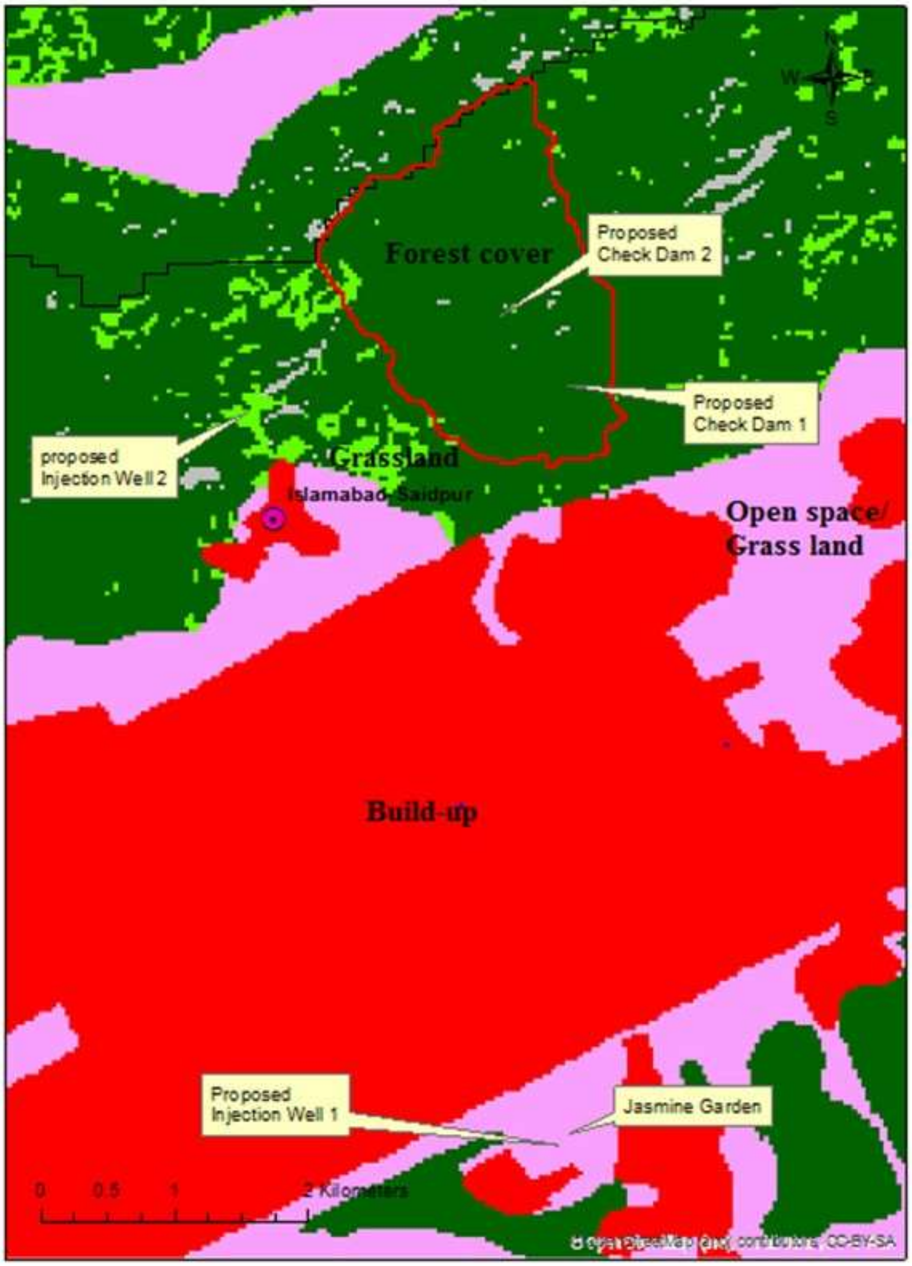


Figure 7.6 land use map of project area.

Map Showing Land Cover, Trail5 Watershed

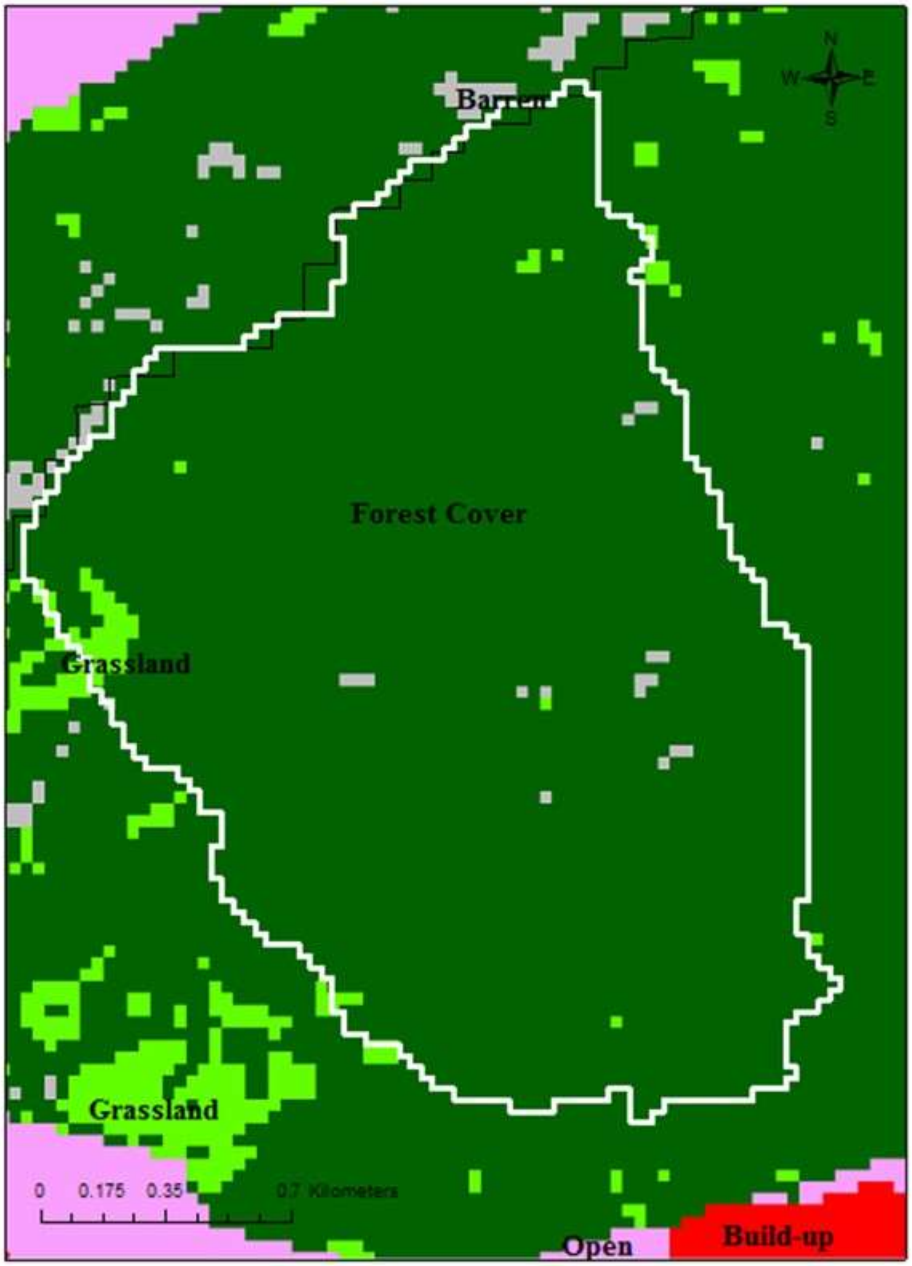


Figure 7.7 land use map of Trail 5 watershed

Simulation of daily runoff in Trail 5 using HEC-HMS computer model was carried out. Results are shown in Figure 7.8. In simulation computations, shorter time step (I hour) is selected so that the flow peaks can be observed as shown in Figure 7.9. Comparing results of the two methods (SMO vs. HEC-HMS) annual runoff in year 2009 by HEC-HMS comes to be 1261 Acre-ft while by SMO method average annual runoff 1959-2017 is 995 Ac-ft. (see Table 7.2 and Table 7.3).

Simulation results also showed that enough water is available in Trail 5 for construction of new check dams. In the absence of recorded flow data, analysis carried out in this section is of preliminary nature and should be updated with the when recorded flow data is available.

Table 7.3.

Summary Results for Subbasin "Trail 5"

Project: MargallaTrail5-2 Simulation Run: Run 2009

Subbasin: Trail 5

Start of Run:	01Feb2009, 00:00	Basin Model:	Basin 1
End of Run:	15Dec2009, 00:00	Meteorologic Model:	Met 1
Compute Time:	13Dec2018, 23:05:46	Control Specifications:	Control 2009

Volume Units: IN AC-FT

Computed Results

Peak Discharge:	52.1 (CFS)	Date/Time of Peak Discharge:	07Apr2009, 00:00
Precipitation Volume:	1616.8 (AC-FT)	Direct Runoff Volume:	1261.6 (AC-FT)
Loss Volume:	355.2 (AC-FT)	Baseflow Volume:	0.0 (AC-FT)
Excess Volume:	1261.6 (AC-FT)	Discharge Volume:	1261.6 (AC-FT)

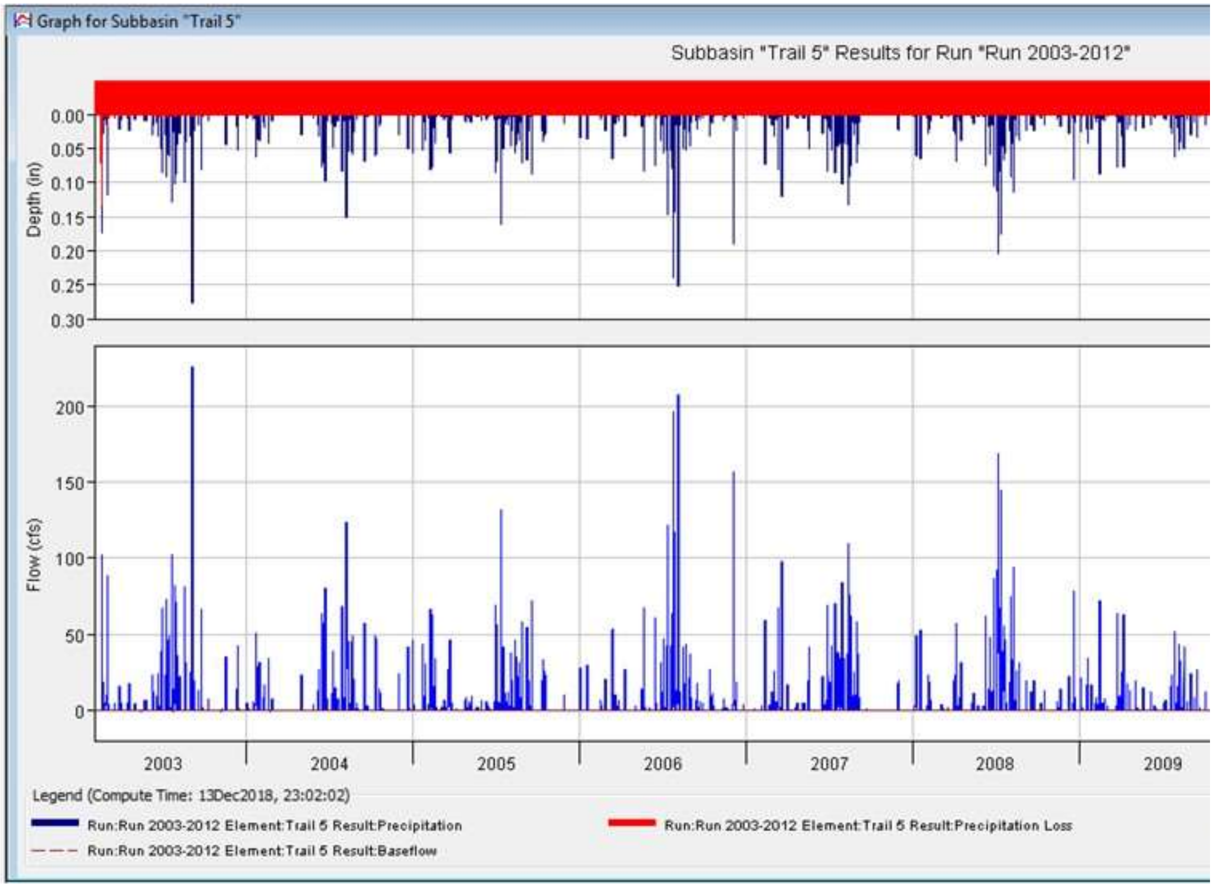


Figure 7.8 Simulation of daily runoff in Trail 5 using HEC-HMS computer model

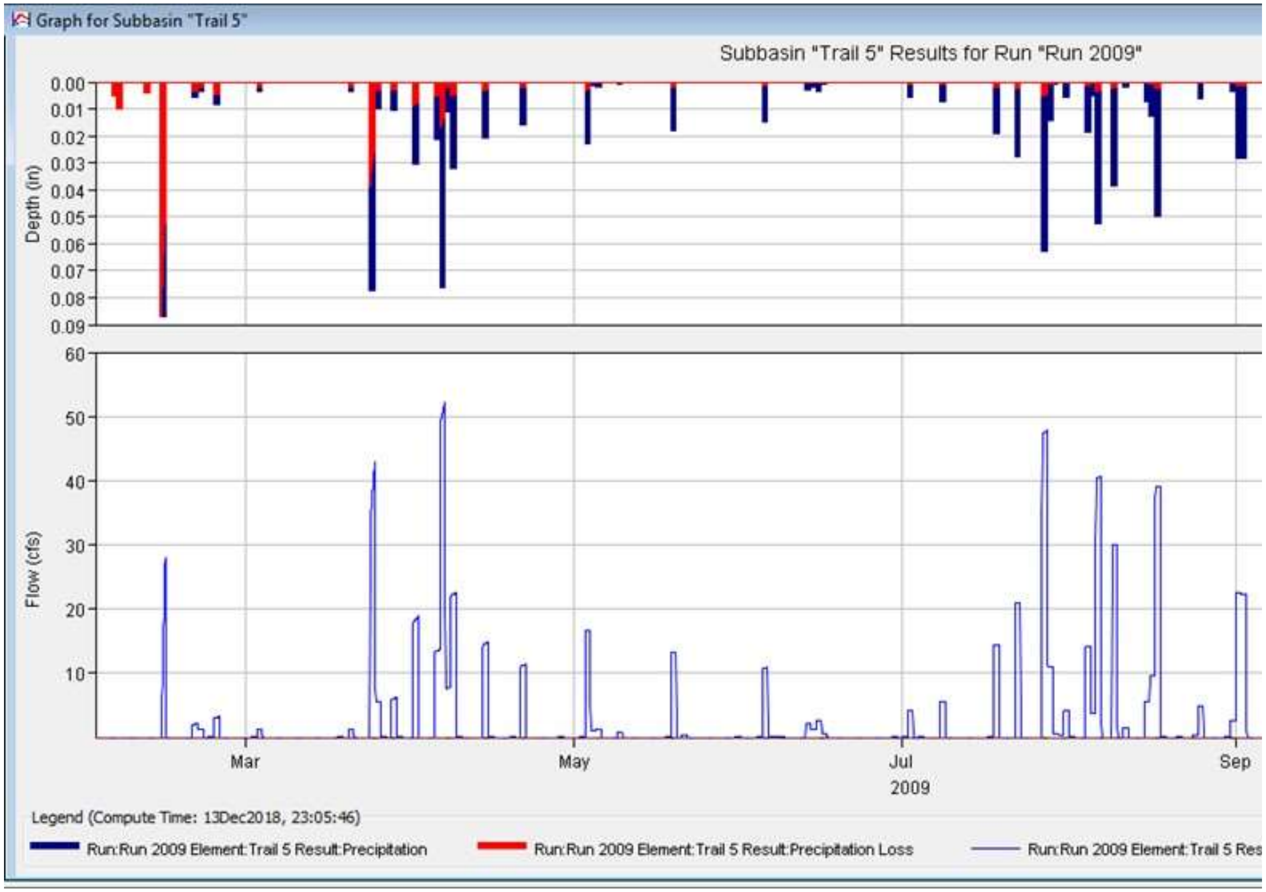


Figure 7.9 Simulation of daily runoff in Trail 5 using HEC-HMS computer model in a low rainfall period, 2009

7.3 Discharge

The data in this section is collected from recently published material (Ahmad et al.2016). The water is being discharged to metropolitan areas of major cities of Islamabad and Rawalpindi, the combined population of which is about 2.8 million, with a density of 880 persons/km^2. Surface water supplies are maintained from Rawal and Simly dams, which provide 21 million gallons per day (MGD) to Rawalpindi city and 17 MGD to Islamabad city. Groundwater supplies are 24 MGD from about 200 public tube wells in Islamabad, and 27 MGD from about 300 public tube wells in Rawalpindi. The average needs of Islamabad and Rawalpindi are 65 and 175 MGD, respectively, which exceed the capacity of available water resources. In Rawalpindi about 300 water wells are being pumped for about 18–22 hour per day year round to meet the growing demand of the inhabitants of the city (Ahmad et al. 2016).

7.4 Recharge

Chaturvedi method, 1973 was used to determine recharge in the watershed at Trail 5 to find possible recharge potential for check dams. The Chaturvedi formula was based on the water level fluctuation method and rainfall amounts. According to (Chaturvedi 1973), groundwater recharge was defined as a function of the annual precipitation. The Chaturvedi formula was used in India where the climate is tropical (Qablawi, 2016). Long term rainfall data (1959-2017) was used to employ Chaturvedi method to estimate recharge in Trail 5 watershed. Results are presented in the following Table 7.4. It is inferred from the results that average annual recharge in Trail 5 was 519 AF (0.72 ft3/s). Maximum annual recharge was 727 AF (1.0 ft3/s) and minimum was 270 AF (0.37 ft3/s)

Table 7.4
Recharge Estimation in watershed of Trail 5 stream based on Chaturvedi formula

Year	Precipitation (in)	Estimated Recharge (in)	Watershed Recharge (AF)	Watershed Recharge (ft3/s)
1959	53.80	8.52	579	0.80
1960	31.24	5.60	381	0.53
1961	45.06	7.52	511	0.71
1962	41.35	7.06	480	0.66
1963	38.40	6.67	453	0.63
1964	27.90	5.03	342	0.47
1965	33.82	6.01	408	0.56
1966	37.36	6.52	443	0.61
1967	44.04	7.40	503	0.69
1968	43.87	7.38	501	0.69
1969	29.03	5.23	356	0.49
1970	40.17	6.91	469	0.65
1971	42.96	7.26	494	0.68
1972	30.31	5.45	371	0.51
1973	51.61	8.28	563	0.78
1974	41.05	7.02	477	0.66
1975	41.02	7.02	477	0.66
1976	62.83	9.43	641	0.89
1977	52.48	8.37	569	0.79
1978	56.33	8.78	597	0.82
1979	37.74	6.58	447	0.62
1980	42.68	7.23	491	0.68
1981	68.31	9.95	676	0.93
1982	64.37	9.58	651	0.90
1983	67.48	9.87	671	0.93
1984	44.98	7.51	511	0.71
1985	44.25	7.42	505	0.70
1986	36.91	6.46	439	0.61
1987	31.32	5.62	382	0.53
1988	49.96	8.10	550	0.76
1989	41.11	7.03	478	0.66
1990	60.22	9.18	624	0.86
1991	46.99	7.75	527	0.73
1992	49.68	8.06	548	0.76
1993	32.69	5.84	397	0.55
1994	66.86	9.81	667	0.92

1995	63.59	9.51	646	0.89
1996	52.11	8.33	566	0.78
1997	55.66	8.71	592	0.82
1998	55.57	8.70	592	0.82
1999	39.85	6.86	467	0.64
2000	39.33	6.80	462	0.64
2001	46.37	7.68	522	0.72
2002	36.63	6.42	436	0.60
2003	49.09	8.00	544	0.75
2004	40.41	6.94	471	0.65
2005	38.54	6.69	455	0.63
2006	62.91	9.44	642	0.89
2007	71.97	10.28	699	0.96
2008	54.65	8.61	585	0.81
2009	22.66	3.97	270	0.37
2010	50.61	8.17	555	0.77
2011	47.94	7.87	535	0.74
2012	40.78	6.99	475	0.66
2013	76.84	10.70	727	1.00
2014	64.75	9.62	654	0.90
2015	68.89	10.00	680	0.94
2016	33.20	5.92	402	0.56
2017	38.32	6.66	452	0.63
		Average =	519	0.72

7.5 Proposed Check Dams and Injection/Dug Wells

Recharge Check Dams

Under the present water scarcity conditions and declining scenario in Islamabad, there is a dire need to initiate water resources management program, with site-specific interventions, especially to harness the available rainwater. This would not only contribute to groundwater recharge in the basin but also supplement the water supplies to meet future water demand for various uses (Ahmad et al. 2016). Surface water drainage system/network (Figure 6.22 and 6.24) carries rainwater and is a potential source for the development. Water-charging check dams need to be constructed in nullahs and distributaries. Such ponds would serve as water storage for emergency as well as for recharging of the groundwater. During present survey, comparatively Trail 5 was found more suitable for locating new sites for check dams. There are five existing check dams along Trail 5 (Figure 7.7). All of these dams need to be repaired. Additional volumes of water can be infiltrated after repairing/cleaning these micro-dams.

Figure 7.7. Existing Check dam in Trail 5

As shown in Figure, 7.1 two new sites were identified during present survey for the construction of recharge check dams. Preliminary data was collected from the proposed check dam sites for the appropriate design. As shown in above figure 7.7, bed material is composed of gravel / boulder material. The typical value of coefficient of permeability (k) of gravel / boulder material was adopted 8.0 x 10^{-4} m/s (227 ft/day). http://www.aqtesolv.com/aquifer-tests/aquifer_properties.htm. Thickness of the channel/alluvium water was about 4.5 ft (1.27 m) at these two sites. The width of the channel at proposed site is about 50 feet (15m). Height of the check dams is proposed 3.0 ft (0.9 m). Figure 7.8 shows the section of check dam. Cross sections at proposed dam axis were drawn with the help of Google Earth and presented in Figure 7.9 and 7.10. At site 2 the valley is deeper than at site 1. However the channel material remains the same. Table 7.5 shows recharge calculations from dam site-1.Using the same configuration for proposed dam 2 in Trail 5, a total of average recharge from the two dams comes to be 0.12 ft^3/s.

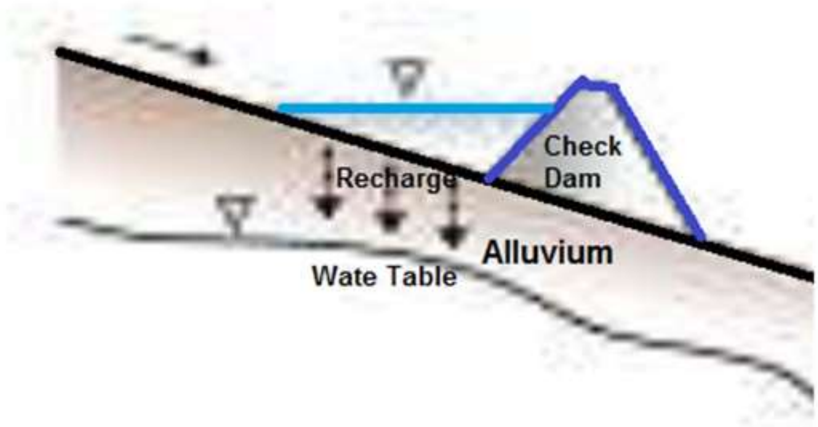


Figure 7.8 Section of Proposed Check Dam

Table 7.5

Calculations for Recharge/Seepage												
Month	Mean Monthly Rainfall	(%) to Sep Rainfall when dam	Head U/S of Dam h1	Head D/S Tail h2	Net Head h = h1-h2	No of Flow Lines m	No of Equip lines n	Coeff of Permeability k	Recharge per unit width q	Width of reservoir w	Recharge from Check Dam Q	Q
	(mm)	is full	(ft)	(ft)	(ft)			(ft/day)	(ft3/day/ft)	(ft)	(ft3/day)	ft3/s
Oct	32	0.3	0.8	0.1	0.7	5	17	227	48	50	2425	0.03
Nov	17	0.1	0.4	0.0	0.4	5	17	227	26	50	1292	0.01
Dec	33	0.3	0.8	0.1	0.7	5	17	227	50	50	2498	0.03
Jan	57	0.5	1.4	0.1	1.3	5	17	227	86	50	4308	0.05
Feb	82	0.7	2.0	0.2	1.8	5	17	227	123	50	6138	0.07
Mar	91	0.8	2.3	0.2	2.0	5	17	227	136	50	6804	0.08
Apr	58	0.5	1.5	0.1	1.3	5	17	227	88	50	4378	0.05
May	38	0.3	0.9	0.1	0.8	5	17	227	56	50	2823	0.03
Jun	70	0.6	1.7	0.2	1.6	5	17	227	105	50	5245	0.06
Jul	287	1.0	3.0	0.3	2.7	5	17	227	180	50	9005	0.10
Aug	317	1.0	3.0	0.3	2.7	5	17	227	180	50	9005	0.10
Sep	120	1.0	3.0	0.3	2.7	5	17	227	180	50	8987	0.10
										Average =	5242	0.06

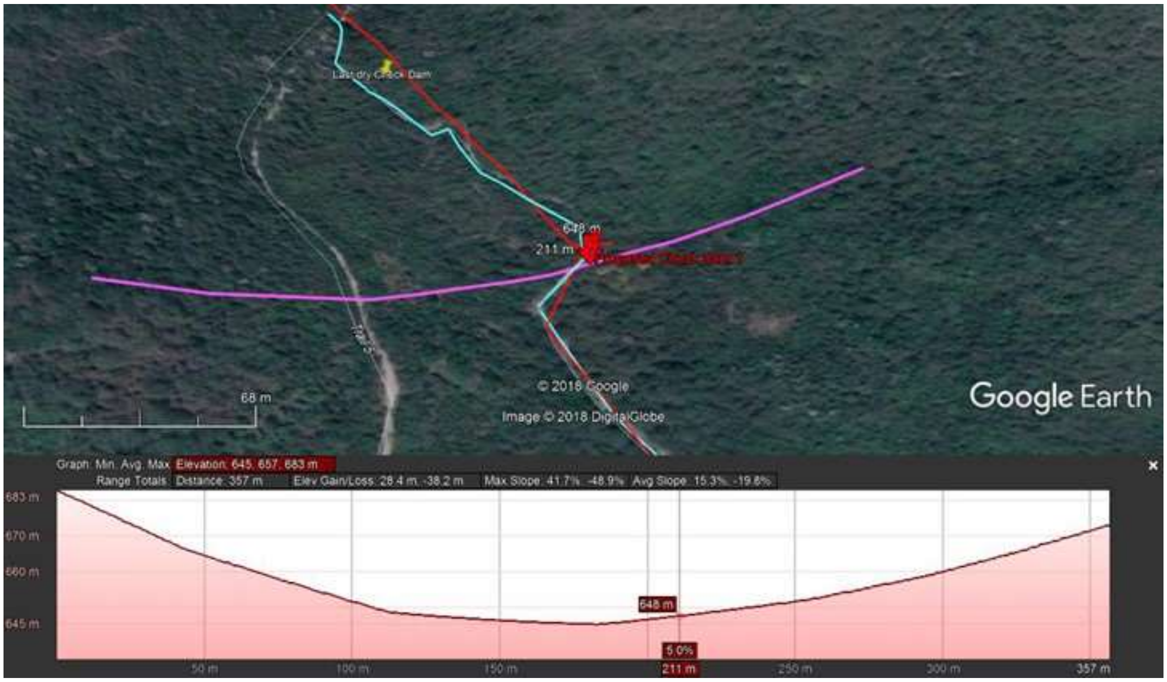


Figure 7.9. Cross section at Proposed Check Dam 1

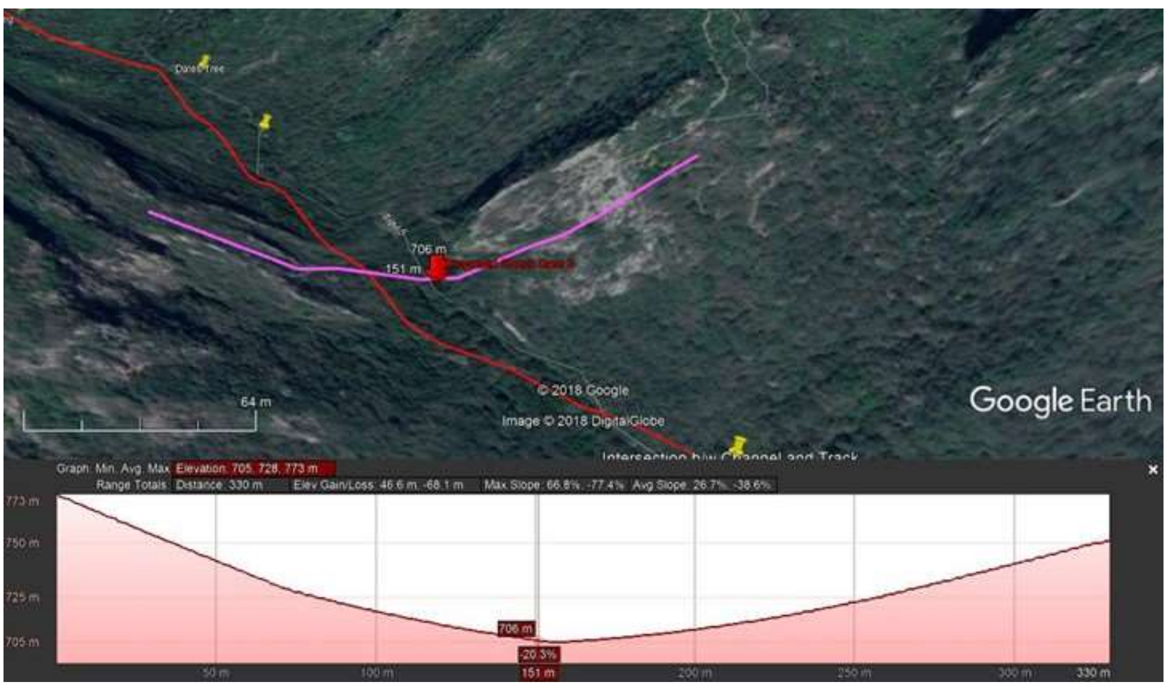


Figure 7.10. Cross section at Proposed Check Dam 2

Injection / Dug Wells

Water can also be infiltrated by injection/ dug wells where low permeability strata overlies aquifer. In Islamabad, parts of watershed containing medium to fine textured soils over calcareous material**.** This technique is suitable for deep-seated aquifers that form a source of groundwater for urban areas lying in the valley plains of the watershed. The water-injecting wells have the advantage that recharging water can bypass thick impervious layers that is resided over most of the permeable portions of the aquifer (Ahmad et al., 2016).

Areas around Faisal Mosque, Shah Allah Ditta Cave, Jasmine Garden were surveyed to determine suitable sites for injection/dug wells. In addition, area around MBT which is tectonically disintegrated and composed of fractured material is also investigated. Two sites for injection wells have been selected, one at Rose and Jasmine Garden and other near MBT.

At Rose and Jasmine Garden the area was surveyed to find suitable injection well location. The well point was selected on the basis of catering maximum storm water from the adjacent storm water stream (Figure 7.11). Filtration system is a mandatory phenomenon prior to proposing an injection well in order to remove suspended solids and to inject rain water into groundwater body. Figure 7.12 shows proposed storm water drain, recharge/filtration structure and Injection well in Rose and Jasmine Garden.

Adjacent to MBT area, survey was carried out to find appropriate location for injection/dug well. The well point was selected on the basis of catering maximum water from the adjacent stream (Figure 7.13). Figure 7.14 shows recharge/filtration structure connecting pipe and Injection well No. 2.

Figure 7.11 Location of the proposed injection well 1, catering maximum storm water in Rose and Jasmine Garden.

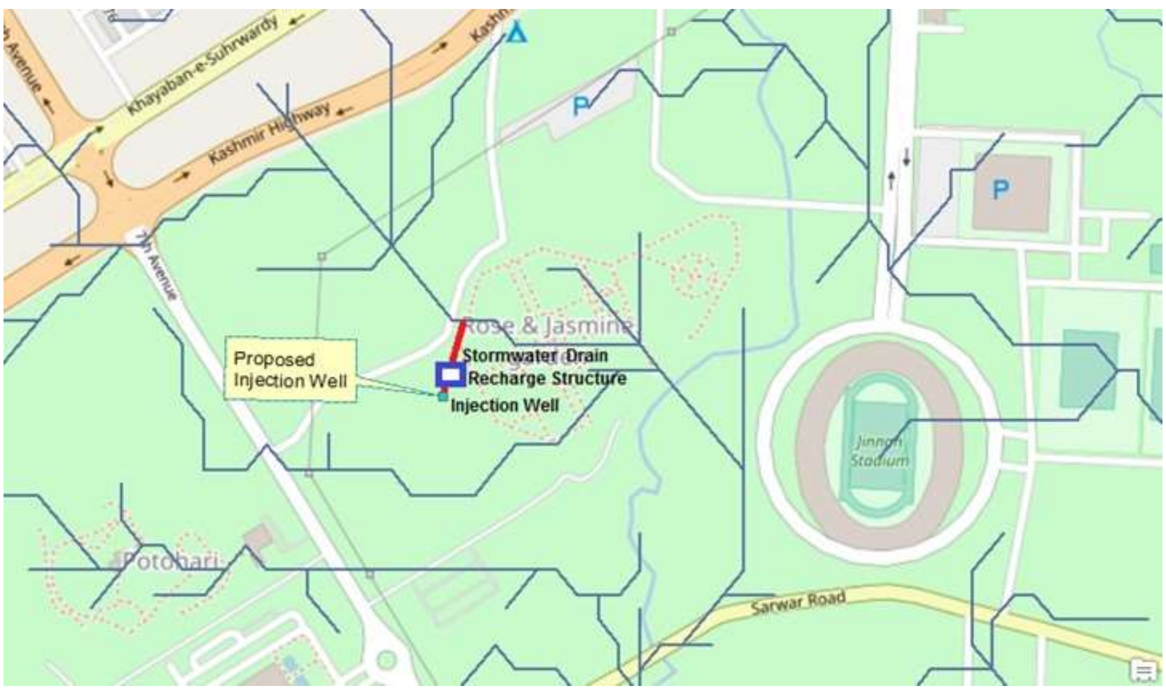


Figure 7.12 Proposed storm water drain, recharge/filtration structure and Injection well in Rose and Jasmine Garden

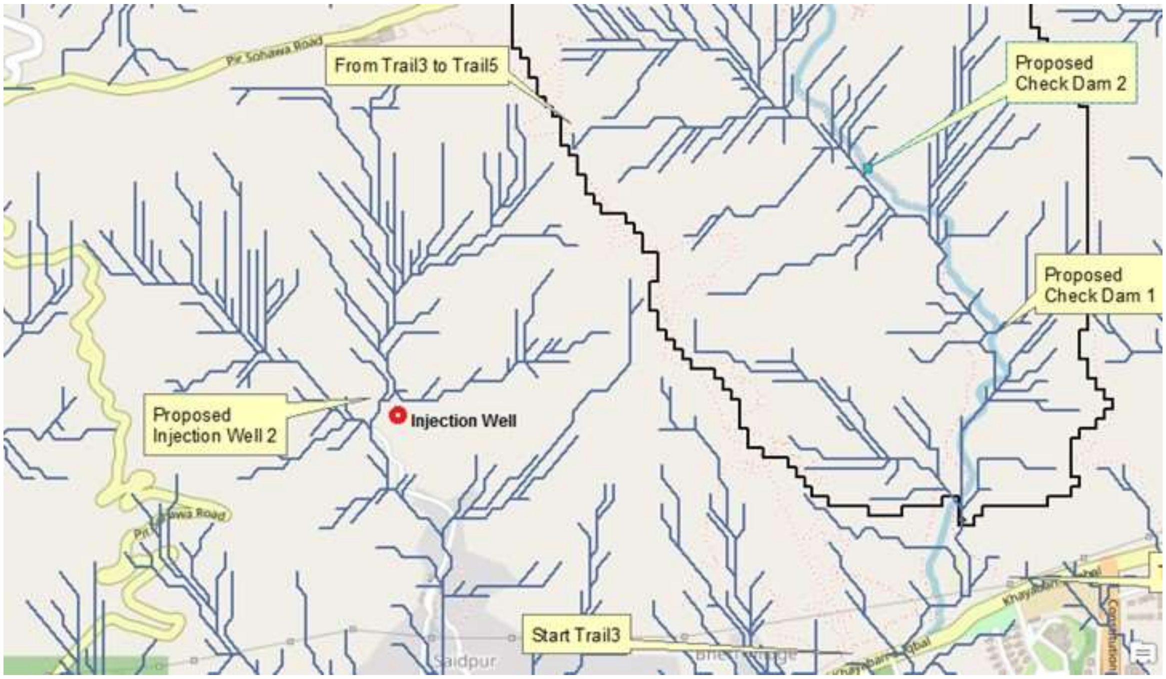


Figure 7.13 Location of the proposed injection well 2 catering water from the adjacent stream near MBT.

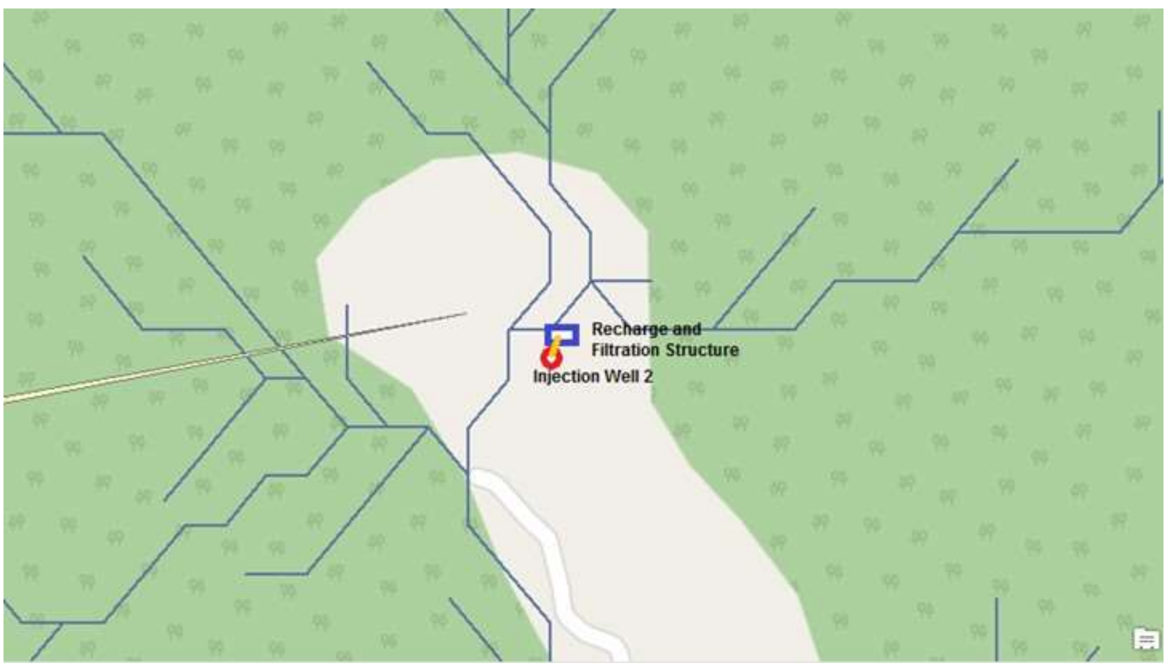


Figure 7.14 Proposed Recharge and Filtration Structure, connecting pipe and injection well 2 near MBT

Recharging capacity of well can be estimated from modification of Darcy's seepage flow equation. Recharging flow Qr by constant head recharge in bore well can be calculated by using

Qr = 2.75 d H k

Where, d = diameter of recharge well (m), H = depth of pervious sand strata depth maximum 20 m or below the groundwater level (m), k = co-efficient of permeability (m/sec), (Patel et al. 2011)

Qr = 2.75 x d x 20 x k

Qr = 55 d k

For study area, well diameter is selected 10 inches (0.254 m) and value of k 0.000313 m/s from Islamabad data (Table 6.1). Recharge capacity of the well into the aquifer is calculated in the following table.

Recharge capacity of Injection Well			
Well Dia, d =		0.254	m
Coeff of Permeability k =		3.13E-04	m/s
		1.03E-03	ft/s
		0.343	m/h
Well Recharge Capacity		Qr = 55 d k	
		0.0044	m3/s
		0.0143	ft3/s
		15.74	**m3/h**

Figure 7.15 can be used to determine diameter of injection wells if recharge rate (Qr) and coefficient of permeability k of the sub-stratum is known. Design of recharge injection well with respect to bore log is shown in Figure 7.16.

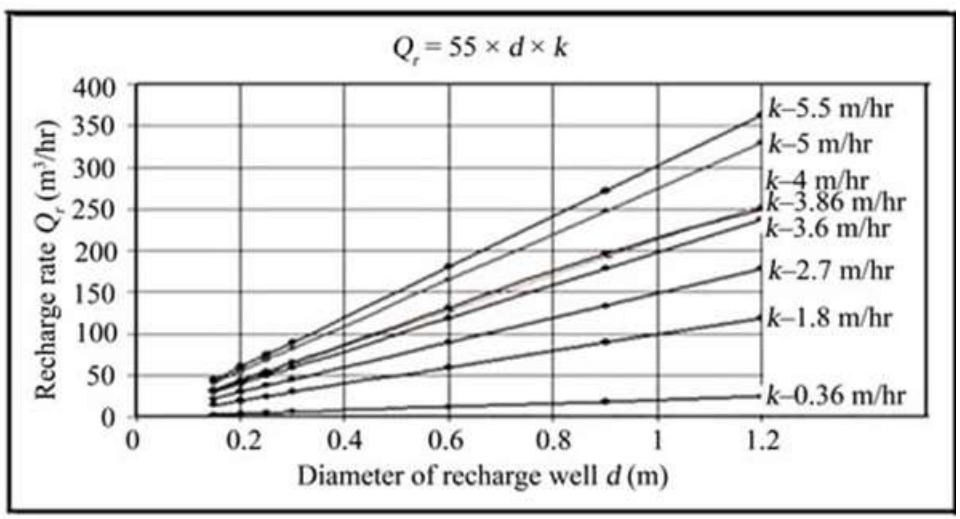


Figure 7.15 Diameter of injection wells for different recharge rates (Qr) and coefficient of permeability k. (Patel et al. 2011)

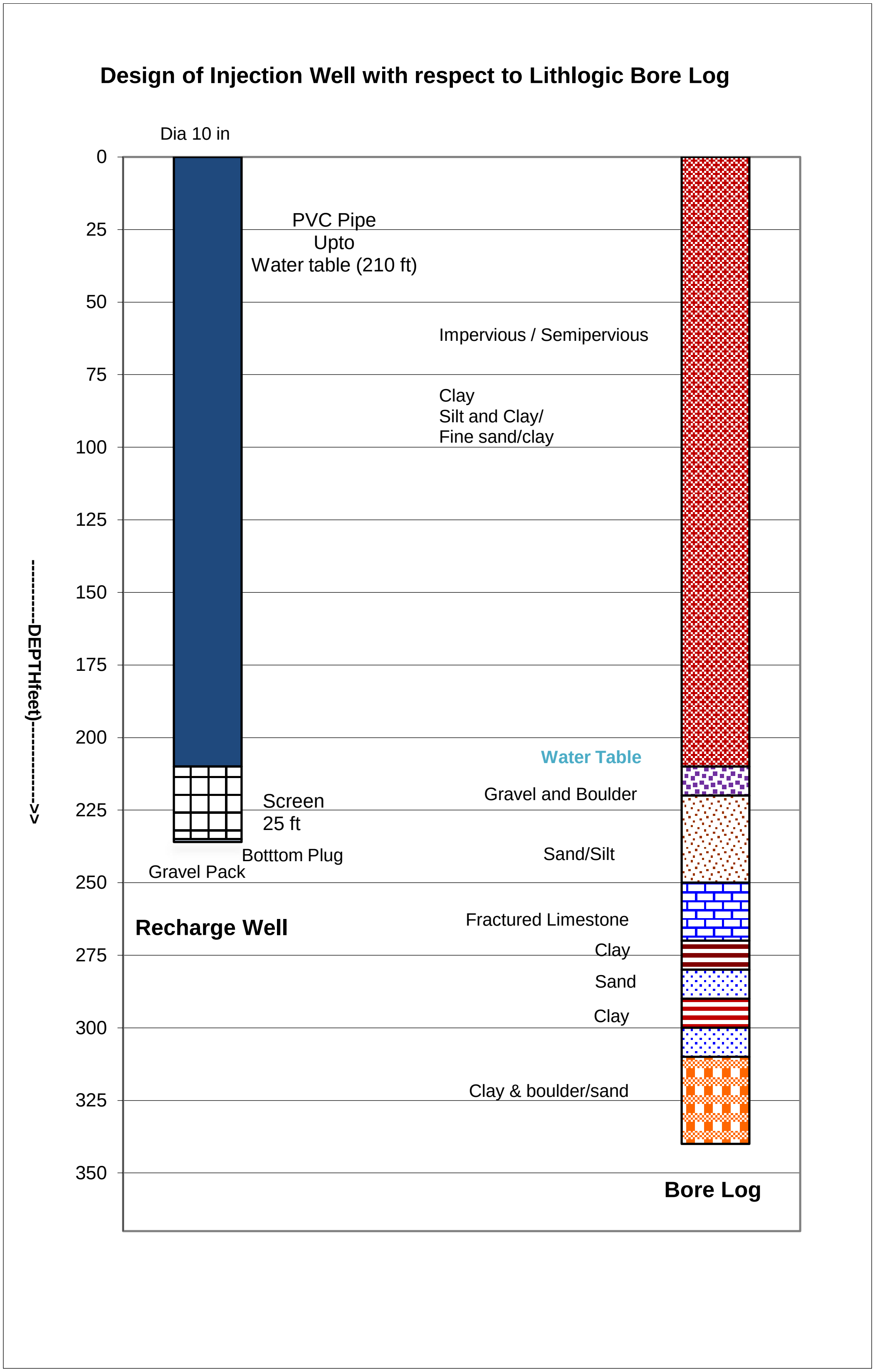


Figure: 7.16 Typical design of recharge injection well with respect to bore log

Monitoring System of Recharge Development

A monitoring system is imperative to determine how effectively the present proposal for artificial recharge for groundwater works out in Islamabad. It requires piezometers to be constructed in the vicinity and further area to monitor the rise or drop of water levels for at least 12 months period. During monitoring, water sampling will be regularly carried out for lab testing to determine whether the quality of water is improving or deteriorating. Monthly time interval for 12 month monitoring system is appropriate. Tentative operation/maintenance program cost to keep the systems in good working conditions will also be needed.

8. CONCLUSIONS AND RECOMMENDATIONS

i. Present study indicated that there is decline in water table due to excessive pumpage in study area.

ii. Using long term climate data, increasing trend in temperature was found that will increase the rate of evapotranspiration of the area. Consequently water losses from surface runoff and existing lakes will be higher.

iii. Study was carried out to find surface and groundwater characteristics of the area in the context of Check Dams and Induced recharge by Dug Wells. These characteristics were found suitable for development of the area.

iv. It is inferred from estimation of runoff, plenty of surface runoff is available for check dams and injection wells.

v. Recharge can replenish the groundwater if proposed check dams and injection wells are constructed in the area.

vi. It is recommended that monitoring of piezometer hydrographs in the selected area over 12 month period should be carried out and data be recorded for future development

References

Abbas I., Sundas Gill Kiyani, Muhammad Sheraz Ahsan, Hassan Akram (2012) Spatio-temporal analysis of water table within Rawalpindi Municipal jurisdiction, NUST, Islamabad

Ahmad Z, Arshad Ashraf and Mohsin (2016) Appraisal of Groundwater Flow Simulation in the Sub-Himalayan Watershed of Pakistan, Intech Open Science, http://dx.doi.org/10.5772/633 24

Ali F (2014) Tectonic evolution of the Margalla hills and a part of the South Eastern Hazara ranges, Pakistan, PhD Thesis, University of Peshawar

Allchin B. (1981) The palaeolithic of the Pothwar plateau Punjab, Pakistan: a fresh approach, Paléorient. 7(1): 123–134. doi:10.3406/paleo.1981 .4291. http://www.persee.fr/web/revues/home/prescript/article/paleo_0153-9345_1981_num_7_1_4291

Bender, Raza, (1995) Geology of Pakistan (Beiträge zur regionalen Geologie der Erde, Gebrüder Borntraeger)

CDA (2013) Conduction of water from Indus River system of Tarbela Dam to Islamabad and Rawalpindi, CDA official website

HESC (2014) Estimation of water sustainability within 30 km radius in Islamabad/Rawalpindi using hydrological & geophysical historic data

JICA (2003) The Study on Comprehensive Flood Mitigation and Environmental Improvement Plan of Lai Nullah Basin in The Islamic Republic of Pakistan, Final Report, CTI Engineering International Co., Ltd., Pacific Consultants International

NESPAK (2013) Hydrogeological study for a deep well in Islamabad

Nestle water (2016) Islamabad water factory constructive critical review of hydrogeological reports

Pratima Patel, Mahesh Desai, Jatin Desai (2011) Geotechnical Parameters Imp act on Artificial Ground Water Recharging Technique for Urban Centers, Journal of Water Resource and Protection, 2011, 3, 275-282

Pratima Patel, M. D. Desai (2010) Artificial ground water recharge field study : site characterization and test results, International Journal of Advanced Engineering Technology, 150-164

Qablawi B. (2016) A comparison of four methods to estimate groundwater recharge for Northeastern South Dakota, MSc Thesis, South Dakota State University

Sheikh and al., 2007 Environmental Geology of the Islamabad-Rawalpindi Area, Northern Pakistan (U.S. Geological Survey)

UN-Habitat (2014) Islamabad, Pakistan - Climate Change Vulnerability Assessment, United Nations Human Settlements Programme (UN-Habitat)

Williams and al, (2007) Geological Map of the Islamabad-Rawalpindi Area, Punjab, Northern Pakistan (U.S. Geological Survey)

Annexure 1 Data of Trail 5 (Present Survey)